# Geoengineering efficiency: Preliminary assessment for year 2100 with an energy-balance climate model

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One of the possible solution of global warming is a loading sulphur particles in the stratosphere to enhance the Earth's albedo (Budyko, 1974) recently entitled as geoengineering (Izrael, 2005; Crutzen, 2006; Wigley, 2006; Mokhov and Eliseev, 2008). In the present paper, we estimate geoengineering efficiency by using an energy-balance climate model.

The governing equation for globally averaged model reads

$$C\frac{dT}{dt} = S(1-\alpha_A(T)) - (A+BT)\eta_C(q) - F_{strat}\,, \qquad (1)$$

where $T$ is globally and annually averaged surface air temperature, $C$ is heat capacity per unit area, $t$ is time, $S$ is one quarter of the insolation at the top of the atmosphere, $\alpha_A$ is planetary albedo, $A$ and $B$ are coefficients of the linear dependence of outgoing longwave radiation (OLR) on temperature (Budyko, 1974), $\eta_C = 1 - c_0 \ln\frac{q(t)}{q_0}$ is OLR greenhouse correction factor, $q$ is $CO_2$ atmospheric content, $q_0$ is its initial value, $c_0 = 1{,}4\cdot 10^{-2}$ (Mokhov, Petukhov, 1978), $F_{strat}$ is mitigation geoengineering forcing. In the linearised setting, this model has a solution which can be represented as a sum of two responses, one due to greenhouse forcing and another due to geoengineering mitigation:

$$T = T_C + T_{strat}\ . \qquad (2)$$

If the buildup of greenhouse gases in the atmosphere (being expressed via "effective $CO_2$" (IPCC, 2001)) has an exponential form: $q = q_0 \cdot \exp(t/t_p)$, ($t_p$ is time scale of $CO_2$ atmospheric content change), then the solutions are:

$$T_C = -\frac{\Delta T_{2xCO_2}}{t_p \ln 2}\left(\frac{1}{p}(e^{pt}-1) - t\right) \qquad (3)$$

$$T_{strat} = \frac{1}{p}\left(-\frac{a\cdot k_e M_{strat}}{4\pi R^2 C}\right)(e^{pt}-1)\ . \qquad (4)$$

In Eq.(3), $\Delta T_{2xCO_2}$ is equilibrium model's response to the doubling of $CO_2$ in the atmosphere, and $p = -\frac{S(1-\alpha_A)c_O \ln 2}{C\cdot \Delta T_{2xCO_2}}$. Eq.(4) is obtained assuming that stratospheric aerosol mass is equilibrated, normaly, $M_{strat} = E_{strat}\cdot t_{strat}$. Here, $E_{strat}$ stands for geoengineering emission and $t_{strat}$ is lifetime of stratospheric aerosols, $k_e$ is a coefficient of extinction of stratospheric sulphur aerosol (it's equal 7.6m$^2$/gS).

With this model, an ensemble simulation is performed with $E_{strat}$ is varied between 0.6 MtS/yr (Izrael, 2005) up to 5 MtS/yr (including values 1-2 TgS/yr as suggested by Crutzen (2006) and Wigley (2006)) but kept independent on time, $t_{strat}$ is varied in the range 1-4 yr, $t_p$ is varied from 50 yr to 250 yr, and $\Delta T_{2xCO_2}$ is varied in the range 1.5-4.5 K which is slightly wider than the range figured in (IPCC, 2007).

Without a geoengineering mitigation, at the end of 21$^{st}$ century temperature changes by 0.5-14.0°C depending on the model parameters (Fig.1).

Fig.1 Temperatures changes in year 2100 without a geoengineering mitigation. The time scales corresponding to the SRES scenarios (taking into account $CO_2$, $CH_4$, and $N_2O$ under the “effective $CO_2$” approximation) (IPCC, 2001) are depicted by horizontal lines.

