Geoengineered sulfate aerosol - microphysical evolution depending on emission parameters

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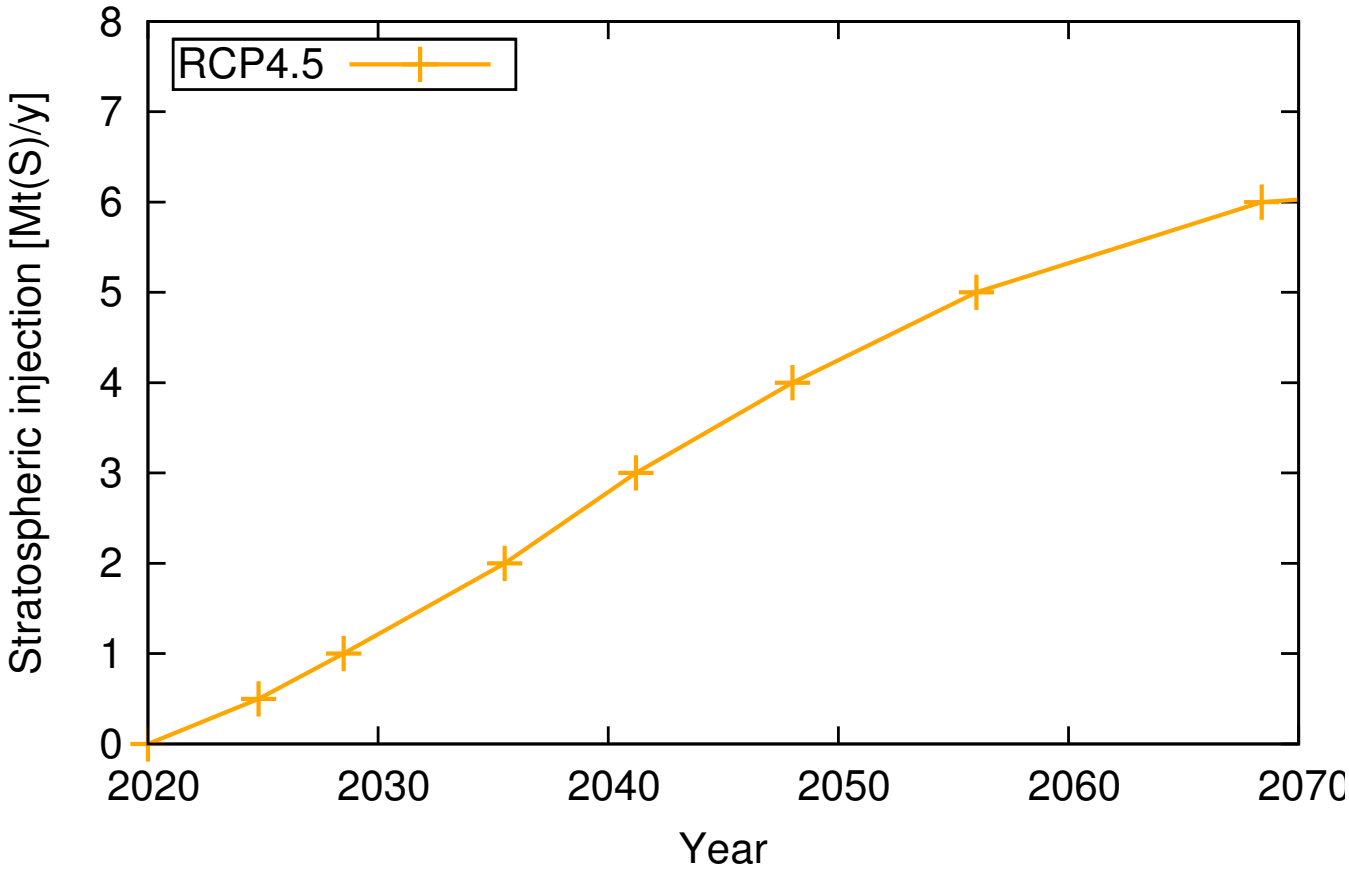
Outline

1. Introduction
2. MAECHAM5-HAM results
3. Comparison to other results
4. Balance RCP8.5 and 4 x CO2?
5. Summary

Balance GHG emissions via sulfur injection



Sulfur injection necessary for GeoMIP G3 simulation in MPI-ESM

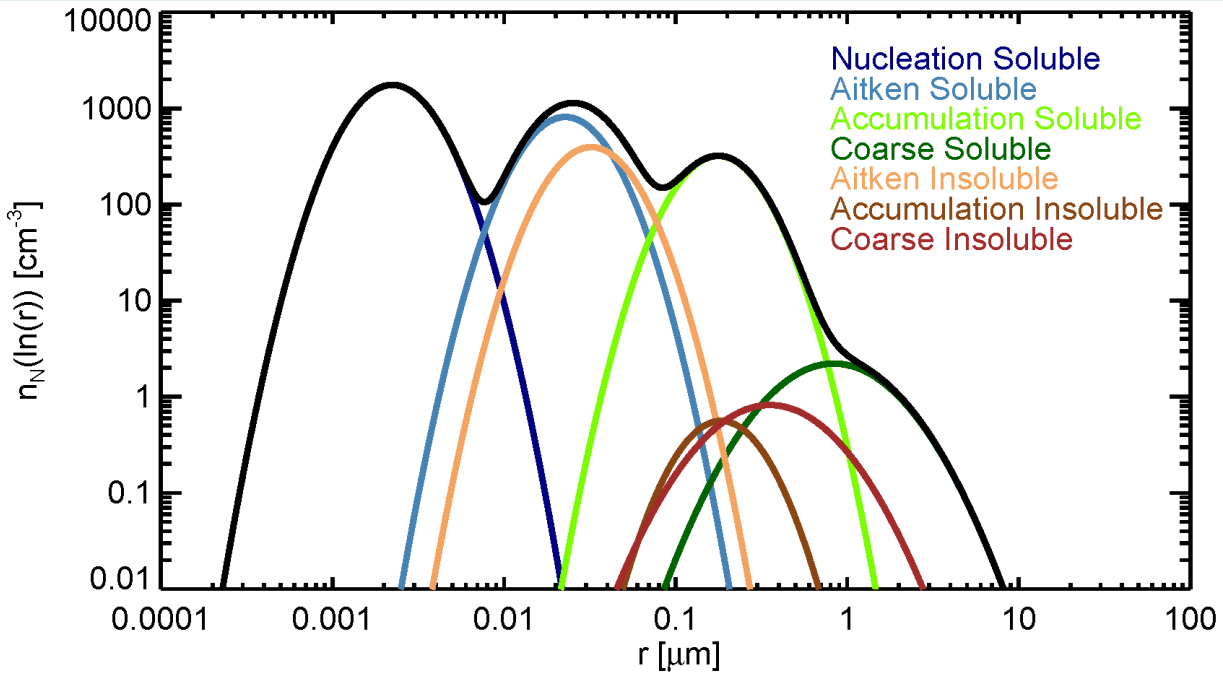
Niemeier et al (2013), JGR,10.1002/2013JD020445

Comparable results?

Previous studies

- Several studies on climate impact of geoengineered sulfate
- Prescribed particle size
- Coarse assumptions on particle evolution
- e.g. Rasch et al (2008), Robock et al (2008), Tilmes et al (2009)
- One study with 2-dimensional aerosol microphysical model
  - Heckendorn et al (2009)
  - Particel size distribution depends on magnitude of injections
- Extension of Heckendorn et al study:
  - Pierce et al (2010)
  - Niemeier et al (2011)
  - English et al (2012)

Aerosol microphysical model HAM



- 7 log-normal distributions:
  - nucleation, aitken, accumulation, coarse mode
  - for soluble and non-soluble species
- calculates microphysical processes (M7):
  - nucleation, condensation, coagulation, accumulation
- sedimentation, dry- and wet deposition

