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**Article type:** Opinion

**Article title:** The impact of Arctic warming on the midlatitude jetstream:  
Can it? Has it? Will it?

**Authors:**

<p><b>Elizabeth A Barnes*</b> Department of Atmospheric Science, Colorado State University, Fort Collins, Colorado, USA; eabarnes@atmos.colostate.edu</p>
<p><b>James A Screen</b> College of Engineering, Mathematics and Physical Sciences, University of Exeter, Exeter, Devon, UK; j.screen@exeter.ac.uk</p>

**Abstract**

The Arctic lower atmosphere has warmed more rapidly than that of the globe as a whole, and this has been accompanied by unprecedented sea ice melt. Such large environmental changes are already having profound impacts on the flora, fauna and inhabitants of the Arctic region. An open question, however, is whether these Arctic changes have an effect on the jetstream and thereby influence weather patterns farther south. This broad question has recently received a lot of scientific and media attention, but conclusions appear contradictory rather than consensual. We argue that one point of confusion has arisen due to ambiguities in the exact question being posed. Here we frame our inquiries around three distinct questions: *Can Arctic warming influence the midlatitude jetstream? Has Arctic warming significantly influenced the midlatitude jetstream? Will Arctic warming significantly influence the midlatitude jetstream?* We argue that framing the discussion around the three questions: *Can it?, Has it?, Will it?* provides insight into the common themes emerging in the literature as well as highlights the challenges ahead.

## 1 Introduction

2 The possibility that recent Arctic sea ice loss and surface warming could be impacting the Northern  
3 Hemisphere jetstream and, thereby, extreme weather in the Northern Hemisphere midlatitudes, has  
4 recently received a lot of scientific and media attention. The devastation wrought by the landfall  
5 of Superstorm Sandy in 2012<sup>1</sup>, the frigid temperatures over North America in the winter of  
6 2013/2014<sup>2</sup>, the cold and snowy winters of 2009/2010 and 2010/2011 over Europe and North  
7 America<sup>3,4</sup> and bouts of extreme summer weather<sup>5-7</sup> have all been linked to Arctic sea ice loss over  
8 the past decade, in both the scientific literature and the media. Furthermore, there are suggestions  
9 that as the Arctic continues to see unprecedented sea ice decline and warmer near-surface  
10 temperatures in the coming decades, extreme weather in midlatitudes may become more  
11 commonplace<sup>7,8</sup>. This hypothesis has been well publicized, to the extent that many non-scientists  
12 believe that future Arctic warming will have major effects on weather where they live<sup>9</sup>. These views,  
13 however, are not shared by the climate science community as a whole, with some scientists  
14 suggesting that there is in fact no robust evidence for such a link between Arctic warming and  
15 midlatitude weather<sup>10</sup> and that, for example, the chances of cold weather extremes in the coming  
16 decades may actually decrease because of Arctic warming<sup>2,11-13</sup>.

17 The Northern Hemisphere jetstream encapsulates the large-scale, atmospheric circulation in the  
18 mid-latitudes and is the “river” on which synoptic storms grow and propagate. Given that the  
19 jetstream is strongly coupled to the storm tracks and related surface weather in this way, we limit  
20 our discussion here to whether Arctic amplification is a major driver of midlatitude jetstream  
21 variability and change. We suggest that confusion has arisen, at least in part, due to ambiguities in  
22 the exact question being posed and the evidence used to answer it. Specifically, that evidence  
23 showing that the Arctic *can* influence the midlatitude jetstream has perhaps been wrongly  
24 interpreted as evidence that the Arctic *has* had a significant influence or that it *will* have a significant  
25 influence in the future. Thus, we choose to frame our discussion using three related, but distinct,  
26 questions:

27 (1) **Can** Arctic warming influence the midlatitude jetstream?

28 (2) **Has** Arctic warming significantly influenced the midlatitude jetstream?

29 (3) **Will** Arctic warming significantly influence the midlatitude jetstream?

30 In what follows, we briefly discuss the state of the science for each of these three questions, and  
31 articulate some of the challenges with answering each.

32 A likely key to the scientific discussion, we note, is the definition of the phrase “significantly  
33 influence”. Does this phrase mean “significantly influence” in a statistical sense, where the impacts  
34 are compared to some null hypothesis? Or does it mean, perhaps, that the impacts are noticed by  
35 the average person? Or does it mean that a particular socioeconomic risk threshold is reached?  
36 There is certainly no single answer that applies in all cases, and a thorough discussion of this topic is  
37 far beyond the scope of this Opinion article. However, we wish to state explicitly that in the context  
38 of our framing questions above, we define “significantly influence” to mean that the effects can be  
39 distinguished from the background internal variability of the midlatitude circulation. This is not to  
40 say other definitions are less valid; we just will not explore them here.

