Geo-engineering side effects: Heating the tropical tropopause by sedimenting sulfate aerosol?

Uncertainties in stratospheric sulphate aerosol modelling

P. Kenzelmann (1), D. Weisenstein (3), T. Peter (1), B.P. Luo (1), S. Fueglistaler (2), E. Rozanov (1,4), L.W. Thomason (5)

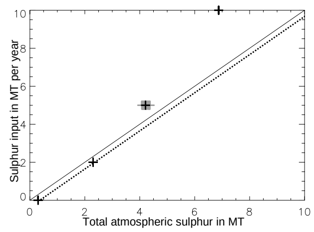
(1) IAC, ETH Zurich, CH. Conntact:: **patricia.kenzelmann@env.ethz.ch.**.(2) DAMTP, U. of Cambridge, UK, (3) AER, Cambridge, Massachusetts, US, (4) PMOD-WRC, Davos, CH, (5) NASA Langley Research Center, Hampton, Virginia, USA

Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

INTRODUCTION

Sulfate aerosols cool earth surface by reflecting short wave radiation from the sun. By injecting sulphur into the stratosphere, part of the anthropogenic climate warming might be compensated due to enhanced albedo [Budyko 1977]. Crutzen [2006] suggested that 1-2 MT S are needed to compensate air cleaning measures and ~5 MT S to compensate doubling of CO_2. Numerous studies showed that large volcanic eruptions in the tropics (e.g. Mt. Pinatubo eruption in 1991) lead to cooling of the earth surface, but as well to reduction of the global total ozone, northern high latitudes winter warmings and alteration of hydrological cycle [Robock 2000 and references herein]. **Still there are remarkable uncertainties in modeling stratospheric impact of tropical volcanoes. Highly non-linear processes involved, complicate the prediction of geo-engineering causes on climate.**

MT S in atmosphere



Non- linearity: MT S remaining in atmosphere

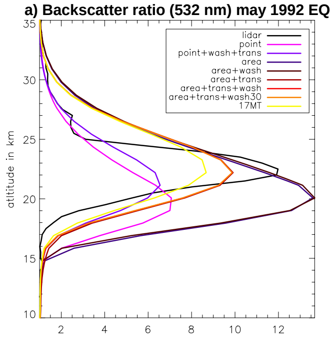
Modelled by AER 2D-Aerosol model. Grey: different Eddy diffusion coefficients

METHODS

- **AER 2-D aerosol** model scenarios [Weisenstein et al., 1997, 1998, 2007]: 1, 2, 5 and 10 MT S per year (EQ 20 km height).
- Mie theory [Mie, 1908].
- **LibRadtran** [Mayer et al.]: Molecular absorption by LOWTRAN band model [Pierluissi &Peng, 1985], SBDART code [Ricchiazzi et al. 1998].
- **CCM SOCOL** [Egorova et al. 2005, Schraner et al. 2008] simulations with different halogen loading and SSTs.

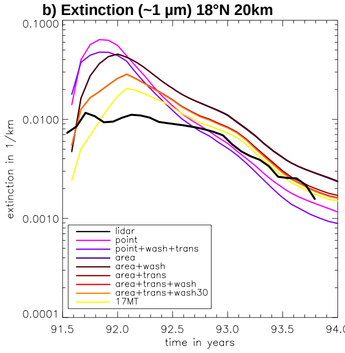
1. Mt. Pinatubo eruption

a) Backscatter ratio (532 nm) may 1992 EQ



Black lines: a) aerborn lidar measurements b) Lidar composite Mauna Loa & Camaquey (pers. comunication L. Thomason) . **Coloredlines:** AER Pinatubo simulation emission of 20 MT SO_2 in different positions Area (16-29 km altitude and from 5S to 14N) Point (1 grid box centered at 9.5N and 22 km) wash: additional washout from 10km to tropopause (40day)-1 trans: using transient circulation instead of climatology.

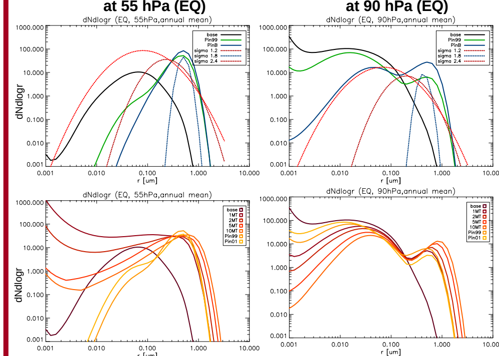
b) Extinction (~1 µm) 18°N 20km



AER model overestimates extinction in lower stratosphere in the early phase after Mt. Pinatubo.

2. AEROSOL SIZE DISTRIBUTION

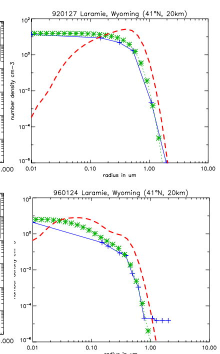
at 55 hPa (EQ) **at 90 hPa (EQ)**



Increased stratospheric sulphur injections lead to increase in mode radius.

Differential number densities:
Straight lines: AER simulations 1MT, 2MT,5MT, 10MT and 2 Pinatubo simulations (area+wash and 17MT). Dotted lines: effective radius from gap filled SAGE data set (ASAP) (with sigma=1.2, 1.8., 2.4)

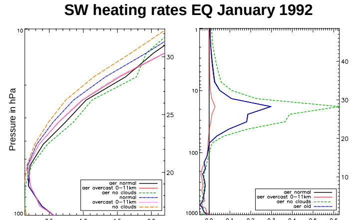
Cumulative number density



Blue cross: Optical particle counter of university of Wyoming, measurements at Laramie (Deshler et al.(2003). Green stars: cumulated number density AER model simulation (area). Red dashed line: differential number density.