Niemeier et al, 2010: http://onlinelibrary.wiley.com/doi/10.1002/asl.304/pdf

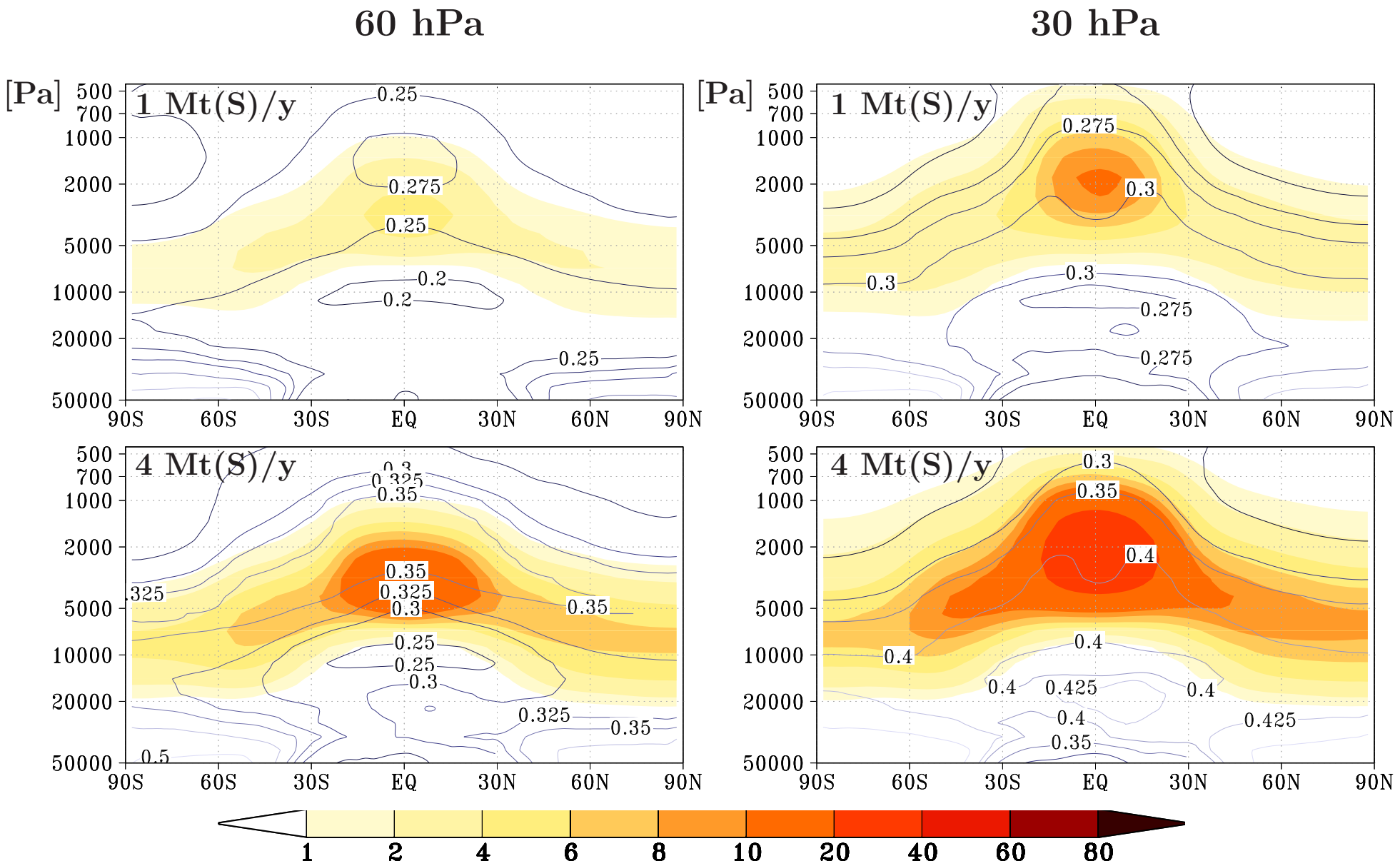
Simulations

Exp.	Height [hPa]	Emission [Mt(S)/y]	area	strategy
I	60	1, 2, 4, 8	one box	continously
II	30	1, 2, 4, 8	one box	continously
III	60	4	one box	pulse, twice a year, 30 days each
IV	60	4	latitude band	continously
V	60	4	one box	continously, H_2SO_4 emissions

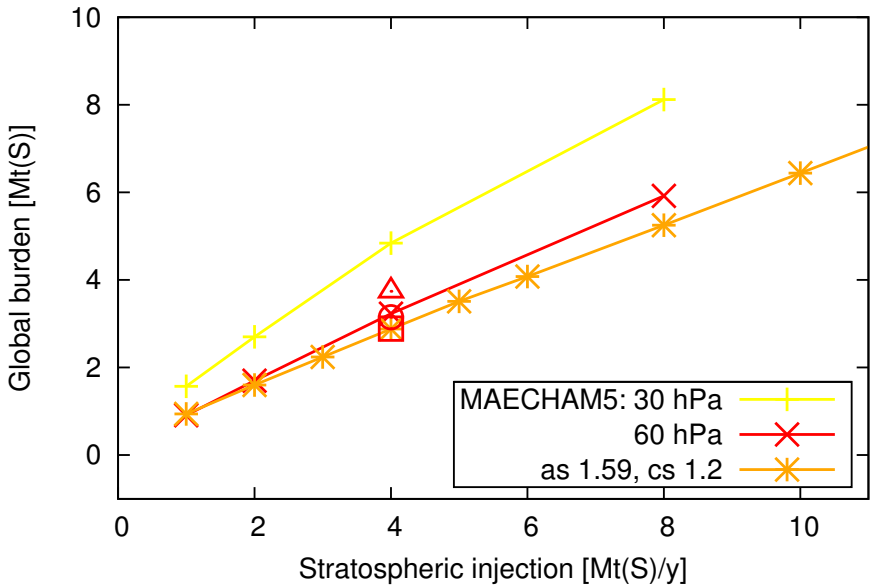
All results are

- Resolution: T42 L39 up to 0.01 hPa, clim. SST
- Geoengineered sulfur dioxide in a global climate model injected into one grid-box: 2.8° x 2.8° at 1.4° N 121° W
- used after three years of initialization;
- mean values over the following three years;
- zonally averaged

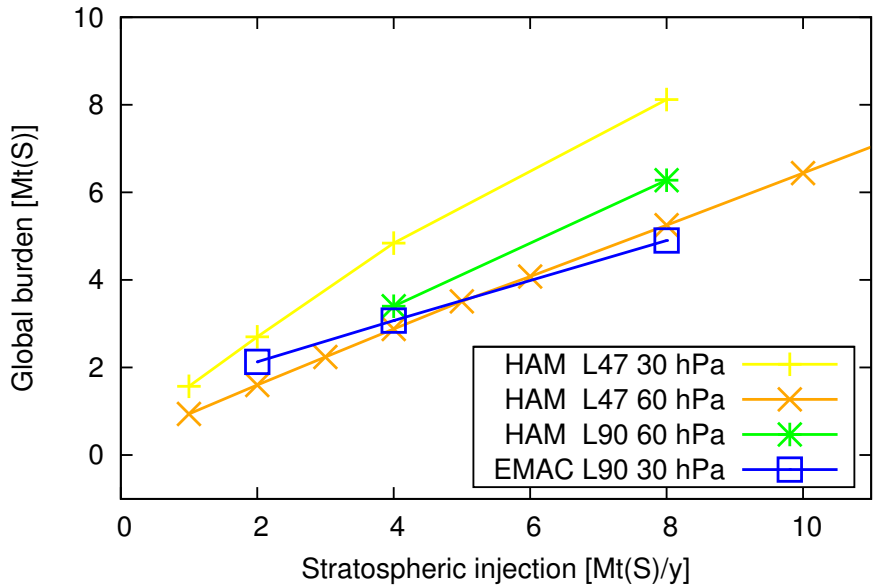
Sulfate concentration [ppb] and effective radius[μm]



