Size-resolved stratospheric aerosol distributions after Pinatubo derived from a coupled aerosol-chemistry-climate model

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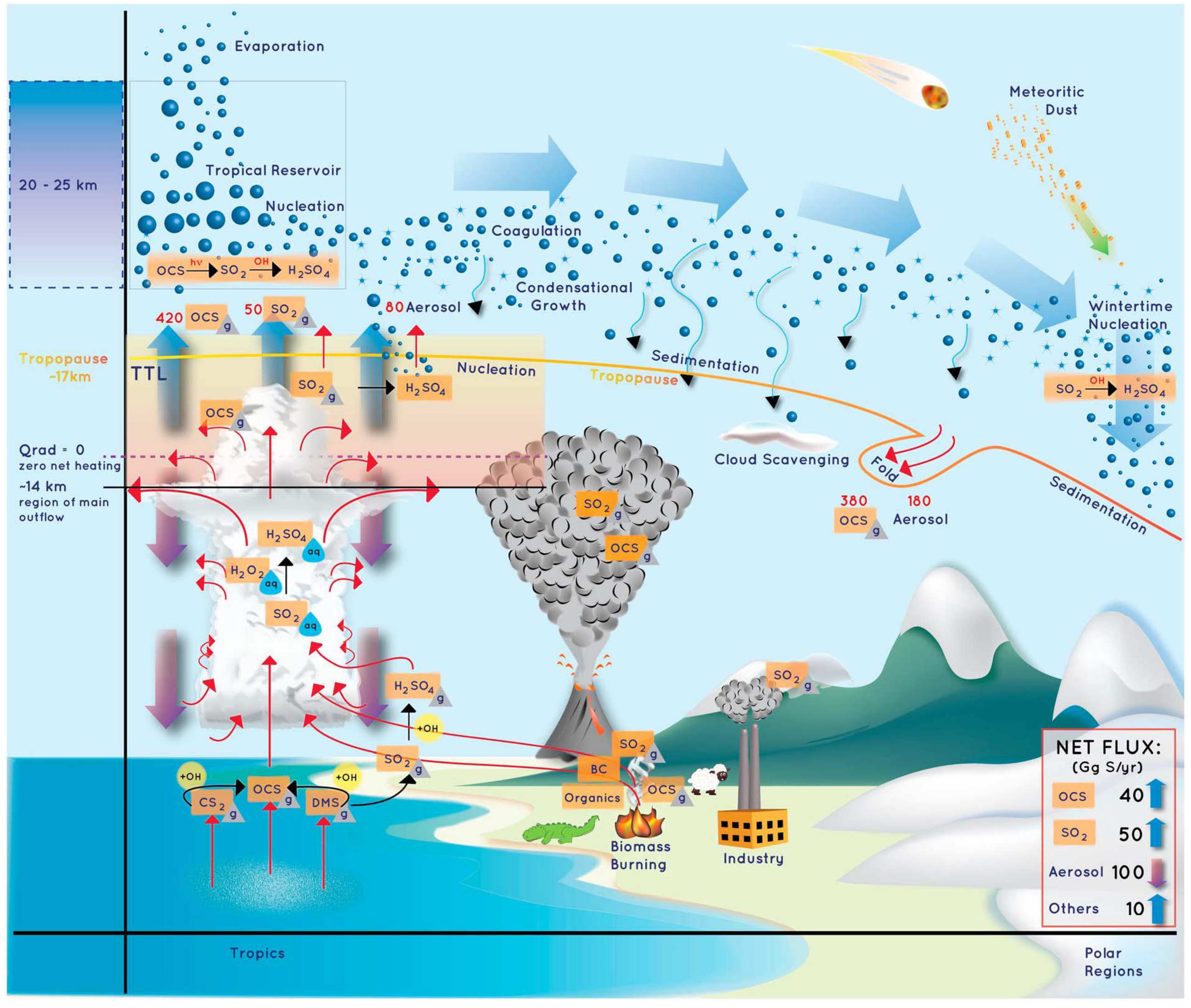


Schematic of the relevant processes that govern the stratospheric aerosol life cycle (Kremser et al., 2016, doi:10.1002/2015RG000511)

