Revisiting the expected radiative forcing from extra-tropical vs. tropical volcanic eruptions

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Background

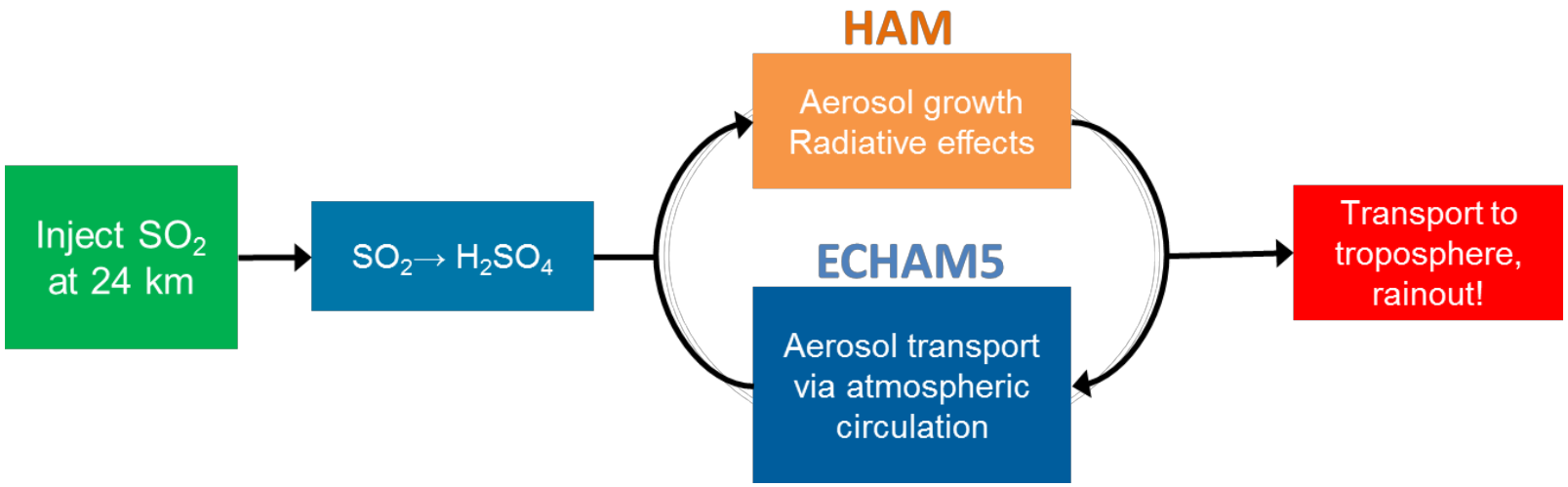
- Climate impact of volcanic eruptions depends on:
  - How much?
    - **Magnitude of stratospheric sulfur injection**
  - Where?
    - **Latitude**
    - **Height**
  - When?
    - **Season**
    - **QBO phase**
    - **ENSO phase**
    - **Solar cycle**

Motivation

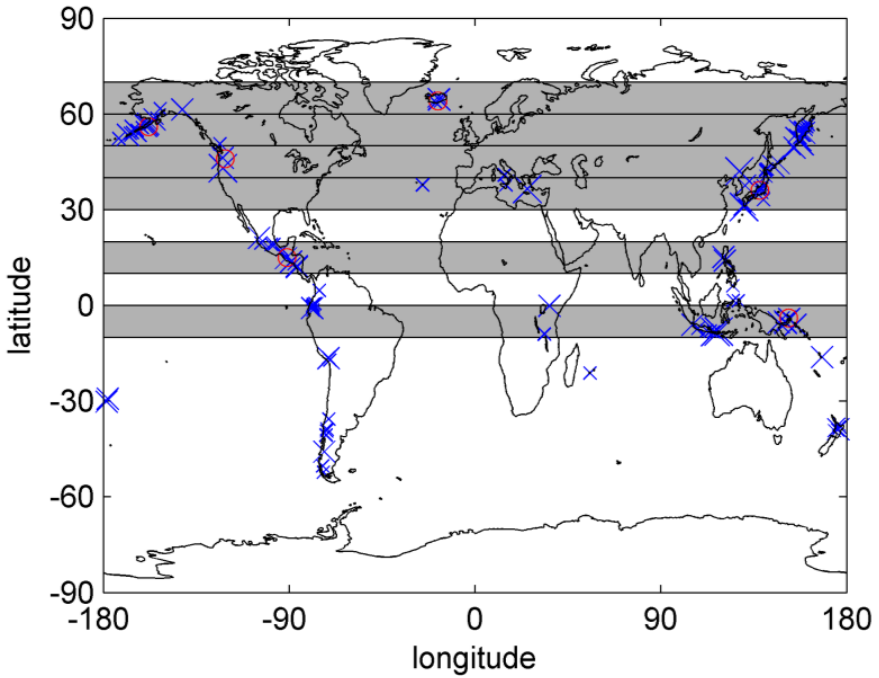
- Often thought that extratropical eruptions lead to weaker climate impact than tropical eruptions
  - … “the key factor in tropical eruptions is that the circulation of the stratosphere (rising in the tropics, subsidence in the high latitudes) favors the worldwide dispersion of tropical sulphates, but pushes high-latitude sulphates right back down again.” – Gavin Schmidt, RealClimate
- On the other hand:
  - Bluth et al. (1997) noted that only tropical eruptions with DRE eruption rates > 40,000 m^3/s produced Δ AOD > 0.001, while extratropical eruptions with eruption rates as little as 1000 m^3/s produced significant AOD changes.
- Stothers (2001) estimated maximum r_{eff} after Katmai (1912, 58°N) of ~0.3 µm, and ~0.5 µm for Pinatubo (1991, 15°N)… maybe aerosol microphysics is important?
- Experiment: simulate Pinatubo-like eruptions at different latitudes

