# Inside the Forecast Factory: The Communication of the UK Met Office's 3-Month Outlook

Submitted by Christopher James Manktelow to the University of Exeter as a thesis for the degree of Doctor of Philosophy in Geography in March 2021.



I certify that all material in this thesis which is not my own work has been identified and that no material has previously been submitted and approved for the award of a degree by this or any other University.

Signature: ……

## Abstract

Seasonal climate forecasts (SCF) provide information about future climate variability from a month up to a year ahead. These forecasts could help organisations mitigate seasonal climatic risks, such as the impact of temperature on the consumption of energy or of severe winter weather upon road, rail and aviation infrastructure. Yet empirical research into the uptake of seasonal climate forecasts suggests that they are not always understood, trusted or used in decision-making. Geographers, other social scientists and climate scientists have tried to improve the communication of SCF either by identifying presentation formats that are easier to understand or by customising the message of a forecast to a stakeholder's decision-making needs. However, both efforts to improve the communication of seasonal climate forecasts focus on how stakeholders interpret and use SCF, rather than on following the people, texts and data that constitute the message of a SCF. This thesis therefore argues that the message of a SCF is not a product that is delivered to an end-user but a web of relations between things (materials) and meanings (semiotics). Drawing upon work within science and technology studies (STS) and geography, I develop an ethnography that follows the relations that form the 3-month outlook, which is based on SCF issued by the UK Met Office. I argue that the 3-month outlook is simultaneously a bounded region in time (3-month averages) and space (for the whole of the UK), a stable network of documents and graphs and a fluid mixture of conversations and emails. The successful communication of 3-month outlook depended on UK Met Office staff holding these elements together so that the message remained the same when it was communicated in different circumstances. I conclude by suggesting that climate scientists need to find ways of adapting the content or style of the message they communicate, so that their messaging remains continuous across stakeholders who have different understandings of what a 'normal' climate is and ought to be like.

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## Acronyms

ANT- Actor-Network Theory

DfT- Department for Transport

ECMWF- European Centre for Medium-Range Weather Forecasting

ENSO- El-Nino Southern Oscillation

ESRC- Economic and Social Research Council

EUPORIAS- European Provision of Regional Impact Assessment for Seasonal and Decadal Timescales

GCM- General Circulation Model

GloSEA5- Global Seasonal Forecast Model 5

IOD- Indian Ocean Dipole

IPCC- Intergovernmental Panel on Climate Change

NAO- North Atlantic Oscillation

OfGEM- Office of Gas and Electricity Markets

QBO- Quasi-Biennial Oscillation

PWSCG- Public Weather Service Customer Group

SCF- Seasonal Climate Forecast

SST- Sea-Surface Temperature

STS- Science and Technology Studies

WMO- World Meteorological Organisation

## Note on Terminology

Specialist terminology in this thesis is highlighted when the concept is first used, so that readers can refer to these definitions in the glossary.

## Acknowledgements

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and family who have prayed for me, encouraged me and shown interest in the PhD. There are too many of you to thank but I really do appreciate your support.

# Chapter 1. Introduction

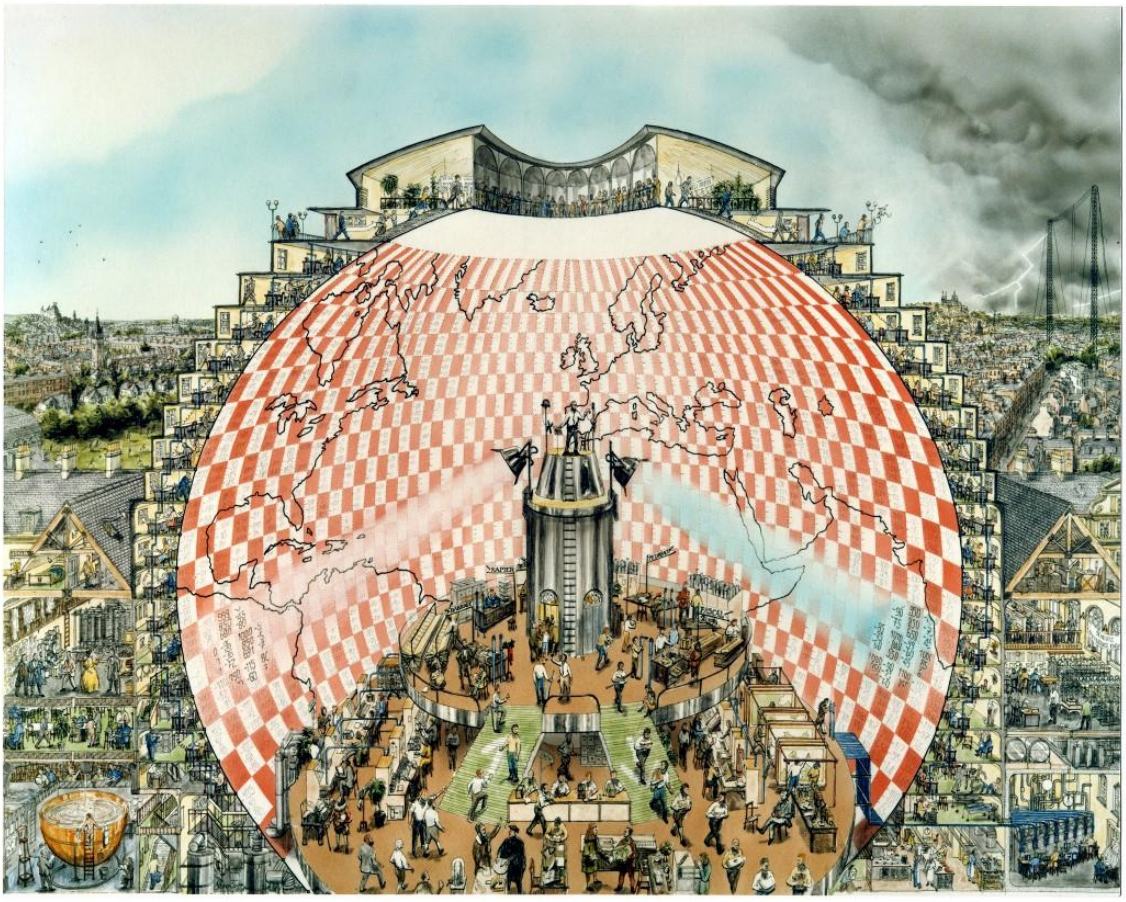


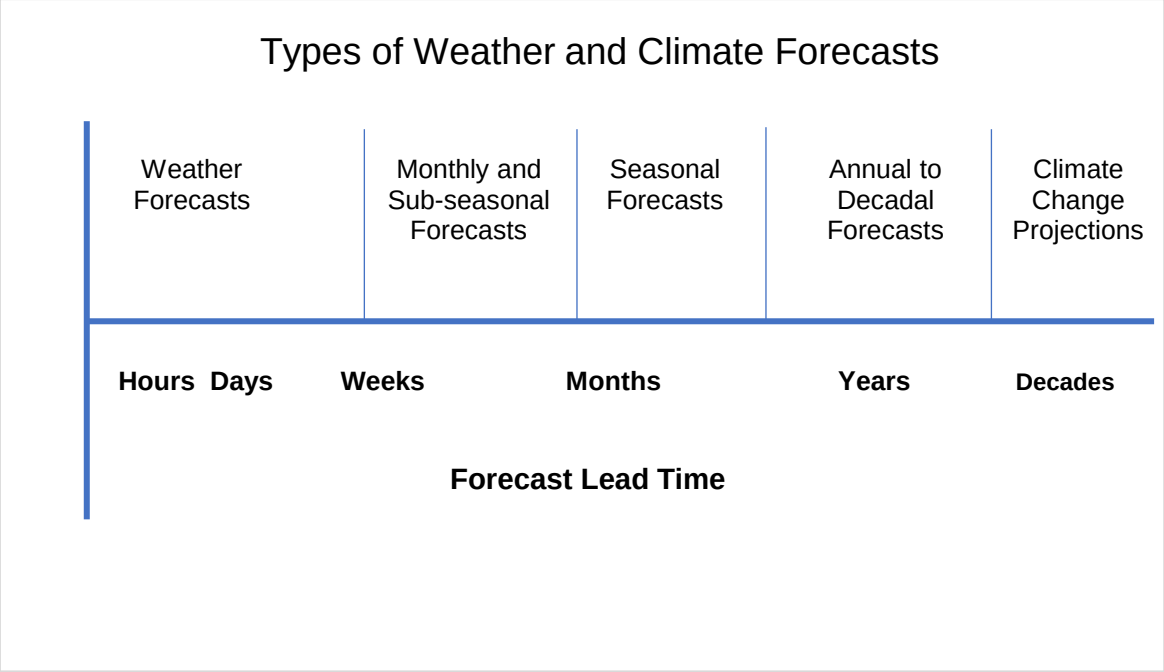
*Figure 1- Illustration of the 'Forecast Factory' from Lewis Fry Richardson's Weather Prediction by Numerical Processes, from Conlin S., (1986).*

## 1.1 Inside the Forecast Factory

In his 1922 book, *Weather Prediction by Numerical Processes*, the mathematician Lewis Fry Richardson dreamt of a 'forecast factory,' that would predict the weather around the world. He asks us to 'imagine a large theatre, except that the circles and galleries go right round through the space usually occupied by the stage' (Richardson, 1922: 219-220). 64,000 people solve equations beneath a giant world map, whilst the manager of the forecast factory stands in a pulpit directing the speed at which the workers make calculations. Next to the manager are four clerks who collect the future weather as fast as they can, sending it by pneumatic carrier to a quiet room. Here the forecast is coded and telephoned out to a radio transmitting station ready to be broadcast around the world. Elsewhere there are buildings for the forecast factory's correspondence, administrative and financial departments. There are even playing fields, houses, mountains and lakes to help the human computers 'breathe freely' and relax (Richardson, 1922: 219-220).

99 years later, Lewis Fry Richardson would be astonished to see the scientific and technological advances that have been achieved since he first attempted to produce a six-hour long weather forecast. Despite the chaos and turbulence that abounds in the atmosphere (Lorenz, 1963), improvements in scientific understanding and computing power have made it possible to predict the weather with a high degree of accuracy. For example, the Met Office[1] reports that its four-day weather forecast is now as accurate as its one-day weather forecast from 1980 (Met Office, 2021a). Furthermore, efforts to understand, identify and simulate climatic phenomena that evolve over longer timescales now mean that climate scientists can predict how the atmosphere might change over weeks (Hoskins, 2013), months (Smith et al., 2012) and even years and decades ahead (Meehl et al., 2014). Some meteorologists and climate scientists have even speculated that it might be possible to produce a seamless forecasting system that identifies the predictable 'music' in the noise of the atmosphere at all timescales (Hoskins, 2013).

*Figure 2- Main Types of Weather and Climate Forecasts (Based on Hoskins, 2013)*




Whilst our ability to predict changes in weather and climate has improved remarkably since Lewis Fry Richardson produced his six-hour long forecast, we know much less about how weather and climate forecasts are communicated.

[1] Future references to the 'Met Office' in this thesis refer to the UK Meteorological Office.

The Met Office might not have its own pneumatic carrier system for transporting weather and climate forecasts, as Lewis Fry Richardson once imagined! However, it does employ nearly two thousand scientists, marketing staff, communications staff and press officers (Met Office, 2018a) who take outputs from the Met Office's supercomputer and assemble them into a message that businesses, governments, journalists and the public can easily understand and use. The success of a 'forecast factory' like the Met Office relies just as much upon how the message of a forecast is communicated as it does upon supercomputers and scientific research. Existing ethnographies of meteorological offices tend to focus on sociological topics, such as the organisational culture of meteorological offices (Fine, 2007), the practice of running models that predict changes in the weather or climate (Sundberg, 2007) and the question of how meteorologists make decisions with uncertain information (Daipha, 2015). However, these ethnographies do not explore how the message of a weather or climate forecast forms or how a forecast is picked and translated from place to another (Callon, 1986). This thesis therefore follows a forecast from the 'factory floor' of the Met Office out to businesses, local authorities, journalists and other stakeholders, so that one can understand how the message changes as it is communicated.

## 1.2 The Communication of SCF

Across the world, many socio-economic activities, such as water resource management, transportation, healthcare, agriculture and energy production and consumption are affected by climate variability from a month up to a year ahead (Taylor et al., 2015). Increases in the frequency and magnitude of extreme weather events, such as flooding, droughts and heatwaves, can lead to loss of life, damage to property and financial losses (Buontempo et al., 2014). Even smaller variations in seasonal climate can affect the generation of revenue within the private sector or increase the cost of running public services (Bruno Soares et al., 2017). Information about seasonal climatic variability therefore is of great social and economic value to organisations and individuals who need to manage weather-related risks (Hewitt et al., 2013).

Seasonal climate forecasts (SCF) sit between short-term weather forecasts and long-term decadal climate predictions and climate change projections. Unlike weather forecasts, the chaotic nature of the atmosphere means that SCF

cannot tell stakeholders what the weather will be like on a specific day or at a specific place from a month to a year ahead (Troccoli, 2010). Instead, they provide stakeholders with probabilistic forecasts of different meteorological variables, such as temperature, storminess or rainfall (Smith et al., 2012), that estimate the range of probable outcomes over the forecast period. SCF are usually presented in the form of regional three-monthly means that are compared against the historical average (Goddard et al., 2010). This gives stakeholders information about how the meteorological variable of interest might vary around the historical average (Goddard et al., 2010). SCF therefore appeal to, and could benefit, stakeholders who need to manage the effects of seasonal climatic variability upon their decision-making and planning (Bruno-Soares et al., 2017).

In some regions of the world, such as in North-East Brazil or Australia, SCF have been used since the 1990s (Hansen et al., 2011a; Parton et al., 2019). This is because tropical climates are more predictable on seasonal timescales than the climates of extratropical regions like the UK or Europe (Dunstone et al., 2016). Organisations in the UK and Europe have therefore often used historical data, such as the historical average (climatology), to predict the likely impact of seasonal climatic variability on their decision-making and planning (Taylor et al., 2015). However, recent advances in scientific understanding and computing power have improved the accuracy of SCF for extratropical regions like Europe and the UK during certain times of the year (Kang et al., 2014; Riddle et al., 2013; Scaife et al., 2014; Stockdale et al., 2015). This means that SCF are now a better predictor of some meteorological variables, such as winter temperature, than the historical average (Weisheimer and Palmer, 2014). Organisations in the UK that need to manage the impacts of seasonal climate variability therefore ought to benefit from recent improvements in the accuracy of SCF.

However, the probabilistic nature of SCF and different cultural understandings of climate can make them much harder to understand than short-term weather forecasts (Roncoli, 2006; Taylor et al., 2015). Experimental studies of different stakeholder groups, such as farmers in Australia (Coventry and Dalgleish, 2015) and Southern Africa (Marx et al., 2007a) and contingency planners in the USA (Wernstedt et al., 2019), have demonstrated that stakeholders often interpret SCF as a binary prediction of weather conditions during the upcoming

season rather than as a probabilistic forecast. Furthermore, experimental studies (Coventry and Dalgleish, 2015), surveys (Budescu et al., 2014) and ethnographic research (Orlove, 2003; Pennesi, 2007a) have identified differences in how scientists and non-scientists interpret key terms associated with SCF, such as ‘probable,’ ‘likely,’ ‘normal’ and ‘season.’ Multiple and varying definitions of these key terms can produce contrasting interpretations of a forecast that sometimes conflict with the message that climate scientists originally intended to communicate (Pennesi, 2011). The inherent uncertainty and complexity of SCF therefore makes them difficult to communicate in a way that is easily understandable.

Furthermore, surveys of businesses, government agencies and civil society actors in the UK and Europe have shown that SCF are not often used to inform decision-making (Bruno Soares et al., 2017; Bruno Soares and Dessai, 2016a). This is in spite of a widespread interest in using SCF amongst businesses (Bruno Soares et al., 2017), governments (Bruno-Soares et al., 2017) and the UK public (Chadwick, 2010) and media (Chadwick, 2010; Usborne, 2014). This gap between the perceived usefulness of SCF and their actual uptake is also replicated in other regions of the world where SCF have historically been more accurate (Lemos et al., 2012). Stakeholders often report being unable to access SCF at the time at which they need them (Dilling and Lemos, 2011) or receiving information in a format that they cannot easily use (Lemos et al., 2012). The mere availability of SCF, even if they are perceived to be useful, therefore does not guarantee that stakeholders will use them to inform their decision-making and planning (Cash et al., 2006).

Finally, the uncertainty in SCF highlights the provisional nature of scientific knowledge, which can make it difficult to communicate the trustworthiness (credibility) of a forecast to a stakeholder. On the one hand, failing to communicate the uncertainty associated with a SCF can give stakeholders a false sense of certainty (Taylor et al., 2015) and produce unrealistic expectations about the kinds of decisions that can be made with SCF (Haines, 2019; Lemos et al., 2012). If these uncertainties are uncovered or the forecast is perceived to not come ‘true’, then this can undermine trust in the both the forecast and institution that issued it (Chadwick, 2010; Taddei, 2014, 2012). On the other hand, overemphasising the uncertainty associated with a SCF can

lead to the information being dismissed by stakeholders as unreliable and irrelevant (Stephens et al., 2012; van der Bles et al., 2019). This could lead to a failure to take necessary precautionary action, since greater uncertainty in a prediction or projection is sometimes associated with higher expected damages (Lewandowsky et al., 2015). Climate scientists therefore need to be able to communicate the uncertainty in a SCF, without undermining its perceived credibility and salience.

## 1.3 The Communication of SCF and Science-Society Relations

The difficulties that stakeholders have in understanding, trusting in and using SCF have prompted geographers and other social scientists to identify ways of improving their communication. One line of investigation identifies systematic biases in how stakeholders interpret SCF and develops presentation formats (language and visualisations) and dissemination approaches (verbal briefings, workshops) that eliminate these biases (Coventry and Dalgleish, 2015; Hansen et al., 2011a; Roncoli, 2006; Taylor et al., 2015). However, whilst stakeholders need to understand the content of a SCF, this does not mean that they will recognise the information as credible and salient in decision-making (Cash et al. 2006, Lemos et al. 2012). This is because scientific knowledge about the world is always incomplete (Stirling, 2010) and can become contested when stakeholders recognise the uncertainties that are associated with a SCF (Lane et al., 2011). For example, a stakeholder might have a low tolerance for uncertainty, which might prevent them from using SCF in certain situations (Taylor et al., 2015). Removing systematic biases in how stakeholders interpret SCF therefore does not change the perceived credibility and salience of a SCF.

Moreover, non-scientists often have specialist knowledge and competencies that can improve how SCF are used and communicated (Lemos et al., 2012). For example, all stakeholders understand the context in which they make decisions with a forecast (Dilling and Lemos, 2011) and many organisations measure and collect data on weather-related impacts that can be used to create bespoke impact-based forecasts (Buontempo et al., 2017). Scientists can work with the competencies and knowledge that a stakeholder has so that they can customise SCF to their decision-making needs (Falloon et al., 2019). Efforts to improve the communication of SCF therefore cannot presuppose a neat distinction between scientific and ‘lay’ knowledge (Callon,1999).

As a result, a second approach to improving the communication of SCF aims to identify aspects of the decision-making environment that either constrain or promote their uptake and usage (Dilling and Lemos, 2011). This area of research often involves engaging with and involving stakeholders in the development of SCF, so that a forecast can be tailored to their decision-making needs (Vincent et al., 2018). It is also associated with efforts to develop a market for climate services, which are decision-making aids that provide stakeholders in the public and private sectors with timely, targeted climate information (Vaughan and Dessai, 2014). This area of research therefore tries to include the knowledge and competencies of stakeholders in the development of climate services in order to make SCF more usable (Lemos et al., 2012).

However, this way of conceptualising the communication process overlooks how scientists are themselves 'users' of SCF as well as the 'producers.' Climate scientists who run climate models are involved in interpreting model outputs (Lahsen, 2005) and communicating SCF to different stakeholders. Similarly, 'users' or 'decision-makers' are also involved in interpreting what a forecast means and in choosing if and how they should communicate the message they have received on to other people. Efforts to customise SCF to the needs of decision-makers are therefore still often based upon an opposition between scientists who produce SCF and non-scientists who use them.

The common assumption that underlies both of these approaches to improving the communication of SCF is that there is a lack of confidence in scientific knowledge and scientific institutions (Callon, 1999). Either stakeholders do not understand a forecast and therefore perceive SCF to be unusable and/or untrustworthy, or stakeholders do not think that a SCF meets their decision-making needs and reject it as unusable and/or untrustworthy. In both cases there is a clear demarcation between scientists and non-scientists in how geographers, other social scientists and climate scientists conceptualise the communication of SCF. However, STS scholars (Callon, 1999; Jasanoff, 2004) and geographers (Lane et al., 2011; Whatmore, 2009) have criticised the idea that there is an irreducible opposition between scientists and 'laypeople' or scientific and 'lay' knowledge. Instead, all people have different kinds of expertise, whether it is in seasonal climate forecasting, farming or writing newspaper articles, that may or may not contribute towards understanding and

addressing the issue of concern (Callon, 1999; Latour, 2005a; Whatmore, 2009). This suggests that there is a need to develop a way of conceptualising the communication of SCF that does not divide the process up into a group of scientists who produce the forecast on the one hand and a group of non-scientists who use it on the other.

As a result, this thesis aims to reimagine how geographers, social scientists and climate scientists think about and practice the communication of SCF. Instead of looking at how a forecast is presented or at the decision-making environment in which it is used, it will follow a forecast, tracing the associations that hold or fail to hold the message together. To do this, the thesis will draw upon material semiotic analyses in STS and geography, which treat objects as an effect of shifting relations between things (materials) and meanings (semiotics) (Law, 2008). This theoretical approach dissolves the conceptual distinction between scientists and non-scientists that sometimes characterises current efforts to improve the communication of SCF. It therefore redirects our attention to the issues that make a SCF difficult to understand, trust and use, rather than to what scientists or a specific stakeholder group think will make a forecast usable, credible and easy to understand. As a result, this thesis will address the following research aim and objectives:

AIM: To understand how the message of a SCF changes as it is communicated.

Objective 1: To explore the utility of material semiotic approaches for analysing the communication of SCF.

Objective 2: To develop a methodology for following the message of a SCF as it is communicated.

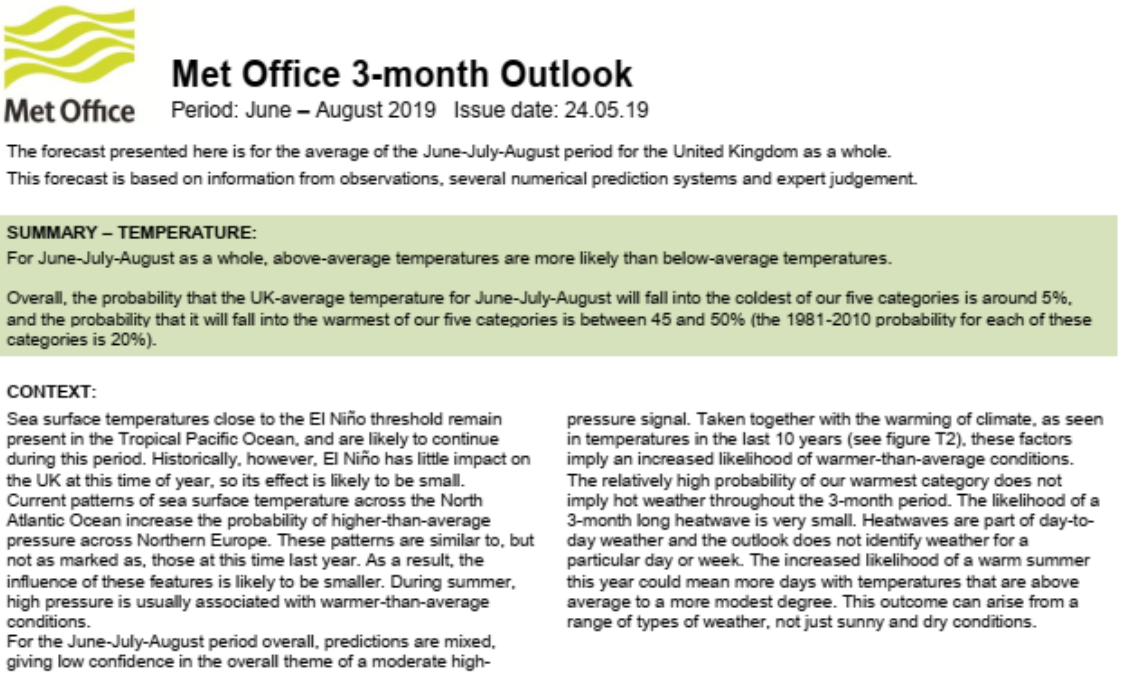
Objective 3: To suggest practical recommendations for reflecting on and reimagining the communication of SCF.

## 1.4 The Met Office's 3-Month Outlook

This thesis focusses on the 3-month outlook issued by the Met Office, which indicates probable trends in precipitation and temperature averaged over the whole of the UK for the next three months (Met Office, 2018b). An example of the 3-month outlook in the format that it was presented during the completion of this thesis is displayed in Figures 3 and 4 over the page. The Met Office refers to it as an outlook rather than a forecast because it is not only based on the Met

Office's own SCF but also on information from observations, SCF from other global long-range forecasting centres and expert judgement (Met Office, 2018b). It is made publicly available on the Met Office website each month, where it can be accessed by journalists and members of the public. It is also communicated in verbal briefings to a stakeholder group convened by the Department for Transport (DfT), a group of stakeholders in the UK energy sector and to contingency planners in the UK government, who anticipate and plan for risks that might disrupt the delivery of public services. A related outlook for winter weather-related transport impacts is also presented alongside the 3-month outlook in briefings for the transport stakeholder group.

*Figure 3- June-July-August 2019 Temperature Outlook*



Met Office

**Met Office 3-month Outlook**

Period: June – August 2019 Issue date: 24.05.19

The forecast presented here is for the average of the June-July-August period for the United Kingdom as a whole.
This forecast is based on information from observations, several numerical prediction systems and expert judgement.

**SUMMARY – TEMPERATURE:**

For June-July-August as a whole, above-average temperatures are more likely than below-average temperatures.

Overall, the probability that the UK-average temperature for June-July-August will fall into the coldest of our five categories is around 5%, and the probability that it will fall into the warmest of our five categories is between 45 and 50% (the 1981-2010 probability for each of these categories is 20%).

**CONTEXT:**

Sea surface temperatures close to the El Niño threshold remain present in the Tropical Pacific Ocean, and are likely to continue during this period. Historically, however, El Niño has little impact on the UK at this time of year, so its effect is likely to be small.
Current patterns of sea surface temperature across the North Atlantic Ocean increase the probability of higher-than-average pressure across Northern Europe. These patterns are similar to, but not as marked as, those at this time last year. As a result, the influence of these features is likely to be smaller. During summer, high pressure is usually associated with warmer-than-average conditions.
For the June-July-August period overall, predictions are mixed, giving low confidence in the overall theme of a moderate high-pressure signal. Taken together with the warming of climate, as seen in temperatures in the last 10 years (see figure T2), these factors imply an increased likelihood of warmer-than-average conditions. The relatively high probability of our warmest category does not imply hot weather throughout the 3-month period. The likelihood of a 3-month long heatwave is very small. Heatwaves are part of day-to-day weather and the outlook does not identify weather for a particular day or week. The increased likelihood of a warm summer this year could mean more days with temperatures that are above average to a more modest degree. This outcome can arise from a range of types of weather, not just sunny and dry conditions.

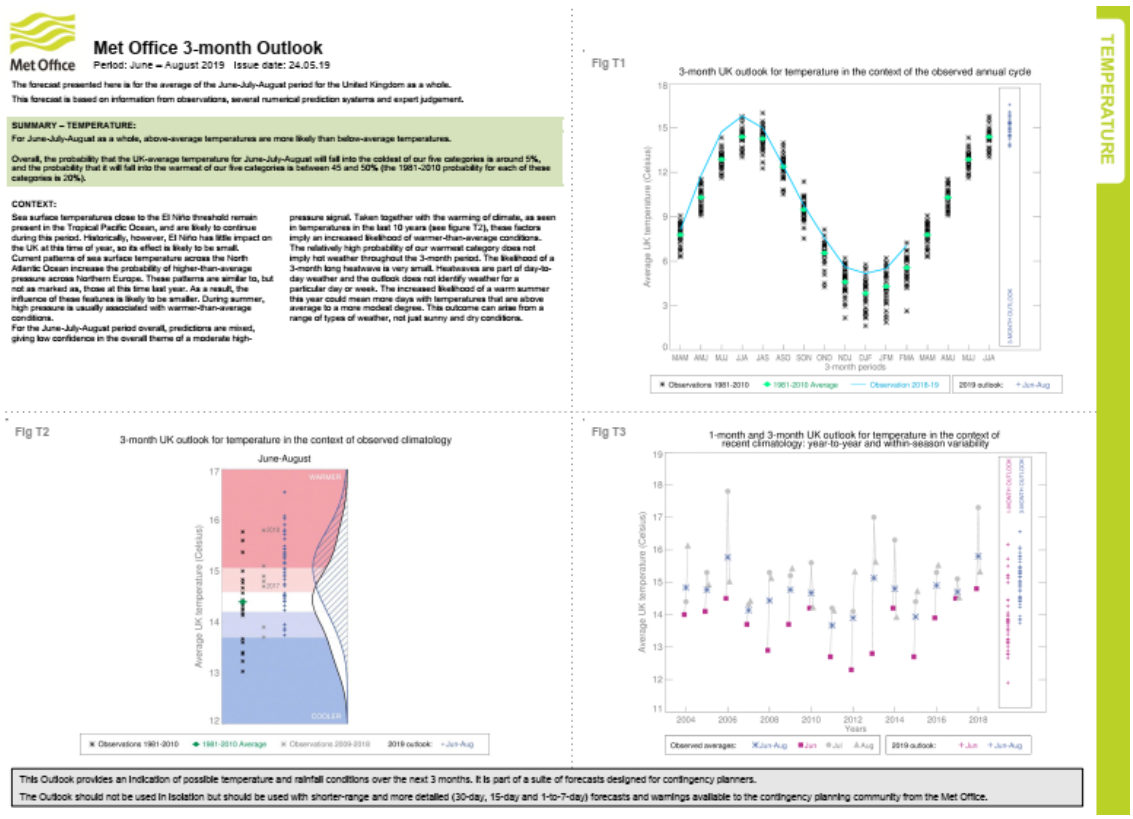



*Figure 4- June-July-August 2019 Precipitation Outlook*

# Met Office 3-month Outlook

Period: June– August 2019 Issue date: 24.05.19

The forecast presented here is for the average of the June-July-August period for the United Kingdom as a whole.
This forecast is based on information from observations, several numerical prediction systems and expert judgement.

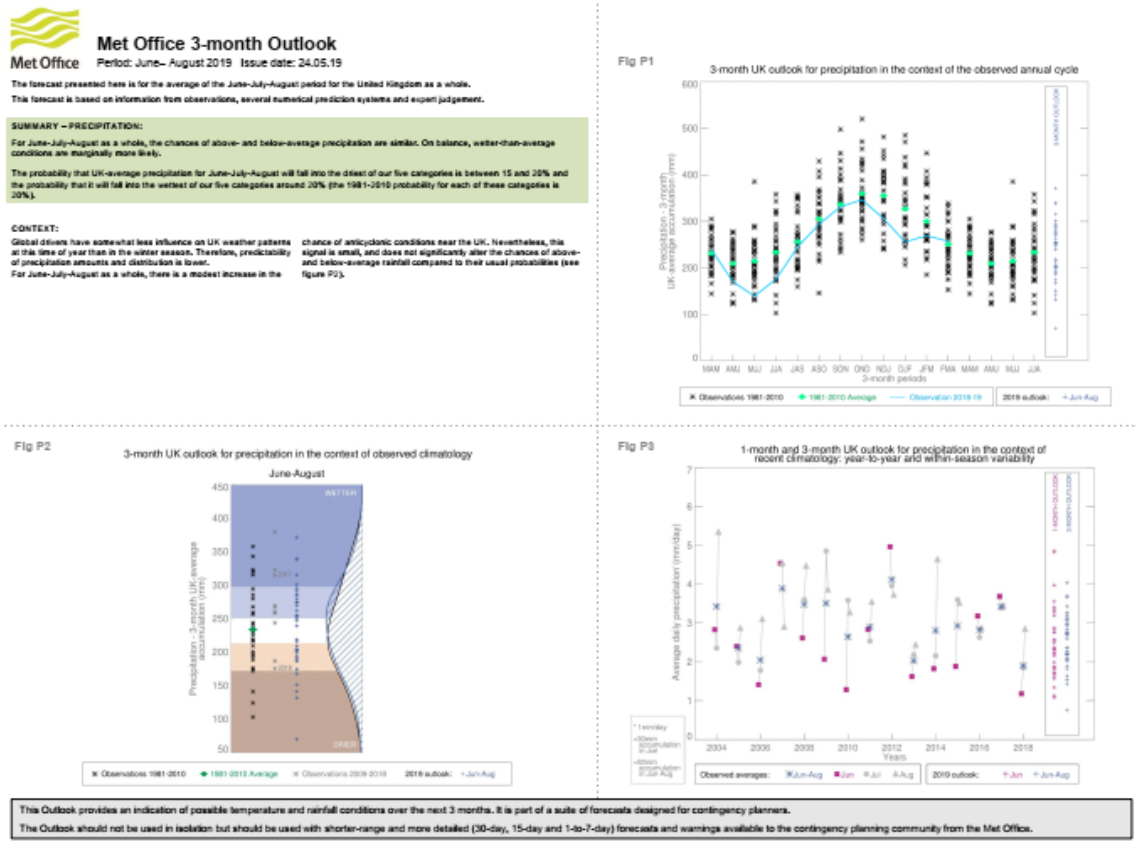
**SUMMARY – PRECIPITATION:**

For June-July-August as a whole, the chances of above- and below-average precipitation are similar. On balance, wetter-than-average conditions are marginally more likely.

The probability that UK-average precipitation for June-July-August will fall into the driest of our five categories is between 15 and 20% and the probability that it will fall into the wettest of our five categories around 20% (the 1981-2010 probability for each of these categories is 20%).

**CONTEXT:**

Global drivers have somewhat less influence on UK weather patterns at this time of year than in the winter season. Therefore, predictability of precipitation amounts and distribution is lower.
For June-July-August as a whole, there is a modest increase in the chance of anticyclonic conditions near the UK. Nevertheless, this signal is small, and does not significantly alter the chances of above- and below-average rainfall compared to their usual probabilities (see figure P2).




The 3-month outlook is suitable outlook to follow for three main reasons. Firstly, the UK Met Office is a World Meteorological Organisation (WMO) global long-range forecasting centre. This means that it has its own seasonal climate model, Global Seasonal Forecast Model 5 (GloSEA5) (MacLachlan et al., 2015), which produces SCF for all regions of the world according to guidelines and standards set by the WMO. As a consequence, staff employed by the Met Office are not only involved in communicating the message of the 3-month outlook but also in assembling the data and information that are needed to form the message. Following the 3-month outlook therefore produces a broader view of the communication process, from the point at which scientists review observations and model outputs all the way through a journalist writing a newspaper article or a transport operator managing the operation of road, rail and aviation infrastructure.

Secondly, the 3-month outlook focusses specifically on the UK, where SCF have only been communicated to the public, the media and other stakeholders over the last 15 years (Graham et al., 2006). Other national meteorological services, such as those in Australia (Leith and Vanclay, 2015) or North-East Brazil (Pennesi, 2007a), have communicated SCF to water managers, farmers,

the media and the public since the 1990s. This is because seasonal climatic variability in tropical regions is more predictable than seasonal climatic variability in extratropical regions like the UK and Europe (Kumar et al., 2007). However, improvements in the accuracy of SCF for extratropical regions (Scaife et al., 2014) now mean that there is an increased interest in using SCF, both from stakeholders in business and government (Bruno-Soares et al. 2017) and from the UK public and media (Chadwick, 2010). Following the 3-month outlook therefore contributes our empirical understanding of how stakeholders in the UK respond to and use a type of climate forecast that they are not familiar with.

Finally, the 3-month outlook is communicated to an unusually wide range of stakeholders who have different expertise, competencies and concerns. On the one hand, this includes stakeholders who are familiar with making strategic plans and decisions one to three months ahead. For example, transport operators need to order in extra salt for clearing roads of snow and ice months in advance, since supply chains in the UK have lead times that can last weeks or months. These stakeholders resemble those who have benefitted from using SCF to mitigate climate-related risks in other parts of the world, such as large farms in Australia (Coventry and Dalgleish, 2015) or contingency planners in the USA (Wehrstedt et al., 2019). On the other hand, the 3-month outlook is made publicly available and is reported on by journalists in the UK media, who published 176 newspaper articles [2]quoting the 3-month outlook during the course of the fieldwork at the Met Office (Chadwick, 2010; Eden, 2011). Members of the public, journalists and editors inevitably have different concerns and competencies to a contingency planner working for the UK government or an energy manager working for a large business. For example, journalists need to make decisions on much shorter timescales than transport operators working for a local authority, in order to keep up with the 24-hour news cycle. Following the 3-month outlook therefore gives the researcher an opportunity to explore how a national meteorological service engages with such a diverse range of stakeholders and manages their expectations.

[2] This statistic is based on a LexisNexis search for three month* OR seasonal forecast* OR contingency planners AND met office between 01/09/2018 and 31/01/2020 for all UK newspapers.

## 1.5 Outline of the Thesis

*Chapter 2* critically reviews various literatures on the communication of weather and climate forecasts. It identifies two idealised models of communication within these literatures, which treat SCF either as information that is transmitted to an end-user or as a product or service that is delivered to an end-user. It discusses the limitations of these two theoretical models and proposes an alternative theoretical framework that treats the message of a SCF as a web of associations between things (materials) and meanings (semiotics) (Law, 2008). *Chapter 3* introduces the background to the study by discussing the science of seasonal climate forecasting and by reviewing empirical research into usage of SCF in the UK and Europe. It also outlines the historical development of seasonal climate forecasting for the UK at the Met Office and explains how the Met Office currently communicates the 3-month outlook. *Chapter 4* explains how this thesis can be described as a multi-sited ethnography (Hine, 2007; Marcus, 1995) that follows the relations that constitute the message of the 3-month outlook, rather than placing the 3-month outlook in a pre-defined cultural or institutional context. It also introduces the research methods that were used to follow the message of the 3-month outlook.

The three discussion chapters of this thesis use the material semiotic approaches (Law, 2008) introduced in Chapter 2 to follow the 3-month outlook as it is communicated. *Chapter 5* uses the concept of translation (Callon, 2007), which is the process of making associations between things and meanings, to understand how meteorological data, people, and other materials form the message of the 3-month outlook. I argue that stakeholders understand and use the 3-month outlook whenever its role and identity is defined in a way that coordinates and aligns the interests of both the Met Office and its stakeholders.

*Chapter 6* uses the concept of ontological multiplicity (Mol, 2002; 1999) to understand why different versions of the message emerge as the 3-month outlook is communicated to different stakeholders. This concept treats an object like the 3-month outlook not as an external entity that can be known from different perspectives but as an object that exists in multiple yet related versions. I argue that the different versions, or 'enactments' (Mol, 2002), of the 3-month outlook are associated with different understandings of what a normal climate is and what a normal climate ought to 'do.' The extent to which these

enactments overlap and conflict with each other explains why some stakeholders find the 3-month outlook easier to understand and use than others.

*Chapter 7* synthesises the conclusions of the previous two chapters by focussing on how the message of the 3-month outlook holds together as the outlook is communicated in changing circumstances. Using the concept of topologies (Law and Mol, 2001; Mol and Law, 1994), I argue that the relations that constitute the message of the 3-month outlook exist in different 'shapes' depending on where and when the outlook is communicated. For example, I argue the 3-month outlook simultaneously exists as a region in time and space, as a network of documents and graphs and as a fluid mixture of conversations and emails. The stability of the message depends on Met Office staff coordinating the different topologies of the 3-month outlook, so that the message remains continuous as it is communicated.

Finally, *Chapter 8* concludes by critically reflecting on the key empirical and theoretical findings of thesis and by suggesting some practical recommendations for improving the communication of seasonal climate forecasts. It offers some concluding reflections upon how this thesis was co-produced with staff employed by the Met Office and on what this means for geographical research that is co-produced with other non-academic stakeholders. It also recommends some possible directions for future geographical research into the communication of weather and climate forecasts.

# Chapter 2. Theoretical Framework

## 2.1 Introduction

Any effort to understand and improve the communication of scientific knowledge involves asking questions about how scientific knowledge should be communicated, why it should be communicated and to whom (Demeritt and Nobert, 2014; Tsouvalis and Waterton, 2012). The answers that scholars give to these kinds of questions often reflect norms about what constitutes 'good' science communication (Demeritt and Nobert, 2014) and about the relationship between science and society (Callon, 1999). These norms are also often linked to different philosophical assumptions that are made about the communication process, including ontological assumptions about what a SCF is and epistemological assumptions about how we know and represent variations in seasonal climate (Goldman et al., 2018). The assumptions that scholars make about the nature of science-society relations therefore produce different ways of conceptualising how SCF are communicated.

As a result, this chapter explores and critiques the theoretical models that geographers, other social scientists and climate scientists use to conceptualise how SCF are communicated. These models and their underlying ontological (what a SCF is), epistemological (how we know about a forecast), normative (how a forecast should be communicated) assumptions are outlined in Table 1 over the page. Each theoretical model is idealised and not all research into the communication of weather and climate forecasts neatly fits into each model. Nevertheless, by creating these theoretical models I intend to summarise the philosophical assumptions that shape research into the communication of weather and climate forecasts, in order to clarify and guide the following discussion.

*Table 1- Theoretical Models of SCF Communication*

| **Model of Communication** | **Ontology (what a SCF is)** | **Epistemology (how people know about SCF)** | **Norms (how SCF should be communicated)** |
|---|---|---|---|
| Transmission Model | Information that is transmitted from a scientist to an end-user. | Scientific experts explain what the message is to an end-user. | The message should be communicated without distortion or bias. |
| Delivery Model | A service or product that is delivered to an end-user. | Forecast providers customise the message so that it can be understood and recognised as usable by decision-makers. | The message should be credible, legitimate and salient. |
| Material Semiotics | An effect of shifting relations between things (materials) and meanings (semiotics). | Forecasts are known through practices, events and activities. | Different versions of the message should hold together as the forecast is communicated. |

The first section of this chapter looks at two conceptual models that are used to theorise the communication of SCF. These models portray communication as either a process of transmitting information or delivering a product or service. I suggest that these two models are problematic because they are based on conceptual and normative assumptions that create an opposition between scientific and non-scientific knowledge. I conclude by arguing that there is a need to conceptualise the communication process in a way that focuses on the issues that both scientists and non-scientists are concerned with, rather than on correcting misinterpretations of a forecast or promoting the use of a product or climate service.

The second section draws upon material semiotic approaches within geography and STS to develop an alternative theoretical framework for analysing the communication of SCF. This theoretical approach conceptualises SCF as an effect of relational, material and multiple practices (Law, 2008; Mol, 2002), rather than as an unchanging message that moves from a forecast provider to an end-user. It also aims to follow the message of a SCF, rather than analysing how the message is presented to an end-user or on the decision-making environment in which a forecast is used. I conclude by suggesting that material semiotic approaches might focus the communication of SCF on those for whom seasonal climate variability is a matter of concern (Lane et al., 2011; Latour, 2005b; Whatmore, 2009), rather than on accurately transmitting information or delivering a product.

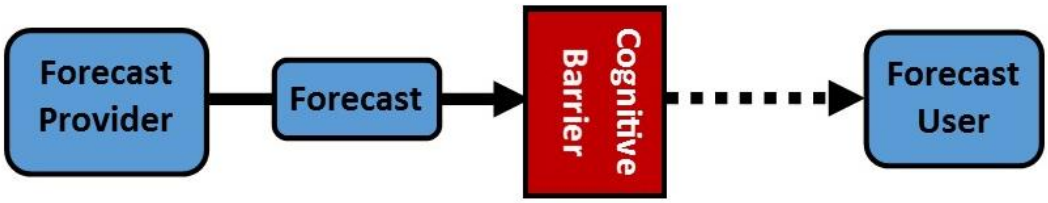
## 2.2 The Communication of SCF as Transmitting Information

Research into the communication of weather and climate forecasts sometimes defines communication as a **process of transmission.** For example, the following review of research into how farmers interpret uncertain climate information defines communication in this way:

*'To communicate is to transmit an idea so that it is satisfactorily understood and, typically, used to guide action.' (Marx et al., 2007, p. 47)*

This definition of communication as transmission is accompanied by a wider set of normative, ontological and epistemological assumptions (see Table 1) that form a theoretical model of how SCF should be communicated, why and to whom (Demeritt and Nobert, 2014). For example, a definition of communication as transmission usually proceeds from the belief that good communication is about transmitting ideas without any bias, distortion or misunderstanding (Demeritt and Nobert, 2014). This produces a linear view of the communication process, in which scientists send a self-contained message out to an end-user. The end-user then decodes the information in a SCF and uses it to inform a decision that preferably has a positive economic outcome (Crane et al., 2010). Successful communication therefore depends on removal and/or correction of systematic biases that prevent stakeholders from understanding the message of a SCF.

*Figure 5- A Transmission Model of Communication*




Most research that defines communication as a process of transmission draws upon theories of risk perception and communication developed within cognitive psychology (Kahneman and Tversky, 1974; Slovic, 2000). It also uses experimental studies and surveys to analyse how people process probabilistic weather and climate information (Joslyn and Savelli, 2010; Morss et al., 2008). This work has evidenced that the presentation format of SCF, such as the language (Coventry and Dalgleish, 2015) and graphics used, (Daron et al., 2015; Lorenz et al., 2015; Taylor et al., 2015) or the dissemination of forecasts in individual and group settings (Marx et al., 2007b; Roncoli et al., 2009), affect comprehension by stakeholders. In particular, these studies show that there are cognitive biases that produce systematic errors in how stakeholders interpret probabilistic information. These biases are one reason why stakeholders either fail to take precautionary action or take maladaptive actions that do not mitigate the impact of seasonal climatic risks (Roncoli et al., 2009; Taylor et al., 2015).

Furthermore, interviews with farmers (Hansen et al., 2004) and surveys of the British (Taylor et al., 2014) and American public (Kempton et al., 1996) suggest that stakeholders interpret climate forecasts and projections in light of pre-existing beliefs about the how the climate varies or changes known as mental models (Hansen et al., 2004; Morgan et al., 2002). These mental models can reduce probabilistic forecasts to a deterministic forecast of a season being hot or cold, or wet or dry, as stakeholders reinterpret new information to fit their own understanding of how the seasonal climate varies. For example, a study of how farmers use SCF in Florida found that they interpreted SCF deterministically because they conceptualised climatic variability in terms of changes in short-term weather events at a localised scale (Hansen et al., 2004). This contrasted with the climate scientists in the same study, who had a much longer-term, global perspective on how the climate varied on seasonal timescales. Prior

assumptions and attitudes about how the climate varies therefore shape how stakeholders interpret and use SCF (Roncoli, 2006).

Scholarship that is based upon a transmission model of communication has generated important insights into how people process uncertain information about the seasonal climate. This represents a valuable contribution to our understanding of how SCF are communicated, since a forecast is ultimately worthless if people cannot understand what it means. It has also prompted additional research that aims to identify and test presentation formats (Coventry and Dalgleish, 2015; Taylor et al., 2015) and dissemination approaches (Roncoli et al., 2009) that might remove systematic biases in how stakeholders interpret SCF. Nevertheless, a transmission model of communication is based on ontological, epistemological and normative commitments that create an opposition between scientific and non-scientific knowledge (Callon, 1999). This results in an excessive focus on the accurate transmission of information, rather than on providing other stakeholders with knowledge that addresses the issue of concern, such as the impact of severe winter weather upon transport infrastructure.

One example of these problematic assumptions underpinning a transmission model of communication is the ontological separation that it makes between science on the one hand and society on the other. This can be seen in the language that is used to describe how SCF are communicated. Forecasts are 'transmitted' or 'disseminated' by a forecast provider to an 'end-user' (Marx et al., 2007). A gap needs to be crossed as a SCF travels from science to society. However, the existence of this ontological dualism has been extensively critiqued by scholars within STS (Jasanoff, 2004; Latour, 1993), anthropology (Descola and Palsson, 1996) and geography (Castree et al., 2014; Mahony and Hulme, 2016). This is because scientific and social activity are not separate entities but processes that mutually constitute, or 'co-produce,' each other (Jasanoff, 2004). For example, a climate scientist running the computer model that is used to create a SCF is as much a user of the forecast as they are a producer (Lahsen, 2005). This is because they are involved in interpreting the data that is used to create a SCF and in choosing what information to communicate on to other people. Similarly, the 'end-user' of a SCF shapes the

production of a forecast through the assumptions that scientists make about the informational needs of a stakeholder (Daipha, 2012) and in the choices that a stakeholder also makes when communicating a forecast on to other people (Morss et al., 2005). It is therefore unhelpful to conceptualise the communication of a SCF as a linear process of transmitting a message to an 'end-user.'

One could argue that a distinction still needs to be made between the 'providers' and 'users' of a forecast because forecast providers have scientific expertise that non-scientists do not have. For example, many stakeholders in the UK and Europe are not familiar with using SCF (Bruno Soares et al., 2017) and are therefore likely to be unable to understand the message without climate scientists first explaining how a forecast ought to be interpreted. However, whilst climate scientists have expertise that laypeople do not have, they are generally only experts within the domain of climate science. For example, climate scientists working for a national meteorological service might not have the expertise needed to explain a forecast clearly to a contingency planner or the expertise needed to develop a presentation format that is easy for a member of the public to understand. Similarly, the 'end-users' of a forecast might have relevant expertise, such as knowledge of when, where and how they make decisions, that could help forecast providers customise a forecast to their needs (Falloon et al., 2018). Expertise is therefore distributed symmetrically across the boundary between science and society (Callon, 1999; Collins and Evans, 2002) and not confined to the scientific community alone.

Moreover, a transmission model of communication assumes that scientific knowledge is a universal phenomenon that travels from one place to another without any cost or effort. The message of a SCF, once it is understood, will travel either because it is true and/or because the scientific methods used to produce a forecast are automatically transferable (Law and Mol, 2001; Shapin, 1998). However, ethnographic studies of scientific laboratories in the 1970s and 80s (Knorr-Cetina, 1981; Latour and Woolgar, 1979) challenged this universal view of science by highlighting how scientific data and theories were made in places. More recent ethnographies of meteorological institutions (Daipha, 2012; Fine, 2007; Sundberg, 2007) and communities of climate scientists (Lahsen,

2005; Mahony and Hulme, 2012; Shackley and Wynne, 1996) support this localised view of science. They all emphasise how skills, unspoken 'tacit' knowledge, organisational routines and technical infrastructures shape the production of weather and climate forecasts, as well as the meteorological context. SCF are therefore not universal representations of the future climate but knowledge that is embedded in the situated actions of people, data and technologies.

Furthermore, SCF are also used and interpreted in places. Ethnographies of stakeholder groups that regularly use SCF around the world, such as water managers (Rayner, 2019; 2017; Rayner et al., 2005) and farmers (Crane et al., 2010; Pennesi, 2007a) suggest that stakeholders often do not find SCF useful, even when the forecasts are accurate. This is because organisational routines (Rayner et al., 2019), regulatory constraints (Dilling and Lemos, 2011) and a mismatch between temporal and spatial scale of a forecast and decision-making needs (Hansen et al., 2011b) often make SCF unusable. The mere availability of a SCF therefore does not guarantee that a stakeholder will find it credible or salient, even if they understand the message (Bruno Soares and Dessai, 2016b; Cash et al., 2006). As a result, a transmission model of communication, with its universal view of scientific knowledge, does not adequately describe the local contexts in which SCF are made and used.

Finally, a transmission model of communication assumes that the purpose of communication is to inform an end-user, who then uses a SCF to guide an action that preferably has a positive social or economic outcome (Crane et al., 2010; Pennesi, 2007a). However, this view of the end-user represents decision-making as a mechanistic process made by an individual (Crane et al., 2010). This does not reflect the complexity of the decisions that are made by stakeholders like farmers (Crane et al., 2010), contingency planners (Anderson, 2010) or water managers (Rayner et al., 2005), who often make decisions that cannot be reduced to a single, measurable economic outcome. Similarly, a narrow definition of usability can be used by scientific institutions to exclude stakeholders that might potentially benefit from using SCF. For example, Pennesi (2007a) argues that subsistence farmers in North-East Brazil were not treated as potential stakeholders by the Brazilian meteorological service because they did not use SCF in a way that generated a measurable economic

outcome. There is therefore a politics to how the usability of a SCF is defined that is not made explicit when communication is defined as a process of transmission.

In summary, a transmission model of communication rightly recognises that there are systematic biases in how stakeholders interpret and make decisions with SCF. It is therefore important to assess how stakeholders interpret the language and graphics used in a SCF, so that presentation formats can be developed that are easier for them to understand. Yet a transmission model of communication is based on an opposition between scientific and non-scientific knowledge. It focuses on educating stakeholders and correcting cognitive biases, whilst presupposing that stakeholders will trust and use a SCF once they understand what it means. However, empirical research into the uptake of SCF (Cash et al., 2006, Lemos et al., 2012) and research within STS (Callon, 1999; Sturgis and Allum, 2004) and geography (Lane et al., 2011) into the public understanding of science suggests that education alone will not help stakeholders recognise SCF as credible and salient. A different theoretical model of communication is therefore needed that is not based on a demarcation between science and society.

## 2.3 The Communication of SCF as Delivering a Product or Service

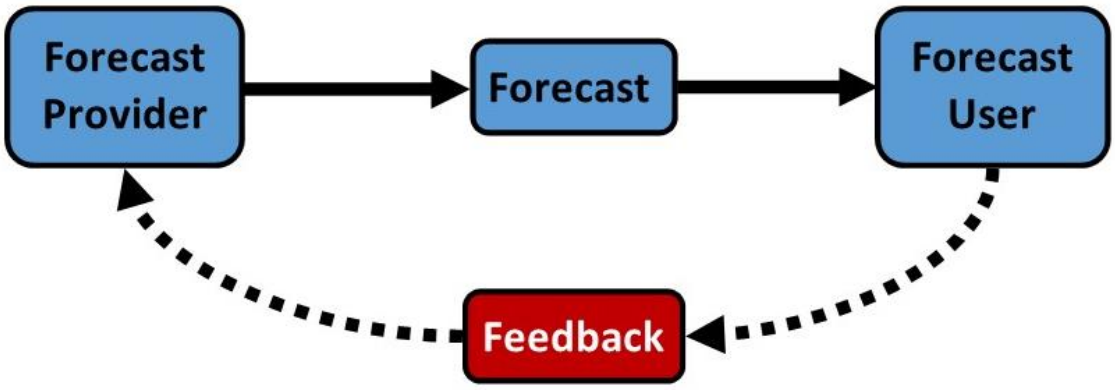
The second model found within research into the communication of weather and climate forecasts compares communication to **delivering a product or service.** For example, the following review of how organisations use climate information compares the process of transforming climate forecasts into usable information to a person choosing a product in a marketplace:

*'The production and use of [climate] information in the model is akin to a market place where all available information is potentially useful as produced (hence where usefulness is a necessary but not sufficient condition), but will only be usable as users 'pick it,' that is, as users effectively incorporate specific information into a decision process.' (Lemos et al., 2012, p. 789)*

According to this delivery model of communication, it is not enough to ensure that a stakeholder understands a SCF (Cash et al., 2006). This is because a stakeholder needs to believe that a SCF is trustworthy (credible), relevant to their decision-making needs (salience) and produced through fair and

transparent processes (legitimate) before they will use it to guide an action (Cash et al., 2003). Forecast providers therefore need to engage with stakeholders to build trust and learn about their decision-making processes (Falloon et al., 2018). This helps a forecast provider customise a forecast so it can be 'fitted' into the decision-making context in which it needs to be used (Lemos et al., 2012).

*Figure 6- A Delivery Model of Communication*




Research that is based upon a delivery model of communication has often been driven by businesses and policymakers who want to use seasonal climate information to manage climate-related risks (Haines, 2019; Vincent et al., 2018). This has led to the development of climate services that provide stakeholders with timely, targeted information for decision-making, usually in the form of tools, products, websites or bulletins (Vaughan and Dessai, 2014). These are developed by either consulting or collaborating with stakeholders so that a service can be tailored to a client's decision-making needs (Vincent et al., 2018). Much of this research therefore focusses on identifying institutional barriers that prevent forecast user-producer interactions (Buizer et al., 2016; Meadow et al., 2015) and organisational approaches that are successful in overcoming them (Bremer and Meisch, 2017). This has created an interdisciplinary literature on how climate information, including SCF, can be transformed into products or services that 'fit' the decision-making contexts in which the information is used (Bremer and Meisch, 2017, Lemos et al., 2012).

Much of this work draws conceptually upon ideas within STS (Bremer and Meisch, 2017), especially the notion of co-production (Jasanoff, 2004). However, these concepts are sometimes picked up and reapplied without acknowledging their theoretical origins or their contested nature (Daly, 2016;

Goldman et al., 2018). The notion of co-production was originally used within STS to describe the mutual constitution of nature and culture (Jasanoff, 2004; Latour, 1993). For example, natures *and* cultures shape both how we imagine and represent changes in climate and how we physically live with and adapt to changes to climate (Hulme, 2015). The concept of co-production in STS therefore challenges the ontological separation of nature and culture that often characterises Western thinking (Latour, 1993) and highlights the relationships that exist between knowledges, norms and ontologies (Goldman et al., 2018). Yet the concept of co-production has been reinterpreted by some geographers and social scientists to refer to the integration of multiple knowledges through engaging with stakeholders who use SCF (Bremer and Meisch, 2017; Daly, 2016). Although this definition of co-production promotes two-way forms of communication in a way that a transmission model of communication does not, it still ignores the ontological and normative dimensions of how the term was originally used by STS scholars (Goldman et al., 2018). This is because co-production is reduced to an epistemological process of integrating knowledges, rather than a process that also generates questions about what a SCF is (ontologies) and how it should be used and communicated (norms).

As a consequence, a delivery model of communication replicates some of the conceptual and practical problems that are associated with a transmission model of communication. This is because a focus on the integration of knowledges means that it still maintains an ontological separation between science on the one hand and society on the other (Callon, 1999). SCF move from a scientist who provides the service to a client who uses the service (Lemos et al., 2012). Even if the idea of delivering a service recognises the need for dialogue in communication, it is still the scientific community that ultimately produces a forecast. A delivery model of communication therefore does not avoid the ontological separation that is often made between science and society.