3. LOWER STRATOSPHERIC HEATING

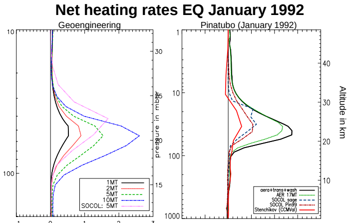
SW heating rates EQ January 1992



Absolute SW heating rate in K/day calculated by ECHAM4

SW HR due to stratospheric aerosol calculated by ECHAM4

Net heating rates EQ January 1992



net HR due to stratospheric aerosol calculated by Libradtran

net HR due to stratospheric aerosol calculated by Libradtran & ECHAM4

ECHAM 4 shortcomings:

- error in SW/NIR radiation code overestimates heating rate by less then 1% (not shown).
- Clear sky part shows "wrong" feature

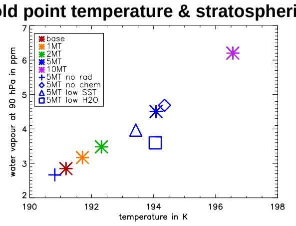
- Discrepancy between ECHAM4 and Libradtran radiation calculation
- AER overestimates heating rate
- AER model predicts heating of tropical tropopause

CONCLUSIONS

- **High uncertainty in aerosol size distribution after Mt. Pinatubo eruption in measurements and model results.**
- **High uncertainty in aerosol size distribution lead to high uncertainty of lower stratospheric heating.**
- **Negative feedback process could be the result of lower stratospheric heating:**
  tropical tropopause heating → more stratospheric H_2O → more heating
- **Future ozone recovery is endangered.**

4. EFFECT ON TEMPERATURE AND TOTAL OZONE?

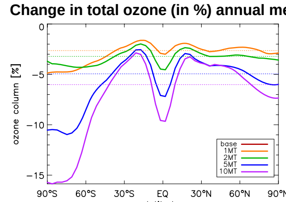
Cold point temperature & stratospheric H_2O



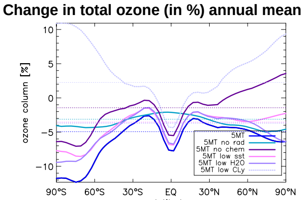
- Heating of lower stratosphere has big impact on whole stratosphere: stratospheric **water vapour** would increase.
- **Ozone** is destroyed by heterogeneous reactions + ozone destruction cycles intensify with increasing temperature.

SCENARIO	Change in global total Ozone in %
1 MT	-2.6
2 MT	-3.2
5 MT	-4.9
10 MT	-6.0
5 MT no radiation	-3.1
5 MT no chemistry	-1.4
5 MT low SSTs	-3.5
5 MT low strat H_2O	-3.7
5 MT low Cl_y	2.3 (-3.0)

Change in total ozone (in %) annual mean



Change in total ozone (in %) annual mean



References

ASAP: Assessment of Stratospheric Aerosol Properties

Budyko, M. I. (1977), Present-day climatic changes, Tellus, 29 (3), 193–204

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

Deshler, T., M. E. Hervig, D. J. Hofmann, J. M. Rosen, and J. B. Liley, Thirty years of in situ stratospheric aerosol size distribution measurements from Laramie, Wyoming (41 N), using balloon-borne instruments, J. Geophys. Res., 108(D5), 4167, doi:10.1029/2002JD002514, 2003.

Egorova, T. A., E. V. Rozanov, V. A.Zubov, E.Manzini,W. Schmutz, and T. Peter (2005), Chemistry-Climate Model SOCOL: a validation present-day climatology, Atmos. Chem. Phys., 5, 1557–1576.

Mayer B. and A. Kylling (2005), Technical note: The libRadtran software package for radiative transfer calculations – description and examples of use. Atmos. Chem. Phys., 5, 1855–187.

Mie, G. (1908), Articles on the optical characteristics of turbid tubes, especially colloidal metal solutions., Annalen Der Physik, 25 (3), 377–445.

Pierluissi, J. and Peng (1985), G.-S.: New molecular transmission band models for LOWTRAN, Optical Engineering, 24, 541–547.

Rasch, P. J., P. J. Crutzen, and D. B. Coleman (2008), Exploring the geoengineering of climate using stratospheric sulfate aerosols: The role of particle size, GeophysicalResearch Letters, 35 (2), L02,809.

Ricchiazzi, P., Yang, S., Gautier, C., and Sowle, D.(1998): SBDART: A research and Teaching software tool for plane-parallel radiative transfer in the Earth's atmosphere, Bulletin of the American Meteorological Society, 79, 2101–2114.

Robock, A. (2000), Volcanic eruptions and climate, Reviews of Geophysics, 38,2, 191–219.

Schraner, M., E. Rozanov, C. Schnadt Poberaj, P. Kenzelmann, A. M. Fischer, V. Zubov, B.P. Luo, C.R. Hoyle, T. Egorova, S. Fueglistaler, S. Brönnimann, W. Schmutz and T. Peter. Technical Note: Chemistry-climate model SOCOL: version 2.0 with improved transport and chmistry/microphysics schemes. Atmos. Chem. Phys, submitted.

Weisenstein, D. K., G. K. Yue, M. K. W. Ko, N. D. Sze, J. M. Rodriguez, and C. J. Scott (1997), A two-dimensional model of sulfur species and aerosols, Journal Of Geophysical Research-Atmospheres, 102 (11D), 13,019–13,035.

Heating rates volcanoes:
http://www.pa.op.dlr.de/CCMVal/Forcings/CCMVal_Forcings_WMO2010.html