ipcc

INTERGOVERNMENTAL PANEL ON climate change

CLIMATE CHANGE 2013

The Physical Science Basis

WG I

WORKING GROUP I CONTRIBUTION TO THE FIFTH ASSESSMENT REPORT OF THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE

WMO UNEP

7

Clouds and Aerosols

Coordinating Lead Authors:

Olivier Boucher (France), David Randall (USA)

Lead Authors:

Paulo Artaxo (Brazil), Christopher Bretherton (USA), Graham Feingold (USA), Piers Forster (UK), Veli-Matti Kerminen (Finland), Yutaka Kondo (Japan), Hong Liao (China), Ulrike Lohmann (Switzerland), Philip Rasch (USA), S.K. Satheesh (India), Steven Sherwood (Australia), Bjorn Stevens (Germany), Xiao-Ye Zhang (China)

Contributing Authors:

Govindasamy Bala (India), Nicolas Bellouin (UK), Angela Benedetti (UK), Sandrine Bony (France), Ken Caldeira (USA), Anthony Del Genio (USA), Maria Cristina Facchini (Italy), Mark Flanner (USA), Steven Ghan (USA), Claire Granier (France), Corinna Hoose (Germany), Andy Jones (UK), Makoto Koike (Japan), Ben Kravitz (USA), Benjamin Laken (Spain), Matthew Lebsock (USA), Natalie Mahowald (USA), Gunnar Myhre (Norway), Colin O'Dowd (Ireland), Alan Robock (USA), Bjørn Samset (Norway), Hauke Schmidt (Germany), Michael Schulz (Norway), Graeme Stephens (USA), Philip Stier (UK), Trude Storelvmo (USA), Dave Winker (USA), Matthew Wyant (USA)

Review Editors:

Sandro Fuzzi (Italy), Joyce Penner (USA), Venkatachalam Ramaswamy (USA), Claudia Stubenrauch (France)

This chapter should be cited as:

Boucher, O., D. Randall, P. Artaxo, C. Bretherton, G. Feingold, P. Forster, V.-M. Kerminen, Y. Kondo, H. Liao, U. Lohmann, P. Rasch, S.K. Satheesh, S. Sherwood, B. Stevens and X.Y. Zhang, 2013: Clouds and Aerosols. In: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

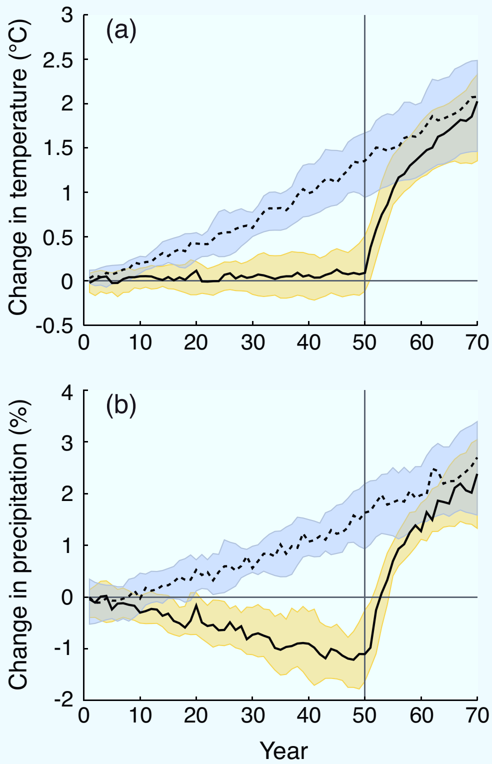
FAQ 7.3 (continued)

the diurnal cycle of surface temperature, even if the average surface temperature is unchanged. As another example, model calculations suggest that a uniform decrease in sunlight reaching the surface might offset global mean CO_2-induced warming, but some regions will cool less than others. Models suggest that if anthropogenic greenhouse warming were completely compensated by stratospheric aerosols, then polar regions would be left with a small residual warming, while tropical regions would become a little cooler than in pre-industrial times.

SRM could theoretically counteract anthropogenic climate change rapidly, cooling the Earth to pre-industrial levels within one or two decades. This is known from climate models but also from the climate records of large volcanic eruptions. The well-observed eruption of Mt Pinatubo in 1991 caused a temporary increase in stratospheric aerosols and a rapid decrease in surface temperature of about 0.5°C.

Climate consists of many factors besides surface temperature. Consequences for other climate features, such as rainfall, soil moisture, river flow, snowpack and sea ice, and ecosystems may also be important. Both models and theory show that compensating an increased greenhouse effect with SRM to stabilize surface temperature would somewhat lower the globally averaged rainfall (see FAQ 7.3, Figure 2 for an idealized model result), and there also could be regional changes. Such imprecise compensation in regional and global climate patterns makes it improbable that SRM will produce a future climate that is 'just like' the one we experience today, or have experienced in the past. However, available climate models indicate that a geoengineered climate with SRM and high atmospheric CO_2 levels would be generally closer to 20th century climate than a future climate with elevated CO_2 concentrations and no SRM.