Moreover, maintaining an ontological separation between scientific and social activity produces a further distinction between universal scientific knowledge and localised ‘lay’ knowledge. Although a delivery model of communication recognises that non-scientists have expertise or competencies that can help scientists customise a forecast to their needs, it still presumes that stakeholders

will use a SCF once they recognise its credibility, salience and legitimacy (Cash et al., 2003; Lemos et al., 2012). However, credibility, salience and legitimacy are not inherent characteristics of scientific knowledge but relational constructs that are negotiated between people that make, use and communicate SCF (Daly, 2016; Wynne, 1992). For example, ethnographic studies of how subsistence farmers in North-East Brazil use SCF suggest that the uptake of forecasts has as much to do with the trust that farmers place in the Brazilian government as it does with trust in scientific knowledge (Pennesi, 2007a; Taddei, 2014). In this case, transparently communicating the uncertainty in a forecast or providing information about the accuracy of a SCF would not change the perceived credibility of the message. This is because the perceived untrustworthiness of the forecast is bound up with how subsistence farmers relate to the political institutions that are involved in its communication. A delivery model of communication therefore assumes that a SCF carries its own universal salience and credibility, when these attributes emerge out of relationships between scientific institutions and their stakeholders.

Finally, reducing communication to a question of integrating different knowledges can obscure the ethical and political questions that are raised when co-producing a usable SCF. Efforts to co-produce climate services sometimes proceed from the assumption that there is a 'usability gap' that must be narrowed by customising SCF to a stakeholder's needs (Lemos et al., 2012). Empirical research into the uptake of SCF in the UK and Europe does suggest that a widespread interest in using them does not always correspond to their actual use in decision-making (Bruno Soares et al., 2017; Dilling and Lemos, 2011). However, these findings do not necessarily justify the claim that we need to make SCF more usable. It may be the case that SCF should not be used to make certain kinds of decisions. For example, water companies regularly make decisions that could have socially and economically costly outcomes, such as people losing their water supply (Lopez and Haines, 2017). Placing too much trust in a SCF could therefore result in a decision being made that has serious consequences for people's livelihoods. Similarly, trying to increase the usability of a SCF at the expense of other considerations, such as communicating the full range of uncertainty in a forecast, could be misleading (Stephens et al., 2012). As a result, it is important to critically reflect upon who is defining notions of

usability and for what purpose these definitions are being used in order to ensure that stakeholders benefit from using SCF (Daly, 2016; Pennesi 2007a).

A delivery model of communication does address some of the problems that are associated with a transmission model of communication by emphasising the importance of trust and dialogue in communication and by incorporating expertise of non-scientists into development of SCF. However, treating SCF as a product or service that is delivered to a client still maintains an asymmetrical relationship between scientists and non-scientists. Stakeholders might have local knowledge that can improve how a SCF is communicated, yet they are still the 'users' of a forecast, rather than stakeholders who are equally involved in interpreting and communicating the message. Moreover, conceptualising the communication process in this way can also produce instrumental forms of co-production, where the involvement of non-scientists is dependent on them agreeing with what forecast providers think is a usable seasonal climate forecast. A different model of communication is therefore needed that includes all stakeholders for whom seasonal climate variability is a matter of concern (Lane et al., 2011; Latour, 2005b; Whatmore, 2009) rather than the forecast provider's definition of the problem.

## 2.4 The Communication of SCF and Material Semiotics

One theoretical tradition that can be used explore and reimagine the communication of SCF is material semiotics (Law, 2008). This is a family of methodological and philosophical approaches that maintains that practices in the social world are simultaneously semiotic (because they are relational and create meanings) and material (because they include material, physical things) (Law, 2008). It includes actor-network theory (ANT) (Callon, 2007), feminist STS scholarship (Haraway, 1988) and 'post-ANT' work that develops and addresses critiques of earlier material semiotic approaches (Law, 1999). Moreover, the emphasis on treating nature and society as relational effects within material semiotics resonates with geographical work on relational understandings of space and place (Harvey, 1996; Massey, 1994) and geography's history of studying human-environment interactions (Demeritt, 2009). Geographers have therefore used material semiotic approaches to study of wide variety of topics, including conservation approaches to managing biodiversity (Whatmore, 2002), biosecurity and the circulation of viruses

(Hinchliffe et al., 2013), the governance of water infrastructure (Lavau, 2013) and the growth of offshore finance (Allen, 2016).

According to STS and geographical scholarship that adopts a material semiotic approach, explanatory or foundational categories like ‘science’ and ‘society’ do not determine how a SCF is communicated (Law and Singleton, 2014). Instead, concepts like the ‘end-user,’ ‘forecast providers’ or the ‘decision-making context’ are a consequence or an effect of shifting relations between people, data and other materials. This means that material semiotic approaches differ from forms of social analysis that presuppose a distinction between science and society (Callon, 1999; Goldman et al., 2016; Law and Singleton, 2014). Any model of communication based on concepts from material semiotics therefore dissolves the producer-user, scientist-non-scientist binaries that characterise the transmission and delivery models of communication discussed in Sections 2.2 and 2.3.

Furthermore, material semiotic approaches maintain that it is important to address questions of ontology (how things exist) as well as epistemology (how we know about the world). Efforts to improve the communication of SCF often focus on identifying language and graphics that are easy to understand or on customising a forecast so that it meets a stakeholder’s decision-making needs. Both transmission and delivery models of communication therefore presume that we already know what constitutes the message of a SCF. However, if objects are a web of shifting social and material relations, then researchers cannot simply focus on the knowledge contained within a document or a visualisation of a SCF. Instead, one needs to understand how the message of a SCF comes into existence, or its ontology. Material semiotic approaches can therefore provide a more detailed and nuanced account of how the message of SCF changes by attending to questions of ontology as well as epistemology.

Finally, material semiotic approaches might also help identify issues that matter to the stakeholders who use SCF. Sometimes efforts to co-produce SCF can be motivated by a desire to promote the uptake or usage of a forecast, rather than on answering the questions that a stakeholder is asking (Goldman et al., 2018; Vincent et al., 2018). This is because delivery and transmission models of communication privilege the role that certified experts, such as academic climate scientists and social scientists, play in the communication of scientific

knowledge over the needs, competencies and knowledge of non-certified experts, such as journalists, contingency planners, transport operators and energy managers (Callon, 1999; Lane et al., 2011). However, material semiotics flattens out this hierarchy by focussing on those for whom seasonal climatic variability is a matter of concern, rather than on maintaining trust or confidence in academic or scientific institutions (Callon, 2007; Lane et al., 2011; Law, 2008). This is because knowledge and expertise is treated as an effect of relations that constitute scientific and social activity, rather than as information that travels from science to society (Law, 2008). Reimaging the distribution of expertise therefore might make it easier to identify issues that make a seasonal climate forecast difficult for stakeholders to use or understand.

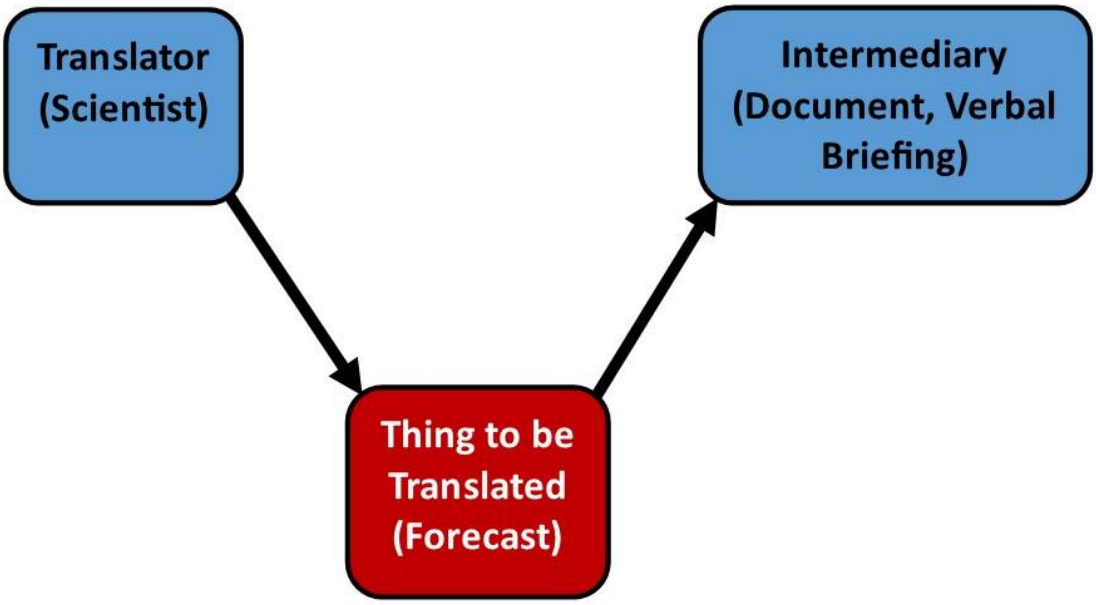
### 2.4.1 The Translation of SCF and Actor-Network Theory

Material semiotics is often associated with the theoretical tradition in STS called actor-network theory (ANT). This is not a 'theory' as such, since it aims to describe social and natural phenomena rather than explain them (Law, 1992). Instead, it is a family of methodological and philosophical sensibilities that treat everything in the social and natural world as the effect of shifting associations or 'actor-networks' (Law, 1992; Michael, 2016). This means that ANT focusses on following actors (Callon, 2007; Latour, 1987) whether they happen to be people, materials or ideas, so that the researcher can trace the complexity and detail of relationships that form the world around us (Michael, 2016). ANT therefore aims to produce descriptions of the associations between both human and non-human actors, rather than explanatory frameworks that appeal to taken-for-granted categories like the 'economy' or 'society' (Michael, 2016).

Unlike linguistic or literary theories of translation, ANT uses the metaphor of translation to follow the movement of ideas and objects through a network (De Wit et al., 2018) (see Figure 5). Firstly, there is a translator, something that is translated and a medium into which the translation is inscribed. For example, a broadcast meteorologist (the translator) might communicate a weather forecast (the thing that needs to be translated) by presenting it on the television (the 'intermediary'). Translation is therefore a triangular process that involves these three different actors and is dependent on past translations (Callon, 1990). It is also a process that implies definition, since the thing that needs to be translated must be defined in a text, technical object, embodied skills or whatever the

intermediary might be (Callon, 1990). A 'sociology of translation' (Callon, 2007) therefore involves tracing processes of mutual definition and inscription as an actor-network is assembled.

*Figure 7- Communication as Translation*




Moreover, the process of translation outlined within early accounts of ANT is also a process that involves 'persuasion' and 'enrolment' (Callon, 2007). The translator who wants to make associations with another actor therefore needs to show the second actor that only they can only realise their interests. For example, a climate scientist might claim that a transport operator can only improve how they manage their road salt stocks by using a seasonal climate forecast. Early accounts of ANT therefore portrayed network building as a process of struggle, domination and persuasion (Callon and Latour, 1981).

Furthermore, early proponents of ANT argued that actor-networks grew through processes of extension. Scientists often maintain 'centres of calculation' (Latour, 1987), such as computer models or laboratories. These allow scientists to extend a network and gain an advantage over actors by mass-producing 'immutable mobiles' (Latour, 1986; Law, 1987). These mobile but stable objects, such as graphs, data, maps or money, organise knowledge in a way that makes it universally recognisable, which then allows theories and data to travel beyond where they were originally produced. As a result, the credibility of scientific knowledge was associated in early forms of ANT with the size and stability of an actor-network (Callon, 2007; Latour, 1987; Law, 1987).

Unlike transmission or delivery models of communication, the concept of translation discussed by various STS scholars (Callon, 2007; Latour, 1987; Law, 1987) emphasises how ideas and objects do not travel on their own. Instead, they need to be materialised to be picked up and transported elsewhere by intermediaries, such as people, infrastructure or goods (De Wit et al., 2018). For example, a SCF needs to be materialised through the intermediary of a document or a teleconference briefing for a stakeholder to receive the message. This material aspect of communication is not included within transmission and delivery models of communication, which only focus on assessing how a forecast is presented or the decision-making context in which a forecast is used. The concept of translation developed within early accounts of ANT therefore highlights the role that non-human actors play in the communication of SCF.

Furthermore, the notion of translation emphasises the role that transformation and movement play in the communication of SCF (De Wit et al., 2018). Literary and linguistic theories of translation recognise that accurate translation is a process fraught with difficulty even within the same culture or language (Hanks and Severi, 2014). This is because a translator must make unavoidable trade-offs between fidelity to the source text and ease of understanding for the target audience (Nida and Taber, 2003). However, the interpretation of translation within ANT goes beyond this to make the transformation of meaning an inherent part of translation. Drawing upon the work of the philosopher Michel Serres (1982), STS scholars who developed early forms of ANT (Callon, 1990; Latour, 1987; Law, 1987) denied the existence of external ‘barriers’ or ‘noise’ that disrupt communication. This is because the very act of communication is predicated on connecting two previously disparate phenomena together (Serres, 1982) by inscribing meanings into an intermediary (Callon, 1990). ‘Perfect translations’ are therefore impossible, since the process of mutual definition and inscription always involves picking up an idea or object and moving it somewhere else (Callon, 1990). The concept of translation in ANT therefore moves away from transmission and delivery models of communication by focussing on the transformation and movement of ideas.

Finally, the interpretation of translation developed in early forms of ANT recognises the political dimensions of communication. For example, the

following definition of translation given by (Callon and Latour, 1981) highlights how translation is linked to the exercise of power:

*'By translation we understand all the negotiations, intrigues, calculations, acts of persuasion and violence, thanks to which an actor or force takes, or causes to be conferred on itself, authority to speak or act on behalf of another actor or force.' (Callon and Latour, 1981: 279)*

Latour and Callon (1981) do not think that ideas and objects neutrally move across space, ready to be 'decoded' and used by an end-user (Demeritt and Nobert, 2014). They argue that the movement of ideas involves negotiation and struggle as new associations are forged between different actors (Callon and Latour, 1981). Objects like a SCF are not used simply because stakeholders recognise their inherent credibility, salience and legitimacy (Cash et al., 2003; Lemos et al., 2012). Instead, the credibility, salience and legitimacy of a forecast emerges out of struggles between different actors as they try to enrol each other's interests. The sociology of translation within early accounts of ANT therefore seeks to give answers to the questions of why ideas take root in some places and why they are rejected or radically transformed in others (De Wit et al., 2018).

As a result, Chapter 5 of this thesis uses the concept of translation to analyse how three versions of the 3-month outlook issued by the Met Office were communicated. These outlooks are the summer 2009 forecast, the July-August-September (JAS) 2019 outlook and the January-February-March (JFM) 2020 outlook. Through tracing the various translations of these three outlooks, I aim to identify instances in which the message of 3-month outlook is either rejected or changed as it travels from one place to another. Similarly, I also aim to identify convergent actor-networks in which all the interests of actors are aligned, enabling the 3-month outlook to move whilst keeping the overall message stable. This approach would highlight when and where the message of a SCF changes as it is communicated, without maintaining a conceptual separation between scientific and social activity.

### 2.4.2 The Ontological Multiplicity of SCF and Post-ANT

ANT's main contribution to social theory is its emphasis on how social and scientific activity are materially heterogeneous and relational (Law and

Singleton, 2014). For example, an object like a SCF is materially heterogeneous because it includes non-human actors, such as documents, graphs, meteorological observations and climate models, and it is relational because the message is generated as an effect of changing relations between these actors. Moreover, early accounts of ANT also recognised that the identity of actors changed over time as relations in a network shifted (Callon, 1990). For example, a contingency planner might summarise the message of a SCF in an email when communicating it to a colleague, rather than printing out the original document, slightly changing the content of the message. Early accounts of ANT therefore acknowledged that objects like a SCF could change their role and identity within an actor-network over time.

However, embedded within ANT is the suggestion that there might not just be ontological variability but also ontological multiplicity (Mol, 2002). Different actors might not just change their identities over time but also have multiple identities that co-exist alongside each other. This meant that early accounts of ANT overlooked the existence of actors that have multiple roles and identities within an actor-network (Law and Mol, 2001). 'Post-ANT' scholarship has therefore extended ANT's emphasis on the relationality and heterogeneity of objects to explore their multiplicity (Law and Singleton, 2014). Drawing upon the work of feminist STS scholars (Haraway, 1988) and anthropologists (Strathern, 1996), who maintain that scientific knowledge is partial and situated, STS scholars argued that objects are enacted through practices (Law, 1999; Mol, 2002, 1999). These produce multiple versions of an object alongside each other, rather than one version that is known or interpreted from different perspectives. However, the ontological multiplicity of objects does not mean that there is a plurality of objects. Instead, the different enactments of an object overlap and conflict with each other, creating an object that is both 'more than one and less than many' (Law, 1999: 9)

Perhaps the best example of post-ANT scholarship exploring the multiplicity of an object is the philosopher Annemarie Mol's (2002) ethnography of the disease arteriosclerosis in *The Body Multiple.* Mol (2002) notes how most people assume that different diagnostic techniques offer multiple perspectives on a single disease. For example, arteriosclerosis can be conceptualised as a single disease that is detected on a radiograph as decreased blood flow, as the

narrowing of blood vessels on a doppler radar and as grey-white material extracted in an operating theatre (Law, 2008). However, Mol (2002) argues that arteriosclerosis does not exist in isolation from the bodies, microscopes, interview techniques and radiographs that are involved in diagnosing the disease. It is not possible to separate out a knowing subject (the doctor) from an inert, passive object (the patient's body) when making a diagnosis. Instead, Mol (2002) argues that diagnostic techniques 'enact' or 'practise' multiple versions of arteriosclerosis at different places and times within the same hospital. Although arteriosclerosis is conceptualised as a single disease in medical textbooks or scientific papers, differences in how the disease is diagnosed in the pathology laboratory, the surgical ward and the outpatient clinic affect how patients are treated and what version of arteriosclerosis is taken seriously. Mol (2002) therefore proposes that a body with arteriosclerosis is not a single object that is known from different perspectives but a 'body multiple.'

Geographers have also used the concept of ontological multiplicity to study how the objects of scientific knowledge are enacted through practice, including the concept of resilience (Simon and Randalls, 2016), the freshness of food (Jackson et al., 2019) and water resources (Lavau, 2013). Much of this work has critiqued a tendency to treat objects as stable phenomena with contested representations, rather than as an object that enacts multiple arrangements of social and material relations. For example, the 'freshness' of food does not simply mean different things to different groups of people. Instead, different enactments of freshness make things happen by qualifying a food as tasty or healthy, affecting commercial competition and changing processes of place-making and ways of narrating personal biographies (Jackson et al., 2019). The concept of ontological multiplicity therefore grounds our knowledge of the world in how people live and act in the world. This removes the division between epistemological and ontological questions that sometimes characterises research by geographers and other social scientists into the communication of weather and climate forecasts (Goldman et al., 2018, 2016; Ingold and Kurttila, 2000).

Of particular relevance to this thesis are a series of studies on how the climate is enacted by scientists, policymakers and non-governmental organisation (NGO) workers on the one hand and local communities in Tanzania (Goldman

et al., 2016), Nepal (Nightingale, 2016) and Tibet (Yeh, 2016) on the other. For example, in Tanzania, Maasai pastoralists and NGO workers, scientists and policymakers enacted multiple versions of the same drought (Goldman et al., 2016). Scientists, policymakers and NGO workers linked the severity of the drought to precipitation measurements and regional averages. However, the Maasai linked the severity of the drought to changes in their ability to predict the weather, pastoral practices and vegetation changes, which had more direct impacts upon their livelihood (Goldman et al., 2016). The concept of a drought was therefore not simply known in different ways, such as through climate modelling or personal and collective memories of past droughts. Instead, what actually counted as a drought differed between the scientists, NGO workers and policymakers on the one hand and Maasai pastoralists on the other. This was because different stakeholders defined what a drought was in ways that were shaped by how they lived with and acted in response to the constantly changing weather (Goldman et al., 2016). Multiple versions of the same drought were therefore enacted in ways that overlapped and conflicted with each other.

Thinking about the ontological multiplicity of climate can therefore highlight where different versions of a SCF overlap, interact and interfere with each other. This makes it easier to understand why disagreements emerge between stakeholders over the scale, distribution and magnitude of the potential impacts indicated by a SCF. For example, ethnographic research into the use of SCF in North-East Brazil (Pennesi, 2007b) and West Africa (Roncoli et al., 2009) suggests that there are often differences in how farmers and climate scientists use the word ‘normal’ or ‘average.’ Climate scientists usually define ‘normal’ as the historical average of a meteorological variable, such as precipitation or temperature (Hulme et al., 2009). SCF therefore often indicate the probability of the seasonal average being above or below the long-term, historical average. However, farmers in North-East Brazil and West Africa defined a ‘good season’ in relation to agricultural yields, the timing of the harvest and the distribution of rainfall throughout a season (Pennesi, 2007b; Roncoli et al., 2009). This made it difficult for farmers to understand what a forecast of ‘above-average’ rainfall meant compared to the weather that they would normally expect at that time of year. Failing to acknowledge different enactments of what a ‘normal’ climate is and what a ‘normal’ climate is expected to do (Hulme et al., 2009; Fleming and

Jankovic, 2011) can therefore make SCF difficult for stakeholders like farmers to understand, trust and use.

As a result, *Chapter 6* of this thesis studies how different stakeholders enact different versions of Met Office's 3-month outlook. Instead of assuming that there is one 3-month outlook with multiple meanings, it looks at how different practices, such as contingency planning or managing energy consumption, enact multiple yet overlapping versions of the 3-month outlook. Adopting this approach to following a SCF avoids the tendency to reduce the communication of SCF to questions of epistemology. It also makes it easier to conceive of and follow multiple versions of an object than early forms of ANT, which only identify changes in what an object is over time (Law and Singleton, 2014).

### 2.4.3 The Topologies of SCF and Post-ANT

A second conceptual problem with early forms of ANT relates to how they describe the movement of scientific knowledge and technologies in and through space. Early accounts of ANT argued that knowledge travels through the production and circulation of 'immutable mobiles,' which are objects that hold their shape whilst being physically or virtually transported (Latour, 1986). This process of making immutable mobiles implies two kinds of spatiality: network space, in which the shape of an object is defined by its relations with other objects, and regional space, in which the place of an object is defined by a relative set of three-dimensional coordinates (Law and Mol, 2001). An immutable mobile like a letter is *immutable* in network space because it holds its shape in relation to other objects and *mobile* in regional space, because it can be physically transported to another location. STS scholars and geographers have therefore tended to rely on these two kinds of spatiality when describing the movement of scientific knowledge and technologies (Allen, 2011; Law and Mol 1994).

However, STS scholars (Law and Mol, 2001) and geographers (Allen, 2016; Hinchliffe et al., 2013) and anthropologists (Strathern, 1996) have questioned the role that these two forms of spatiality play within their respective disciplines. Network and regional spaces both imagine distance in terms of extension and reach (Hinchliffe et al., 2013; Strathern, 1996), whether it is the distance from one city to another on a map (regional space) or the number of connections between two people on a social media platform (network space). This limits how

we imagine the movement of knowledge, objects and lives by ignoring the characteristics of relationships that join actors together. For example, avian influenza does not diffuse into disease free spaces but becomes pathological through the intensity of relationships that exist between the virus, its host and the environment in which it is incubated (Hinchliffe et al., 2013). Similarly, financial activities undertaken by banks can be lifted from one jurisdictional domain and placed 'offshore' in order to avoid regulatory oversight by national governments (Allen, 2016). In both cases, the border between diseased and disease-free space or the border between 'offshore' and 'onshore' finance depends on the intensity of relationships, rather than on barriers or the number of connections. The metaphors of regions and networks therefore might not adequately describe the spaces that are created by SCF as they are communicated.

Furthermore, the network metaphor in ANT is also associated with a particular conceptualisation of power, in which scientific knowledge outcompetes other forms of knowledge through processes of domination and standardisation (Shapin, 1998; Strathern, 1996). For example, early proponents of ANT argued that knowledge produced by centres of calculation, such as the Met Office, outcompetes other forms of knowledge through the mass production and circulation of immutable mobiles (Latour, 1987; Law, 1987). The widespread usage of the 3-month outlook would therefore depend on Met Office's ability to assemble more meteorological data, enrol more stakeholders and produce more stable, portable versions of the 3-month outlook than its competitors. However, treating the exercise of power as an effect of network size and stability can obscure different kinds of relations within and among different actors and processes (Hinchliffe, 2000; Sheppard, 2009). For example, there might be other ways of communicating the 3-month outlook that do not rely upon the mass production of portable graphics and documents that circulate amongst different stakeholder groups. This suggests that there is a need to think about space in ways that do not only rely upon images of connectivity that are associated with the metaphors of a region or network (Law and Mol, 2001; Strathern, 1996).

STS scholars (Law and Mol, 2001; Mol and Law, 1994) and geographers (Hinchliffe et al., 2013; Martin and Secor, 2014) have therefore used the

concept of topology from mathematics to explore other ways of thinking about space. Topology is a branch of geometry that measures space by using coordinates that are intrinsic to a surface, rather than by using an external set of three-dimensional coordinates (Martin and Secor, 2014). For example, a bagel and a mug of coffee are topologically the same shape because they are three-dimensional surfaces with one hole in it. One shape, the mug of coffee, can be deformed into another, the bagel, without changing or cutting the surface. By defining space in terms of its intrinsic properties, the notion of topology opens up other ways of thinking about geometrical space in mathematics (Stahl and Stenson, 2014) and the spaces that are created by social and scientific activity (Mol and Law, 1994).

One example of where the concept of topology has been particularly useful has been in helping STS scholars think about spatiality in terms of fluidity as well as connectivity (Mol and Law, 1994). For example, in their study of how Zimbabweans used a water pumping device, de Laet and Mol (2000) argue that is was widely used because it could easily be fixed and adapted to the needs of different stakeholders. The water pump functioned simultaneously as 'a mechanical object, a hydraulic system, a device installed by the community, a health promoter and a nation-building apparatus' (de Laet and Mol, 2000, p. 252). The relations that held the shape of the pump together gradually changed over time, allowing the pump to be used by different stakeholders. Objects like the Zimbabwean water pump can therefore be configured in a fluid topology, as well as in network and regional topologies (Law and Mol, 2001; Mol and Law, 1994).

Geographers have extended the work of STS scholars to look at a wide variety of topics, including the multiple topologies of viruses (Hinchliffe et al., 2013; Lavau, 2013), global finance (Allen, 2016), drought (Goldman et al., 2016) and anthropogenic climate change (Blok, 2010). This has opened up more complex ways of thinking about space that focus on the characteristics of relationships that link actors together, rather than on the number or proximity of those relationships (Hinchliffe et al., 2013). Moreover, the notion of fluid topologies also disassociates geographical research from conceptualisations of power that are associated with regional and network space, which often conceive of power as a force that is 'extended outwards over mappable distances' (Allen, 2016, p.

2). This does not mean that fluid topologies should supersede network and regional topologies (Martin and Secor, 2014). Such a move would simply replace one dominant way of imagining space with another. However, the concept of topology does allow one to identify the different relations and actors that form the message of a SCF, without limiting how one thinks about space to only one metaphor for relationality. Following the Met Office's 3-month outlook through multiple topologies could therefore help one understand how the message of SCF holds together (or does not hold together) as it is picked up and used by stakeholders in different circumstances.

As a result, Chapter 7 of this thesis uses the concept of topology to follow the changing 'shape' of the 3-month outlook as it travels between the different stakeholders that use it. Using the concept of topology makes it possible to identify moments where the communication of the 3-month outlook depends on the fluidity of the message, rather than on keeping the content of the message exactly the same. It also makes it possible to understand the how the message of the 3-month outlook changes as it is communicated between stakeholders that have different or conflicting ontologies of climate. Following the 3-month outlook through multiple topologies therefore focusses on the characteristics of the relationships that hold the message together, which are not discussed within early forms of ANT or empirical research into the communication of SCF.

# Chapter 3. An Overview of the 3-Month Outlook: A Background to the Study

## 3.1 Introduction

This background chapter introduces the 3-month outlook, which is the seasonal climate outlook that will be followed in this study. The first section outlines the scientific background of the 3-month outlook by describing the science of how SCF for the UK and Europe are produced. It is necessary to understand the underlying science because the choices scientists make when communicating a SCF are shaped by the meteorological context in which a forecast is issued. Gaining an overview of the underlying science therefore helps one understand how the message of a SCF is communicated.

The second section introduces what is currently known about how SCF are used in decision-making in the UK and Europe. It is important to know about how SCF are currently used in the UK and Europe to understand the expectations and knowledge needs that decision-makers have. These expectations and needs shape how stakeholders interpret the 3-month outlook, since stakeholders interpret SCF in light of existing assumptions and attitudes (Roncoli, 2006). Moreover, assumptions that people make about the expectations and needs of other stakeholders also shape how a SCF is communicated. This is because the communicator of a SCF makes choices about what to communicate based on what they think their audience will find relevant and understand (Daipha, 2012). Understanding how SCF are used in the UK and Europe therefore provides important background information on what the expectations and needs of the stakeholders that use the 3-month outlook might be.

The final section introduces the historical background of how the 3-month outlook was developed at the Met Office. Weather and climate forecasts are not static, unchanging objects. Instead, they have a history to them and are shaped by scientific innovations (Graham et al., 2006), the availability of funding and the changing expectations and needs of stakeholders that use the outlook (Neale and May, 2020). This chapter therefore gives a historical overview of how the communication of the 3-month outlook has changed before describing how it is currently communicated. This historical overview relies upon both my own research and the secondary source material. It does not aim to be an

exhaustive history of seasonal climate forecasting at the Met Office. However, it does identify moments where the Met Office changed how it communicated the 3-month outlook and who it communicated the 3-month outlook to. Identifying these key events therefore provides an insight into the development of the 3-month outlook at the Met Office, which will then be expanded upon in chapters 5,6 and 7 of this thesis.

## 3.2 The Science of Seasonal Climate Forecasting

### 3.2.1 Terminology

Before introducing the scientific context behind the production of SCF, it is important to define some key terms that are used within the scientific literature. Forecasts and predictions are interchangeable terms and refer to the act of anticipating future weather or climatic conditions (Meehl et al., 2014). An outlook slightly differs from a forecast because it is a summary of forecast information that includes an element of expert judgement by scientists. For example, scientists at the Met Office combine evidence from observations and several seasonal forecasting systems to produce an outlook of UK temperature and precipitation over the next three months (Met Office, 2018b). Finally, predictability refers to the ability of a meteorological variable to be predicted in principle, rather than the current ability to predict a meteorological variable (Meehl et al., 2014).

### 3.2.2 The Predictability of Climate on Seasonal Timescales

All meteorologists and climate scientists must grapple with the question of how to measure, order and predict the changing atmosphere. Both weather forecasting and climate prediction start from the principle that the laws of physics are universal and stable. This makes it possible to explain and analyse the weather in terms of physical laws, such as the laws of thermodynamics and the law of mass conservation (Richardson, 1922). However, meteorological research has demonstrated that not all physical processes are as predictable as each other. Some physical processes follow regular patterns and can be predicted far into the future, such as the 11-year solar cycle in sunspot activity (Smith et al., 2012) (Section 3.26, page 48). Other physical processes, such as atmospheric circulation, are highly sensitive to changes in their initial conditions, making them chaotic (Lorenz 1963). This means that errors made in representing the initial state of the atmosphere are amplified as a prediction

moves forward in time. For example, imprecisely locating the position of a thunderstorm, even by a few miles, will produce large differences in location in a forecast that is only a few hours ahead. This means that the chaotic behaviour of the atmosphere places a limit on the predictability of weather more than two weeks ahead (Slingo and Palmer, 2011).

Something therefore must give when predicting the state of the atmosphere on monthly to decadal timescales. Climate scientists resolve this problem by using longer averaging periods and larger geographical areas when making long-range predictions (Troccoli, 2010). This makes it possible to identify large-scale patterns of order that emerge out of the chaotic behaviour of the atmosphere. For example, a SCF cannot tell you that it will snow on the 25th December in London three months in advance. However, it is possible in principle to predict that the UK temperature might be colder than average between November and January. Climate scientists can therefore identify sources of predictability on seasonal timescales, even though the physical behaviour of the atmosphere is chaotic.

### 3.2.3 Sources of Predictability

The state of the atmosphere is predictable on seasonal timescales because it interacts with other physical processes (Troccoli, 2010). These include changes in sea-surface temperatures (SSTs), sea-ice cover, land-surface cover, soil moisture, solar radiation and the concentration of gases and particles in the atmosphere (Smith et al., 2012). All of these external constraints, or boundary conditions (Lorenz, 1963), change at a much slower rate than the atmosphere. This means that they retain information from their initial state for much longer, making them predictable on monthly, seasonal and even decadal timescales (Meehl et al., 2014). Efforts to predict seasonal climate variability therefore focus on identifying relationships between these boundary conditions and atmospheric circulation (Palmer and Anderson, 1994).

Further predictability on seasonal timescales also emerges from internal constraints known as modes of variability or modes of oscillation (Palmer and Anderson, 1994). These are large-scale patterns of atmospheric circulation that evolve over monthly to decadal timescales, such as the El-Nino Southern Oscillation (ENSO) over the Pacific Ocean (Troccoli, 2010). These modes of variability often generate changes in atmospheric circulation both within the

region in which they take place and elsewhere in the world through what are known as teleconnections (Smith et al., 2012). For example, there is a relationship between circulation patterns associated with the 'El-Nino' phase of ENSO and reduced tropical cyclone activity over the Atlantic Ocean (Frank and Young, 2007). However, it is important to realise that teleconnections do not determine the evolution of weekly or daily weather. For example, a strong El-Nino does not guarantee that there will be no powerful hurricanes in the Atlantic Ocean. Instead, it only decreases the chance of them happening and may have little effect if there are other competing influences on tropical cyclone activity. Nevertheless, teleconnections that are internal to the atmosphere and boundary conditions that are external to it do make climate prediction possible on seasonal timescales.

### 3.2.4 The Production of SCF

SCF can be produced using both empirical and dynamical methods (Smith et al., 2012). Empirical climate forecasts are based on observed relationships between meteorological variables, such as tropical SSTs and precipitation. The relationship between these observations is then used as a statistical model of future climatic conditions and can be highly accurate in certain areas of the world. For example, empirical climate forecasts can be made of March-May rainfall in North-East Brazil using tropical SSTs in the South Atlantic Ocean (Smith et al., 2012). Assessments of these forecasts show that they can be as accurate as predictions made using dynamical methods (Hastenrath et al., 2009). However, empirical climate forecasts depend on there being a history of accurate observations for the variable of interest (Smith et al., 2012). Many empirical climate forecasts also assume that the Earth's climate is stationary with historical relationships between different meteorological variables (Smith et al., 2012). Anthropogenic climate change has made this assumption problematic by heating up the global climate. This may significantly alter the historical relationships that empirical climate forecasts rely on for their accuracy (Smith et al., 2012). Dynamical methods for producing SCF are therefore now often preferred to empirical methods (Doblas-Reyes et al., 2013).

Dynamical climate forecasts are made using numerical models that are run by supercomputers (Doblas-Reyes et al., 2013). These numerical models are based upon fundamental physical laws, such as the laws of thermodynamics

and the conservation of mass (Smith et al., 2012). These mathematical equations describe important physical processes and are usually resolved by calculating average values in a three-dimensional grid that covers the entire globe. Some physical processes are too small-scale or complex to be accurately resolved by the equations in an individual grid box (Doblas-Reyes et al. 2013). For example, it is often difficult to represent cloud cover within climate models, since the grid boxes are often tens of kilometres wide, whereas some clouds are only hundreds of metres wide. The average effect of these processes is therefore represented by simplified equations in a process known as parameterisation.

The role of the oceans, land surface and cryosphere in driving predictability on seasonal timescales means that dynamical climate models must include these boundary conditions to produce accurate forecasts. Most climate models are therefore based on a general circulation model (GCM), which represents atmospheric circulation, that is coupled to other models representing interactions with the oceans, land and cryosphere. For example, the Met Office's current seasonal forecasting system, GloSEA5, consists of a GCM that is coupled to other models representing the land surface, sea ice cover and ocean circulation (MacLachlan et al., 2015). Before a forecast is made, each of these coupled models must be initialised using observations. This refers to the process of using observations to create a set of initial conditions that best represents the current state of the climate system. The model is then run forward for specified period of time to create a SCF.

### 3.2.5 Assessing Uncertainty in Seasonal Climate Forecasting

Uncertainty can be broadly understood as the degree of confidence that someone places in knowledge (Brown, 2010). Ignorance differs from uncertainty because people are *aware* that knowledge is uncertain (Brown, 2004; Smithson, 1989). A person's state of confidence might range from being certain that a belief is true and justified to accepting that they cannot know that a belief is justified and true. It is this spectrum of confidence that produces different types and sources of uncertainty. Nevertheless, at both of ends of the spectrum the person is claiming that they are aware of how incomplete or imperfect the knowledge is. However, a person who is in a state of ignorance does not how complete the knowledge is, regardless of their state of confidence (Brown,

2004). Knowledge, uncertainty and ignorance are therefore fundamentally distinct but related concepts.

Within the interdisciplinary literature on uncertainty a distinction is often made between two orders of uncertainty (Taylor et al., 2015). First-order uncertainty, which also known as aleatory uncertainty, probability or risk, refers to the likelihood of an event occurring (Smithson, 1989; Spiegelhalter et al., 2011). Second-order uncertainty, which is also known as epistemic uncertainty, refers to 'uncertainties about uncertainty' that emerge from a lack of scientific understanding or a lack of data (Spiegelhalter et al., 2011). SCF contain both orders of uncertainty, which emerge from the chaotic nature of the climate system and from our imperfect knowledge of it (Taylor et al., 2015). First-order uncertainty is represented by running multiple model simulations known as an ensemble forecast (Joliffe and Stephenson, 2003) in order to a generate a probability distribution. However, missing inputs into a model, the incorrect measurement of inputs and the and imperfect simulation of these inputs produce second-order uncertainties in SCF (Slingo and Palmer, 2011). These second-order uncertainties are usually represented by using measures of reliability (how well forecasts match observations) or measures of skill (how well forecasts perform against a reference forecast like the historical average) (Joliffe and Stephenson, 2003). The assessment of uncertainty in SCF therefore involves identifying and communicating both first-order and second-order uncertainties.

### 3.2.6 Seasonal Climate Forecasting in the UK and Europe

Until recently, the UK climate was thought to be unpredictable on seasonal timescales (Scaife et al., 2014). This is because model simulations of atmospheric circulation showed little response to slowly evolving components of the climate system, such as the oceans or sea-ice extent (Smith et al. 2016). Although meteorologists have been producing skilful SCF for tropical regions since the 1990s (Goddard et al., 2010), the skill of predictions for extratropical regions like the UK has historically been much lower (Dunstone et al., 2016). This led some climate scientists to conclude that little predictability existed for important climatic events in extratropical regions, such as extreme winters (Jung et al., 2011).

However, over the last 15 years advances in scientific understanding and computing power have led to the development of skilful SCF for European winter climate (Scaife et al., 2014). Most of these scientific advances have centred around predicting a mode of variability known as the North Atlantic Oscillation (NAO).The NAO is an indicator of the average strength and direction of atmospheric circulation over the North Atlantic Ocean (Hurrell et al., 2003). It can be defined in different ways but is usually measured using the sea-level pressure difference between a weather station in the Azores, Lisbon or Gibraltar and a weather station in Iceland (Jones et al., 1997). The NAO index has two phases that represent differences from the mean sea-level pressure difference between the Arctic and subtropical Atlantic. A positive NAO index indicates a larger than average sea-level pressure difference and a negative NAO index indicates a smaller than average sea-level pressure difference (Hurrell et al., 2003).

Interannual variability in the NAO is the most important influence on year-to-year fluctuations in UK climate during the winter months (Smith et al., 2016). Unusually negative NAO indices are associated with winters in the UK that are much colder and drier than normal. For example, highly negative NAO conditions during the winter of 2009/10 weakened and reversed the usual pattern of westerly winds coming off the North Atlantic. This drew in cold, dry air from Scandinavia and Russia, which produced disruptive winter weather over the UK (Fereday et al., 2012). Conversely, a strongly positive NAO during the winter of 2013/14 strengthened the usual pattern of westerly winds coming off the North Atlantic Ocean (Huntingford et al., 2014). This drew in mild, wet air, which produced an unusually stormy winter with record breaking rainfall over the UK (Kendon et al., 2014). Developing skilful predictions of the NAO therefore could lead to useful predictions of winter climate over the UK and Northern Europe (Smith et al. 2016).

Climate scientists have identified four drivers of NAO variability that make the wintertime NAO predictable on seasonal timescales. The first source of predictability is North Atlantic SSTs. Early observational studies (Ratcliffe and Murray, 1970) and later modelling experiments have identified a relationship between North Atlantic SSTs and the wintertime NAO (Rodwell et al., 1999; Rodwell and Folland, 2002). Warmer than average SSTs are associated with

positive NAO conditions and colder-than-average SSTs are associated with negative NAO conditions. However, the implications of modelling experiments for the predictability of the wintertime NAO are difficult to interpret (Smith et al., 2016). This is because chaotic variations in storm activity are known to have a large influence on the variability of SSTs outside of the tropics (Bretherton and Battisti, 2000). Nevertheless, recent evaluations of the Met Office's seasonal forecasting system, GloSEA5 (Scaife et al., 2014) concluded that North Atlantic SSTs do function as a source of predictability during the winter months. North Atlantic SSTs therefore do seem to have an influence on the winter NAO, even if the current generation of climate models do not always represent this process well (Smith et al., 2016).

The second source of predictability for the wintertime NAO are teleconnections associated with changes in tropical SSTs. Observational studies have identified a link between the El-Nino phase of ENSO and negative NAO conditions in late winter and the opposite during the La-Nina phase of ENSO (Brönnimann, 2007). Modelling experiments have replicated this teleconnection and have identified a mechanism through which ENSO disrupts stratospheric circulation over the North Atlantic Ocean (Cagnazzo and Manzini, 2009; Ineson and Scaife, 2009). These changes in stratospheric circulation then move down into the troposphere where they affect the NAO and surface climate. Moreover, the Indian Ocean Dipole (IOD), may have affected the NAO during the winter of 2019/20. This is because the IOD produced record-high SSTs in the Indian Ocean during the second half of 2019 (Bureau of Meteorology, 2019). There is currently little known about how the IOD affects the NAO, since most research has focussed on the impact of ENSO (Behera et al., 2013). Nevertheless, the teleconnections that link ENSO with the NAO suggest that the IOD might have a similar impact on the UK winter climate.

The third source of predictability is the role of solar activity in producing variations in the wintertime NAO. Observational studies have identified a relationship between an increased chance of negative NAO conditions and low solar radiation associated with the 11-year sunspot cycle, as well as the opposite effect during periods of increased solar radiation (Lockwood et al., 2010). However, the strength of this signal varies in the historical record and the physical mechanisms behind this relationship are not understood well (Smith et

al., 2016). Nevertheless, NAO responses similar to those found in the historical record have been generated using modelling experiments (Ineson et al., 2011; Matthes et al., 2006). This suggests that interannual variations in solar radiation are a potential source of seasonal predictability for the European winter climate.

The fourth and final source of predictability for the wintertime NAO is a teleconnection with a mode of variability known as the quasi-biennial oscillation (QBO). This is a series of alternating easterly and westerly wind patterns over the tropics that descend from the top of the stratosphere to the top of troposphere over a period of approximately 28 months (Anstey and Shepherd, 2014; Smith et al., 2012). Observational studies have found that the QBO is associated with changes in stratospheric circulation over high-latitude regions (Anstey and Shepherd, 2014). These changes in stratospheric circulation sometimes move down into troposphere, where they then affect the NAO (Anstey and Shepherd, 2014). Easterly QBO phases are associated with an increased chance of negative NAO conditions and westerly QBO phases are associated with an increased chance of positive NAO conditions (Anstey and Shepherd, 2014). The QBO is highly predictable on seasonal timescales (Scaife et al., 2014) and observed teleconnections with the NAO have been reproduced within some modelling experiments (Marshall and Scaife, 2009). However, models still often have difficulties in representing this teleconnection when producing actual SCF for the UK and Europe (Scaife et al., 2014). The QBO is therefore an important mode of variability that can affect European winter climate, even if it is not represented well within existing climate models.

### 3.2.7 The Quality of SCF for the UK and Europe

Both the Met Office's GloSEA5 model (Scaife et al., 2014) and other seasonal forecasting systems (Kang et al., 2014; Riddle et al., 2013; Stockdale et al., 2015) have recently demonstrated useful levels of skill in predicting the NAO or its hemispheric equivalent the Arctic oscillation. For example, Scaife et al., (2014) report a correlation of 0.62, ($p<0.01$) between the simulated and observed NAO index between 1993 and 2012. This value exceeds the skill of a persistence forecast (0.15), which assumes that the upcoming three months will be the same as the previous three months. Moreover, skill in predicting the wintertime NAO has also led to the development of skilful predictions of societally important impacts in the UK. These include winter river flows

(Svensson et al., 2015), impacts on road, rail and aviation infrastructure (Palin et al., 2016) and energy demand and supply (Clark et al., 2017). However, skilful predictions of the winter NAO have not always translated into skilful predictions of meteorological variables like rainfall and temperature. For example, a recent evaluation of three seasonal forecasting systems, including the Met Office's GloSEA5 system, found that the overall skill of temperature and rainfall forecasts during the European winter was still limited (Mishra et al., 2019). The quality of SCF during the UK winter is therefore improving but is still limited in comparison to tropical regions.

Whilst the skill of SCF for the UK winter are improving, current seasonal forecasting systems have shown little skill in predicting the European summer climate (Mishra et al., 2019). This may simply reflect inherent unpredictability in the European climate during the summer months (Kumar et al., 2007). However, there is evidence that suggests that the low level of skill reflects an incomplete understanding of sources of seasonal predictability. For example, observational studies have identified a relationship between springtime North Atlantic SSTs and variation in summertime atmospheric circulation over Europe (Ossó et al., 2018). This potential source of predictability also resulted in the Met Office's seasonal forecasting system reproducing some of the variations in European summer rainfall (Dunstone et al., 2018). However, current seasonal forecasting systems still cannot skilfully predict large-scale changes in atmospheric circulation associated with the summer NAO (Dunstone et al., 2018). Forecasts of European summer temperature also remain unskilful, if the warming trend associated with anthropogenic climate change is removed from the models (Doblas-Reyes et al., 2013). SCF of the UK summer climate are therefore still unskilful and of little use to stakeholders who want to use them in decision-making and planning.

## 3.3 The Uptake and Usage of SCF in the UK and Europe

Recent improvements in the skill of SCF for the UK and Europe mean that they now outperform the historical average as a predictor of some meteorological variables (Scaife et al., 2014; Taylor et al., 2015). These scientific advances, along with a demand for SCF from organisations in climate-sensitive sectors, have led to organisations in Europe using SCF to inform their decision-making and planning (Bruno Soares et al., 2017). However, less is known about the

uptake and usage of SCF in the UK and Europe when compared to regions of the world where SCF have historically been more skilful and reliable. Moreover, most empirical research into the uptake and usage of SCF focusses on organisations in the public and private sector, rather than on the public or the media. This means that there is currently little known about how these two other stakeholder groups use SCF in the UK and Europe. Nevertheless, this area of research does identify some of the expectations and knowledge needs that organisations in the public and private sector have regarding SCF. This information can then be used to help one understand how the Met Office communicates the 3-month outlook when engaging with stakeholders who are not part of the media or the public.

### 3.3.1 The Uptake of SCF in the UK and Europe

Most research into the use of SCF in Europe has concentrated on assessing the informational requirements and decision-making processes of specific stakeholder groups, such as contingency planners (Demeritt, 2016) or energy managers (Dubus, 2014). However, there are relatively few studies that compare the use of SCF in Europe by organisations in different economic sectors. Much of what geographers do know comes from a series of studies produced by an EU-funded research programme called EUPORIAS (European Provision of Regional Impact Assessment for Seasonal and Decadal Timescales). These studies were based on 80 semi-structured interviews with participants recruited through the EUPORIAS stakeholder consortium (Bruno Soares et al., 2017; Bruno Soares and Dessai, 2015; Bruno Soares and Dessai, 2016b). Participants were purposively sampled to include a range of views from 10 economic sectors, which were energy, water, emergency services, transport, tourism, health, finance/insurance, forestry, agriculture and other (Bruno Soares and Dessai, 2016a). The results also drew upon an online survey, which was based on a convenience sample of 462 organisations recruited through EUPORIAS partners and contacts (Bruno Soares et al., 2017).

Out of the 462 survey respondents, 119 organisations used SCF (Bruno Soares et al., 2017). This is less than the number of organisations who used short-term weather forecasts, but more than the number who use decadal climate predictions or climate change projections (Bruno Soares et al., 2017). However, only 25 out of the 80 interview participants reported using SCF. This made SCF

the least used type of weather or climate information amongst the participants (Bruno Soares et al., 2017). The results of these two studies therefore suggest that interview participants and survey respondents might have had different ways of defining what 'using' a SCF means. However, it is still possible to identify general trends in the uptake of SCF by organisations within the UK and Europe. In particular, results from the online survey and stakeholder interviews suggest that there is a relationship between the size of an organisation and the uptake of SCF. Large organisations employing over one thousand people were widely represented in the survey (Bruno Soares et al., 2017) and interview respondents who did not use SCF reported not having the financial resources and in-house expertise needed to interpret and use SCF (Bruno Soares and Dessai, 2016a). This suggests that greater financial resources and the ability to employ people with meteorological expertise makes it easier for large organisations to use SCF in their decision-making, which is consistent with empirical research into the uptake of SCF elsewhere in the world (Bolson and Broad, 2013; Lemos et al., 2012).

### 3.3.2 The Usage of SCF in the UK and Europe

In their interviews with participants from the EUPORIAS consortium, Bruno Soares and Dessai, (2016a) distinguish between three 'levels' of SCF usage in the UK and Europe. These describe how SCF are integrated into existing decision-making processes. The first level, *low usage*, refers to organisations that only use SCF to gain a general overview of climatic conditions during the upcoming season. In this case the forecasts are not directly used to support decision-making. The second level, *moderate usage*, refers to the routine use of SCF as a piece of textual information to qualitatively support decision-making. The third and final level, *advanced usage*, describes organisations that routinely input SCF as data into their operational models. It is important to note that these categories should not be taken as a value judgement on the best way of using SCF in decision-making. Organisations may have valid reasons for only using SCF at a 'low' level. Nevertheless, the levels of SCF use defined by Bruno Soares and Dessai (2016a), provide a helpful starting point for understanding how SCF are used by organisations in their decision-making and planning.

*Table 2-Usage of SCF Amongst Organisations in the UK and Europe in Decision Making and Planning*

| Economic Sector | Current Uses of SCF | 'Level' of Usage | References |
|---|---|---|---|
| Energy | Maintenance scheduling, electricity and gas demand forecasting, managing stocks and inventories, forecasting hydropower and wind power production. | Advanced, Moderate | Dubus (2014), Troccoli, (2018), Bruno-Soares and Dessai, (2015, 2016a, 2017) |
| Emergency Services | Contingency planning, overview of future meteorological conditions | Moderate, Low | Demeritt (2016), (Met Office PWSCG, 2016), Bruno-Soares et al. (2016a, 2017) |
| Water | Maintenance scheduling, budgeting for maintenance, overview of future hydrological conditions | Moderate, Low | Haines et al., (2017), Prudhomme et al., (2017), Viel et al., (2016) |
| Transport | Contingency planning, managing stocks of road salt or de-icing materials, overview of future meteorological conditions. | Moderate, Low | Palin et al., (2016), Buontempo et al., (2017), Bruno-Soares et al., (2016a, 2017) |
| Tourism | Overview of future meteorological conditions | Low | Bruno-Soares et al., (2016a, 2017) |
| Health | Contingency planning, curtailing elective surgeries, overview of future meteorological conditions | Moderate, Low | Demeritt, (2016), Ballester et al., (2016), Lowe et al., (2016) |
| Finance and Insurance | Trading energy derivatives, understanding the financial impact of seasonal climatic variability on insurance contracts. | Advanced | Randalls, (2010, 2006), Troccoli, (2018) |
| Forestry | Understanding the risk of forest fires during the upcoming season, contingency planning. | Moderate, Low | Bruno Soares and Dessai, (2015) |
| Agriculture | Overview of future meteorological conditions, planning when to spray or plant crops. | Moderate, Low | Bruno-Soares and Dessai (2016a, 2017), Buontempo et al., (2017); Falloon et al., (2018) |

Table 2 outlines some of the activities that SCF are currently used for in Europe and the 'level' at which they are used in decision-making (Bruno Soares and Dessai, 2016). Whilst types of decision-making activities vary both between different economic sectors and within economic sectors, the energy and financial sectors tend to use SCF at a more advanced level than other

economic sectors. This is because large energy and insurance companies often have the in-house expertise and financial resources to input seasonal climate information into their own operational models, which are then used to forecast energy demand and supply or to assess financial risk (Randalls, 2010). Some energy traders and insurance companies also use SCF to gain a competitive advantage as well as to manage climate-related risks (Cooper, 2010; Randalls, 2010). This might encourage these organisations to integrate seasonal climate information into their models, so they can benefit from any advantage that this might give them over competitors that use SCF at only a moderate or low level.

### 3.3.3 Accessing SCF in the UK and Europe

Organisations in the UK and Europe generally access seasonal climate forecasts through national meteorological and hydrological services (Bruno Soares et al., 2017; Bruno Soares and Dessai, 2015) or international research institutes like ECMWF. Some organisations pay to use tailored SCF from private companies, such as Meteogroup, Predictia and Weather Services International (Bruno Soares et al., 2017; Bruno Soares and Dessai, 2015). However, these companies still buy data and forecasts that are produced by the WMO's global long-range forecasting centres, which are then used to developed customised products (Predictia, 2018). The provision of SCF within the UK and Europe is currently organised around the WMO's global long-range forecasting centres, which include the UK Met Office, ECMWF and Meteofrance. However, this process is currently being overtaken by the Copernicus Climate Change Service, which is an organisation that supports adaptation and mitigation policies in the Europe by providing stakeholders with information about the past, present and future climate (Copernicus, 2021). The provision of SCF in the UK and Europe is therefore dominated by organisations that have the financial capital and scientific expertise needed to develop and run seasonal climate models and to produce SCF that meet internationally recognised standards.

However, the process through which organisations access SCF produced by global long-range forecasting centre varies in its complexity. In some cases, stakeholders simply view a SCF on the website of a national meteorological or hydrological service (Bruno Soares and Dessai, 2016b; Prudhomme et al., 2017). However, in cases where an organisation obtains seasonal climate data

and integrates it into an operational model, the process is often much more complicated. For example, EDF Energy used SCF from global long-range forecasting centres within Europe, such as ECMWF, and outside of Europe, such as the National Centre for Environmental Prediction (NCEP) (Marta Bruno Soares and Dessai, 2015). The data from these institutions was then transformed by a national meteorological service (Meteo-France) and the technical division of EDF Energy into a format that could be used in other departments within the organisation (Bruno Soares and Dessai, 2015). The network that constitutes a SCF can therefore be global in extent and involve many different actors. This undermines the assumption that organisations are stable, bounded entities that produce SCF and disseminate them to 'end-users.' Instead, it highlights how organisations are webs of relations that link together a diverse range of both human and non-human actors (Latour, 2005a; Law, 2008; Pallett and Chilvers, 2015).

## 3.4 The Historical Development of the 3-Month Outlook at the Met Office

As empirical research into the uptake of SCF in the UK and Europe shows, forecasts are not discrete objects that are produced by bounded scientific institutions. An outlook like the 3-month outlook therefore cannot be followed as if it were a single, self-contained message that is transmitted from a provider to an end-user. Instead, a researcher following a SCF needs to trace the relations that link together different knowledges, objects and practices as the forecast moves from one place to another. This involves not only following the journey that a SCF takes across space but also the journey that it takes across time by linking a forecast with past events. The next section of this chapter therefore introduces the historical background to the Met Office's 3-month outlook by discussing events that continue shape it how it is communicated today. The account is based on documentary sources in the public domain, such as papers published by Met Office scientists and government reports, as well interviews with Met Office staff, which are discussed in further detail in Chapter 4.

### 3.4.1 The UK Winter 2005/2006 Forecast

Before 2005, SCF for the UK were not communicated by the Met Office to stakeholders outside of the scientific community (Graham et al., 2006). The Met Office did have its own seasonal forecasting system, GloSEA, which routinely

produced SCF for different regions of the world (Folland et al., 2006a). However, forecasts from this model were only used operationally in tropical regions where SCF have historically demonstrated higher levels of skill (Folland et al., 2006a; Kumar et al., 2007). Seasonal climate forecasting for the UK and Europe was therefore a developing area of science that was not considered by Met Office scientists to be relevant to stakeholders outside of the Met Office.

However, when scientists did identify a source of seasonal predictability for the UK, it prompted the Met Office to publicly issue its first SCF for the UK winter. In the early 2000s scientists at the Met Office identified a relationship between North Atlantic SSTs and the NAO phase the following winter (Deser et al., 2003; Rodwell et al., 1999). Subsequent modelling experiments suggested that this relationship offered a potential source of predictability for the European winter climate (Peng et al., 2005). Then, in May 2005, unusually cool SSTs were observed off the coast of Southern Greenland and Eastern Canada (Folland et al., 2006b). This set of observations, combined with a recent run of mild winters, created a concern within the Met Office that there was an increased risk of disruptive cold weather during the upcoming winter. As a result, the Met Office decided to issue a warning to contingency planners in the UK government in August 2005 (Graham et al., 2006). This was followed by a wider release in September, which involved putting the forecast on the Met Office website, as well as press releases and interviews with journalists (Graham et al., 2006).

The UK winter 2005/06 forecast generated a variety of responses from the UK government, businesses, journalists and the public. The Met Office's decision to proactively publicise the forecast through interviews with journalists and on its website generated a substantial amount of media coverage and interest from the public, as the following headlines illustrate:

*'And now for January's weather forecast . . .: The Met Office has released a severe weather warning for winter, predicting heavy snowfalls and bitter temperatures to come. How on earth do they know? Tim Radford investigates the extremely inexact science of long-range forecasting.' (The Guardian, 20th September 2005)*

*'Coldest winter for a decade could spark energy crisis.' (The Times, October 10th, 2005)*

Climate scientists at the time thought that 'most reporting in the media reflected the Met Office's forecast fairly' (Graham et al., 2006: 334). However, they also thought that some journalists had sensationalised the forecast by claiming that the winter would be the coldest since 1962/3 (Graham et al., 2006). Moreover, oil and gas prices also rose sharply when a cold snap hit the UK in mid-November (Troccoli and Huddleston, 2006). This volatility in the energy market may have been prompted by widespread media and public interest in the winter forecast, which made the energy market sensitive to the onset of cold weather (Graham et al., 2006; Hulme et al., 2009).

The possible reaction of the energy market to the winter 2005/06 forecast and sensationalist headlines in the press highlighted the difficulties that were involved in communicating SCF to a wide range of stakeholders. Met Office staff were particularly concerned about communicating the uncertainty in SCF (Folland et al., 2006a; Graham et al., 2006). The original message of the forecast predicted a 'two-in-three chance of a colder than average winter for much of Europe' (Graham et al., 2006: 333). However, when the Met Office received feedback on the forecast, they found that many stakeholders did not understand what 'colder-than-average' meant (Troccoli and Huddleston, 2006). This resonates with psychological research into the communication of probability, which has shown that the use of words alone can generate multiple and inconsistent interpretations of probability statements (Budescu et al., 2014). As a result, communications staff at the Met Office began trialling quantitative presentation formats on the Met Office website, including histograms and probability maps. These aimed to communicate the uncertainty in a forecast to the public and the media with a greater degree of precision (Graham et al., 2006).