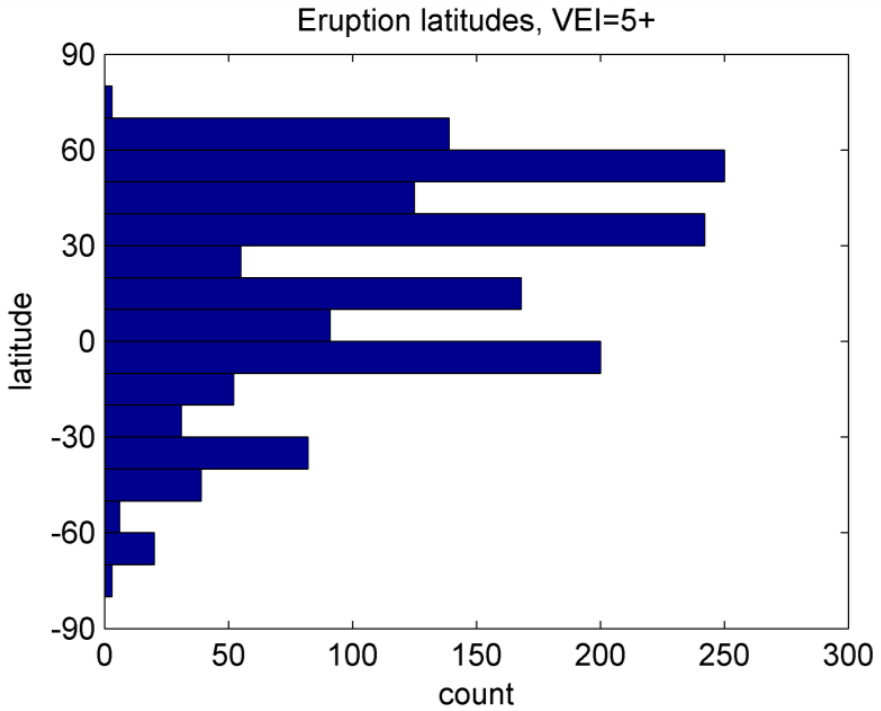
Model: MAECHAM5-HAM

- **ECHAM:** GCM developed at MPI-M, Hamburg
  - Middle atmosphere version: 39 vertical levels up to 0.01 hPa (~80 km)
  - T42 horizontal resolution
  - Climatological sea surface temperatures, no QBO, no chemistry
- **HAM**: Aerosol microphysical module
  - Modified for simulation of stratospheric volcanic aerosols
  - Models aerosol growth, radiative effects, eventual removal



Eruption latitudinal distribution





- Identified historical VEI>=5 eruptions from the Global Volcanism Program Holocene eruption database: http://volcano.si.edu/

Experiment

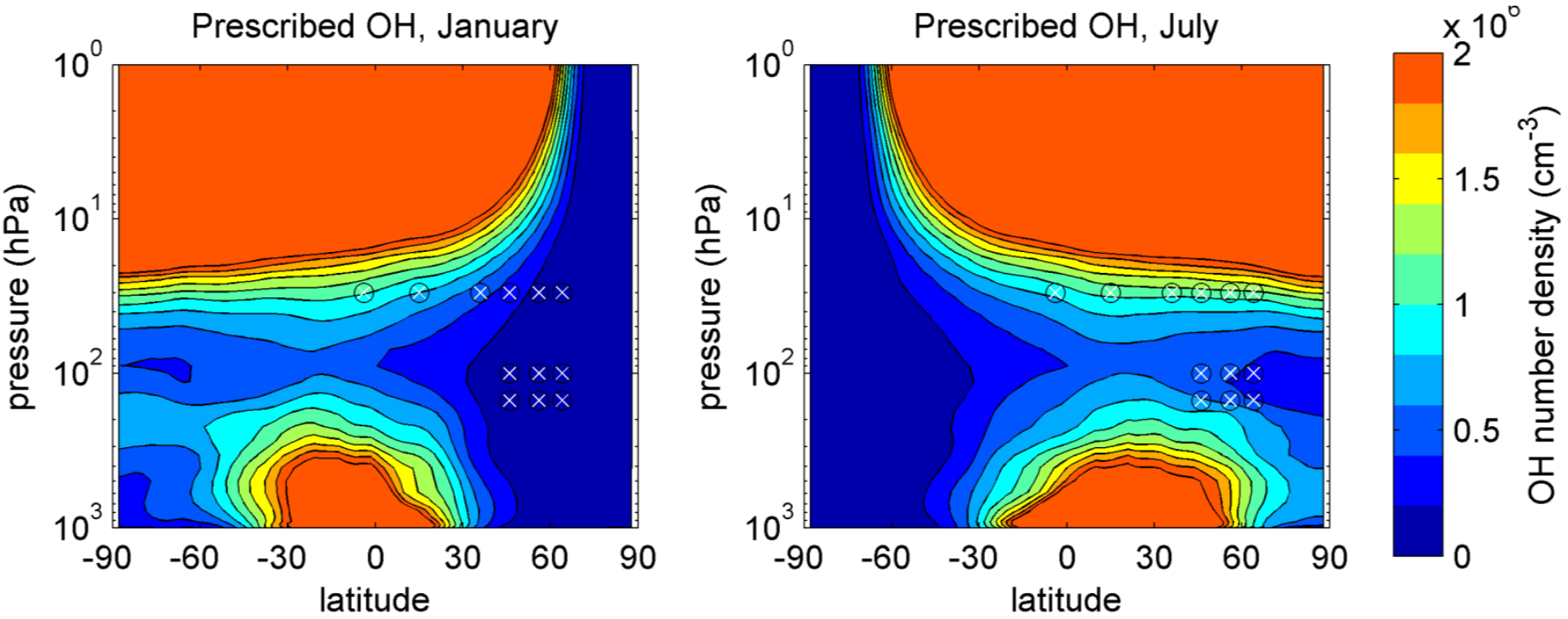
Part 1: Pinatubo (8.5 Tg S) at different latitudes