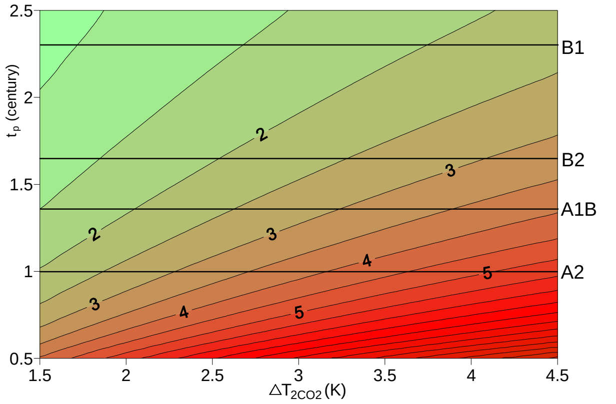
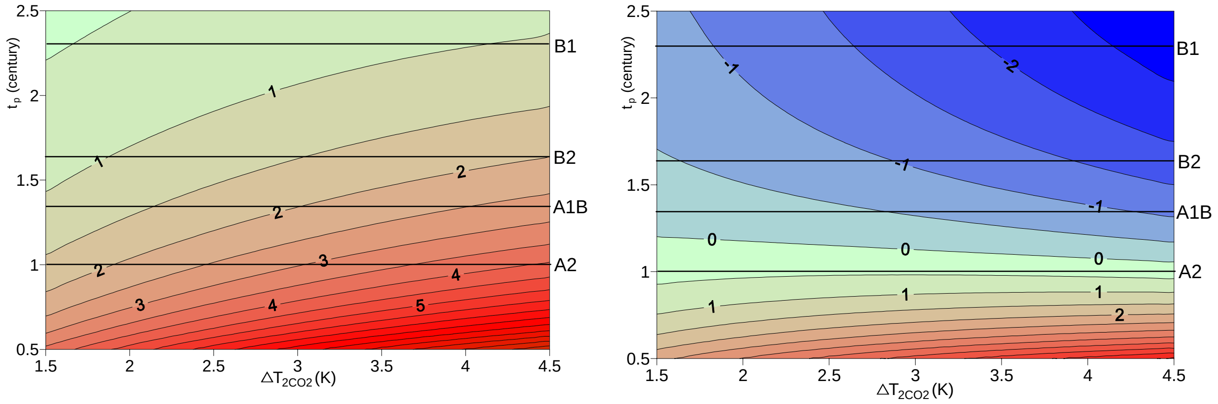



Fig.2 Temperatures changes in year 2100 with a geoengineering mitigation for $E_{strat}$ =1.0 MtS/yr (left) and $E_{strat}$ =4.0 MtS/yr (right).




According to obtained results, it is possible to slow down current anthropogenic warming by applying a geoengineering approach (Fig.2). This mitigation is very efficient (and even excessive) if geoengineering emissions and/or life time of sulphates in the stratosphere are large enough and, additionally, the $CO_2$ atmospheric buildup is not too rapid. However, for $E_{strat}$ from the lower part of the studied range, the residual warming is still substantional, especially for the scenarios with small $t_p$ (e.g., for the SRES A2 and A1B scenarios).

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## References


M.I. Budyko. *Climate Changes*. Gidrometeoizdat, Leningrad, 1974. [English transl. published in 1977 by the American Geophysical Union, Washington, D.C.].

*Climate Change 2001: The Scientific Basis, IntergovernmentalPanel on Climate Change*, Ed. by J. T. Houghton, *et al.* Cambridge Univ. Press,Cambridge, 2001.

*Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change,* Ed by S. Solomon, *et al.* Cambridge University Press, Cambridge, 2007.

P.J. Crutzen. Albedo enhancement by stratospheric sulfur injections: A contribution to resolve a policy dilemma? *Clim. Change*, 77(3-4):211–219, 2006.

Yu.A. Izrael. An efficient way to regulate global climate is the main goal of the climate problem solution. *Rus. Meteorol. Hydrol.*, 30(10):1–4, 2005.

I.I. Mokhov and A.V. Eliseev Geoengineering efficiency: Preliminary assessment with a climate model of intermediate complexity *Research Activities in Atmospheric and Oceanic Modelling*, J. Cote (ed.). 2008, this volume.

I.I. Mokhov and V.K. Petukhov. *Parameterization of outgoing longwave radiation for climate models*. Institute of Atmospheric Physics, USSR Academy of Sciences, 1978, [in Russian].

T.M.L. Wigley. A combined mitigation/geoengineering approach to climate stabilization. *Science*, 314(5798):452–454, 2006.