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Effect of Geoengineering Aerosols on Cirrus

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Introduction

- In a geoengeneering scenario a large amounts of sulphur aerosols injected in the lower stratosphere enhance the Earth's albedo (Crutzen, 2006).
- The impact of modified sulphate aerosol concentrations in the tropopause region on the formation and evolution of cirrus clouds is investigated.
- A box model is used for idealized simulations of cirrus cloud formation concentrating on moderate constant updrafts with different background aerosol mass and number concentrations in response to geoengineering measures.

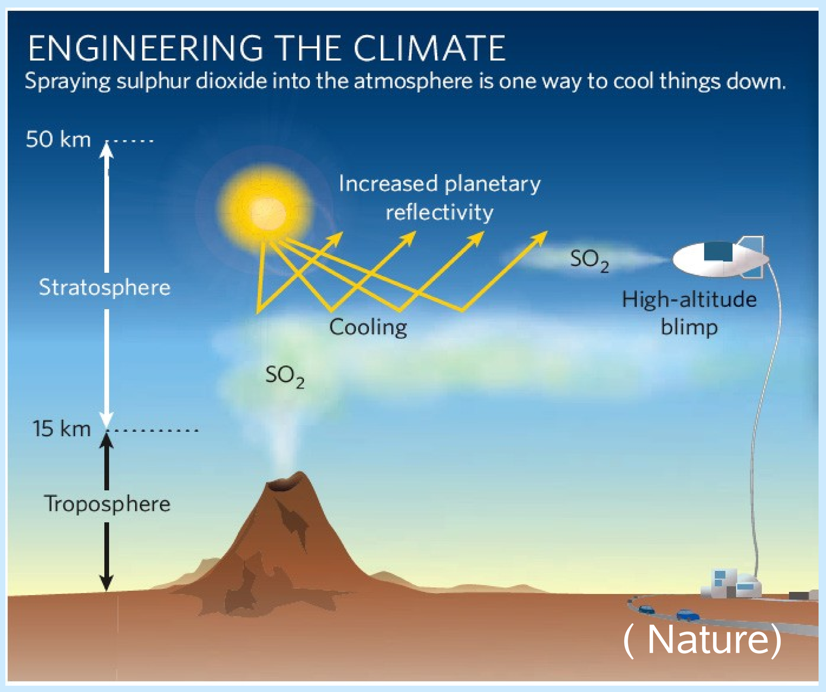
Model description (general)

Box model with bulk ice microphysics (see Spichtinger and Gierens, 2009):

- Two moment scheme (prognostic equations for ice crystal number and mass concentration; prescribed ice crystal size distribution, i.e. lognormal type with fixed width $\sigma = 1.4$)
- Arbitrary many classes of ice, discriminated by formation mechanism
- Each ice class consists of ice crystal mass and number concentration and related background aerosol mass and number concentration
- Parameterised processes: nucleation (homogeneous/heterogeneous), diffusional growth/evaporation and sedimentation
- For homogeneous nucleation the water activity based parameterisation according to Koop et al. (2000) is used
- A new concept using sedimentation fluxes is used (Spichtinger and Cziczo, 2009) allowing simulations of processes in a prescribed region of the cirrus clouds

Geoengeneering effect

- Crutzen (2006) suggested that 1-2Mt of sulphur injected into the lower stratosphere could compensate future clean air act measures and that 5-6Mt of sulphur could compensate doubling of carbon dioxide (CO_2)
- For large injections of SO_2 some sulphate aerosol particles grow to such sizes that they sediment to lower altitudes and eventually reach the troposphere, where they can be used as ice crystal nuclei or they are rapidly washed out



Setup

- Artificially produced stratospheric aerosols are modelled with the AER 2D aerosol model (Weisenstein et al., 2007).
- Geoengineering studies with continuous 1 and 5 Mt/year sulphur injection into the lower tropical stratosphere were considered.
- Box model initial conditions: layer thickness Δz = 50m, constant vertical velocity w = 1/5/10/20/50 cm/s, T = 190/210 K, p = 200/300 mb, RH_i = 100%, time step Δt = 0.1 s.
- Results are compared with the Lagrangian spectral microphysical box model (Luo et al., 2003).
- Response to temperature fluctuations caused by high-frequency waves is also analyzed (l_0=2.5e3nm, u_0=10m/s, ampl. = 100m)