Latitude	Longitude	Injection height (hPa)	Ensemble size	Actual volcano
4°S	152°E	30	2 Jan, 2 Jul	Rabaul, Papua New Guinea
15°N	91°W	30	10 Jan, 10 Jul	Atitlan, Guatemala
36°N	138°E	30	2 Jan, 2 Jul	Haruna, Japan
46°N	121°W	30	2 Jan, 2 Jul	Rainier, USA
56°N	158°W	30	5 Jan, 5 Jul	Aniakchak, Alaska, USA
64°N	74°E	30	2 Jan, 2 Jul	Laki, Iceland

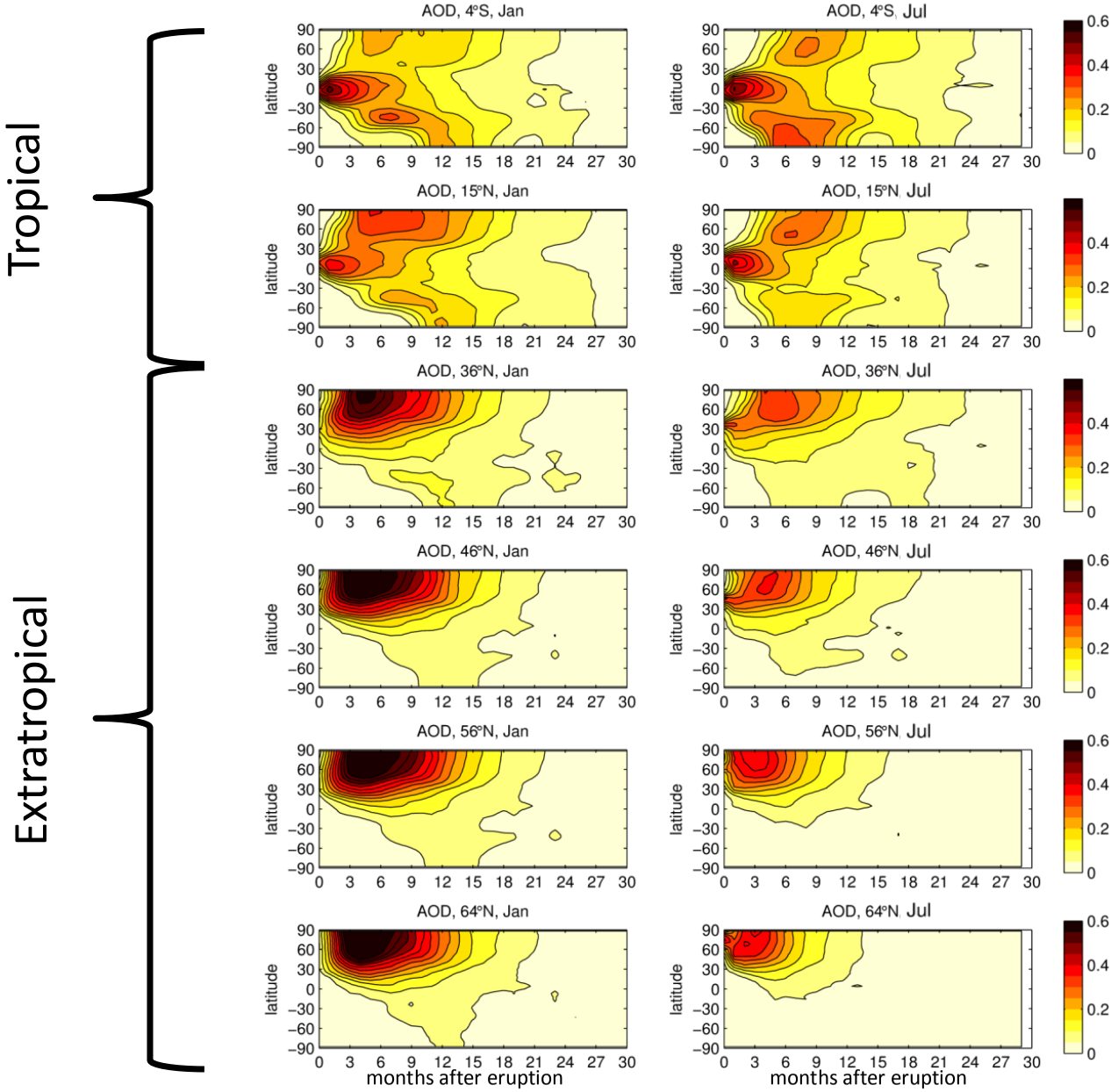
Part 2: High latitude Pinatubo with different injection heights

