

# Short-lived uncertainty?

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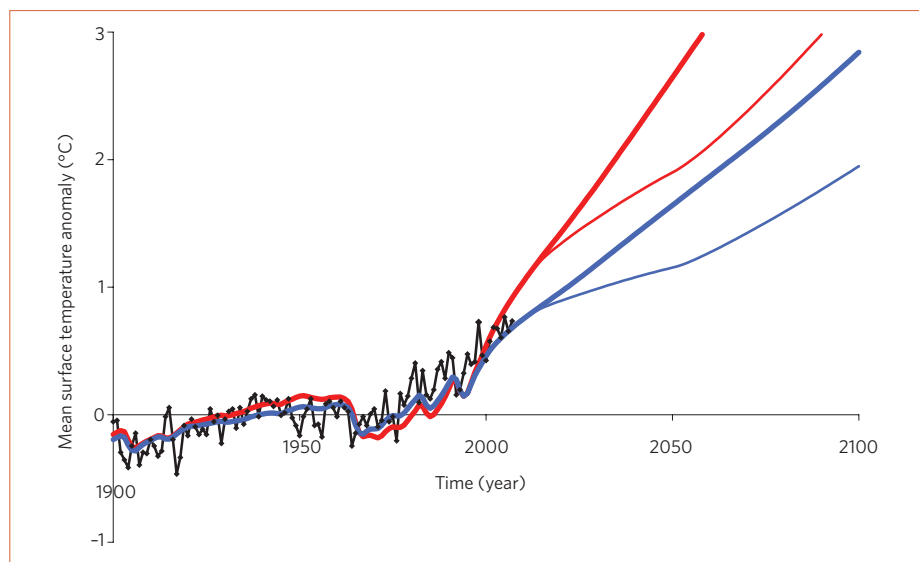
Short-lived greenhouse gases and black-carbon aerosols have contributed to past climate warming. Curbing their emissions and quantifying the forcing by all short-lived components could both mitigate climate change in the short term and help to refine projections of global warming.

Earth's climate can only be stabilized by bringing carbon dioxide emissions under control in the twenty-first century. But rolling back anthropogenic emissions of several short-lived atmospheric pollutants that lead to warming — such as methane, tropospheric ozone precursors and black-carbon aerosols — could significantly reduce the rate of climate warming over the next few decades<sup>1–3</sup>. However, other short-lived pollutants, particularly scattering aerosols, cool the climate; reducing these will tend to increase the rate of warming<sup>4,5</sup>.

It is at present impossible to accurately determine climate sensitivity (defined as the equilibrium warming in response to a doubling of atmospheric carbon dioxide concentrations) from past records, partly because carbon dioxide and short-lived species have increased together over the industrial era. Warming over the past 100 years is consistent with high climate sensitivity to atmospheric carbon dioxide combined with a large cooling effect from short-lived aerosol pollutants, but it could equally be attributed to a low climate sensitivity coupled with a small effect from aerosols. These two possibilities lead to very different projections for future climate change (Fig. 1).

We argue that to distinguish between these possibilities, and to provide short-term relief from climate warming, the short-lived compounds that induce warming need to be brought under control within a timescale of a few decades. The resulting changes in atmospheric composition and climate forcing must be accurately measured and modelled for the duration of these emissions reductions. Following this strategy, we will then be able to disentangle the warming and cooling contributions from carbon dioxide and short-lived pollutants, hence placing much tighter constraints on climate sensitivity, and therefore on future climate projections.

Of the short-lived species, methane, tropospheric ozone and black carbon



**Figure 1** | Temperature anomalies, compared with the average for 1950–1980, from observations of global mean surface air temperature (black diamonds) and from climate model simulations for two values of climate sensitivity<sup>12</sup>. Warming projections vary dramatically between a climate sensitivity of 5 °C (upper red curve), and 2 °C (upper blue curve), for a simulation based on an IPCC scenario with high emissions (A2)<sup>4,5</sup>. Linearly decreasing the total anthropogenic radiative forcing owing to methane, tropospheric ozone and black carbon — starting in 2010 and achieving pre-industrial levels by 2050 — results in significant near-term climate mitigation (lower blue and red curves, respectively).

are key contributors to global warming, augmenting the radiative forcing of carbon dioxide by 65%. Others — such as sulphate, nitrate and organic aerosols — cause a negative radiative forcing, offsetting a fraction of the warming owing to carbon dioxide<sup>6</sup>. Yet other short-lived species, such as nitrogen oxides, carbon monoxide and volatile organic compounds, can modify the abundance of both the climate-warming and climate-cooling compounds, and thereby affect climate change.