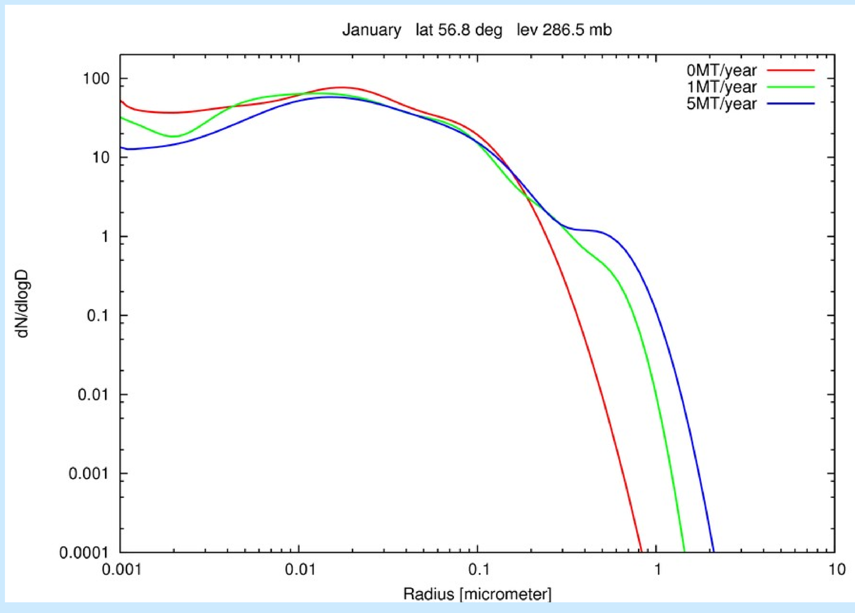


Figure 1:The size distribution of the background stratospheric aerosol particles at the 286.5 mb for different amounts of SO_2 injection obtained from the AEM 2-D aerosol model.