Injection height (hPa)	Latitude	Ensemble size
30	46/56/64°N	9 Jan, 9 Jul
100	46/56/64°N	6 Jan, 6 Jul
150	46/56/64°N	6 Jan, 6 Jul

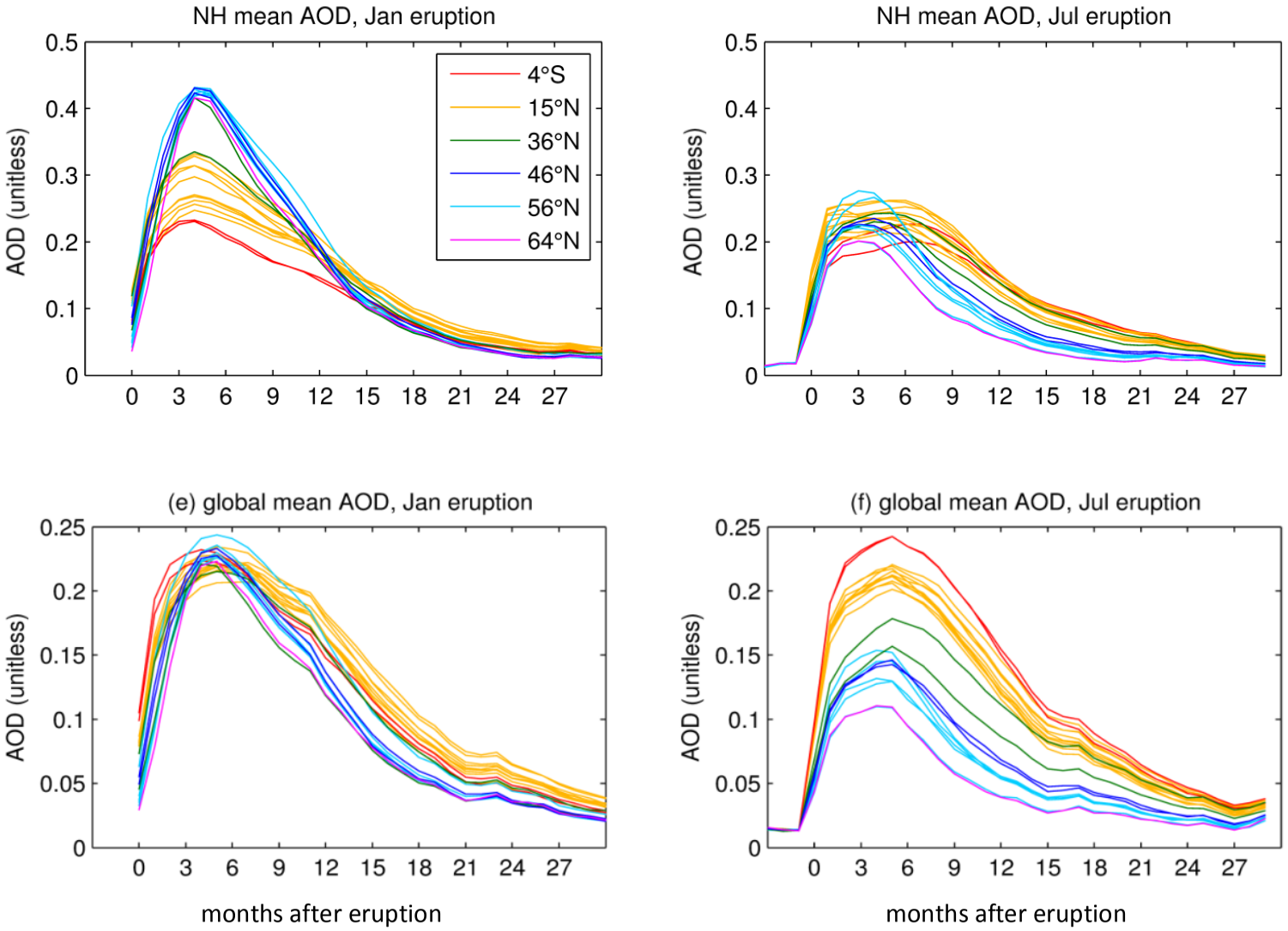