Further questions were also raised around how the Met Office should communicate the uncertainty in seasonal climate forecasts to journalists and editors. The 2005/06 winter forecast was proactively communicated to the media with press releases and interviews with meteorologists from the Met Office (Graham et al., 2006). However, at the time other meteorologists and climate scientists questioned the Met Office's communication strategy. There were concerns that the press releases attracted too much attention, fuelling sensationalist reporting of the forecast within the media (Troccoli and

Huddleston, 2006). Some meteorologists were also concerned about the risk of communicating 'low skill-high impact' forecasts, that could easily damage the Met Office's credibility if the forecasts were perceived to be wrong (Troccoli and Huddleston, 2006). The communication of the 2005/06 forecast to the UK media and public therefore highlights how SCF can create expectations that institutions like the Met Office cannot easily control.

Finally, the winter 2005/06 forecast established a dialogue between the Met Office and contingency planners within the UK government and private sector (Graham et al., 2006). These stakeholders were interested in using SCF to prepare for weather-related risks, especially during the winter months. The interest generated by the winter 2005/06 forecast amongst the contingency planning community initiated further research at the Met Office that aimed to improve its seasonal forecasting capability for the UK (Graham et al., 2006). It also formed another group of potential stakeholders alongside journalists and members of the public to whom the Met Office could communicate SCF. The winter 2005/06 forecast therefore created a relationship between the contingency planning community and the Met Office that shaped the future development and communication of SCF.

### 3.4.2 The Summer 2009 Forecast

On the 30th April 2009, the Met Office issued the following forecast for the summer on its website:

*'The coming summer is 'odds on for a barbeque summer,' according to long-range forecasts. Summer temperatures across the UK are likely to be warmer than average and rainfall near or below average.'* (Met Office, 2009a)

Unlike in previous years (Graham et al., 2006), the Met Office Press Office held an additional news briefing at the Science Media Centre in London about the 2009 summer forecast (Met Office, 2009a). Met Office scientists presented the forecast, answered questions from the audience and gave one on one interviews with journalists and editors who wanted to find out more (Met Office, 2009a). The presentation given at the news briefing included the same 'odds on for a barbeque summer' tagline issued on the Met Office website and claimed that a 'repeat of the summers of 2007 and 2008 was unlikely' (Met Office, 2009: 5). In the previous two summers, the UK had experienced above-average

rainfall and severe flooding (Blackburn et al., 2008) that was widely reported on by the UK news media (Gavin et al., 2011). This statement in the news briefing, combined with the image of a 'barbeque summer,' created the expectation amongst journalists that the summer of 2009 would be exceptionally warm and dry, as the following headlines illustrate:

*'Britain will have first decent 'barbecue summer' in three years with temperatures regularly above 80 F.' (The Daily Telegraph, 30th April 2009)*

*'Warm, dry summer on the way, says Met Office.' (Guardian, 30th April 2009)*

Although the summer turned out to be warmer than the 1971-2000 average as predicted (Eden, 2011), it was also significantly wetter than the 1971-2010 average in parts of the UK (Met Office, 2021b). Furthermore, the upward trend in temperatures associated with anthropogenic climate change meant that 16 out of the previous 20 summers had been warmer than normal, when compared to the 1971-2000 average (Eden, 2011). This meant that temperatures that UK residents experienced in summer 2009 were unexceptional in comparison to recent years. Several journalists and editors therefore felt mislead by scientists at the Met Office (Chadwick, 2010) and published news stories criticising the Met Office for the poor quality of its SCF:

*'Rain puts dampers on 'barbeque summer.' (Guardian 29th July 2009)*
*'Met Office cools summer forecast.' (BBC News, 29th July 2009)*

The criticism that the Met Office faced following the summer 2009 forecast had a large impact on the future communication of SCF by the Met Office. According to the chair of the Met Office's Public Weather Service Customer Group (PWSCG), a public consultation was held, during which the respondents said that they 'did not find it very useful in the way it [the SCF] was presented, and that they would rather have received a shorter-term forecast' (Science and Technology Select Committee, 2012: 54). SCF were therefore not presented alongside the Met Office's short-term weather forecasts and were replaced with a 30-day outlook (House of Commons Transport Committee, 2012: 54). At the same time, the Met Office focussed on communicating SCF to contingency planners in government and business. A new '3-month outlook' was developed

specifically for contingency planners in the UK government (Met Office, 2018b). This was made publicly available but was not placed alongside short-term weather forecasts that members of the public regularly view. It provided contingency planners with an indication of probable trends in temperature and rainfall over the next three months. It also used a more technical, scientific style of communication in comparison to the SCF that were communicated to the media and the public before 2009. The 3-month outlook is still issued each month on the Met Office website, although the presentation format has changed slightly since the end of the fieldwork.

### 3.4.3 The Expansion of Seasonal Forecasting Capability at the Met Office

Although the summer 2009 forecast changed who the Met Office thought of as its principal stakeholders, the Met Office continued to develop its seasonal forecasting capability in the years that followed. This was given further impetus by the transport disruption caused by the cold UK winters of 2009/10 and 2010/11 (Palin et al., 2016). Contingency planners and transport operators within the UK government and private sector were heavily criticised for not being sufficiently prepared for severe winter weather (Department for Transport, 2010). This generated a demand amongst policymakers for SCF that could be used to prepare for possible disruption to transport infrastructure during the UK winter. For example, in 2011 a government report into improving winter resilience recommended providing additional funding to the Met Office to improve its seasonal forecasting capabilities:

*'The current seasonal predictions—such as the forecast provided to the Cabinet Office in October—do not provide a firm basis on which decision makers can act with confidence. £10 million would be a small price to pay for improving the Met Office's long-range forecasting capability, given the cost to the UK economy of transport disruption due to severe winter weather. We recommend that the Secretary of State press the Ministry of Defence to investigate the case for providing the Met Office with additional funding for enhanced computing power and to report back to us with the outcome.' (House of Commons Transport Committee, 2011: 9).'*

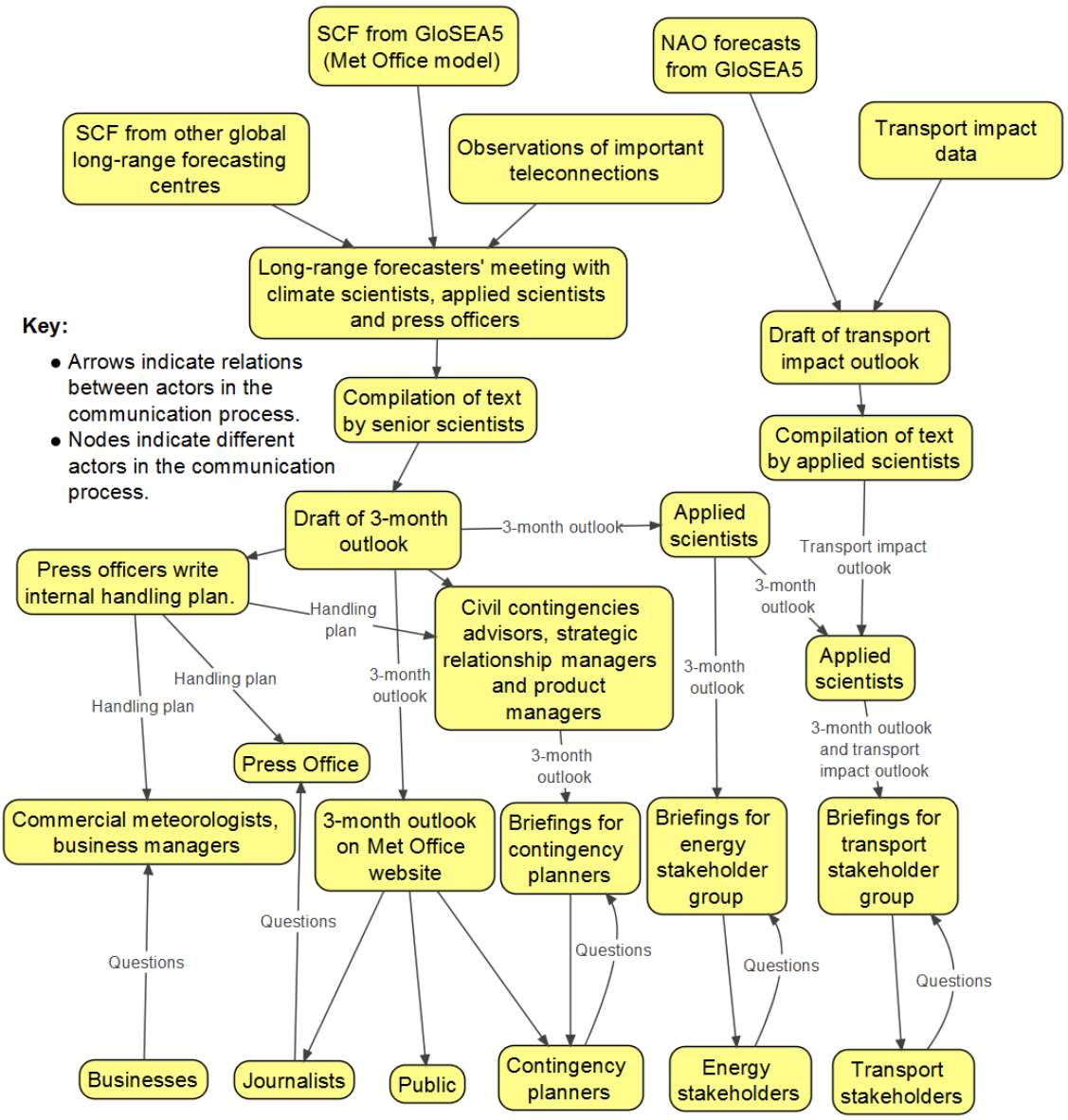
Until 2014, Met Office staff did not think that SCF for the UK were skilful enough to provide useful predictions of winter transport disruption (Palin et al., 2016).

However, in 2014 scientists at the Met Office succeeded in producing skilful predictions of the wintertime NAO (Scaife et al., 2014). Subsequent studies made use of these findings to identify relationships between the wintertime NAO and impacts on transport infrastructure (Palin et al., 2016). The Met Office has therefore used these scientific advances to secure funding from the Department for Transport to develop a risk-based impact outlook (Buontempo et al., 2017). This was first issued in winter 2015/16 and provides stakeholders with information on the risk of adverse impacts upon road, rail and aviation infrastructure (Buontempo et al., 2016). It was disseminated to a wide range of stakeholders, including representatives from rail, road, aviation organisations, local authorities, and devolved administrations (Buontempo et al. 2016). Developments in the science of seasonal climate forecasting therefore opened new opportunities for the Met Office to meet commercial and government demands for information on winter weather transport impacts.

Moreover, Met Office scientists have also made use of the skilful NAO forecasts reported by Scaife et al., (2014) to produce skilful predictions of energy demand (Clark et al., 2017). The possible reaction of UK energy suppliers and energy trading markets to the winter 2005/06 forecast shows that stakeholders in the energy sector have always been interested in SCF made by the Met Office (Troccoli and Huddleston, 2006). This is because both gas and electricity demand are strongly driven by daily temperature variability, once socioeconomic factors are removed (Thornton et al., 2019). Seasonal forecasts of electricity or gas demand could therefore help energy companies make better trading decisions and help organisations reduce electricity and heating costs. The skilful predictions of energy demand reported by Clark et al. (2017) suggest that it is possible to produce SCF that are potentially useful to the UK energy industry. However, the Met Office does not currently produce a customised impact outlook in the way that it does for stakeholders in the transport sector.

### 3.4.4 The Current Communication Process for the 3-Month Outlook

*Figure 8- Diagram of the Communication Process for the 3-Month Outlook*




SCF at the Met Office are currently communicated in the following way (see Figure 8). Each month meteorologists and climate scientists from the monthly-decadal prediction team meet to review the scientific evidence upon which they will base the message of the 3-month outlook. This consists of meteorological observations and SCF from models at the WMO's global long-range forecasting centres. These forecasts include predictions from the latest version of the Met Office's own seasonal climate model, GloSEA5 (MacLachlan et al. 2015). The scientists use their expert judgement to decide on whether the forecast from the Met Office model should be modified to account for known biases in the Met Office model or uncertainties in the observations that they have reviewed. The

outcome of this meeting then forms the scientific basis of the message of the Met Office's 3-month outlook.

After the meeting the message of the 3-month outlook is summarised by scientists and press officers in a document that is designed for contingency planners to use. The Met Office Press Office also creates a handling plan to help staff in other departments answer questions that they receive from Met Office customers, the UK government, journalists and the public. The 3-month outlook is initially released under embargo to stakeholders in the UK government and private sector. It is then made publicly available on the Met Office website, although it is not uploaded to a part of the website that is regularly accessed by the public. The 3-month outlook is not proactively communicated to the media or the public by the Met Office Press Office. Instead, the Met Office Press Office only responds reactively to inquiries from the media and the public about seasonal climate forecasting.

In addition to the publicly available 3-month outlook, the Met Office briefs three stakeholder groups during the winter months. The first of these stakeholder groups is a stakeholder group convened by the DfT, who use SCF to minimise the impact of winter weather on transport infrastructure. They receive the 3-month outlook during a teleconference briefing where a Met Office scientist gives a presentation and adds wider explanation that is not included in the publicly available version of the 3-month outlook. The transport stakeholder group also receives the bespoke transport impact outlook after the 3-month outlook has been presented. Transport stakeholders can ask Met Office scientists questions about the 3-month outlook and transport impact outlook at the end of these briefings. The briefings are held between October and December in advance of the UK winter.

The second stakeholder group that the Met Office briefs the 3-month outlook to are a group of stakeholders in the UK energy sector. This group consists of stakeholders from government organisations, such as OfGEM, energy providers, such as EON or EDF Energy, energy managers employed by local authorities and businesses, and energy traders (Met Office, 2018c). These stakeholders use SCF to manage both the consumption of energy and the supply of energy from renewable sources, such as wind power. They receive the 3-month outlook and a 1-month outlook during a teleconference briefing.

During these briefings a scientist presents the two outlooks whilst adding wider explanation for the energy stakeholders. Stakeholders are then given an opportunity to ask questions about what they have just heard. Unlike the transport stakeholder group, the energy stakeholder group do not currently receive a bespoke impact outlook. The briefings take place between November and January during the UK winter.

The final group of stakeholders that the Met Office briefs the 3-month outlook to are contingency planners within the UK government. The Met Office has several civil contingencies advisors, who advise contingency planners in the UK government on the impact that severe weather and climatic variability might upon the delivery of government services. These advisors sometimes brief contingency planners on the 3-month outlook during local resilience forums, which are multi-agency forums where representatives from local public services discuss, review and make emergency plans that will prevent or mitigate the impact of an incident upon their community (Government, 2019). Contingency planners also can access the 3-month outlook through the Met Office website and through a link on Hazard Manager, which is a web-based portal that contingency planners use to receive weather warnings from the Met Office.

## 3.5 Conclusions

This background chapter has described the underlying science of producing SCF for the UK and Europe, the social contexts in which SCF are used in decision-making and the historical development of the 3-month outlook at the Met Office. Each of these literatures provide important information that can help one understand the current communication of the 3-month outlook. However, this information is not simply background knowledge that is needed to understand how the 3-month outlook is communicated. This is because this contextual information has theoretical and methodological implications for how a researcher might 'follow' a SCF.

Firstly, research into seasonal climate forecasting for the UK and Europe highlights the complexity and inherent uncertainty of the underlying science. Even though it is now possible to produce skilful predictions of European winter climate (Scaife et al., 2014; Stockdale et al., 2015), the amount of uncertainty still varies with the meteorological context in which a SCF is issued. Scientists must make choices about what uncertainties that they need to communicate

every time they issue a SCF. This highlights the importance of understanding the meteorological context in which a SCF is issued, since it shapes how scientists interpret and communicate the overall message. The 3-month outlook therefore needs to be followed from the point at which Met Office scientists review evidence upon which they will base the outlook, rather than the point at which Met Office scientists communicate the 3-month outlook to different stakeholders.

Secondly, empirical research in the uptake and usage of SCF in the UK and Europe undermines the linear 'transmission' model of communication discussed in Chapter 2. SCF are not transmitted from a forecast 'provider' to an individual 'end-user.' Instead, there are many different stakeholders involved in producing and communicating a SCF. These form a network of relationships between different knowledges, spaces and practices, rather a linear relationship between knowledge producers and users. This highlights the importance of not privileging different actors when analysing the communication of SCF. It also means that 'following' needs to be a non-linear process of tracing the journeys that a SCF takes as it moves between different groups of people. A SCF therefore needs to be followed in a way that avoids reproducing a discursive boundary between knowledge 'producers' and 'users.'

Finally, the historical development of the 3-month outlook suggests that previous forecasts and relationships with different stakeholder groups shape how the Met Office communicates SCF in the present. In particular, the criticism that the Met Office faced following the summer 2009 forecast changed how it communicated the 3-month outlook and who it communicated the 3-month outlook to. Whilst the 3-month outlook is still made publicly available, the Met Office now focusses on communicating the 3-month outlook to three groups of 'principal' stakeholders. These stakeholder groups are the transport stakeholder group convened by DfT, the energy stakeholder group and contingency planners in the UK government. This change in audience was also accompanied by a move towards a more detailed, technical style of communication that would meet the perceived needs and expectations of these three principal stakeholder groups. The communication of the 3-month outlook therefore needs to be analysed as a historically contingent process, shaped by past events like the communication of the summer 2009 forecast.

# Chapter 4. Research Design and Methodology

## 4.1 Introduction

In this chapter, I discuss how I produced a multi-sited ethnography of the UK Met Office's 3-month outlook (Hine 2007, Marcus 1995) based on the theoretical framework developed in Chapter 2. I also describe the research methods that I used to follow the 3-month outlook, along with how I analysed the data that was generated through using these methods. To conclude, this chapter reflects upon the process of completing a multi-sited ethnography of the 3-month outlook. I suggest that geographers need to speak about their practical experiences of doing fieldwork when writing methodologies, in addition to explaining why they chose a specific method and how they implemented that method (Hitchings and Latham 2020a; Law 2004).

## 4.2 Developing a Multi-Sited Ethnography of the 3-Month Outlook

Empirical research into the communication of weather and climate forecasts is often based on the conceptual assumption that there is a distinction between science on the hand and on society on the other (Section 2.2). This means that studies often focus on how a SCF is used by stakeholders within 'society' rather than on following the message of the SCF itself. For example, work that is associated with a transmission model of communication (see Section 2.2) normally looks at how different presentation formats are interpreted by 'end-users' in surveys or experimental settings (Budescu et al., 2014; Coventry and Dalgleish, 2015). Similarly, research that is based upon a delivery model of communication often relies upon interviews with individuals from organisations that use SCF or upon ethnographic case studies of institutions that use SCF (Rayner et al., 2005). Current research into the communication of SCF therefore tends to focus on the point at which a SCF is received by a forecast user in society from a forecast provider within the scientific community.

However, anthropologists (Marcus, 1995), STS scholars (Callon, 1990; Latour, 2005b) and geographers (Cook, 2004) have argued that researchers do not impose a pre-determined social context on the object of inquiry. Instead, people, things, stories and metaphors travel through different spaces and our lives are bound with up with the journeys that they take (Marcus, 1995). This means that researchers enact social contexts and theoretical frameworks through uncontrolled encounters with what they are studying (Law, 2004;

Marcus, 1995; Tsing, 2010). For example, a researcher studying how a water company uses SCF does not understand the decision-making context or how the institution functions in advance of beginning the research. Instead, it is through the process of building relationships with participants, choosing research methods and analysing data that a social context for the study is created. Anthropologists (Marcus, 1995), geographers (Cook, 2004) and STS scholars (Hine, 2007; Law, 2004) have therefore argued that there is a need to develop methodologies that that acknowledge the role that the researcher plays in creating the context or field in which the research takes place.

This study therefore develops a multi-sited ethnography (Marcus, 1995) of a SCF by following the message of the Met Office's 3-month outlook as it is communicated. A multi-sited ethnography uses conventional ethnographic methods, such semi-structured interviews, textual analyses of documents, visual analyses and participant observation to produce a 'thick description' of what is being studied (Geertz, 1973; Hammersley and Atkinson, 1996). However, a multi-sited ethnography differs from a conventional ethnography in that it follows connections and relations between sites, rather than contextualising a site within a larger social order, such as a community, people group or locale (Marcus 1995, 1998). Multi-sited ethnographies therefore emphasise the role that both the researcher and the participants play in shaping where, when and how ethnographic research takes place.

It is important to recognise that multi-sited ethnographies are not the same as multi-sited fieldwork (Marcus 1995). This is because it is possible for a multi-sited ethnography to take place at a strategic locale, where social and material connections with other places are followed and explored (Gielis, 2011; Marcus, 1995). For example, STS scholars have argued that scientific laboratories are not confined to the physical buildings where they are located. This is because laboratories are places where 'inside/outside relations are reversed' (Latour, 1983: 160). Scientists enrol the interests of government officials, private companies, materials, and animals far beyond the physical walls of a laboratory in order to produce and distribute new knowledge and technologies (Latour, 1983). Scientific institutions like laboratories are therefore not bounded entities, containing coherent and homogenous groups of people. Instead, they are webs of stable (Latour, 1986) and fluid relations (Mol and Law, 1994) that connect

people, technologies and knowledges that are both global and local (Massey, 1994).

Multi-sited ethnographies within geography (Mahony, 2013) and STS (Hine, 2007; Law and Mol, 2001) therefore treat the spatiality of science itself as the object of inquiry. Through following a scientific idea or artefact, an ethnographer can develop descriptions that are more attentive to multiplicity of what they are studying (Law, 2004). For example, it is unlikely that de Laet and Mol, (2000) would have concluded that the Zimbabwean bush pump had a fluid identity if they had set out with a predefined idea of what the bush pump was and where they should study its use (see Section 2.4.3). However, by tracing the associations that constituted the bush-pump they were able to see how it simultaneously functioned as a mechanical object, hydraulic device, health promoter and a nation-building apparatus, depending on which stakeholder was using it (de Laet and Mol, 2000). Their multi-sited ethnography therefore allowed them to engage with the fluidity and multiplicity of the bush-pump in a way that a conventional ethnography cannot.

Moreover, multi-sited ethnographies highlight how research methods constitute rather than represent what is being studied. STS scholars (Law, 2004) and geographers (Hitchings and Latham, 2021; 2020) have argued that methodologies often present the process of research as a linear narrative. A researcher moves from the formulation of a research question through to the collection and analysis of data before finishing off with a set of positive results that answer the original question. This linear narrative assumes that an ethnographer can impose their methodological procedures upon what is being studied and produce an account that faithfully reports on that given reality. However, the world around us is complex and research methods are inherently selective (Law, 2004). For example, semi-structured interviews produce a specific type of qualitative data that might answer some questions whilst excluding other questions and types of data that could be answered through the use of a focus group. A multi-sited imaginary therefore helps the ethnographer reflect upon the complexity of what they are studying by emphasising how the choice of research methods enact and shape what is being studied (Hine, 2007; Mol, 2002).

Although the following methodology follows a linear narrative to make it easier to read, I highlight points at which the fieldwork does not match the chronology presented in the text. The reason for doing this is to respond to calls within geography for researchers to be more open about how data collection strategies were selected and why (Hitchings and Latham, 2020). Sometimes the discussion of qualitative research methods within geography focusses on highlighting methodological innovation or on applying and developing a new theory (Hitchings and Latham, 2021) without talking about the actual experience of research. The methodology section of a thesis or journal article therefore becomes a means to the end of producing novel or insightful results (Law, 2004). As a result, the following methodology reflects upon the process of conducting research, as well explaining how I completed a multi-sited ethnography of the Met Office's 3-month outlook.

## 4.3 Data Collection

### 4.3.1 Gaining Access to the Met Office

Access to the Met Office was initially granted through my supervisor, Prof. Richard Betts, who is a member of staff employed by both the Met Office and the University of Exeter. He helped me obtain the security clearance needed to attend the Met Office as a visiting scientist and put in me in contact with Met Office staff on the monthly-decadal prediction team who had key roles in communicating the 3-month outlook. This allowed me to build relationships with other Met Office staff involved in communicating the 3-month outlook, who I then worked with during the rest of the ethnographic fieldwork. Ethical approval to conduct research at the Met Office was granted by the University of Exeter ethics committee in May 2018.

### 4.3.2 Mapping the Communication of the 3-Month Outlook

After some initial meetings with Met Office staff in October 2018, we decided that it would be helpful for me to learn about what Met Office staff already knew about the communication of SCF for the UK. I therefore completed a short literature review of the Met Office's own internal market research into how it communicated the 3-month outlook to contingency planners, energy stakeholders and transport stakeholders. Whilst this review provided important background information on how the Met Office's principal stakeholders interpreted and used the 3-month outlook, it also highlighted how there was no

research within the last ten years on how the media and public used the 3-month outlook. Moreover, the internal research that the Met Office had completed only looked at how individual stakeholder groups used the 3-month outlook. This meant that there was no overview of who was communicating the 3-month outlook within the Met Office or of how Met Office staff communicated the 3-month outlook during stakeholder briefings. I therefore began identifying who the 3-month outlook was being communicated to and mapping where it went within the organisation. I did this by using information gained from informal conversations, phone-calls with Met Office staff and semi-structured interviews to create a diagram of the overall communication process. This was then reviewed by Met Office staff to check that it was accurate. Figure 8 in Section 3.4.4 is a simplified version of the original diagram that I created.

### 4.3.3 Interviews with Met Office Staff

Between January and April 2019, I completed nine semi-structured interviews with ten members of Met Office staff (see Table 3). The participants were selected through a process of purposive sampling, in which I identified and spoke to staff who were involved or had been involved in communicating the 3-month outlook. This process was also guided by the diagram of the communication process, which helped me select participants who were involved in engaging with specific stakeholder groups. Participants were sent a project information sheet before the interview explaining what the research was about (see Appendix 1) and then asked to verbally give their consent at the beginning of the interviews, which were audio-recorded. The interviews were then transcribed and then sent back to participants by email, who could review the transcripts if they wished to do so. This gave participants the chance to change anything that they did not feel they had explained clearly and redact anything that they did not want included in the final transcript. Although this process could have removed material that was important for understanding the communication of the 3-month outlook, it was necessary to ensure that Met Office staff had consented to making potentially sensitive information public.

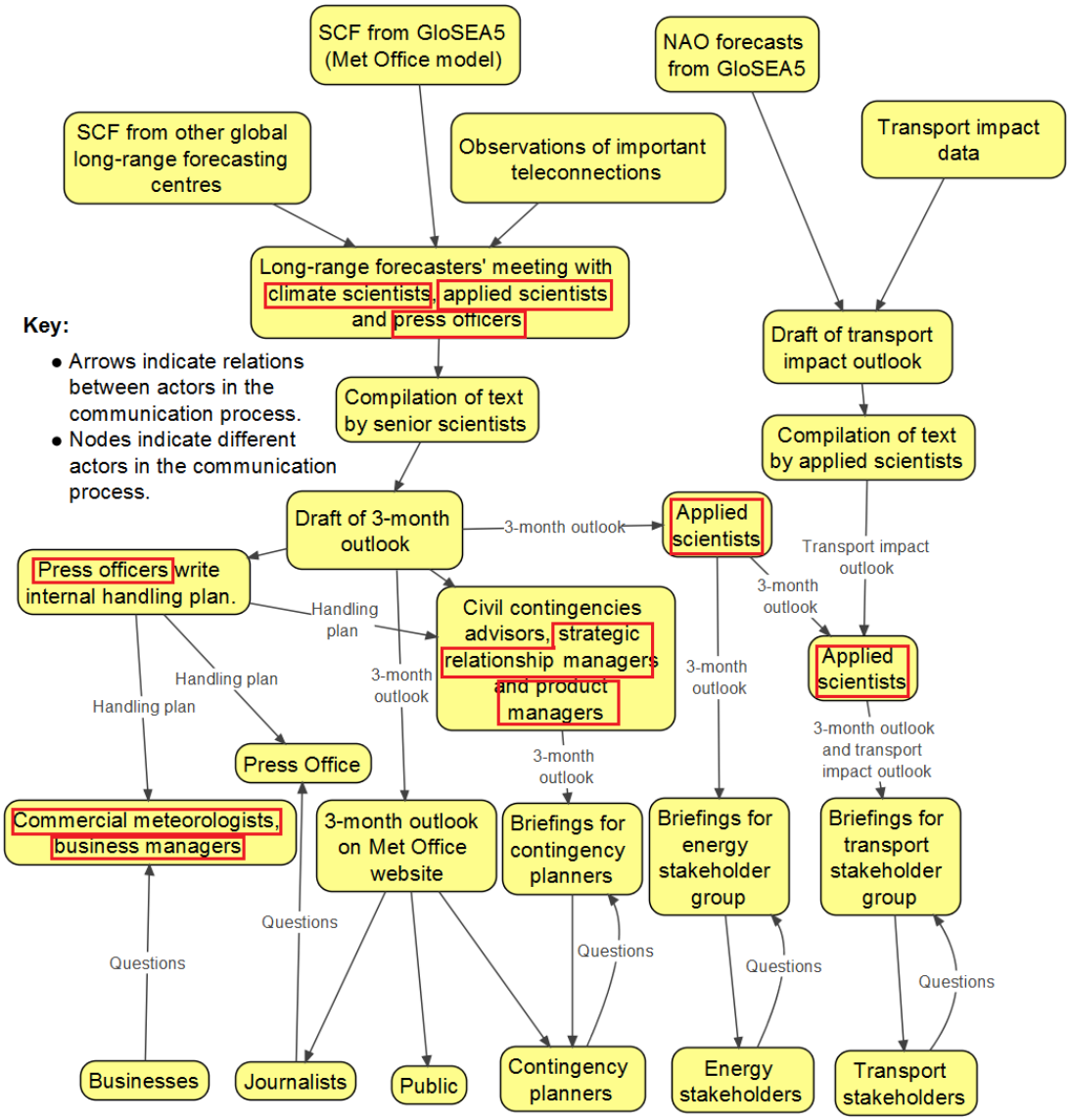
During the interview, Met Office staff were asked questions about why the Met Office made the 3-month outlook, how they communicated it and how accurate they thought it was. The participants were also presented with a copy of the January-February March (JFM) 2019 outlook, which was used as a prompt to

understand how Met Office staff interpreted the 3-month outlook. All the interviews took place in person at the Met Office, except for an interview on 05-02-19, which was completed using Skype. Any personal or commercially sensitive information, such as dates, specific locations and the names of companies that are Met Office customers, are anonymised in the quotes that I have included in this thesis.

*Table 3-Interviews with Met Office Staff*

| **Date** | **Participant** |
|---|---|
| 07-01-19 | 2 press officers |
| 11-01-18 | Business manager |
| 17-01-19 | Commercial meteorologist |
| 05-02-19 | Product manager |
| 05-02-19 | Applied scientist |
| 25-02-19 | Strategic relationship manager |
| 04-03-19 | Climate scientist |
| 12-03-19 | Applied scientist |
| 13-03-19 | Press officer |

*Figure 9- Met Office Staff Mapped onto the Communication Process for the 3-Month Outlook*




The sample does not include every member of staff involved in communicating the 3-month outlook within the Met Office. Nevertheless, it does include the views of staff working within the Met Office Press Office, the monthly-decadal prediction team and staff who were involved in engaging with energy stakeholders, transport stakeholders and contingency planners (see interview participants highlighted in Figure 9). The data that was generated by these interviews therefore gives an overview of how staff within different Met Office departments communicated the 3-month outlook. However, it is important to recognise that the transcripts from these interviews are not straightforward representations of what Met Office staff think but dialogical texts, shaped by my

own intentions and the participants' efforts to shape interpretations of the original conversation (Hammersley and Atkinson, 1996). For example, during some of the interviews I spoke to younger members of staff at the Met Office. Our similar interests, age and social background meant that younger participants sometimes told me more about the research they were doing and about how they were involved in the communication of SCF than older participants. This meant that I needed to pay as much attention to what older members of staff told me in interviews when I analysed the transcripts, even if they did not say as much. The qualitative data gathered through interviews with Met Office staff should therefore be treated as a relational construct, rather than as an objective representation of what Met Office staff think about the communication of the 3-month outlook.

### 4.3.4 Ethnographic Observation of the Long-Range Forecasters' Meeting

Each month climate scientists and meteorologists at the Met Office meet to review the scientific evidence upon which the 3-month outlook is based (see Figure 8). I initially did not think that the long-range forecasters' meeting was helpful for learning about the communication of the 3-month outlook, since I presumed that discussions would focus on the technicalities of the underlying science. However, after attending and making notes during the long-range forecasters' meeting in May 2019, I realised that discussions in the meeting did shape how the message of the 3-month outlook was eventually communicated. I therefore decided to continue attending the meetings and made notes during four more meetings between September and December 2019. These notes were then written down in a notebook and typed up shortly afterwards. This means that the notes are a reconstruction based on my memory and should not be treated as a verbatim report of what Met Office staff said during the meeting. However, they do contain information that I thought was important for understanding how the 3-month outlook would be communicated. The notes that I made during the long-range forecasters' meeting therefore complement the interview data by highlighting how the monthly-decadal prediction team assessed the scientific evidence upon which an outlook was based.

### 4.3.5 Ethnographic Observation of Stakeholder Briefings

Each winter Met Office scientists give briefings on the 3-month outlook and the transport impact outlook to a stakeholder group convened by the DfT and briefings on the 3-month outlook to a group of energy stakeholders (see Figure 8). Between October 2018 and December 2018, I attended three stakeholder briefings with the DfT stakeholder group. In December 2019, a transport stakeholder also gave me permission to make notes during a briefing, which helped me understand what it was like to listen in to one of the briefings. I also attended briefings for energy stakeholders between November 2019 and January 2020. During stakeholder briefings I asked for permission to take handwritten notes which I then later typed up. I did not audio-record any of the briefings or interrupt to ask questions, since I did not want to disturb Met Office scientists or their stakeholders during the briefings.

The decision to attend and observe these stakeholder briefings was opportunistic, since I was not aware that they existed before the start of the fieldwork at the Met Office. However, the notes that I gathered during stakeholder briefings became an important part of the ethnography. This was because the briefings gave me an opportunity to understand how Met Office staff explained the 3-month outlook and answered questions from stakeholders. Moreover, STS scholars (Law, 2004), anthropologists (Traweek, 1988) and geographers (Mahony, 2013) have argued that the descriptions that scientists give of an event or activity during interviews often differ from how an ethnographer might interpret the same event or activity. Observing the briefings therefore allowed me to produce data that was my own interpretation of how Met Office staff were communicating the 3-month outlook. This could then be compared with the accounts that were created with Met Office staff during interviews with them. Combining ethnographic observations of stakeholder briefings with interviews with Met Office staff therefore produced a different kind of data, which would have not been possible if I had only relied upon data gathered through interviews with Met Office staff.

### 4.3.6 Interviews with Stakeholders

Between October 2019 and January 2020, I completed 15 semi-structured interviews with stakeholders outside of the Met Office who regularly use the 3-month outlook. These interviews included transport stakeholders, energy

stakeholders and contingency planners in the UK's central and devolved governments (see Table 4). I decided to not interview participants from the UK public and to focus instead on journalists and the other three principal stakeholder groups. This was because it was difficult to obtain information on how members of the public were accessing and using the 3-month outlook on the Met Office website. Members of the public also read online and print news articles that quote the 3-month outlook, making journalists an important intermediary in the communication of the Met Office's 3-month outlook. The final sampling strategy therefore selected journalists, energy stakeholders, transport stakeholders and contingency planners that the Met Office is currently in contact with.

*Table 4-Interviews with Stakeholders*

| **Stakeholder Group** | **Date** | **Participant** |
|---|---|---|
| Transport Stakeholders | 27-02-19 | Operations Manager |
| | 24-10-19 | Emergency Planning Officer |
| | 29-11-19 | Winter Service Manager |
| | 16-12-19 | Drainage Engineer |
| | 08-01-20 | Transport Resilience Manager |
| Contingency Planners | 09-01-20 | Emergency Planning Officer |
| | 22-01-20 | Senior Resilience Manager |
| Energy Stakeholders | 01-11-19 | Energy Analyst |
| | 06-11-19 | Energy Manager |
| | 13-11-19 | Energy Analyst |
| Journalists | 15-10-19 | Newspaper Journalist |
| | 31-10-19 | Freelance Journalist |
| | 05-11-19 | Freelance Journalist |
| | 11-12-19 | Climate Correspondent |
| | 20-12-19 | Science Editor |

Before starting interviews with stakeholders, a three-way non-disclosure agreement was drawn up between myself, the Met Office legal team and my supervisors, who represented the University of Exeter. The purpose of drawing up this non-disclosure agreement was to ensure that the research was compliant with new legislation introduced in the Government Data Protection Regulations (GDPR) Act (UK Government, 2018) and to maintain the confidentiality of Met Office customer data. Signing the agreement was a protracted process and took nearly three months to complete.

During the summer of 2019, several meetings took place where I developed the interview protocols for stakeholders with Met Office staff who were involved in communicating the 3-month outlook. Initially we discussed designing a new presentation format for 3-month outlook that could be given to the Met Office's stakeholders during an interview. This would produce data on how stakeholders interpret the 3-month outlook and the results used by the Met Office to develop a new presentation format. However, we concluded that this would not be a worthwhile exercise, since not enough was known about how contingency planners and energy stakeholders used the 3-month outlook or the extent to which they understood the existing presentation format. Staff at the Met Office therefore decided to wait until I had completed interviews with the Met Office's stakeholders so that they could use and reflect upon my initial findings.

Transport stakeholders, energy stakeholders and contingency planners were initially contacted through stakeholder relationship managers at the Met Office. I then contacted stakeholders who wanted to participate myself, sending them a project information sheet and arranging a time and location for the interview. The Met Office Press Office also put me in contact with three of the journalists who participated, along with my supervisor, Prof. Richard Betts, who put me in contact with another two. The process through which stakeholders were contacted means that the sample primarily includes participants who had a working relationship with Met Office staff. It therefore does not include organisations and individuals who started using the 3-month outlook and then stopped using it or organisations that switched to using seasonal climate forecasts issued by another research institute or private company. Nevertheless, the data produced through the interviews does highlight how stakeholders who are in contact with the Met Office use the 3-month outlook and how they communicate it on to other stakeholders.

Participants verbally gave their consent at the start of each interview and each interview was audio-recorded. They were also sent a copy of the transcript to review after the interview, following the same process that I had gone through with Met Office staff (see Section 4.3.3). During the interviews, participants were asked questions on their role within the organisation that they worked for, how they used the 3-month outlook alongside other sources of information and on how they assessed the trustworthiness and accuracy of the outlook.

Participants were also presented with the Dec-Jan-Feb 2019 outlook and the internal handling plan[3] that was produced by Met Office Press Office for the same outlook. Participants were asked questions about how they interpreted these documents and about how useful they thought they were. Eight interviews were completed over the phone and the other seven took place in person. I made sure that at least one of the interviews for each stakeholder group took place in person. This was because I could ask participants to show me how they had used the 3-month outlook during in-person interviews, rather than asking them to report how they had used the 3-month outlook from memory. Doing this helped to highlight any differences in how people remembered using the 3-month outlook and in how they used and communicated the 3-month outlook in practice.

The data generated through these stakeholder interviews is knowledge that is co-produced through interactions I had with the participant. The transcripts are not a mirror of what a participant thinks but a conversation between what both me and the participant were discussing at that time and in that location (Hammersley and Atkinson, 1996; Mahony, 2013). For example, several participants were keen to tell me about how the Met Office could improve the communication of the 3-month outlook. As a result, several interviews produced important information on how participants struggled to understand the 3-month outlook and their suggested improvements to the communication process. However, the amount of this material means that it is easy to discount other conversations with participants who were less interested in offering suggested improvements. I therefore have tried to focus on the full range of topics and experiences discussed within the interviews, as well as the improvements suggested by some participants.

### 4.3.7 Collection of Relevant Documents

Throughout the research project, documents that played a significant role in the communication of the 3-month outlook were collected with the permission of

[3] The internal handling plan is a document that the Met Office Press Office circulates around public-facing staff containing a summary of the 3-month outlook, FAQs and links to webpages explaining meteorological phenomena, such as the NAO and ENSO. The purpose of this document to help Met Office staff answer questions about the 3-month outlook from customers and to ensure that Met Office staff communicate a consistent message. A copy cannot be included with this thesis because the document contains commercially sensitive information about Met Office customers who use the 3-month outlook.

Met Office staff when they were not in the public domain. This included presentations given during the stakeholder briefings, internal handling plans that are circulated around Met Office staff to help them answer questions from stakeholders and copies of the 3-month outlook. Stakeholders also gave me permission to use various documents in the research, including examples of emails sent to colleagues about the 3-month outlook and in the case of journalists, newspaper articles that they had personally written about the 3-month outlook. Online news articles in the public domain were also gathered whenever Met Office staff became aware of journalists who were quoting the 3-month outlook. These were accessed through the database LexisNexis by using keyword searches for *three month*, seasonal forecast, contingency planners* and *Met Office.* A full list of the documents collected during the ethnography is included in Appendix 6 of this thesis.

The documents gathered during the ethnography provide examples of how stakeholders enacted different versions of the 3-month outlook whenever they were communicating in writing or using images and graphics to visualise the 3-month outlook. This complements data produced through observations of verbal briefings and through interviews with Met Office staff and the Met Office's stakeholders. Including documents as data in the ethnography also highlighted the role of physical materials in assembling and communicating the message of the 3-month outlook. This resonates with the material semiotic approaches discussed in Chapter 2, which aim to symmetrically analyse the webs of relations that form between both human and non-human actors (Law, 2008).

## 4.5 Data Analysis

A constructivist interpretation of grounded theory (Charmaz and Bryant, 2011) was used to analyse data generated from ethnographic observations, semi-structured interviews and documents and newspaper articles collected during the fieldwork. Grounded theory is an analytical approach that emphasises the development of theories that are grounded in the iterative inductive coding of qualitative data (Glaser and Strauss, 1967). Early forms of grounded theory tended to assume that researchers could adopt an objective, theory-neutral position and watch theories and categories 'emerge' as they analysed their data (Charmaz and Bryant, 2011; Glaser and Strauss, 1967). This epistemology ignores the role of the researchers' interests, as well as their contextual and

changing viewpoints, in shaping the production and analysis of qualitative data (Charmaz and Bryant, 2011). Furthermore, the claim that a researcher can avoid reading pre-existing theories into the data during analysis is a theoretical position in itself (Baxter et al., 1999). Adopting a constructivist interpretation of grounded theory therefore recognises the role of the researcher in generating rather than 'extracting' theories from qualitative data (Strauss, 1987). This enabled me to strike a balance between iterative inductive coding on the one hand and the use of pre-existing concepts on the other (Mahony, 2013; Sundberg, 2007). For example, I used the concept of multiplicity to guide the articulation of categories and themes when looking at how the 3-month outlook was communicated. However, I then used inductive coding to identify the multiple enactments of the 3-month outlook that formed during the communication process. Adopting a constructivist interpretation of grounded theory therefore meant that I avoided making problematic epistemological assumptions, whilst retaining the analytic strength of iterative and inductive approaches to coding qualitative data.

I started the analysis of the data as soon as the fieldwork began in October 2018, since the process of transcribing notes and interview transcripts is itself an initial stage of analysis (Cook and Crang, 2007). After the interview transcripts had been reviewed by participants, they were also uploaded onto the qualitative data analysis software package, Nvivo. Relevant documents, interview transcripts and field notes were all coded inductively first, guided by the overall aims and objectives of this research project. Then as recurring themes were constructed through the coding process, I also began to code the data deductively by organising data around emergent themes. All the materials, including documents containing images, were symmetrically treated as actors that generate meanings in relation to other actors (Law and Singleton, 2014). This meant that documents containing images, such as PowerPoint presentations and newspaper articles, were coded in the same way as written texts.

## 4.6 Concluding Reflections Upon the Research Design and Methodology

Although the previous section followed a linear narrative, there was no sequential process of gaining access to the Met Office and its stakeholders,

followed by the collection of data, analysing the data and writing up the thesis. Instead, attending particular events or activities prompted both the generation of data, the analysis of data and in some instances, the writing of material that would be included in the final thesis. My experience of completing a multi-sited ethnography of the 3-month outlook therefore highlights how ethnographic research is an iterative process (Cook and Crang, 2007; Law, 2004), in which the collection, evaluation and writing up of materials proceeds in a non-linear fashion.

Furthermore, this ethnography of the 3-month outlook highlights how it was often the process of being granted access to an activity within the Met Office or a stakeholder group that shaped the choice of individual methods and how they were implemented. Often textbooks on research design and qualitative research methods give the impression that selection of individual methods is primarily driven by pre-existing theories and a researcher's understanding of the literature (see for example Shaw et al., 2010: 9-25). However, whilst it is true that the overall design of this ethnography had a theoretical focus on following the message of the 3-month outlook, often the selection of individual methods, such as ethnographic observations of stakeholder briefings, was shaped by opportunities that were available at the time. For example, I had not originally planned to observe stakeholder briefings outside of the Met Office, since I did not think I would be given permission to do this by the Met Office's customers. However, when a participant offered to let me make notes whilst they listened in to the transport stakeholder briefing, I suddenly had the opportunity to observe a stakeholder briefing from the perspective of a transport stakeholder.

One could argue an opportunistic approach to choosing and implementing qualitative research methods is not theoretically informed and therefore lacks validity and rigour. However, unless an ethnographer is trying to test a hypothesis, in which it is important to control confounding variables, then taking advantage of opportunities like the one mentioned can improve the conclusions that an ethnographer reaches. This is because attending new events and activities creates different sources of qualitative data within an ethnography. These multiple sources can then be compared with each other and with developing theories to produce a thicker, more nuanced description of the phenomenon that the ethnographer is studying (Geertz, 1973; Marcus, 1995).

The limited opportunistic use of research methods therefore does not prevent an ethnographer from developing a theoretically informed understanding of what they are studying.

Finally, co-producing this ethnography with staff who are employed by the Met Office has highlighted how the close involvement of other stakeholders shaped the development of the research design and methodology. For example, Met Office staff granted me access to their principal stakeholders, reviewed interview protocols and discussed how we would negotiate ethical and practical issues that emerged during the ethnographic fieldwork. Similarly, the Met Office was also involved in formulation of research aims and objectives and in shaping the overall direction of the research project through advice of my PhD supervisor, Prof. Richard Betts. It is therefore important to critically reflect upon how the close involvement of the Met Office in this thesis shaped the development of the research and the conclusions that I have drawn. As a result, Section 8.5 in the concluding chapter will offer some further reflections on the ethical and practical implications of co-producing research with a non-academic stakeholder like the Met Office.

# Chapter 5. The Translation of the 3-Month Outlook

## 5.1 Introduction

In this chapter, I use the concept of translation (Callon, 2007) to study the means by which meteorological data, materials and people are drawn together to form the message of the 3-month outlook. The process of translation involves four different steps (Callon, 2007). Firstly, there is an actor that needs to 'interest' another actor to help them achieve their goal (interessement). To do this, the first actor needs to define the identity of the second actor in such a way as to establish themselves as an 'obligatory passage point' in the network of relationships they are building (problematisation). For example, the Met Office promotes the uptake and usage of its SCF by defining the 3-month outlook as an 'obligatory passage point' for information about how future UK seasonal climate might vary. The process of translation is successful if one actor manages to 'enrol' the interests of the other actor (enrolment), whilst also displacing them from associations with other actors (displacement). For example, the Met Office will have successfully enrolled another stakeholder if the Met Office maintains the stakeholder's interest in using the 3-month outlook, rather than another SCF. Finally, an actor-network becomes stable when all the actors 'converge'- that is, 'work together' within their mutually defined roles (Callon, 1990). A strongly convergent actor-network around the 3-month outlook would therefore be one in which all the actors- climate models, documents, journalists, transport operators and so on, all coordinate and align their different interests.

I use the concept of translation to analyse the communication of three SCF issued by the Met Office. The first of these is the summer 2009 forecast issued by the Met Office in April 2009. The translation of this forecast failed because the identity and purpose of the summer 2009 forecast was not defined in a way that aligned the interests of Met Office scientists and press officers on the one hand and journalists, editors and members of the UK public on the other. Although the summer 2009 forecast was communicated in a different way to the 3-month outlook, its unsuccessful translation changed how the Met Office communicated SCF in the following decade. It is therefore important to look at the translation of the summer 2009 forecast in order to understand how the 3-month outlook is currently communicated.

The second forecast is the January-February-March (JFM) 2020 outlook, which was issued in December 2019. I argue that this forecast was successfully translated because the Met Office enrolled the interests of transport stakeholders, contingency planners and energy stakeholders who used the 3-month outlook to make contingency plans in the way that Met Office staff intended. This was achieved by problematising the 3-month outlook as a 'watching brief,' rather than as a forecast that could be used to commit resources or take immediate action.

The third forecast is the July-August-September (JAS) 2019 outlook, which was quoted in a series of newspaper articles published in July 2019. This outlook illustrates how the Met Office was sometimes reactively drawn into actor-networks that formed around newspaper articles quoting the 3-month outlook. I argue that the Met Office was often unable to disassociate itself from these actor-networks, even though the Met Office Press Office had chosen to not actively publicise the 3-month outlook. This is because journalists often quoted the 3-month outlook alongside other forecast providers, which prevented the Met Office Press Office from asking for quotes that they disagreed with to be withdrawn or changed. The speed at which at which news stories were published and shared online also meant that any rebuttals issued by the Met Office Press Office often went unnoticed.

Finally, I conclude by highlighting how the successful translation of the 3-month outlook depends on it having a stable, mutually defined role within an actor-network. In the case of the JFM 2020 outlook, the Met Office's principal stakeholders used the 3-month outlook in the way that Met Office scientists intended because it had been mutually defined as a 'watching brief.' The actor-network that formed around the JFM 2020 outlook was therefore convergent and well-aligned (Callon, 1990). However, newspaper articles quoting the JAS 2019 outlook illustrate how the Met Office Press Office was sometimes unable to prevent journalists from treating the 3-month outlook as a deterministic forecast of weather events during the upcoming season, rather than as a probabilistic climate outlook. This suggests that any future efforts to communicate SCF to the UK media need to focus on finding a use for SCF that aligns both the interests of journalists and editors and national meteorological services like the Met Office.

## 5.2 The Translation of the Summer 2009 Forecast

The issuing of the summer 2009 forecast had a significant impact on how the Met Office currently communicates the 3-month outlook (see Section 3.42). This is because it was this event that resulted in the Met Office proactively communicating the 3-month outlook to energy stakeholders, transport stakeholders and contingency planners, rather than to members of the public or the media. The Met Office's response to criticism from journalists and members of the public following the summer 2009 forecast also shaped how the Met Office Press Office and media enquiries team now engage with these two stakeholder groups. It is therefore important to understand why the translation of the summer 2009 forecast was unsuccessful, so that one can understand the translation of the current 3-month outlook.

According to press officers at the Met Office, the decision to issue the tagline 'odds on for a barbeque summer' reflected an effort to make SCF easier for journalists and editors to understand and report on:

*'Well, the barbeque summer is a very good example- we gave it a headline and we said 'odds on for a barbeque summer' because we were trying to work with the probabilistic nature of it. It started off with the summer lovely and warm and then it started to rain. Now we also said that there was a quite a high chance of above average rainfall, but it was forgotten because of the headlines.' (Press Officer, 07-01-19)*

As the press officer explains, they chose to use the tagline 'odds on for a barbeque summer' because it communicated the probabilistic nature of SCF to journalists who were only familiar with reporting deterministic weather forecasts. Giving a news briefing also meant that Met Office scientists and public relations staff could tailor the communication of the 2009 summer forecast to the needs of journalists and answer any questions that they might have. The Met Office Press Office therefore tried to enrol (Callon, 2007) the interests of journalists by providing them with a tagline would be easy to publish as a news story, whilst also communicating the probabilistic nature of SCF.

However, press officers and scientists at the Met Office ultimately failed to align their own interests with the interests of journalists when they communicated the summer 2009 forecast. This is because Met Office staff did not clearly define

the meaning of the summer 2009 forecast when it was communicated through the intermediaries of the tagline and news briefing. For example, the following science editor who attended the news briefing in 2009 describes how they thought that the tagline 'odds for a barbeque summer' did not communicate what Met Office staff really meant:

*'By using barbeque, you immediately mean dry. To further translate it, you've got a bloody good chance of going out in the evenings this summer. They didn't quite mean that. If I recall this now, they meant that it was a good chance of being warmer than average but they either forgot about the precipitation bit or I don't know how they referred to that. I think the problem was that in a commendable quest to use colloquial language they weren't quite accurate enough. They picked words that didn't quite reflect what they mean.' (Science Editor 20-12-19)*

As the science editor explains, the tagline 'odds on for a barbeque summer' is associated with sunny weather, which is a meteorological variable that was not included in the original forecast (Met Office, 2009b). The imprecise language used in the tagline therefore raised the expectation of weather conditions that were not actually predicted in the summer 2009 forecast amongst journalists and editors. However, one could also argue that the tagline did accurately summarise aspects of the summer 2009 forecast in colloquial language. For example, the phrase 'odds on' reflects the probabilistic nature of SCF and 'barbeque summer' indicates weather that is warmer and drier than average, which is what the forecast originally predicted (see Section 3.4.2). This suggests that the difficulties that journalists and editors had in understanding the meaning of the summer 2009 forecast cannot only be attributed to how the tagline was worded.

Another possible explanation for the contested meaning of the summer 2009 forecast relates to how journalists and editors assessed the forecast's accuracy. The presentation given during the briefing seems to have contained little guidance on how to interpret SCF and on how they differ from short-term weather forecasts. For example, only one slide at the end of the presentation contained any information on the differences between SCF and short-term weather forecasts (Met Office 2009b: 13). Journalists and editors present at the

news briefing might therefore have assumed that the 2009 summer forecast could be verified against their personal experience of the weather in the same way as a short-term weather forecast. However, it is not possible to claim that a single seasonal climate forecast is ‘right’ or ‘wrong.’ An unskilful and unreliable seasonal forecasting system can produce a ‘correct’ forecast purely by chance. Instead, the skill and reliability of a seasonal forecasting system can only be assessed over a much longer period by running hindcasts (see Section 3.27) (Taylor et al., 2015). The meaning of the summer 2009 forecast might therefore have become unstable because the Met Office did not provide journalists and editors with the information that they needed to assess its accuracy fairly.

As a result, the unsuccessful translation of the 2009 summer forecast highlights the importance of explaining what a SCF is, what it can be used for and how its accuracy can be assessed before introducing the content of the message. If the intermediary (Callon, 1990) of a news briefing or tagline is not clearly defined, the actor-network will diverge as stakeholders disagree on what a seasonal climate forecast is and on what kind of information it can provide. For example, journalists and editors came away from the news briefing expecting an exceptionally warm, dry summer when the summer 2009 forecast only predicted an increased risk of a warm, dry summer (Met Office 2009b). This meant that they felt like they had been misled by the Met Office when the wet weather that they experienced did not correspond to what they thought the summer 2009 forecast said (Chadwick, 2010). The successful translation of SCF therefore depends on scientists and other stakeholders agreeing upon a mutual definition of what a SCF is and how it should be interpreted and used, so that they can coordinate and align their interests.

## 5.3 The Translation of the JFM 2020 Outlook

### 5.3.1 The 3-Month Outlook

After facing criticism from journalists and members of the public for how it communicated the summer 2009 forecast, the Met Office needed to problematise (Callon, 2007) SCF in a way that would interest potential stakeholders whilst also communicating the uncertain and probabilistic nature of SCF. Staff at the Met Office therefore decided to review how they communicated SCF to the UK media and public:

*'So, we had a problem, a miscommunication of the forecast and we had a review following that which highlighted recommendations. So, we changed the product. It was a combination of the scientists and government services dealing with the principal stakeholders who came up with this format.' (Climate Scientist, 04-03-19)*

The internal review mentioned by this climate scientist highlighted recommendations for improving the communication of SCF for the UK. This included a public consultation during which members of public reported not finding SCF useful in the way that they were presented:

*'We were heavily involved in a discussion about withdrawing the previous seasonal forecasting approach. The consultation we undertook showed that people did not find it very useful in the way it was presented, and that they would rather have received a shorter-term forecast so that the three-month forecast was replaced with a 30-day rolling forecast. A lot of work has gone on since then with the Met Office, and over the next week or so it will introduce a new seasonal forecasting methodology for civil contingency communities, which includes a better explanation of the uncertainty facing us. [...] It is important that people are organised and have a good understanding of that forecast. We have been funding that information and it will be released through the Cabinet Office.' (Chair of Public Weather Service Customer Group, Science and Technology Select Committee, 2012: Q79)*

A decision was therefore taken to replace the SCF with a 30-day rolling forecast that was perceived to be more useful by members of the public who participated in the consultation. Meanwhile, the Met Office 'changed the product' (Climate Scientist, 04-03-19) to communicate SCF to contingency planners in the UK government, who had been receiving them from the Met Office since the winter of 2005/06 (see Section 3.4.1). The Met Office did this by problematising its SCF as a 'useful planning tool to government and to those sectors who are experienced in routinely managing risk based on a probability of outcomes' (House of Commons Transport Committee, 2011: 18: Evw10). This established the Met Office as an obligatory passage point (Callon, 2007) for information about seasonal climatic risks that contingency planners in the UK government and private sector needed to know about. By transforming SCF into a risk

management tool, Met Office staff aimed to enrol stakeholders that they thought would be more familiar with using probabilistic information. This aligned the interests of Met Office staff, who wanted stakeholders to use SCF in a way that acknowledged their probabilistic nature, with the interests of contingency planners, who wanted to prepare for potential disruption to the delivery of government services (House of Commons Transport Committee, 2011).

The Met Office continues to problematise SCF in a similar way by defining it as a 'watching brief' that can be used to 'highlight areas to watch' and to facilitate long-term, strategic planning (Met Office, 2018b). For example, the following guidance on the 3-month outlook document describes how contingency planners should use the 3-month outlook as a watching brief:

*'This outlook provides an indication of possible temperature and rainfall conditions over the next 3 months. It is part of a suite of forecasts designed for contingency planners. The Outlook should not be used in isolation but should be used with shorter-range and more detailed (30-day, 15-day and 1-to-7-day) forecasts and warnings available to the contingency planning community from the Met Office.' (User Guidance on the 3-Month Outlook Document)*

This caveat is placed at the bottom of the document so that contingency planners see it each time they view the 3-month outlook on the Met Office website. It suggests that there is a difference between a seasonal climate outlook and a short-term weather forecast by telling contingency planners that they should not use it in isolation but alongside shorter-term, more detailed weather forecasts. It also describes how the 3-month outlook gives contingency planners information about probable trends rather than specific weather events. Defining the 3-month outlook as a watching brief is therefore a way in which the Met Office establishes itself as an obligatory passage point for information about seasonal climate related-risks, so that it can enrol the interests of potential stakeholders in the UK government and the private sector.