SRM techniques would probably have other side effects. For example, theory, observation and models suggest that stratospheric sulphate aerosols from volcanic eruptions and natural emissions deplete stratospheric ozone, especially while chlorine from chlorofluorocarbon emissions resides in the atmosphere. Stratospheric aerosols introduced for SRM are expected to have the same effect. Ozone depletion would increase the amount of ultraviolet light reaching the surface damaging terrestrial and marine ecosystems. Stratospheric aerosols would also increase the ratio of direct to diffuse sunlight reaching the surface, which generally increases plant productivity. There has also been some concern that sulphate aerosol SRM would increase acid rain, but model studies suggest that acid rain is probably not a major concern since the rate of acid rain production from stratospheric aerosol SRM would be much smaller than values currently produced by pollution sources. SRM will also not address the ocean acidification associated with increasing atmospheric CO_2 concentrations and its impacts on marine ecosystems.



FAQ 7.3, Figure 2 | Change in globally averaged (a) surface temperature (°C) and (b) precipitation (%) in two idealized experiments. Solid lines are for simulations using Solar Radiation Management (SRM) to balance a 1% yr^{-1} increase in CO_2 concentration until year 50, after which SRM is stopped. Dashed lines are for simulations with a 1% yr^{-1} increase in CO_2 concentration and no SRM. The yellow and grey envelopes show the 25th to 75th percentiles from eight different models.

Without conventional mitigation efforts or potential CDR methods, high CO_2 concentrations from anthropogenic emissions will persist in the atmosphere for as long as a thousand years, and SRM would have to be maintained as long as CO_2 concentrations were high. Stopping SRM while CO_2 concentrations are still high would lead to a very rapid warming over one or two decades (see FAQ7.3, Figure 2), severely stressing ecosystem and human adaptation.

If SRM were used to avoid some consequences of increasing CO_2 concentrations, the risks, side effects and shortcomings would clearly increase as the scale of SRM increase. Approaches have been proposed to use a time-limited amount of SRM along with aggressive strategies for reducing CO_2 concentrations to help avoid transitions across climate thresholds or tipping points that would be unavoidable otherwise; assessment of such approaches would require a very careful risk benefit analysis that goes much beyond this Report.

and a warmer North Pacific adjacent to a cooler northwestern Canada, produced a SST response with a La Niña-like pattern. One study has noted regional shifts in the potential hurricane intensity and hurricane genesis potential index in the Atlantic Ocean and South China Sea in response to cloud brightening (Baughman et al., 2012), due primarily to decreases in vertical wind shear, but overall the investigation and identification of robust side effects has not been extensively explored.

Irvine et al. (2011) tested the impact of increasing desert albedo up to 0.80 in a climate model. This cooled surface temperature by –1.1°C (versus –0.22°C and –0.11°C for their largest crop and urban albedo change) and produced very significant changes in regional precipitation patterns.

7.7.4 Synthesis on Solar Radiation Management Methods

Theory, model studies and observations suggest that some SRM methods may be able to counteract a portion of global warming effects (on temperature, sea ice and precipitation) due to high concentrations of anthropogenic GHGs (*high confidence*). But the level of understanding about SRM is low, and it is difficult to assess feasibility and efficacy because of remaining uncertainties in important climate processes and the interactions among those processes. Although SRM research is still in its infancy, enough is known to identify some potential benefits, which must be weighed against known side effects (there could also be side effects that have not yet been identified). All studies suggest there would be a small but measurable decrease in global precipitation from SRM. Other side effects are specific to specific methods, and a number of research areas remain largely unexplored. There are also features that develop as a consequence of the combination of high CO_2 and SRM (e.g., effects on evapotranspiration and precipitation). SRM counters only some consequences of elevated CO_2 concentrations; it does not in particular address ocean acidification.

Many model studies indicate that stratospheric aerosol SRM could counteract some changes resulting from GHG increases that produce a RF as strong as 4 W m^{-2} (*medium confidence*), but they disagree on details. Marine cloud brightening SRM has received less attention, and there is no consensus on its efficacy, in large part due to the high level of uncertainty about cloud radiative responses to aerosol changes. There have been fewer studies and much less attention focused on all other SRM methods, and it is not currently possible to provide a general assessment of their specific efficacy, scalability, side effects and risks.

There is robust agreement among models and *high confidence* that the compensation between GHG warming and SRM cooling is imprecise. SRM would not produce a future climate identical to the present (or pre-industrial) climate. Nonetheless, although models disagree on details, they consistently suggest that a climate with SRM and high atmospheric CO_2 levels would be closer to that of the last century than a world with elevated CO_2 concentrations and no SRM (Lunt et al., 2008; Ricke et al., 2010; Moreno-Cruz et al., 2011), as long as the SRM could be continuously sustained and calibrated to offset the forcing by GHGs. Aerosol-based methods would, however, require a continuous program of replenishment to achieve this. If CO_2 concentrations and SRM were increased in concert, the risks and residual climate change produced by the imprecise compensation between SRM and CO_2 forcing would also increase. If SRM were terminated for any reason, a rapid increase in surface temperatures (within a decade or two) to values consistent with the high GHG forcing would result (*high confidence*). This rate of climate change would far exceed what would have occurred without geoengineering, causing any impacts related to the rate of change to be correspondingly greater than they would have been without geoengineering. In contrast, SRM in concert with aggressive CO_2 mitigation might conceivably help avoid transitions across climate thresholds or tipping points that would be unavoidable otherwise.

Acknowledgements

Thanks go to Anne-Lise Barbanes (IPSL/CNRS, Paris), Bénédicte Fisset (IPSL/CNRS, Paris) and Edwina Berry for their help in assembling the list of references. Sylvaine Ferrachat (ETH Zürich) is acknowledged for her contribution to drafting Figure 7.19.