Injection location conditions

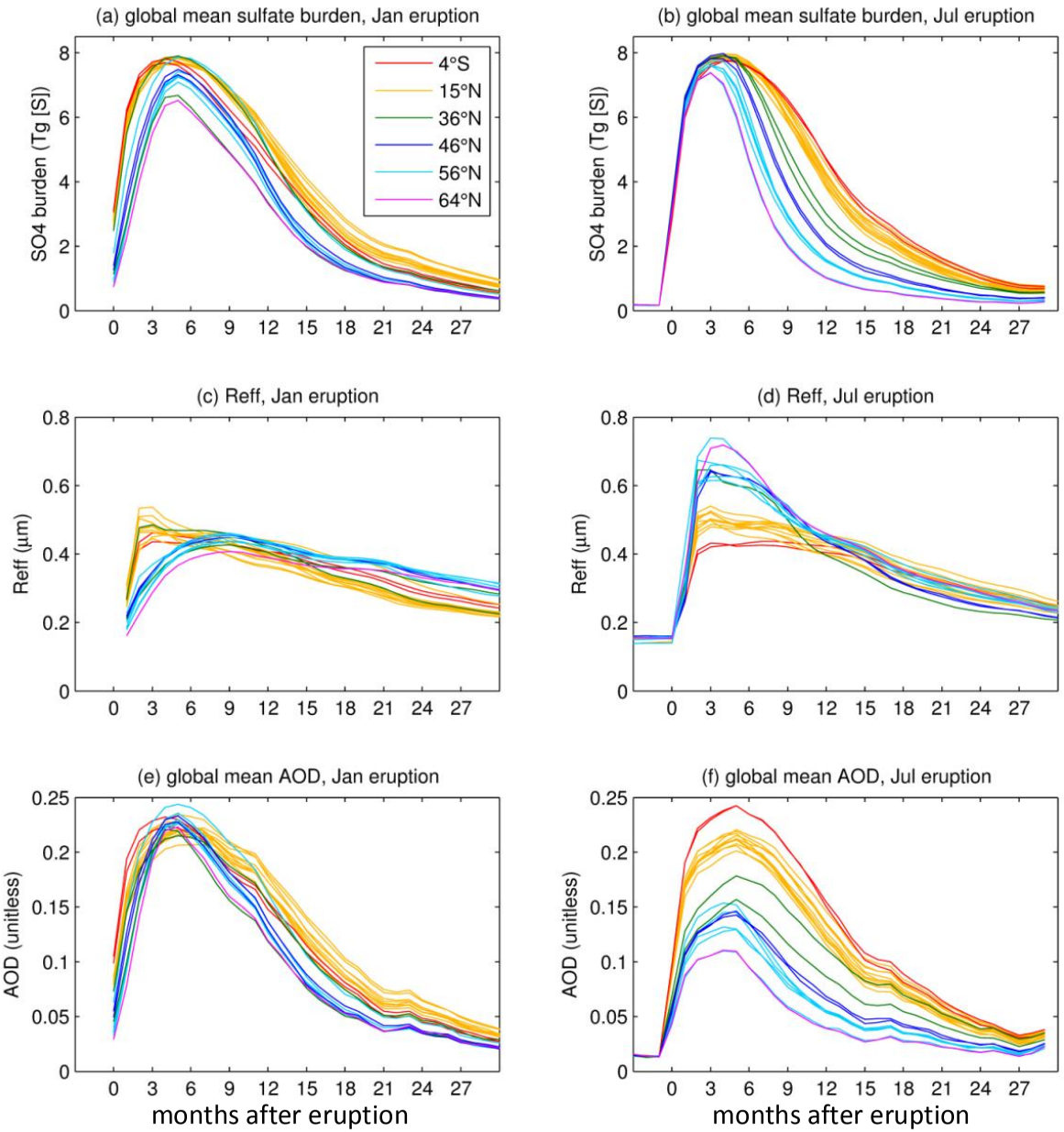


OH fields from coupled chemistry simulations (Timmreck et al., 2003)