Sulfate Burden MAECHAM-HAM and EMAC

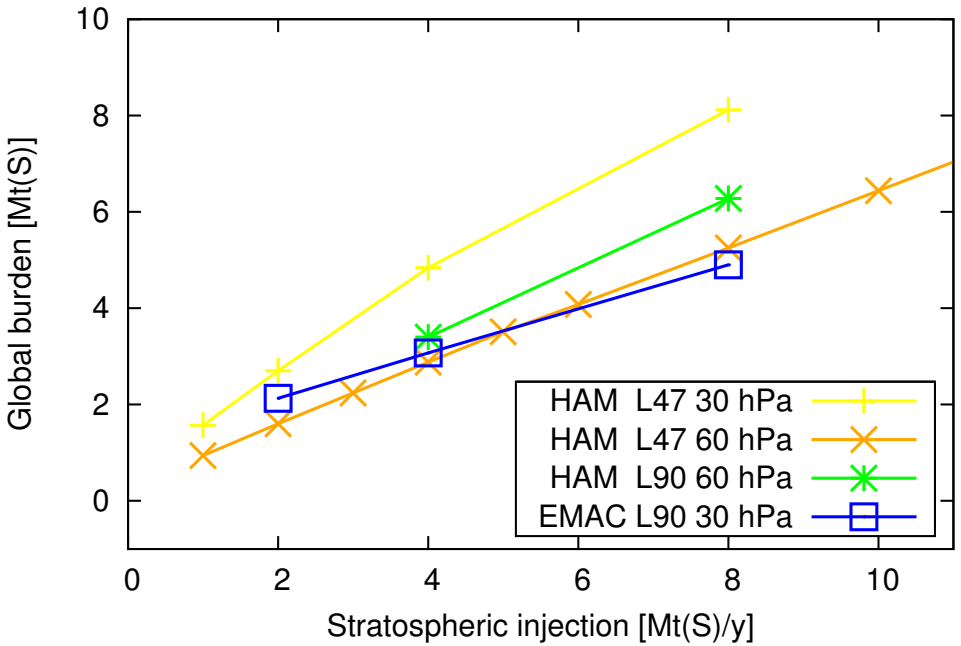


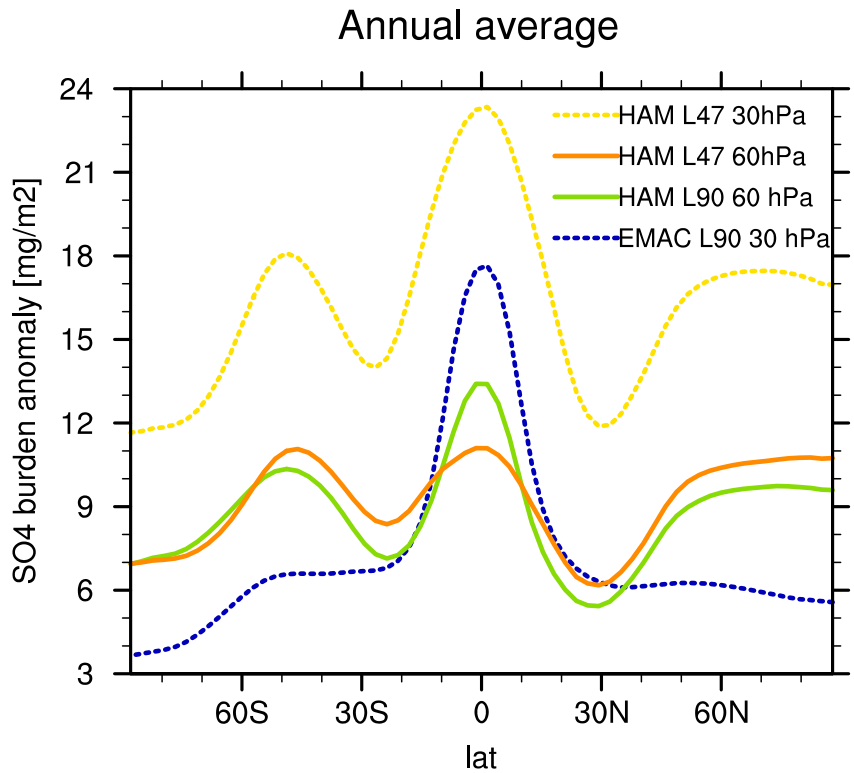
ECHAM-HAM results



additional 90 levels results ECHAM-HAM and EMAC

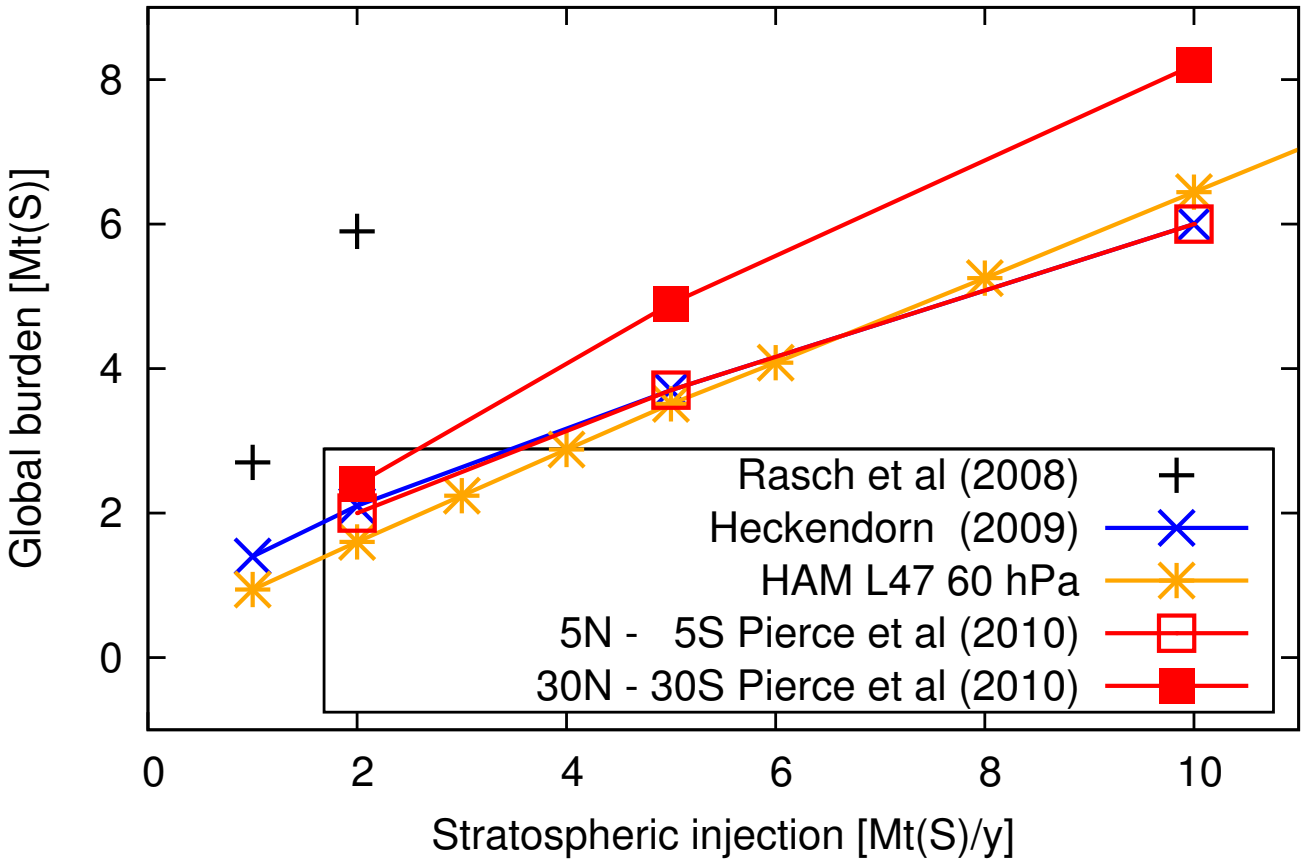
Sulfate Burden: zonal mean (8 Mt(S)/y)