### *The Construction of the JFM 2020 Outlook*

Every 3-month outlook issued by the Met Office begins in the long-range forecasters' meeting, where climate scientists and meteorologists meet each month to review evidence of how the UK climate might evolve during the outlook period. During the meeting a meteorologist gives a presentation that

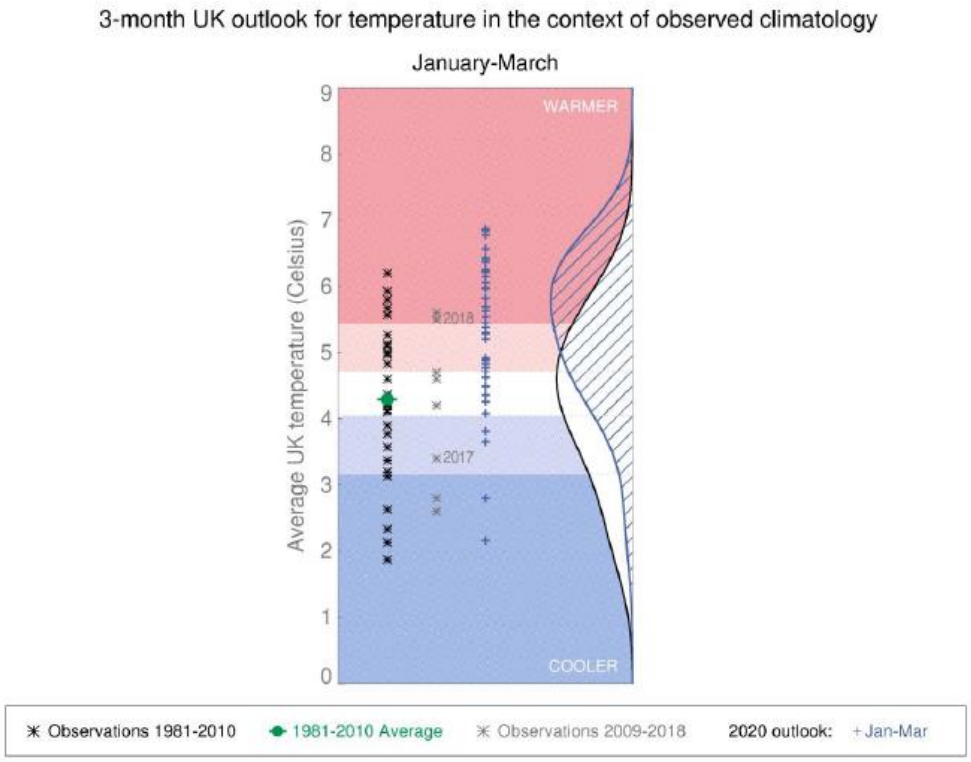
goes through observations of relevant teleconnections, then SCF from other global long-range forecasting centres and finally the forecast from the Met Office's own seasonal climate model, GloSEA5 (MacLachlan et al. 2015). Attendees are encouraged to ask questions about the data that is presented and discuss how it should be interpreted. The format of the meeting allows the monthly-decadal prediction team to enrol various actors (Callon 1986), such as the expert judgement of other Met Office scientists, observations of relevant teleconnections and SCF from other global long-range forecasting centres. This allows a network to form and stabilise as the climate scientists agree upon what the summary message of 3-month outlook should be.

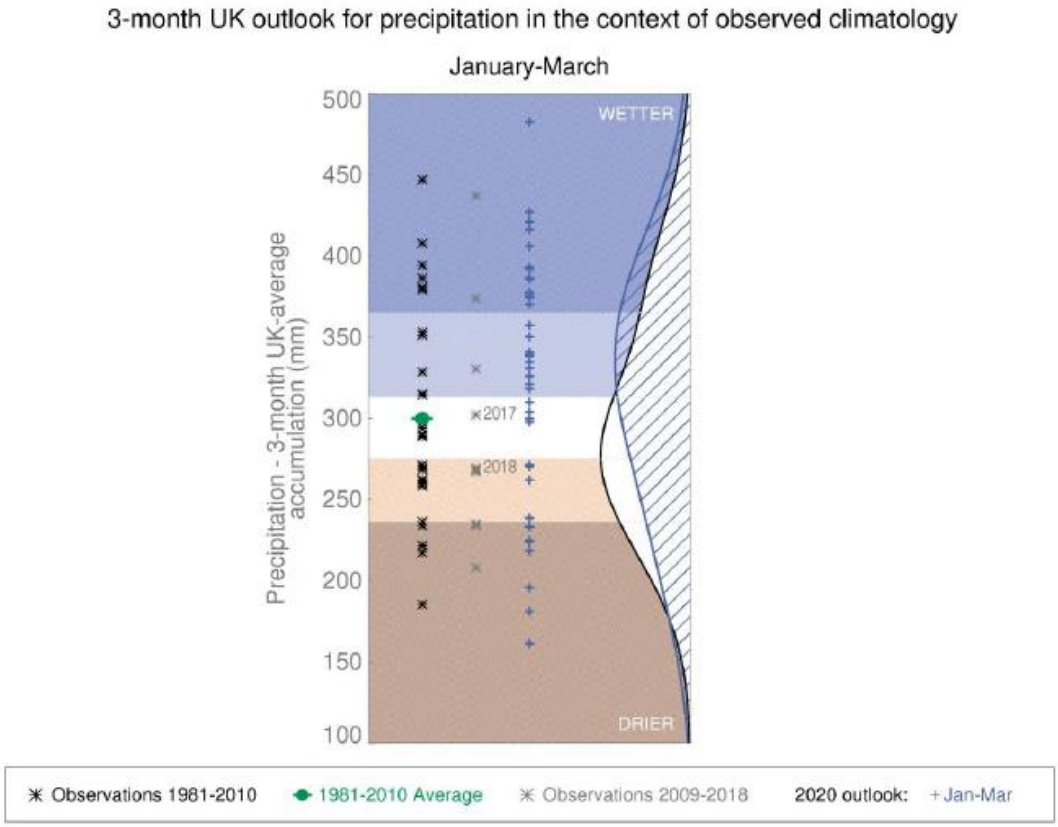
During the meeting for the JFM 2020 Outlook, the process of agreeing upon the message of the 3-month outlook was relatively straightforward. Warmer than average SSTs in the Indian Ocean and North Atlantic Ocean, precipitation patterns in the Pacific Ocean and a strong stratospheric polar vortex all favoured positive NAO conditions (Notes from the Forecasters' Meeting, 10-12-19). Positive NAO conditions during the winter increase the chance of mild, wet and windy weather over the UK. Only the solar minimum and drier than average conditions over the tropical Atlantic Ocean favoured negative NAO conditions (Notes from the Forecasters' Meeting, 10-12-19). The forecasts from the Met Office and other global-range forecasting centres all replicated the outlook for mild, wet and windy weather over the UK indicated by the observations (Notes from the Forecasters' Meeting, 10-12-19). The scientists therefore found it relatively easy to form associations between these sources of evidence and develop expectations of what the UK climate might be like between January and March 2020.

Once Met Office scientists have reviewed the evidence included in the presentation, they decide upon whether to modify the SCF from GloSEA5 to account for known biases in the Met Office's model. This involves adjusting the probability of five categories (well below average, below average, average, above average, well above average) and a graph showing the full probability distribution (see Figure 10 over the page). Often this point in the meeting involves extensive discussion, since it involves bringing together the evidence that the scientists have just reviewed, their own expertise and assumptions about how other stakeholders might respond to the message of the 3-month

outlook. However, the process of agreeing upon the summary message for the JFM 2020 was relatively straightforward. This was because the scientists thought that the forecast from GloSEA5 was consistent with the observations and forecasts from other global long-range forecasting centres. Met Office scientists were therefore able to stabilise and unify their interpretation of the data by forming associations between the different forecasts, observations and their own expertise.

*Figure 10- Probability Distributions for the JFM 2020 Temperature and Precipitation Outlooks*






After the long-range forecasters' meeting, the modified graph and categories from the meeting are sent to a group of senior meteorologists and climate scientists in the Met Office (Climate Scientist, 04-02-19). The graph is not changed in any way and the categories are written up by the scientists as a summary statement. This summary presents the 3-month outlook as a verbal probability statement and a numerical probability statement, which only quotes the highest and lowest categories in the outlook. The final probability distribution and summary message for the JFM 2020 temperature and precipitation outlooks were as follows:

**JFM 2020 Temperature Outlook Summary**

*'For January-February-March as a whole, above-average temperatures are more likely than below-average temperatures. Impacts from cold weather remain possible, but they are less likely than normal.*

*Overall, the probability that the UK-average temperature for January-February-March will fall into the coldest of our five categories is 5% and the probability that it will fall into the warmest of our five categories is around 50% (the 1981-2010 probability for each of these categories is 20%).'*

**JFM 2020 Precipitation Outlook Summary**

*For January-February-March as a whole, above-average precipitation is more likely than below-average precipitation.*

*The probability that UK-average precipitation for January-February-March will fall into the driest of our five categories is between 15% and 20% and the probability that it will fall into the wettest of our five categories is around 30% (the 1981-2010 probability for each of these categories is 20%).*

Both the summary message and the probability distributions functioned within the Met Office as stable intermediaries (Callon, 1990). By transforming the discussions that took place in the forecasters' meeting into a fixed summary statement or visualisation, the JFM 2020 outlook could travel around and be understood by other staff within the Met Office. For example, the same summary message and visualisation appeared on the Met Office website, in the energy and transport stakeholder briefings and in a handling plan that was circulated around press office staff to help them answer questions on the 3-month outlook (Strategic Relationship Manager, 25-02-19). Figure 8 on page 70 provides a visual overview of how the 3-month outlook travelled from the long-range forecasters' meeting to other places within the Met Office. The formation of stable relationships between people, fixed summary statements, handling plans, and graphics therefore facilitated the translation of the 3-month outlook from the long-range forecasters' meeting to other contexts, such as the energy and transport stakeholder briefings.

### *The Communication of the JFM 2020 Outlook*

The response of principal stakeholders to the JFM 2020 outlook did suggest that the Met Office was successful in helping them understand and use the 3-month outlook as a watching brief. For example, during the transport stakeholder briefing the following flood drainage engineer seemed to understand the overall message of the JFM 2020 outlook:

*A member of Met Office staff finished the meeting and ended the conference call.*

*After the call I spoke to the duty engineer about what he would take away from the briefing. They said that the Met Office were predicting a Jan-Feb-Mar that*

*wetter than normal and milder than normal. (Notes from Transport Stakeholder Briefing, 16-12-19).*

The JFM 2020 outlook predicted a 50% chance of JFM 2020 being in the warmest category and a 30% chance of it being in the wettest category. This meant that there was increased chance of JFM 2020 being warmer and wetter than normal. When I asked the flood drainage engineer about what they would take away from the briefing, they replied by saying that they thought that the Met Office was predicting wetter and warmer than average weather over the next three months. The participant's response therefore indicates that they understood the main message of the 3-month outlook. Moreover, the same participant also seems to have used the 3-month outlook as a 'watching brief' in the way that Met Office staff intended. For example, in the following interview they describe using the 3-month outlook 'as guidance,' rather than to commit resources or make operational decisions:

*'It's more of a heads up so that say, February and March are going to be really cold, dry long cold spells, prolonged spells, snow maybe, it leads in the back of our minds to think, 'January, February, maybe we need to think more about the flooding side, February-March, more about the snow side. We really just use it as a guidance or a heads up.' (Flood Drainage Engineer, 16-12-19)*

As the participant indicates, they did not use the 3-month outlook or the associated transport impact outlook to make specific decisions or to mobilise resources at the county council that they worked for. Instead, the 3-month outlook gave the participant 'guidance' or a 'heads up' as to what kind of weather they might expect over the next three months. Other principal stakeholders, who were involved in managing energy consumption (Energy Manager 06-11-19) or making contingency plans for the National Health Service (NHS) (Emergency Resilience Manager 22-01-20) also reported using the 3-month outlook 'as guidance.' By problematising the 3-month outlook as a 'watching brief,' the Met Office was therefore able to enrol the interests of transport stakeholders, energy stakeholders and contingency planners who wanted to prepare for weather-related risks over the next three months.

However, the 3-month outlook did not easily move beyond the individuals who initially received the outlook from the Met Office. For example, the flood

drainage engineer only briefed other staff in their local authority at a monthly highways coordination meeting:

*'Interviewer: Would you forward it [the 3-month outlook] on by email or...?*

*Participant: Mainly verbal.*

*Interviewer: OK, mainly just conversations.*

*Participant: After the back of these meetings we don't do a big global email out at all or anything like that. It's basically something we keep to ourselves, although obviously we are mindful of it. We might speak to our drainage team as well. Obviously, the highways coordination meeting for all the heads of service, they're there. It's more of an early warning process really.' (Flood Drainage Engineer, 16-12-19).*

The flood drainage engineer explains that they did talk to other members of staff about the JFM 2020 outlook during these meetings. This comment is also supported by the response of another participant who worked at the same county council, who reported receiving information from the duty engineers on what weather is 'going to be coming up on our radar' over the next three months (Emergency Planning Officer, 09-01-20). However, the flood drainage engineer did not widely circulate the 3-month outlook by email, even though documentation is sent to transport stakeholders by the Met Office in advance of a briefing (Interview with Applied Scientist, 05-02-19). This might be because transport stakeholders did not think that the 3-month outlook document contained important information that they needed to pass on to their colleagues. However, the fact that this participant sometimes briefed colleagues during meetings suggests that they may have thought that the documents sent by the Met Office were difficult for other staff in the county council to understand. The response of other stakeholders who used the 3-month outlook supports this possibility:

*'I look at this 3-month page that you provide us with and if I'm honest it's overwhelming. I find it overwhelming and for me to relay it other people who do not work in this sector. So, people who have no direct investment in that information, this would just completely swamp them, in terms of 'what is it you*

*are telling me, what is it that I'm supposed to understand from this, what is it that I'm supposed to do with it?'" (Transport Resilience Manager, 08-01-20)*

The transport resilience manager explained how the scientific context and graphics used within 3-month outlook document made it difficult for them to communicate the information on to other people in their organisation. Met Office staff had included this material in the 3-month outlook document to 'communicate the complexity within the forecast and to give context to the forecast for the next three months (Marketing and Communications Officer, 13-03-19).' However, according to this transport resilience manager, the scientific terminology and graphics were not understood by other people in their organisation who were not from a meteorological or contingency planning background. As a result, the participant could not pass on the documentation that the Met Office had provided to other members of staff. Instead, they had to re-interpret the 3-month outlook using terminology that their colleagues would understand. Some principal stakeholders therefore found it difficult to enrol the interests (Callon, 2007) of their colleagues because they either did not understand the message or see the relevance of the 3-month outlook to their decision-making and planning processes.

### 5.3.2 The Transport Impact Outlook

In addition to problematising the 3-month outlook as a watching brief, the Met Office began issuing a bespoke impact outlook to enrol transport stakeholders into the actor-network that had formed around the 3-month outlook:

*'I suppose I ought to talk about our initial engagement with the Department for Transport stakeholder group. It was [Met Office scientist] who initially engaged with the Department for Transport- they asked him to speak to them about the seasonal forecast for the winter season. Out of that came a prototype service.' (Applied Scientist, 05-02-19)*

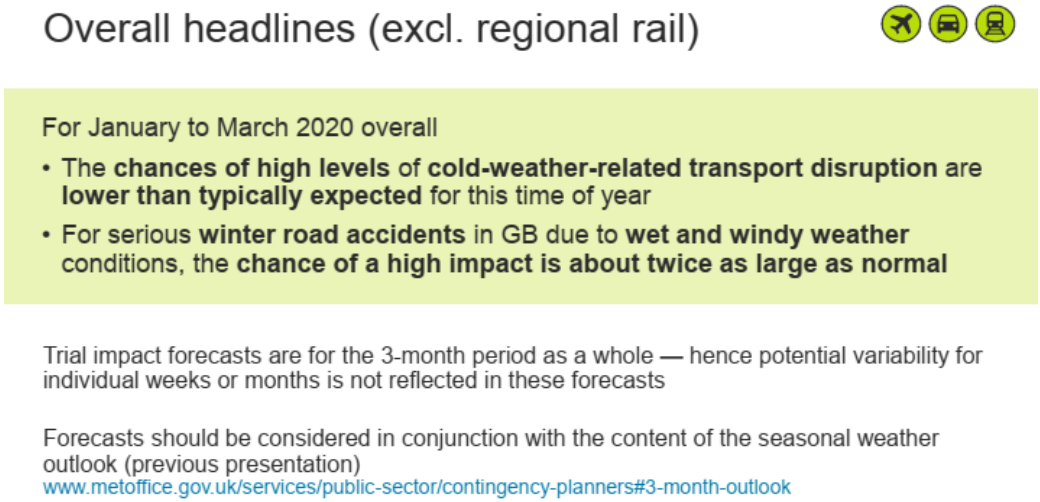
According to this applied scientist, staff from the Department for Transport asked Met Office scientists to provide them with verbal briefings on the 3-month outlook during the UK winter of 2014/15 (Buontempo et al., 2016, p. 18). Contingency planners and transport operators in the UK transport sector had been criticised for not being adequately prepared for the severe winter weather that the UK experienced during the winters of 2009/10 and 2010/11 (House of

Commons Transport Committee, 2011). The 3-month outlook therefore became an intermediary that realised the interests of Met Office staff, who wanted to enrol stakeholders who would benefit from using their SCF, and the Department for Transport, who wanted to improve the resilience of the UK transport sector to severe winter weather. Moreover, improvements in the skill of forecasts of the UK wintertime NAO (see Scaife et al., 2014) created an opportunity to provide the transport stakeholder group with an outlook that was more relevant to the kinds of decisions that they made with the 3-month outlook. Met Office scientists therefore applied for funding from the European Union to co-produce a bespoke impact outlook with transport stakeholders.

The transport impact outlook was successful in enrolling the interests of transport stakeholders because it defined variations in seasonal climate in terms of what climate 'does,' rather than only describing changes in temperature or precipitation (Fleming and Jankovic, 2011). This made it easier for transport operators to understand the JFM 2020 outlook and to communicate it on to other people in their organisation:

*'But if you look at the information that we get from DfT now, and that's why I gave you this, if you look at the little summary in the UK outlook for winter transport impacts, the little table document, you can actually see the summary says, 'from January to March, the chances of high-level cold-weather related transport disruption are lower than typically expected. Serious winter road accidents due to wet and windy weather, the chance of high impact is about twice.' So, what we can take from that is what we can articulate that in a way that non-meteorological and non-resilience people can understand.' (Transport Resilience Manager, 08-01-20)*

*Figure 11- JFM 2020 Transport Impact Outlook Headlines*




The transport resilience manager argues that people without expertise in meteorology or contingency planning found the transport impact outlook easier to understand because it presented them with information about how changes in winter climate would impact or affect road, rail and aviation infrastructure. Experimental studies within social and cognitive psychology suggest that using concrete, vivid imagery to describe the impacts of climatic variability and change reduces our psychological distance from the predicted event, which makes climate projections and forecasts easier to understand (Marx et al., 2007a; Weber, 2016). In this case, presenting transport stakeholders with an impact-based outlook seems to have had this effect. Presenting transport stakeholders with information about winter weather-related impacts meant that they could visualise what the impacts of the weather might be like between January and March 2020. Transport stakeholders therefore felt that they could communicate the transport impact outlook to their colleagues, without needing to reinterpret the message for people who did not have expertise in meteorology or contingency planning.

As a result, creating a bespoke impact outlook that provided transport stakeholders with information about what the climate 'does' (Hulme, 2015; Fleming and Jankovic, 2011) was particularly successful in enrolling the interests of transport stakeholders. The Department for Transport stakeholder group is now the largest of the Met Office's three principal stakeholder groups. Participants in this stakeholder group also reported regularly using the 3-month

outlook to gain an overview of possible weather conditions and to activate existing contingency plans. Moreover, many transport stakeholders did not just use the transport impact outlook by themselves but forwarded on the documentation by email to other people in their organisation that they thought might benefit from receiving the outlook. This contrasts with the 3-month outlook, which participants often had to summarise and explain in less technical language.

Nevertheless, the Met Office was still successful in enrolling the interests of energy stakeholders and contingency planners who did not receive a bespoke impact outlook. This was because the Met Office problematised it as a 'watching brief' rather than as a 'forecast.' Stakeholders therefore did not expect either the transport impact outlook or the 3-month outlook to provide information at the same level of certainty as a short-term weather forecast. They also used the 3-month outlook as supporting evidence when they made decisions, rather than to mobilise resources or change operational arrangements. The actor-network that included the Met Office's three principal stakeholder groups was therefore convergent (Callon, 1991), in the sense that all the actors agreed on what the 3-month outlook is (a watching brief or outlook) and how it should be used in decision-making (as guidance or supporting evidence). Finding a way of problematising the 3-month outlook that distinguished it from a short-term weather forecast therefore prevented contingency planners, transport stakeholders and energy stakeholders from interpreting it deterministically. This meant that the Met Office did not experience the same difficulties in communicating the uncertain and probabilistic nature of SCF that the Met Office encountered when communicating the summer 2009 forecast to the UK public and media.

## 5.4 The JAS 2019 Outlook and the UK News Media

### 5.4.1 Media Coverage of the JAS 2019 Outlook

Following the unsuccessful translation of the summer 2009 forecast, the Met Office stopped issuing SCF for the UK public and media. The 3-month outlook is still made publicly available on the Met Office website, which means that interested members of the public and journalists can access and report on the 3-month outlook if they want to. However, newspaper articles quoting the 3-month outlook were not frequently published. This is because the 3-month

outlook was thought to be too uncertain to provide material for a news story on its own:

*'But again, using the disciplines of journalism, I'm looking at that from the point of view of is there a story there? Is there a clear story there that I'm going to be able a) communicate and b) get published? And the answer would be no. There's not any kind of certainty in the factors.' (Freelance Journalist, 31-10-19)*

When this freelance journalist read a copy of the 3-month outlook during the interview, they noted how the summary statement was too uncertain to pitch as a story to a newspaper editor. Journalists are often trained to look for stories with a clear beginning, middle and an end that will engage a potential reader (Adam, 2006). However, the participant thought that an outlook claiming that the 'chances of above and below average precipitation are approximately similar' (DJF Outlook 2019) was not dramatic enough to provide a hook for an interesting news story. Journalists therefore only quoted the 3-month outlook when it could be associated with narratives about the 'British' cultural fascination with the weather (Fox, 2014; Hulme, 2016) or other developing news stories. The timeline over the page (Figure 12) indicates one instance in July 2019 where journalists did publish articles quoting the 3-month outlook.

*Figure 12- July-August-September 2019 Outlook: Timeline of Response Within the UK News Media. Based on Met Office (2019), Inews (2019), The Times (2019)*

As Figure 11 illustrates, journalists did not publish articles every time the Met Office issued the 3-month outlook. Instead, the 3-month outlook was often only included in newspaper articles in response to weather events that had already become a news story. However, in order to write an article that would be published, journalists needed to associate the 3-month outlook with other images, newspaper articles and weather forecasts in order to create a story that would appeal to potential readers. For example, the following newspaper article published in The Times (2019) associates the July-August-September (JAS) 2019 outlook with short-term weather forecasts that the Met Office issued during third week of July 2019:

*'Britain is set to bask in a "continental heat dome" with above-average temperatures over the next three months, forecasters say, with a high of 32C in southern and eastern England by the end of August.*

*The higher temperatures are eight times more likely than cooler than average temperatures until the end of September, the Met Office says. The south and east will be the hottest and driest regions but the north and west are also likely to have hotter than usual conditions. Temperatures could reach 27C on Wednesday.*

*"For July to September, above-average temperatures are more likely than below average," the Met Office's three-month forecast said.*

*"The probability that UK average temperature will fall into the warmest of our five categories is 35-40 per cent. The coldest of our five categories is 5 per cent."' (The Times, 15th July 2019)*

The newspaper article combines the summary statement of the JAS 2019 outlook with a short-term weather forecast published by the Met Office during that week. This gives the impression that high temperatures predicted by the short-term weather forecast will last for the next three months, especially when combined with the headline, which claims that a 'continental heat dome will sizzle the UK during the summer holidays' (The Times, 2019). However, the 3-month outlook does not provide this kind of information, since it only predicts the probability of temperatures being above or below the 1981-2010 average

(Met Office, 2018b). This newspaper article in The Times therefore highlights how journalists often struggled to report on the 3-month outlook without treating it like a short-term weather forecast. This resonates with the work of scholars within journalism studies (Usher, 2014) and geographers who study mass media representations of anthropogenic climate change (DiFrancesco and Young, 2011; Boykoff, 2008), who argue that journalists find it easier to report stories that culminate in immediate events, rather than 'creeping events' that evolve slowly over time. The JAS 2019 outlook therefore needed to be associated with short-term weather forecasts to change the 3-month outlook into a dramatic, immediate event that could be easily communicated to potential readers.

Furthermore, journalists would often quote other forecasters alongside the Met Office's 3-month outlook in order to create a compelling story that they could pitch to a newspaper editor. For example, The Times article mentioned above also quoted two other forecast providers. The first of these was a short-term weather forecast from Meteogroup, a private company that issues both short-term weather forecasts and SCF (Meteogroup, 2020). The second was a 30-day forecast from Brian Gaze, an independent forecaster who issues long-range weather and climate forecasts based on his interpretation of forecasts from global long-range forecasting centres (Gaze, 2020). The journalists who participated in this study gave different explanations as to why they quoted multiple forecasters in the same article. One participant associated the inclusion of multiple forecasters in their newspaper articles with objective, balanced reporting, arguing that they aimed to 'purely present' what each forecaster was saying (Freelance Journalist 05-11-19). This suggests that they associated the quotation of multiple forecasters in an article with maintaining journalistic norms of balance and objectivity (Bennett, 2012). Other participants were more sceptical about the quotation of multiple forecasters in newspaper articles, suggesting that it was a way of finding an 'interesting angle that will catch their [the reader's] eye' (Science Editor, 20-12-19). Nevertheless, the inclusion of multiple forecasters had a similar effect in that it helped journalists give a weather-related news story a clear thematic structure or narrative.

Finally, newspaper editors who published news stories quoting the 3-month

outlook often placed news copy alongside headlines and images that are associated with narratives about the 'British' cultural fascination with the weather:

*'As I said, within newspapers there is a big appetite for weather stories. In the industry you talk about what I said to you- it's a talker- so, what do people talk about? We talk about the weather. We're British. The British are renowned for talking about the weather.' (Freelance Journalist, 31-10-19)*

As the participant says, weather stories are 'a talker'- a topic that British people regularly talk about. Anthropologists (Fox, 2014), geographers (Hulme, 2016) and psychologists (Harley, 2003) have argued that weather-talk is an expression of solidarity in a shared sense of a stable British climate. Fox (2014) even argues that the weather functions like a 'member of the family' (Fox, 2014), who can be complained about by UK citizens but cannot be criticised by 'foreigners' who do not understand the subtleties of British weather. Newspaper editors therefore often drew upon this connection between weather and national identity when publishing stories that quoted the 3-month outlook. For example, The Times article that quoted the JAS 2019 outlook was headed by a picture of holidaymakers on Lyme Regis beach on the south coast of England (see Figure 13).

*Figure 13- Picture from an Online News Article in The Times Quoting the JAS 2019 Outlook, from McMahon (2019)*

By placing this image below a headline claiming that the UK was going to sizzle under a ‘continental heat dome’ (The Times, 2019), the editors were associating expectations of a prolonged heatwave with nostalgic memories of summer holidays in the UK spent beside the sea. This engages with wider cultural narratives around how the UK public expects the atmosphere to ‘perform’ during the summer months (Hulme, 2016). As one press officer at the Met Office put it, the public ‘want a hot summer that they can enjoy and a little bit of snow in the winter they can enjoy so long as it goes away relatively quickly (Press Officer, 07-01-19).’ However, an image like the one placed at the top of this newspaper article was not necessarily linked to the actual content of the 3-month outlook. This is because the JAS 2019 outlook only predicted an increased chance of above-average temperatures, which does not guarantee instances of sunny, hot, dry weather like those depicted in the image. Instead, the eye-catching headline, the JAS 2019 outlook, other weather forecasts and the image of holidaymakers on Lyme Regis beach were woven together into a news story that was designed to fit with pre-established narratives about what a British summer should be like.

### 5.4.2 The Met Office’s Response to Newspaper Articles Quoting the JAS 2019 Outlook

Although the Met Office no longer issues SCF for the UK media and public, Met Office scientists and press officers thought that newspaper articles often misrepresented the message of the 3-month outlook. For example, the following press officer explains how they did not agree with how journalists and editors communicated the 3-month outlook because of how the 3-month outlook was presented alongside other forecasts:

*‘So, they [journalists] will often go to other met. services, weather forecasters, private organisations- those sort of people- who will potentially give the answer that they want- so that they can then take ‘Met Office says increased chance of colder temperatures,’ which we do- but then get one of the other private weather organisations quotes to go with it with our names at the top of it. And that can be quite frustrating to deal with because you can’t go back to them and get them to change it because what they’ve written is correct- but it’s the*

*implication that we agree with everything else that is quoted in the article.' (Press Officer 08-01-19).*

The press officer explains that the Met Office often could not ask for quotes from the 3-month outlook in newspaper articles to be withdrawn or changed, since these quotes were usually a direct quotation from the 3-month outlook published on the Met Office website. However, the way in which the 3-month outlook was presented alongside other forecasts often created a story that the Met Office Press Office did not agree with. The quotation of the 3-month outlook alongside other forecasters therefore meant that press officers within the Met Office could not displace (Callon, 2007) the 3-month outlook from newspaper articles that they thought were misleading.

During July 2019, the Met Office Press Office did not publish any blog posts or other materials that corrected headlines about the JAS 2019 outlook. However, Met Office staff did respond to journalists who asked questions about the possibility of a heat wave and corrected what they thought was a misinterpretation of the JAS 2019 outlook. For example, in the following online newspaper article the journalist quotes a Met Office spokesperson who disagreed with newspaper articles predicting a three-month long heatwave:

*'The Met Office said reports of a possible heatwave over the next three months have come from its three-month outlook.*

*A spokesman said: "The hot weather in Europe, coupled with our outlook for July, August and September have led people to believe there will be a heatwave. That is not the case.*

*"There has been a suggestion that there will be a period of three months of warmer temperatures. This is a large timeframe over a large area so temperatures could well rise and fall but overall, we expect the next three months to be warmer than average.*

*"There are a lot of different factors but there is a consolidating belief that we will be getting warmer temperatures."' (Inews.co.uk, 17th July 2019)*

The Met Office spokesperson questions claims of a three-month long heatwave by explaining that the 3-month outlook is based on a long-averaging period for

the whole of the UK. This meant that there could be daily or weekly variation in temperatures, even if temperatures were likely to be above-average between July and September 2019. In this case, the rebuttal issued by the Met Office's spokesperson actually became the news hook upon which the article was based, since the headline was 'UK weather forecast: Met Office says there isn't a heatwave coming despite reports of 'roasting continental heat dome (INews, 2019).' The Met Office spokesperson therefore was successful in enrolling the interests of the journalist and editors who wrote and published the online news article. As a result, the Met Office was sometimes able to influence the interpretation of the 3-month outlook through a third party, without issuing blog posts or other materials that might have drawn too much attention to the emerging news story.

However, the speed at which news stories quoting the 3-month outlook were published and/or shared online meant that rebuttals issued by Met Office Press Office were not always noticed:

*'It slowly seeps into every nook and cranny of society. This drip feed of fake forecasting. And by the time the Met Office issues any kind of rebuttal then it's already too late because then the public read, 'oh yeah, the Met Office says it's not happening,' but it's too late. They need to get in before all the rubbish is written.' (Newspaper Journalist, 15-10-19)*

This newspaper journalist criticised the Met Office for not being proactive enough in how it communicated SCF. They argued that the Met Office needed to set the news agenda by deliberately publicising the 3-month outlook, so that the Met Office could get their own view across to the public before other 'fake forecasters.' Whilst we do not know about the extent to which members of the UK public were aware of rebuttals issued by the Met Office Press Office, the journalist does highlight how the Met Office was reactively drawn into the actor-network of images, forecasts and narratives that formed around newspaper articles quoting the 3-month outlook. This meant that the Met Office was unable to define the identity and role that the 3-month outlook played within an actor-network as it was translated by journalists and editors. The actor-network that formed around newspaper articles quoting 3-month outlook was therefore highly divergent, as the Met Office Press Office, newspaper journalists and editors disagreed over how the 3-month outlook should be interpreted and used.

Although the Met Office was reactively drawn into the actor-networks that formed around newspaper articles quoting the 3-month outlook, the Met Office Press Office was able to exercise greater control over how the 3-month outlook was communicated through the broadcast media:

*'Interviewer: Can you give me any examples of news stories since then [the summer 2009 forecast] where you have covered seasonal forecasts?*

*Participant: Do you know, I'm not sure that I have actually. If there's a press release about them I probably note them, I probably read them, I might well and I'm just trying to think of an example of this, I might well reflect them in some broadcasting in due course. But I don't think it's been a huge part of our coverage. It goes back to this point that they're now probably making such an effort to be as cautious as possible to the point of boredom. Whenever I do read these things, either I don't quite get it, or it's so caveated it's almost not worth reporting.' (Science Editor, 20-12-19)*

The science editor, who works for a UK broadcaster, explains how they have not produced any news reports on SCF issued by the Met Office since the 2009 summer forecast. Their response suggests that they thought that the 3-month outlook was too uncertain and 'caveated' be worthy of a news report in an already crowded programming schedule. However, the participant also relied on press releases from the Met Office Press Office as a source of information for potential news stories. Since the Met Office Press Office does not issue press releases on the 3-month outlook (Press Officer 07-01-19), it is not surprising that the science editor was not aware of broadcasting any news stories that referred to the Met Office's 3-month outlook. The Met Office was therefore able to displace (Callon, 2007) the 3-month outlook from broadcast journalists who relied upon the Met Office Press Office as a source of potential news stories.

In summary, the actor-network that formed around newspaper articles quoting the JAS 2019 outlook was highly divergent (Callon, 2007), since Met Office staff and newspaper journalists did not agree on how the 3-month outlook should be interpreted and used. Newspaper journalists and editors wrote and published news stories that resonated with narratives about the 'British' cultural fascination with the weather by weaving together images, the JAS 2019 outlook, the Met Office's short-term weather forecasts and quotes from other

forecasters. These newspaper articles were then published in print newspapers and communicated through other media including radio, online news sites, social media platforms and print newspapers. However, Met Office scientists and press officers often thought that these newspaper articles interpreted the 3-month outlook deterministically, treating the 3-month outlook as if it were a short-term weather forecast. They also did not always agree with content of the weather forecasts and SCF that were sometimes quoted alongside the Met Office's 3-month outlook. Met Office scientists and press officers were therefore unable to problematise the 3-month outlook in a way that aligned their interest in communicating the probabilistic nature of the 3-month outlook to the public, and the interests of newspaper journalists, who wanted to publish news stories that resonated with cultural narratives about what 'British' weather should be like at that time of year.

Whilst Met Office staff did not always agree with how the 3-month outlook was interpreted and used within the UK media, the Met Office Press Office was still able to exercise some influence over how the 3-month outlook was translated. For example, the Met Office Press Office displaced broadcast journalists from the actor-networks that formed around newspaper articles quoting the 3-month outlook. This is because broadcast journalists often relied upon press releases from the Met Office Press Office as their primary source of news stories about extreme weather and anthropogenic climate change. Moreover, the Met Office Press Office was able to enrol the interests of some newspaper journalists by correcting news stories that they disagreed with whenever newspaper journalists phoned the press office or media enquiries team to ask questions. However, the Met Office's decision to not widely publicise the 3-month outlook meant that it could only ever issue rebuttals to news stories that quoted the 3-month outlook. This limited how the Met Office could respond once the 3-month outlook had become part of an emerging news story. The concept of translation therefore highlights how the Met Office was reactively drawn into actor-networks that formed around online or print newspaper articles. This prevented Met Office scientists and journalists from coordinating and aligning their interests with the interests of newspaper journalists and editors who reported on the 3-month outlook.

## 5.5 Discussion

This chapter has traced the translation of three seasonal climate forecasts issued by the Met Office, which are the summer 2009 forecast, the JFM 2020 outlook and the JAS 2019 outlook. The first forecast issued in summer 2009 was not understood or used in the way that the Met Office intended because Met Office staff and journalists did not agree on how the summer 2009 forecast should be used and interpreted. The actor-network that formed around the forecast therefore became divergent as journalists interpreted and used the summer 2009 forecast in a similar way to a deterministic weather forecast, rather than as a probabilistic climate outlook. The Met Office responded to the unsuccessful translation of the summer 2009 forecast by problematising (Callon, 2007) its SCF as a 'watching brief' that could be used to facilitate the management of risk and promote long-term, strategic planning. This enabled the Met Office to enrol the interests of contingency planners, transport stakeholders and energy stakeholders, who did use outlooks like the JFM 2020 outlook in a way that acknowledged the probabilistic and uncertain nature of SCF. However, even though the Met Office does not issue SCF for the public and media, it was still reactively drawn into actor-networks that formed around newspaper articles quoting the 3-month outlook. As the translation of the JAS 2019 outlook illustrates, these actor-networks were divergent, since journalists who published newspaper articles on the 3-month outlook were primarily interested in writing weather stories that fitted cultural narratives about what 'British' weather should be like at that time of year (Hulme, 2016; Fleming and Jankovic, 2011). This conflicted with the interests of Met Office scientists and press officers, who defined the 3-month outlook as an outlook of probable trends in temperature and precipitation averaged over the whole of the UK. The Met Office has therefore been unable to problematise SCF in a way that aligns the interests of scientists and press officers with the interests of newspaper journalists who want to communicate and publish news stories about the 3-month outlook.

The translation of the summer 2009 forecast, the JFM 2020 outlook and the JAS 2019 outlook therefore highlights how the successful communication of SCF depends on stakeholders mutually agreeing upon what a SCF is and how it should be used, so that everyone can coordinate and realise their interests. By defining the 3-month outlook as a 'watching brief,' the Met Office was

successful in communicating how it wanted the 3-month outlook to be interpreted and used to its principal stakeholders. Developing a bespoke impact outlook was also helpful for transport stakeholders, since it explained how changes in climate might disrupt road, rail and aviation infrastructure. This made it easier for them understand and use seasonal climate information in their strategic decision-making and planning. However, defining the 3-month outlook as a watching brief did not enrol the interests of journalists and newspaper editors, since these stakeholders do not need to make long-term, strategic plans. Met Office scientists and press officers would therefore need to problematise the 3-month outlook in a way that aligns their interest in communicating the probabilistic nature of SCF with the interests of journalists and editors, who want to communicate and publish news stories. However, SCF are an uncertain, gradual event that does not conform to journalistic norm of dramatization, where journalists emphasise the reporting of immediate and extreme events over the mundane and everyday. It would therefore be difficult for the Met Office to problematise the 3-month outlook in a way aligns its own interests as an organisation with the interests of newspaper journalists and editors working within the UK media.

Furthermore, following the translation of the summer 2009 forecast, the JFM 2020 outlook and JAS 2019 outlook has challenged the idea that SCF are a self-contained message that is produced by scientists and communicated to an end-user. Instead, it has highlighted the relationality of SCF, which are constituted of shifting associations between different actors that are involved in the communication process. For example, newspaper articles quoting the JAS 2019 outlook were formed of associations that journalists made between the 3-month outlook, other weather forecasts, images and cultural narratives about the 'British' fascination with the weather. Similarly, the 3-month outlook itself is constituted by a web of relations that link together meteorological data, documents, graphics, internal handling plans, scientists, communications staff and external stakeholders. This suggests that SCF cannot be reduced to a discrete message that is presented to stakeholder and disseminated through a verbal briefing or a document. Improving the communication of SCF is therefore not just about developing new presentation formats or dissemination approaches but also about identifying the people, texts and skills that are

needed hold the message together as a SCF is communicated in different circumstances.

Although the notion of translation highlights the relationality of the 3-month outlook and explains why conflicts emerge over how it should be interpreted and used, the concept struggles to account for existence of actors that have multiple rather than singular identities. For example, many of the transport stakeholders who were interviewed for this study found it easier to use the bespoke transport impact outlook provided by the Met Office than the 3-month outlook. These difficulties in using the 3-month outlook can partly be attributed to the meteorological context issued by the Met Office, which was either too technical for transport stakeholders to understand or perceived to not be relevant to what they wanted to use the 3-month outlook for. However, the 3-month outlook was also in some sense harder for transport stakeholders to explain to their colleagues because it did not 'fit' with how they perceived variations in the seasonal climate. Transport stakeholders wanted to know about how the climate might affect or impact upon road, rail and aviation infrastructure, rather than about probable trends in temperature and precipitation over the next three months. The climate therefore seemed to be conceptualised in different ways and have multiple identities depending on who was using the 3-month outlook and when they were using it. This suggests that early forms of ANT, which treat actors as singular, unchanging entities, cannot identify differences within actor-networks and give reasons for why these differences emerge and persist. The next chapter therefore seeks to address this problem by identifying different conceptualisations of what a 'normal' climate is and analysing how the multiplicity of the climate (Mol, 2002) affects the translation of the 3-month outlook.

# Chapter 6. An Outlook Multiple: The Ontological Multiplicity of the Met Office's 3-Month Outlook

## 6.1 Introduction

This chapter aims to address a limitation of the argument made in Chapter 5 by identifying differences within actor-networks and explaining how these differences emerge and affect the communication of SCF. To do this, it draws upon post-ANT scholarship within geography and STS, which maintains that knowledge exists in practices, events and activities, rather than only as ideas in the mind of a knowing subject (Law and Singleton, 2014; Mol, 2002). This means that the UK climate is not a singular, external object to which people attribute multiple meanings. Instead, different material and discursive practices, such as climate modelling or contingency planning, enact multiple yet related versions of same climate (Jackson et al., 2019; Mol, 2002). I therefore argue that the Met Office's 3-month outlook exists in multiple ontologies, each arising from different enactments of what a 'normal' climate is and what stakeholders expect a 'normal' climate to do.

Moreover, this chapter extends the work of geographers who have used the concept of ontological multiplicity (Mol, 1999; Mol, 2002) to study how the climate is enacted by scientists and local communities in Tanzania (Goldman et al., 2016) and Tibet (Yeh et al., 2016; Nightingale et al., 2016). This work has highlighted how different material and discursive practices enact multiple ontologies of climate (Popke, 2016; Nightingale et al., 2016). It has also emphasised how there is a politics around which version of a climatic risk, such as drought, is recognised as 'official' (Goldman et al., 2016; Yeh et al., 2016). This can result in local communities being excluded from efforts to adapt to future climate change and variability if their understanding of a climatic risk is not recognised by policymakers, NGOs and scientists (Goldman et al., 2016). However, these studies of community adaptation to climate change and climate variability do not focus on SCF. They also do not explore how the ontological multiplicity of the climate affects the communication of complex and uncertain science to a range of different stakeholders. This chapter therefore develops these analyses by studying how a SCF is enacted in practice and reflects upon the practical implications of this for the communication of SCF. However, it is important to recognise that the concept of ontological multiplicity (Law and Singleton, 2014; Mol, 2002) does not mean that objects like a SCF or the

climate are plural. As Annemarie Mol (2002) argues in *The Body Multiple*, the presence of different enactments of an object does not mean that there is a plurality of objects. The communication of SCF therefore creates multiple enactments of a forecast, a 'forecast multiple,' rather than a plurality of forecasts.

As a result, the following section discusses how the 3-month outlook was enacted in practice by four different stakeholder groups who are involved in its communication and use (Mol, 2002). These stakeholder groups are Met Office scientists, energy stakeholders, contingency planners and transport stakeholders, and broadcast and newspaper journalists. Contingency planners and transport stakeholders are grouped together, since they both had a similar understanding of what a normal climate is and because contingency planners were often involved in making similar plans and decisions to many transport stakeholders. In each case, the analysis outlines what counted as a normal climate (ontology) for stakeholders, how they produced knowledge about the climate (epistemology) and what they thought a normal climate ought to be like (norms). These are summarised in Table 5 over the page. The analysis also discusses how these ontological, epistemological and normative assumptions about what a normal climate is enacted different versions of the 3-month outlook as it was communicated.

*Table 5-Multiple Ontologies of Climate and Stakeholders Who Use the 3-Month Outlook*

| Stakeholders | Ontology (what a climate is or does) | Epistemology (how we know about climates) | Norms (what weather should do in a 'normal' climate) | Usage of the 3-Month Outlook |
|---|---|---|---|---|
| Met Office Scientists | The statistical distribution of weather over the whole of the UK between 1980 and 2010. | Climate models, observations of weather. | The weather ought to be similar to the 1981-2010 UK average. | Running seasonal climate models, producing the 3-month outlook. |
| Energy Stakeholders | The seasonal average in electricity or gas consumption. | Energy demand models, data on energy production and consumption. | The weather ought to be similar to the seasonal average for electricity or gas consumption. | Managing electricity and gas consumption, trading energy, maintenance scheduling. |
| Transport Stakeholders | An accumulation of remembered weather events that disrupted transport infrastructure. | Collective memories of disruptive weather events, data on road salt usage and de-icing stocks, personal experiences. | The weather ought to not disrupt transport infrastructure. | Managing road-salt stocks, highlighting areas to watch, updating policies and contingency plans, warning contractors, maintenance scheduling. |
| Contingency Planners | An accumulation of remembered weather events that disrupted the delivery of government services. | Collective memories of disruptive weather events, personal experiences. | The weather ought to not disrupt the delivery of government services. | Highlighting areas to watch, updating policies and contingency plans, warning relevant people and organisations, maintenance scheduling. |
| Journalists | An accumulation of remembered weather events that were widely reported within the media. | Collective memories, personal experiences. | The weather ought to be familiar to the British public and not disrupt leisure activities or travel plans. | Publishing and communicating news stories. |

## 6.2 The Ontological Multiplicity of the 3-Month Outlook

### 6.2.1 The Met Office Climate

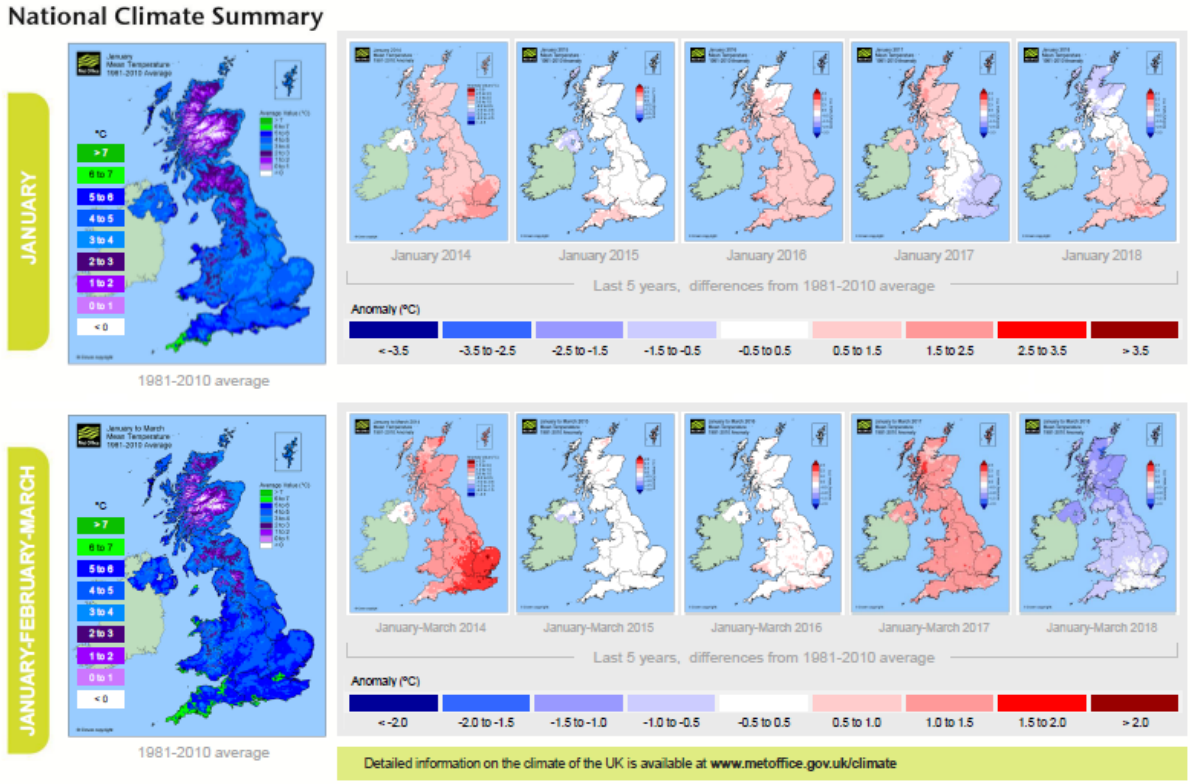
#### *The 3-Month Outlook*

The 3-month outlook compares the three-monthly average of UK temperature and precipitation with the historical 30-year average between 1981 and 2010

(Met Office, 2018b). This is in accordance with WMO guidelines (WMO, 2018) and other global long-range forecasting centres, which also use 30-year historical averages as the climatic normal (WMO, 2020). However, Met Office scientists often described the 1981-2010 average as being ‘out of date’ during the long-range forecasters’ meeting where they agree upon the message of the 3-month outlook. 10-30 years of warming associated with anthropogenic climate change meant that the definition of ‘normal’ within the 3-month outlook was no longer representative of the weather that the UK typically experiences, especially in the case of temperature. Met Office scientists therefore thought that the definition of a normal climate used within the 3-month outlook did not describe the climate that stakeholders in the UK now live with.

Whilst it might be theoretically possible to create an outlook that compares the seasonal average with a linear historical trend rather than a 30-year historical average, Met Office scientists continued to use the 1981-2010 average as the climatology. This ensured that the Met Office was compliant with WMO guidelines on how national meteorological and hydrological services should define what a normal climate is (WMO, 2020). It also maintained consistency across SCF issued by the Met Office for other regions of world, which use the 1981-2010 historical average as the climatology (Met Office, 2020a). Nevertheless, Met Office scientists were aware that stakeholders might have a different way of defining what a normal climate is. For example, Met Office scientists issued maps alongside each 3-month outlook, which displayed the UK 1981-2010 average for temperature and precipitation and annual averages from recent years. These maps were intended to contextualise the current outlook and provide a definition of what ‘normal’ temperature or precipitation was (see Figure 14 over the page). Met Office scientists therefore felt that they needed to ensure that their stakeholders’ expectations of what a normal climate is matched the definition used within the 3-month outlook.

*Figure 14- Maps Showing the UK 1981-2010 Temperature Climatology for January and January-February-March and for January and January-February-March 2014-2018, from Met Office (2018b).*




## *The Transport Impact Outlook*

When I interviewed Met Office staff who were involved in designing the transport impact outlook, they explained how the outlook had not always had the same presentation format. For example, the following scientist describes how the Met Office switched from predicting the risk of low, moderate and high impact winters to only predicting the risk of a high-impact winter:

*'So, we then decided to do a binned, categorical forecast. This also used historical observations of impact. So, you split the observations into three categories – the lowest 20% (low impact), the highest 20% (high impact) and the rest – the middle 60% (moderate impact), and then use these categories in the forecast. That's what we used the probability plots and bar charts for. Then the users said that 'we don't care about moderate or low impact winters.' They are not going to buy less salt if it's going to be a low impact winter. So, we decided to present the outlook in a "high impact, not high impact" format. So, the outlook shows how near or how far it is to a high impact winter.' (Applied Scientist, 05-02-19)*

The applied scientist explains how the transport impact outlook used to predict

the risk of low, high and moderate impacts in a way that was similar to the 3-month outlook. However, transport stakeholders were only interested in the risk of high impacts from snow and ice or flooding and high winds. The Met Office therefore changed how it communicated the transport impact outlook to have a 'high impact, not high impact' format. This change aimed to make the outlook easier for transport stakeholders to understand by meeting their expectations of what a normal or abnormal winter looked like in terms of preparing for the impact of severe winter weather.

As a result, neither the 3-month outlook nor the transport impact outlook defined what a normal climate is in a way that reflected purely technical concerns. Although the 3-month outlook and the transport impact outlook represent the climate as a statistical index, the process of defining what a normal or abnormal climate is was often shaped by other social and institutional norms. This included issues like meeting the expectations of transport stakeholders, following official guidelines from the WMO on how a 'normal' climate should be defined and maintaining consistency with the statistical baselines used in other SCF issued by the Met Office. The version of the 3-month outlook and transport impact outlook that Met Office scientists issued was therefore bound up with how they defined what a normal climate is (ontology), how they produced knowledge about the climate (epistemology) and what they thought a normal climate ought to be like (norms).

### 6.2.2 The Energy Stakeholder's Climate

Each year between November and January the UK Met Office gives monthly briefings to a group of energy analysts and energy managers who have expressed an interest in using the 3-month outlook. For this group of stakeholders, the climate was not just a statistical index that described the state of the atmosphere but an agent or force (Fleming and Jankovic, 2011) that explained changes in the demand for energy. For example, the following energy stakeholder defines the UK winter climate as a statistical index describing average temperatures and as an agent that explains changes in energy consumption:

*'So, what we categorise as winter is a six-month period and an extreme weather event could be snow for three or four days. It's important but not crucial. It could push demand up for those three or four days and everyone will remember those*

*three or four days of snow and we'll turn round at the end of it and say, 'you know what, we had less customer demand overall.' And that's something we recognise as well- that people get focussed on one small part of a winter, whereas the reality can be five months of mild weather and then one month of seasonally abnormal cold weather.' (Energy Analyst, 01-11-19)*

As the energy analyst explains, short-term fluctuations in temperature did not have a large impact on customer demand for energy at their organisation. Instead it was the seasonal trend in comparison to the historical average that had the biggest impact on energy consumption. This suggests that this participant and Met Office staff both defined a 'normal climate' as the historical UK average, even if the energy stakeholder defined winter as a six month period between the end of October and the beginning of March (Energy Analyst, 01-11-19). It also suggests that the participant was interested in comparing seasonal norms with the historical average in the same way that the 3-month outlook does. This energy stakeholder therefore found it relatively easy to understand and use the 3-month outlook because they had a similar way of defining what a normal climate is to Met Office staff.

However, this energy stakeholder did not just treat the climate as a descriptive statistical index. Although the participant compared the seasonal average with the historical average in a similar way to the 3-month outlook, they did not use concept of climate as a statistical tool for organising and quantifying the state of the atmosphere. Instead, they treated the seasonal average temperature as an agent that explained fluctuations in energy consumption over the winter months. For example, the participant describes how they used to brief their colleagues about the impact that the climate might have energy consumption, rather than describing possible trends in temperature or precipitation over the next three months:

*'So, I would summarise the information from the call, in terms of impact, things like that and other factors that might influence consumer demand from the forecast.' (Energy Analyst, 01-11-19)*

The climate, for this energy analyst, was an entity defined by what it did as well by what it is (Fleming and Jankovic, 2011). Or to put it in terms used by Mol (2002), the climate was not simply known by the energy analyst but was

enacted through how they managed energy consumption at their organisation. The energy stakeholder's way of living with the climate therefore enacted a different set of expectations about what the climate ought to do (norms), which then shaped how they conceptualised (ontology) and knew seasonal changes in climate (epistemology). However, their interest in comparing the seasonal average with the historical average meant that the 3-month outlook fitted their own understanding of how the climate might change over the next three months. The version of the 3-month outlook enacted by energy stakeholders therefore overlapped and cohered with the version that was communicated to them by Met Office scientists. This made it easier for the energy stakeholders who participated in this study to understand and use the 3-month outlook when managing the consumption of energy.

### 6.2.3 The Transport Stakeholder's Climate

Whilst expectations of what a normal climate should be like were enacted in similar way by Met Office scientists and energy stakeholders, transport stakeholders working for local government had different expectations of what a normal climate was and what it did:

*'And again, it'll be a hundred millimetres of rain that'll fall on my head over the three months. But the question I need to know is, will 100 mm of rain fall on my head in one day or will it fall in 90 days over three months? Because again, as you will see in the news with climate change, heavier rainfall, sudden rainfalls can cause impactful rainfalls can cause quite impactful situations quite quickly, whereas the same volume of rainfall over a longer period of time is what I would describe as not worth getting out of bed for.' (Transport Resilience Manager, 08-01-20).*

Unlike energy stakeholders or Met Office scientists, this participant did not organise variability in precipitation around the seasonal average. They were simply not interested in the overall trend in precipitation. Instead, the transport resilience manager wanted to know about the likelihood of extreme rainfall events and when and where these would happen. This is because it was extreme rainfall events that caused landslides or washed away road and rail infrastructure, rather than the same amount of rainfall spread over a longer time. This different ontology of climate was therefore associated with how the

stakeholder thought that precipitation might affect transport infrastructure during the UK winter.

However, this focus on the likelihood of extreme events was not just motivated by a concern with the kind of weather that would disrupt transport infrastructure. This is because transport stakeholders also assessed what a normal or abnormal climate was in relation to existing contingency plans:

*'So, our worst-case is when we get a week of snow because we are not set up in this country for weeks and weeks of snow because we normally get a week and then its melted and then it goes. So, the government have given us a benchmark and the benchmark is that we should be able to go out 12 times continuously salting on 12 days. So, 3 times a day for 12 days. For us that's 16, 800 tonnes of salt. So, when I've got my 23,000 tonnes of salt, I'm well above the government's recommendation of what we need to have for a worst-case scenario, which 12 days.' (Winter Service Manager, 29-11-19)*

The participant explains how the UK government currently requires local authorities to store enough road salt to allow gritters to go out 12 times continuously for 12 days. This meant that a worst-case scenario for this participant was a winter in which they experienced a period of snow and ice continuously for more than 12 days. Although the participant ensured that their local authority was prepared for a 'worst-case scenario' by stockpiling more than the UK government required, the government guidelines still acted as a benchmark for distinguishing between 'high-impact' and 'low-impact' winters. The ontology of climate enacted by this transport stakeholder therefore revolved around prolonged cold weather that would deplete existing road salt stockpiles, rather than around the historical average.

As a result, transport stakeholders organised changes in seasonal climate around a distinction between high-impact and low-impact winters, rather than in relation to the historical average as Met Office scientists and energy stakeholders did. The transport impact outlook issued by the UK Met Office tried to accommodate this ontological difference by providing transport operators with information about the risk of a high-impact winter, rather than the probability of temperature or precipitation being above or below-normal (Buontempo et al., 2017). However, the following conversation from a transport stakeholder

briefing illustrates how even the creation of a bespoke impact outlook did not always resolve conflicts between these two ontologies of climate:

*Stakeholder Q2 [On call]: It seems that that the seasonal impact forecast[4] is more extreme than the contingency planner's forecast- you are making links with the winters of 2009/10 and 2010/11. Why is that?*

*One scientist responded by saying that the impact forecast is not linked to the seasonal climate forecast.*

*Another scientist expanded on this comment by explaining what is meant by a high impact winter. They said that on the forecast, out of a dataset of 20 years, 1 in 5 would be classified as 'high impact.' This winter's forecast predicts that the chance of a high impact winter is 1.5 times the chance of 20% of all winters in the data set. They emphasised that the high impact winters listed at the bottom of the graphic were there for context and that not all high impact winters were equally severe.*

*The stakeholder from a county council asked where the winter of 2009/10 or 2010/11 would be on the graphic.*

*The first scientist responded by saying that they can't do that. They said again that out of 20 winters of data, 1/5 will count as high impact. Within those high impact winters, there is variation and not all will be as severe as 2009/10 and 2010/11. (Notes from Transport Stakeholder Briefing, 28-11-18)*

The notes that I made during this conversation illustrate a conflict that existed between how transport stakeholders defined what a high-impact winter is, and the statistical definition of a high impact winter used within the UK Met Office's transport impact outlook. As the Met Office scientist explains, out of a dataset of twenty years, 1 in 5 winters would be classified as a high impact winter. However, even though the transport impact outlook predicts the risk of a high-impact winter, the transport stakeholder on call struggled to relate the transport impact outlook and the 3-month outlook to the weather they had personally experienced. For example, the transport stakeholder repeatedly asks the scientists about whether the Met Office was predicting a repeat of the winters of

[4] 'Forecast' rather than 'outlook' is used in this quotation from my notes because the discussion in the briefing used this terminology.