Quantifying the combined impact of short-lived species on Earth's radiative forcing is complex. Short-lived pollutants — particularly those with an atmospheric lifetime of less than two

months — tend to be poorly mixed, and concentrate close to their sources. This uneven distribution, combined with physical and chemical heterogeneities in the atmosphere, means that the impact of short-lived species on radiative forcing can vary by more than a factor of ten with location or time of emission<sup>7,8</sup>. The situation is further complicated by nonlinear chemical reactions between short-lived species in polluted areas, as well as by the interactions of clouds with aerosols and ozone. These processes add further uncertainty to the estimates of radiative forcing.

It is not clear how to reduce short-lived species to afford the largest benefits to climate change mitigation under the

present conditions. Nor do we know how the relative influences of various species may change in a warming climate. Finally, many short-lived pollutants will be controlled in the future for different reasons, namely to alleviate health impacts or damage to crops and natural ecosystems. The impacts of such improvements to air quality on climate change are poorly understood, and evaluation of potential climate impacts often neglects or insufficiently considers co-emitted species<sup>9</sup>.

These uncertainties in atmospheric chemistry and physics must be reduced to build an optimal control strategy for short-lived pollutants that affect the climate. We propose that, given a focused effort including atmospheric observations and sensitivity studies using climate models, the questions needed to address an optimal strategy can be answered within the time frame of the Fifth Assessment from IPCC, that is, by 2013. Following that, a science-based strategy for the reduction of short-lived species can be implemented, together with measurements and modelling

to quantify their climate forcing. Indeed, the near-term benefits of controlling these compounds are increasingly being considered in policy discussions<sup>10,11</sup>.

Although the precise contribution of short-lived pollutants to climate forcing is uncertain, it is clear that anthropogenic emissions of methane and black carbon, and the precursors of ozone and aerosols, have in part controlled climate change over the past century. With a clear understanding of how large these contributions to radiative forcing are, we can constrain climate sensitivity to atmospheric carbon dioxide concentrations. □

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## References

1. Hansen, J. E. & Sato, M. *Proc. Natl Acad. Sci. USA* **98**, 14778–14783 (2001).
2. Jackson, S. C. *Science* **326**, 526–527 (2009).
3. Molina, M. *et al. Proc. Natl Acad. Sci. USA* **106**, 20616–20621 (2009).
4. Arneeth, A. *et al. Science* **326**, 672–673 (2009).
5. Fuglestedt, J. *et al. Environ. Sci. Technol.* **43**, 9057–9062 (2009).
6. Forster, P. *et al. in IPCC Climate Change 2007: The Physical Science Basis* (eds Solomon, S. *et al.*) 129–234 (Cambridge Univ. Press, 2007).
7. Wild, O., Prather, M. J. & Akimoto, H. *Geophys. Res. Lett.* **28**, 1719–1722 (2001).
8. Stevenson, D. S. & Derwent, R. G. *Geophys. Res. Lett.* **36**, L17810 (2009).
9. Kopp, R. E. & Mauzerall, D. L. *Proc. Natl Acad. Sci. USA* **107**, 11703–11708 (2010).
10. <http://go.nature.com/Mm3J3e>
11. [www.uncece.org/press/pr2010/10env\\_p20e.htm](http://www.uncece.org/press/pr2010/10env_p20e.htm)
12. Hoffert, M. I., Callegari, A. J. & Hsieh, C.-T. *J. Geophys. Res.* **85**, 6667–6679 (1980).

Published online: 1 August 2010