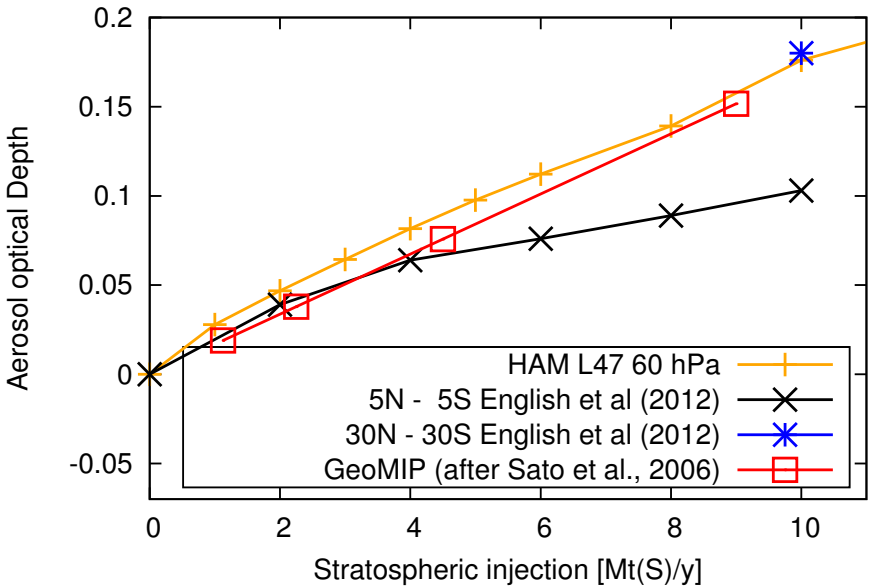


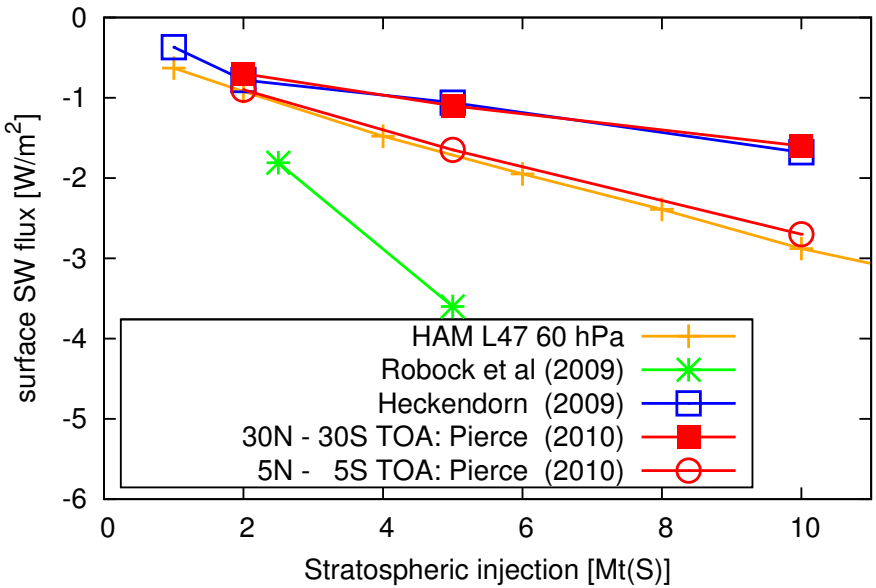
- L90 versus L47: Sedimentation, numerical diffusion (vertical)
- 30 hPa versus 60 hPa: less poleward transport

Sulfate Burden: comparison to literature



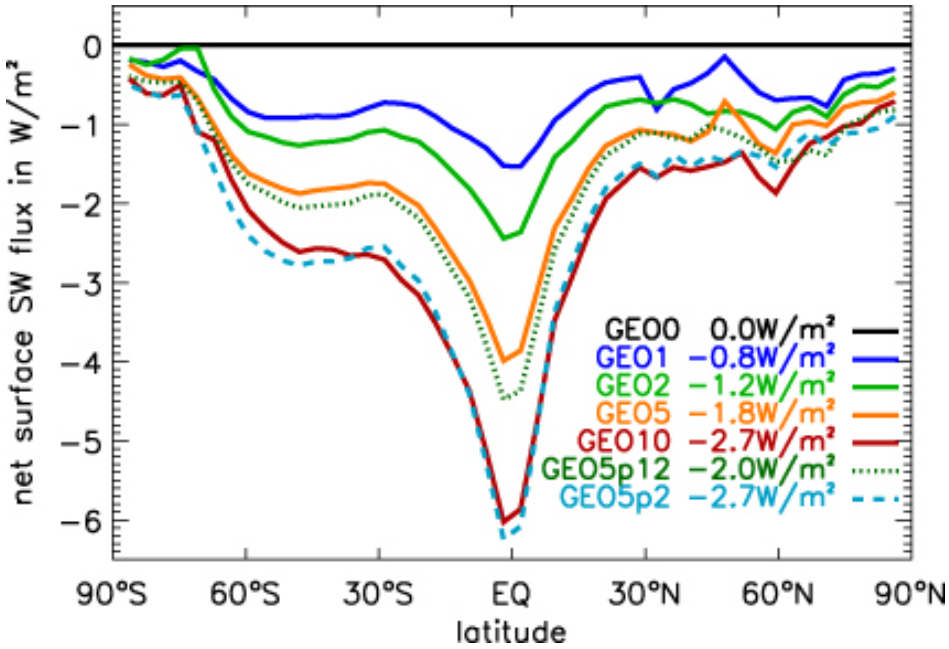
Radiative impact: AOD and SW Flux



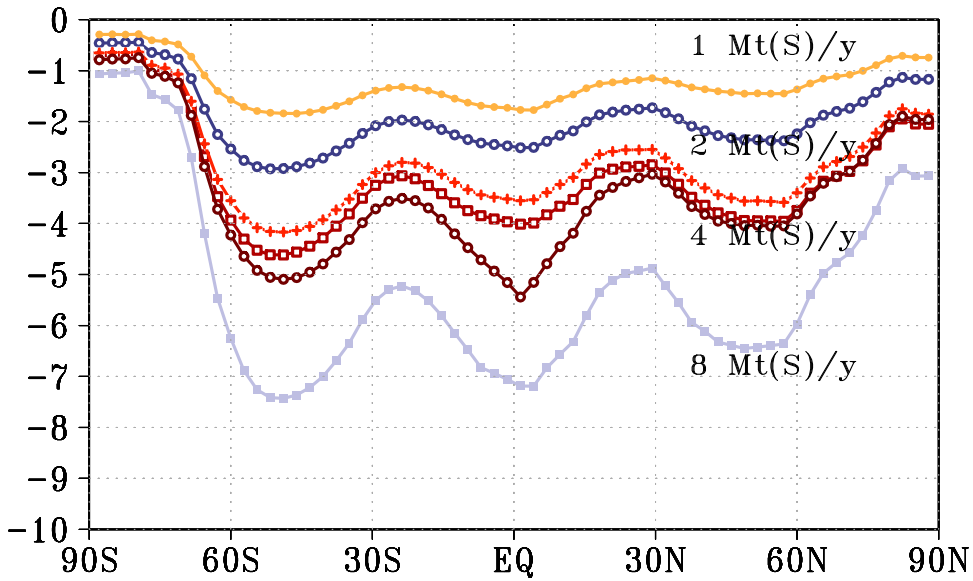


SW flux (clear sky) [W/m^2]

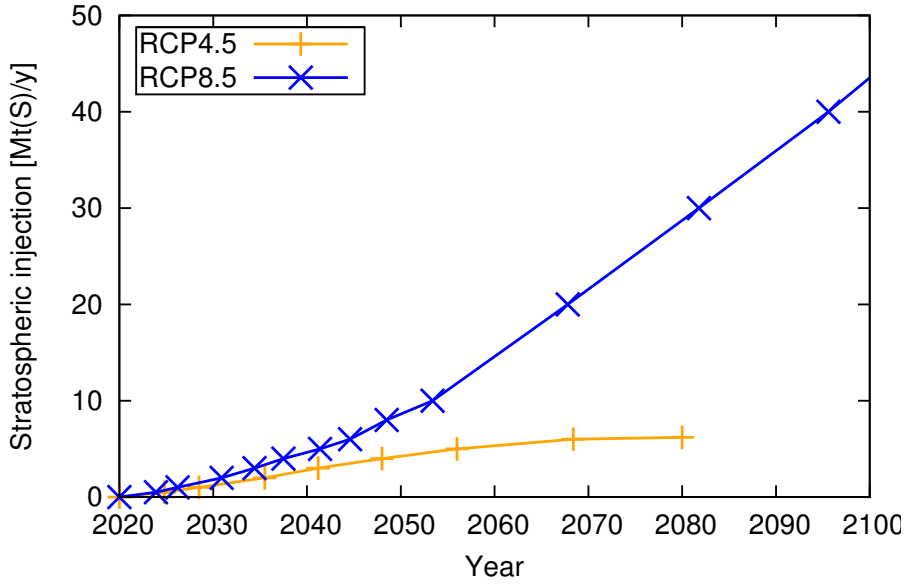
Heckendorn et al (2009)



MAECHAM/HAM



Injection rate to balance RCP8.5 or 4 x CO2?



Estimated for MPI-ESM from ECHAM5-HAM results

- 50 Mt(S)/y balance 6 W/m^2 radiative forcing of GHG
- RCP8.5: about 43 Mt(S)/y to balance rad forcing of 5.6 W/m^2
- 4xCO_2: rad forcing about 6.5 to 9.6 W/m^2 in 4 models (Schmidt et al, 2012)
- Further results on G3? See poster!