2009/10 and 2010/11. These were both severe winters in the UK that caused significant disruption to transport infrastructure (Palin et al., 2016). However, the statistical definition of a high-impact winter in the impact outlook cannot provide stakeholders with that kind of information. As one of the Met Office scientists says, not all high impact winters will be as severe as the winters of 2009/10 and 2010/11. The transport stakeholder's definition of what a high-impact winter is, which was based on their memories of the severe UK winters of 2009/10 and 2010/11, therefore conflicted with the statistical definition of a high-impact winter in the transport impact outlook.

One could conclude at this point that Met Office staff and transport stakeholders had different ways of *knowing* changes in seasonal climate. The transport stakeholders were drawing upon their knowledge of previous disruptive climatic events to make sense of predicted changes in seasonal climate. Similarly, the current transport impact outlook was unable to provide information that met the demand for knowledge about the possible recurrence of a winter that was as severe as the winters of 2009/10 and 2010/11. However, treating this conflict as an outcome of epistemological differences does not adequately explain how conflicting versions of an outlook emerge. This is because Met Office staff had already tried to resolve epistemological differences between transport operators and climate scientists by creating the transport impact outlook. The outlook integrates knowledge about the underlying meteorology (the NAO index) with knowledge that stakeholders have about transport impacts (transport impact data from the road, rail and aviation sectors) to make new knowledge (the transport impact outlook) that ought be easier for transport operators to understand and use in their decision-making. Yet the conversation during the transport stakeholder briefing indicates that transport stakeholders still sometimes found the impact outlook difficult to interpret and use. Their ontology of climate, which was enacted through memories of past winters, contingency plans and government guidelines, could not be recreated in an outlook that combined meteorological data with data on weather-related transport impacts.

The difficulties that Met Office staff sometimes had in explaining the 3-month outlook and transport impact outlook to transport operators therefore highlights how communication of SCF cannot be reduced to questions of epistemology. The transport stakeholders did not simply have a different perspective on what

a normal winter climate is, that could be included within meteorological definitions of a what a winter climate is by creating a bespoke impact outlook. Instead, the transport stakeholders had a different ontology of climate, that was bound up with memories of past winters, the contingency plans that they had already made and the duration and intensity of weather events that damaged transport infrastructure. Their way of knowing changes in climate (epistemology) was implicated in how they lived with and experienced changes in climate (ontology) (Goldman et al., 2016; Ingold and Kurttila, 2000; Leyshon née Brace and Geoghegan, 2012). Effective communication therefore involves negotiating both epistemological and ontological differences in how stakeholders interpret and use SCF.

### 6.2.4 The Journalist's Climate

Whilst journalists did not receive the 3-month outlook through briefings from Met Office scientists, different norms and ontologies of climate did shape how they assessed the newsworthiness of the 3-month outlook. For example, journalists often became interested in the 3-month outlook when the message resonated with recent memorable weather events, as the following freelance journalist explains:

*'Basically, once weather becomes the potential for news, that's when newspapers get really interested in it. And obviously the time when there was the 'Beast from the East' twelve months ago was an almost life-changing experience. It changed the course of my business because of the demand for information and because I had good contacts at the Met Office to get that information and disseminate it quite quickly.' (Freelance Journalist, 31-10-19)*

Between February and March 2018, the UK experienced a period of unusually cold and snowy weather, which was later called the 'Beast from the East' by the British press (Lee and Butler, 2020). The participant explains how reporting on the 'Beast from the East' completely changed the course of their business, as the demand for weather stories from newspapers increased. The way in which the participant describes this climatic event suggests that it had profound effect on their livelihood, shaping their memory of past climates and their expectations of how the climate might change in the future. Other journalists and editors seemed to have similar memories of the 'Beast from the East,' which then affected how they evaluated the newsworthiness of other weather events. This

is highlighted by a series of newspaper articles that journalists published in January 2019 (Lee and Butler, 2020), which used the 'Beast from the East' as a benchmark to assess the newsworthiness of SCF issued by the UK Met Office:

*'Beast from the East 2? UK in the midst of a 'sudden stratospheric warming (Sky News, 29th December 2018).'*

*'UK SNOW forecast: SHOCK weather chart shows snow set to engulf Britain' (Daily Express, 4th January 2019)*

The 'Beast from the East' in 2018 was preceded by meteorological phenomenon called a sudden stratospheric warming event (Lee and Butler, 2020). This is a rapid increase in temperatures 6-30 miles above the Earth's surface that sometimes disrupts westerly winds that produce mild, wet and windy weather over the UK (Greening and Hodgson, 2019). In January 2019 another sudden stratospheric warming event took place, which resulted in the Met Office scientists issuing a 3-month outlook that predicted an increased chance of below average temperatures (Met Office, 2019a). Newspaper journalists therefore linked the sudden stratosphere warming event to their memories of what had happened during the previous spring by publishing a series of online and print news articles about the possibility of a 'Beast from the East 2.' As it happened, the UK never did see a repeat of the cold weather that it experienced in February-March 2018. This was because the effects of the sudden stratospheric warming event did not move down into the lower atmosphere as they did in February and March 2018 (Lee and Butler, 2020). Nevertheless, media interest in the Met Office's 3-month outlook in January 2019 illustrates how personal and cultural memories of past climates shape how SCF are enacted.

Moreover, the comparisons that journalists made between the 3-month outlook and memorable weather events both fuelled a desire for sensation and reassured members of the public that the UK climate was still normal:

*'But for someone like me it's really valuable because if I see the word 'summer heatwave' coming up in the middle of March or April and I'm going what's this about and then I find that all the local media outlets are copying the tabloids and they're all coming up with the same headlines- sizzler summer, three-month*

*headlines, record-breaking- they love the word record-breaking. Everything's record-breaking.' (Newspaper Journalist, 15-10-19)*

This participant, who often used news aggregators to see what other journalists were writing about, emphasises how newspapers often publish headlines claiming that the summer or winter will be 'record-breaking.' These headlines heighten the *immediacy* of a SCF and emphasise how the weather during the upcoming three months will be *exceptional.* Both qualities are often enacted by newspaper journalists whenever they are writing a story that they perceive to be newsworthy (Harcup and O'Neill, 2017; Usher, 2014). However, this desire for sensation was balanced by benchmarking the 3-month outlook against memorable weather events. For example, the following headline in *The Sun,* which quotes the June-July-August (JJA) 2019 outlook, refers back to the heatwave that the UK had experienced during summer of 2018:

*Long Hot Summer: UK weather forecast- Three-month long heatwave expected for Brits after Bank Holiday washout*
*The warm temperatures come after the UK fried during last year's record-breaking summer (The Sun, 22nd May 2019).*

The headline draws a comparison between the JJA 2019 outlook, which was predicting a 50% chance of temperatures falling into the warmest category, with the breaking of temperature records during UK heatwave of July 2018 (McCarthy et al., 2019). Hulme and Burgess (2019) argue that this practice of benchmarking weather forecasts against past records reassures the public by emphasising how the weather has been similar or more extreme in the past. This reduces public anxieties by emphasising how the weather during the next three months will be exceptional but within the boundaries of the weather that the UK normally experiences. Journalists therefore enacted the 3-month outlook in a way that met a desire for sensation, whilst emphasising that the weather would not go beyond what their readers thought was a normal climate.

Journalists therefore had a different ontology of climate to Met Office scientists and energy stakeholders, in the sense that their expectations of what a normal climate is were based on an accumulation of memorable weather events, rather

than the historical average. However, the version of the 3-month outlook that journalists enacted was also associated with normative assumptions made by editors and publics about what the climate ought to be like. Journalists who did publish news articles on the 3-month outlook often transformed it into a prediction of immediate and exceptional weather, whilst also connecting the outlook to cultural memories of past weather events to make the outlook seem familiar to the UK public. This conflicted with the version of the 3-month outlook enacted by Met Office scientists, who emphasised how the 3-month outlook cannot provide information about weekly or even monthly variations in temperature or precipitation. Journalists therefore enacted versions of the 3-month outlook that did not always cohere with the version communicated by the Met Office.

## 6.3 Discussion

This chapter has argued that the multiplicity of the UK climate produces multiple yet related versions of the 3-month outlook, as stakeholders reinterpret the message to fit their own understanding of what a normal climate is. Met Office scientists and energy stakeholders defined a normal climate as the historical average, although energy stakeholders differed from Met Office scientists in that they also treated the climate as a prescriptive agent that affected demand for energy. Transport stakeholders and contingency planners were not concerned with seasonal variation around the historical average but in the likelihood of extreme weather events that would disrupt transport infrastructure and the delivery of government services. Similarly, journalists wanted to communicate and publish news stories that connected the 3-month outlook to other memorable weather events that they thought their readership could relate to. The different needs and concerns of stakeholders therefore produced a close relationship between ontologies of climate (what the climate is) and norms (what the climate ought to do), which then affected how the Met Office's 3-month outlook was interpreted and used.

Difficulties in understanding and using the 3-month outlook were often associated with the extent to which ontologies of climate cohered with each other. For example, energy stakeholders found it much easier to understand the 3-month outlook because they wanted to know about how the seasonal average compared with the historical average. This was similar to the ontology of climate

enacted by Met Office scientists, who used the 30-year historical average as their climatic normal. However, transport stakeholders defined what a climate is in relation to the likelihood of extreme and/or disruptive weather events. Similarly, journalists defined what a normal or abnormal climate is in relation to memories of weather events that were recent and that they had written and published news stories about. These multiple ontologies of climate created expectations about the future seasonal climate that did not cohere with the information presented to them in the 3-month outlook. This meant that the 3-month outlook did not connect with their understanding of climate and the questions that journalists and transport stakeholders asked in their professional lives. Conflicts between different ontologies of climate can therefore make SCF difficult to communicate to wide range of stakeholders.

One could reconcile conflicting ontologies of climate by developing impact-based forecasts that merge the 'local' knowledge of stakeholders with scientific knowledge about the future climate (Callon, 1999; Lane et al., 2011). These present stakeholders with information about the risk of weather-related impacts that might affect their livelihoods, rather than with abstract information about future trends in precipitation and temperature (Palin et al. 2016; Red Cross Red Crescent Climate Centre, 2020). However, the difficulties that transport stakeholders sometimes had in understanding the Met Office's transport impact outlook highlight how impact-based forecasts are not always easier for stakeholders to understand or use in their decision-making. This is because impact-based forecasts treat communication as an epistemological conflict that can be solved by putting 'local' knowledge into existing models. However, knowledges are always implicated in how stakeholders live and act in the world, whether they happen to be climate scientists or contingency planners (Geoghegan and Leyshon, 2012; Ingold and Kurtilla, 2000). For example, the Met Office's transport stakeholders did not just organise their understanding of the UK winter climate around transport impact data but also around memories of disruptive weather events, knowledge of existing contingency plans and government guidelines. This makes it difficult to represent the 'local' knowledge of impacts within a model without changing a stakeholder's understanding of climate to fit scientific epistemologies, norms and ontologies (Callon, 1999; Lane et al., 2011; Goldman et al. 2018).

Meteorologists and climate scientists who are involved in communicating SCF, therefore need to acknowledge the ontological and normative dimensions of how people understand climatic change and variability. What people think a climate is and ought to be shapes how they interpret predicted changes in climate and how they adapt to those changes. Attending to multiple ontologies of climate does not mean that it is not worthwhile developing impact-based forecasts or customising an outlook to a stakeholder's decision-making needs. However, it is important understand how stakeholders conceptualise changes in climate, before customising a forecast to a stakeholder's decision-making needs and choosing the best way of presenting and disseminating a forecast. For example, if transport operators define what a normal climate is in relation to the likelihood of disruptive events, then it might be better to design a forecast that provides them with information about the likelihood of extreme rainfall events rather than the likelihood of rainfall being above or below the historical average. Developing impact-based forecasts that acknowledge the ontological multiplicity of the climate could therefore make outlooks easier for stakeholders to understand and use in decision-making.

As a result, the concept of ontological multiplicity (Mol 1999, 2002) does address some of the limitations of using the concept of translation (Callon, 2007) to understand how a SCF changes as it is communicated, which were outlined in the previous chapter. By identifying different network formation processes, the concept of ontological multiplicity explains why different and even incoherent understandings of the same 3-month outlook can emerge amongst different stakeholders. The 3-month outlook takes on multiple forms as the relations between the 3-month outlook, memories of past weather events, institutional guidelines and economic and political pressures are enacted or not enacted. This addresses a tendency within early accounts of ANT to trace chains of associations without ever arriving at an explanation for differences in networks and the actors that constitute them (Müller, 2015). Furthermore, the notion of ontological multiplicity also explains why some stakeholder groups find it easier to understand the 3-month outlook than others. This is because the concept of multiplicity identifies overlapping or conflicting understandings of the climate, which then produce multiple versions of the same outlook. This adds explanatory depth to the notion of translation (Callon, 2007), which only

attributes divergent understandings of the same outlook to disagreements over what a SCF is and how it should be used.

However, the concept of ontological multiplicity suggests the 3-month outlook is understood in different ways by stakeholders with different needs and concerns (Law and Singleton, 2014). This raises an important question about how the message of a SCF can hold together when it exists in multiple yet related versions. This conceptual problem is only heightened when considering the conclusions of chapter 5, which claimed that successful translation of the 3-month outlook is dependent on stakeholders agreeing upon what kind of information a SCF can or cannot provide and how the forecast should be used in decision-making. Chapter 7 will therefore address this tension by looking at how the multiple versions of the 3-month outlook hold together as they are communicated.

# Chapter 7. Topologies and the Communication of the 3-Month Outlook

## 7.1 Introduction

In Chapter 5 I used the concept of translation (Callon, 2007) to argue that the 3-month outlook is not a self-contained message but a web of relations between different actors that are involved the communication process. The interests of stakeholders in an actor-network *converge* when they mutually agree upon what the 3-month outlook is and how it should be interpreted and used. The interests of stakeholders within an actor-network *diverge* when the 3-month outlook does not have a defined role and identity within an actor-network. Then, in Chapter 6 I argued that the 3-month outlook is an ontologically multiple rather than a singular object. This is because there are multiple ontologies and epistemologies of climate that shape how stakeholders use and interpret the 3-month outlook. However, the conclusions of Chapter 6 stand in tension with the argument of the previous chapter, which claims that the successful communication of the 3-month outlook depends on actors mutually agreeing upon what it is and how it should be used. In this chapter, I therefore aim to resolve this tension by using the concept of topologies (Law and Mol, 1994) to understand if and how the message of the 3-month outlook holds together as it is communicated.

Topology is a branch of mathematics that measures space by using coordinates that are intrinsic to a shape, rather than by using an external set of three-dimensional coordinates that measure lengths and angles (Martin and Secor, 2014). For example, a ring doughnut and a cup of tea are topologically the same shape because they are both three-dimensional surfaces with one hole in it. One shape, the cup of tea, can be transformed into another, the doughnut, without cutting the surface or outline in any way. Spaces are therefore topologically equivalent when they have properties that remain the same under continuous transformation.

Geographers (Allen, 2016; Martin and Secor, 2014) and STS scholars (Law and Mol, 1994, 2001) have used the concept of topology to understand how concepts and objects, such as viruses (Hinchliffe et al., 2013), borders (Allen and Axelsson, 2019) and disease (Law and Mol, 1994), retain their identity as they are transformed in space. The concept of topology can therefore be used

to identify which properties of the 3-month outlook remain the same as it is communicated in different circumstances. In this chapter, I argue that the 3-month outlook is configured in three different topologies. The first is a regional topology, where an external boundary keeps the shape of an object the same in different locations and at different times (Law and Mol, 1994). For example, the 3-month outlook is an outlook for the whole of the UK (a geographical boundary) averaged over the next three months (a temporal boundary). The second is a network topology, in which the message of the 3-month outlook is held together by relations between *immutable* actors, such as documents, graphs, and texts, which become *mobile* as they move from one location to another (Latour, 1986). The third is a fluid topology where the message of the 3-month outlook is held together by a fluid mix of conversations, emails and verbal briefings (Law and Mol,1994; 2001). These conversations might change the information presented to a stakeholder but not the overall meaning of the 3-month outlook.

Furthermore, I argue that these three topologies are not mutually exclusive or superior to each other. Instead, all three topologies are needed to hold together the message of the 3-month outlook. Regional topologies are necessary because the chaotic nature of the atmosphere means that climate scientists can only issue SCF with long averaging periods over a large geographical area. Network topologies are needed to produce regional topologies by ensuring that Met Office staff communicate the same message in different local contexts around the UK. Finally, fluid topologies are necessary to ensure that the message is understood by stakeholders who have different ontologies of climate (what the climate is), or to ensure that stakeholders understand the amount of uncertainty in an individual outlook. The 3-month outlook therefore needs to be communicated in all three topologies for the message to be understood and used by different stakeholders.

Finally, I conclude by suggesting that national meteorological services like the Met Office could spend more time communicating SCF in a fluid topology. Existing approaches to improving the communication of weather and climate forecasts tend to focus communicating SCF in regional and network topologies. For example, there are surveys and experimental studies that aim to identify language and graphics that reduce systematic biases in how people interpret

the message of a SCF (Taylor et al., 2015; Coventry and Dalgleish, 2015). However, following the 3-month outlook has highlighted how Met Office scientists often needed to adapt their messaging help stakeholders understand what the 3-month outlook meant for them. This suggests that dissemination approaches that give room for scientists to adapt their messaging, such as verbal briefings and phone calls, might be preferable to those that only involve issuing a fixed set of lines or graphics.

## 7.2 The 3-Month Outlook and Regional Topologies

Most people think of objects, including abstract ones like the 3-month outlook, as a volume occupying a region within time and space. For example, the 3-month outlook predicts the chance of temperature or precipitation being above or below average for the whole of the UK over next three months (Met Office, 2021b). The transport impact outlook also does the same for the whole of the UK but with winter weather-related transport impacts (Buontempo et al., 2016). Both outlooks therefore draw a boundary around the UK and a 3-month time period, creating an internally homogenous region in time and space. This enables Met Office scientists to make universal, quantifiable and authoritative statements (Hulme, 2020) about expected climate variability over the UK for the next three months.

However, creating a region in time and space raises the question of where to draw the boundary around it. Atmospheric circulation is not confined by national boundaries and often produces spatial variations in climate that do not map neatly onto political borders. For example, a strongly positive phase of the NAO (see Section 3.2.6) tends to increase the chance of above-average precipitation in the North-West Scotland during the winter months and decreases the chance of above-average precipitation in the East of England (Baker et al., 2018). This is because strong south-westerly winds usually drive storms over the north-west of the UK during a positive NAO phase. In contrast, a strongly negative NAO decreases the chance of above-average precipitation in North-West Scotland and increases the chance of above-average precipitation in the East of England (Baker et al., 2018). This is because storm tracks shift southwards during a negative NAO phase and are often accompanied by easterly winds blowing off the North Sea (Overland et al., 2020). Drawing a boundary around the UK

therefore does not map onto how atmospheric circulation patterns are arranged over the British Isles.

Moreover, a 3-month average for the whole of the UK suppresses differences in climate that are created by variations in latitude, topography and the land surface. Many of the Met Office's principal stakeholders are aware of these local variations in climate because they produce vulnerabilities within the infrastructure that they are responsible for managing. For example, the following transport stakeholder explains how the altitude of roads within their county affects how they respond to severe winter weather:

'*What we're particularly focussed on is snow in places where we would not expect to see disruption- so on the lower ground where it's affecting the major road network.' (Operations Manager, 27-02-19)*

This participant was much more concerned about snow and ice on lower ground, since they already had resources and plans in place for clearing roads of snow and ice on higher ground. Local topography therefore makes some roads more vulnerable to the impact of unusually cold weather than others, which then shapes how transport operators prepare for the upcoming winter. However, the large averaging area in the 3-month outlook obscures any local climates that are associated with variations in topography. This means that the 3-month outlook cannot give any detailed information about how winter weather might affect vulnerable points within the road network. Similarities are therefore stressed within the 3-month outlook over the many local climates that exist within the UK.

Finally, the regional topology of the 3-month outlook obscures monthly and weekly variations in the weather that people experience and remember:

*'And then the third thing is about averages. So, when we produce these forecasts, we are talking about average conditions over a month and average conditions over three months. So, we can talk about below-average temperatures being more likely. So, in the period as a whole, three months might be below average but if we get a week of very warm weather, people's understanding of how that fits into the averages is quite hard to communicate effectively. So, what these forecasts don't provide you, in summary, is, is the*

*period of the 3rd March to the 10th March going to be sunny or cold?' (Marketing and Communications Manager, 13-03-19)*

The marketing and communications manager explains how the 3-month long averaging period obscures short-term variations in precipitation or temperature on daily, weekly and even monthly timescales. However, personal and cultural memories of seasonal climatic variability are not organised around three-monthly intervals. Instead, people often remember recent weather events (Taylor et al., 2014), weather events that are associated with personal and familial milestones (Hall and Endfield, 2016; Harley, 2003) or extreme weather events that disrupt people's lives and are widely reported within the media (Hall and Endfield, 2016; Taylor et al., 2014). These memories are often of a snapshot in time, rather than of the weather that people have experienced over a 3-month long period. This can produce a sharp contrast between popular imaginations of seasonal climate variability and meteorological observations. For example, the cold snap known as the 'Beast from the East' in March 2018 was extensively reported on by the UK media (Greening and Hodgson, 2019) and caused widespread disruption to communities around the UK (Galvin et al., 2019). However, the January to March 2018 average temperature was warmer than the 1981-2010 climatology (Met Office, 2020b). Long averaging periods therefore stress similarities across the forecast period in a way that produces differences between the 3-month outlook and the weather that people experience and remember.

As a result, the spatial and temporal boundaries of the 3-month outlook suppress local variations in climate and short-term, chaotic changes in the atmosphere (Lorenz, 1963) so that scientists can make skilful predictions for the whole of the UK. However, the spatial and temporal detail that is lost through averaging means that the message of 3-month outlook will always be an abstraction from the weather that people experience over a 3-month period in any given location. There is therefore always a mismatch between the regional message of a SCF and the local context in which it is interpreted and used in decision-making. Organisations like the Met Office therefore need to communicate SCF in other topologies, such as a network topology (Latour, 1986), in order to hold the relationship between regions and local contexts stable (Law and Mol, 2001).

## 7.3 The 3-Month Outlook and Network Topologies

ANT maintains that scientific knowledge does not travel by itself (Law and Mol, 2001). Instead, the relationship between a knowledge claim about a region and the context in which it is used needs to be stabilised for it to be accepted as a fact (De Wit et al., 2018). For example, a contingency planner in Scotland needs to accept that the 3-month outlook issued by Met Office staff in Exeter is trustworthy and relevant to their local context, even though there are different climates in these two locations. Regional spaces are therefore generated by bringing together locations that are far away in terms of metrical distance in time and space. This is achieved by creating 'immutable mobiles' (Latour, 1986). These are *immutable* sets of relations in network space, such as texts, money, maps and graphs, that are *mobile* within regional space. For example, the following applied scientist describes how the probability distributions and summary message become immutable mobiles (Latour, 1986) that help them communicate the 3-month outlook in different contexts:

*'The most important messaging is given by the part in green and the panel at the bottom that has the 3-month outlook on it. The most useful part is the plot- it gives the user an indication of what the outlook actually is for the next three months and it puts it in context of previous winters. The message at the top is an interpretation of the plot.' (Applied Scientist, 05-02-19)*

This member of Met Office staff was not always able to attend the long-range forecasters' meeting where scientists meet to agree upon the message of the 3-month outlook. This is because the long-range forecasters' meeting is primarily attended by climate scientists from the monthly-decadal prediction team who are involved in running and developing the Met Office's seasonal climate model (Interview with Climate Scientist, 04-03-19). However, the applied scientist was still able to understand and communicate the 3-month outlook on to other stakeholders, even though they were not able to attend each meeting. This is because the plot displaying the probability distributions for the forecast and the summary message became immutable mobiles (Latour, 1986). Both objects summarised the conclusions of the long-range forecasters' meeting and could be transported in a document by email or as a physical piece of paper. The summary statement and graphics therefore meant that Met Office scientists who

were not part of the monthly-decadal prediction team could understand and communicate the 3-month outlook in different circumstances.

Furthermore, the Met Office produced an internal handling plan to ensure that press officers and marketing and communications staff communicated the same message whenever they were asked questions by principal stakeholders:

*'This has got words in in the top left-hand corner anyway that are replicated here. But this is their internal plan. Most of the words here are words that they would use if they were answering any questions or if they needed to signpost people to particular pieces of information.' (Strategic Relationship Manager, 25-02-19)*

The internal handling plan produced by the Met Office Press Office contains the summary message of the 3-month outlook, along with links to webpages explaining scientific terminology and FAQs that the Met Office's stakeholders might ask. It was immutable because it provided Met Office staff with an official summary of the 3-month outlook and it was mobile, because it could be emailed to Met Office staff no matter where they were located. This ensured that a strategic relationship manager at the Met Office in Exeter would communicate the same message as a civil contingencies advisor briefing contingency planners in Edinburgh. Moreover, as the strategic relationship manager explains, the FAQs and links to webpages explaining scientific terminology helped staff who were not part of the monthly-decadal prediction team give precise and consistent answers to questions. The internal handling plan therefore played an important role in ensuring that Met Office staff delivered a consistent message when engaging with both its principal stakeholders and the media and public.

Enacting the 3-month outlook in a network topology enabled staff within the Met Office to both understand the conclusions of the long-range forecasters' meeting and to present a consistent message in different circumstances. A series of immutable mobiles, such as the 3-month outlook document, plots displaying probability distributions and the internal handling plan created a stable message that could easily be moved around. It is therefore not surprising that the Met Office often communicated the 3-month outlook in a network topology when engaging with its principal stakeholders, the media and

members of the UK public. For example, the Met Office published maps of the climatology and annual averages from the last five years on the Met Office website so that contingency planners would understand what a outlook for 'above-average' or 'below-average' temperatures or precipitation meant (see Section 6.2.1). This would then ensure that 3-month outlook remained stable as it moved from the Met Office to a contingency planner working in a local authority, devolved administration or central government. Similarly, Met Office staff also included information on the meteorological context for each outlook to make sure that contingency planners, as well as the media and public, understood what it meant once it was published on the Met Office website:

*'And then what we've done since that [the summer 2009 forecast] is take a much more scientific approach to the communication of the seasonal forecast. So, using these bits of paper that we have in front of us now- you break it down in terms of what's happening with temperature and precipitation and very much base it in a story of how it differs from observed climatology.' (Marketing and Communications Officer, 13-03-19)*

The marketing and communications officer explains how the scientific context and the graphs in the 3-month outlook document were designed to 'base the 3-month outlook in a story of how it differs from the observed climatology.' For example, figure T1 displays the 3-month outlook in the context of the observed annual cycle (see figure 15 over the page), figure T2 shows how the 3-month outlook differs from the climatology (see figure 16) and figure T3 in the context of year-to-year and within seasonal variability (see figure 17). The scientific context below the summary message also includes further information about the meteorological context at the time when the 3-month outlook was issued. The contextual information provided within the 3-month outlook document was therefore meant to stabilise the message of the 3-month outlook as it was used in different circumstances.

*Figure 15- Figure T1 from the 3-Month Outlook*

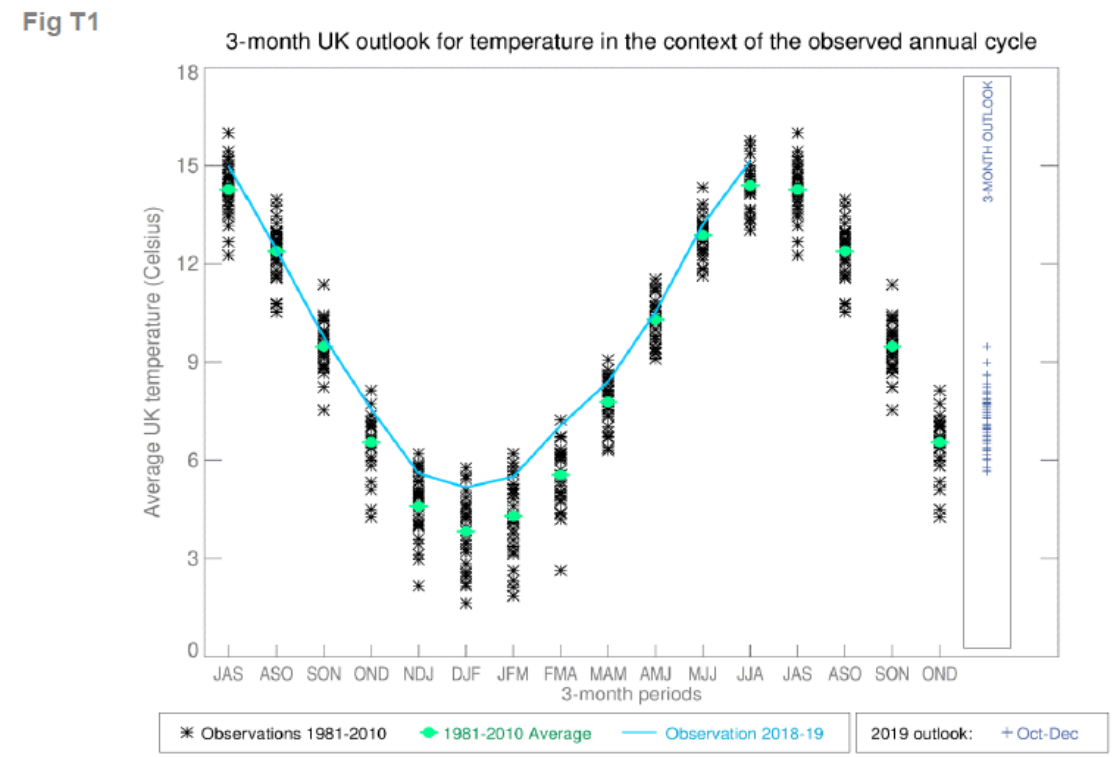



*Figure 16- Fig. T2 from the 3-Month Outlook*

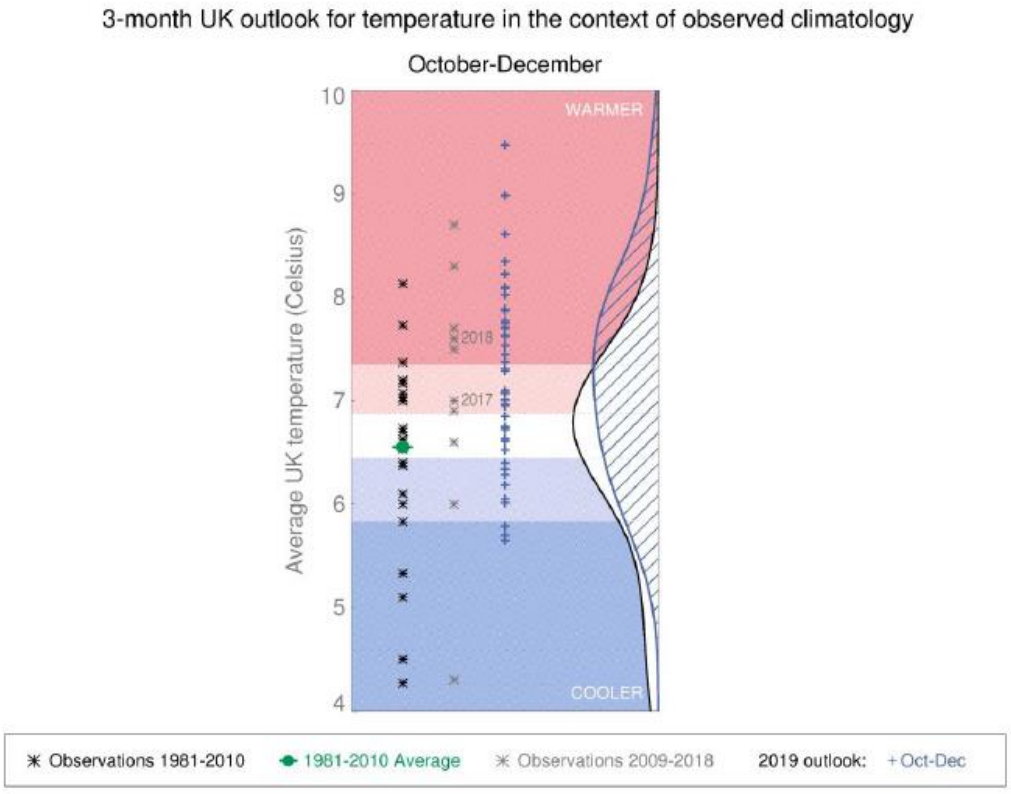
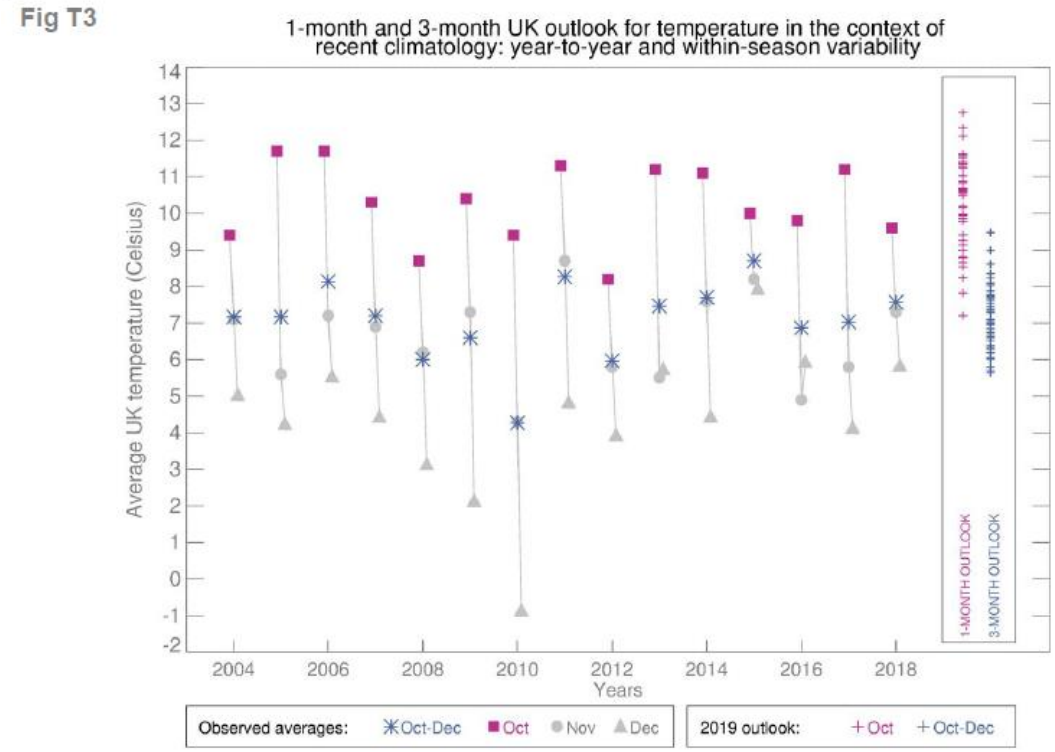


*Figure 17- Fig. T3 from the 3-Month Outlook*




However, the 3-month outlook document often did not remain an immutable mobile (Latour, 1986) once it was accessed by contingency planners through the Met Office website. This was because the contextual information provided with the 3-month outlook sometimes failed to stabilise how contingency planners understood the message:

*'Having looked at the context and looked at the summary, I would say that the top sentence doesn't give the way I interpreted the context. So, the way I read that is the 'chances above or below are approximately similar.' But actually, the context says it was going to be- my interpretation- was that it's going to be warmer and wetter.' (Emergency Resilience Manager, 22-10-20)*

When the emergency resilience manager was presented with a copy of the December-January-February (DJF) 2019 precipitation outlook, they thought that the summary message contradicted the information provided in the scientific context. For example, the emergency resilience manager thought that the scientific context was saying that it might be warmer and wetter than average. However, the summary statement for the DJF 2019 precipitation outlook said that 'for December-January-February as a whole, the chances of above- or below-average precipitation are approximately similar' (Met Office, 2019b). As a result, the scientific context for the 3-month outlook did not stabilise the

relationship between the 3-month outlook and the context in which it was used in the way that Met Office staff intended. Instead, the technical language used within the contextual information made it harder for this participant to understand the summary message of the 3-month outlook. The message of the 3-month outlook document published on the Met Office website therefore sometimes changed once it was used outside of the Met Office.

One could argue that the difficulties participants had in understanding the 3-month outlook document were simply the result of them not understanding the technical language and graphics. Problems with communicating the 3-month outlook could therefore be solved by developing graphics and summary statements that are easier to understand. However, even when parts of the 3-month outlook did act as immutable mobiles (Latour, 1986) outside of the Met Office, they did not always stabilise the overall message of the 3-month outlook. This is because associations often formed between the graphs and documents that made up the 3-month outlook and other forecasts, images and texts, producing a different narrative or message. For example, the following journalist describes how other journalists would often quote the summary of the 3-month outlook to give newspaper articles a 'veneer of scientific respectability:'

*'So, what they've done- the tabloids have gone into the 3-month contingency planning forecast and they've cherry picked- in fact, it's not even cherry-picking- they've misunderstood what the Met Office means. They don't understand probability, they don't understand average, they don't understand the categories, they certainly don't understand the diagrams and they don't understand the explanation. Although, they will often paste and cut the context without understanding it. But what that does it that it gives them a veneer of scientific respectability, often with gross exaggeration.' (Newspaper Journalist, 15-01-19)*

The journalist perceives that tabloid newspaper articles often quote the summary statement of the 3-month outlook alongside other immutable mobiles (Latour, 1986), such as images, diagrams, and quotes from other forecasters, in order to make the online or print news article look 'scientifically respectable.' This suggests that the circulation of immutable mobiles within the media (Latour, 1986), such as fixed summary statements, internal handling plans and

maps of the UK climatology, did not stabilise the message of the 3-month outlook outside of the Met Office in the way that they did internally. Instead, journalistic norms of balanced, objective reporting (Bennett, 2012), along with the UK public's familiarity with the Met Office as a scientific institution (Hall, 2012) meant that journalists often quoted the 3-month outlook alongside other forecasters and sources in order to demonstrate the scientific credibility of the news story. However, newspaper articles often did not always report on the 3-month outlook in a way that the Met Office Press Office thought was fair and accurate (see Section 5.4.2). This is because the 3-month outlook was often quoted alongside other short-term weather forecasts or private forecasters who issued SCF that Met Office scientists did not think were scientifically credible. The fixed summaries and graphics within the publicly available 3-month outlook document therefore failed to stabilise the relationship between the 3-month outlook and the newspaper articles in which it was quoted.

As a result, enacting the 3-month outlook in a network topology only generated the regional space of the 3-month outlook when it was communicated by Met Office staff. The production and circulation of immutable mobiles, such as graphs, summary statements and the internal handling plan, transformed the localised conclusions of monthly-decadal prediction team into a 3-month outlook for the whole of the UK that was understood by staff in other Met Office departments. This helped Met Office staff without expertise in seasonal climate forecasting communicate the same message no matter where they were located or who they were engaging with. However, the rigidity of immutable mobiles circulating outside of the Met Office also meant that the message could not be adapted to meet the needs and concerns of both the Met Office's principal stakeholders and the media and public. Summary statements and contextual information in the publicly available 3-month outlook document were therefore either ignored or associated with other images and texts in ways that changed the message. Communicating the 3-month outlook through fixed summaries, graphics and maps therefore did not stabilise the relationship between the regional space of the 3-month outlook and the local contexts in which it was used outside of the Met Office. SCF therefore cannot just be communicated in a network topology when other stakeholders have different

informational needs (Lemos et al., 2012) and ways of defining what a normal climate is.

## 7.4 The 3-Month Outlook and Fluid Topologies

The difficulties that the Met Office encountered when communicating the 3-month outlook in a network topology suggest that there is need to explore other topologies that use different metaphors to describe how objects are configured in space. This is because the metaphor of a network assumes that actors like the 3-month outlook well-defined and singular (Law and Mol, 1994; 2001) and says little about the characteristics of the relationships that hold the message of the 3-month outlook together beyond notions of extension and proximity (Hinchliffe et al., 2013). One topology that does not rely upon notion of networks or regions is a fluid topology (Law and Mol, 1994). Unlike in a network topology, the durability and shape of a fluid object is not an effect of network stability. Instead, in fluid space actors and relations gradually change over time in a way that holds the shape of an object together (Law and Mol, 1994). This means that there can be 'mutable mobiles' that retain the same identity under continuous transformation (DeLaet and Mol, 2000). Identifying where the 3-month outlook is communicated in a fluid topology therefore highlights where its stability depends upon varying configurations of actors, as well as unchanging configurations.

Often the 3-month outlook became a mutable mobile (DeLaet and Mol, 2000) when it travelled between different ontologies and epistemologies of climate. For example, transport stakeholders often treated climates as an agency that 'affects' or 'impacts' government services, rather than as a descriptive index (Jankovic and Fleming, 2011). The Met Office's civil contingencies advisors would therefore often adapt their messaging to talk about what the climate might 'do' whenever they briefed contingency planners:

*'I think it's far easier to talk about the impacts with people, because that's what they understand. People are not very good outside my world on taking likelihood. It can confuse people. So, 'high likelihood of low impacts' confuses people because it has two opposites. It has high and low. And what I have to say there is, 'I'm fairly certain, that there's going to be very little impact' from this, whatever that is- wind, rain, snow and then they go, 'I get that.' Civil contingencies advisors are very good at that and very sensitive to wording. It's*

*very much the thing that I use at this point which is 'with great power comes great responsibility.' They're very aware that if they look at their own words, people can misconstrue them and go off at a great tangent.'*
*(Transport Resilience Manager, 08-01-20)*

The transport resilience manager explained how the Met Office's civil contingencies advisors changed how they communicated the 3-month outlook at local resilience forums to talk about its impact upon transport infrastructure. This made the 3-month outlook easier for transport stakeholders to understand, since they understood and were interested in how the seasonal climate might affect transport infrastructure, rather than in descriptions of probable trends in temperature and precipitation. Civil contingencies advisors therefore adapted the language they used to explain the 3-month outlook in local resilience forums to fit a different ontology and epistemology of climate. This suggests that the stability of the 3-month outlook sometimes depends on it becoming a mutable mobile (deLaet and Mol, 2000) rather than an immutable mobile (Latour, 1986).

Similarly, Met Office staff giving verbal briefings would sometimes change their messaging to talk about the probability of disruptive weather events, rather than the probability of the seasonal average being above or below the historical average:

*'Something that was interesting within that was covered in more detail within the conference calls, which is where you get some wider explanation. They [Met Office scientists] said that although this outlook is only showing a slight change in temperature, a lot of weather tends to be around freezing point. So, a small change can have a big impact. So, in my summary I would explain that we could have a cold February that might be colder than average. Then I would use that info. on the increased chance of below zero temperatures to discuss the implications in terms of maintenance and to alert people to some of the issues. So, I might talk to asset management, who are responsible for the buildings. They might want to have a look at heating and fuel bills. They might want to make sure that the boilers are serviced. It's all about alerting people to the wider issues.' (Emergency Planning Officer, 24-10-19)*

Many of the Met Office's transport stakeholders define changes in seasonal

climate in relation to previous disruptive weather events, rather than in relation to the historical average (see Section 6.2.3). This meant that they wanted to know about the future risk of disruptive snow and ice instead of the overall trend in temperature or precipitation. Although the 3-month outlook itself does not contain information on the risk of increased snowfall, the member of Met Office staff giving the briefing knew that transport stakeholders were often interested in this information. They therefore took what they knew about the number of days below freezing during the winter months and combined this knowledge with the 3-month outlook so that they could adapt the message to fit their ontology and epistemology of climate. This allowed the emergency planning officer to take information about the increased risk of snow and ice over the next three months and use it to alert and prepare their colleagues. The emergency planning officer was therefore able to use the 3-month outlook to prepare for severe winter weather because the content of the message was changed to fit a different ontology and epistemology of climate. The fluidity of the 3-month outlook therefore made it easier for transport stakeholders to understand and use in their decision-making and planning.

Moreover, Met Office staff adapted their messaging in verbal briefings to highlight the amount of uncertainty in an individual outlook:

*Stakeholder Question 2: How does this winter's forecast compare to the contingency planner's forecast for 2017?*

*The climate scientist replied, saying that they were more confident in the forecast last winter because the probabilities were higher. They said that this time last winter the forecast was for a warmer than average winter. Last winter as a whole was an average winter but the overall averages obscured the intense cold period from February to March. This year the lower confidence comes from competing forcings. For example, the GloSEA5 model [Met Office seasonal climate model] is showing only a weak signal. Pressure anomalies are only one or two HPA [hectopascals] different from the climatology, whereas this time last year they were double that. Confidence in this year's DJF forecast is therefore lower.*

*(Notes from Dec-Jan-Feb 2019 Transport Stakeholder Briefing, 28-11-19)*

During the transport stakeholder briefing for the DJF 2019 outlook, a transport

stakeholder asked about how the DJF 2019 outlook compared to the previous year's outlook. This gave the climate scientist giving the briefing the opportunity to explain that there was a higher level of uncertainty associated with the DJF 2019 outlook due to conflicting evidence from different teleconnections. However, this extra explanation is not included in the 3-month outlook document published on the Met Office website, since there is not enough space to compare one outlook with the level of uncertainty in previous outlooks. The fluidity of the 3-month outlook therefore not only helped the 3-month outlook change to fit different ontologies and epistemologies of climate but also helped Met Office staff communicate the amount of uncertainty in an individual outlook to its principal stakeholders. As a result, the fluidity of the 3-month outlook stabilised the overall message by helping Met Office staff manage the expectations of its principal stakeholders.

Furthermore, the fluidity of the 3-month outlook not only stabilised the overall message but also generated regional spaces that adapted the outlook to the local context in which it was used (Law and Mol, 2001). For example, the following climate scientist responds to a question asked by a transport stakeholder by explaining how the January-February-March (JFM) 2019 outlook might result in drier than average weather over Scotland:

*From Transport Scotland: You said that it would be drier than average in the North with wetter than average weather over the South of the UK. Does that mean that Scotland will be drier than average?*

*The climate scientist responded by agreeing with the stakeholder. They said they were correct in thinking this, as the influence of the NAO would result in wetter than average conditions over France and the South of the UK and drier than average conditions elsewhere. They said that low pressure systems would miss them up in Scotland, resulting in less precipitation.*

*(Notes from JFM 2019 Transport Stakeholder Briefing, 19-12-18)*

Although the 3-month outlook only indicates possible trends in temperature and precipitation averaged over the whole of the UK, negative NAO conditions are associated with reduced precipitation in Scotland and increased precipitation over the South-East of the UK (Baker et al., 2018). In this instance, the climate scientist felt that they were able to adapt the content of the 3-month outlook by

providing this additional information, without going beyond the level of detail that the Met Office's seasonal forecasting system can currently provide. For example, GloSEA5 cannot currently produce skilful precipitation forecasts for regions like Southwest England (Baker et al., 2018), even if a positive NAO indicates that there is likely to be a south east to north west gradient in seasonal average precipitation over the British Isles (Scaife et al., 2014). Nevertheless, the fluidity of the 3-month outlook meant that Met Office scientists were able to talk about the regional implications of the message for stakeholders within the limitations of the Met Office's seasonal forecasting system.

Whilst the content of 3-month outlook did sometimes change to fit differences within regions, there were also times where Met Office scientists were unable to adapt the message to provide stakeholders with the information that they wanted:

*Stakeholder Question: Is it possible to put a number on the increase in wind energy due to increased risk of storminess e.g. January-March will be 3% more energetic than the LTA [long-term average]?*

*The climate scientist replied by saying that they wouldn't put a number on this. They said that different wind farms were affected by different wind strengths in their specific locations. They highlighted the uncertainty in the outlooks for temperature and rainfall and said that you would get the same uncertainty for storminess. They said that they could do this 1 on 1 with some wind farms. However, they then said that that downscaling the information in this way could get complicated very quickly.*

*(Notes from Energy Stakeholder Briefing, 17-12-19)*

The energy stakeholder wanted to know if the Met Office could provide them with information about the increased risk of storminess for their wind farm over a three-month period. However, the climate scientist giving the briefing had to explain that wind farms had their own microclimates and that it would be difficult to downscale the outlook for a specific windfarm due to the large spatial resolution of the Met Office's seasonal forecasting system. This meant that some aspects of the message, such as the size of the geographical area, could not be substantially changed without giving stakeholders unrealistic expectations about the level of detail that the 3-month outlook could provide.

There were therefore limits to the amount of detail that the 3-month outlook could give about regional variations in climate over a three-month period.

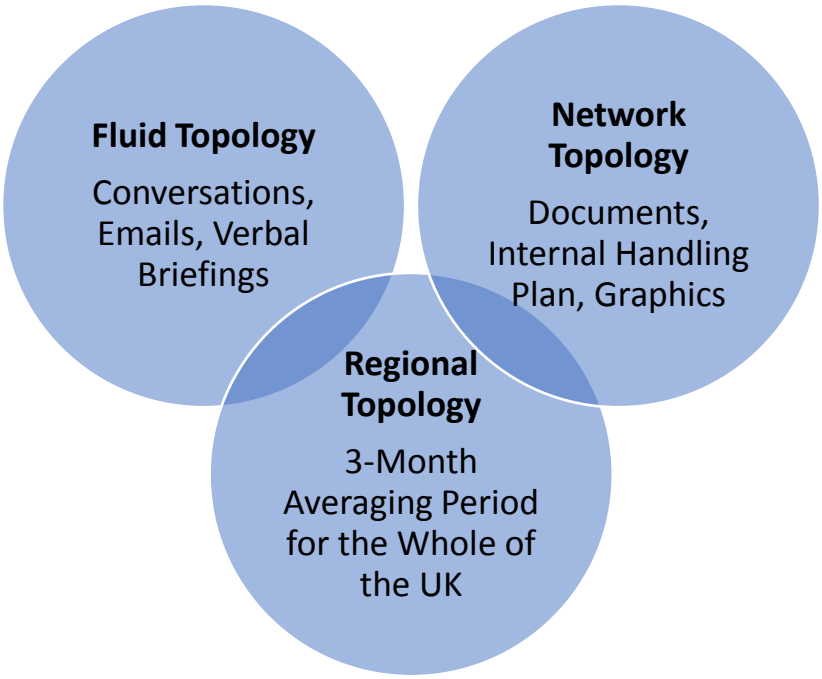
Although Met Office scientists were limited in the wider explanation that they could provide alongside the 3-month outlook, they were able to adapt their messaging to fit different ontologies and epistemologies of climate and to highlight uncertainties in different outlooks. In contrast, the 3-month outlook document published on the Met Office website could not be changed to fit a different epistemology and ontology of climate or to highlight the relative level of uncertainty. The message of the 3-month outlook became unstable as fixed graphics, summary statements and maps were either ignored or associated with other immutable mobiles in ways that produced different or conflicting narratives. The stability of the 3-month outlook within the principal stakeholder briefings therefore suggests that these briefings were largely successful in adapting the message of the 3-month outlook to the context in which it was used.

Furthermore, the communication of the 3-month outlook in verbal briefings suggest that fluid topologies create, maintain and interact with network and regional topologies. A fluid topology is not, as some geographers have argued (Martin and Secor, 2014), a replacement or an improvement upon network or regional topologies. For example, Met Office staff needed to be consistent in their messaging to avoid confusing stakeholders who received the 3-month outlook through multiple channels of communication. The production and circulation of immutable mobiles (Latour, 1986) like the summary statement of the 3-month outlook helped Met Office staff do this by creating a unified and coherent message. Similarly, the large spatial and temporal resolution of the Met Office's seasonal climate model meant that the 3-month outlook had to be issued as an outlook for the whole of the UK over a three-month period in order to avoid giving stakeholders a false sense of certainty. Meanwhile, fluid briefings, conversations and emails about the 3-month outlook created and maintained regions and networks by changing actors and relations so that the message could hold together. Fluid topologies are therefore not the 'other' of regions and networks but are another topological system that is needed to hold together the message of a SCF.

## 7.5 Discussion

This chapter has used the concept of topology (Law and Mol, 1994; 2001) to address the apparent tension between the concept of translation (Callon, 2007) in Chapter 5, which suggests that communication depends on stakeholders agreeing upon what a SCF is and how it should be used, and Chapter 6, which argues that SCF are enacted in multiple yet related versions as they are communicated (Mol, 1999; 2002). By recognising that space can be defined topologically through the characteristics of the relationships that constitute an object, rather than through metrical distance, it becomes possible to understand how the message of a SCF can hold together even as it changes. For example, the 3-month outlook is simultaneously a region in time and space, a network of fixed documents, texts, and graphs and a fluid mixture of conversations, verbal briefings and emails (see Figure 18). The successful communication of the 3-month outlook therefore depends on holding these different topologies together, so that the message remains continuous under transformation.

*Figure 18- The Multiple Topologies of the 3-Month Outlook*




Furthermore, a topological approach highlights how geographers and climate scientists sometimes restrict themselves to understanding the communication of SCF within only one topology. For example, scientific research into improving the quality of SCF often focusses improving the skill and reliability of a seasonal forecasting system, so that climate scientists can issue SCF that have a higher level of spatial and temporal detail (Arnal et al., 2018; Baker et al., 2018).

However, a SCF for the South-West of the UK or with a month-by-month breakdown is not necessarily easier for stakeholders to understand and use than a 3-month outlook for the whole of the UK. The message of a SCF needs to be communicated consistently with graphics and summaries and it needs to be communicated fluidly, in order to adapt the message for varying levels of uncertainty and multiple ontologies of climate. Efforts to add regional and temporal detail to SCF therefore need to be accompanied by networked and fluid modes of communication that stabilise the message with a specific regional topology.

Similarly, social scientific research into the communication of SCF has often focussed on identifying presentation formats that can be easily understood (Coventry and Dalgleish, 2015; Taylor et al., 2015), or on identifying ways of disseminating a forecast that end-users can easily access (Roncoli et al., 2008). Creating a network of graphs, people, texts and documents through which stakeholders can easily understand and access information about the future seasonal climate is therefore seen as critical to the communication process. However, it is less common to find studies that analyse the fluid mixture of conversations, briefings and emails that sustain the networks and regions upon which a SCF depends. This suggests that geographers and other social scientists often only imagine the communication of SCF in terms of extension and reach, rather than in terms of the intensity of relationships that hold the message together (Allen, 2016; Hinchliffe et al. 2013). It also suggests that current efforts to improve the communication of SCF might not be effective in helping forecasters communicate with stakeholders who have a different understanding of what a normal climate is and what that climate ought to do (Jankovic and Fleming, 2011). Reimagining a SCF as an object that is arranged in multiple topologies therefore highlights other ways of holding the message together that go beyond the notion of regions and networks.

Finally, treating the 3-month outlook as an object in multiple topologies helps geographers, other social scientists and climate scientists reimagine the communication of SCF without presupposing a distinction between scientific and social activity (Callon, 1999). Often efforts to improve the communication of SCF, including the Met Office's own 3-month outlook, revolve around a perceived tension between maintaining scientific integrity and making a forecast

‘usable’ for different audiences (Lemos et al., 2012). For example, should a graph show the entire probability distribution to communicate the full range of uncertainty in the 3-month outlook or would this make the 3-month outlook harder for stakeholders to understand? Do stakeholders need to understand the meteorological context to interpret the 3-month outlook correctly or can they just be provided with a summary statement? Can the Met Office communicate the 3-month outlook to journalists and members of the public or is it too complicated or uncertain for them to understand or find useful? In each of these questions, there is a similar tension between wanting to make SCF easier to understand and use and communicating the complexity and inherent uncertainty of the underlying science. Discussions around improving the communication of SCF are therefore often based upon a demarcation between science on the one hand and society on the other (Callon, 1999).

However, if the 3-month outlook is a set of practices that enact and re-enact a message (Law and Mol, 2001; Mol, 2002), then it does not make sense to turn communication into a binary choice between scientific integrity and usability. Instead, a better question to ask is ‘what do we need to do to keep the message of the 3-month outlook the same in different circumstances?’ For example, a topological approach suggests that in some places the content of the 3-month outlook needed to change to keep the message stable, such as when it was communicated to transport stakeholders who had a different ontology and epistemology of climate. In some cases, then, a fluid topology is needed to help stakeholders understand and use SCF. However, at other times the stability of the message depended on aspects of the 3-month outlook not changing. For example, some of the energy stakeholders asked for information about specific locations at a level of detail that the Met Office’s seasonal forecasting system cannot currently provide. In this instance, Met Office scientists had to tell energy stakeholders that the 3-month outlook only provides information about probable trends in temperature and precipitation across the whole of the UK. A topological approach to analysing the communication of SCF could therefore identify when and where scientists need to adapt their messaging, without creating an unnecessary tension between maintaining the scientific integrity of a SCF and making SCF more user-friendly.

# Chapter 8: Conclusion

## 8.1 Introduction

This thesis aimed to understand how the message of a SCF changes as it is communicated. In this concluding chapter, I discuss the empirical contributions that this thesis makes to our understanding of how SCF are communicated and used within the UK and the theoretical contributions that it makes to how geographers conceptualise the communication of SCF. Next, I reflect upon the practicalities of completing an interdisciplinary thesis with the Met Office as an engaged stakeholder and suggest that it is possible for interdisciplinary research to both solve societal problems and transform existing ways of thinking about an issue. Finally, I offer some recommendations for improving the communication of SCF and for future geographical research into the communication of weather and climate forecasts.

## 8.2 Key Findings

This thesis aimed to understand how the message of a SCF changes as it is communicated. To do this, I used the concepts of translation (Callon, 2007), multiplicity (Mol, 1999; 2002) and topologies (Law and Mol 1994; 2001) to theorise the 3-month outlook as an effect of shifting relations between meanings (semiotics) and human and non-human things (material) (Law and Singleton, 2014). This material semiotic approach differs from existing ways of conceptualising the communication of weather and climate forecasts, which tend to treat forecasts either as information that is transmitted to an end user (a transmission model of communication) or as a product that is customised to a user's decision-making needs (a delivery model of communication). This section therefore argues that material semiotic approaches can contribute to geographical research by illustrating how SCF are heterogeneous, relational, multiple and arranged in different topologies.

