Impacts of stratospheric sulfate geoengineering on tropospheric sulfate burdens

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Mt. Pinatubo (1991) demonstrated cooling

- 1992: Temperature dropped 0.5°C; coolest year in the past 25 years
- We also saw ozone loss, hydrological changes

~20 Tg SO$_2$ into stratosphere
Why are sulfate aerosols so special?

Sulfates have high extinction (ability to reflect and absorb radiation)

Sulfates have high Single Scattering Albedo (they prefer to reflect radiation rather than absorb it)

What does SO$_2$ have to do with sulfate aerosols?
The sulfate aerosol life cycle

1. emissions
   Mt. Pinatubo (20 Tg SO$_2$), geoengineering (? Tg SO$_2$)

2. chemistry
   Sulfuric acid is made

3. nucleation
   an aerosol is born

4. growth
   evaporation, condensation

5. coagulation
   particles collide and combine

6. deposition
   particles fall to the earth

SO$_2_{(g)}$ + OH$_{(g)}$ $\rightarrow$ H$_2$SO$_4_{(g)}$

Most climate models parameterize some of these processes (esp. nucleation, growth, coagulation)
Aerosol radiative effects not coupled, but het chem is
5 year simulations; 5th year analyzed
Five SO$_2$ injection schemes (50 mb, 4N-4S, all longitudes)
Geoengineered effective radius is larger
Simulated Pinatubo $R_{\text{eff}}$ reaches peak sooner than obs; Simulated Geoeng $R_{\text{eff}}$ larger than Pinatubo
Larger particles fall faster and RF less effective
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\[ V_{\text{fall}} (\text{mm/s}) \]

Particle radius (microns)

Mass scattering efficiency (m²/g)

0 Tg, 1 Tg, 2 Tg, 5 Tg, 10 Tg, Pinatubo yr1, Pinatubo yr2, Pinatubo yr3, Pinatubo yr4
Two microphysical studies compare well, and differ significantly from GCM-only simulations.

![Graph showing aerosol burden vs. stratospheric sulfur injection (Tg S/yr). The graph includes data points and lines representing Rasch et al., Heckendorn et al., and This Work.](image-url)
1/3 of total burden is in the troposphere; 1/3 of that is in the first 100 hPa below the tropopause.

Aerosol Burden (Tg S)

- Rasch et al.
- Heckendorn et al.
- Whole Atmos.
- Troposphere
- First 100 hPa
- 600-1000 hPa
- Stratosphere
- Second 100 hPa

Stratospheric Sulfur Injection (Tg S/yr)

Aerosol Burden (Tg S) vs. Stratospheric Sulfur Injection (Tg S/yr) graph.
10 Tg injection increases upper 100 hPa burden by 30x
Geoeng increases tropospheric burden in the upper troposphere and high latitudes up to 100x

\[
\frac{(1 \text{ Tg} - 0 \text{ Tg})}{0 \text{ Tg}}
\]

\[
\frac{(10 \text{ Tg} - 0 \text{ Tg})}{0 \text{ Tg}}
\]
Our 3D microphysical simulations of stratospheric SO$_2$ injection suggest...

- Geoengineered effective radius is larger than Pinatubo; shorter lifetime limits aerosol burden to ~6 Tg burden (~2 W m$^{-2}$)
  - Results compare favorably to Heckendorn et al.

- Geoeng increases tropospheric aerosol burden, especially high altitude and latitude
  - Troposphere increases 5x; upper troposphere by 30x; high latitudes by 30x
  - Could impact tropospheric clouds, radiative forcing, and chemistry

- Other consequences previously identified:
  - Ozone destruction / stratospheric chemistry changes
  - Acid deposition in mid/high latitudes
  - Hydrological changes/reduced precipitation

- Stratospheric lifetime may be increased by
  - Sulfur sources with slower conversion to aerosol
  - Other aerosol types
  - Higher injection / more spread out
...And the particles that are there, aren’t as effective at scattering radiation

Pinatubo: 6 m²/g

13 Tg geoeng: 2 m²/g