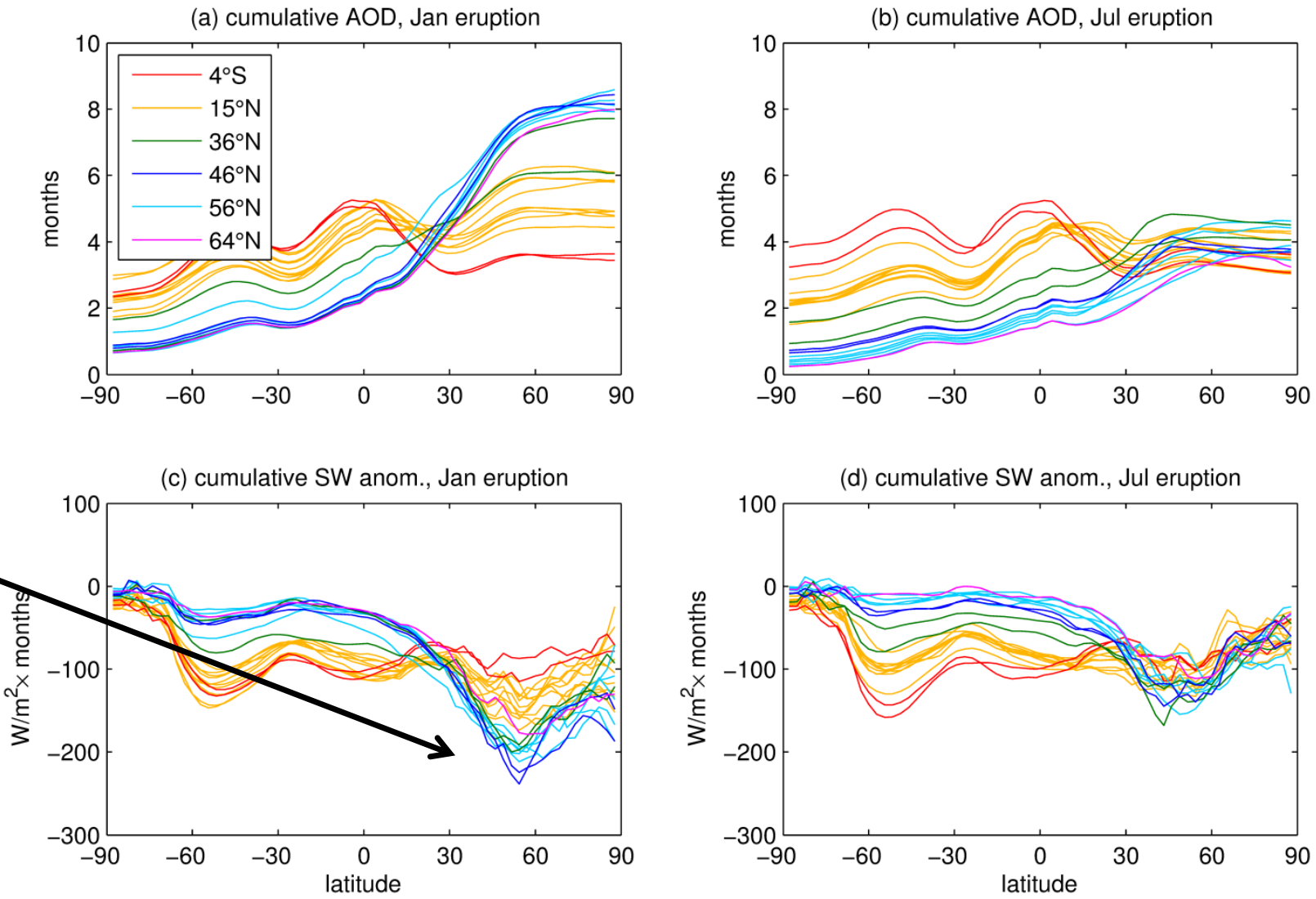


Part 1: Pinatubo simulations (8.5 Tg S) at different latitudes

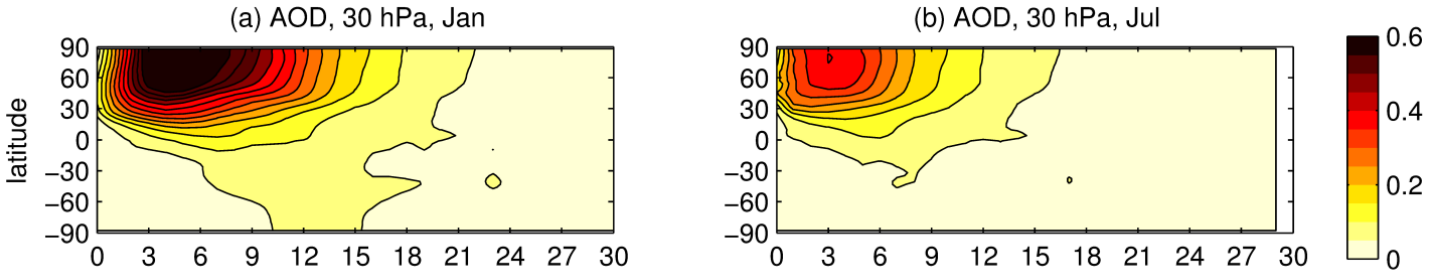

NH mean AOD, Jan eruption
NH mean AOD, Jul eruption
(e) global mean AOD, Jan eruption
(f) global mean AOD, Jul eruption
AOD (unitless)
months after eruption
4°S
15°N
36°N
46°N
56°N
64°N
0
0.1
0.2
0.3
0.4
0.5
0.05
0.15
0.25
0 3 6 9 12 15 18 21 24 27


(a) global mean sulfate burden, Jan eruption
SO4 burden (Tg [S])
4°S
15°N
36°N
46°N
56°N
64°N
(b) global mean sulfate burden, Jul eruption
SO4 burden (Tg [S])
(c) Reff, Jan eruption
Reff (μm)
(d) Reff, Jul eruption
Reff (μm)
(e) global mean AOD, Jan eruption
AOD (unitless)
months after eruption
(f) global mean AOD, Jul eruption
AOD (unitless)
months after eruption