## 1 Can it?

2 Whether Arctic warming *can* influence the midlatitude jetstream requires isolating the effects of  
3 Arctic warming from other aspects of climate variability and change, and thus, one typically cannot  
4 use observations alone to determine a causal link. Instead, the ‘*Can it?*’ is best explored with well-  
5 designed model simulations and supporting theoretical arguments.

## 6 Modeling efforts

7 Atmospheric General Circulation Model (AGCM) experiments with imposed sea ice loss or Arctic  
8 warming have been used extensively to explore whether the Arctic can impact the midlatitude  
9 atmospheric circulation. Nearly all of these experiments demonstrate a clear causal influence of  
10 Arctic warming on the midlatitude circulation<sup>14-17</sup>. In many of these studies, the wintertime Northern  
11 Hemisphere circulation is found to exhibit a weaker and more equatorward jetstream (often  
12 interpreted as a negative Arctic Oscillation/North Atlantic Oscillation) in response to a warmer and  
13 less sea-ice-covered Arctic<sup>18-20</sup>. This large-scale response is associated with colder and drier winters  
14 in northern Europe and eastern North America. In fact, this weakening and equatorward shift of the  
15 jetstream in response to polar warming can also be simulated in very simple models, such as in a dry  
16 dynamical core with imposed surface heating<sup>21</sup> (Figure 1). Thus, model simulations clearly  
17 demonstrate that Arctic warming *can* impact the jet (and therefore, surface weather) in midlatitude  
18 regions. However, we note that in most of these simulations the responses are small compared to  
19 the internal variability, and this will be discussed in more detail in the next section.

20 Even such carefully designed modeling studies do not always agree on the atmospheric response to  
21 the same Arctic change. Recent work showed that two state-of-the-art AGCMs forced with identical  
22 sea ice loss produce significantly different circulation responses<sup>22</sup>: one model produced *no*  
23 significant Arctic Oscillation response, while the other produced a *positive* Arctic Oscillation  
24 response. Therefore, not only did the models disagree with respect to the circulation changes, but  
25 neither model exhibited the *negative* Arctic Oscillation response that has been identified in other  
26 model experiments. Other studies have documented that the same model can produce very  
27 different responses to Arctic surface changes, depending on the precise details of the sea ice and sea  
28 surface temperature anomalies imposed<sup>23</sup>. Thus, while model experiments consistently show a  
29 response of the midlatitude jetstream to surface changes in the Arctic, the nature of the response is  
30 far from robust and may be highly non-linear.

31 A different modeling approach is to consider the improvement, or not, of hindcasts (retrospective  
32 forecasts) when Arctic conditions are known. Whereas a forecast makes a prediction based only on  
33 known starting conditions, a hindcast can selectively incorporate some of aspects of the observed  
34 evolution of weather (i.e., what actually happened) to see if knowledge of these aspects improves  
35 the hindcast in other ways. Studies have shown a more realistic depiction of midlatitude winter  
36 weather (e.g, surface temperature, mid-tropospheric circulation) in hindcasts that incorporate the  
37 known evolution of Arctic conditions<sup>24,25</sup>. Such improvement in simulating the midlatitude circulation  
38 appears to be a result of imposing a more realistic Arctic state and therefore constitutes another  
39 strand of evidence of an Arctic influence in midlatitudes.

40

## 1 **Synthesis**

2 Model evidence strongly suggests that near-surface Arctic warming and sea ice loss can modify the  
3 midlatitude jetstream. Complications arise, however, when we ask *how* does circulation respond to  
4 this Arctic warming? Exactly how this influence propagates from high to low latitudes and how it is  
5 manifest in midlatitudes is far from understood. Many mechanisms and plausible pathways have  
6 been explored (see Sidebar 1), however, no single dominant pathway has emerged, owing in part to  
7 model disagreement on the response itself. Finally, the fact that Arctic warming *can* influence the  
8 midlatitude jetstream does not imply it *has* had a significant impact, nor does it imply it *will* have a  
9 significant impact in the future. We address these additional two questions in the following sections.

## 10 **Has it?**

11 Arctic sea ice has exhibited an unprecedented decline over the past three decades. At the same  
12 time, near-surface Arctic air temperatures have warmed substantially more than the global average.  
13 The question many people ask is: “Have the rapid changes in the Arctic significantly influenced the  
14 weather where I live?” Causality is difficult, if not impossible, to determine unambiguously from  
15 observations alone. Furthermore, no consensus currently exists among scientists in the field on  
16 whether significant changes in the midlatitude jetstream have even been detected, let alone  
17 whether Arctic warming is to blame.