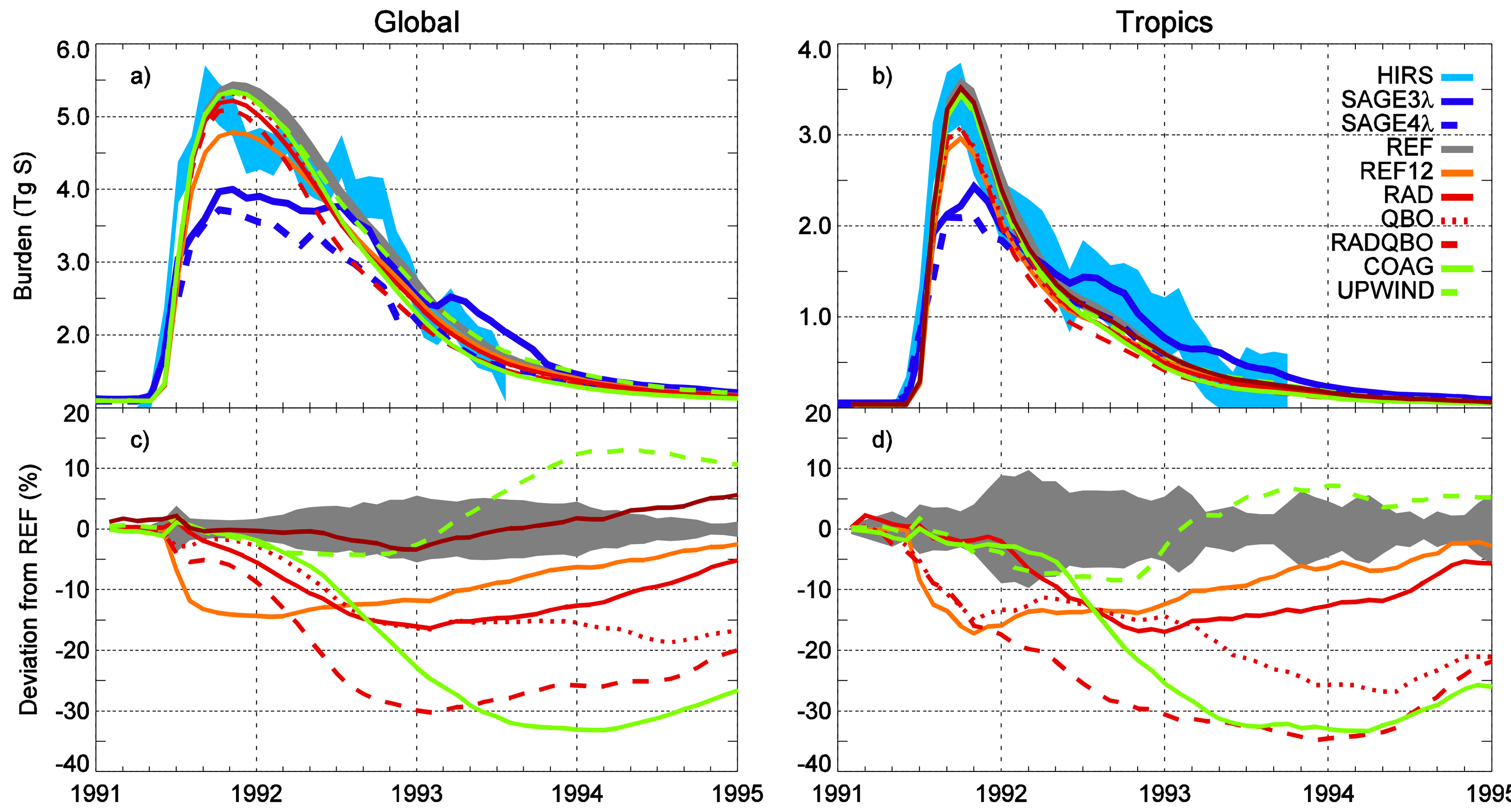
Introduction

We evaluate how the coupled aerosol-chemistry-climate model SOCOL-AER represents the influence of the 1991 eruption of Mt. Pinatubo on stratospheric aerosol loading, aerosol microphysical processes, radiative effects, and atmospheric chemistry. The aerosol module includes comprehensive sulfur chemistry and microphysics, in which the particle size distribution is represented by 40 size bins spanning radii from 0.39 nm to 3.2 µm. Radiative forcing is computed online using aerosol optical properties calculated according to Mie theory. SOCOL-AER simulations are compared with satellite and in situ measurements of aerosol parameters, temperature reanalyses, and ozone observations. In addition to the reference model configuration, we performed a series of sensitivity experiments looking at different processes affecting the aerosol layer.

