Geoengineering efficiency: Preliminary assessment with a climate model of intermediate complexity

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Recently, a renewed interest appeared in an emploiment of the M.I. Budyko's [3] suggestion to load sulphur particles in the stratosphere to enhance the Earth's albedo and to mitigate the global warming, an approach of geoengineering [7, 4, 9]. In the present paper, the climate model of intermediate complexity developed at the A.M. Obukhov Insitute of Atmospheric Physics RAS (IAP RAS CM) [8] is used to estimate geoengineering efficiency to mitigate climate changes.

In the IAP RAS CM, the value of extinction coefficient $k_{e,strat}$ for stratospheric sulphates is derived from estimations for the Mt. Pinatubo eruption in 1991. During this eruption, total loading of sulphates in the stratosphere is estimated to be 10 TgS [1] and maximum global mean optical depth for volcanic aerosols is estimated to be close to 0.15 [6]. This leads to $k_{e,strat} = 7.6\ m^2/gS$.

A simulation is performed with the IAP RAS CM forced by the anthropogenic emissions of CO_2 and CH_4 (their concentrations are computed interactively in the model by modules forcarbon and methane cycles) and atmospheric concentration of N_2O and sulphate aerosols in accordance to historical data for the 19th–20th centuries and in accordance to scenario SRES A1B for the 21st century. More detailed description of these forcing scenarios is reported in [5].

Without a geoengineering mitigation, near–surface atmosphere warms by about 2.8 K till the end of the 21st century with respect to the equilibrated preindustrial state, and by about 2.1 K with respect to the late 20th century.

For a geoengeenering mitigaton, local concentratation of stratospheric sulphates is computed as a product of their gloobal loading $M_{geoeng,g}$ and a prescribed latitudinal profle$f(\phi)$. This distribution is chosen either uniform or triangular with respect to sine of latitude (with zeroes at the North and South Poles and with a maximum at a prechosen latitude $\phi_{m,1}$ varying between 50^oS and 70^oN) or trapesoidal (with zeroes at the North and South Poles and a with flat maximum in the latitudinal range $\phi^o_{m,2}S - \phi^o_{m,2}N$; $\phi_{m,2} = 0^o - 70^o$). Global loading of anthropogenic stratospheric sulphates is modelled by solving equation

$$\frac{dM_{geoeng,g}}{dt} = E_{geoeng,g} - \frac{M_{geoeng,g}}{\tau_{strat}}$$

where global geoengineering emissions $E_{geoeng,g}$ amount $1 - 2\ TgS/yr$ [4, 9] starting from year 2012 and equal to zero before this date. The lifetime of stratospheric sulphates τ_{strat} is set to 2 yr [7].

After a geoengineering emissions start, difference in globally and annually averaged surface air temperature, $\Delta T_{geoeng,g}$ between the simulation pairs with and without geoengineering emissions becomes stationary within few decades and changes only marginally after 2050's. For $E_{geoeng,g} = 1\ TgS/yr$ ($E_{geoeng,g} = 2\ TgS/yr$) in the late 21st century it amounts $0.07 - 0.11\ K$ ($0.13 - 0.22\ K$) depending on $f(\phi)$ and scaling linearly between different values of $E_{geoeng,g}$.

To assess the sensitivity of the obtained results to this value, $k_{e,strat}$ varied in additional simulations between 5 m^2/gS and 10 m^2/gS in the performed simulations with the IAP RAS CM. In this, respective ranges of $\Delta T_{geoeng,g}$ widen to $0.04 - 0.15\ K$ ($0.09 - 0.30\ K$).

Among the mentioned above $f(\phi)$, the most effective latitudinal distribution of aerosol loading is either triangular with $\phi_{m,1}$ in the range beteen 50^oN and 70^oN or uniform distribution. The least effective are trapesoidal distributions especially that with $\phi_{m,2} = 30^o$. In terms of $\Delta T_{geoeng,g}$, geoengineering efficiency differs between the most and the least effecitve $f(\phi)$ by a factor of 1.5.

According to the obtained results, it is possible to slow down current anthropogenic warming by applying geoengineering approach. However, the residual warming is still substantinal. For the SRES A1B scenario this residual warming in the 21st century is estimated to be greater than 1.8 K.

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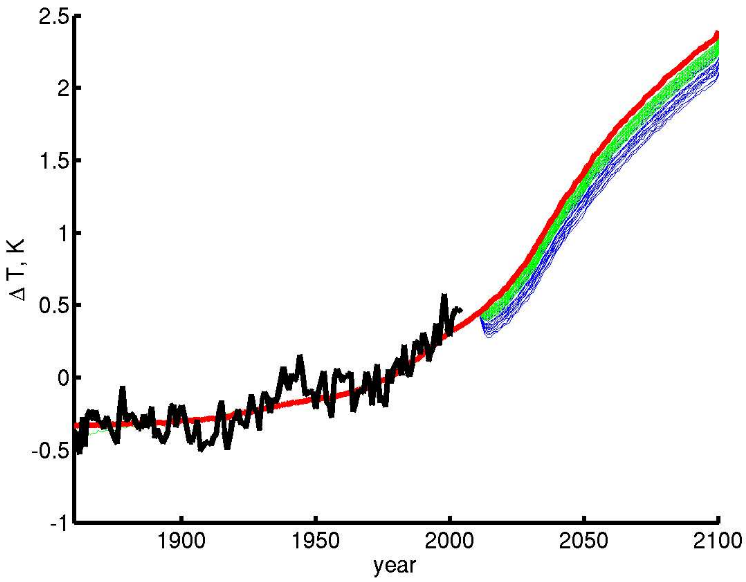

Figure 1: Change of globally and annually averaged surface air temperature as simulated by the IAP RAS CM with the combined anthropogenical historical+SRES A1B forcings in comparison to the observations [2] (black line) greenhouse gases and sulphate aerosol forcings (red curve) and geoengineering ensembles for $E_{geoeng,g} = 1\ TgS/yr$ and $E_{geoeng,g} = 2\ TgS/yr$ (green and blue lines respectively).

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