Material semiotic approaches emphasise the interweaving of theory and empirical research by using empirical case studies of events, activities and controversies to develop new theoretical insights (Law, 2008). This thesis has taken the same approach by following the relations that that constitute the Met Office's 3-month outlook in order to understand how the message of a SCF changes as it is communicated. The theoretical contributions that this thesis makes to geographical and social scientific research into the communication of

scientific knowledge therefore cannot be separated from the empirical contributions that this thesis makes to our understanding of how stakeholders in the UK interpret and use SCF. The theoretical and empirical contributions of this thesis are therefore presented alongside each other in the following section, in order to stress the continuities that exist between theory and empirical data.

### 8.2.1 The Heterogeneity of SCF

STS scholars (Law and Singleton, 2014; Mol, 2002) and geographers (Hinchliffe et al., 2013; Jackson et al., 2019) who use material semiotic approaches maintain that there is no distinction between the materials in the world around us and meanings that they symbolise or create (Law, 2008). This means that material semiotics emphasises the heterogeneity of scientific knowledge, which needs to be materialised in people, data, documents, physical infrastructure and skills in order to circulate (De Wit et al., 2018). Material semiotics therefore can contribute to how geographers, other social scientists and climate scientists conceptualise the communication of SCF by identifying actors that are not usually considered to be relevant when understanding the communication process. In particular, this thesis has identified three kinds of actors that play a critical role in the communication of SCF that are not always included within existing empirical studies of how SCF are communicated.

Firstly, this thesis has highlighted how the communication of SCF depends on non-human actors as well as human actors. Current research into the communication of weather and climate forecasts focusses on how 'end-users' interpret the language and graphics that are used to present a forecast (Coventry and Dalgleish, 2015) or on customising a SCF to a stakeholder's decision-making needs (Lemos et al., 2012). This means that theoretical models of how weather and climate forecasts ought to be communicated only focus on the human beings that are involved in the communication process. However, both early forms of ANT (Callon, 2007; Latour, 1987; Law, 1987) and post-ANT work within geography (Jackson et al., 2019), anthropology (De Wit et al., 2018) and STS (Law, 1999; Mol, 2002) maintain that knowledge needs to be materialised before it can be picked up and used in different location. For example, the quality of forecasts issued by the Met Office's seasonal climate model, GloSEA5, depend upon accurate observations of variables that might influence climatic variability over the UK (Taylor et al., 2015). The monthly-

decadal prediction team needs meteorological observations and forecasts from other global long-range forecasting centres to assess the credibility of the forecast produced by GloSEA5. Other Met Office staff need graphics, summary statements and internal handling plans to ensure that they communicate the same message as the monthly-decadal prediction team. Met Office scientists and transport stakeholders need teleconferencing software that easy to access and run, so that they can hear the message and ask Met Office scientists any questions that they might have. Throughout the communication process, there are non-human actors that materialise the knowledge that constitutes the message of the Met Office's 3-month outlook. Material semiotics therefore contributes to our understanding of how SCF are communicated by identifying the arrangements of materials that make communication possible.

Secondly, the communication of SCF depends on the expertise and skills of non-scientists, as well as the skills and expertise of scientists who specialise in seasonal climate forecasting. Transmission and delivery models of how weather and climate forecasts are communicated (see Sections 2.2 and 2.3) divide up the communication of SCF into forecast providers and forecast users (Crane et al., 2010; Lemos et al., 2012). However, following the Met Office's 3-month outlook highlighted how it is often difficult make this conceptual distinction in practice. Climate scientists from the Met Office's monthly-decadal prediction team were not the only people involved in the communication of 3-month outlook. Applied scientists, civil contingencies advisors and meteorologists would sometimes give verbal briefings on the 3-month outlook, even though these members of Met Office staff do not develop and use seasonal climate models. Non-scientists within the Met Office, such as product managers, press officers and communications staff were also involved in communicating the 3-month outlook. Similarly, outside of the Met Office, energy stakeholders, transport stakeholders and contingency planners often took on the role of communicators, briefing their colleagues on the content of the 3-month outlook and what it meant for the organisation that they worked for. Asymmetrical models of communication, which separate forecast providers from forecast users, therefore cannot account for the diverse range of people, skills, and expertise that were needed to communicate the 3-month outlook. As a result, material semiotic approaches contribute to our understanding of how SCF are

communicated by removing the conceptual separation between scientific and social activity.

Finally, this thesis highlights how the communication of SCF often involves stakeholders that do not fit the profile of a typical 'end-user,' such as journalists or members of the public. Most empirical research into the uptake and usage of SCF studies organisations and individuals in climate-sensitive sectors that use SCF to inform their decision-making and planning (Bruno Soares et al., 2017; Cash et al., 2006; Dilling and Lemos 2011; Rayner et al., 2005). Focussing on these stakeholders is a pragmatic and understandable decision, since stakeholders like farmers, water companies or contingency planners are often the intended recipients of SCF. However, by treating all stakeholders as equally important actors in the communication of SCF, material semiotic approaches draw attention to stakeholders that are not always included in empirical studies of how SCF are communicated. For example, although the Met Office does not proactively communicate the 3-month outlook to the UK public and media, it still makes the 3-month outlook publicly available on its website. This means that the Met Office must engage with journalists and members of the public who do not use the 3-month outlook to make long-term, strategic plans or to manage resources with long lead-time supply chains. Material semiotic approaches therefore contribute to our understanding of how SCF are communicated by identifying stakeholders that are not always included within empirical studies of how SCF are used within the UK and Europe.

### 8.2.2 The Relationality of SCF

Recognising the heterogeneity of SCF illustrates how conceptual divisions between materials and meanings, science and society and users and non-users can be somewhat arbitrary (Law and Singleton, 2014). Instead, the message of a SCF emerges as a relational effect of how these materially diverse actors are arranged. Acknowledging the heterogeneity of SCF therefore also involves acknowledging the relationality of SCF. As a result, material semiotics can contribute to how geographers conceptualise the communication of SCF by tracing relations between the actors that shape and form the message of a SCF.

Research that is based on a transmission or delivery model of communication (see Section 2.2 and 2.3) either treats SCF as information that is presented to

an end-user or as a self-contained product. Both models of communication therefore conceptualise SCF as discrete objects, rather than as webs of shifting relations between people, data, texts and conversations. This means that empirical research into the interpretation and use of SCF often focus on the end of the communication process where the user receives the forecast. For example, some studies analyse how 'end-users' make decisions with a forecast (Lemos et al., 2012), whilst other studies aim to identify systematic biases in how stakeholders interpret the graphics and language that are used to present a forecast (Coventry and Dalgleish, 2015; Taylor et al., 2015). However, if SCF are relational, then geographers and other social scientists cannot just study the point at which a stakeholder receives a product or decodes the information in a SCF. Instead, geographers and other social scientists need to go to meetings with climate scientists, listen to briefings with transport stakeholders and read online news articles quoting SCF, if they want to think well about how SCF are communicated.

Chapter 5 of this thesis therefore used the concept of translation (Callon, 2007) to follow patterns of association and disassociation as the 3-month outlook is communicated. This highlighted how the successful translation of the 3-month outlook depended on definition of a stable intermediary that enrolled the interests of the Met Office's stakeholders and communicated the uncertainty in the 3-month outlook. The Met Office achieved this by problematising the 3-month outlook as a 'watching brief' that should be used as qualitative information to guide strategic planning, rather than to commit resources or to make short-term operational plans (see Section 5.3). Although transport stakeholders, energy stakeholders and contingency planners only ever used the 3-month outlook as a watching brief, this did not prevent them from using the 3-month outlook to achieve a variety of commercial and institutional goals. For example, energy stakeholders used the 3-month outlook to anticipate consumer demand for gas and electricity and to schedule maintenance (see Section 6.2). Transport stakeholders used the 3-month outlook to schedule maintenance, anticipate winter expenditure, manage stocks of de-icing materials and to warn colleagues and external contractors (see Section 5.3). Finally, contingency planners used the 3-month outlook to highlight areas to watch and to update policies and contingency plans (see Section 5.3). The usage of the 3-month

outlook by the Met Office's principal stakeholders suggests that SCF can be used in the UK and Europe to inform decision-making, so long as forecasts are problematised in a way that communicates any uncertainties to a potential stakeholder. The concept of translation therefore contributes to our understanding of how SCF are communicated by identifying stable configurations of actors that hold the message together.

Moreover, the concept of translation (Callon, 2007) can be used to identify unstable configurations of actors that make SCF difficult to communicate. For example, the actor-network that formed around the summer 2009 forecast became divergent as journalists interpreted and used the summer forecast 2009 in a similar way to the deterministic weather forecasts that they are more familiar with, rather than as a probabilistic climate outlook. Even though the Met Office decided to stop publicising SCF for the UK following this event, journalists still sometimes report on the 3-month outlook when they think that it has the potential to be included in a news story. However, the reporting of the JAS 2019 outlook in the UK media suggests that Met Office staff have not been able to problematise the 3-month outlook in way that reconciles their interest in communicating the probabilistic nature of the 3-month outlook with the interests of journalists, who often want to publish news stories that resonate with narratives about 'British' cultural fascination with the weather (Fox, 2014; Hulme and Burgess, 2019). The concept of translation therefore extends our understanding of how SCF are communicated by identifying unstable configurations of actors that produce contested interpretations of the message.

### 8.2.3 The Multiplicity of SCF

Whilst the concept of translation highlights the relationality of the 3-month outlook and describes how conflicts emerge over how the 3-month outlook should be interpreted and used, it assumes that the successful translation of a SCF will produce a coherent and coordinated network. This means that the notion of translation cannot account for the existence of actors that have multiple identities or describe how differences in actor-networks emerge and persist (Müller, 2015). Chapter 6 of this thesis therefore introduces the concept of ontological multiplicity (Mol, 2002) in order to identify and understand the multiple actor-networks, or enactments, that emerged during the communication of the 3-month outlook.

Treating the 3-month outlook as an object that exists as different things in different practices highlights how contested interpretations of a forecast are not just an effect of epistemological differences (how we know changes in climate) but also of ontological differences (what the climate is). Most efforts to improve the communication of SCF assume that there is one climate that has multiple meanings. For example, stakeholders often do not know what the historical average is and therefore struggle to understand what 'below-normal' or 'above-normal' means within a SCF (Pennesi, 2007b). As a result, Met Office scientists provided stakeholders with maps displaying the UK climatology and recent annual averages (see Section 6.2.4), so that stakeholders would know what an outlook for 'above-normal' temperatures or precipitation meant. However, following the 3-month outlook highlighted how stakeholders not only attributed different meanings to the concept of a 'normal' climate but also organised and conceptualised variations in climate in ways that differed from Met Office scientists. For example, energy stakeholders defined what a normal climate is in relation to the historical seasonal average in similar way to Met Office scientists. However, transport stakeholders defined what a normal climate is in relation to the likelihood of extreme weather events that cause disruption to transport infrastructure, which sometimes made it harder for them to understand the content of 3-month outlook and the transport impact outlook. This suggests that there are not just multiple epistemologies of climate (how we know changes in climate) but multiple ontologies of climate (what the climate is) that shape how stakeholders understand and use SCF. It also means that climate scientists need to identify and understand these ontological differences, so that they can find out what scientific terms mean to other stakeholders.

Furthermore, the concept of ontological multiplicity highlights the relationships that exist between how people know changes in climate (epistemology), how people conceptualise changes in climate (ontology) and how people expect the climate to affect their livelihood and/or organisation (norms). Often the communication of weather and climate forecasts is reduced to an epistemological problem that can either be solved by correcting misinterpretations of a forecast (Coventry and Dalgleish, 2015; Morss et al., 2008) or by integrating knowledge about weather-related impacts into a forecast so that it can be customised to a user's decision-making needs (Lemos et al.,

2012). This separates a stakeholder's epistemology of climate from their understanding of what the climate is and what it ought to do (Goldman et al., 2018; Ingold and Kurtilla, 2000; Jankovic and Fleming, 2011). However, I argue that both epistemologies and ontologies of climate are often linked to what stakeholders expect the climate to do. For example, the Met Office's energy stakeholders defined what a normal climate is in relation to the historical seasonal average because it was the seasonal average temperature that had the largest impact on consumer demand for gas or electricity, rather than daily or weekly variations in temperature. However, the Met Office's transport stakeholders were interested in the likelihood of extreme weather events rather than the seasonal average because it was extreme weather events caused disruption to road, rail and aviation infrastructure. In both cases, different ontologies of climate were associated with how stakeholders lived with changes in seasonal climate and how they expected the seasonal climate to change based on their past experience. Treating SCF as an object that is 'more than one and less than many' (Mol, 1999) therefore highlights how the interpretation and use of a forecast is often shaped by normative assumptions about what the climate ought to do.

### 8.2.4 The Topologies of SCF

Although the concept of ontological multiplicity explains how a SCF can exist in multiple enactments, it also creates a tension with the argument introduced in Chapter 5. This is because the concept of translation (Callon, 2007) suggests that Met Office staff and their stakeholders need to agree upon what the 3-month outlook is and how it should be used in order to hold the message together. Chapter 7 of this thesis therefore introduces the concept of topology (Law and Mol, 1994) to resolve the apparent contradiction between these two arguments. I argue that the 3-month outlook simultaneously exists in three topologies. The first of these is a region bounded in space (the whole of the UK) and time (three months), in which the message is held together in bounded clusters. The second is a network of graphs, documents, handling plans and summary statements, in which the message is held together by connections between similar elements. The third is a fluid mixture of conversations, briefings and emails, in which the message is held together by relations that remain continuous under transformation. The 3-month outlook needs to be communicated in all three of these topologies for the message to hold together.

For example, the 3-month outlook can only be issued for whole of the UK because the Met Office's seasonal forecast system is not yet skilful enough for Met Office scientists to downscale the 3-month outlook for smaller geographical regions. Similarly, the 3-month outlook cannot exist as an outlook for the whole of the UK without the network of graphs and documents that ensure that Met Office staff communicate a consistent message to their stakeholders. However, communicating the 3-month outlook in a fluid topology proved to be particularly important in holding the message together. This is because it meant that Met Office staff could adapt the message of the 3-month outlook to fit different ontologies of climate or to account for varying levels of uncertainty in individual outlooks. It was therefore often the 'fluid topology' (Law and Mol, 1994) of the 3-month outlook that made the message coherent, even when the 3-month outlook was enacted in multiple versions.

The concept of topologies and the notion of ontological multiplicity can therefore help geographers reimagine how the message of a SCF changes as it is communicated. A SCF is not a package of information that is delivered to an end-user. Instead, the message of a SCF is a web of relations between different practices or enactments (Mol, 2002). The 3-month outlook is a group of Met Office scientists discussing the wording of the summary statement, a press officer answering questions from a journalist over the phone or a transport operator sending an email to a colleague. The successful communication of a SCF depends on each of these practices being held together, whether through regions in time and space, networks of documents or fluid conversations, so that the different versions of a forecast do not contradict each other. It is the careful coordination of each these practices that makes it possible for stakeholders to understand and use SCF.

This thesis has therefore highlighted how important it is to critically examine the topological assumptions that geographers, other social scientists and climate scientists make when they conceptualise the communication of SCF. Ideas about what constitutes the message of a SCF have consequences for how we communicate them. If SCF are information that is transmitted to an end-user, then scholars will identify cognitive biases in how end-users interpret a forecast and develop new presentation formats to correct these biases. If SCF are a network of documents and graphs, then scholars might identify inconsistencies

in the message and develop new ways of disseminating a forecast to ensure that the message does remain consistent. None of the approaches to theorising the communication of a SCF are inherently problematic. This is because stakeholders need to understand the language and graphics that are used to present a forecast and because stakeholders need to receive a consistent message to avoid any confusion. However, if geographers, other social scientists or climate scientists only rely upon one set of topological assumptions to theorise the communication of SCF, then this can restrict the kinds of questions that are asked and prevent certain problems from being addressed. For example, emailing a fixed summary statement to a stakeholder might make it more difficult to adapt to the message of the outlook to their understanding of what a normal climate is and ought to be. Expanding our topological vocabulary to recognise the heterogeneity, relationality, multiplicity and fluidity of SCF can therefore identify ways of improving the communication of SCF that are not restricted by the assumptions that geographers, other social scientists and climate scientists often make about the characteristics of social and scientific spaces.

## 8.3 Key Contributions

The key findings discussed in previous section have important implications for how geographers theorise climate-culture relations, for how STS scholars analyse the ontology of scientific objects and for how climate scientists and geographers conceptualise the communication of SCF. The following section outlines how this thesis contributes to each of these areas of research.

### 8.3.1 Contributions to Geographical Research on the Multiplicity of Climate

Over the last twenty years, geographers have sought to ‘re-culture’ the concept of climate by treating it as an object that exists in multiple ontologies, rather than only as a standardised numerical index (Hulme, 2008; Tadaki et al., 2012). For example, a climatic event like a heatwave can exist simultaneously as a physical event, a statistical construct and as an imaginative idea in art and literature (Hulme, 2012). Similarly, geographers have drawn attention to how the multiplicity of climate is bound up with social and political norms that shape our understanding of what kind of climate is desirable or ‘natural’ (Caseldine, 2015; Osaka and Bellamy, 2020) and of how stable a normal climate ought to

be (Hulme et al., 2009). Geographical work on the multiplicity of climate therefore challenges dominant scientific accounts of what a normal climate is by showing how the idea of climate is a culturally, historically and geographically contingent concept (Hulme, 2015; Hall and Endfield, 2016).

However, there is a risk that emphasising the cultural contingency of climate could lead to geographers downplaying the materiality of the spaces that are created by climatic variability. For example, the definition of a normal climate within the 3-month outlook is dependent upon a global network of scientific instruments, meteorological measurements and seasonal climate models. Similarly, transport stakeholders working at local authorities in the UK interpreted the 3-month outlook in relation to memories of disruptive climatic events, such as the cold UK winter of 2009/10. These memories were based on sensory experiences of cold weather and local, embodied practices, such as working long hours to answer phone calls from engineering teams who were clearing roads of snow and ice. Defining climate as a discourse that is constantly being co-produced (Jasanoff, 2010; Mahony and Hulme, 2018) potentially overlooks these material aspects of how climate forecasts and projections are made and communicated. This suggests that theoretical accounts of climate-culture relations are needed that do not treat 'culture' as a category that is separated from the climates and places in which people live (Latour, 2005).

The material semiotic approach adopted in this thesis provides one way in which geographers could materialise the geographies that are created by climatic variability and cultural variability. Material semiotics relativizes the distinction between climate and culture by treating SCF as a web of relations between things and meanings (Law, 2008). This moves geographers away from debates around how climate and culture relate to one another to focus on the material properties of the climate and how these shape geographical and cultural relations. For example, following the 3-month outlook showed how its movement depended on the skills, knowledge and actions of people involved in its communication. However, it also highlighted how the translation of the 3-month outlook was grounded in the circulation of documents, technical infrastructure and the meteorological context in which an outlook was issued. Treating the 3-month outlook as an institutional discourse or as a constructed

idea would have overlooked the role that non-human actors play in the forecasting and communication process. Similarly, it would have neglected the regional, networked and fluid spaces that were created by the meteorological data, climate models, people and documents that form the 3-month outlook. Material semiotics can therefore contribute to geographical research into the multiplicity of climate by showing how non-human actors make a difference to how climates and cultures are arranged in space.

### 8.3.2 Contributions to STS Work on Material Semiotics

The impact of material semiotic approaches within STS has generated significant interest in questions of ontology, where STS scholars interrogate what objects are (Woolgar and Lezaun, 2013). Much of this work aims to show how objects that appear 'ready-made' or 'finished' exist in multiple, discontinuous forms (Law and Singleton, 2005). This often achieved by appealing to ethnographies of mundane practices, such as Atlantic salmon farming (Law and Lien, 2013), in order to show how practices enact multiple versions of an object like the Atlantic salmon. There is also a political dimension to much of this work, since it often aims to destabilise dominant understandings of an issue by highlighting how there are other policy options or political actions that are available (Law and Singleton, 2014).

However, some STS scholars have questioned what a 'turn to ontology' adds to our understanding of how scientific knowledge is made and communicated (Aspers, 2015). For example, the 3-month outlook could be understood as a boundary object that acts as a bridge between different social groups with different cultures (Star and Griesemer, 1989). Stakeholders might have different interpretations of the 3-month outlook, yet the message has enough interpretative flexibility for them to understand its overall meaning (Star and Griesemer, 1989). STS scholars have therefore questioned whether there is qualitative difference between recognising that an object can be interpreted in multiple ways by different social groups and claiming that an object is ontologically multiple (Aspers, 2015).

STS scholars who do propose that objects are ontologically multiple have responded by claiming that a focus on multiple interpretations of an object overlooks the discontinuity and otherness of objects (Law and Singleton, 2005). For example, an object like a patient's body is not a single object that is known

from different perspectives but something that takes on a multiple forms or identities depending on who is making the diagnosis (Mol, 2002). This means that it is important to not only ask questions about how we construct knowledge about an object but also to examine what an object is in the first place. However, this response does not explain how scientists negotiate the discontinuity and multiplicity of objects in praxis. How, for example, does the message of the 3-month outlook remain coherent, if it also exists in multiple and potentially conflicting versions? This suggests that there is a need for STS scholars to explore what the ontological multiplicity of objects means for how scientific knowledge is communicated in praxis.

As a result, this thesis contributes to material semiotic approaches within STS by showing what effect the ontological multiplicity of a SCF has on its communication. For example, overlapping ontologies of climate meant that energy stakeholders found the 3-month outlook easier to understand and use than contingency planners, transport stakeholders and journalists. Similarly, the fluid topology of the 3-month outlook in verbal briefings kept the message stable when Met Office scientists communicated with stakeholders who had a different understanding of what a normal climate is. By asking ontological questions about what the 3-month outlook is, it became possible to understand not only its multiplicity but also to learn about how Met Office scientists negotiated this multiplicity when communicating the 3-month outlook. A focus on questions of ontology can therefore identify multiple versions of an object like a SCF and identify ways in which scientists can better coordinate these versions. This contrasts with an epistemological approach, which tends to reduce objects like the 3-month outlook to a trading zone between different cultures, without acknowledging the discontinuity and 'messiness' of scientific objects and artefacts (Law and Singleton, 2005). Using a material semiotic approach to understand how scientific knowledge is communicated in praxis therefore contributes to recent conversations within STS about the value of a 'turn to ontology' (Woolgar and Lezaun, 2013).

### 8.3.3 Reconceptualising the Communication of SCF

Efforts to improve the communication of SCF are increasingly moving away from a linear, transmission model of communication towards a focus on co-producing climate services that are usable for decision-making (Cash et al.,

2003, Lemos et al. 2012). However, a delivery model of communication still presupposes that there is a boundary between forecast providers in the scientific community and users in society. This overlooks the important role that climate scientists play in constructing the message of a SCF before stakeholders are given a forecast and the effect this has on how a SCF is communicated. Similarly, a model of communication that ignores the boundary between forecast providers and users ignores the onward communication of a SCF once a stakeholder has received the message. This is also an equally important stage in the communication process, since stakeholders need to brief their colleagues on the content of a SCF or write documents or newspaper articles that explain what a SCF means for a particular audience.

Material semiotics could therefore help geographers reimagine the communication of SCF by relativizing the boundary between science and society, and by extension, the distinctions that are made between forecast providers and users. A material semiotic approach counteracts the tendency to only focus on the point in the communication process where a stakeholder hears the message in a verbal briefing or receives a document from a scientist. It also suggests that following a SCF, or at the very least, studying other stages in the communication process, could yield valuable insights into how SCF are picked up, understood and used in decision-making. Treating SCF as a web of relations between things and meanings therefore can draw attention to parts of the communication process that are neglected within existing conceptual models of communication.

Moreover, material semiotics contributes to how we conceptualise the communication of SCF by foregrounding the materiality of seasonal climate forecasting and communication processes. Both transmission and delivery models of communication on focus on the social dimensions of communication by treating human beings as the primary actors in the making and communication of a SCF. However, this asymmetrical approach prevents scholars understanding how documents, data, climate models and the meteorological context itself make a difference to how SCF are communicated. In contrast, material semiotics flattens the distinction that is made between the material and the social by treating humans and non-humans as equally important actors in the communication process (Law, 2008). Such an approach

does not involve treating actors as if they have same kind of agency, since human beings can form intentions and do things that non-human actors cannot (Sayes, 2014). However, a material semiotic approach does involve treating all things, human and non-human, as actors that could make a difference to how SCF are communicated (Latour 2005, Sayes, 2014). For example, internal handling plans circulated by Met Office staff played an important role in how the 3-month outlook was communicated by ensuring that public-facing staff were communicating a consistent message. Similarly, the meteorological context made a difference to how an individual outlook was communicated, since Met Office staff had to adapt their messaging to account for the strength of signals from different teleconnections, such as ENSO or the IOD. Material semiotics therefore contributes to our understanding of how SCF are communicated by grounding conceptual models of communication in the materiality of forecasting and communication processes.

Finally, material semiotics reconceptualises how we understand the communication of SCF by highlighting the importance of fluidity in the translation of a SCF from one place to another. Most conceptual models of how SCF are communicated emphasise the importance of maintaining a consistent message whose content does not change. For example, a transmission model of communication focusses on maintaining the accurate transmission of information without any distortion or bias from a forecast provider to an end-user. Even a delivery model of communication, which recognises that a SCF needs to be tailored to the needs of a client, can give the impression that a SCF is a self-contained product that a user fits into their decision-making processes (Lemos et al., 2012). However, the material semiotic approach taken this thesis highlighted how the content of the message sometimes needs to change for a SCF to function as a stable intermediary (deLaet and Mol, 2000). For example, varying levels of uncertainty in the 3-month outlook and multiple understandings of what a normal climate is meant that Met Office scientists sometimes had to adapt the content of their messaging in verbal briefings to help stakeholders understand a forecast. Emphasising the fluidity of SCF does not mean that climate scientists should vary their messaging to the extent that it undermines the overall meaning of a forecast. However, it does suggest that conceptual models of how SCF are communicated need to acknowledge that there are

times and places where the content of a SCF needs to change to keep the overall message the same. Material semiotics therefore contributes to how scholars conceptualise the communication of SCF by emphasising the importance of fluid messaging in keeping the overall forecast continuous and stable.

## 8.4 Practical Recommendations for Improving the Communication of SCF

Material semiotic approaches develop theories through in-depth, empirical case studies (Law and Singleton, 2014). This means that I cannot make specific recommendations about which presentation formats stakeholders will find easy to understand or about which dissemination approaches stakeholders will find easiest to access. Nevertheless, it is possible to identify several practical insights from following the Met Office's 3-month outlook that climate scientists can learn from when communicating SCF. The following section therefore outlines four recommendations that might help climate scientists communicate SCF in a way that makes them easier to understand and use in decision-making. The same principles are also outlined in a research briefing for Met Office staff, which can be found in Appendix 7 of this thesis. Each principle builds on the heterogenous, relational, multiple and fluid conceptualisation of what a SCF is outlined in the previous section, as well the empirical findings of this thesis.

1) **Talking about the possible impacts of seasonal climate variability, rather than only describing the underlying meteorology, could make SCF easier to understand and use.**

Stakeholders often wanted to know about how seasonal variations in climate might affect their livelihood or their organisation, rather than about the underlying meteorology. The UK Met Office has already recognised this to an extent by developing an impact-based outlook for its transport stakeholder group. However, this principle does not mean that national meteorological services must develop an impact-based forecast for each stakeholder group that they are engaged with. Instead, it might simply mean using more concrete language to present the message of an outlook, rather than abstract language that is detached from the weather that we personally experience. For example, here are the original summary statement of the November-December-January

(NDJ) 2019 precipitation outlook, which describes what the climate might be like over the next three months:

*For November-December-January as a whole, above-average precipitation is more likely than below-average precipitation.*

*The probability that UK-average precipitation for November-December-January will fall into the driest of our five categories is between 10% and 15% and the probability that it will fall into the wettest of our five categories is between 35% and 40% (the 1981-2010 probability for each of these categories is 20%).*

This summary message could be reworded in the following way to talk about what the climate might *do* over the next three months:

*Summary*

*For November, December and January, there is a high risk (35-40%) of the next three months being wetter than normal* and a low risk (10-15%) of the next three months being drier than normal. This means that there is an increased risk of disruption from heavy rain and flooding.*

**'Wetter than normal' is defined as the wettest 20% of years recorded between 1981 and 2010 for November, December and January. 'Drier than normal' is defined as the driest 20% of years recorded between 1981 and 2010 for November, December and January.*

Rewording the summary message of a SCF so that it talks about the risk of what the climate might *do* can therefore be achieved without creating a bespoke impact-based forecast. Doing this resonates with the weather that stakeholders are likely to experience, which makes it easier for them to understand and use a SCF in their decision-making and planning.

2) **Communications and public relations staff could learn about how stakeholders define variations in seasonal climate by listening carefully to questions asked in verbal briefings or through more formal means, such as interviews or focus groups.**

A key finding of this thesis is that there is not one definition of what a normal climate is but multiple yet related enactments of a normal climate (Mol, 1999; 2002). It is therefore important for communications and public relations staff

employed by national meteorological services like the UK Met Office to learn about how their stakeholders define changes in seasonal climate. Data on different enactments of what a normal climate is could be generated through workshops, interviews or focus groups with stakeholders, or simply through informal conversations with them after verbal briefings. Learning about how their stakeholders conceptualise changes in climate could help communications and public relations staff brief scientists on the questions that stakeholders are likely to ask. It also might help communications and public relations staff identify and use visualisations and language that is more likely to be understood by a specific stakeholder group. For example, the Met Office could design graphics that visualise changes in seasonal average temperature for energy stakeholders and graphics that visualise changes in the risk of extreme winter weather for transport stakeholders. Understanding how stakeholders enact different versions of the climate could therefore help both climate scientists and communications and public relations staff improve how they present and explain the message of a SCF.

3) **Explaining the difference between weather forecasts and probabilistic climate forecasts *before* introducing the content of a SCF could help stakeholders learn about the questions that a SCF can and cannot answer.**

In Chapter 5 of this thesis, I argued that difficulties in understanding and using the Met Office's 3-month outlook emerged when stakeholders did not have a shared definition of what a seasonal climate forecast is and what it should be used for (Callon, 1992; 2007). For example, journalists sometimes used the 3-month outlook like a weather forecast to predict specific events, rather than to anticipate general trends in the weather over the next three months (Section 5.2). Conversely, when Met Office staff defined the 3-month outlook as a 'watching' brief for making long-term, strategic plans, contingency planners, energy stakeholders and transport stakeholders used the 3-month outlook in a way that acknowledged the uncertainty in SCF (Section 5.3). This suggests that it is important to explain how SCF differ from short-term weather forecasts before introducing the content of the message. Distinguishing between the two types of forecasts stabilises the intermediary in an actor-network by defining its role and identity. This helps stakeholders understand which of their questions a

SCF can or cannot answer. Making a clear distinction between weather forecasts and SCF could therefore help national meteorological services manage the expectations of stakeholders that use SCF.

4) **Developing SCF that predict the probability of extreme events occurring or the probability of a variable crossing a maximum or minimum threshold could make SCF easier for transport stakeholders and contingency planners to understand and use.**

The ontological multiplicity of the Met Office's 3-month outlook not only has practical implications for communications and public relations staff employed by national meteorological services but also for climate scientists and meteorologists. Often SCF still predict how a seasonal average might vary from the historical average (Taylor et al., 2015). Stakeholders who do not organise variations in seasonal climate around the historical average, such as contingency planners and the Met Office's transport stakeholders, can therefore find them difficult to understand and use in decision-making. As a result, applied scientists could explore ways of developing SCF that are tailored to how specific stakeholder groups define variations in seasonal climate. For example, Met Office scientists could develop SCF that predict the risk of extreme weather events, or the risk of a seasonal average crossing a maximum or minimum threshold, for contingency planners and transport stakeholders. Developing SCF that 'fit' different epistemologies and ontologies of climate might therefore help some stakeholders understand and use a forecast in their decision-making and planning.

## 8.5 Concluding Reflections on Completing an Interdisciplinary PhD Studentship

The Met Office was involved as a closely engaged stakeholder throughout the development of this PhD thesis. The following section therefore reflects upon the collaborative nature of this PhD thesis and the nature of the Met Office's role as an engaged stakeholder, from my perspective as an early-career researcher. My reflections should not be read as a criticism of staff who are employed by the Met Office, who were consistently helpful, supportive and open to learning about new ideas. Instead, I intend to use my experiences of working with staff at the Met Office to reflect upon the practicalities and ethical responsibilities of completing an interdisciplinary PhD with the Met Office's

support. In particular, I aim to do so in the context of efforts within geography to promote interdisciplinary or transdisciplinary research that involves collaborative engagement with non-academic stakeholders (Castree et al., 2014; Hulme et al., 2009; Wainwright, 2010).

Geographers are increasingly using collaborative and participatory methods to engage with non-academic stakeholders when studying climatic change (Castree et al., 2014). Non-academic stakeholders have worked with geographers studying issues like flood risk management (Barr and Woodley, 2019; Lane et al., 2011), municipal adaptation to climate change (Wamsler, 2017) and even the development of climate services (Falloon et al., 2018). Often these studies use the term ‘co-production’ to describe any form of participatory or collaborative engagement with non-academic stakeholders. However, it is not enough to simply define co-production as iterative interaction between stakeholders (Bremer and Meisch, 2017; Lemos et al., 2012) without describing the dynamics of those interactions. A stricter set of definitions is therefore needed, if we are to understand the role that I, Met Office staff and other stakeholders played when participating this research project.

The concept of co-production implies that non-academic stakeholders are involved in producing something together with the researcher, which distinguishes it from consultative or participatory forms of public engagement (Callon, 1999; Lane et al., 2011). However, this definition of co-production could apply to a wide range of activities, from writing an interview protocol together with a participant all the way up to initiating and planning the entire research project together. It is therefore important to clarify what we mean when we talk about ‘producing’ research with a non-academic stakeholder. One helpful way of doing this is to distinguish between co-creation, co-production and co-design. Co-creation refers to where non-academic stakeholders are involved in developing the research aims, as well solving problems together with the researcher and delivering the research project (Brandsen and Honingh, 2018). Co-production refers to where non-academic stakeholders are involved in solving problems and delivering the research project together but not in creating the research aims with the researcher (Brandsen and Honingh, 2018). Finally, co-design refers to where a non-academic stakeholder is involved in shaping the aims and design of the research but not in delivering and implementing the

research (Bremer et al., 2019). These distinctions can be used to understand the dynamics of participation and to evaluate whether these forms of participation are achievable, desirable or necessary.

### 8.5.1 The Involvement of the Met Office in the Research

The topic for this PhD thesis originally emerged out of discussions between my PhD supervisors and the monthly-decadal prediction team at the Met Office. As discussed in Section 3.4, the Met Office had experienced difficulties in communicating SCF to different audiences in the UK, especially to members of the UK public and the news media. Met Office staff therefore thought that it would be helpful to understand how the message of a SCF changed as it was communicated to stakeholders outside of the Met Office. As a result, my supervisors successfully applied for funding from the Economic and Social Research Council (ESRC) to create a PhD studentship on this general topic, to which I then applied.

The Met Office therefore already had an interest in this thesis prior to my involvement, in the sense that Met Office scientists wanted an external PhD student to look at how they communicated SCF. However, in contrast to other collaborative, practitioner-focussed research projects (Evans and Randalls, 2008; Wiersma, 2016) this thesis was not joint funded by the Met Office. This had a positive impact on the research project, since the aims of joint funded studentships are often defined in advance of the study, which can restrict the questions that are asked and the methods that are used before the research has started (Wiersma, 2016). Both I and Met Office staff therefore had greater freedom to discuss how we would design and implement an ethnography of the 3-month outlook, which might not have been the case if the research project was funded by both the Met Office and the ESRC.

The Met Office primarily shaped the development of this thesis through the influence of my supervisor, Prof. Richard Betts, who is an employee of both the University of Exeter and the Met Office. Richard Betts gave me advice on the overall design of the research along with my other two supervisors, Saffron O'Neill and Karen Bickerstaff. He was also involved in putting me in contact with potential participants, including Met Office staff and a number of journalists that he knew personally (see Section 4.3.1). Richard therefore acted as intermediary between the Met Office and the support that I received from the University of

Exeter, helping me build relationships with potential participants and giving me a ‘Met Office’ perspective on the ideas that I developed during the course of the research.

Although other scientists at the Met Office were involved in initiating the research project, they and other Met Office staff were not involved in developing the overall aims and objectives of the research. Instead, they were largely involved in co-designing and co-producing research activities at the Met Office after I started ethnographic fieldwork there in October 2018. These activities initially involved producing the following outputs:

- A literature review of the Met Office’s internal market research, which we used to identify what the Met Office already knew about the communication of the 3-month outlook.
- A conceptual map of the internal communication process for the 3-month outlook, which was based on information gathered from formal interviews, informal conversations and meetings with Met Office staff.
- A report based on interviews with and ethnographic observations of Met Office staff summarising the initial findings of my research into the internal communication of the 3-month outlook.

Following this first stage of the ethnography, Met Office scientists, marketing and communications staff were involved in co-designing and reviewing the interview protocols for its principal stakeholders (see Appendix 4). Members of the Met Office legal team also assisted me in drawing up a non-disclosure agreement between myself and the University of Exeter that would allow the Met Office to share its customer data with me. I completed interviews with external stakeholders on my own and then presented initial findings to staff involved in the communication of the 3-month outlook in March 2020. A briefing summarising the key findings and recommendations of the research in included in Appendix 7, which will be given to Met Office staff once this thesis has been marked.

Met Office staff were therefore involved in co-designing and co-producing some aspects of the ethnography and in the case of my supervisor Richard Betts, giving me advice on the development of the research design. One could argue that the close involvement of the Met Office in the research was motivated by a

concern that the research activities could create public controversy, especially after how the Met Office was criticised for how it communicated the 2009 summer forecast (see Section 5.2). However, most Met Office staff that I worked with became involved in the research because they were interested in it and because they wanted to help me complete the research in an ethically responsible way. For example, I completed an initial literature review of the Met Office's internal market research in order to avoid asking stakeholders questions that marketing and communications staff had already asked them. Similarly, the non-disclosure agreement that I signed was drawn up in order to ensure that my use of customer data was compliant with new legislation introduced in the Government Data Protection Regulations Act (Government, 2018). The close involvement of staff employed by the Met Office was therefore primarily motivated by a shared interest in understanding and improving the communication of the 3-month outlook.

What is perhaps more problematic is how other non-academic stakeholders, such as journalists, transport stakeholders or energy stakeholders, were not involved in co-designing or co-producing any of the research activities. This is because I was only able to contact these stakeholders with the permission of marketing and communications staff at the Met Office, which meant that the ethnography was already partly completed by the time that other stakeholders became involved in the research. This ethnography of the 3-month outlook therefore is a 'Met Office centred' ethnography, since I spent most of my time interacting with Met Office staff and was dependent on their contacts with other stakeholders. As a result, I might have excluded relevant expertise that other stakeholders had that could have contributed to the development of this thesis.

### 8.5.2 Reflections upon the Involvement of the Met Office in the Research

Efforts to promote collaborative engagement with non-academic stakeholders within geography are often motivated by two kinds of argument. The first of these maintains that non-academic stakeholders should be involved in research because research ought to be accountable to society and provide affected stakeholders with knowledge that is useful to them (Whatmore, 2009). Collaboration with non-academic stakeholders is therefore often motivated by a 'logic of accountability' (Barry et al., 2008). At one level this thesis was shaped

by a logic of accountability, since I was accountable to the Met Office and intended to produce knowledge that they could use to improve how they communicated SCF to their principal stakeholders. Similarly, the Met Office's own internal market research is motivated by a logic of accountability because it aims to gather information that could be used to customise SCF to the decision-making needs of their stakeholders. Both I, Met Office scientists and marketing and communications staff therefore had similar aims in that we wanted to make the 3-month outlook easier for the Met Office's stakeholders to understand and use.

Whilst collaboration that is motivated by a logic of accountability (Barry et al., 2008) can produce knowledge that a stakeholder like the Met Office finds useful, these forms of collaboration can sometimes rely upon a narrow definition of the problem that the research is addressing. For example, during the summer of 2019 I had several meetings with Met Office staff where we talked about using stakeholder interviews to obtain feedback on a new presentation format for the 3-month outlook (see Section 4.3.6). However, giving participants a new presentation format presupposed that communication difficulties were the result of systematic biases in how stakeholders interpreted the language and graphics used within the 3-month outlook document (Demeritt and Nobert, 2014). Whilst participants might have found the 3-month outlook document difficult to understand, this framing of the problem ignored other potential issues with the communication of the 3-month outlook. For example, external stakeholders might have understood what the message of the 3-month outlook meant in a technical sense but not recognised the information as usable in their decision-making and planning (Lemos et al., 2012). Efforts to co-design or co-produce research that are only motivated by a logic of accountability can therefore lock in pre-existing ways of thinking about a research problem, rather than changing or constructively critiquing them.

Furthermore, my experience of working with Met Office staff suggests that research activities that are motivated a logic of accountability (Barry et al., 2008) can sometimes conflict with the ethical responsibilities that a researcher has towards other participants. For example, at one point during the research I was asked if the Met Office could use transcripts from some of my interviews with its principal stakeholders, so that marketing and communication staff could

use the transcripts as data in an internal research project. However, it became unclear as to whether other participants had given consent to the Met Office using research data in this way. The participants had originally agreed to sharing the findings of the PhD research with Met Office staff, including quotes from interviews, but not the whole transcript (see Appendix 4). The non-disclosure agreement I had signed with the Met Office and the University of Exeter was also not detailed enough to cover a specific issue like this. As a result, we agreed that I would share the results of the research with Met Office staff with quotations from the interview transcripts, rather than the transcripts themselves.

The Met Office's interest in using interview transcripts for their own internal market research highlights how my desire to produce information that is useful to one stakeholder conflicted with the ethical responsibilities that I had towards other participants. It also illustrates how the disclosure of personal and confidential information in an ethnography can resist guidelines outlined in a legal framework like a non-disclosure agreement. Informed consent therefore needs to be carefully negotiated throughout a research project and cannot be established through legal frameworks alone (Dilger et al., 2019). In particular, my experience suggests that clear, transparent communication between all participants, and not just those who are most engaged in the research, is needed. This ensures that all the participants know what data will be disclosed and how their data will be used and managed.

A second motivation for collaborating with non-academic stakeholders is to effect an ontological change in the object(s) of the research and/or an ontological change in the relations between the researcher and other participants (Barry et al., 2008). Geographers (Whatmore, 2009; Whitman et al., 2015) and STS scholars (Lövbrand, 2011) have argued that forms of collaboration that are motivated by a 'logic of ontology' (Barry et al., 2008) can redistribute expertise (Lane et al., 2011) and encourage innovation (Whitman et al. 2015). For example, working closely with Met Office staff changed how I conceptualised the communication of SCF. Before starting the ethnography, my thinking had been shaped by empirical research into the delivery of climate services. This area of research argues that sustained, iterative dialogue between knowledge producers and users helps forecasters tailor a climate

service to a user's needs, which then improves the perceived credibility, salience and legitimacy of the information that is provided (Lemos et al., 2012; Cash et al., 2003). However, during the ethnography some of the marketing staff within the Met Office suggested that it would be helpful for me to produce a conceptual map that provided them with an overview of how the 3-month outlook was communicated within the Met Office. It was only after I produced a conceptual map of who and where the 3-month outlook was communicated to that I realised that the 3-month outlook was more like a web of relations than a discrete product or service that was delivered to a user. This suggested that material semiotic approaches might provide a helpful set of concepts for analysing and following the 3-month outlook, since material semiotics treats objects as an effect of shifting material relations (Latour, 2005; Law and Singleton, 2014). Collaborating with Met Office staff therefore added to my own understanding of how the 3-month outlook was communicated, which then helped me develop a theoretical framework for analysing its communication.

Collaborative, interdisciplinary research can therefore generate moments of ontological transformation, in which the researcher and the participants change how they conceptualise and relate to the object (s) of the research (Barry et al., 2008; Buller, 2009; Lane et al., 2011). The process of mapping out the communication of the 3-month outlook serves as a good example of where both I and staff employed by the Met Office changed our understanding of what the 3-month outlook is and how it was communicated. This suggests that collaborative engagement motivated by a logic of ontology is not inherently opposed to a logic of accountability (Barry et al., 2008). Instead, reconceiving the object of research is useful to a non-academic stakeholder precisely because it transforms how the researcher and the participants understand what they are studying. This opens up different kinds of questions and helps a non-academic stakeholder like the Met Office critically reflect upon their own practices. Collaborative or participatory forms of research that are motivated by a logic of ontology (Barry et al., 2008) can therefore produce knowledge that is also accountable to the needs of non-academic stakeholders.

However, developing forms of collaboration with non-academic stakeholders that transform existing ways of thinking about an issue *and* produce knowledge that solves societal problems is not always easy to do in practice. This is

because participants have different values and epistemological positions, which are associated with asking specific kinds of questions and using particular methods to study an issue. It therefore takes time for the researcher and other participants to learn how to communicate with each other. For example, it took me several months to learn about what Met Office staff already knew about the 3-month outlook and about what their concerns and priorities were. Similarly, I have struggled to learn how to translate academic concepts from critical theories like material semiotics into language that Met Office staff and other stakeholders can easily understand. Collaborative research that is orientated towards to ontological change, as well producing useful knowledge, is therefore highly dependent on the researcher's ability to communicate clearly and build trust with other participants.

All this suggests that more intensive and immersive forms of collaboration, such as co-creation (Brandsen and Honingh, 2018), are more likely to transform pre-existing ways of thinking about an issue than less intensive and immersive forms of participation, such as co-designing a project or consulting stakeholders. Involving different members of staff from the Met Office in the co-creation of research aims and objectives, as well other stakeholders who use the 3-month outlook, would have given us more time to understand each other's priorities, values and epistemological positions. This might have then made it easier to communicate with and learn from each other when solving problems and delivering outputs together. However, co-creating a research project in this way is time consuming and, in my case, was not practically achievable. For example, I would not have been able to include other stakeholders apart from the Met Office in the initial development of research aims and objectives. At the start of the research project I did not know who used the Met Office's 3-month outlook and even if I did, it would have been ethically problematic for me to contact the Met Office's customers without the Met Office's permission. Geographers therefore need to consider whether more radical forms of participation are achievable or even desirable given the time and resources that are available to them.

Nevertheless, my experience of working with Met Office staff suggests that even less immersive forms of interdisciplinary collaboration can go beyond producing useful knowledge to redefine the object(s) of study and the practice

of studying that object. Working with Met Office staff added to my own understanding of how the 3-month outlook was communicated and helped me develop the theoretical framework that was used in this thesis. It also identified areas where the Met Office could change how it communicated the 3-month outlook to make it easier for its principal stakeholders to understand and use. Collaborative research with geography, other social sciences and climate science therefore can be both motivated by a logic of ontology and a logic of accountability (Barry et al., 2008).

## 8.6 Recommendations for Future Research

This thesis has identified three potential avenues for future geographical and social scientific research into the communication of climate science and meteorology. First, future research could explore how short-term weather forecasts, seasonal to decadal climate forecasts and climate change projections become objects of political controversy. STS scholars (Latour, 2005b; Mol, 1999; Stengers, 2005) and geographers (Lane et al. 2011; Whatmore, 2009) have highlighted how political controversies often form around non-human objects, rather than between abstract values, institutions and ideologies. Anthropogenic climate change, biosecurity, and flood risk management are all examples of issues that cross the boundaries between science, technology and politics and generate diverse collectives that often include concerned publics (Müller, 2015). Each of these issues cannot easily be settled by appeals to scientific evidence, or 'matters of fact' (Latour, 2005) and resist being defined and known in only one way (Law and Singleton, 2014). This means that these issues have their own ontological politics (Mol, 2002), in which stakeholders argue over what counts as a biologically secure facility or over what changes in the climate can be attributed to human beings or natural causes (Osaka and Bellamy, 2020).The ontological multiplicity of non-human objects therefore can have political implications, even if these political debates are shaped by interests, ideologies and institutions that are traditionally associated with politics.

Completing a multi-sited ethnography of the Met Office's 3-month outlook highlighted how SCF sometimes became political 'matters of concern' (Latour, 2005). The summer 2009 forecast is a good example of such a forecast, in which controversies over what the forecast meant generated debates about the

quality of scientific research at the Met Office (Usborne, 2014) about how the Met Office is funded and about how scientific experts should communicate uncertainty (Science and Technology Select Committee, 2012). The public and media reaction to the summer 2009 forecast resonates with work within geography (Lane et al., 2011; Tsouvalis and Waterton, 2012; Whatmore, 2009) and STS (Latour, 2005; Mol, 1999; Stengers, 2005) on how political debates coalesce around material things and issues of concern rather than around abstract values, ideologies and beliefs. The material semiotic approach developed in this thesis could therefore be extended to explore the 'ontological politics' (Mol, 2002) of how different versions of weather and climate forecasts come to exist.

One potentially interesting line of enquiry would be to explore how different publics form around weather and climate forecasts on social media platforms. STS scholars (Marres, 2007; Marres and Moats, 2015) and geographers (Sandover et al., 2018) have explored the ontological politics (Mol, 1999) of how online publics form around issues like the culling of badgers to prevent bovine tuberculosis (Sandover et al., 2018). Unlike other analyses that map online publics by political interests or affiliations (Williams et al., 2015) these material semiotic analyses focus on the 'what' of the issue rather than on 'who' is involved. A similar approach could therefore be taken to studying how online publics (Marres and Moats, 2015; Sandover et al., 2018) form around SCF, short-term weather forecasts or climate change projections. Future research could explore how different versions of a forecast are articulated, contested and publicised by different stakeholders. Triangulating quantitative methods, such as social network analyses, with qualitative methods, such as narrative analyses of audio-visual and written content, would also help researchers both map the structure of the communities that form around a forecast and critically evaluate what content is being shared within those communities. Studying how weather and climate forecasts become 'matters of concern' (Latour, 2005) within digital spaces is therefore one way in which the work of this thesis could be extended.

Secondly, future geographical research could explore the relationship between cultural memories of past weather events and the socio-material arrangements that support different enactments of a SCF. Archival and ethnographic research

by geographers suggests that cultural memories of past weather events are often used as 'benchmarks' to assess current meteorological conditions (Hall and Endfield, 2016; Hulme and Burgess, 2019) and to develop expectations about how the future climate might change (Hulme, 2016). These accumulated memories shape how publics assess the risk of predicted or projected changes in climate (Hall and Endfield, 2016; Taylor et al., 2014), as well as how publics construct the degree of continuity between past and future climates (Fincher et al., 2015; Walshe et al., 2020). Furthermore, organisational memories of the decisions and strategies that were used to respond to historical weather events can affect their vulnerability and resilience to future climatic variability and change. For example, the response to one weather event might lock in a set of institutional arrangements that make it harder for an organisation to act on a weather or climate forecast in the future (Adamson et al., 2018). Similarly, responses to historical weather events can sometimes be forgotten and regarded as unimportant (Walshe et al., 2020). This might make an organisation less likely act on a forecast for a similar weather or climatic event in the future (LeClerc and Joslyn, 2015). There is therefore large body of research within geography on how cultural memories shape how publics and organisations anticipate future changes in climate.

Much of this research focusses on how people *represent* past weather events and on how they *construct* expectations about future changes in climate. Existing geographical research on cultural memories of past climates is therefore completed within a representational mode of thinking, in which meaning is thought to primarily reside in language, texts and images. However, this thesis has argued that SCF are not just texts but webs of shifting relations that hold together people, skills, data, documents and images. The meaning of a forecast is therefore dependent on the socio-material arrangements that make it possible to produce and circulate texts and images that carry symbolic meanings (Law, 2008). Future research could therefore bring together the material semiotic approach developed in this thesis with geographical research into cultural and organisational memories of past weather events. For example, one could imagine an ethnography of a local authority that looks at how organisational memories of past weather events shape the usage of short-term weather forecasts. The ethnographer could use archival research, ethnographic

observations and oral histories to identify the meanings that are attributed to different weather events and forecasts. They could then use interviews and ethnographic observations to follow the socio-material relations that constitute the message of a forecast in a similar way to this thesis. Synthesising these approaches would enable the researcher to understand how interpretations of a forecast gain power through socio-material networks of things, as well as the role of memories and meanings in shaping and stabilising socio-material arrangements. As a result, future research ought to explore both the materiality and the meaning of memories that shape how stakeholders interpret and use weather and climate forecasts.

Finally, this thesis highlights the value of developing and funding interdisciplinary research projects that sit between human and physical geography. There have been many efforts within geography to initiate dialogue 'across the divide' around shared concepts (Lane, 2001; Massey, 1999), philosophical reflection upon methodologies and practice (Couper, 2007; Rhoads, 2006) and by studying the human dimensions of environmental change (Adger, 2000). However, interdisciplinary research does not need to only be motivated by a search for a common core of what geography is or by an effort to make geography more relevant or accountable to society (Demeritt, 2009). Instead, interdisciplinary collaborations often work best when they redefine and recontextualise the object of study and/or the relationship between researchers and participants (Barry et al., 2008; Buller, 2009; Lane et al., 2011). For example, before mapping out where the 3-month outlook was communicated within the Met Office, this project lacked a well-developed theoretical framework. However, completing the mapping exercise for Met Office staff helped me see how the 3-month outlook could be treated as a web of relations rather than as a single message. Having discussions with marketing and communications staff at the Met Office changed my understanding of the 3-month outlook and suggested that material semiotic approaches might provide a helpful set of concepts for following the 3-month outlook as it was communicated. Interdisciplinary research can therefore create new possibilities and shared understanding between physical and human geographers, if it is done respectfully and with a willingness to explore new ways of thinking about a research problem. Future research into the communication of weather and

climate forecasts therefore ought to explore the multiplicity of research problems (Mol, 2002; Barry et al., 2008) by crossing disciplinary boundaries and by experimenting with juxtapositions of conceptual approaches and methods.

# Appendix 1: Sample Project Information Sheet for Met Office Staff

## Following the Forecast: The Communication of the Met Office's 3-Month Outlook

Chris Manktelow, PhD candidate in the Department of Geography, College of Life and Environmental Sciences, University of Exeter, C360 Amory Building, Rennes Drive, Exeter EX4 4RJ, cjm236@exeter.ac.uk

Supervisors: Dr. Karen Bickerstaff (University of Exeter), Dr. Saffron O'Neill (University of Exeter), Prof. Richard Betts (University of Exeter and Met Office)

What is the research project about?

The Met Office has recently begun to develop operational seasonal forecasts for the UK. These forecasts can provide useful information for organisations and individuals who are affected by seasonal climate related-risks, such as contingency planners working for the UK government. However, seasonal forecasts are inherently uncertain, which makes the message of the forecast difficult to understand and communicate. Existing social scientific research also suggests that forecast providers and users often have different views on what makes a seasonal forecast credible and usable. This research project will therefore aim to understand how different groups of people understand, interpret and perceive the 3-month outlook by following the forecast from its point of production to its point of use. Doing this will involve looking at how the message of the forecast changes as it is communicated and exploring the different views that people have on the purpose, credibility and usability of the 3-month outlook. Research outputs will include publications intended for both academic and public audiences. They will also include briefings and reports for Met Office staff and members of external organisations that are interested in seasonal forecasting.

Who is funding the research?

The research project is funded by the Economic and Social Research Council (ESRC) as part of the South West Doctoral Training Partnership.

When is the research taking place?

The research will take place at the Met Office between January and September 2019. It will involve interviewing Met Office staff who are involved in producing and communicating the 3-month outlook, analysing existing user feedback and observing stakeholder briefings. Interviews will be recorded using a voice recorder and will take place at a mutually agreeable time and place. Informal conversations with Met Office staff will not be used as data but they will inform the questions I ask in interviews.

What will happen with the research data?

All transcripts of interviews or field notes will be stored on a password protected server at the University of Exeter, with a password protected backup elsewhere. Written copies of any field notes will also be kept in a secure location.

I will use quotes from interview transcripts or field notes in the PhD thesis and other research outputs. I cannot guarantee the personal anonymity of participants during the research project. This is because there are only a small number of people involved in communicating the 3-month outlook, which might make participants identifiable even if I did not disclose their names. I will therefore ask for your consent to use your name or job title. If you wish, I am happy to share with you a copy of the interview transcript for you check and/or amend. Other sensitive information, such as places or other personal information, will be anonymised.

How will the research data be protected?

Apart from your name or job title, all personal information will remain confidential and will not be shared with anyone. All data will be deleted when no longer needed for the purposes of this study and within five years at the latest.

What do you need to consider when participating in this study?

Before you decide to participate in this study, please read the information carefully and let me know if you have any questions about the research project. Your participation is voluntary, and you are free to withdraw from the study before the publication of any data by emailing Chris Manktelow at cjm236@exeter.ac.uk.

## Appendix 2: Sample Project Information Sheet for Stakeholders

# The Communication of Long-Range Forecasts by the Met Office

Chris Manktelow, PhD Student in the Department of Geography, College of Life and Environmental Sciences, University of Exeter, C360 Amory Building, Rennes Drive, Exeter EX4 4RJ, cjm236@exeter.ac.uk, 07526663970

Supervisors: A/Prof. Karen Bickerstaff (University of Exeter), A/Prof. Saffron O'Neill (University of Exeter), Prof. Richard Betts (University of Exeter and Met Office)

What is the research project about?

The Met Office produces long-range forecasts that provide an indication of possible temperature and rainfall conditions over the whole of the UK for the next three months.

This PhD research project aims to understand how these long-range forecasts are communicated to, interpreted and used by different stakeholders.

Interviews, participant observation of meetings and document analysis will be used to generate detailed, qualitative data. The research objectives for this project are as follows:

Objective 1: To understand how Met Office stakeholders receive, interpret and use long-range forecasts.

Objective 2: To establish how easy or difficult it is to understand the information provided.

Objective 3: To understand what affects stakeholders' perceptions of how credible long-range forecasts are.

Objective 4: To evaluate how the communication of uncertainty and complex science might be informed by studying the communication of long-range forecasts.

Who is funding the research?

The research project is funded by the Economic and Social Research Council (ESRC) as part of the South West Doctoral Training Partnership.

When is the research taking place?

The research will take place with external organisations who use long-range climate forecasts between October 2019 and December 2020. Interviews will ideally be recorded using a voice recorder and will take place in person at a mutually agreed time and place.

What will happen with the research data?

All interview transcripts will be stored on a password protected server at the University of Exeter, with a password protected backup elsewhere. Participants will remain personally anonymous and will be referred to using a generic identifier e.g. energy trader. If you wish, I am happy to send a copy of the interview transcript for you to check and/or amend. Other sensitive information, such as places or other personal information, will also be anonymised.

How will the research data be protected?

All personal information will remain confidential and will not be shared with anyone. All data will be destroyed when no longer needed for the purposes of this study and within five years at the latest.

What do you need to consider when participating in this study?

Before you decide to participate in this study, please read the information carefully and let me know if you have any questions about the research project. Your participation is voluntary, and you are free to withdraw from the study before the publication of any data by emailing Chris Manktelow at cjm236@exeter.ac.uk.

How will you benefit from the results of this study?

The results of this research project will be used by the Met Office to review how long-range forecasts are communicated. I will also send you a summary of the results of this project once they have been reviewed and published.