Name	QBO nudged	Aerosol radiative feedback	Sedimentation scheme	Coagulation efficiency	Intensity (Tg SO_2)
REF	Yes	Yes	Walcek	α = 1 everywhere	14
REF12	Yes	Yes	Walcek	α = 1 everywhere	12
UPWIND	Yes	Yes	Upwind	α = 1 everywhere	14
RAD	Yes	No	Walcek	α = 1 everywhere	14
QBO	No	Yes	Walcek	α = 1 everywhere	14
RADQBO	No	No	Walcek	α = 1 everywhere	14
COAG	Yes	Yes	Walcek	α based on LJP	14

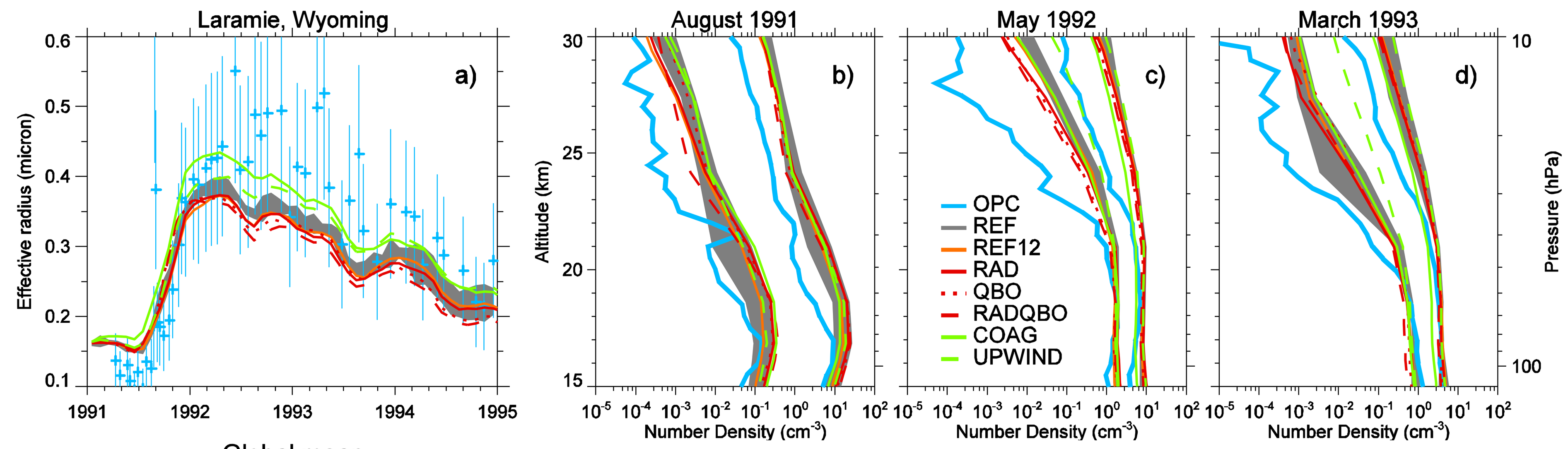
List of experiments (1991-1995, 5 ensemble members each, horizontal resolution 2.8°- 2.8°, 39 vertical levels, prescribed ocean)

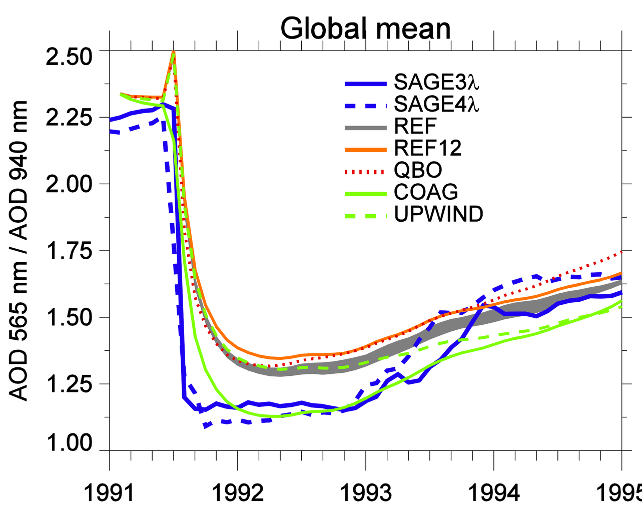
Stratospheric Burden



Evolution of model-calculated global (pole to pole, left) and tropical (20S-20N, right) stratospheric aerosol burden (Tg S) compared with the HIRS, SAGE4λ, and SAGE3λ observational data. Upper panels – absolute values, lower panels – deviation from REF in %. Grey shaded area – 2-σ uncertainty from the REF ensemble.