Niemeier et al (2013) http://onlinelibrary.wiley.com/doi/10.1002/2013JD020445/pdf

Summary

Dependence on emission strategy

- Increase of SO2 emissions:
  - No similar increase in radiative forcing
  - Aerosol particle size increases
- Lifetime of particles depends on emission height
- Increased emission height causes:
  - Burden almost twice the burden for 60 hPa
  - Emissions technically more challenging
- Niemeier et al, 2010:
  http://onlinelibrary.wiley.com/doi/10.1002/asl.304/pdf

Summary

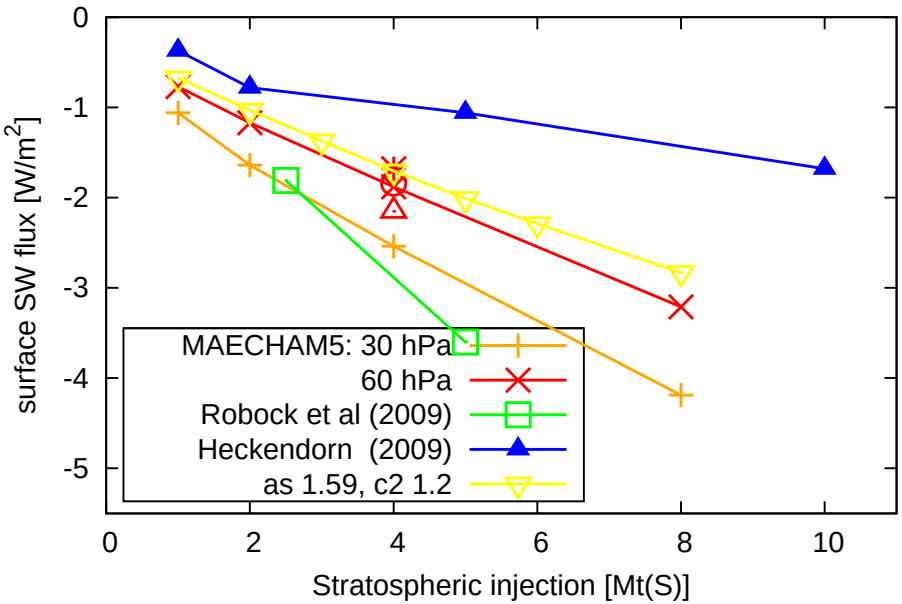
Why differ results strongly between models?

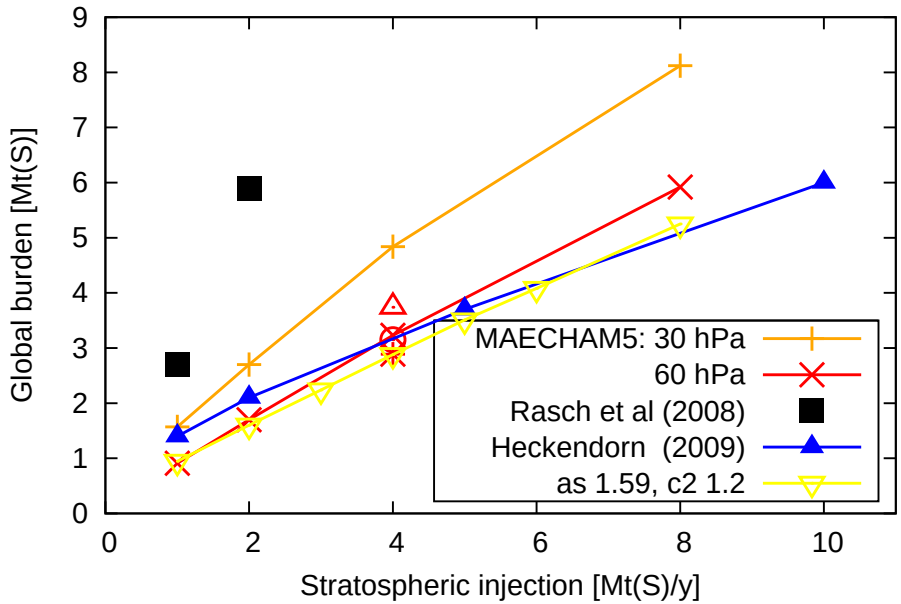
- Different emission height
- Different emission area
- Different particle size and sedimentation
- Bin versus modal model

Transport to poles is very different!

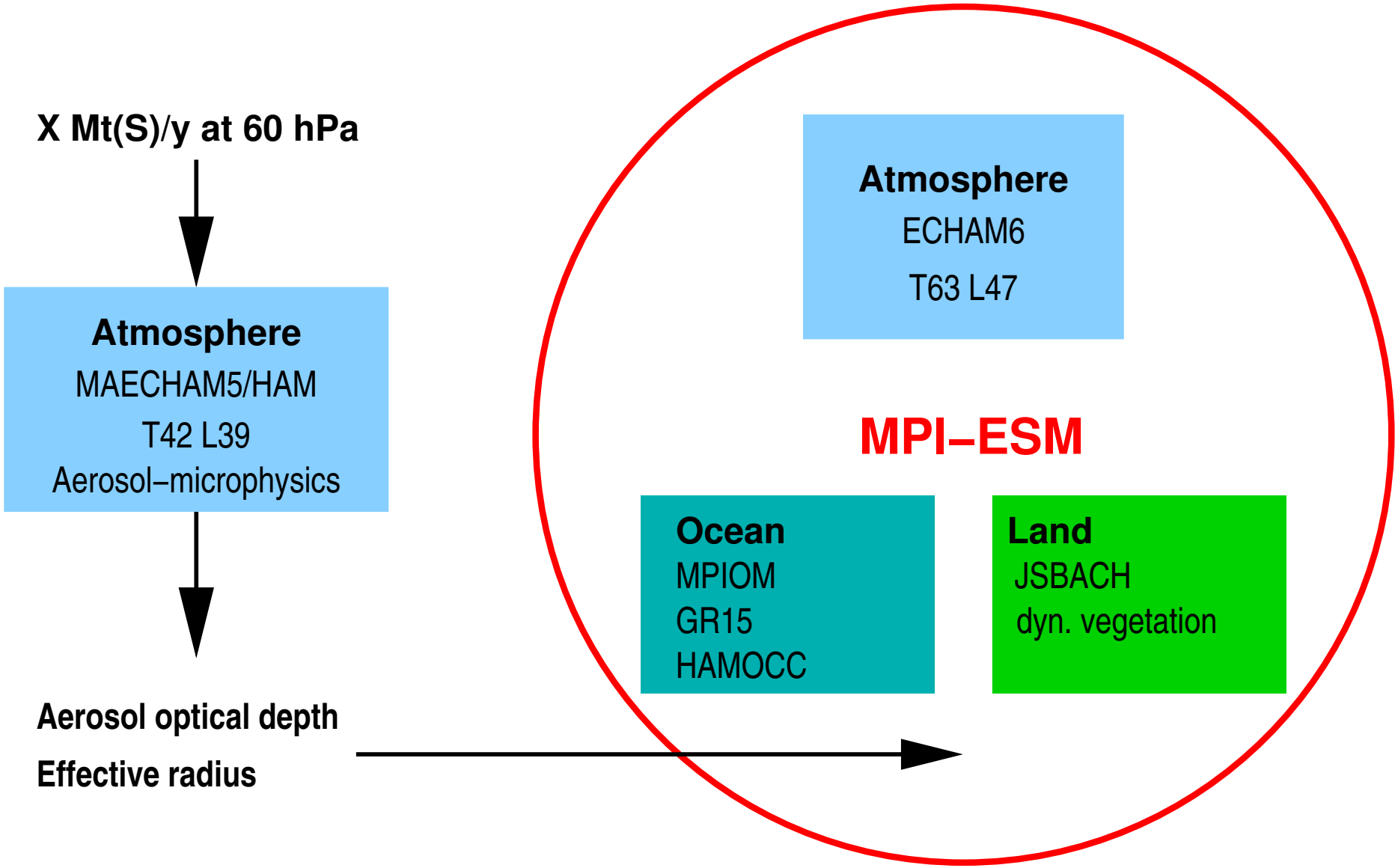
- Coupling to radiation?
- Sulfate as a passive tracer?
- Pinatubo as a test case
  - Transport to both hemispheres?
  - Differs between models

Mode-width in HAM





Next steps


X Mt(S)/y at 60 hPa
Atmosphere
MAECHAM5/HAM
T42 L39
Aerosol–microphysics
Aerosol optical depth
Effective radius
Atmosphere
ECHAM6
T63 L47
MPI–ESM
Ocean
MPIOM
GR15
HAMOCC
Land
JSBACH
dyn. vegetation

