Global carbon budgets: determining limits on fossil fuel emissions

Weather – July 2020, Vol. 75, No. 7

Pierre Friedlingstein
University of Exeter, College of Engineering, Mathematics and Physical Sciences, Exeter, UK

How much CO_2 can the world emit and still avoid dangerous climate change?

Carbon dioxide (CO_2) from fossil fuels burning and land-use change is accumulating in the atmosphere. Current levels are over 40% higher than in the pre-industrial era and a continued increase of atmospheric CO_2 will lead to further warming of the planet. In the Paris Agreement, countries set out to *hold the increase in the global average temperature to well below 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5°C*. There is an upper limit to CO_2 emissions compatible with these objectives. Current knowledge from climate models indicates that the relationship between total or 'cumulative' CO_2 emissions and surface warming is broadly linear, meaning that if we double the total amount of CO_2 emissions, we would see a doubling of the warming. From this relationship, one can estimate the remaining carbon budget that could be emitted to the atmosphere in order to remain below +1.5 or +2.0 degC. These carbon budgets were first assessed in the *IPCC 5th Assessment Report* in 2013, but were revisited in recent publications and in the *IPCC Special Report on Global Warming of 1.5°C* released in October 2018. These newer estimates better account for the historical CO_2 emissions and level of warming already observed.

Given a present-day warming of about +1.0 degC above pre-industrial levels and historical emissions of about 2200GtCO$_2$, these studies broadly agree that the +1.5 and +2.0 degC limits would impose a remaining budget from 2018 of less than about 580GtCO$_2$ and 1500GtCO$_2$, respectively. These remaining carbon budgets would be used up in less than about 15 years and 35 years, respectively, at current rate of global CO_2 emissions.

How are these carbon budgets developed?

Models that simulate both the climate and the land and ocean carbon cycle response to CO_2 emissions are the main tools used to quantify the carbon budget. In general, these models start from a 'pre-industrial' base and run all the way to 2100, using historical CO_2 emissions for the past and scenarios of CO_2 and non-CO_2 emissions for the 21st century. From these simulations, one can diagnose the CO_2 emissions by the time the simulated global warming reaches +1.5 or +2.0 degC. Knowing the historical warming and associated CO_2 emissions, one can infer the remaining budget compatible with these climate targets. Alternatively, remaining carbon budgets can be estimated from the linear relationship between cumulative CO_2 emissions and surface warming diagnosed from models, accounting for the historical warming and the future warming expected from non-CO_2 greenhouse gases and aerosols.

What are the uncertainties?

In current carbon budget estimates, there are three major uncertainties: (1) climate sensitivity, (2) carbon cycle feedbacks, and (3) contribution from non-CO_2 emissions. (1) Climate sensitivity refers to the amount of warming that goes along with an increase in atmospheric CO_2 concentration. There is a large range of plausible estimates of climate sensitivity, due to uncertainty in physical feedbacks, such as cloud feedbacks. The climate change briefing 'Climate Sensitivity: How much warming results from increases in atmospheric carbon dioxide (CO_2), (Hawkins *et al.*, 2019) dealt with this topic in depth. (2) Carbon cycle feedbacks refer to the effects of increased atmospheric CO_2 on the land and ocean carbon system. With higher concentrations of atmospheric CO_2, land and ocean CO_2 uptake increases, hence slowing the growth of atmospheric CO_2. At the same time, atmospheric CO_2 increase also induces climate change that tends to reduce the global land and ocean CO_2 uptake, hence accelerating the growth of atmospheric CO_2. Uncertainties in both the climate sensitivity and the carbon cycle feedbacks have direct implications for the size of the remaining carbon budget. (3) Greenhouse gases such as methane (CH_4), nitrous oxide (N_2O), and aerosols also play a role in current and future warming. A quantification of the remaining carbon budget consistent with a climate target needs to make assumptions on the level of future non-CO_2 emissions as well as their associated warming.

Furthermore, there are additional processes that are currently not represented in climate models which could also affect the size of the remaining carbon budget such as carbon release from the thawing of permafrost. Because of these uncertainties, remaining carbon budgets are usually given in probabilistic terms. Nevertheless, it is clear that the world will urgently need to reduce emissions and become carbon neutral well within this century if we wish to achieve the Paris Agreement target.