Size Distribution



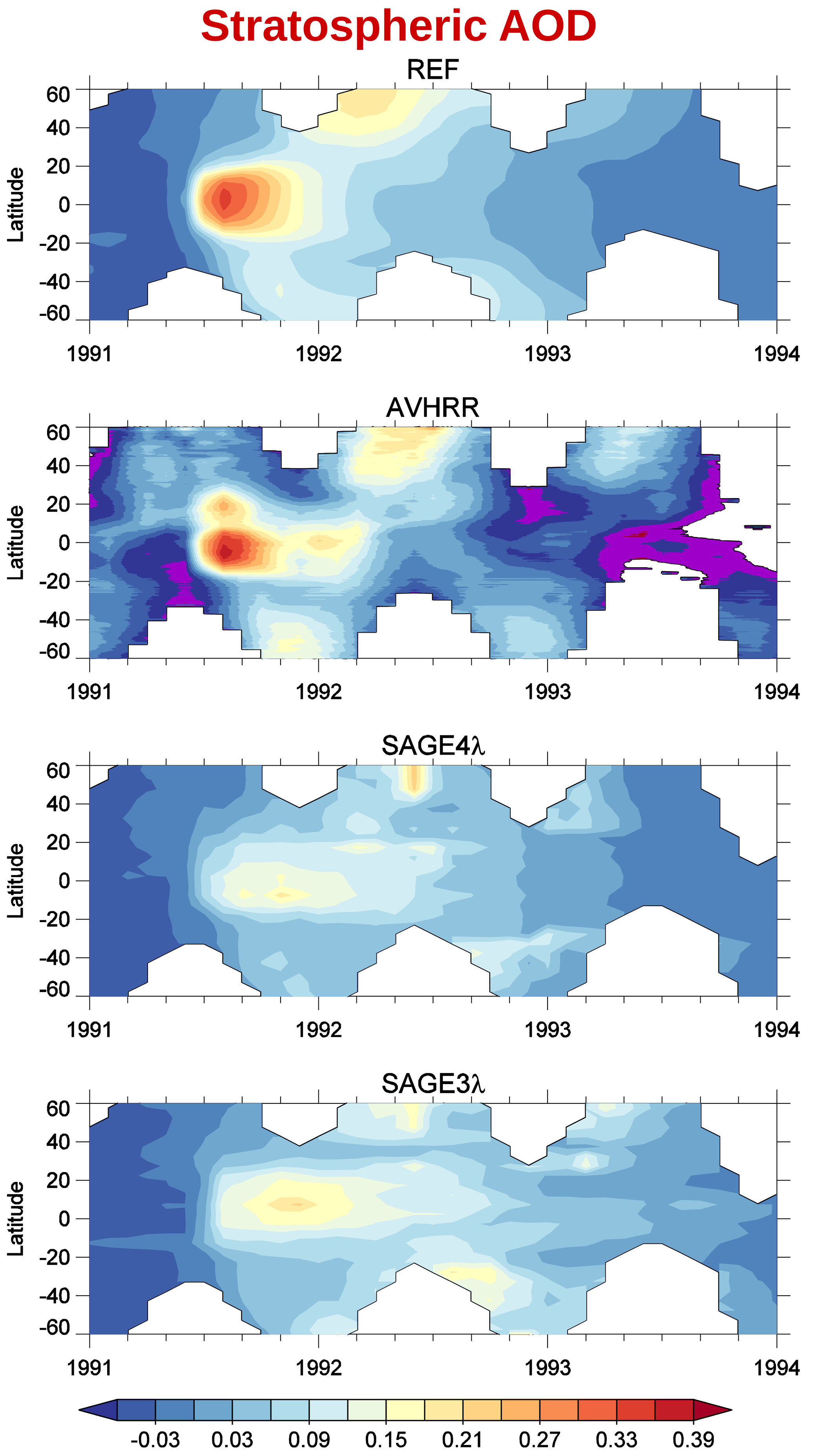


Upper panels: balloon-borne in situ OPC measurements above Lamarie, Wyoming (Deshler et al., 2003, doi:10.1029/2002JD002514), and SOCOL-AER results for stratospheric effective particle radius averaged for 14-30 km altitude (a), cumulative number distributions for two size channels with radii R > 0.15 and > 0.5 µm in August 1992, May 1992, and March 1993 (b-d).