# Appendix 3: Sample Interview Schedule for Met Office Staff

## INTERVIEW PROTOCOL MET OFFICE STAFF

### INTRODUCTION

Thank you for agreeing to talk to me today. Before we start I'm going to tell you a bit about what this research project is on and what your participation will involve. All the information I am about to tell you is on the project information sheet that I emailed through. Did you have a chance to read this?

So, I'm a geography PhD student at the University of Exeter. My research project is looking at how different groups of people produce, communicate and use the 3-month outlook made by the Met Office.

I'm speaking to you today because you are involved in communicating the 3-month outlook. I'd like to talk about the purpose, credibility and usability of the seasonal forecasts that the Met Office produces. I'd also like to discuss about the 3-month outlook for January to March 2019, which I emailed through to you. Did you get a chance to look at it?

Although I will be asking you questions, there are no right or wrong answers- I just want to hear about your experiences of producing and communicating seasonal forecasts. If you do not know or cannot give an answer to a question, then that is fine too.

Because of the small number of people involved in seasonal forecasting at the Met Office, I cannot guarantee your personal anonymity. I will therefore use either your name or job title when I write up this interview. Which would you prefer to use? [NOTE DOWN]

Data from the interview may be used in teaching, publications or presentations. I am happy to give you a draft version of the interview transcript for you to check and amend before I use it as data. Would you like to do this? [NOTE DOWN]

I am intending to produce a short report on the outcomes of this research that will be given to Met Office staff and members of external organisations who are interested in seasonal forecasting. If there any quotes I use from this interview that might be sensitive, I will contact you in advance to check that you are happy for the quote to be used.

I would like to record this interview because it means I can concentrate fully on what you are saying, rather than writing it down. Is it OK for me to do this?

Is there anything you want to ask before we start?

(TURN THE RECORDER ON AND ASK THEM TO GIVE YOU THEIR CONSENT)- …... Do you give me your consent to interview you? Thank you…

## COMMUNICATION OF SEASONAL FORECASTS

I'm going to start by asking some general questions about how you communicate the 3-month outlook.

Could you tell me about how the Met Office communicates the 3-month outlook to the media? Prompts: What kind of media organisations does Met Office work with? Which social media platforms does the Met Office use to communicate the 3-month outlook? How does the Met Office communicate the forecasts on social media? How does the Met Office communicate the 3-month outlook to journalists? How regularly do you meet with the users that you are in contact with?

What is the biggest challenge that the Met Office faces when responding to interest in the 3-month outlook on social media and in the news media? Prompts: Are there challenges involved in communicating the uncertainty in a forecast? Are there challenges involved in understanding what users want? Are there challenges involved in presenting the information?

What kind of feedback have you received from journalists who are interested in the 3-month outlook? Prompts: Would you say the feedback is positive, negative or mixed? Is it possible to change anything with the feedback you are given?

What kind of feedback have you received from the general public who are interested in the 3-month outlook? Would you say the feedback is positive, negative or mixed? Is it possible to change anything with the feedback you are given?

## PRODUCTION OF SEASONAL FORECASTS

I'm now going to ask you one or two questions about the process of making seasonal forecasts.

Could you describe to me how seasonal forecasts are made at the Met Office? Prompts: Which teams are involved in making the seasonal forecasts? Can you tell me about how those teams are involved? When are they involved in the forecasting process? Could you tell me about how everyone decides upon the final message of the seasonal forecast?

What is the biggest challenge that the Met Office faces when putting together the overall message of the 3-month outlook? Prompts: Working with other teams in the Met Office? Understanding what users want? Working with users?

## COMMUNICATION OF THE JFM 3-MONTH OUTLOOK

I'd now like to ask you some questions about the 3-month outlook for January-March 2019, which I emailed to you in advance of this interview. Feel free to take a few minutes to read it. Once you are ready, please could you tell me what you think are the most important or interesting messages from the 3-month outlook?

Could you tell me about how the Met Office has responded to recent interest in the January-March 2019 outlook on social media and in the news media? Can you give or show me an example of how the Met Office has responded? Are there any interpretations of the forecast that the Met Office is trying to correct or challenge?

## EXPECTATIONS PLACED ON SEASONAL FORECASTS

I'm now going to ask you a few questions about the purpose of producing the 3-month outlook.

What would you say is the main motivation for producing the 3-month outlook at the Met Office?

Could tell me about how the Met Office funds the production of the 3-month outlook?

Have there been any significant changes in the type of forecast users that the Met Office interacts with? Prompts: What do you think has influenced those changes?

Has the Met Office made any significant changes to how it produces and communicates the 3-month outlook? Prompts: What influenced those changes?

Were those changes effective? Can you give me any other examples of changes?

## CLOSING QUESTIONS

Is there anything else you think I should know to understand the process of producing and communicating seasonal forecasts better?

THANK YOU for taking part in this interview. I really appreciate you taking the time to do this.

Do you have any recommendations for other people I could speak to? Would you be able to give me their contact details?

Thanks again. I'll turn off the recorder now.

# Appendix 4: Sample Interview Schedule for Stakeholders

## INTERVIEW PROTOCOL 3-MONTH OUTLOOK EXTERNAL STAKEHOLDERS

### INTRODUCTION

Thank you for agreeing to talk to me today. Before we start, I'm going to tell you a bit about this research project and what your participation will involve. All the information I am about to tell you is on the project information sheet that I emailed through. Did you have a chance to read this?

So, I'm a geography PhD student at the University of Exeter. My research project is looking at how different groups of people communicate, interpret and use the 3-month outlook made by the Met Office.

I'm speaking to you today because you are involved in writing news articles on seasonal forecasting. I'd also like to talk about how you communicate, use and interpret seasonal forecasts. I'd also like to discuss the 3-month outlook for January-March 2019, which I emailed through to you. Did you get a chance to look at it?

Although I will be asking you questions, there are no right, or wrong answers- I just want to hear about your experiences of using long-range forecasts. If you do not know or cannot give an answer to a question, then that is fine too.

Because the Met Office has shared its customer details with me, you will remain personally anonymous when I use data from this interview. You will be referred to using a generic identifier, such as 'news journalist.' Is that OK?

Data from the interview may be used in teaching, publications or presentations. I am happy to give you a draft version of the interview transcript for you to check and amend before I use it as data. Would you like to do this? [NOTE DOWN]

I am intending to produce a short report on the outcomes of this research that will be given to Met Office staff and members of external organisations who are interested in long-range forecasting. If there are any quotes that I use from this interview that might be sensitive, I will contact you in advance to check that you are happy for the quote to be used.

I would like to record this interview because it means I can concentrate fully on what you are saying, rather than writing it down. Is it OK to do this?

Is there anything else you want to ask before we start?

(TURN THE RECORDER ON AND ASK THEM TO GIVE YOU THEIR CONSENT)- …... Do you give me your consent to interview you? Thank you…

## ROLE PROFILE

I am going to start by asking a few general questions about your background and your role within this news publication.

Could you tell me about your job/role within this news publication? What does it involve?

How long have you been working at this organisation/as a journalist?

Could you tell me about how familiar you are with using weather and climate information?

Could you tell me about how familiar you are with using mathematical and statistical information?

## USAGE OF THE 3-MONTH OUTLOOK

## USAGE OF LONG-RANGE FORECASTS

Could you tell me about why you are interested in using long-range forecasts in news stories? Prompts: Could you tell me about why long-range forecasts make for interesting news stories? What about newspapers in general? What motivates them to publish news stories on long-range forecasts?

Can you show me an example of a news story that you have written that includes a long-range forecast? Prompts: Could you describe how you went about researching and writing this article? Could you describe the process by which this news article is edited and published? Is the final, published article different to the original article that you had written? If so, would you be able to show me what was edited in the original article?

## USAGE OF 3-MONTH OUTLOOK FROM THE MET OFFICE

Can you tell me about how you receive information on long-range forecasts from the Met Office? Prompts: Do you find this information helpful? Is it easy to understand?

Could you tell me about how accurate you think long-range forecasts made by the Met Office are? Prompts: Could you tell me what you think an accurate seasonal forecast looks like? What level of accuracy in a seasonal forecast would you find acceptable?

## USE OF OTHER SOURCES

Do you use long-range forecasts that are not produced by the Met Office?

Could you tell me about how you use these forecasts alongside information from the Met Office?

Could you tell me about how judge the accuracy of each of these different sources? Prompts: Do you think that

How consistent are the messages that you receive from these different long-range forecasts? [If inconsistent] When the messaging is inconsistent, how do you interpret those differences?

Could you tell me about how you respond to or use other news articles on long-range forecasts? Prompts: Can you give me a specific example of how you responded to or used a news article on long-range forecasts? Where do you normally read these news articles? On social media? Which social media platforms? On online newspapers?

## INTERPRETATION AND UNDERSTANDING OF THE 3-MONTH OUTLOOK

I'd now like to ask you some questions about how you interpret the 3-month outlook made by the Met Office. Here is the 3-month outlook from January-March 2019, which I emailed to you in advance of this interview. Feel free to take a few minutes to read it. Once you are ready, please could you tell me what you think are the most important or interesting messages from this 3-month outlook.

Could you tell me what you know about how the Met Office produces the 3-month outlook? Prompts: What happens next? Could you tell me what that means?

### CLOSING QUESTIONS

Is there anything else you think I should know to understand the process of using and communicating long-range forecasts better?

THANK YOU for taking part in this interview. I really appreciate you taking the time to do this.

Do you have any recommendations for other people I could speak to? Would you be able to give me their contact details?

Thanks again. I'll turn off the recorder now

## Appendix 5: Ethnographic Observations

| Type of Briefing or Meeting | Date of Briefing or Meeting | 3-Month Outlook |
|---|---|---|
| Long-Range Forecasters' Meetings | 25-05-19 | June-July-August 2019 |
| | 23-07-19 | August-September-October 2019 |
| | 25-09-19 | October-November-December 2019 |
| | 22-10-19 | November-December-January 2019 |
| | 19-11-19 | December-January-February 2019 |
| | 10-12-19 | January-February-March 2020 |
| | 21-01-20 | February-March-April 2020 |
| Transport Stakeholder Briefings | 29-10-18 | November-December-January 2018 |
| | 28-11-18 | December-January-February 2018 |
| | 18-12-18 | January-February-March 2018 |
| | 19-12-18 | February-March-April 2018 |
| | 16-12-19 | January-February-March 2020 |
| Energy Stakeholder Briefings | 26-11-19 | December-January-February 2019 |
| | 17-12-19 | January-February-March 2020 |
| | 28-01-20 | February-March-April 2020 |

# Appendix 6: List of Analysed Documents

**Documents Related to Chapter 5**

| Number | Title | Author (s) | Publisher | Date | Type |
|---|---|---|---|---|---|
| 1 | JFM 2020 Outlook | Met Office | Met Office | December 2019 | Scientific Publication |
| 2 | Summer 2009 Forecast | Met Office | Met Office | 30/04/09 | Website |
| 3 | Press Briefing on the Summer 2009 Forecast | Met Office | Met Office | 30/04/09 | Press Release |
| 4 | JFM 2020 Transport Impact Outlook | Met Office | Met Office | December 2019 | Scientific Publication |
| 5 | Warm, dry summer on the way, says Met Office | Aldred J. | Guardian | 30/04/09 | Online News Article |
| 6 | Britain will have first decent 'barbecue summer' in three years with temperatures regularly above 80 F. | Alleyne J. | Daily Telegraph | 30/04/09 | Online News Article |
| 7 | 'Continental heat dome' to sizzle UK during school holidays | Badshah N. | The Times | 15/07/19 | Online News Article |
| 8 | UK weather forecast: Met Office says there isn't a heatwave coming, despite reports of 'roasting continental heat dome' | Wynne-Davies B. | I-News | 17/07/19 | Online News Article |

**Documents Related to Chapter 6**

| Number | Title | Author (s) | Publisher | Date | Type |
|---|---|---|---|---|---|
| 1 | ASO 2019 Outlook | Met Office | Met Office | July 2019 | Scientific Publication |
| 2 | DJF 2019 Outlook | Met Office | Met Office | November 2019 | Scientific Publication |
| 3 | DJF 2019 Transport Impact Outlook | Met Office | Met Office | November 2019 | Scientific Publication |
| 4 | Beast from the East 2? UK in the midst of a 'sudden stratospheric warming' | Binding L. | Daily Telegraph | 29/12/18 | Online News Article |
| 5 | BEAST FROM THE EAST 2: Temperatures to PLUNGE as process behind deadly storm returns | Gavin H. | Daily Express | 13/01/19 | Online News Article |

| | | | | | |
|---|---|---|---|---|---|
| 6 | National Climate Information Centre Maps of 1981-2010 Climatology and Annual Averages | Met Office | Met Office | August 2019 | Scientific Publication |
| 7 | Internal Handling Plan DJF 2019 | Met Office Press Office | Met Office Press Office | November 2019 | Institutional Document |

## Documents Relating to Chapter 7

| Number | Title | Author | Publisher | Date | Type |
|---|---|---|---|---|---|
| 1 | Internal Handling Plan MAM 2019 | Met Office Press Office | Met Office Press Office | April 2019 | Institutional Document |
| 2 | National Climate Information Centre Maps of 1981-2010 Climatology and Annual Averages | Met Office | Met Office | August 2019 | Scientific Publication |
| 3 | DJF 2019 Transport Impact Outlook | Met Office | Met Office | November 2019 | Scientific Publication |
| 4 | JFM 2019 Outlook | Met Office | Met Office | December 2019 | Scientific Publication |
| 5 | Email to Leadership Team | Emergency Planning and Business Continuity Officer | District Council | 24/10/19 | Email Correspondence |

# Appendix 7: Research Briefing for UK Met Office Staff

UNIVERSITY OF EXETER

E·S·R·C ECONOMIC & SOCIAL RESEARCH COUNCIL

## The Communication of the UK Met Office's 3-Month Outlook


### Executive Summary

The 3-month outlook predicts potential variations in temperature and rainfall for the whole of the UK over the next three months. This seasonal climate outlook is publicly available on the UK Met Office website and is communicated through verbal briefings to contingency planners and stakeholders in the energy and transport sector during the winter and autumn. However, seasonal climate outlooks are more uncertain than weather forecasts and are used by stakeholders who have different understandings of what a 'normal' climate ought to be like. This research briefing therefore recommends making a clear distinction between weather forecasts and probabilistic climate outlooks when they are communicated. It also suggests tailoring the communication of seasonal climate outlooks to fit how a stakeholder group understands variations in seasonal climate.


### Key Recommendations

This briefing makes the following recommendations to scientists, communications and public relations staff at the UK Met Office:

- Talking about the possible impacts of seasonal climate variability, rather than only describing the underlying meteorology, makes seasonal climate outlooks easier to understand and use.
- Communications and public relations staff could learn about how stakeholders define variations in seasonal climate by listening carefully to questions asked in verbal briefings or through more formal means, such as interviews or focus groups.
- Explaining the difference between weather forecasts and probabilistic climate outlooks *before* introducing the content of a seasonal climate outlook could help stakeholders learn about the questions that a seasonal climate outlook can and cannot answer.
- Developing seasonal climate outlooks that predict the probability of extreme events occurring or the probability of a variable crossing a maximum or minimum threshold could make seasonal climate outlooks easier for transport stakeholders and contingency planners to understand and use.

### Key Findings

#### Defining the 3-month outlook as a 'watching brief' helped contingency planners, transport stakeholders and energy stakeholders understand uncertainty.

Interviews with transport stakeholders, contingency planners and energy stakeholders suggested that they understood the uncertainty in the 3-month outlook. This is because they reported using the 3-month outlook as 'watching brief' to guide their strategic planning, rather than to commit resources or inform immediate action:

*... it leads us in the back of our minds to think, 'January, February, maybe we need to think more about the flooding side, February-March, more about the snow side. We really just use it as a guidance or a heads up.*

### Energy stakeholders understood and used the 3-month outlook in decision-making because they were interested in changes in seasonal average temperature.

Energy managers and analysts used the 3-month outlook to anticipate changes in demand for gas and electricity during the winter. Variations in demand were not affected by short-term variations in temperature but by changes in seasonal average temperature:

*'So, what we categorise as winter is a six-month period and an extreme weather event could be snow for three or four days. It's important but not crucial. It could push demand up for those three or four days and everyone will remember those three or four days of snow and we'll turn round at the end of it and say, 'you know what, we had less customer demand overall.' (Energy Analyst 01-11-19)*

Energy stakeholders therefore found the 3-month outlook easier to use than other stakeholder groups because the outlook predicts changes in 3-monthly average.

### Transport stakeholders and contingency planners found the 3-month outlook harder to understand and use because they were interested in extreme events that might disrupt transport infrastructure or the delivery of public services.

Transport stakeholders and contingency planners wanted to know about changes in the risk of extreme weather events:

*But the question I need to know is, will 100 mm of rain fall on my head in one day or will it fall in 90 days over three months? ...Sudden rainfall can cause quite impactful situations quite quickly, whereas the same volume of rainfall over a longer period of time is what I would describe as not worth getting out of bed for.' (Transport Resilience Manager, 08-01-20)*

This meant that they found the 3-month outlook harder to understand and use because it only provided them with information about changes in seasonal average temperature or rainfall.

### Journalists thought that the 3-month outlook was too uncertain to communicate and publish as a news story and only quoted the 3-month outlook when it could be associated with recent or culturally significant weather events.

During the third week of July 2019, the UK Met Office issued weather forecasts predicting high temperatures across the UK. The UK experienced a heatwave at the end of June 2019. This created a demand for news stories about whether there would be another heatwave and how long the heatwave might last. Some newspaper articles therefore quoted the July-August-September 2019 outlook alongside weather forecasts from the UK Met Office and other forecasters.

## Methodology

| Time Period | Method |
|---|---|
| October 2018-December 2018 | Observations of Briefings for Transport Stakeholders |
| January 2019-April 2019 | 10 interviews with Met Office Staff |
| May 2019-January 2020 | Observations of the Long-Range Forecasters' Meeting |
| October 2019-January 2020 | 15 interviews with transport stakeholders, contingency planners, energy stakeholders and journalists. |
| November 2019-January 2020 | Observations of Briefings for Energy Stakeholders |

## The Research

This research is funded by the Economic and Social Research Council. The briefing is based on the conclusions of a PhD thesis titled "Inside the Forecast Factory: The Communication of the UK Met Office's 3-Month Outlook

## Contact the Researcher

Chris Manktelow, University of Exeter, Geography PhD Candidate

Email: cjm236@exeter.ac.uk

## Appendix 8: Summer 2009 Forecast Presented During News Briefing at the Science Media Centre

Met Office

# Summer 2009 forecast

Summer 2009 is expected to be 'better' than the last two summers with times when temperatures will be above 30°Celsius and much lower rainfall

### Rainfall

For the UK and much of northern Europe rainfall is likely to be near or below average. **A repeat of the wet summers of 2007 and 2008 is unlikely.**

### Temperature

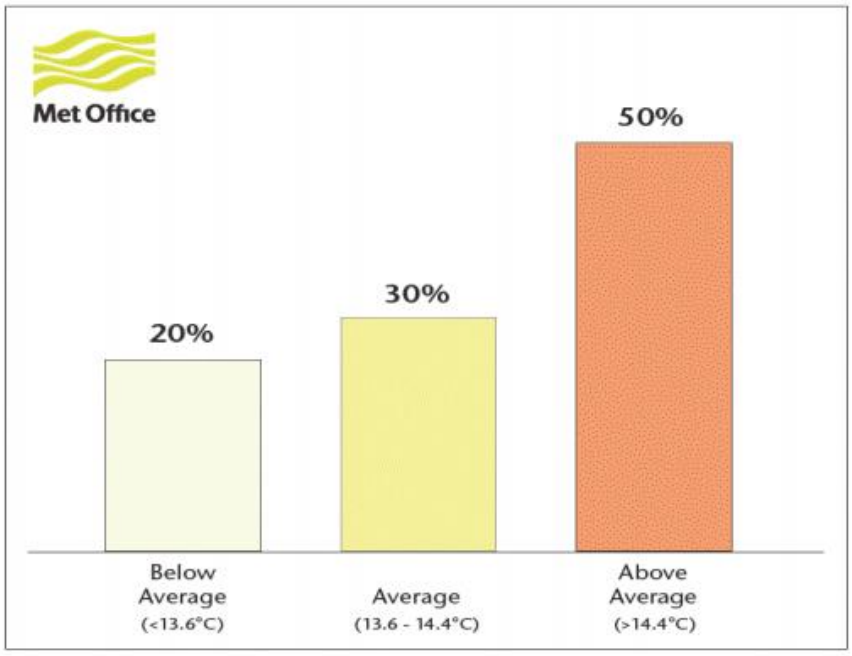
For the UK and much of Europe temperatures are likely to be above average.

Met Office

# UK temperature probabilities

The graphic shows the probability of getting certain conditions in a season.

Summer 2009 sees the greatest probability of temperatures being above average but does not rule out average conditions. We are expecting times when temperatures will be above 30°Celsius.



# Appendix 9: January-February-March 2020 Outlook

## Met Office 3-month Outlook

Period: January – March 2020  Issue date: 12.12.19

The forecast presented here is for the average of the January-February-March period for the United Kingdom as a whole.
This forecast is based on information from observations, several numerical prediction systems and expert judgement.

**SUMMARY – TEMPERATURE:**

For January-February-March as a whole, above-average temperatures are more likely than below-average temperatures. Impacts from cold weather remain possible, but they are less likely than normal.

Overall, the probability that the UK-average temperature for January-February-March will fall into the coldest of our five categories is 5% and the probability that it will fall into the warmest of our five categories is around 50% (the 1981-2010 probability for each of these categories is 20%).

**CONTEXT:**

The El Niño-Southern Oscillation (ENSO) is currently in a neutral phase, with little likelihood of a significant El Niño or La Niña event developing during the Outlook period. It is therefore not expected to influence UK weather patterns.
The Indian Ocean Dipole (IOD) remains in a positive phase, with warmer-than-average sea surface temperatures (SSTs) in the western part of the Tropical Indian Ocean and cooler-than-average temperatures in the east. The IOD is expected to continue disrupting rainfall patterns in the Tropics in the first part of the 3-month period. These changes have an influence on the European region, increasing the chances of mild, westerly winds.
Sea surface temperatures in the North Atlantic continue to show a pattern that increases the likelihood of the positive phase of the North Atlantic Oscillation (NAO). Positive NAO in winter is associated with milder-than-average conditions. Patterns of predicted rainfall in the tropical Atlantic Ocean, however, increase the chances of a negative phase of the NAO.

The Stratospheric Polar Vortex (SPV) – the circulation of winds in the stratosphere above the Arctic – is currently strengthening and has an increased likelihood of remaining stronger than average in the first part of the Outlook period. A strong SPV favours a more active jet stream across the Atlantic, increasing the likelihood of milder-than-average conditions. On the other hand, the sun is close to a minimum in its 11-year cycle of activity, which increases the chances of weakening of the SPV in late winter.
For January-February-March as a whole, the Met Office long-range prediction system and systems from other centres around the world are in good agreement in showing an increased chance of the positive phase of the NAO. This is consistent, on balance, with the influences outlined above. Along with the warming of climate, it contributes to an increase in the probability of above-average temperatures (see figure T2). Note that below-average temperatures remain possible, although less likely.

Met Office 3-month Outlook
Period: January – March 2020  Issue date: 12.12.19
The forecast presented here is for the average of the January-February-March period for the United Kingdom as a whole.
This forecast is based on information from observations, several numerical prediction systems and expert judgement.
SUMMARY – TEMPERATURE:
For January-February-March as a whole, above-average temperatures are more likely than below-average temperatures. Impacts from cold weather remain possible, but they are less likely than normal.
Overall, the probability that the UK-average temperature for January-February-March will fall into the coldest of our five categories is 5% and the probability that it will fall into the warmest of our five categories is around 50% (the 1981-2010 probability for each of these categories is 20%).
CONTEXT:
The El Niño-Southern Oscillation (ENSO) is currently in a neutral phase, with little likelihood of a significant El Niño or La Niña event developing during the Outlook period. It is therefore not expected to influence UK weather patterns.
The Indian Ocean Dipole (IOD) remains in a positive phase, with warmer-than-average sea surface temperatures (SSTs) in the western part of the Tropical Indian Ocean and cooler-than-average temperatures in the east. The IOD is expected to continue disrupting rainfall patterns in the Tropics in the first part of the 3-month period. These changes have an influence on the European region, increasing the chances of mild, westerly winds.
Sea surface temperatures in the North Atlantic continue to show a pattern that increases the likelihood of the positive phase of the North Atlantic Oscillation (NAO). Positive NAO in winter is associated with milder-than-average conditions. Patterns of predicted rainfall in the tropical Atlantic Ocean, however, increase the chances of a negative phase of the NAO.
The Stratospheric Polar Vortex (SPV) – the circulation of winds in the stratosphere above the Arctic – is currently strengthening and has an increased likelihood of remaining stronger than average in the first part of the Outlook period. A strong SPV favours a more active jet stream across the Atlantic, increasing the likelihood of milder-than-average conditions. On the other hand, the sun is close to a minimum in its 11-year cycle of activity, which increases the chances of weakening of the SPV in late winter.
For January-February-March as a whole, the Met Office long-range prediction system and systems from other centres around the world are in good agreement in showing an increased chance of the positive phase of the NAO. This is consistent, on balance, with the influences outlined above. Along with the warming of climate, it contributes to an increase in the probability of above-average temperatures (see figure T2). Note that below-average temperatures remain possible, although less likely.

Fig T1

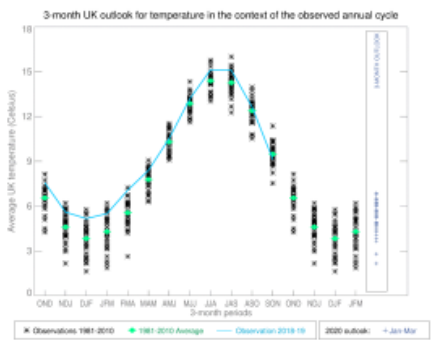



Fig T2

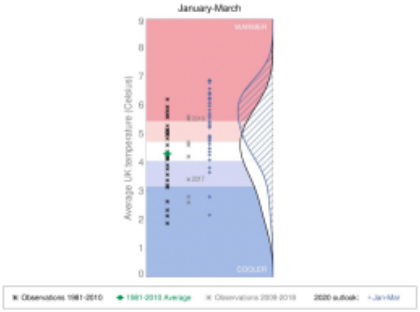
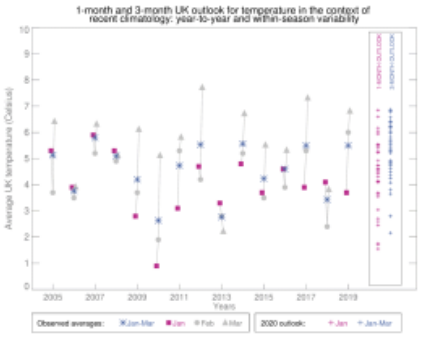



Fig T3




This Outlook provides an indication of possible temperature and rainfall conditions over the next 3 months. It is part of a suite of forecasts designed for contingency planners.
The Outlook should not be used in isolation but should be used with shorter-range and more detailed (30-day, 15-day and 1-to-7-day) forecasts and warnings available to the contingency planning community from the Met Office.

TEMPERATURE

# Met Office 3-month Outlook

Period: January– March 2020  Issue date: 12.12.19

The forecast presented here is for the average of the January-February-March period for the United Kingdom as a whole.
This forecast is based on information from observations, several numerical prediction systems and expert judgement.

**SUMMARY – PRECIPITATION:**

For January-February-March as a whole, above-average precipitation is more likely than below-average precipitation.

The probability that UK-average precipitation for January-February-March will fall into the driest of our five categories is between 15% and 20% and the probability that it will fall into the wettest of our five categories is around 30% (the 1981-2010 probability for each of these categories is 20%).

**CONTEXT:**

The influence of global drivers on UK weather patterns is strongest during winter and predictability is higher than at other times of year. For January-February-March, there is a greater-than-usual likelihood of a positive phase of the North Atlantic Oscillation (NAO), with westerly winds bringing excess moisture from the Atlantic to the UK (see temperature Outlook). The chances of above-average precipitation are therefore greater than the chances of below-average precipitation (see figure P2). The Outlook implies an increase in the risks from high winds and heavy rainfall compared to what is normally expected at this time of year.
The increased probability of our wettest category does not imply extreme precipitation or storminess throughout the 3-month period. Indeed, the Outlook does not identify weather for a particular day or week. In addition, despite increased chances of the Outlook period being wetter than average, a drier-than-average outcome remains possible, although less likely.

Met Office 3-month Outlook
Period: January– March 2020  Issue date: 12.12.19
The forecast presented here is for the average of the January-February-March period for the United Kingdom as a whole.
This forecast is based on information from observations, several numerical prediction systems and expert judgement.
SUMMARY – PRECIPITATION:
For January-February-March as a whole, above-average precipitation is more likely than below-average precipitation.
The probability that UK-average precipitation for January-February-March will fall into the driest of our five categories is between 15% and 20% and the probability that it will fall into the wettest of our five categories is around 30% (the 1981-2010 probability for each of these categories is 20%).
CONTEXT:
The influence of global drivers on UK weather patterns is strongest during winter and predictability is higher than at other times of year. For January-February-March, there is a greater-than-usual likelihood of a positive phase of the North Atlantic Oscillation (NAO), with westerly winds bringing excess moisture from the Atlantic to the UK (see temperature Outlook). The chances of above-average precipitation are therefore greater than the chances of below-average precipitation (see figure P2). The Outlook implies an increase in the risks from high winds and heavy rainfall compared to what is normally expected at this time of year.
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Fig P1

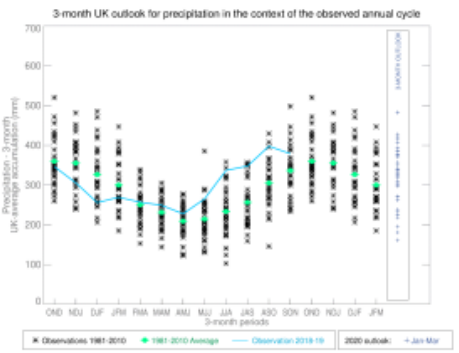



Fig P2

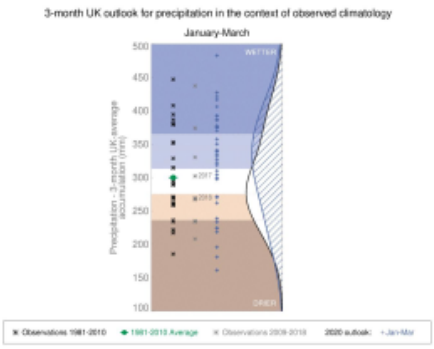
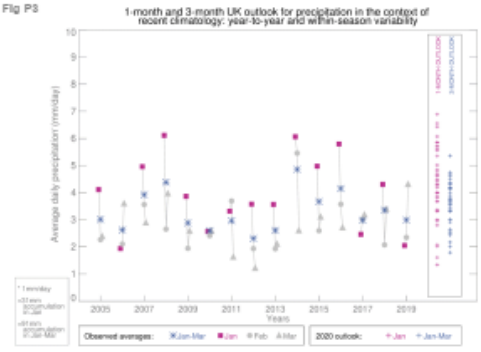



Fig P3




This Outlook provides an indication of possible temperature and rainfall conditions over the next 3 months. It is part of a suite of forecasts designed for contingency planners.
The Outlook should not be used in isolation but should be used with shorter-range and more detailed (30-day, 15-day and 1-to-7-day) forecasts and warnings available to the contingency planning community from the Met Office.

# Appendix 10- July-August-September 2019 Outlook

## Met Office 3-month Outlook

Period: July – September 2019  Issue date: 27.06.19

The forecast presented here is for July and the average of the July-August-September period for the United Kingdom as a whole. The forecast for July will be superseded by the long-range information on the public weather forecast web page (www.metoffice.gov.uk/public/weather/forecast/#?tab=regionalForecast), starting from 5 July 2019.

This forecast is based on information from observations, several numerical prediction systems and expert judgement.

**SUMMARY – TEMPERATURE:**

For July and July-August-September as a whole, above-average temperatures are more likely than below-average temperatures.

Overall, the probability that the UK-average temperature for July-August-September will fall into the coldest of our five categories is 5% and the probability that it will fall into the warmest of our five categories is between 35 and 40% (the 1981-2010 probability for each of these categories is 20%).

**CONTEXT:**

Sea surface temperatures in the Tropical Pacific Ocean remain close to El Niño thresholds. Long-range forecast systems show little chance of the emergence of a significant El Niño or La Niña in the coming months, so there is not expected to be an influence on UK weather patterns through the period of this outlook.

The pattern of sea surface temperature anomalies in the North Atlantic Ocean slightly increases the probability of higher-than-average pressure across Northern Europe. These patterns are similar to, but not as well defined as, those at this time last year. As a result, the influence of these features is likely to be smaller. During summer, high pressure is usually associated with warmer-than-average conditions.

For July and July-August-September as a whole, long-range forecast systems from around the world, including the Met Office system, show small and rather mixed surface pressure signals. This implies that the chances of a generally settled or more unsettled season are fairly well balanced. Despite this, climate warming leads to an increased likelihood of warmer-than-average conditions compared to the long-term average (see figure T2).

The relatively high probability of our warmest category does not imply hot weather throughout the 3-month period. The likelihood of a 3-month long heatwave is very small. Heatwaves are part of the day-to-day weather and the outlook does not identify weather for a particular day or week. The increased likelihood of warm conditions through this period could mean more days with temperatures that are above average to a more modest degree. As stated above, there is just as much chance of a generally unsettled 3-month period as of more settled conditions. Above-average temperatures can arise from a range of types of weather, not just sunny and dry conditions.

Met Office 3-month Outlook
Period: July – September 2019  Issue date: 27.06.19
The forecast presented here is for July and the average of the July-August-September period for the United Kingdom as a whole. The forecast for July will be superseded by the long-range information on the public weather forecast web page (www.metoffice.gov.uk/public/weather/forecast/#?tab=regionalForecast), starting from 5 July 2019.
This forecast is based on information from observations, several numerical prediction systems and expert judgement.
SUMMARY – TEMPERATURE:
For July and July-August-September as a whole, above-average temperatures are more likely than below-average temperatures.
Overall, the probability that the UK-average temperature for July-August-September will fall into the coldest of our five categories is 5% and the probability that it will fall into the warmest of our five categories is between 35 and 40% (the 1981-2010 probability for each of these categories is 20%).
CONTEXT:
Sea surface temperatures in the Tropical Pacific Ocean remain close to El Niño thresholds. Long-range forecast systems show little chance of the emergence of a significant El Niño or La Niña in the coming months, so there is not expected to be an influence on UK weather patterns through the period of this outlook.
The pattern of sea surface temperature anomalies in the North Atlantic Ocean slightly increases the probability of higher-than-average pressure across Northern Europe. These patterns are similar to, but not as well defined as, those at this time last year. As a result, the influence of these features is likely to be smaller. During summer, high pressure is usually associated with warmer-than-average conditions.
For July and July-August-September as a whole, long-range forecast systems from around the world, including the Met Office system, show small and rather mixed surface pressure signals. This implies that the chances of a generally settled or more unsettled season are fairly well balanced. Despite this, climate warming leads to an increased likelihood of warmer-than-average conditions compared to the long-term average (see figure T2).
The relatively high probability of our warmest category does not imply hot weather throughout the 3-month period. The likelihood of a 3-month long heatwave is very small. Heatwaves are part of the day-to-day weather and the outlook does not identify weather for a particular day or week. The increased likelihood of warm conditions through this period could mean more days with temperatures that are above average to a more modest degree. As stated above, there is just as much chance of a generally unsettled 3-month period as of more settled conditions. Above-average temperatures can arise from a range of types of weather, not just sunny and dry conditions.

Fig T1

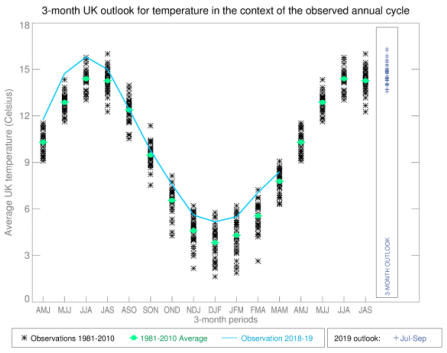



Fig T2

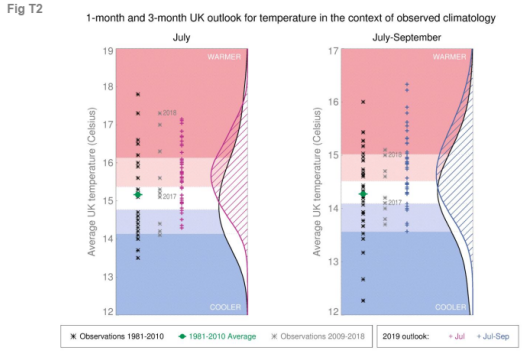
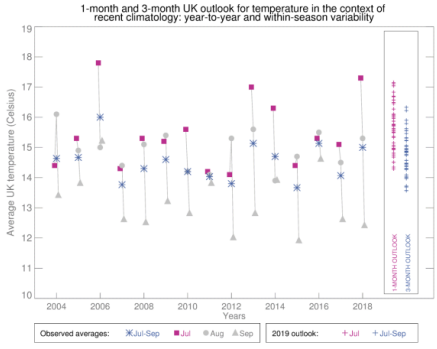



Fig T3




This Outlook provides an indication of possible temperature and rainfall conditions over the next 3 months. It is part of a suite of forecasts designed for contingency planners.

The Outlook should not be used in isolation but should be used with shorter-range and more detailed (30-day, 15-day and 1-to-7-day) forecasts and warnings available to the contingency planning community from the Met Office.

# Met Office 3-month Outlook

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This forecast is based on information from observations, several numerical prediction systems and expert judgement.

## SUMMARY – PRECIPITATION:

For July, wetter-than-average conditions are marginally more likely. For July-August-September as a whole, the chances of above- and below-average precipitation are similar.

The probability that UK-average precipitation for July-August-September will fall into the driest of our five categories is around 20% and the probability that it will fall into the wettest of our five categories is between 15% and 20% (the 1981-2010 probability for each of these categories is 20%).

## CONTEXT:

Global drivers have somewhat less influence on UK weather patterns at this time of year than in the winter season. Therefore, predictability of precipitation amounts and distribution is lower. Currently, signals from long-range forecast systems suggest balanced chances of settled and unsettled conditions.
For July, there is a moderate increase in the likelihood of wetter-than-average conditions. This is consistent, to a degree, with the tendency for higher rainfall in the last 10 years (see left-hand graph of figure P2). A notably dry July is less likely than usual, but again the shift in likelihood is moderate.
For July-August-September as a whole, the chances of above- and below-average rainfall do not deviate significantly from their usual probabilities (see right-hand graph of figure P2).

Met Office 3-month Outlook
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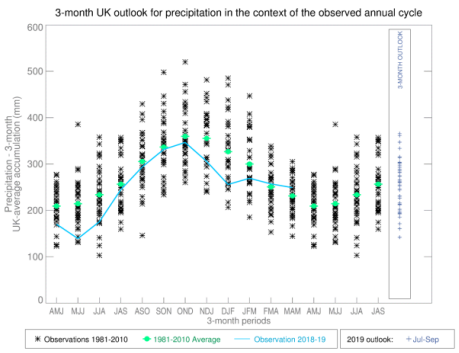



Fig P2

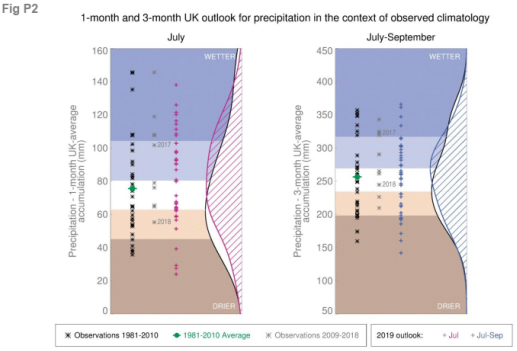
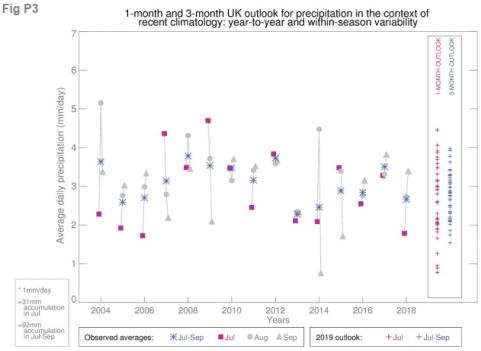



Fig P3

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# Glossary

**Meteorological Terminology**

Anthropogenic Climate Change- changes in the climate that are driven by human activity.

Boundary Conditions- a condition or value that is used to calculate the future *variability* of weather. For example, a change in amount of energy absorbed or emitted by the oceans (boundary condition) can be used to calculate what kinds of weather we might get (higher or lower average temperatures).

Chaos- a system, such as the Earth's atmosphere, that is highly sensitive to changes in its initial conditions.

Climatology- the historical average of a meteorological variable for a specific location, usually over a 30-year period.

Climate Projection- an estimate of future climate that is dependent on a particular scenario, such as the response to changes in greenhouse gas emissions.

Climate Services- a decision-making tool based on climate information that assists individuals and organisations in their decision-making.

Climate System- the complex system made up of the atmosphere and its interactions with the biosphere (ecosystems and living organisms), hydrosphere (water and oceans), cryosphere (ice sheets, glaciers and sea ice) and the lithosphere (upper layer of the Earth's crust).

Cryosphere- areas of the Earth covered in ice.

Deterministic Forecast- a prediction of whether a weather or climatic event will happen or not.

Downscaling- inferring high-resolution information from low-resolution information in a climate model.

Dynamical Climate Forecast- a forecast that predicts future changes in climate by using model simulations.

El-Nino Southern Oscillation (ENSO)- a change in sea-surface temperatures, surface pressure patterns and wind direction in the equatorial Pacific that occurs every 2 to 7 years.

Empirical Climate Forecast- a climate forecast that predicts future changes in climate using known relationships between meteorological variables, such as between rainfall and sea-surface temperatures.

Ensemble Forecast- a forecast where multiple simulations are used estimate the range of possible outcomes for a future weather or climatic event.

Extratropical- regions outside of the tropics.

First-Order Uncertainty- the likelihood of an event happening. Also known as probability.

General Circulation Model- a model that simulates atmospheric circulation.

Hindcasting- ‘re-forecasts’ of past climatic events that are used to measure the skilfulness and reliability of seasonal climate forecasts.

Histogram- a graph that depicts the frequency of observations occurring within certain ranges of values, such as above-average, average and below-average.

Impact-Based Forecasts- forecasts that assess the risk of impacts from a weather or climate hazard.

Indian Ocean Dipole (IOD)- a change in sea-surface temperatures, surface pressure patterns and wind direction in the Indian Ocean that usually occurs every 3-5 years.

Initial Conditions- a condition or value that used to calculate future variations in the weather. For example, a temperature forecast calculates the change from an estimated or observed temperature (the initial condition) to an expected temperature (the forecast).

Initialisation- inputting data into a weather or climate model to produce a set of initial conditions.

Mode of Oscillation/Mode of Variability- a cyclical or recurring change in the global or regional climate.

North Atlantic Oscillation (NAO)- a change in atmospheric circulation between the Arctic and the subtropical Atlantic that produces changes in climate over Europe and North America.

Parameterisation- replacing processes in a weather or climate model that are too small-scale or complex to represent accurately with simplified processes.

Persistence Forecast- a reference forecast where scientists assume that the future will be the same as past.

Predictability- the ability of a weather or climatic event to be predicted, rather than the ability to predict the weather or climate.

Probability Distribution- the chance of different outcomes occurring.

Probabilistic Forecast- a forecast that estimates the range of possible outcomes for a future weather or climate event.

Probability Maps- a map that shows that probability of a variable being above or below the historical average.

Quasi-Biennial Oscillation (QBO)- an alternating pattern of easterly and westerly winds in the stratosphere over the tropics, that usually switches every 27 months.

Reference Forecast- a forecast that is used to assess the quality of a seasonal forecasting system, such as the historical average or a persistence forecast.

Reliability- how well the predictions of a climate model match observations.

Seamless Forecasting System- a forecasting system that issues predictions at all timescales.

Seasonal Climate Forecast- a forecast that predicts climate variability from a month up to a year ahead.

Seasonal Climate Outlook- a summary of seasonal forecast information that includes expert judgement.

Second-Order Uncertainty- our confidence in the predicted likelihood of an event or ‘uncertainty about the uncertainty.’ It is a result of our imperfect knowledge, rather than the chaotic nature of Earth’s climate.

Skill- how well a forecast performs relative to a ‘reference forecast,’ such as the historical average, or a persistence forecast, where the future event is assumed to be the same as the present.

Stratosphere- the part of Earth’s atmosphere that is above the troposphere and extends to 31 miles above the Earth’s surface.

Stratospheric Polar Vortex- a circulation of winds around the polar regions up to 30 miles above the Earth’s surface.

Sudden Stratospheric Warming Event (SSW)- a sudden increase in temperatures 6-30 miles above the Earth’s surface created by the stratospheric polar vortex weakening or reversing.

Troposphere- the part of the Earth’s atmosphere where temperature decreases with height. It extends from the surface up to the stratosphere.

Tropical Cyclone- a rapidly, rotating storm system that occurs in the tropics.

Teleconnection- relationships between atmospheric changes that are in different parts of the world.

Uncertainty- the amount of confidence someone places in knowledge.

Variable- a varying quantity or measurement.

**Journalism Studies Terminology**

‘Beast from the East’- the nickname given by the press to a period of cold weather that affected the UK between February and March 2018.

Broadcast Journalist- a journalist who researches and presents news stories on television or radio.

Broadsheet Newspapers- newspapers that are double the size of tabloid newspapers. Broadsheet newspapers are often associated with a style of journalism that is in-depth, ‘serious’ and aims to inform people.

Dramatization- the process by which editors and journalists choose aspects of events that can easily be dramatized as stories.

Freelance Journalist- a journalist who is not employed by one publication.

Media- In this thesis, the media is defined as any person that is involved in communicating news to the public, such as newspaper journalists, broadcast journalists and editors.

Newsworthiness- the ease at which a journalist can report an event. This is often assumed to be inherent to an event but is often dependent on informal journalistic criteria known as news values.

News Agenda- the importance placed on a topic by the news media.

News Aggregator- a website that brings together journalism in one online location, such as Google News or NewsNow.

News Copy- the written content of newspaper articles submitted by a journalist.

News Hook- an element at the start of news story that is designed to attract attention.

Sensationalism- a tendency in the reporting of events in the mass media to dramatize and exaggerate events in order to attract attention and increase audience share or circulation.

Social Media- online and mobile technologies and platforms, such as Twitter or Facebook, that allow users to interact and share content.

Tabloid Newspapers- newspapers that are half the size of broadsheet newspapers. Tabloid newspapers are often associated with a style of journalism that is more colloquial, sensationalistic and focussed on entertainment

Tagline- a short text or sentence that is designed to catch a reader's attention.

**Met Office Terminology**

Applied Scientist- a meteorologist or climate scientist that applies scientific knowledge and techniques to deliver products, services and consultancy to government and commercial stakeholders.

Civil Contingencies Advisors- staff within the Met Office who advise contingency planners within the UK government.

Civil Contingency Planner- someone who develops plans that are designed to mitigate the impacts of an emergency or critical situation on UK government

services (also known as emergency planning officers or emergency resilience managers).

Energy Manager- someone who plans, monitors and regulates energy use in an organisation.

Energy Analyst- someone who analyses energy markets who locates, gathers, analyses data to provide information and analysis to their organisation or a client.

Global Long-Range Forecasting Centre- national meteorological services that produce global seasonal climate forecasts according to standards defined by the WMO.

GloSEA5- the acronym for the Met Office's current seasonal climate model (see MacLachlan et al. 2015).

Hazard Manager- a web-based portal where UK government staff can access weather warnings and forecasts.

Local Resilience Forums- multi-agency partnerships of public and private sector organisations in the UK that regularly meet to plan and prepare for emergencies.

Monthly-Decadal Prediction Team- the team at the Met Office that researches monthly and decadal climate prediction.

Media Enquiries Team- the team at the Met Office that answers questions from the media.

Product Manager- someone who markets the weather and climate services the Met Office produces.

Strategic Relationship Manager- someone who manages the Met Office's strategic relationships with customers in the public and private sector.

Transport Operator- someone who plans and organises an organisation's transportation activities.

World Meteorological Organisation (WMO)- an agency of the United Nations that facilitates international cooperation in the design and delivery of meteorological services.

**Material Semiotics Terminology**

Actor- an intermediary that puts other intermediaries into circulation

Actor-Network- a term that refers to the idea that actors are always defined in relation to other actors.

Actor-Network Theory (ANT)- a family of methodological and philosophical approaches that treat everything in the 'social' and 'natural' world as an effect of shifting associations. These approaches maintain that new knowledge claims or technologies become established by building associations of human and non-human actors known as actor-networks.

Centres of Calculation- institutions, technologies or locations that mass produce immutable mobiles, such as the UK Met Office.

Displacement- the process of one actor joining actors in another network.

Enactment- bringing a version of an object into existence.

Enrolment- The process by which roles are defined and assigned to actors that accept them.

Fluid Space- spaces that are held together by relations that remain continuous under transformation.

Heterogeneity- the diversity of materials and people that constitute an actor-network.

Immutable Mobile- a stable representation that is unchanging in network space but can be transported to other locations, such as maps, documents and money.

Interessement- actions by which an actor defines and stabilises the roles of other actors in a network.

Intermediary- anything passing between actors that defines the relationship between them. For example, the contingency planners' outlook defines the relationship between the Met Office and civil contingency planners.

Network Space- spaces that are held together by stable, well-defined relations between actors.

Obligatory Passage Point- An actor that other actors need to associate with to realise their interests.

Ontological Multiplicity- the idea that multiple versions of an object can exist. It differs from perspectivalism, which claims that there are different ways of 'looking at' at a single object, and from pluralism, which claims that the different versions of an object are mutually exclusive.

Post-ANT- a family of methodological and philosophical approaches that have developed in response to criticisms of earlier forms of actor-network theory.

Problematisation- Defining a set of actors in a way that makes them indispensable to another actor that wants to realise their interests.

Regional Space- spaces that consist of similar actors surrounded by boundaries.

Topologies- the spatial characteristics of relationships between actors in an actor-network.

Translation- The process of defining, associating and enrolling the interests of another actor.

**Other Social Scientific Terminology**

Agency- the ability of a person or thing to act.

Credibility- the perceived trustworthiness of a SCF.

Epistemology- how we can know about something.

Grounded Theory- an analytical approach that grounds the development of theories in the iterative, inductive coding of qualitative data.

Legitimacy- the perceived transparency and fairness of the process by which weather and climate information is produced.

Mental Models- cognitive assumptions and representations that shape how people filter and absorb information about the climate.

Multi-Sited Ethnography- an ethnography that complicates the object of study, rather than contextualising the object of study within a wider social order.

Tacit Knowledge- knowledge that is difficult to communicate by writing it down or talking about it.

Ontology- how things can exist

Public- In this thesis, the public or members of the public refers to people from the wider UK population who use the Met Office's seasonal climate forecasts, rather than to news organisations, businesses or government agencies.

Salience- the perceived usability of a SCF in decision-making.

Spatiality- how people and objects are arranged in space.

Stakeholder- In this thesis, a stakeholder refers to any individual or organisation that has an interest or concern in using seasonal climate forecasts. This includes customers that pay to use seasonal climate forecasts, as well as members of the public, journalists and government agencies.

Vulnerability- the susceptibility of a structure or community to damage or harm.

# Bibliography


Adamson, G.C.D., Hannaford, M.J., Rohland, E.J., 2018. Re-thinking the present: The role of a historical focus in climate change adaptation research. Glob. Environ. Change 48, 195–205. https://doi.org/10.1016/j.gloenvcha.2017.12.003

Adger, W.N., 2000. Social and ecological resilience: are they related? Prog. Hum. Geogr. 24, 347–364. https://doi.org/10.1191/030913200701540465

Allen, J., 2016. Topologies of Power: Beyond Territories and Networks. Routledge, London.

Allen, J., Axelsson, L., 2019. Border topologies: The time-spaces of labour migrant regulation. Polit. Geogr. 72, 116–123. https://doi.org/10.1016/j.polgeo.2019.04.008

Anderson, B., 2010. Preemption, precaution, preparedness: Anticipatory action and future geographies. Prog. Hum. Geogr. 34, 777–798. https://doi.org/10.1177/0309132510362600

Anne DiFrancesco, D., Young, N., 2011. Seeing climate change: the visual construction of global warming in Canadian national print media. Cult. Geogr. 18, 517–536. https://doi.org/10.1177/1474474010382072

Anstey, J.A., Shepherd, T.G., 2014. High-latitude influence of the quasi-biennial oscillation: High-Latitude Influence of the QBO. Q. J. R. Meteorol. Soc. 140, 1–21. https://doi.org/10.1002/qj.2132

Arnal, L., Cloke, H.L., Stephens, E., Wetterhall, F., Prudhomme, C., Neumann, J., Krzeminski, B., Pappenberger, F., 2018. Skilful seasonal forecasts of streamflow over Europe? Hydrol. Earth Syst. Sci. 22, 2057–2072. https://doi.org/10.5194/hess-22-2057-2018

Aspers, P., 2015. Performing ontology. Soc. Stud. Sci. 45, 449–453. https://doi.org/10.1177/0306312714548610

Baker, L.H., Shaffrey, L.C., Scaife, A.A., 2018. Improved seasonal prediction of UK regional precipitation using atmospheric circulation. Int. J. Climatol. 38, e437–e453. https://doi.org/10.1002/joc.5382

Ballester, J., Lowe, R., Diggle, P.J., Rodó, X., 2016. Seasonal forecasting and health impact models: challenges and opportunities: Seasonal forecasting and health impact models. Ann. N. Y. Acad. Sci. 1382, 8–20. https://doi.org/10.1111/nyas.13129

Barr, S., Woodley, E., 2019. Enabling communities for a changing climate: Re-configuring spaces of hazard governance. Geoforum 100, 116–127. https://doi.org/10.1016/j.geoforum.2019.02.007

Barry, A., Born, G., Weszkalnys, G., 2008. Logics of interdisciplinarity. Econ. Soc. 37, 20–49. https://doi.org/10.1080/03085140701760841

Baxter, J., Eyles, J., Bailey, C., White, C., Pain, R., 1999. Prescripition for Research Practice: Grounded Theory in Qualitative Evaluation. Area 31, 179–183.

BBC News, 2009. Met Office cools summer forecast. URL http://news.bbc.co.uk/1/hi/sci/tech/8173533.stm

Behera, S., Ratnam, J.V., Masumoto, Y., Yamagata, T., 2013. Origin of extreme summers in Europe: the Indo-Pacific connection. Clim. Dyn. 41, 663–676. https://doi.org/10.1007/s00382-012-1524-8

Bennett, W.L., 2012. How Journalists Report the News, in: News: The Politics of Illusion. Pearson Education, USA, pp. 153–183.

Blackburn, M., Methven, J., Roberts, N., 2008. Large-scale context for the UK floods in summer 2007. Weather 63, 280–288. https://doi.org/10.1002/wea.322

Blok, A., 2010. Topologies of Climate Change: Actor-Network Theory, Relational-Scalar Analytics, and Carbon-Market Overflows. Environ. Plan. Soc. Space 28, 896–912. https://doi.org/10.1068/d0309

Boykoff, M.T., 2008. The cultural politics of climate change discourse in UK tabloids. Polit. Geogr. 27, 549–569. https://doi.org/10.1016/j.polgeo.2008.05.002

Brandsen, T., Honingh, A., 2018. Definitions of Co-Production and Co-Creation, in: Co-Production and Co-Creation: Engaging Citizens in Public Citizens. Routledge, Abingdon, pp. 9–17.

Bremer, S., Meisch, S., 2017. Co-production in climate change research: reviewing different perspectives: Co-production in climate change research. Wiley Interdiscip. Rev. Clim. Change 8, e482. https://doi.org/10.1002/wcc.482

Bremer, S., Wardekker, A., Dessai, S., Sobolowski, S., Slaattelid, R., van der Sluijs, J., 2019. Toward a multi-faceted conception of co-production of climate services. Clim. Serv. 13, 42–50. https://doi.org/10.1016/j.cliser.2019.01.003

Bretherton, C.S., Battisti, D.S., 2000. An interpretation of the results from atmospheric general circulation models forced by the time history of the observed sea surface temperature distribution. Geophys. Res. Lett. 27, 767–770. https://doi.org/10.1029/1999GL010910

Brönnimann, S., 2007. Impact of El Niño-Southern Oscillation on European climate: ENSO Impact in Europe. Rev. Geophys. 45, 1-28. https://doi.org/10.1029/2006RG000199

Brown, J.D., 2010. Prospects for the open treatment of uncertainty in environmental research. Prog. Phys. Geogr. Earth Environ. 34, 75–100. https://doi.org/10.1177/0309133309357000

Brown, J.D., 2004. Knowledge, uncertainty and physical geography: towards the development of methodologies for questioning belief. Trans. Inst. Br. Geogr. 29, 367-381 https://doi.org/10.1111/j.0020-2754.2004.00342.x

Bruno Soares, M., Alexander, M., Dessai, S., 2017. Sectoral use of climate information in Europe: A synoptic overview. Clim. Serv. https://doi.org/10.1016/j.cliser.2017.06.001

Bruno Soares, M., Dessai, S., 2016a. Barriers and Enablers to the Use of Seasonal Climate Forecasts Amongst Organisations in Europe. Clim. Change 137, 89–103.

Bruno Soares, M., Dessai, S., 2016b. Barriers and Enablers to the Use of Seasonal Climate Forecasts Amongst Organisations in Europe. Clim. Change 137, 89–103.

Bruno Soares, Marta, Dessai, S., 2015. Exploring the use of seasonal climate forecasts in Europe through expert elicitation. Clim. Risk Manag. 10, 8–16. https://doi.org/10.1016/j.crm.2015.07.001

Bruno Soares, M., Dessai, S., 2015. Report Summarising Users' Needs for Seasonal to Decadal Predictions (No. 308291).

Budescu, D.V., Por, H.-H., Broomell, S.B., Smithson, M., 2014. The interpretation of IPCC probabilistic statements around the world. Nat. Clim. Change 4, 508–512. https://doi.org/10.1038/nclimate2194

Buizer, J., Jacobs, K., Cash, D., 2016. Making short-term climate forecasts useful: Linking science and action. Proc. Natl. Acad. Sci. 113, 4597–4602. https://doi.org/10.1073/pnas.0900518107

Buller, H., 2009. The lively process of interdisciplinarity. Area 41, 395–403. https://doi.org/10.1111/j.1475-4762.2008.00856.x

Buontempo, C., Falloon, P., Palin, E.J., Hanlon, H.M., Soubeyroux, J.-M., Beaulant, A.-L., Viel, C., Jimenez, I., Calmanti, S., 2016. Release an Impact Forecast for the Prototype Services and Analysis of its Impact (Demonstrator No. 42.3). Met Office, Exeter.