## 18 **Observational evidence**

19 Multiple studies over the past few years have reported observational evidence that near surface  
20 Arctic warming has modified the jetstream in the midlatitudes. One study in particular by Francis  
21 and Vavrus<sup>8</sup> (refer to Box 1) has garnered a lot of attention and suggests that Arctic warming has  
22 caused slower-moving circulation patterns and larger north-south deviations in the jetstream in all  
23 seasons but spring. However, this work has received significant criticism from the atmospheric  
24 science community<sup>15-17</sup>. Specifically, that the observations do not support this hypothesized  
25 mechanism<sup>26-28</sup>, and that the conclusions are highly sensitive to the choice of methodology<sup>26,27</sup>.

26 Other studies have attempted to address “*Has it?*” by searching for correlations between the  
27 atmospheric circulation and Arctic conditions (both sea ice and temperature) over the historical  
28 period<sup>4,6,29-31</sup>. This approach has significant drawbacks however, given that causality is very difficult  
29 to demonstrate using observations alone and nearly impossible to pin down without a hypothesis  
30 based solidly in atmospheric dynamics. Below we list three of the major obstacles that confront  
31 these types of observational studies.

### 32 *Decoupling from internal atmospheric variability*

33 One of the major issues with using observations alone is that the internal variability of the  
34 midlatitude circulation is substantial. For example, the jetstream position can vary by up to 10  
35 degrees latitude from year to year (Figure 2). Even on decadal timescales, the jet and the associated  
36 storm track exhibits enhanced fluctuations in both strength and position<sup>32</sup> (Figure 2). Thus, with only  
37 30 years or so of reliable satellite-era atmospheric (and sea ice) data, it would be nearly impossible  
38 to distinguish a forced signal from the background variability<sup>17</sup>. To further support the dominance of  
39 internal variability, Screen and coauthors<sup>22</sup> analyzed the midlatitude circulation in an ensemble of

1 model simulations where sea ice concentrations were reduced at the observed rate, and they  
2 concluded that if only Arctic sea ice were changing, it would take 50 years or more for the forced  
3 signal in the large-scale winds to be distinguishable from internal variability.

#### 4 *Which way does the arrow point?*

5 The issue of correlation versus causation plagues all sciences, and the topic of Arctic linkages with  
6 midlatitude weather is no exception. For example, while it is not yet clear how important the Arctic  
7 state is in driving midlatitude jetstream variability (the topic of this article), it is well accepted by the  
8 scientific community that the midlatitude circulation is an important driver of Arctic climate<sup>33-35</sup>. In  
9 such a strongly coupled system, diagnosing cause and effect is a nearly intractable problem with  
10 observations alone. For this reason, recent work has turned to a “modeling attribution” approach  
11 and multiple studies have implicated fluctuating sea surface temperatures outside the Arctic as an  
12 important driver of Arctic warming over the past two decades<sup>10,34,36,37</sup>. Thus, if recent Arctic warming  
13 is partly driven by processes outside of the polar cap<sup>34,35</sup> (Figure 3), any significant correlations  
14 between the high-latitude warming and the lower-latitude circulation patterns could reflect the role  
15 of midlatitudes forcing the Arctic, rather than the other way around.

#### 16 *Incomplete mechanistic understanding*

17 Studies on this topic have argued for links between Arctic warming and wave amplitudes<sup>8</sup>, blocking  
18 anticyclones<sup>8,38</sup>, heat waves<sup>6,7</sup>, cold snaps<sup>3,4,39,40</sup>, hurricanes<sup>1</sup> and extreme precipitation events<sup>41</sup>, just  
19 to name a few. In arguably all cases, the precise mechanisms remain uncertain and thus, the  
20 proposed linkages should be viewed with extreme caution. Without concerted efforts to better  
21 understand the mechanisms underpinning these proposed linkages, the community will likely  
22 continue to search and identify correlations between the Arctic and a slew of atmospheric  
23 phenomena, confronted at every step with this issue of correlation versus causation.

#### 24 **Synthesis**

25 Whether recent Arctic surface warming and sea ice loss has significantly impacted the midlatitude  
26 jetstream is still a topic of much debate. The weight of evidence suggests that if there has been  
27 Arctic influence on the midlatitude circulation to date, it has probably been small compared to  
28 internal atmospheric variability. It is our opinion that that no study (or set of studies) has sufficiently  
29 demonstrated a significant Arctic influence on the jetstream, and that many alternative hypotheses  
30 exist that can account for the observed variability that are well-supported by fundamental  
31 atmospheric dynamics theory and model experiments. Furthermore, the simplest explanation still  
32 cannot be ruled out – namely, that the jetstream behavior we have observed over the past few  
33 decades is no more than internal midlatitude variability.