Lower panel: comparison of remote measurements of aerosol optical depth (AOD) ratios at two wavelenghts, a proxy of particle size, with SOCOL-AER simulations.

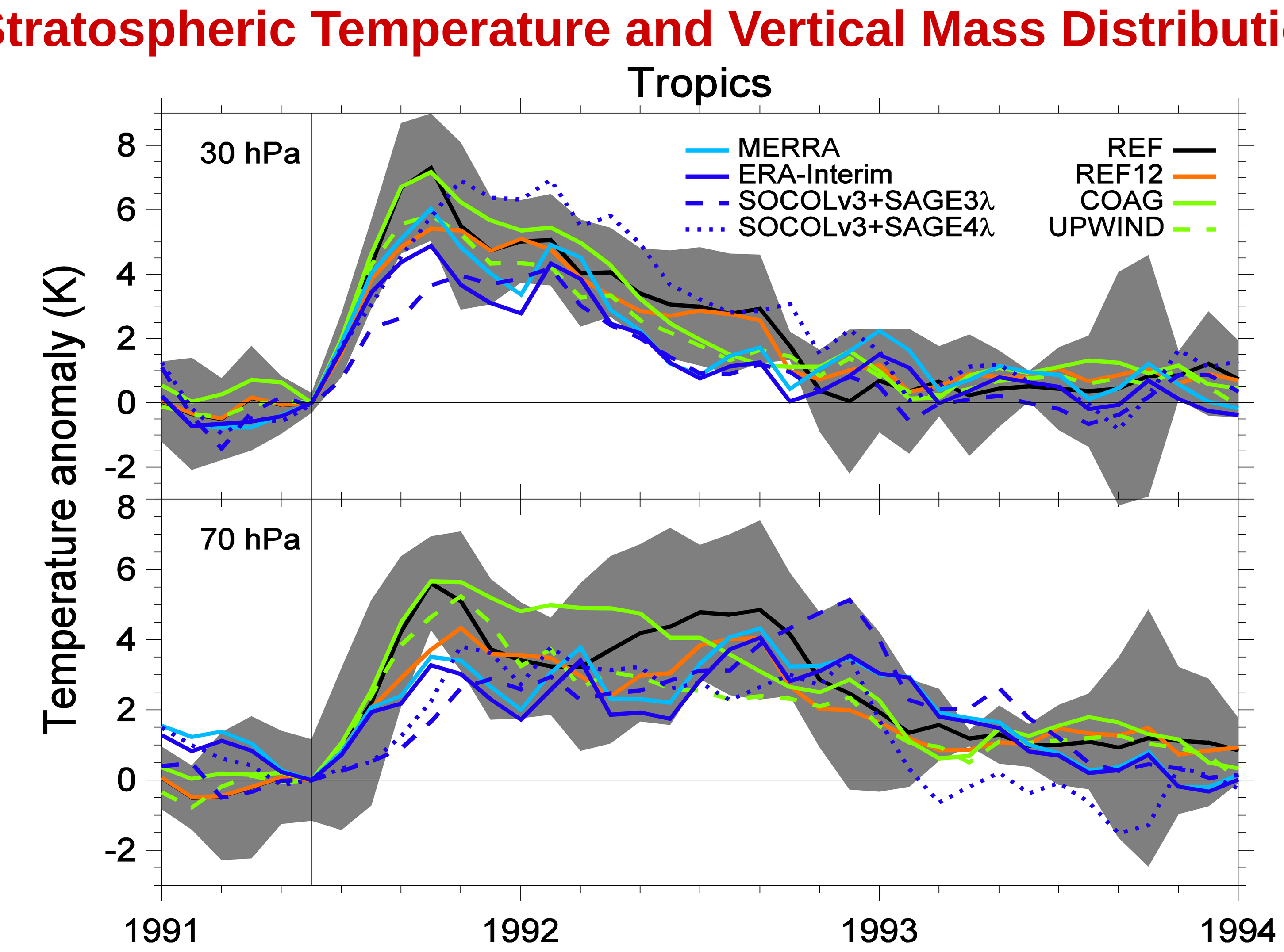
Grey shaded area: 2- σ ensemble spread of the REF experiment. All other experiments are shown as ensemble means.