Buontempo, C., Hanlon, H.M., Bruno Soares, M., Christel, I., Soubeyroux, J.-M., Viel, C., Calmanti, S., Bosi, L., Falloon, P., Palin, E.J., Vanvyve, E., Torralba, V., Gonzalez-Reviriego, N., Doblas-Reyes, F., Pope, E.C.D., Newton, P., Liggins, F., 2017. What have we learnt from EUPORIAS climate service prototypes? Clim. Serv. https://doi.org/10.1016/j.cliser.2017.06.003

Buontempo, C., Hewitt, C.D., Doblas-Reyes, F.J., Dessai, S., 2014. Climate service development, delivery and use in Europe at monthly to inter-annual timescales. Clim. Risk Manag. 6, 1–5. https://doi.org/10.1016/j.crm.2014.10.002

Bureau of Meteorology, 2019. Tracking Australia's Climate Through 2019. URL http://www.bom.gov.au/climate/updates/articles/a036.shtml (accessed 3.3.20).

Cagnazzo, C., Manzini, E., 2009. Impact of the Stratosphere on the Winter Tropospheric Teleconnections between ENSO and the North Atlantic and European Region. J. Clim. 22, 1223–1238. https://doi.org/10.1175/2008JCLI2549.1

Callon, M., 2007. Some Elements of a Sociology of Translation Domestication of the Scallops and the Fishermen of St. Brieuc Bay, in: Technoscience: The Politics of Interventions. Oslo, pp. 57–78.

Callon, M., 1999. The Role of Lay People in the Production and Dissemination of Scientific Knowledge. Sci. Technol. Soc. 4, 81–94. https://doi.org/10.1177/097172189900400106

Callon, M., 1990. Techno-economic Networks and Irreversibility. Sociol. Rev. 38, 132–161. https://doi.org/10.1111/j.1467-954X.1990.tb03351.x

Callon, M., Latour, B., 1981. Unscrewing the big Leviathan: how actors macro-structure reality and how sociologists help them to do so, in: Advances in Social Theory and Methodology: Toward an Integration of Micro-and Macro-Sociologies. Routledge, London, pp. 277–303.

Caseldine, C., 2015. So what sort of climate do we want? Thoughts on how to decide what is ‘natural’ climate: So what sort of climate do we want? Geogr. J. 181, 366–374. https://doi.org/10.1111/geoj.12131

Cash, D.W., Borck, J.C., Patt, A.G., 2006. Countering the Loading-Dock Approach to Linking Science and Decision Making: Comparative Analysis of El Niño/Southern Oscillation (ENSO) Forecasting Systems. Sci. Technol. Hum. Values 31, 465–494. https://doi.org/10.1177/0162243906287547

Cash, D.W., Clark, W.C., Alcock, F., Dickson, N.M., Eckley, N., Guston, D.H., Jäger, J., Mitchell, R.B., 2003. Knowledge systems for sustainable development. Proc. Natl. Acad. Sci. 100, 8086–8091. https://doi.org/10.1073/pnas.1231332100

Castree, N., Adams, W.M., Barry, J., Brockington, D., Büscher, B., Corbera, E., Demeritt, D., Duffy, R., Felt, U., Neves, K., Newell, P., Pellizzoni, L., Rigby, K., Robbins, P., Robin, L., Rose, D.B., Ross, A., Schlosberg, D., Sörlin, S., West, P., Whitehead, M., Wynne, B., 2014. Changing the intellectual climate. Nat. Clim. Change 4, 763–768. https://doi.org/10.1038/nclimate2339

Chadwick, R., 2010. The science of seasonal forecasting: challenges and prospects. Weather 65, 269–269. https://doi.org/10.1002/wea.616

Charmaz, K., Bryant, A., 2011. Grounded Theory and Credibility, in: Qualitative Research. SAGE Publications, London, pp. 291–309.

Clark, R.T., Bett, P.E., Thornton, H.E., Scaife, A.A., 2017. Skilful seasonal predictions for the European energy industry. Environ. Res. Lett. 12, 024002. https://doi.org/10.1088/1748-9326/aa57ab

Collins, H.M., Evans, R., 2002. The Third Wave of Science Studies: Studies of Expertise and Experience. Soc. Stud. Sci. 32, 235–296. https://doi.org/10.1177/0306312702032002003

Conlin, S., 1986. Image based on the description in “Weather Prediction by Numerical Process”, by L.F. Richardson, CUP 1922, and on advice from Prof. John Byrne, Trinity College Dublin.

Cook, I., 2004. Follow the Thing: Papaya. Antipode 36, 642–664. https://doi.org/10.1111/j.1467-8330.2004.00441.x

Cook, I., Crang, M., 2007. Conceptualising the Subject, in: Doing Ethnographies. SAGE Publications, London, pp. 7–15.

Cooper, M., 2010. Turbulent Worlds. Theory Cult. Soc. 27, 167–190. https://doi.org/10.1177/0263276409358727

Copernicus, 2021. Copernicus Climate Change Service. URL https://www.copernicus.eu/en (accessed 6.14.21).

Couper, P., 2007. Fluvial geomorphology and semiotics: a Wittgensteinian perspective of the ?divide? between human and physical geography. Trans. Inst. Br. Geogr. 32, 279–294. https://doi.org/10.1111/j.1475-5661.2007.00262.x

Coventry, W.L., Dalgleish, L.I., 2015. Differences between the single-event and frequency formats of seasonal-climate-forecast probability. Int. J. Climatol. 35, 444–451. https://doi.org/10.1002/joc.3993

Crane, T., Roncoli, C., Paz, J., Breuer, N., Broad, K., Ingram, KT., 2010. Forecast Skill and Farmers' Skills: Seasonal Climate Forecasts and Agricultural Risk Management in the Southeastern United States. Weather Clim. Soc. 2, 44–59. https://doi.org/doi.org/10.1175/2009WCAS1006.1

Daily Express, 2019. BEAST FROM THE EAST 2: Temperatures to PLUNGE as process behind deadly storm returns. URL https://www.express.co.uk/news/weather/1071264/beast-from-the-east-2-uk-weather-forecast-snow-latest

Daily Telegraph, 2009. Britain will have first decent 'barbecue summer' in three years with temperatures regularly above 80 F. URL http://www. telegraph.co.uk/topics/weather/5250745/Britain-willhave-first-decent-barbecue-summer-inthree-years-withtemperatures-regularly-above-80-F.html.

Daipha, P., 2015. Masters of Uncertainty: Weather Forecasters and Ground Truth. University of Chicago Press, London.

Daipha, P., 2012. Weathering Risk: Uncertainty, Weather Forecasting, and Expertise: Uncertainty, Weather Forecasting, and Expertise. Sociol. Compass 6, 15–25. https://doi.org/10.1111/j.1751-9020.2011.00437.x

Daly, M.E., 2016. Co-Production and the Politics of Usable Knowledge for Climate Adaptation in Tanzania. University of Colorado.

Daron, J.D., Lorenz, S., Wolski, P., Blamey, R.C., Jack, C., 2015. Interpreting climate data visualisations to inform adaptation decisions. Clim. Risk Manag. 10, 17–26. https://doi.org/10.1016/j.crm.2015.06.007

de Laet, M., Mol, A., 2000. The Zimbabwe Bush Pump: Mechanics of a Fluid Technology. Soc. Stud. Sci. 30, 225–263. https://doi.org/10.1177/030631200030002002

De Wit, S., Pascht, A., Haug, M., 2018. Translating Climate Change Anthropology and the Travelling Idea of Climate Change* – Introduction. Sociologicus 68, 1–20.

Demeritt, D., 2016. The Perception and Use of Public Weather Services by Emergency and Resilience Professionals in the UK: A Report for the Met Office Public Weather Service Customer Group. King's College London, London.

Demeritt, D., 2009. From externality to inputs and interference: framing environmental research in geography. Trans. Inst. Br. Geogr. 34, 3–11. https://doi.org/10.1111/j.1475-5661.2008.00333.x

Demeritt, D., Nobert, S., 2014. Models of Best Practice in Flood Risk Communication and Management. Environ. Hazards Hum. Policy Dimens. 13, 313–328.

Department for Transport, 2010. The Resilience of England's Transport Systems in Winter. Department for Transport.

Descola, P., Palsson, G., 1996. Nature and Society: Anthropological Perspectives. Routledge, London.

Deser, C., Alexander, M., Timlin, M.S., 2003. Understanding the Persistence of Sea Surface Temperature Anomalies in Midlatitudes. J. Clim. 16, 56–72.

Dilger, H., Pels, P., Sleeboom-Faulkner, M., 2019. Guidelines for data management and scientific integrity in ethnography. Ethnography 20, 3–7. https://doi.org/10.1177/1466138118819018

Dilling, L., Lemos, MC., 2011. Creating Usable Science: Opportunities and Constraints for Climate Knowledge Use and Their Implications for Science Policy. Glob. Environ. Change 21, 680–689. https://doi.org/10.1016/j.gloenvcha.2010.11.006

Dilling, Lisa, Lemos, M.C., 2011. Creating usable science: Opportunities and constraints for climate knowledge use and their implications for science policy. Glob. Environ. Change 21, 680–689. https://doi.org/10.1016/j.gloenvcha.2010.11.006

Doblas-Reyes, F.J., García-Serrano, J., Lienert, F., Biescas, A.P., Rodrigues, L.R.L., 2013. Seasonal climate predictability and forecasting: status and

prospects. Wiley Interdiscip. Rev. Clim. Change 4, 245–268. https://doi.org/10.1002/wcc.217

Dubus, L., 2014. Weather and Climate and the Power Sector: Needs, Recent Developments and Challenges, in: Troccoli, A., Dubus, L., Haupt, S.E. (Eds.), Weather Matters for Energy. Springer New York, New York, NY, pp. 379–398. https://doi.org/10.1007/978-1-4614-9221-4_18

Dunstone, N., Smith, D., Scaife, A., Hermanson, L., Eade, R., Robinson, N., Andrews, M., Knight, J., 2016. Skilful predictions of the winter North Atlantic Oscillation one year ahead. Nat. Geosci. 9, 809–814. https://doi.org/10.1038/ngeo2824

Dunstone, N., Smith, D., Scaife, A., Hermanson, L., Fereday, D., O'Reilly, C., Stirling, A., Eade, R., Gordon, M., MacLachlan, C., Woollings, T., Sheen, K., Belcher, S., 2018. Skilful Seasonal Predictions of Summer European Rainfall. Geophys. Res. Lett. 45, 3246–3254. https://doi.org/10.1002/2017GL076337

Eden, P., 2011. From Observations to Forecasts - Part 14: Communicating forecasts. Weather 66, 325–327. https://doi.org/10.1002/wea.872

Evans, J., Randalls, S., 2008. Geography and paratactical interdisciplinarity: Views from the ESRC–NERC PhD studentship programme. Geoforum 39, 581–592. https://doi.org/10.1016/j.geoforum.2006.03.007

Falloon, P., Soares, M.B., Manzanas, R., San-Martin, D., Liggins, F., Taylor, I., Kahana, R., Wilding, J., Jones, C., Comer, R., de Vreede, E., Som de Cerff, W., Buontempo, C., Brookshaw, A., Stanley, S., Middleham, R., Pittams, D., Lawrence, E., Bate, E., Peter, H., Uzell, K., Richards, M., 2018. The land management tool: Developing a climate service in Southwest UK. Clim. Serv. 9, 86–100. https://doi.org/10.1016/j.cliser.2017.08.002

Fereday, D.R., Maidens, A., Arribas, A., Scaife, A.A., Knight, J.R., 2012. Seasonal forecasts of northern hemisphere winter 2009/10. Environ. Res. Lett. 7, 034031. https://doi.org/10.1088/1748-9326/7/3/034031

Fincher, R., Barnett, J., Graham, S., 2015. Temporalities in Adaptation to Sea-Level Rise. Ann. Assoc. Am. Geogr. 105, 263–273. https://doi.org/10.1080/00045608.2014.988101

Fine, G.A., 2007. Authors of the Storm: Meteorologists and the Culture of Prediction. University of Chicago Press, London.

Fleming R., Jankovic V., 2011. Revisiting Klima. Osiris 1, 1-15. https://doi.org/10.1086/661262

Folland, C.K., Parker, D.E., Scaife, A.A., Kennedy, J.J., Colman, A.W., Brookshaw, A., Cusack, S., Huddleston, M.R., 2006a. The 2005/06 winter in Europe and the United Kingdom: Part 2 – Prediction techniques and their assessment against observations. Weather 61, 337–346. https://doi.org/10.1256/wea.182.06

Folland, C.K., Parker, D.E., Scaife, A.A., Kennedy, J.J., Colman, A.W., Brookshaw, A., Cusack, S., Huddleston, M.R., 2006b. The 2005/06 winter in Europe and the United Kingdom: Part 2 – Prediction techniques and their assessment against observations. Weather 61, 337–346. https://doi.org/10.1256/wea.182.06

Fox, K., 2014. Weather-Talk. Hodder, London, pp. 35–49.

Frank, W.M., Young, G.S., 2007. The Interannual Variability of Tropical Cyclones. Mon. Weather Rev. 135, 3587–3598. https://doi.org/10.1175/MWR3435.1

Galvin, J., Kendon, M., McCarthy, M., 2019. Snow cover and low temperatures in February and March 2018: Snow cover and low temperatures in February and March 2018. Weather 74, 104–110. https://doi.org/10.1002/wea.3469

Gavin, N.T., Leonard-Milsom, L., Montgomery, J., 2011. Climate change, flooding and the media in Britain. Public Underst. Sci. 20, 422–438. https://doi.org/10.1177/0963662509353377

Gaze, B., 2020. Weather Outlook. URL https://www.theweatheroutlook.com/ (accessed 7.28.20).

Geertz, C., 1973. Thick Description: Towards an Interpretative Theory of Culture, in: The Interpretation of Cultures. Fontana UK, London, pp. 3–32.

Gielis, R., 2011. The value of single-site ethnography in the global era: studying transnational experiences in the migrant house: The value of single-site ethnography in the global era. Area 43, 257–263. https://doi.org/10.1111/j.1475-4762.2011.01020.x

Glaser, BL., Strauss, A., 1967. The Discovery of Grounded Theory: Strategies for Qualitative Research, 7th ed. Aldine Transactions, London.

Goddard, L., Aitchellouche, Y., Baethgen, W., Dettinger, M., Graham, R., Hayman, P., Kadi, M., Martínez, R., Meinke, H., 2010. Providing Seasonal-to-Interannual Climate Information for Risk Management and Decision-making. Procedia Environ. Sci. 1, 81–101. https://doi.org/10.1016/j.proenv.2010.09.007

Goldman, M.J., Daly, M., Lovell, E.J., 2016. Exploring multiple ontologies of drought in agro-pastoral regions of Northern Tanzania: a topological approach: Exploring multiple ontologies of drought. Area 48, 27–33. https://doi.org/10.1111/area.12212

Goldman, M.J., Turner, M.D., Daly, M., 2018. A critical political ecology of human dimensions of climate change: Epistemology, ontology, and ethics. Wiley Interdiscip. Rev. Clim. Change 9, e526. https://doi.org/10.1002/wcc.526

Government, 2019. Local Resilience Forums: Contact Details. URL https://www.gov.uk/guidance/local-resilience-forums-contact-details

Graham, R.J., Gordon, C., Huddleston, M., Davey, M., Norton, W., Colman, A., Scaife, A.A., Brookshaw, A., Ingleby, B., McLean, P., Cusack, S., McCallum, E., Elliott, W., Groves, K., Cotgrove, D., Robinson, D., 2006. The 2005/06 winter in Europe and the United Kingdom: Part 1 – How the Met Office forecast was produced and communicated. Weather 61, 327–336. https://doi.org/10.1256/wea.181.06

Greening, K., Hodgson, A., 2019. Atmospheric analysis of the cold late February and early March 2018 over the UK. Weather 74, 79–85. https://doi.org/10.1002/wea.3467

Guardian, 2005. And now for January's weather forecast . . . URL https://www.theguardian.com/science/2005/sep/20/meteorology.weather

Guardian, 2009. Rain puts dampers on barbeque summer. URL https://www.theguardian.com/uk/2009/jul/29/summer-weather-forecast-rain-holiday

Guardian, 2009. Warm, dry summer on the way, says Met Office. URL https://www.theguardian.com/uk/2009/apr/30/warm-summer-uk-forecast

Haines, S., 2019. Managing expectations: articulating expertise in climate services for agriculture in Belize. Clim. Change 157, 43–59. https://doi.org/10.1007/s10584-018-2357-1

Haines, S., Imana, C.A., Opondo, M., Ouma, G., Rayner, S., 2017. Weather and climate knowledge for water security: Institutional roles and relationships in Turkana. (REACH Working Paper No. 5). University of Oxford.

Hall, A., 2012. Risk, blame, and expertise: The Meteorological Office and extreme weather in post-war Britain. University of Manchester, Manchester.

Hall, A., Endfield, G., 2016. “Snow Scenes”: Exploring the Role of Memory and Place in Commemorating Extreme Winters. Weather Clim. Soc. 8, 5–19. https://doi.org/10.1175/WCAS-D-15-0028.1

Hammersley, M., Atkinson, P., 1996. Ethnography: Principles in Practice, 2nd ed. Routledge, London.

Hanks, W.F., Severi, C., 2014. Translating worlds: The epistemological space of translation. HAU J. Ethnogr. Theory 4, 1–16. https://doi.org/10.14318/hau4.2.001

Hansen, J., Marx, S., Weber, EU., 2004. The Role of Climate Perceptions, Expectations and Forecasts in Farmer Decision-Making: The Argentine Pampas and Florida (No. 04–01). International Research Institute for Climate Prediction, New York.

Hansen, J.W., Mason, S.J., Sun, L., Tall, A., 2011b. Review of Seasonal Climate Forecasting for Agriculture in Sub-Saharan Africa Exp. Agric. 47, 205–240. https://doi.org/10.1017/S0014479710000876

Haraway, D., 1988. Situated Knowledges: The Science Question in Feminism and the Privilege of Partial Perspective. Fem. Stud. 14, 575–599.

Harcup, T., O’Neill, D., 2017. What is News?: News values revisited (again). Journal. Stud. 18, 1470–1488. https://doi.org/10.1080/1461670X.2016.1150193

Harley, TA., 2003. Nice Weather for the Time of Year: The British Obsession with the Weather, in: Weather, Climate and Culture. Berg Publishers, Oxford, pp. 103–118.

Harvey, D., 1996. Justice, Nature and the Geography of Difference. Wiley-Blackwell, London.

Hastenrath, S., Sun, L., Moura, A.D., 2009. Climate prediction for Brazil’s Nordeste by empirical and numerical modeling methods. Int. J. Climatol. 29, 921–926. https://doi.org/10.1002/joc.1770

Hewitt, C., Buontempo, C., Newton, P., 2013. Using Climate Predictions to Better Serve Society's Needs. Eos 94, 105–107.

Hinchliffe, S., 2000. Entangled Humans: Specifying Powers and the Spatialities, in: Entanglements of Power: Geographies of Domination/Resistance. London, pp. 219–237.

Hinchliffe, S., Allen, J., Lavau, S., Bingham, N., Carter, S., 2013. Biosecurity and the topologies of infected life: from borderlines to borderlands: *Biosecurity and the topologies of infected life*. Trans. Inst. Br. Geogr. 38, 531–543. https://doi.org/10.1111/j.1475-5661.2012.00538.x

Hine, C., 2007. Multi-sited Ethnography as a Middle Range Methodology for Contemporary STS. Sci. Technol. Hum. Values 32, 652–671. https://doi.org/10.1177/0162243907303598

Hitchings, R., Latham, M., 2021. Qualitative Methods III: On Different Ways of Describing Our Work 48, 1–10.

Hitchings, R., Latham, M., 2020. Qualitative Methods II: On Geographical Ethnography 44, 972–980.

Hoskins, B., 2013. The potential for skill across the range of the seamless weather-climate prediction problem: a stimulus for our science. Q. J. R. Meteorol. Soc. 139, 573–584. https://doi.org/10.1002/qj.1991

House of Commons Transport Committee, 2011. Keeping the UK moving: The impact on transport of the winter weather in December 2010.

Hulme, M., 2020. Climates Multiple: Three Baselines, Two Tolerances, One Normal. Acad. Lett. https://doi.org/10.20935/AL102

Hulme, M., 2016. Climate change and memory, in: Memory in the Twenty-First Century. Palgrave Macmillan, London, pp. 159–162.

Hulme, M., 2015. Climate and its changes: a cultural appraisal: Climate and its changes. Geo Geogr. Environ. 2, 1–11. https://doi.org/10.1002/geo2.5

Hulme, M., 2012. 'Telling a different tale': literary, historical and meteorological readings of a Norfolk heatwave. Clim. Change 113, 5–21. https://doi.org/10.1007/s10584-012-0400-1

Hulme, M., 2008. Geographical work at the boundaries of climate change: Boundary Crossings. Trans. Inst. Br. Geogr. 33, 5–11. https://doi.org/10.1111/j.1475-5661.2007.00289.x

Hulme, M., Burgess, N., 2019. London's weather and the everyday: two centuries of newspaper reports. Weather 74, 286–290. https://doi.org/10.1002/wea.3302

Hulme, M., Dessai, S., Lorenzoni, I., Nelson, D.R., 2009. Unstable climates: Exploring the statistical and social constructions of 'normal' climate. Geoforum 40, 197–206. https://doi.org/10.1016/j.geoforum.2008.09.010

Huntingford, C., Marsh, T., Scaife, A.A., Kendon, E.J., Hannaford, J., Kay, A.L., Lockwood, M., Prudhomme, C., Reynard, N.S., Parry, S., Lowe, J.A., Screen, J.A., Ward, H.C., Roberts, M., Stott, P.A., Bell, V.A., Bailey, M., Jenkins, A., Legg, T., Otto, F.E.L., Massey, N., Schaller, N., Slingo, J., Allen, M.R., 2014. Potential influences on the United Kingdom's floods of winter 2013/14. Nat. Clim. Change 4, 769–777. https://doi.org/10.1038/nclimate2314

Hurrell, J.W., Kushnir, Y., Ottersen, G., Visbeck, M., 2003. An overview of the North Atlantic Oscillation, in: Hurrell, J.W., Kushnir, Y., Ottersen, G., Visbeck, M. (Eds.), Geophysical Monograph Series. American Geophysical Union, Washington, D. C., pp. 1–35. https://doi.org/10.1029/134GM01

Ineson, S., Scaife, A.A., 2009. The role of the stratosphere in the European climate response to El Niño. Nat. Geosci. 2, 32–36. https://doi.org/10.1038/ngeo381

Ingold, T., Kurttila, T., 2000. Perceiving the Environment in Finnish Lapland. Body Soc. 6, 183–196. https://doi.org/10.1177/1357034X00006003010

Inews, 2019. UK weather forecast: Met Office says there isn't a heatwave coming, despite reports of 'roasting continental heat dome.' URL https://inews.co.uk/

Jackson, P., Evans, D.M., Truninger, M., Meah, A., Baptista, J.A., 2019. The multiple ontologies of freshness in the UK and Portuguese agri-food sectors. Trans. Inst. Br. Geogr. 44, 79–93. https://doi.org/10.1111/tran.12260

Jasanoff, S., 2010. A New Climate for Society. Theory Cult. Soc. 27, 233–253. https://doi.org/10.1177/0263276409361497

Jasanoff, S. (Ed.), 2004. States of knowledge: the co-production of science and social order, International library of sociology. Routledge, London ; New York.

Joliffe, I.T., Stephenson, D.B., 2003. Forecast Verification: A Practitioner's Guide to the Atmospheric Sciences, First. ed. Wiley-Blackwell, London.

Jones, P.D., Jonsson, T., Wheeler, D., 1997. Extension to the North Atlantic Oscillation Using Instrumental Pressure Observations From Gibraltar and South-West Iceland 17, 1433–1450.

Joslyn, S., Savelli, S., 2010. Communicating forecast uncertainty: public perception of weather forecast uncertainty. Meteorol. Appl. 17, 180–195. https://doi.org/10.1002/met.190

Jung, T., Vitart, F., Ferranti, L., Morcrette, J.-J., 2011. Origin and predictability of the extreme negative NAO winter of 2009/10: THE EXTREME NEGATIVE NAO WINTER OF 2009/10. Geophys. Res. Lett. 38, n/a-n/a. https://doi.org/10.1029/2011GL046786

Kahneman, D., Tversky, A., 1974. Judgement Under Uncertainty: Heuristics and Biases. Science 185, 1124–1131.

Kang, D., Lee, M.-I., Im, J., Kim, D., Kim, H.-M., Kang, H.-S., Schubert, S.D., Arribas, A., MacLachlan, C., 2014. Prediction of the Arctic Oscillation in boreal winter by dynamical seasonal forecasting systems. Geophys. Res. Lett. 41, 3577–3585. https://doi.org/10.1002/2014GL060011

Kempton, W., Boster, J.S., Hartley, J.A., 1996. Environmental Values in American Culture. MIT Press, London.

Kendon, M., McCarthy, M., Jevrejeva, S., 2014. State of the UK Climate 2014. Met Office, National Climate Information Centre.

Knorr-Cetina, KD., 1981. The Manufacture of Knowledge: An Essay on the Constructivist and Contextual Nature of Science. Pergamom Press, Oxford.

Kumar, A., Jha, B., Zhang, Q., Bounoua, L., 2007. A New Methodology for Estimating the Unpredictable Component of Seasonal Atmospheric Variability. J. Clim. 20, 3888–3901. https://doi.org/10.1175/JCLI4216.1

Lahsen, M., 2005. Seductive Simulations? Uncertainty Distribution Around Climate Models. Soc. Stud. Sci. 35, 895–922. https://doi.org/10.1177/0306312705053049

Lane, S.N., 2001. Constructive comments on D Massey 'Space-time, "science" and the relationship between physical geography and human geography:rsquo; Trans. Inst. Br. Geogr. 26, 243–256. https://doi.org/10.1111/1475-5661.00018

Lane, S.N., Odoni, N., Landström, C., Whatmore, S.J., Ward, N., Bradley, S., 2011. Doing flood risk science differently: an experiment in radical scientific method: Doing flood risk science differently. Trans. Inst. Br. Geogr. 36, 15–36. https://doi.org/10.1111/j.1475-5661.2010.00410.x

Latour, B., 2005a. Part 1: How to Deploy Controversies About the Social World-Second Source of Uncertainty: Action is Overtaken. Oxford University Press, Oxford, pp. 43–62.

Latour, B., 2005b. Reassembling the Social: An Introduction to Actor-Network Theory, First. ed. Oxford University Press, Oxford.

Latour, B., 1993. We Have Never Been Modern. Harvard University Press, Cambridge, Massachusetts.

Latour, B., 1987. Science in Action: How to Follow Engineers and Scientists Through Society. Harvard University Press, London.

Latour, B., 1986. Visualisation and Cognition: Drawing Things Together, in: Knowledge and Society: Studies in the Sociology of Culture Past and Present. pp. 1–32.

Latour, B., 1983. Give Me a Laboratory and I will Raise the World. SAGE Publications, Bristol, pp. 141–170.

Latour, B., 1979. Laboratory Life: The Construction of Scientific Facts, 1st ed. Princeton University Press, Princeton.

Lavau, S., 2013. Going with the Flow: Sustainable Water Management as Ontological Cleaving. Environ. Plan. Soc. Space 31, 416–433. https://doi.org/10.1068/d25411

Law, J., 2008. On Sociology and STS. Sociol. Rev. 56, 623–649. https://doi.org/10.1111/j.1467-954X.2008.00808.x

Law, J., 2004. After Method. Routledge, London.

Law, J., 1999. After Ant: Complexity, Naming and Topology. Sociol. Rev. 47, 1–14. https://doi.org/10.1111/j.1467-954X.1999.tb03479.x

Law, J., 1992. Notes on the Theory of the Actor-Network: Ordering, Strategy, and Heterogeneity. Syst. Pract. 5, 379–393.

Law, J., 1987. On the Social Explanation of Technical Change: The Case of the Portuguese Maritime Expansion. Technol. Cult. 28, 227–252.

Law, J., Lien, M.E., 2013. Slippery: Field notes in empirical ontology. Soc. Stud. Sci. 43, 363–378. https://doi.org/10.1177/0306312712456947

Law, J., Mol, A., 2001. Situating Technoscience: An Inquiry into Spatialities. Environ. Plan. Soc. Space 19, 609–621. https://doi.org/10.1068/d243t

Law, J., Singleton, V., 2014. ANT, multiplicity and policy. Crit. Policy Stud. 8, 379–396. https://doi.org/10.1080/19460171.2014.957056

Law, J., Singleton, V., 2005. Object Lessons. Organization 12, 331–355. https://doi.org/10.1177/1350508405051270

LeClerc, J., Joslyn, S., 2015. The Cry Wolf Effect and Weather-Related Decision Making: Crying Wolf and Weather-Related Decision Making. Risk Anal. 35, 385–395. https://doi.org/10.1111/risa.12336

Lee, S.H., Butler, A.H., 2020. The 2018–2019 Arctic stratospheric polar vortex. Weather 75, 52–57. https://doi.org/10.1002/wea.3643

Leith, P., Vanclay, F., 2015. Translating Science to Benefit Diverse Publics: Engagement Pathways for Linking Climate Risk, Uncertainty, and Agricultural Identities. Sci. Technol. Hum. Values 40, 939–964. https://doi.org/10.1177/0162243915577636

Lemos, MC., Kirchchoff, CJ., Ramprasad, V., 2012. Narrowing the Climate Information Usability Gap. Nat. Clim. Change 2, 789–794. https://doi.org/10.1038/NCLIMATE1614

Lewandowsky, S., Ballard, T., Pancost, R.D., 2015. Uncertainty as knowledge. Philos. Trans. R. Soc. Math. Phys. Eng. Sci. 373, 20140462. https://doi.org/10.1098/rsta.2014.0462

Leyshon née Brace, C., Geoghegan, H., 2012. Anticipatory objects and uncertain imminence: cattle grids, landscape and the presencing of climate change on the Lizard Peninsula, UK: Anticipatory objects and uncertain imminence. Area 44, 237–244. https://doi.org/10.1111/j.1475-4762.2012.01082.x

Lockwood, M., Harrison, R.G., Woollings, T., Solanki, S.K., 2010. Are cold winters in Europe associated with low solar activity? Environ. Res. Lett. 5, 024001. https://doi.org/10.1088/1748-9326/5/2/024001

Lopez, A., Haines, S., 2017. Exploring the Usability of Probabilistic Weather Forecasts for Water Resources Decision-Making in the United Kingdom. Weather Clim. Soc. 9, 701–715. https://doi.org/10.1175/WCAS-D-16-0072.1

Lorenz, E., 1963. Deterministic Non-Periodic Flow. J. Atmospheric Sci. 20, 130–141.

Lorenz, S., Dessai, S., Forster, P.M., Paavola, J., 2015. Tailoring the visual communication of climate projections for local adaptation practitioners in Germany and the UK. Philos. Trans. R. Soc. Math. Phys. Eng. Sci. 373, 20140457. https://doi.org/10.1098/rsta.2014.0457

Lövbrand, E., 2011. Co-producing European climate science and policy: a cautionary note on the making of useful knowledge. Sci. Public Policy 38, 225–236. https://doi.org/10.3152/030234211X12924093660516

Lowe, R., García-Díez, M., Ballester, J., Creswick, J., Robine, J.-M., Herrmann, F., Rodó, X., 2016. Evaluation of an Early-Warning System for Heat Wave-Related Mortality in Europe: Implications for Sub-seasonal to Seasonal Forecasting and Climate Services. Int. J. Environ. Res. Public. Health 13, 206. https://doi.org/10.3390/ijerph13020206

MacLachlan et al., 2015. Description of GloSea5: the Met Office High Resolution Seasonal Forecast System. https://doi.org/10.1002/qj.2396

Mahony, M., 2013. Epistemic Geographies of Climate Change: The IPCC and the Spaces, Boundaries and Politics of Knowing. University of East Anglia, Norwich.

Mahony, M., Hulme, M., 2018. Epistemic geographies of climate change: Science, space and politics. Prog. Hum. Geogr. 42, 395–424. https://doi.org/10.1177/0309132516681485

Mahony, M., Hulme, M., 2012. Model migrations: mobility and boundary crossings in regional climate prediction. Trans. Inst. Br. Geogr. 37, 197–211.

Marcus, G.E., 1995. Ethnography in/of the World System: The Emergence of Multi-Sited Ethnography. Annu. Rev. Anthropol. 24, 95–117. https://doi.org/10.1146/annurev.an.24.100195.000523

Marres, N., 2007. The Issues Deserve More Credit: Pragmatist Contributions to the Study of Public Involvement in Controversy. Soc. Stud. Sci. 37, 759–780. https://doi.org/10.1177/0306312706077367

Marres, N., Moats, D., 2015. Mapping Controversies with Social Media: The Case for Symmetry. Soc. Media Soc. 1, 205630511560417. https://doi.org/10.1177/2056305115604176

Marshall, A.G., Scaife, A.A., 2009. Impact of the QBO on surface winter climate. J. Geophys. Res. 114. https://doi.org/10.1029/2009JD011737

Martin, L., Secor, A.J., 2014. Towards a post-mathematical topology. Prog. Hum. Geogr. 38, 420–438. https://doi.org/10.1177/0309132513508209

Marx, SM., Weber, EU., Orlove, BS., Leiserowitz, A., Krantz, DH., Roncoli, C., Philips, J., 2007a. Communication and Mental Processes: Experiential and Analytic Processing of Uncertain Climate Information. Glob. Environ. Change 17, 47–58. https://doi.org/10.1016/j.gloenvcha.2006.10.004

Massey, D., 1999. Space-Time, “Science” and the Relationship between Physical Geography and Human Geography. Trans. Inst. Br. Geogr. 24, 261–276. https://doi.org/10.1111/j.0020-2754.1999.00261.x

Massey, D., 1994. A Global Sense of Place, in: Space, Place and Gender. Polity Press, London, pp. 146–156.

McCarthy, M., Christidis, N., Dunstone, N., Fereday, D., Kay, G., Klein-Tank, A., Lowe, J., Petch, J., Scaife, A., Stott, P., 2019. Drivers of the UK summer heatwave of 2018. Weather 74, 390–396. https://doi.org/10.1002/wea.3628

McMahon, C., 2019. Lyme Regis, Dorset, UK. 31st July 2018. UK Weather: Hot sunshine and blue sky returns to Lyme Regis. Holidaymakers flock back to the picturesque beach at the seaside resort of Lyme Regis to enjoy the return of the summer heatwave. Temperatures are set to rise across the UK once again this week.

Meadow, A.M., Ferguson, D.B., Guido, Z., Horangic, A., Owen, G., Wall, T., 2015. Moving toward the Deliberate Coproduction of Climate Science Knowledge. Weather Clim. Soc. 7, 179–191. https://doi.org/10.1175/WCAS-D-14-00050.1

Meehl, G.A., Goddard, L., Boer, G., Burgman, R., Branstator, G., Cassou, C., Corti, S., Danabasoglu, G., Doblas-Reyes, F., Hawkins, E., Karspeck, A., Kimoto, M., Kumar, A., Matei, D., Mignot, J., Msadek, R., Navarra, A., Pohlmann, H., Rienecker, M., Rosati, T., Schneider, E., Smith, D., Sutton, R., Teng, H., van Oldenborgh, G.J., Vecchi, G., Yeager, S., 2014. Decadal Climate Prediction: An Update from the Trenches. Bull. Am. Meteorol. Soc. 95, 243–267. https://doi.org/10.1175/BAMS-D-12-00241.1

Met Office, 2021a. Comparing Forecast Accuracy. URL https://www.metoffice.gov.uk/about-us/what/accuracy-and-trust/comparing-forecast-accuracy (accessed 2.2.21).

Met Office, 2021b. UK Actual and Anomaly Maps. URL https://www.metoffice.gov.uk/research/climate/maps-and-data/uk-actual-and-anomaly-maps (accessed 5.2.21).

Met Office, 2020a. Seasonal Climate Outlooks User Guide. URL https://www.metoffice.gov.uk/services/government/international-development/climate-outlook-user-guide (accessed 1.14.20).

Met Office, 2020b. UK Climate Averages. URL https://www.metoffice.gov.uk/research/climate/maps-and-data/uk-climate-averages (accessed 5.5.20).

Met Office, 2019a. January-February-March 2019 Outlook.

Met Office, 2019b. December-January-February 2019 Outlook.

Met Office, 2018a. Management of Met Office. URL https://www.metoffice.gov.uk/about-us/who/management

Met Office, 2018b. Contingency Planners.

Met Office, 2018c. Seasonal Forecasts for the Energy Industry.

Met Office, 2009a. Spring Forecast 2009. URL https://webarchive.nationalarchives.gov.uk/20090416114034/http://www.metoffice.gov.uk/science/creating/monthsahead/seasonal/2009/spring.html (accessed 4.16.20).

Met Office, 2009b. Spring Forecast 2009: Seasonal Forecasting at the Met Office.

Met Office PWSCG, 2016. Met Office Seasonal Forecasting Consultation (Consultation). Met Office, Exeter.

Meteogroup, 2020. Main Webpage. Meteogroup. URL https://www.meteogroup.com/product/forecasts/grid-stability# (accessed 7.28.20).

Michael, M., 2016. Actor-Network: Trials, Trails and Translations. CTI Group Press, Croydon, London.

Mishra, N., Prodhomme, C., Guemas, V., 2019. Multi-model skill assessment of seasonal temperature and precipitation forecasts over Europe. Clim. Dyn. 52, 4207–4225. https://doi.org/10.1007/s00382-018-4404-z

Mol, A., 2002. The Body Multiple. Duke University Press, London.

Mol, A., 1999. Ontological Politics. A Word and Some Questions. Sociol. Rev. 47, 74–89. https://doi.org/10.1111/j.1467-954X.1999.tb03483.x

Mol, A., Law, J., 1994. Regions, Networks and Fluids: Anaemia and Social Topology. Soc. Stud. Sci. 24, 641–671. https://doi.org/10.1177/030631279402400402

Morgan, MG., Fischoff, B., Bostrom, A., Atman, CJ., 2002. Risk Communication: A Mental Models Approach. Cambridge University Press, Cambridge.

Morss, RE., Demuth, JL., Lazo, JK., 2008. Communicating Uncertainty in Weather Forecasts: A Survey of the US Public. Weather Forecast. 23, 974–991. https://doi.org/doi:10.1175/2008WAF2007088.1

Morss, R.E., Wilhelmi, O.V., Downton, M.W., Gruntfest, E., 2005. Flood Risk, Uncertainty, and Scientific Information for Decision Making: Lessons from an Interdisciplinary Project. Bull. Am. Meteorol. Soc. 86, 1593–1602. https://doi.org/10.1175/BAMS-86-11-1593

Müller, M., 2015. Assemblages and Actor-networks: Rethinking Socio-material Power, Politics and Space: Assemblages and Actor-networks. Geogr. Compass 9, 27–41. https://doi.org/10.1111/gec3.12192

Neale, T., May, D., 2020. Fuzzy boundaries: Simulation and expertise in bushfire prediction. Soc. Stud. Sci. 030631272090686. https://doi.org/10.1177/0306312720906869

Nida, E.N., Taber, C., 2003. The Theory and Practice of Translation, 4th ed. Brill, Leiden.

Nightingale, A.J., 2016. Adaptive scholarship and situated knowledges? Hybrid methodologies and plural epistemologies in climate change adaptation research: Adaptive scholarship and situated knowledges? Area 48, 41–47. https://doi.org/10.1111/area.12195

Orlove, B., 2003. How people name seasons, in: Weather, Climate and Culture. Bloomsbury Academic, London, pp. 121–140.

Osaka, S., Bellamy, R., 2020. Natural variability or climate change? Stakeholder and citizen perceptions of extreme event attribution. Glob. Environ. Change 62, 102070. https://doi.org/10.1016/j.gloenvcha.2020.102070

Ossó, A., Sutton, R., Shaffrey, L., Dong, B., 2018. Observational evidence of European summer weather patterns predictable from spring. Proc. Natl. Acad. Sci. 115, 59–63. https://doi.org/10.1073/pnas.1713146114

Overland, J., Hall, R., Hanna, E., Karpechko, A., Vihma, T., Wang, M., Zhang, X., 2020. The Polar Vortex and Extreme Weather: The Beast from the

East in Winter 2018. Atmosphere 11, 664. https://doi.org/10.3390/atmos11060664

Palin, E.J., Scaife, A.A., Wallace, E., Pope, E.C.D., Arribas, A., Brookshaw, A., 2016. Skillful Seasonal Forecasts of Winter Disruption to the U.K. Transport System. J. Appl. Meteorol. Climatol. 55, 325–344. https://doi.org/10.1175/JAMC-D-15-0102.1

Pallett, H., Chilvers, J., 2015. Organizations in the making: Learning and intervening at the science-policy interface. Prog. Hum. Geogr. 39, 146–166. https://doi.org/10.1177/0309132513518831

Palmer, TN., Anderson, DLT., 1994. The Prospects for Seasonal Forecasting: A Review Paper. Q. J. R. Meteorol. Soc. 120, 755–793.

Parton, K.A., Crean, J., Hayman, P., 2019. The value of seasonal climate forecasts for Australian agriculture. Agric. Syst. 174, 1–10. https://doi.org/10.1016/j.agsy.2019.04.005

Peng, S., Robinson, W.A., Li, S., Hoerling, M.P., 2005. Tropical Atlantic SST Forcing of Coupled North Atlantic Seasonal Responses. J. Clim. 18, 480–496. https://doi.org/10.1175/JCLI-3270.1

Pennesi, K., 2011. Making Forecasts Meaningful: Explanations of Problematic Predictions in Northeast Brazil. Weather Clim. Soc. 3, 90–105. https://doi.org/10.1175/WCAS-D-10-05005.1

Pennesi, K., 2007a. The Predicament of Prediction: Rain Prophets and Meteorologists in North East Brazil. University of Arizona.

Pennesi, K., 2007b. Improving Forecast Communication: Linguistic and Cultural Considerations. Bull. Am. Meteorol. Soc. 88, 1033–1044. https://doi.org/10.1175/BAMS-88-7-1033

Predictia, 2018. What is Seasonal Forecasting? URL http://predictia.es/en/seasonal-forecast (accessed 4.18.20).

Prudhomme, C., Hannaford, J., Harrigan, S., Boorman, D., Knight, J., Bell, V., Jackson, C., Svensson, C., Parry, S., Bachiller-Jareno, N., Davies, H., Davis, R., Mackay, J., McKenzie, A., Rudd, A., Smith, K., Bloomfield, J., Ward, R., Jenkins, A., 2017. Hydrological Outlook UK: an operational streamflow and groundwater level forecasting system at monthly to seasonal time scales. Hydrol. Sci. J. 62, 2753–2768. https://doi.org/10.1080/02626667.2017.1395032

Randalls, S., 2010. Weather profits: Weather derivatives and the commercialization of meteorology. Soc. Stud. Sci. 40, 705–730. https://doi.org/10.1177/0306312710378448

Randalls, S.C., 2006. Firms, Finance and the Weather: The UK Derivatives Market. University of Birmingham, Birmingham.

Ratcliffe, R.A.S., Murray, R., 1970. New lag associations between North Atlantic sea temperature and European pressure applied to long-range weather forecasting. Q. J. R. Meteorol. Soc. 96, 226–246.

Rayner, S., 2019. Rhythms of Prediction in South Australian Water Resource Management. Weather Clim. Soc. 11, 277–290. https://doi.org/10.1175/WCAS-D-18-0103.1

Rayner, S., 2017. Are weather forecasts still for wimps?

Rayner, S., Lach, D., Ingram, H., 2005. Weather Forecasts are for Wimps: Why Water Resource Managers Do Not Use Climate Forecasts. Clim. Change 69, 197–227.

Red Cross Red Crescent Climate Centre, 2020. The Future of Forecasting: Impact-Based Forecasting for Early Action. Red Cross Red Crescent Climate Centre.

Rhoads, B.L., 2006. The Dynamic Basis of Geomorphology Reenvisioned. Ann. Assoc. Am. Geogr. 96, 14–30. https://doi.org/10.1111/j.1467-8306.2006.00496.x

Richardson, L.F., 1922. Weather Prediction by Numerical Process. Cambridge University Press, Cambridge.

Riddle, E.E., Butler, A.H., Furtado, J.C., Cohen, J.L., Kumar, A., 2013. CFSv2 ensemble prediction of the wintertime Arctic Oscillation. Clim. Dyn. 41, 1099–1116. https://doi.org/10.1007/s00382-013-1850-5

Rodger Fleming, J., Jankovic, V., 2011. Revisiting *Klima*. Osiris 26, 1–15. https://doi.org/10.1086/661262

Rodwell, M.J., Folland, C.K., 2002. Atlantic air–sea interaction and seasonal predictability. Q. J. R. Meteorol. Soc. 128, 1413–1443. https://doi.org/10.1002/qj.200212858302

Rodwell, M.J., Rowell, D.P., Folland, C.K., 1999. Oceanic Forcing of the Wintertime North Atlantic Oscillation and European Climate. Nature 398, 320–323.

Roncoli, C., 2006. Ethnographic and Participatory Approaches to Research on Farmers' Responses to Climate Predictions. Clim. Res. 33, 81–99.

Roncoli, C., Jost, C., Kirshen, P., Sanon, M., Ingram, K.T., Woodin, M., Somé, L., Ouattara, F., Sanfo, B.J., Sia, C., Yaka, P., Hoogenboom, G., 2009. From accessing to assessing forecasts: an end-to-end study of participatory climate forecast dissemination in Burkina Faso (West Africa). Clim. Change 92, 433–460. https://doi.org/10.1007/s10584-008-9445-6

Sandover, R., Kinsley, S., Hinchliffe, S., 2018. A very public cull – The anatomy of an online issue public. Geoforum 97, 106–118. https://doi.org/10.1016/j.geoforum.2018.08.016

Sayes, E., 2014. Actor–Network Theory and methodology: Just what does it mean to say that nonhumans have agency? Soc. Stud. Sci. 44, 134–149. https://doi.org/10.1177/0306312713511867

Scaife, A. A., Arribas, A., Blockley, E., Brookshaw, A., Clark, R.T., Dunstone, N., Eade, R., Fereday, D., Folland, C.K., Gordon, M., Hermanson, L., Knight, J.R., Lea, D.J., MacLachlan, C., Maidens, A., Martin, M., Peterson, A.K., Smith, D., Vellinga, M., Wallace, E., Waters, J., Williams, A., 2014. Skillful long-range prediction of European and North American winters: Scaife et al.: Predictability of the NAO. Geophys. Res. Lett. 41, 2514–2519. https://doi.org/10.1002/2014GL059637

Scaife, Adam A., Athanassiadou, M., Andrews, M., Arribas, A., Baldwin, M., Dunstone, N., Knight, J., MacLachlan, C., Manzini, E., Müller, W.A., Pohlmann, H., Smith, D., Stockdale, T., Williams, A., 2014. Predictability of the quasi-biennial oscillation and its northern winter teleconnection on seasonal to decadal timescales: QBO PREDICTION. Geophys. Res. Lett. 41, 1752–1758. https://doi.org/10.1002/2013GL059160

Science and Technology Select Committee, 2012. Science in the Met Office: Science to Service: The Communication of Forecasts. UK Government, London.

Serres, M., 1982. The Parasite. John Hopkins University Press, Baltimore.

Shackley, S., Wynne, B., 1996. Representing Uncertainty in Global Climate Change Science and Policy: Boundary Ordering Devices and Authority. Sci. Technol. Hum. Values 21, 275–302.

Shapin, S., 1998. Placing the View from Nowhere: Historical and Sociological Problems in the Location of Science. Trans. Inst. Br. Geogr. 23, 5–12. https://doi.org/10.1111/j.0020-2754.1998.00005.x

Shaw, I., Dixon, D.P., Paul Jones, P., 2010. Theorizing Our World, in: Research Methods in Geography: A Critical Introduction. Wiley-Blackwell, Singapore, pp. 9–25.

Sheppard, E., 2009. The Spaces and Times of Globalization: Place, Scale, Networks, and Positionality*. Econ. Geogr. 78, 307–330. https://doi.org/10.1111/j.1944-8287.2002.tb00189.x

Simon, S., Randalls, S., 2016. Geography, ontological politics and the resilient future. Dialogues Hum. Geogr. 6, 3–18. https://doi.org/10.1177/2043820615624047

Sky News, 2018. Beast from the East 2? UK in the midst of a “sudden stratospheric warming.” URL https://news.sky.com/story/beast-from-the-east-2-uk-in-the-midst-of-a-sudden-stratospheric-warming-11593440

Slingo, J., Palmer, T., 2011. Uncertainty in weather and climate prediction. Philos. Trans. R. Soc. Math. Phys. Eng. Sci. 369, 4751–4767. https://doi.org/10.1098/rsta.2011.0161

Slovic, P., 2000. The Perception of Risk. Routledge, London.

Smith, D.M., Scaife, A.A., Eade, R., Knight, J.R., 2016. Seasonal to decadal prediction of the winter North Atlantic Oscillation: emerging capability and future prospects. Q. J. R. Meteorol. Soc. 142, 611–617. https://doi.org/10.1002/qj.2479

Smith, D.M., Scaife, A.A., Kirtman, B.P., 2012. What is the current state of scientific knowledge with regard to seasonal and decadal forecasting? Environ. Res. Lett. 7, 015602. https://doi.org/10.1088/1748-9326/7/1/015602

Smithson, M., 1989. Ignorance and Uncertainty: Emerging Paradigms. Springer, London.

Spiegelhalter, D., Pearson, M., Short, I., 2011. Visualizing Uncertainty About the Future. Science 333, 1393–1400. https://doi.org/10.1126/science.1191181

Stahl, S., Stenson, K., 2014. Introduction to Topology and Geometry, Second. ed. Wiley-Blackwell.

Star, S.L., Griesemer, J.R., 1989. Institutional Ecology, `Translations' and Boundary Objects: Amateurs and Professionals in Berkeley's Museum of Vertebrate Zoology, 1907-39. Soc. Stud. Sci. 19, 387–420. https://doi.org/10.1177/030631289019003001

Stengers, I., 2005. The Cosmopolitical Proposal, in: Making Things Public. MIT Press, Cambridge, Massachusetts, pp. 994–1003.

Stephens, EM., Edwards, TL., Demeritt, D., 2012. Communicating Probabilistic Information from Climate Model Ensembles- Lessons from Numerical Weather Prediction. WIREs Clim. Change 3, 409–426. https://doi.org/10.1002/wcc.187

Stirling, A., 2010. Keep it Complex. Nature 468, 1029–1033.

Stockdale, T.N., Molteni, F., Ferranti, L., 2015. Atmospheric initial conditions and the predictability of the Arctic Oscillation: Predictability of the AO. Geophys. Res. Lett. 42, 1173–1179. https://doi.org/10.1002/2014GL062681

Strathern, M., 1996. Cutting the Network. J. R. Anthr. Inst. 2, 517–535.

Strauss, A., 1987. Qualitative Analysis for Social Scientists. Cambridge University Press, Cambridge.

Stuart Adam, G., 2006. Notes Towards a Definition of Journalism: Understanding an Old Craft as an Art Form, in: Journalism: The Democratic Craft. Oxford University Press, New York, pp. 344–370.

Sturgis, P., Allum, N., 2004. Science in Society: Re-Evaluating the Deficit Model of Public Attitudes. Public Underst. Sci. 13, 55–74. https://doi.org/10.1177/0963662504042690

Sundberg, M., 2007. Making Meteorology: Social Relations and Scientific Practice. Stockholm University, Stockholm, Sweden.

Svensson, C., Brookshaw, A., Scaife, A.A., Bell, V.A., Mackay, J.D., Jackson, C.R., Hannaford, J., Davies, H.N., Arribas, A., Stanley, S., 2015. Long-range forecasts of UK winter hydrology. Environ. Res. Lett. 10, 064006. https://doi.org/10.1088/1748-9326/10/6/064006

Tadaki, M., Salmond, J., Le Heron, R., Brierley, G., 2012. Nature, culture, and the work of physical geography: Nature, culture, and the work of physical geography. Trans. Inst. Br. Geogr. 37, 547–562. https://doi.org/10.1111/j.1475-5661.2011.00495.x

Taddei, R., 2014. On the Social Performativity of (Climate) Forecasts, in: Anthropologies of the Future. Routledge, London, pp. 244–263.

Taddei, R., 2012. The Politics of Uncertainty and the Fate of Forecasters. Ethics Policy Environ. 15, 252–267. https://doi.org/10.1080/21550085.2012.685603

Taylor, AL., Dessai, S., Bruin de Bruine, W., 2015. Communicating Uncertainty in Seasonal and Interannual Forecasts in Europe. Philos. Trans. R. Soc. A 373, 20140454–20140470. https://doi.org/10.1098/rsta.2014.0454

Taylor, A.L., Dessai, S., Bruine de Bruin, W., 2014. Public perception of climate risk and adaptation in the UK: A review of the literature. Clim. Risk Manag. 4–5, 1–16. https://doi.org/10.1016/j.crm.2014.09.001

The Times, 2019. 'Continental heat dome' to sizzle UK during school holidays. URL https://www.thetimes.co.uk/article/continental-heat-dome-weather-forecast-g9nz99q6z

The Sun, 2019. LONG HOT SUMMER UK weather forecast – Three-month 'heatwave' expected for Brits after Bank Holiday weekend washout URL https://www.thesun.co.uk/news/9131644/uk-weather-forecast-heatwave-brits/

Thornton, H.E., Scaife, A.A., Hoskins, B.J., Brayshaw, D.J., Smith, D.M., Dunstone, N., Stringer, N., Bett, P.E., 2019. Skilful seasonal prediction of winter gas demand. Environ. Res. Lett. 14, 024009. https://doi.org/10.1088/1748-9326/aaf338

Traweek, S., 1988. Beamtimes and Lifetimes: The World of High Energy Physics. Harvard University Press, London.

Troccoli, A., 2018. Weather and Climate Services for the Energy Industry. Palgrave Macmillan.

Troccoli, A., 2010. Seasonal climate forecasting. Meteorol. Appl. 251–268. https://doi.org/10.1002/met.184

Troccoli, A., Huddleston, M., 2006. Forecasting UK and European winters. Weather 61, 356–357. https://doi.org/10.1256/wea.152.06

Tsing, A., 2010. Worlding the Matsutake Diaspora: Or, Can Actor-Network Theory Experiment with Holism, in: Experiments in Holism: Theory and Practice in Contemporary Anthropology. Wiley-Blackwell, Oxford, pp. 47–66.

Tsouvalis, J., Waterton, C., 2012. Building ‘participation’ upon critique: The Loweswater Care Project, Cumbria, UK. Environ. Model. Softw. 36, 111–121. https://doi.org/10.1016/j.envsoft.2012.01.018

UK Government, 2018. General Data Protection Regulation Act. URL https://www.gov.uk/data-protection

Usborne, S., 2014. Weather wars at the Met Office: Is it going to be a “barbecue summer” this year? The Independent.

Usher, N., 2014. Making News at the New York Times, University of Michigan Press. ed. USA.

van der Bles, A.M., van der Linden, S., Freeman, A.L.J., Mitchell, J., Galvao, A.B., Zaval, L., Spiegelhalter, D.J., 2019. Communicating uncertainty about facts, numbers and science. R. Soc. Open Sci. 6, 181870. https://doi.org/10.1098/rsos.181870

Vaughan, C., Dessai, S., 2014. Climate services for society: origins, institutional arrangements, and design elements for an evaluation framework: Climate services for society. Wiley Interdiscip. Rev. Clim. Change 5, 587–603. https://doi.org/10.1002/wcc.290

Viel, C., Beaulant, A.-L., Soubeyroux, J.-M., Céron, J.-P., 2016. How seasonal forecast could help a decision maker: an example of climate service for water resource management. Adv. Sci. Res. 13, 51–55. https://doi.org/10.5194/asr-13-51-2016

Vincent, K., Daly, M., Scannell, C., Leathes, B., 2018. What can climate services learn from theory and practice of co-production? Clim. Serv. 12, 48–58. https://doi.org/10.1016/j.cliser.2018.11.001

Wainwright, J., 2010. Climate Change, Capitalism, and the Challenge of Transdisciplinarity. Ann. Assoc. Am. Geogr. 100, 983–991. https://doi.org/10.1080/00045608.2010.502439

Walshe, R.A., Adamson, G.C.D., Kelman, I., 2020. Helices of disaster memory: How forgetting and remembering influence tropical cyclone response in Mauritius. Int. J. Disaster Risk Reduct. 50, 101901. https://doi.org/10.1016/j.ijdrr.2020.101901

Wamsler, C., 2017. Stakeholder involvement in strategic adaptation planning: Transdisciplinarity and co-production at stake? Environ. Sci. Policy 75, 148–157. https://doi.org/10.1016/j.envsci.2017.03.016

Weber, E.U., 2016. What shapes perceptions of climate change? New research since 2010: What shapes perceptions of climate change? Wiley Interdiscip. Rev. Clim. Change 7, 125–134. https://doi.org/10.1002/wcc.377

Weisheimer, A., Palmer, T.N., 2014. On the reliability of seasonal climate forecasts. J. R. Soc. Interface 11, 20131162–20131162. https://doi.org/10.1098/rsif.2013.1162

Wernstedt, K., Roberts, P.S., Arvai, J., Redmond, K., 2019. How emergency managers (mis?)interpret forecasts. Disasters 43, 88–109. https://doi.org/10.1111/disa.12293

Whatmore, S.J., 2009. Mapping knowledge controversies: science, democracy and the redistribution of expertise. Prog. Hum. Geogr. 33, 587–598. https://doi.org/10.1177/0309132509339841

Whatmore, S.J., 2002. Hybrid Geographies: Natures, Cultures, Spaces. SAGE Publications, London.

Whitman, G.P., Pain, R., Milledge, D.G., 2015. Going with the flow? Using participatory action research in physical geography. Prog. Phys. Geogr. Earth Environ. 39, 622–639. https://doi.org/10.1177/0309133315589707

Wiersma, B., 2016. Public Acceptability of Offshore Renewable Energy in Guernsey: Using Visual Methods to Investigate Local Energy Deliberations. University of Exeter, Exeter.

Williams, H.T.P., McMurray, J.R., Kurz, T., Hugo Lambert, F., 2015. Network analysis reveals open forums and echo chambers in social media discussions of climate change. Glob. Environ. Change 32, 126–138. https://doi.org/10.1016/j.gloenvcha.2015.03.006

WMO, 2020. Our Mandate- Climate. URL https://public.wmo.int/en/our-mandate/climate

WMO, 2018. Global Producing Centres for Long-Range Forecasts. URL https://public.wmo.int/en/programmes/global-data-processing-and-forecasting-system/global-producing-centres-of-long-range-forecasts

Woolgar, S., Lezaun, J., 2013. The wrong bin bag: A turn to ontology in science and technology studies? Soc. Stud. Sci. 43, 321–340. https://doi.org/10.1177/0306312713488820

Wynne, B., 1992. Misunderstood misunderstanding: social identities and the public understanding of science. Public Underst. Sci. 1, 281–304.

Yeh, E.T., 2016. ‘How can experience of local residents be “knowledge”?’ Challenges in interdisciplinary climate change research: ‘How can experience of local residents be “knowledge”?’ Area 48, 34–40. https://doi.org/10.1111/area.12189