Comparison of bulk and spectral model results

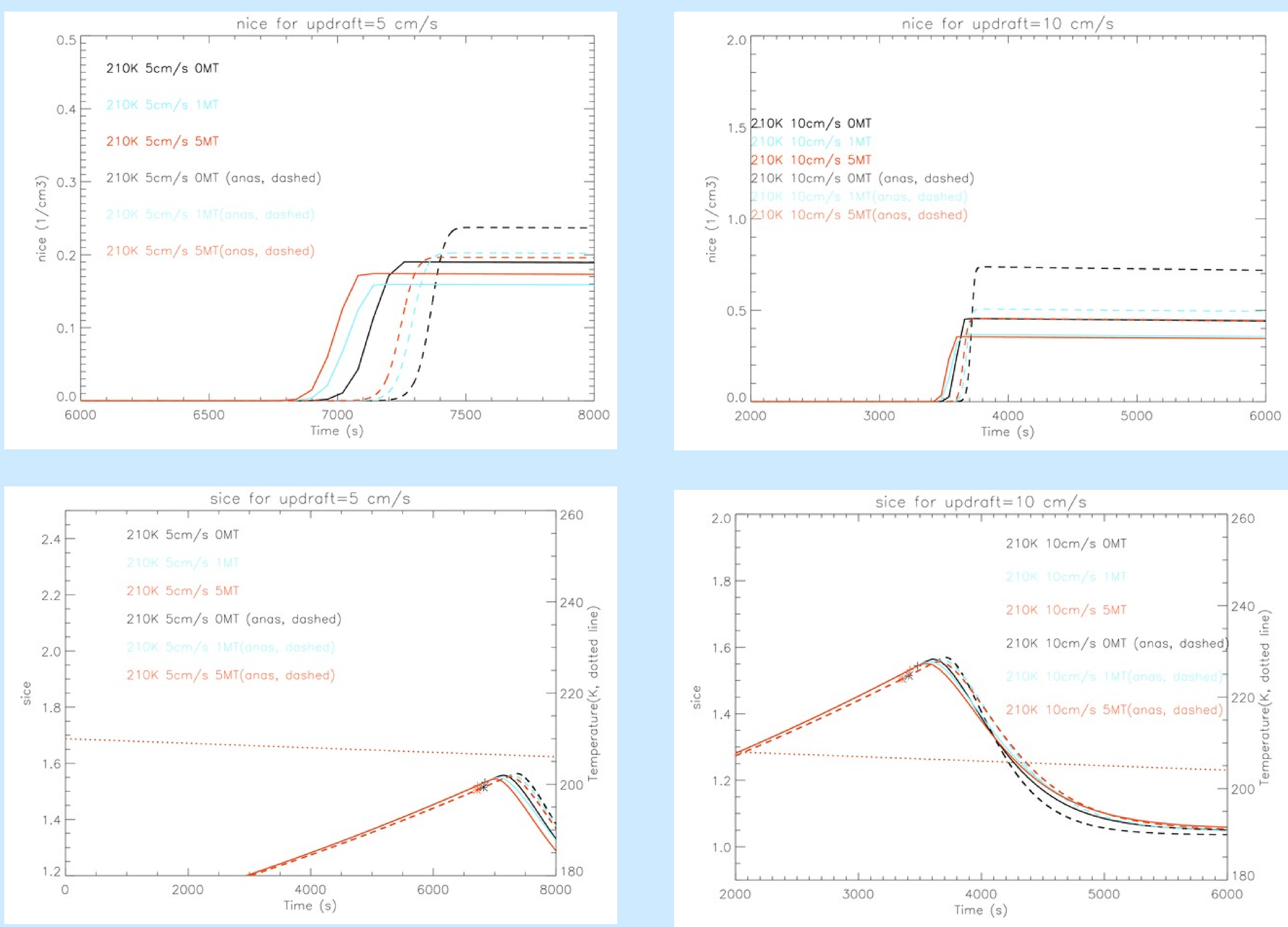


Figure 2: The evolution of relative humidity wrt ice (bottom) and ice crystal number density (per cm^3, top) for different values of constant vertical updraft (w=5cm/s, left column; w=10cm/s, right column) and initial temperature of T=210K in the mid-latitude region.