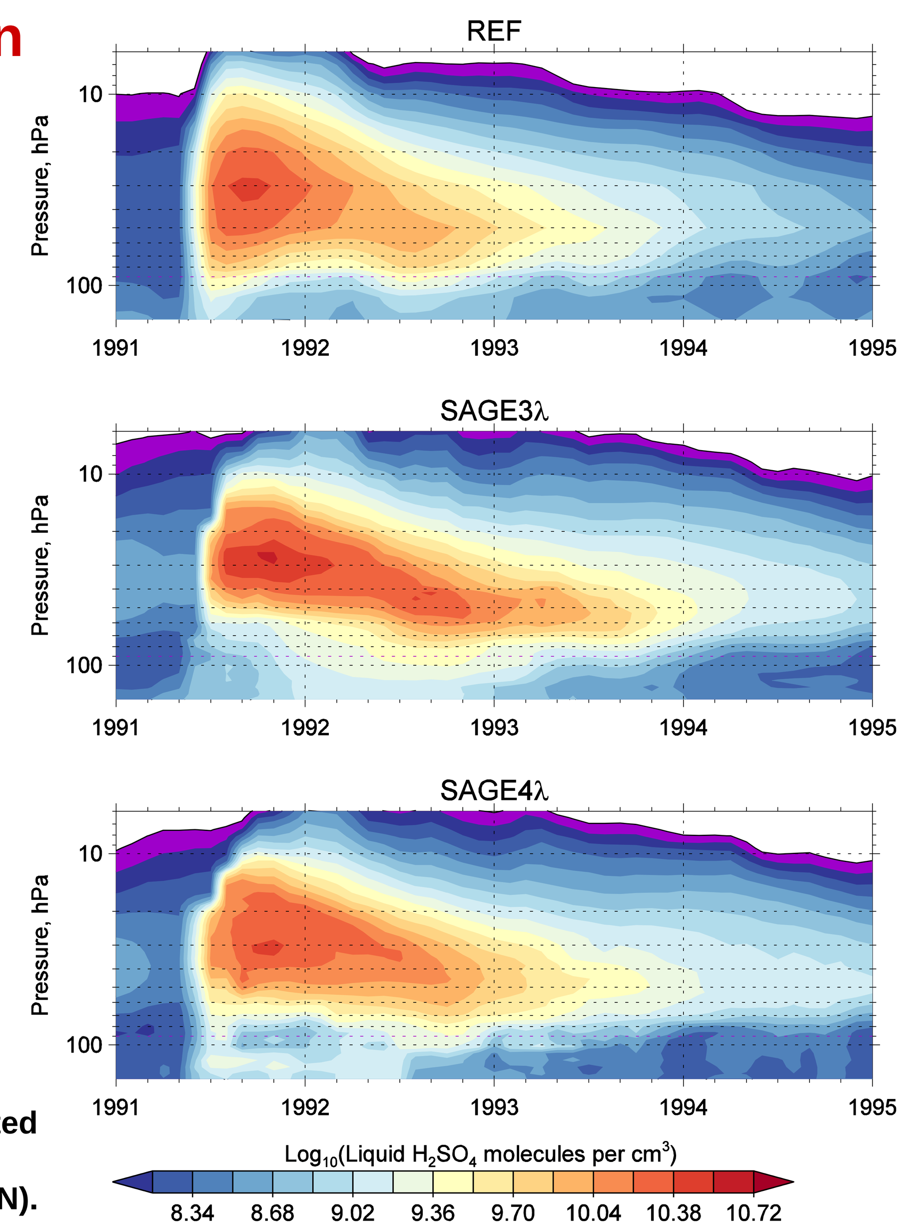
Stratospheric AOD



Monthly zonal average total AOD over oceans measured at 0.63 µm by AVHRR (Zhao et al., 2013, doi:10.1002/jgrd.50278) and calculated at 0.56 µm by SOCOL-AER and provided by SAGE3,4-λ composites. Background values are subtracted from all data sets, which may result in slightly negative values. All panels are masked at winter high latitudes where AVHRR data are missing.