#### 34 **Will it?**

35 While there is strong modeling evidence that lower-tropospheric Arctic warming *can* cause  
36 significant changes in the midlatitude jetstream (see previous discussion), this does not imply that  
37 Arctic warming *will* have a tangible effect on future jet behavior. While the “*Can it?*” captures the  
38 relevant processes when all other factors are held fixed, e.g., only considering the influence of Arctic  
39 warming, the “*Will it?*” captures our best guess of the most likely path our climate system will take in

1 the coming years. Thus, one must consider the effects of increasing greenhouse gas concentrations  
2 at all latitudes, altitudes and scales and assess whether these responses will interact constructively  
3 or destructively over the next century. To do this, we look to the fifth Coupled Model  
4 Intercomparison Project (CMIP5) experiments, which offer state-of-the-art projections as to how all  
5 of the different pieces in the climate system may interact. Although these models exhibit well-  
6 known biases in relevant aspects of the large-scale circulation (e.g. jetstream position<sup>42</sup>), they are  
7 the best tools we have for predicting the feedbacks and interactions of the climate system over the  
8 next century.

## 9 **Tug-of-war: Tropics versus Poles**

10 As an example, although every CMIP5 model projects that the Arctic will warm substantially over the  
11 21<sup>st</sup> Century, these models tend to exhibit a robust *poleward* shift of the Northern Hemisphere  
12 jetstreams in all seasons but winter<sup>42</sup> (Figure 5a; in winter, model spread is too large to discern any  
13 robust response). Recall that models with imposed near-surface Arctic warming or sea ice loss tend  
14 to depict an *equatorward* shift of the jet<sup>18-21</sup>. A more poleward jet is associated with less frequent  
15 blocking episodes, which is opposite to the changes some have proposed due to Arctic sea ice loss<sup>3,8</sup>.

16 This apparent discrepancy is likely due to the many competing effects of climate change on the  
17 midlatitude jetstream response. Referring back to our example above, while the Arctic lower-  
18 troposphere is projected to warm more than the tropics by 2100, the opposite is true in the upper-  
19 troposphere, where tropical warming is projected to dominate (Figure 4). Thus, the north-south  
20 temperature gradient is projected to decrease near the surface, but increase at upper-levels. An  
21 increased upper-level temperature gradient has been shown to shift the jetstream poleward and  
22 increase storm track activity, while a decreased lower-level temperature gradient may shift the  
23 jetstream equatorward and decrease storm track activity<sup>43</sup>. A handful of studies have assessed the  
24 relative importance of polar versus tropical warming in models of varying complexity<sup>21,44-47</sup>, and  
25 although all of these studies agree that both the Arctic and tropical warming responses are relevant  
26 to the circulation response, it is still uncertain which effect will ultimately win the tug-of-war on the  
27 jetstream.

## 28 **A modulating influence**

29 The tug-of-war on the jetstream due to the differing effects of tropical warming and Arctic warming  
30 suggests that Arctic warming has the potential to *modulate* the response of the midlatitude  
31 circulation to future climate change. Analyzing the CMIP5 models, Barnes and Polvani<sup>47</sup> showed that  
32 while the models do not agree on the whether the North America/North Atlantic jetstream will  
33 speed up or slow down by 2100 (Figure 5b), the model spread of the response is highly correlated  
34 with the degree of Arctic warming in spring and summer (Figure 5d). In addition, the jet latitude  
35 response is negatively correlated with the degree of Arctic warming in winter (Figure 5c), suggesting  
36 that wintertime Arctic amplification may reduce the magnitude of the poleward shift driven by the  
37 tropical warming (Figure 5a).

38 Other studies have also concluded that the projected changes in the mid-tropospheric winds and  
39 storm tracks are correlated with the magnitude of Arctic warming<sup>45-47</sup>. While we stress that causality  
40 cannot be explicitly determined from correlation analysis, these results suggest that future Arctic  
41 warming may modulate the circulation response to increasing greenhouse gas emissions.

1 Nonetheless, the net response of the circulation — that is, our best estimate of what  
2 ultimately *will* occur — may not be what is expected from Arctic warming alone.

### 3 **Synthesis**

4 The response of the midlatitude jetstream over the 21<sup>st</sup> Century will ultimately be determined by the  
5 nonlinear interaction of many factors, only one of which is Arctic surface warming. While the latest  
6 climate models suggest a possible role for Arctic warming in modulating this response, all of these  
7 competing influences must be considered if one is interested in the ultimate fate of midlatitude  
8 weather.