Summary

- Increase of SO2 emissions:
  - No similar increase in radiative forcing
  - Aerosol particle size increases
  - Lifetime decreases
- Lifetime of particles depends on emission height
- Increased emission height causes:
  - Burden almost twice the burden for 60 hPa
  - Small SAD, but emission level similar to ozone max concentration
  - Emissions technically more challenging
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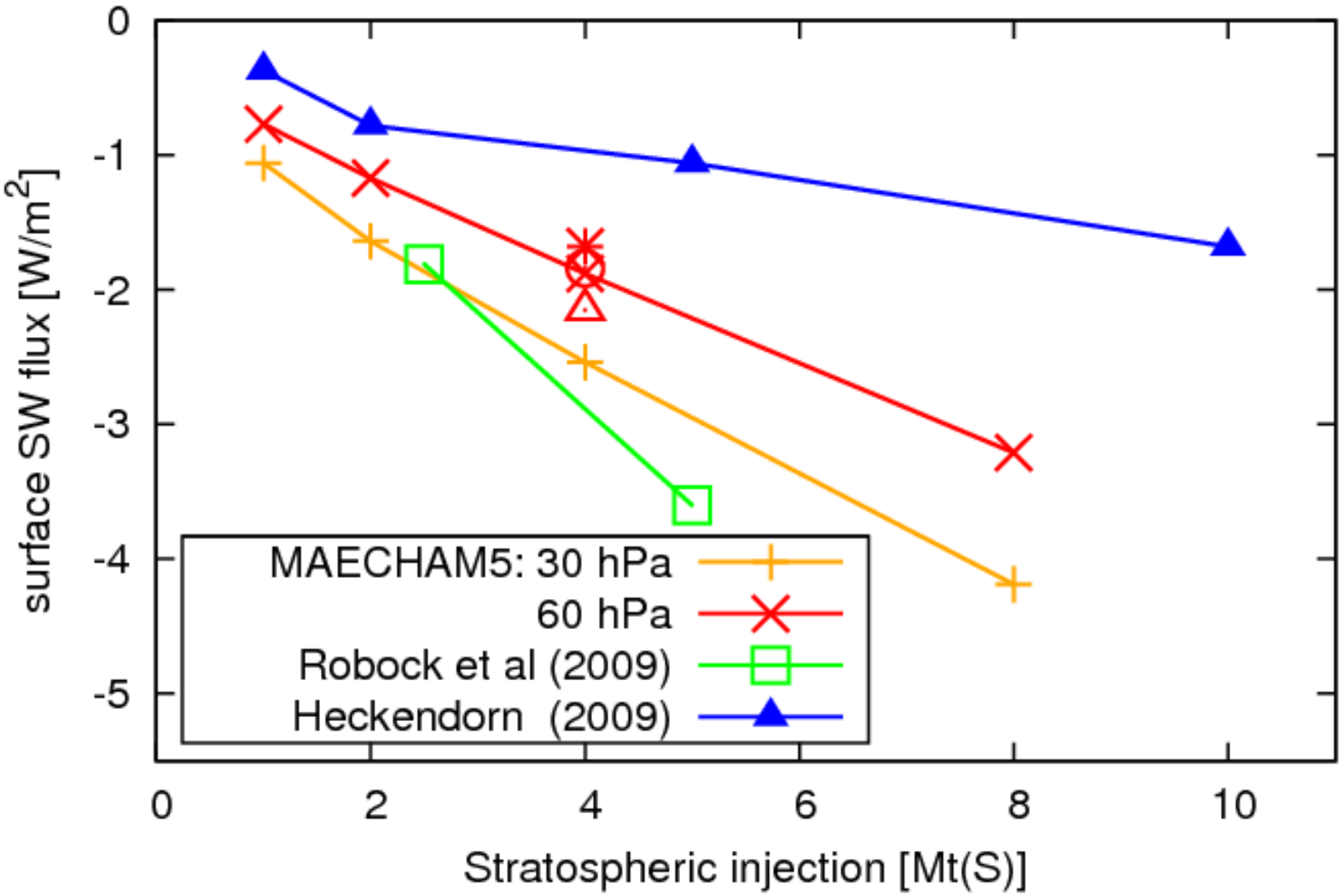
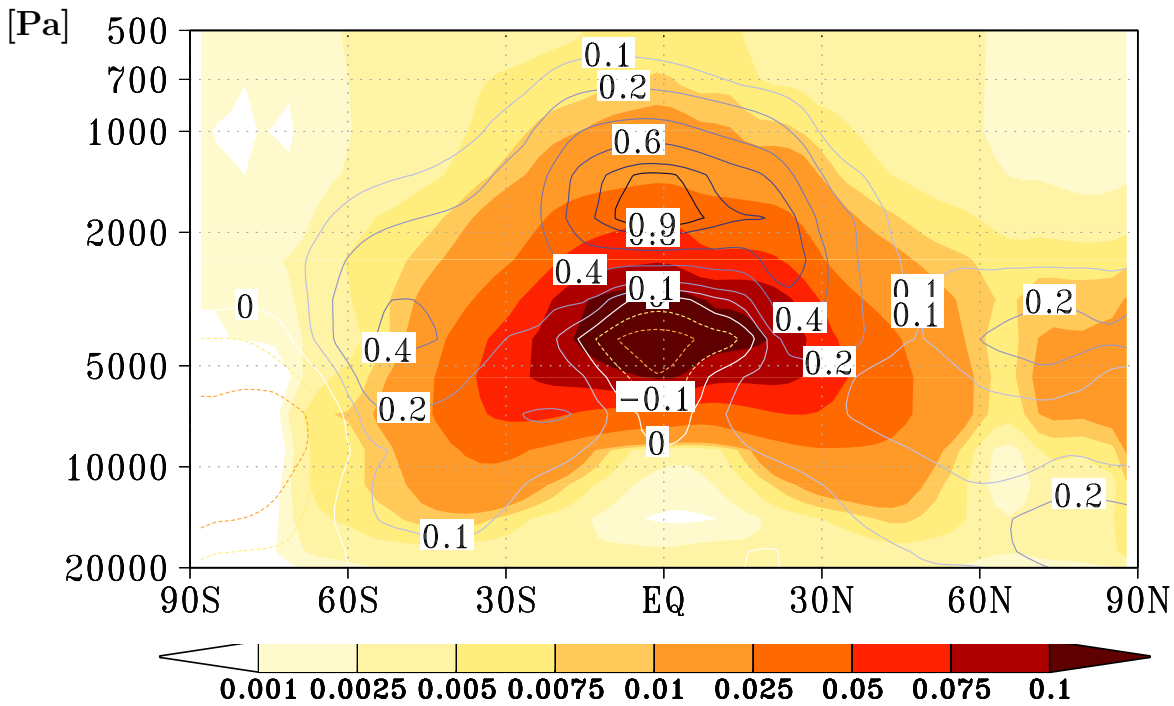
Data for Earth System Model



Dynamical feedback

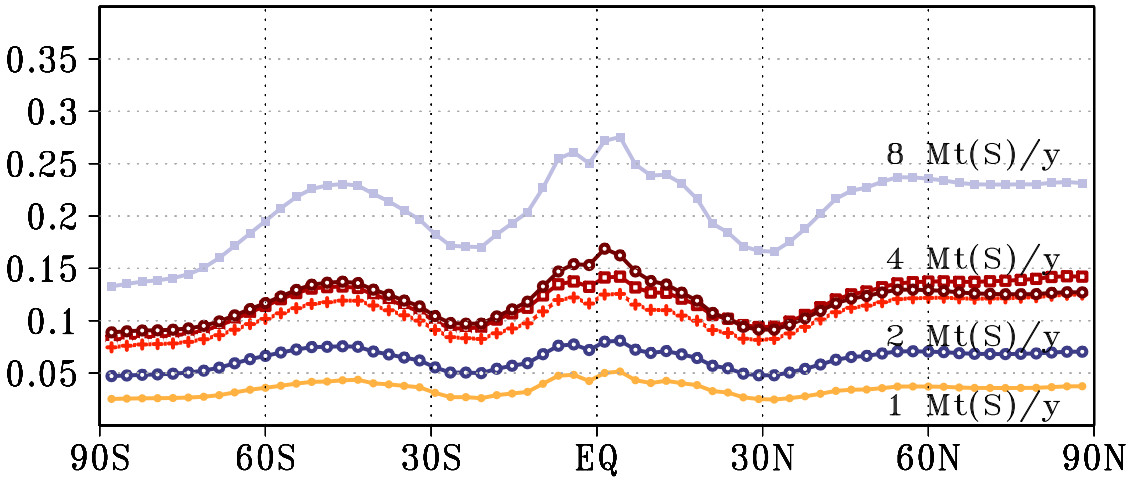


Difference of sulfate concentration [ppb] of a simulation with aerosol coupled to radiation calculations and without.