Acknowledgements

This paper was developed in collaboration with the Royal Meteorological Society's Climate Science Communications Group. The Society would like to thank Kasia Tokarska, Kirsten Zickfeld and Joeri Rogelj for reviewing the paper.

References

IPCC. 2013. Climate change 2013: the physical science basis. In: Stocker TF, Qin D, Plattner G-K, *et al.*, eds. *Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press: Cambridge, UK and New York, NY, USA.

IPCC. 2018. Summary for policymakers. In: Masson-Delmotte V, Zhai P, Pörtner H-O, *et al.*, eds. *Global Warming of 1.5°C. An IPCC Special Report on the impacts of global* *warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty*. World Meteorological Organization: Geneva, Switzerland.

Hawkins E, Forster P and The Climate Science Communications Group. 2019. Climate Sensitivity: How much warming results from increases in atmospheric carbon dioxide (CO_2). *Weather* **74**: 134.

Correspondence to: Pierre Friedlingstein

P.Friedlingstein@exeter.ac.uk

doi:10.1002/wea.3734

One Scottish snow patch survives until winter 2019/2020

Iain Cameron[1] and Blair Fyffe[2]

[1]*Stirling, Scotland*
[2]*Fort William, Scotland*

This is the 24th annual report on the survival of Scottish snow patches, following the account for 2018 in Cameron and Watson (2019).

Methods

Once again, the quality of information presented to the authors by amateur enthusiasts was of a very high standard, and we are indebted to all contributors. Measurements of patches give the greatest length, breadth and depth in that order. References to seasons are meteorological as opposed to astronomical. All unattributed observations were made by the authors Iain Cameron and Blair Fyffe.

Weather in winter through to autumn

For the third consecutive winter, 2018/19 precipitation amounts across the Highlands were lower than the 1981–2010 mean (https://tinyurl.com/wajf3mh), in some areas by as much as 50%. Temperatures for the same season stood at 1.5degC above the mean (https://tinyurl.com/soes8b5). As a result, the level of snow cover at the end of February 2019 ranked among the lowest since 1998, which itself was the leanest since 1954 (Watson *et al*., 1999). Spring temperatures exceeded the 1981–2010 mean but were punctuated by some cooler spells. The most notable of these occurred between 2 and 11 May, with snow falling frequently above 2000 ft (610m).

Summer was warmer and wetter than normal, and fresh snow was noted on only 2 days in June to September: 13 and 21 June. Autumn temperatures were below average but only marginally.

Figure 1. Author Iain Cameron stands on the last patch of snow south of the Central Belt, at Cramalt Craig on 22 April 2019. On this date, it was 50m long. (© Iain Cameron.)

Patches in late spring, summer and autumn 2019

April–July

Southern Uplands and Southern Highlands

Far fewer patches were evident in general in these areas at the start of April than in 2018, although more than 2017.

The last snow on the Ochil hills near Stirling, on King's Seat Hill, endured until 21 April. In the Galloway Highlands, Corserine had a small patch in its eastern corrie on 20 April, which disappeared a few days later. The last recorded snow south of the Central Belt was on Cramalt Craig in the Scottish Borders. It measured 50 × 20 × 1m on 22 April (Figure 1) but was much reduced by the time of its next viewing, on 5 May. We estimate its final melting less than a week thereafter.

On Ben Lomond, Scotland's most southerly Munro (a hill over 914m), M. Gray spotted a deep and long wreath in the northeast corrie on 19 April. Mild weather shrank this remnant quickly, and it was gone by the middle of May. On a trip to Beinn Ime on 11 May, Iain Cameron found a 45 metre-wide patch in the usual location, a deep bowl southeast of the summit cone. K. Cooper confirmed its disappearance on 23 June when he walked to the hill's summit. Iain Cameron visited Ben More near Crianlarich on 8 June and found its Cuidhe Chrom (the only snow patch we are aware of that is named on Ordnance Survey maps) wreath in excess of 50m long, but shallow (Figure 2). We estimate that it persisted until around 22 June. At Ben Lui, also on 8 June, a patch was noted at the normal position on its northeast flank. We judge that its demise would not have been any later than 20 June.

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