### 9 **Conclusions**

10 Does rapid Arctic warming have tangible implications for weather in lower latitudes? The jury is still  
11 out. While there is a growing consensus in the model-based literature that that Arctic warming *can*,  
12 in isolation, significantly influence the midlatitude circulation, this neither implies that it *has* in the  
13 past, nor that it *will* in the future. This is because internal atmospheric variability may obscure the  
14 influence of Arctic warming and/or the Arctic influence may be small compared to other factors that  
15 control midlatitude weather. We suggest that it useful to frame inquiries using the “*Can it?*”, “*Has*  
16 *it?*” and “*Will it?*” approach. The “*Can it?*” and “*Will it?*” questions are potentially tractable as we  
17 continue to improve our mechanistic understanding of the high-to-mid- latitude connections, and as  
18 our models improve in their ability to simulate the related dynamics. However, the “*Has it?*” is likely  
19 to continue to be more challenging to answer given the short observational record and large internal  
20 variability of the midlatitude atmosphere.

21 The last two questions (“*Has it?*” “*Will it?*”) are likely still a long way from being fully answered.  
22 However, to more fully understand the influence of rapid Arctic change on weather in lower  
23 latitudes, we must make appreciable progress towards addressing both of these questions  
24 separately. And even if our efforts ultimately lead us to the conclusion that the answers are “no”,  
25 there’s still a good chance we’ll have learned a lot about our climate system along the way.

26

## 1 Sidebar 1: Possible pathways for Arctic warming to influence midlatitude weather

### 2 *Reduced meridional temperature gradient*

3 If the Arctic surface warms faster than that at lower-latitudes, the lower-tropospheric temperature difference between the  
4 tropics and the pole will decrease. This reduced gradient implies reduced baroclinicity, which would lead to reduced storm  
5 activity. Furthermore, a reduction in the meridional temperature gradient would be expected to lead to smaller  
6 temperature variations across the midlatitudes, and thus, fewer temperature extremes than one might expect due solely  
7 to the climate shifting toward warmer temperatures<sup>11-12</sup>.

### 8 *A more sinuous jetstream*

9 One widely debated mechanism by which Arctic warming could influence midlatitude weather extremes is through  
10 changes in the undulations of the jetstream. If the meridional temperature gradient decreases (see above), and one  
11 assumes that the midlatitude surface winds and storm tracks remain unchanged, the jet stream may be expected to slow  
12 down due to the relationship between temperature and wind known as thermal wind balance (which states that a reduced  
13 meridional temperature gradient is dynamically linked to a reduced vertical gradient in wind). Francis and Vavrus<sup>8</sup>  
14 hypothesized that the slower jetstream may cause more amplified Rossby waves, increasing the frequency of atmospheric  
15 blocking and thus, persistent and extreme weather in midlatitudes. However, this hypothesis has been questioned in the  
16 recent literature<sup>26-28,42,48</sup>, and we note, leads to more extreme temperature variations, while the pathway described in the  
17 section above would lead to fewer.

### 18 *Trapped atmospheric waves*

19 Coumou and coauthors<sup>7</sup> proposed a similar, but distinct, mechanism whereby a weaker meridional temperature gradient  
20 favors the occurrence of splits in the jetstream. Double jet configurations occur when the jet stream splits into two distinct  
21 filaments, one usually following a more northerly route and the other a more southerly route, with this jet pattern more  
22 common in summer than in winter. These double jets act as barriers trapping the lower level atmospheric flow in the mid-  
23 latitudes. In such circumstances, known as “quasi-resonance”<sup>5,7</sup>, circulation patterns tend to stagnate, leading to bouts of  
24 persistent and extreme summer weather.

### 25 *Modified storm tracks*

26 At more regional scales, changes in sea ice can alter local temperature gradients because the newly open ocean is warmer  
27 than the surrounding sea-ice surface. This leads to local warming of the atmosphere overlying the newly open water, which  
28 can trigger anomalous planetary wave activity with downstream effects<sup>30,39-41</sup>. The large temperature gradients at the ice-  
29 ocean boundary act as a hot spot for the growth of mesoscale storm systems. As the average sea ice edge migrates in a  
30 warming climate so do the regions of cyclogenesis, which can affect the larger-scale circulation by modifying the storm  
31 tracks<sup>38,49</sup>.