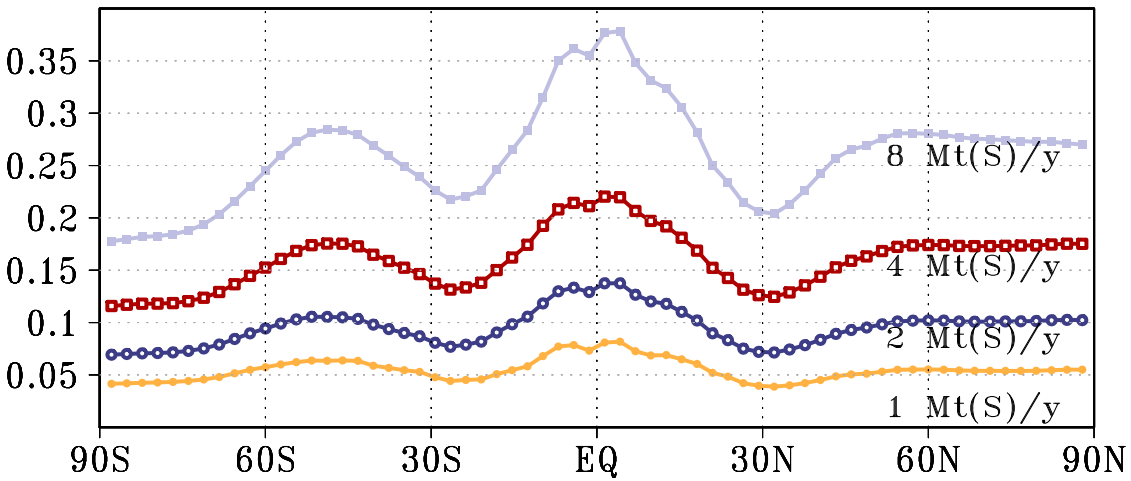
Lifetime: burden/emissionrate

Emission Mt(S)/y	Lifetime 60 hPa	Lifetime 30 hPa	Lifetime pulse	Lifetime lonband	Lifetime H_2SO_4
1	0.91y	1.57y			
2	0.85y	1.35y	0.72y	0.84y	0.94y
4	0.80y	1.21y			
8	0.74y	1.02y			

Aerosol optical depth



60 hPa

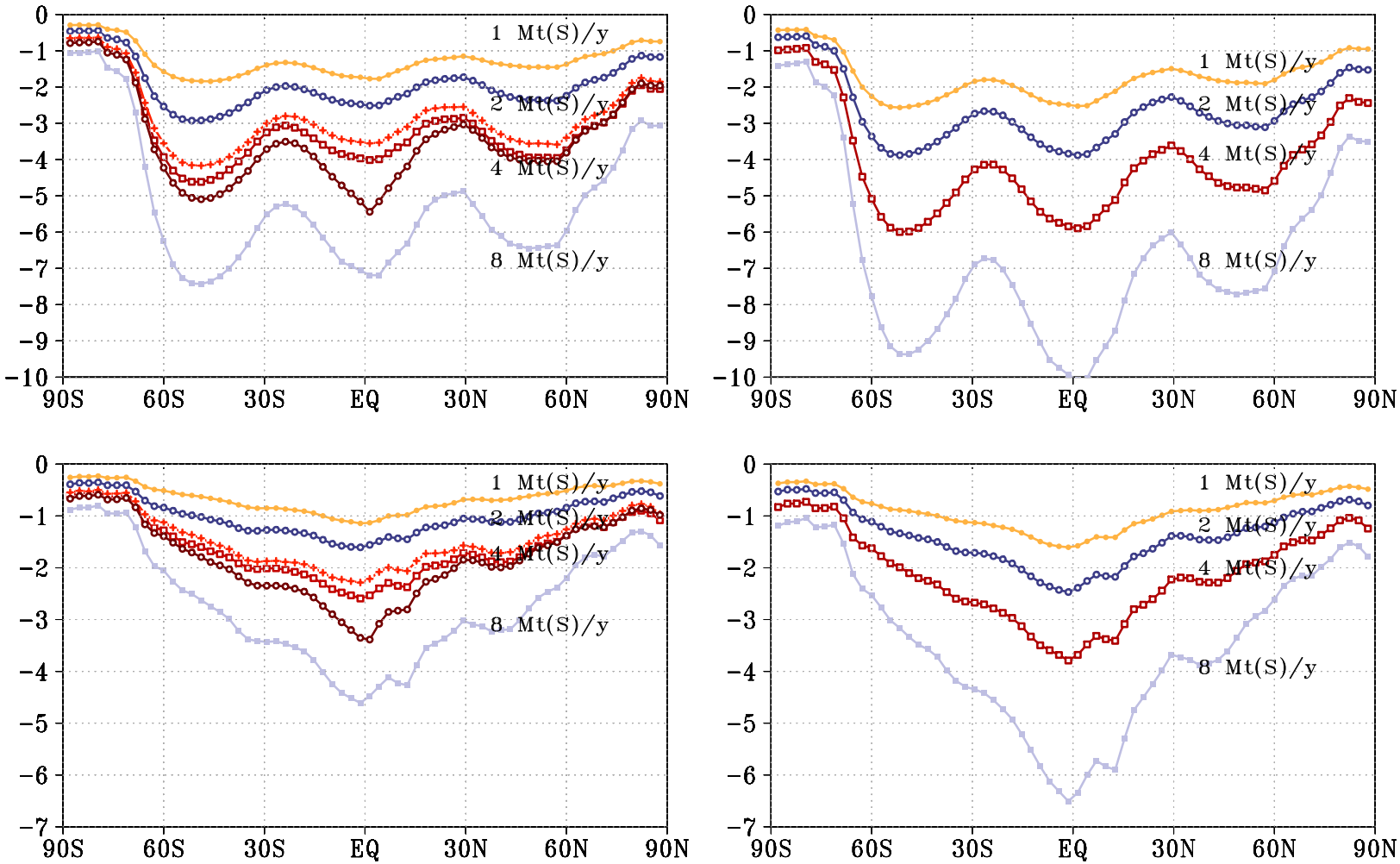


30 hPa

Contours are given for different emission rates.
Emissions as latitude band (red cross) and H_2SO_4 (dark red).

SW-flux anomaly [W/m^2]

60 hPa **30 hPa**



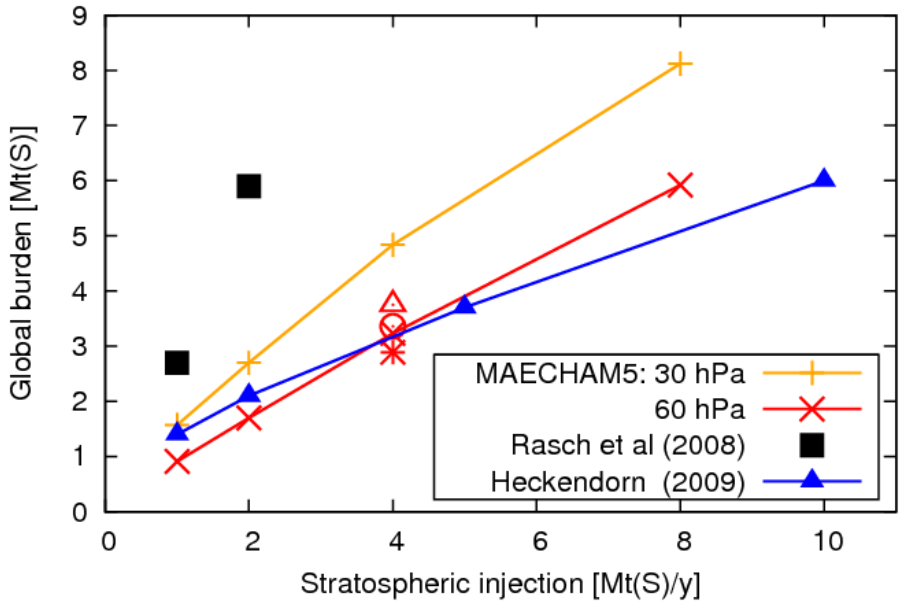
clear sky

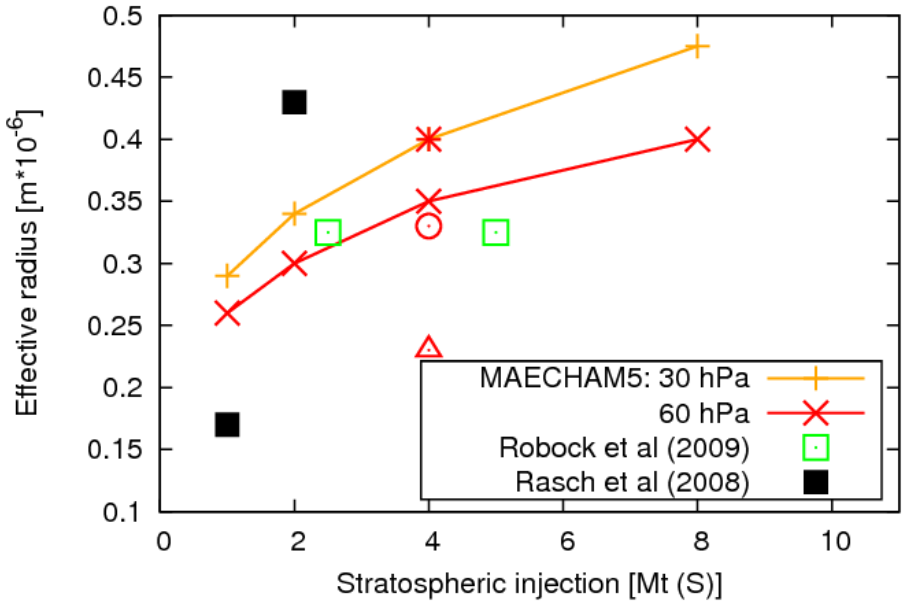
all sky

Emissions as latitude band (red cross) and H_2SO_4 (dark red).