Largest direct NH radiative impact for January, 46°N eruption



Part 2: High latitude, injection height dependence



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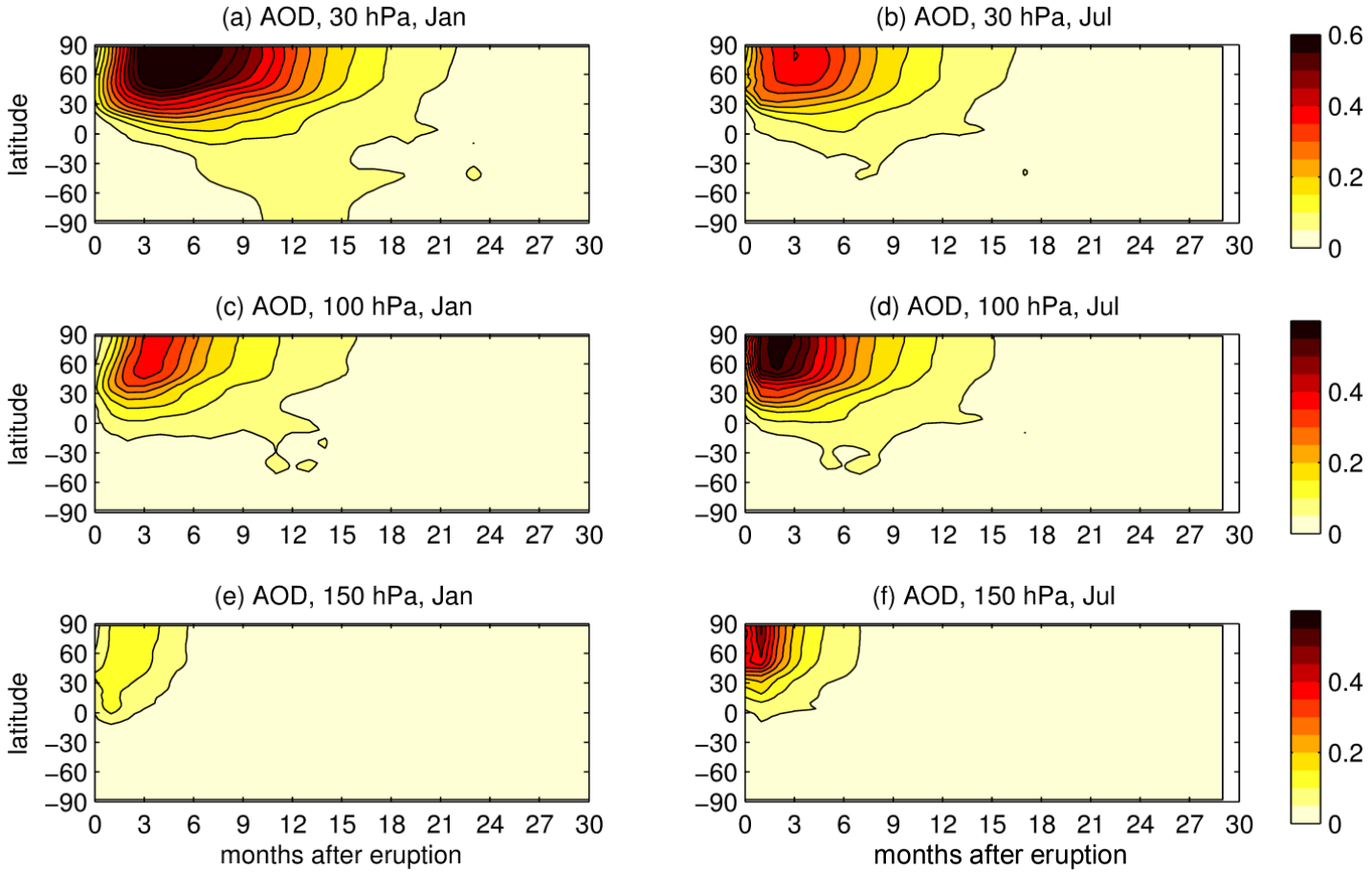
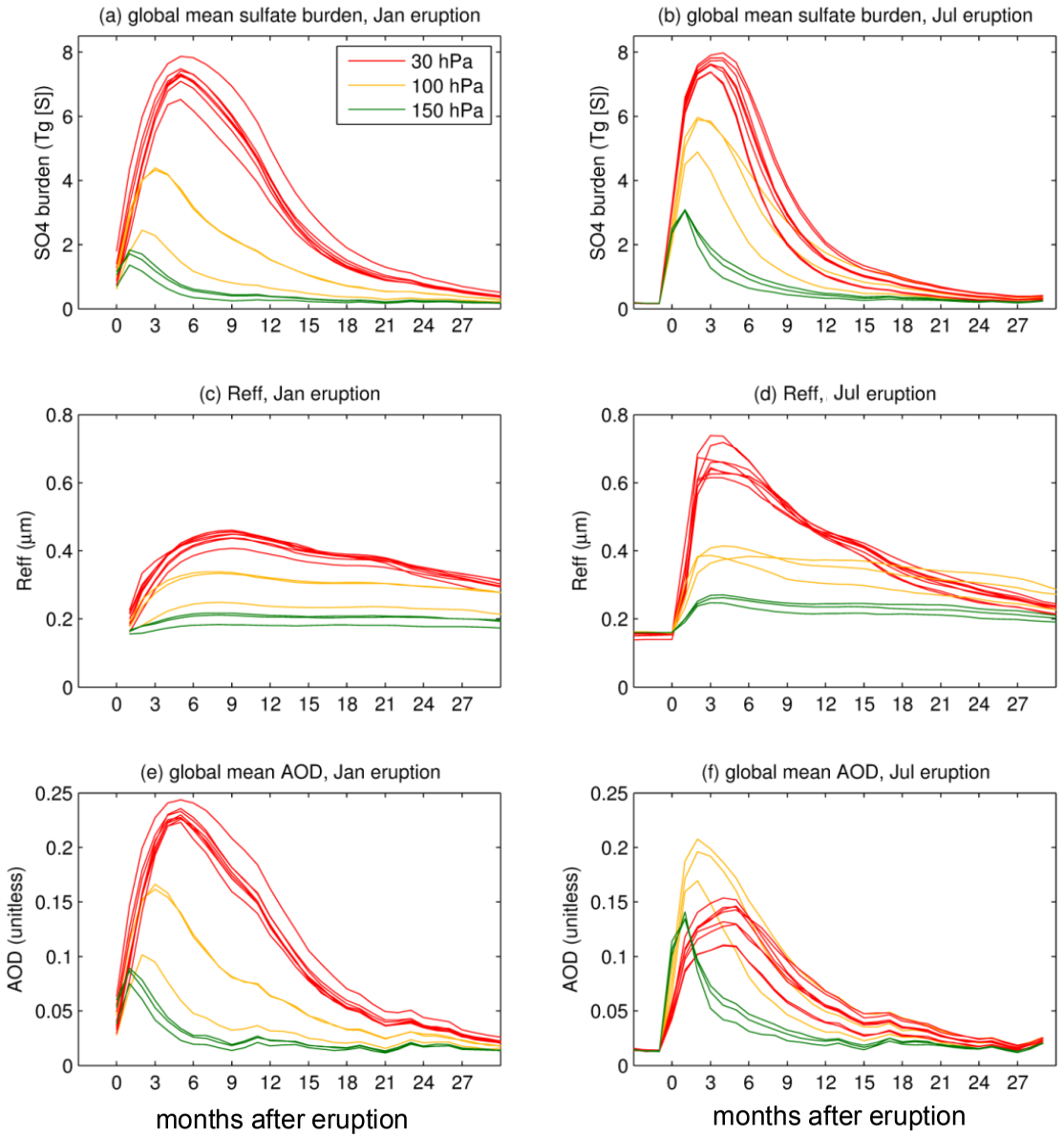
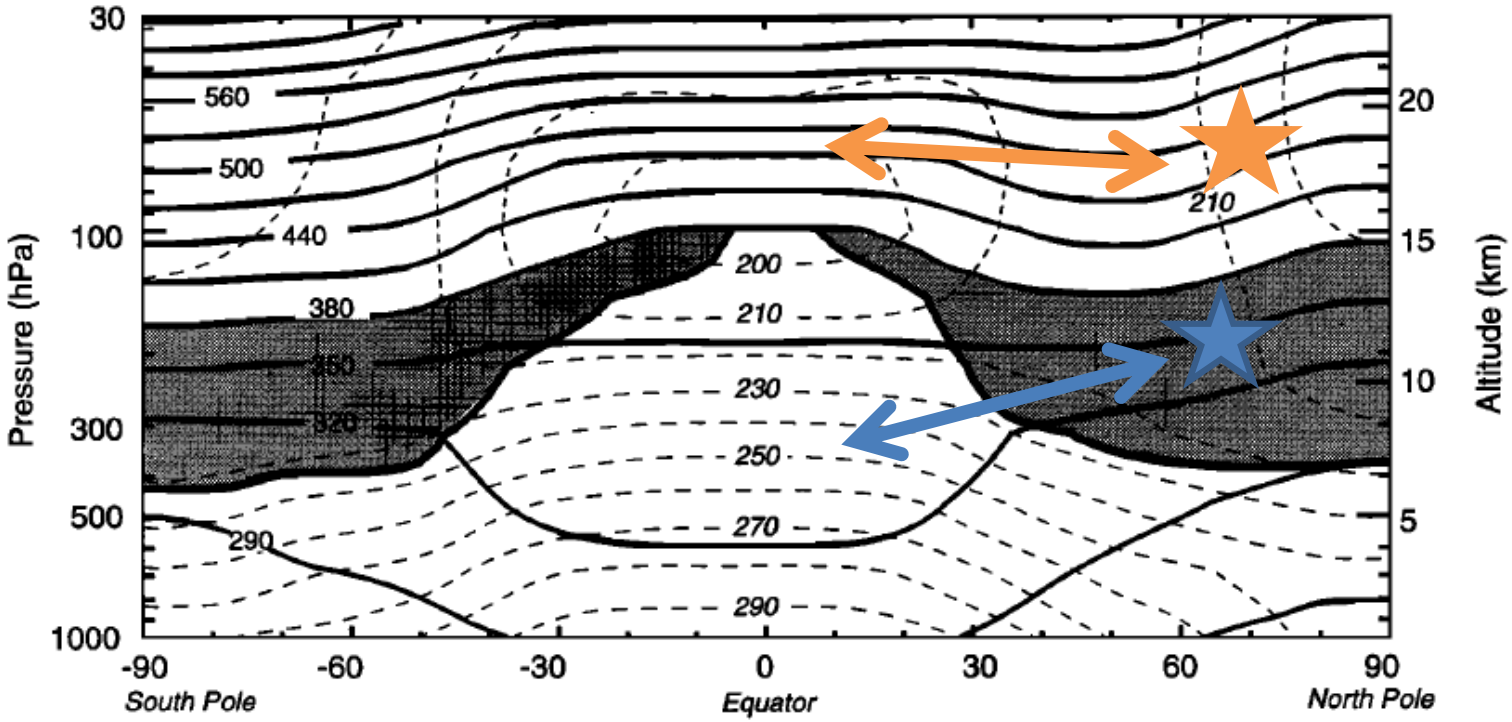



(a) global mean sulfate burden, Jan eruption
(b) global mean sulfate burden, Jul eruption
(c) Reff, Jan eruption
(d) Reff, Jul eruption
(e) global mean AOD, Jan eruption
(f) global mean AOD, Jul eruption
30 hPa
100 hPa
150 hPa
SO4 burden (Tg [S])
Reff (μm)
AOD (unitless)
months after eruption
months after eruption

Where to draw the line?



Holton et al., 1995

Conclusions

- MAECHAM5-HAM simulations imply that extratropical eruptions, with high injection altitudes can have strong climate impacts.
  - extratropical eruptions lead to global mean radiative forcing ½-1 × tropical eruptions (depending on season)
- Injection height very important – not just troposphere/stratosphere, but height within the stratosphere crucially important
- Season of eruption very important for extratropical eruptions
  - For lowermost stratosphere injection, summer eruptions are stronger radiative forcing due to simultaneity of short-lived forcing with solar insolation maximum (Kravitz and Robock, 2011), but also faster transport during winter
  - For “overworld” injection, winter eruptions lead to stronger forcing, since they create smaller particles, due to low OH values and/or more mixing during winter