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# Geoengineering to Avoid Overshoot: An Analysis of Uncertainty

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Even if a drastic 50% CO2-equivalent emissions reduction is achieved by year 2050, the chances of exceeding a 2°C warming are still substantial due to the uncertainty in the climate system (Meinshausen et al., 2009). Moreover, a strong mitigation is accompanied by overshoot, in which the global-mean temperature temporarily exceeds the target before arriving there.

We are motivated by the question as to how much geoengineering would be considered if it were to be used to avoid overshoot even combined with a strong mitigation? How serious would the side effects be expected? This study focuses on stratospheric sulfur injections among other geoengineering proposals, the idea of which has been put forward by Crutzen (2006) and reviewed by Rasch et al. (2008). There are a number of concerns over geoengineering (e.g. Robock, 2008). But the concept of geoengineering requires further research (AMS, 2009). Studying geoengineering may be instructive to revisit the importance of mainstream mitigation strategies.

The motivations above led to the following two closely linked studies:

1) Mitigation and Geoengineering
The first study investigates the magnitude and start year of geoengineering intervention with the intent to avoid overshoot. This study explores the sensitivity of geoengineering profile to associated uncertainties in the climate system (climate sensitivity, tropospheric aerosol forcing, and ocean diffusivity) and in mitigation scenarios (target uncertainty (450ppm CO2-eq and 400ppm CO2-eq) and baseline uncertainty (A2, B1, and B2)). This study builds on Wigley's premise that demonstrated a basic potential of such a combined mitigation/geoengineering approach (Wigley, 2006) – however it did not examine the sensitivity of the climate response to any underlying uncertainties.

This study uses a set of GGI low mitigation scenarios generated from the MESSAGE model (Riahi et al., 2007). The reduced-complexity climate and carbon cycle model ACC2 (Tanaka, 2008; Tanaka et al., 2009) is employed to calculate climate responses including associated uncertainty and to estimate geoengineering profiles to cap the warming at 2ºC since preindustrial. The inversion setup for the model ACC2 is used to estimate the uncertain parameters (e.g. climate sensitivity) against associated historical observations (e.g. global-mean surface air temperature).

Our preliminary results show that under climate and scenario uncertainties, a geoengineering intervention to avoid an overshoot would be with medium intensity in the latter half of this century ($\approx$ 1 Mt. Pinatubo eruption every 4 years in terms of stratospheric sulfur injections). The start year of geoengineering intervention does not significantly influence the long-term geoengineering profile. However, a geoengineering intervention of the medium intensity could bring about substantial environmental side effects such as the destruction of stratospheric ozone. Our results point to the necessity to pursue persistently mainstream mitigation efforts.

2) Pollution Abatement and Geoengineering
The second study examines the potential of geoengineering combined with air clean policy. A drastic air pollution abatement might result in an abrupt warming because it would suddenly remove the tropospheric aerosols

which partly offset the background global warming (e.g. Andreae et al, 2005, Raddatz and Tanaka, 2010). This study investigates the magnitude of unrealized warming under a range of policy assumptions and associated uncertainties. Then the profile of geoengineering is estimated to suppress the warming that would be accompanied by clean air policy. This study is the first attempt to explore uncertainty in the warming caused by clean air policy – Kloster et al. (2009), which assess regional changes in climate and hydrological cycle, has not however included associated uncertainties in the analysis.

A variety of policy assumptions will be devised to represent various degrees of air pollution abatement. These assumptions are used in the GAINS model to generate pollutants emissions scenarios. Such scenarios are combined with a set of GGI low mitigation scenarios and prescribed to the climate and carbon cycle model ACC2. ACC2 is employed to quantify the warming due to air pollution abatement and the geoengineering profile to avoid such a warming. Furthermore, the implications of such geoengineering interventions (e.g. ecosystem impact and adaptation capacity) are examined.

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