Global values
&
comparison to other results

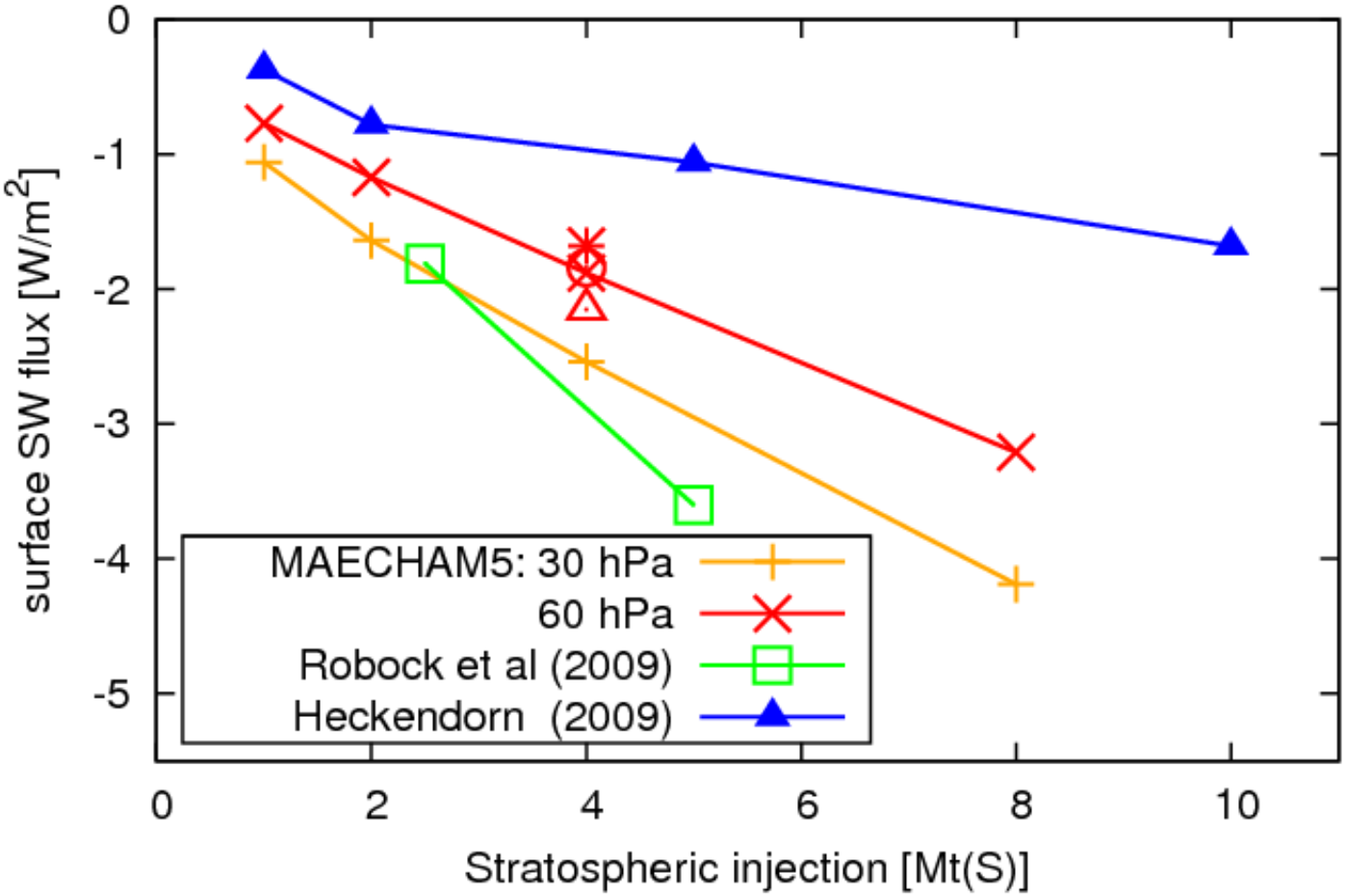
Global burden and eff. radius





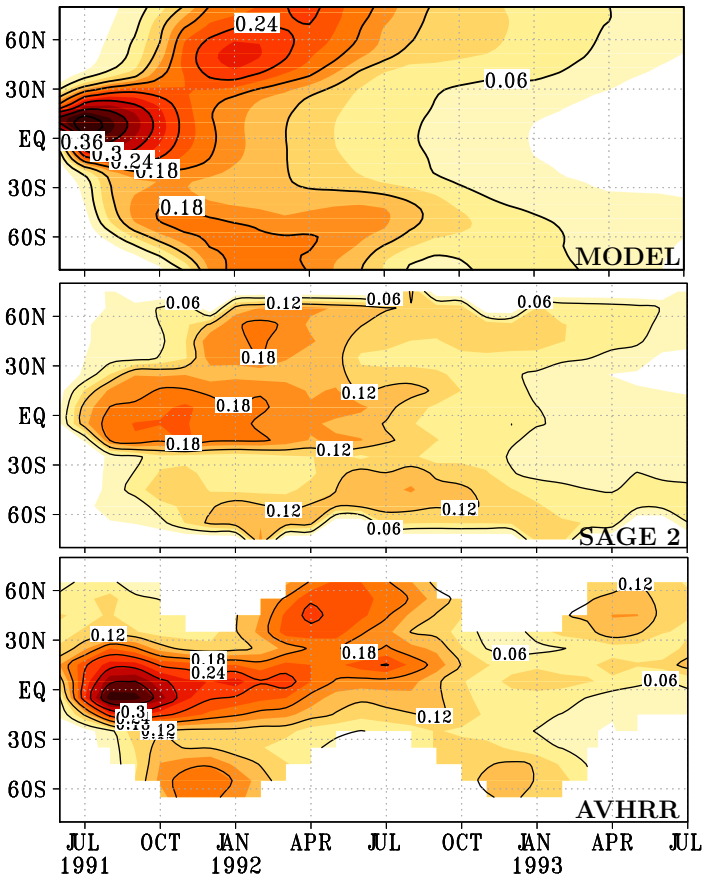
Pulsed emissions (circle)
Longitudional emissions along the equator (star)
H_2SO_4 emissions (triangle)

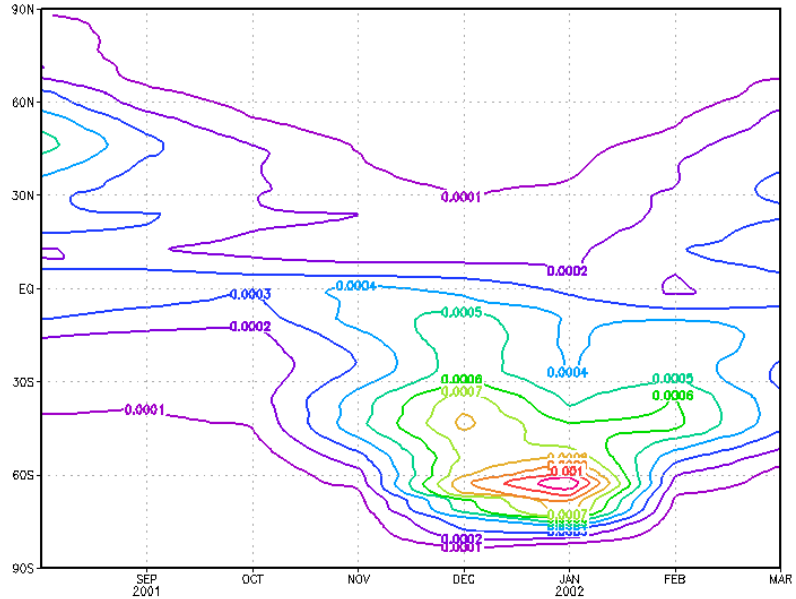
Global SW surface flux anomaly (all sky)



Pulsed emissions (circle)
Longitudional emissions along the equator (star)
H_2SO_4 emissions (triangle)

AOD after Mt Pinatubo and Cerro Hudson eruptions





Cerro Hudson:
1 Mt(S) at 80 hPa in early August