### 32 *Weakened stratospheric polar vortex*

33 Another possible pathway involves the two-way interaction between the troposphere and the stratosphere above it.  
34 Planetary-scale Rossby waves transfer energy from the troposphere to the stratosphere. When these waves reach the  
35 stratosphere they “break” (analogous to an ocean wave at the beach) and this stratospheric wave breaking impacts the  
36 strength of the polar vortex. Increased vertical wave propagation tends to weaken and warm the polar vortex in early  
37 winter. Anomalies in the stratosphere in early winter descend back down into the troposphere by mid-to-late winter.  
38 Specifically, a weakened stratospheric polar vortex often precedes the negative phase of the Arctic Oscillation or North  
39 Atlantic Oscillation, which tends to be associated with cold midlatitude winters at the Earth’s surface. Decreased autumn  
40 sea ice, especially in the Barents and Kara seas, has been proposed to trigger anomalous vertical wave propagation into the  
41 stratosphere. This process weakens the polar vortex, which shifts the Arctic Oscillation towards its negative phase, and  
42 ultimately, favours cold winter conditions over North America and Eurasia<sup>15,50</sup>.



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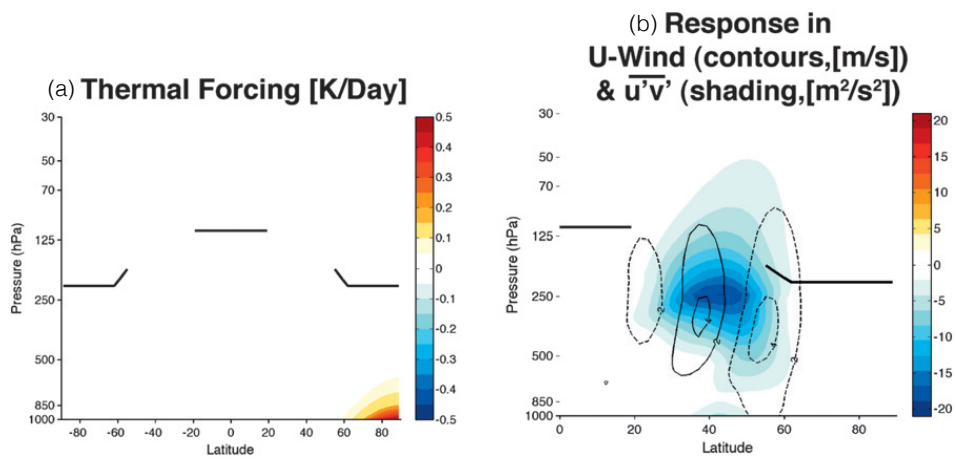
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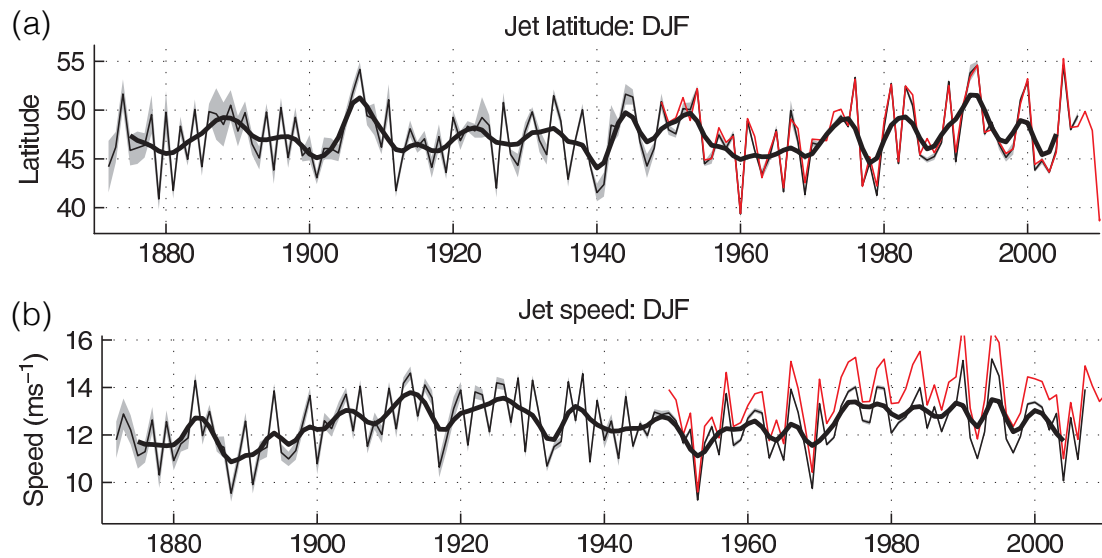
23 **Figures**