Response to temperature fluctuations

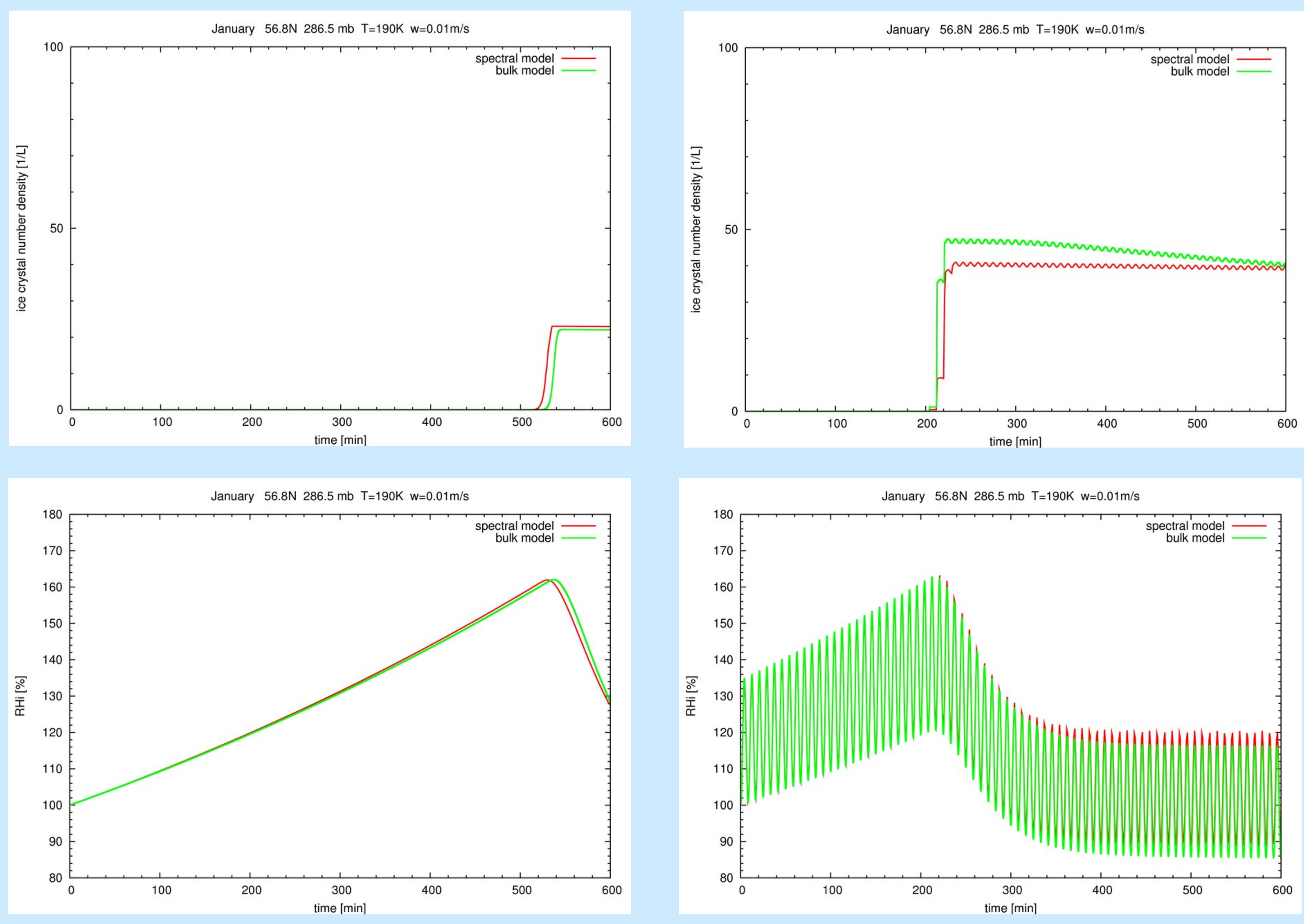


Figure 3: The evolution of relative humidity wrt ice (in %, bottom) and ice crystal number density (in L^{-1}, top) including trajectory with a slow vertical updraft w=1cm/s and a high-frequency wave. Initial temperature T=190K.

Summary

- Modified sulphate aerosol concentrations in the lower stratosphere show a significant impact on cirrus cloud formation.
- Larger aerosol particles deplete a lot of water vapour leading to decrease in ice crystal number concentration.
- The initial values of temperature and constant updraft have a great influence on the final nucleation event.
- Including high-frequency waves leads to earlier nucleation process and larger ice crystal number concentration.
- Decrease in optical depth of the cirrus cloud is significant (reduction of 20%).

Optical depth

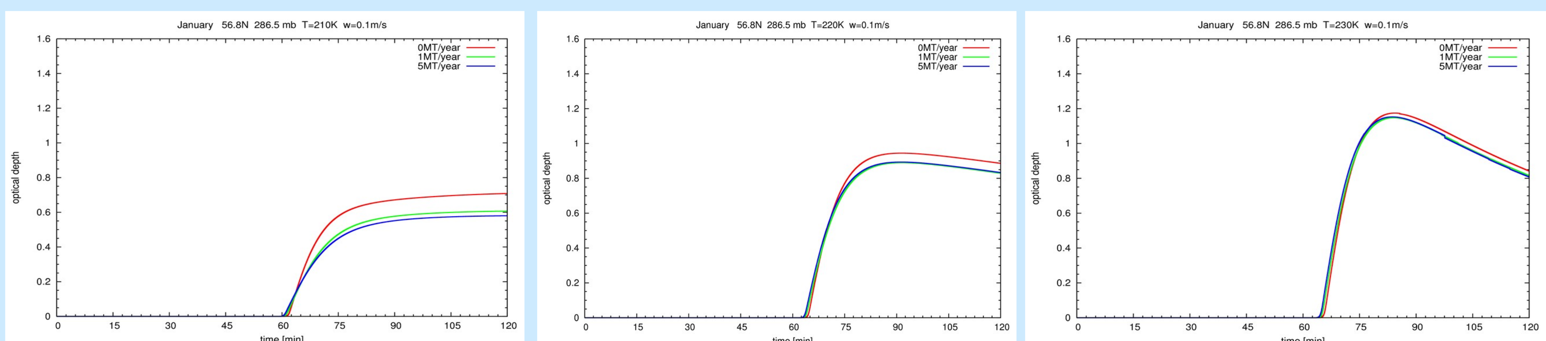


Figure 4: The evolution and decrease of optical depth with higher amount of SO_2 injected into lower stratosphere (cirrus thickness 1250m).

References

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