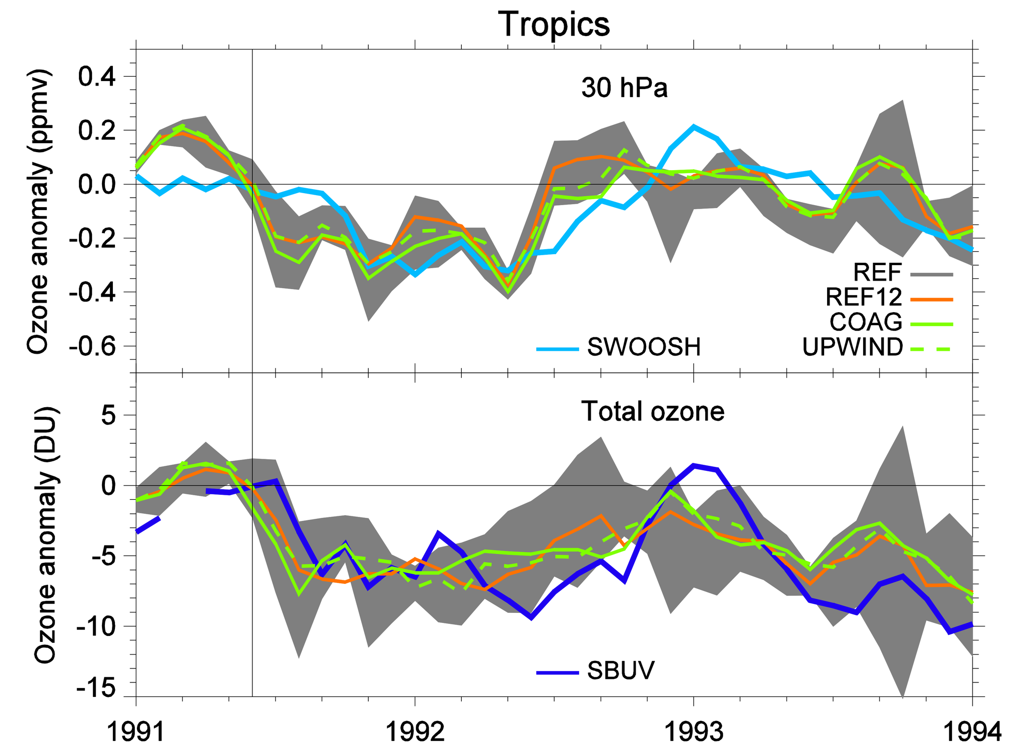
Stratospheric Temperature and Vertical Mass Distribution





Left panels: zonal mean temperature and ozone anomalies for tropics (20S—20N) at 30 hPa calculated by SOCOL-AER and derived from MERRA and ERA-Interim temperature reanalyses.
Right panels: vertical distribution of liquid H_2SO_4 concentration averaged over the tropics (20S—20N).

Ozone



Upper panel: ozone mixing ratio at 30 hPa. Lower panel: total ozone column. Observational data sets SWOOSH and SBUVv8.6 are denoted by light and dark blue lines, respectively.

Conclusions

- An accurate sedimentation scheme is found to be essential to prevent particles diffusing too rapidly to high and low altitudes.
- The aerosol radiative feedback and the use of a nudged quasi-biennial oscillation help to keep aerosol in the tropics and significantly affect the evolution of the stratospheric aerosol burden, which improves the agreement with observed aerosol mass distributions.
- Changes in the aerosol distribution affected by an inclusion of Van der Waals forces to the particle coagulation scheme suggest improvements in particle effective radius, although other parameters (such as aerosol longevity) deteriorate. Modification of the Pinatubo emission rate also improves some aerosol parameters, while worsens others compared to observations.
- Observations themselves are highly uncertain and render it difficult to conclusively judge the necessity of further model reconfiguration.
- Our results show that SOCOL-AER is capable of predicting the most important global-scale atmospheric and climate effects following volcanic eruptions, which is also a prerequisite for improved understanding of anthropogenic effects from sulfur emissions

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