24

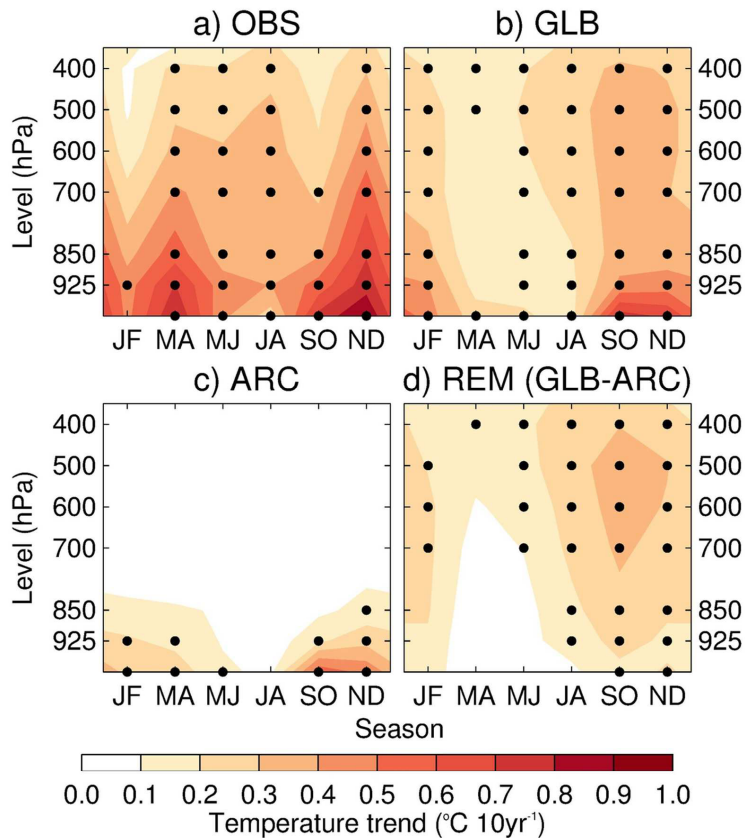


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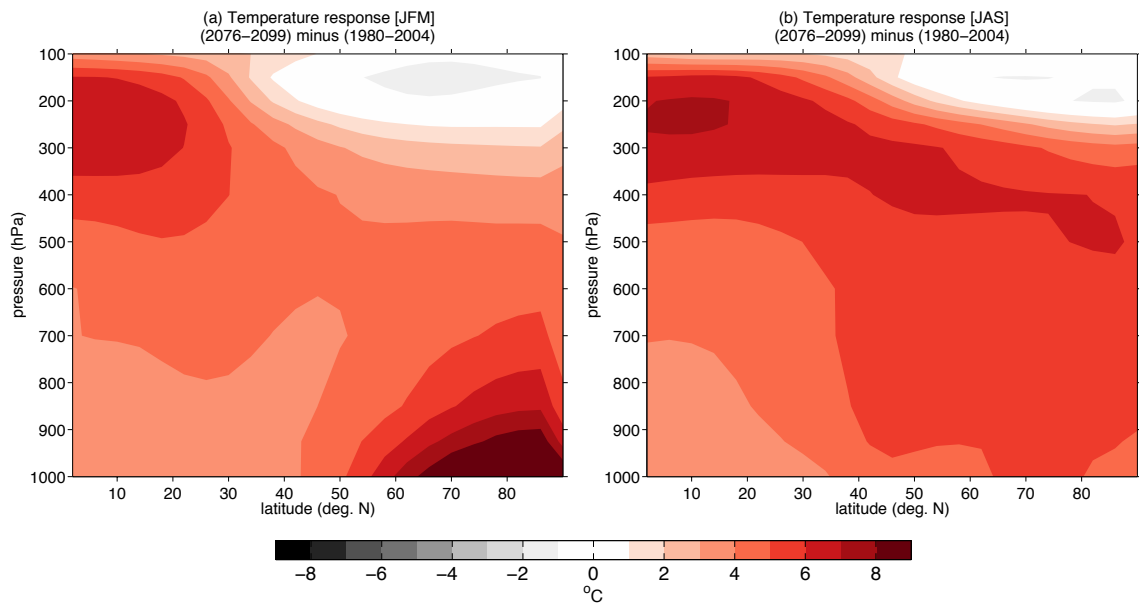
2 **Figure 1: Circulation response to polar surface heating in a simplified GCM. (a)** The applied thermal  
 3 forcing (K/day) in the GFDL dry dynamical core. **(b)** The total eddy momentum flux response  
 4 (shading) ( $\text{m}^2/\text{s}^2$ ) and the zonal-mean zonal wind response (contours) (m/s). Bold black lines denote  
 5 the control run tropopause. The model simulation was run under perpetual equinoctial conditions.  
 6 [Adapted from Butler et al 2010<sup>21</sup>].



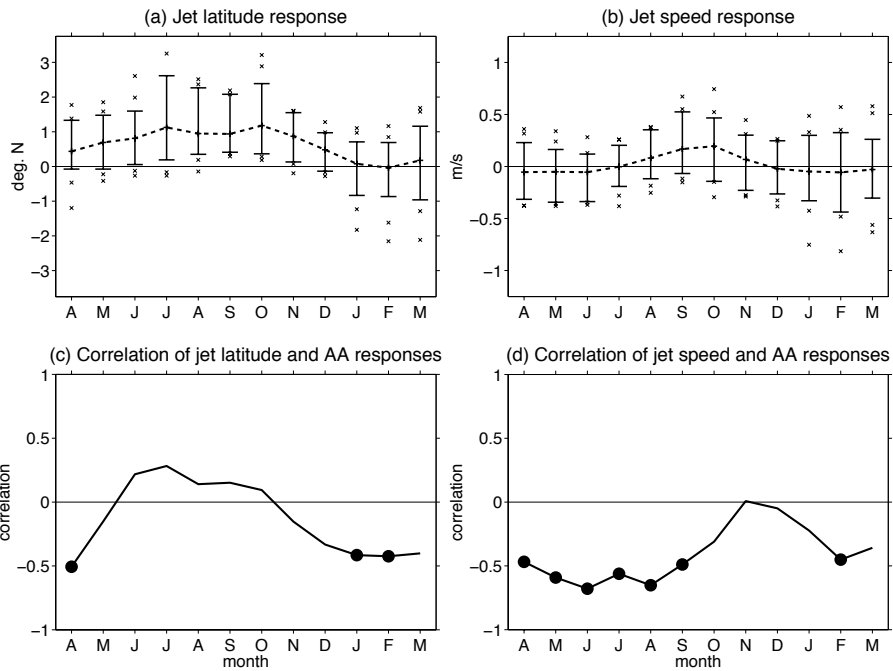
1  
2 **Figure 2: Internal variability of the jetstream.** Time series of winter (December-January-February)  
3 mean jet latitude (a) and jet speed (b) from the 20th Century Reanalysis (black), with the  $\pm 2$   
4 standard deviation range across the ensemble (shaded). The thick lines show versions that have  
5 been smoothed with a 7-point binomial filter, which strongly damps time scales shorter than 5 years.  
6 Red lines indicate indices derived from the NCEP–NCAR reanalysis in recent decades. [Adapted from  
7 Woollings et al 2014<sup>32</sup>]



1  
2 **Figure 3: Local versus remote causes of Arctic warming.** Vertical and seasonal structure of Arctic-  
3 mean temperature trends (1979-2008) in observations (a), in model ensembles forced by global sea  
4 ice and sea surface temperature changes (b) and forced by only Arctic sea ice and sea surface  
5 temperature changes (c) and their difference (d). Panels c and d provide estimates of the local and  
6 remote influences on Arctic warming, respectively. Black dots show trends that are statistically  
7 significant at the 95 percent level [From Screen et al 2012<sup>35</sup>].



1  
 2 **Figure 4: The horizontal and vertical pattern of projected warming.** Zonal-mean, multi-model mean  
 3 air temperature response (shading) between 2099-2076 and 1980- 2004 under RCP8.5 for 21 CMIP5  
 4 models for winter (**a**; January-February-March) and summer (**b**; July-August-September). [Adapted  
 5 from Barnes and Polvani 2014<sup>47</sup>]



1  
 2 **Figure 5: Relationships between projected future Arctic Amplification and the jetstream.** North  
 3 Atlantic jet latitude (a) and jet speed (b) responses as a function of month between 2099-2076 and  
 4 1980- 2004 under RCP8.5 for 21 CMIP5 models. Bars signify the 10th-90th percentile range and  
 5 crosses denote model responses outside of this range. (c-d) Correlation across the CMIP5 models of  
 6 the North Atlantic jet latitude (c) or jet speed (d) and Arctic amplification responses as a function of  
 7 month. Solid circles denote correlations significant at the 95% confidence level. [Adapted from  
 8 Barnes and Polvani 2014<sup>47</sup>]

9

10 **Further Reading/Resources**

11

- 12 1. US National Academy of Sciences report *Linkages between Arctic warming and midlatitude*  
 13 *weather patterns*: [http://www.nap.edu/openbook.php?record\\_id=18727](http://www.nap.edu/openbook.php?record_id=18727)  
 14 2. Annual reports (since 2011) explaining the extreme weather events in the past year from a  
 15 climate perspective: <http://www.ncdc.noaa.gov/bams-state-of-the-climate/extreme-events/>

16

17 **Related Articles**

DOI	Article title
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WCC150	Past and recent changes in the North Atlantic Oscillation