Using WACCM/CARMA to study a stratospheric sulfur injection geo-engineering scheme

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Motivation
In the future we may need to choose between the risks and consequences of climate change vs climate geo-engineering

The stratospheric sulfur injection idea
Volcanic eruptions demonstrate temporary reduced SW flux; ozone loss; hydrological cycle changes \((\text{Trenberth and Dai 2007})\)

Simulations of continuous injection suggest large uncertainty in temperature efficacy

\[ (\text{Heckendorn et al. 2009}) \]

\[ (\text{Robock et al. 2008}) \]

\[ (\text{Heckendorn et al. 2010}) \]
1. Emissions

- SO₂ (UT source only)
- OCS (510 pptv boundary condition)

2. Chemistry

- H₂SO₄ formed
- Oxidants OH, O, O₃, NO₃

3. Nucleation

- Nuc: Zhao and Turco 1995
- H₂O vp: Lin & Tabazadeh 2001
- H₂SO₄ vp: Giauque/Ayers/Kulmala

4. Condensational growth

- H₂SO₄ vp: Giauque/Ayers/Kulmala
- Wt %: Tabazadeh 1997

5. Coagulation

- Brownian, convective, & gravitational effects
  - Toon et. al. 1988

6. Deposition, Sedimentation

- 4° x 5° resolution
- WACCM 3.1.9
- CARMA
  - 38 bins
  - \( r_{\text{dry}} = 0.2 \text{ nm}-1.0 \text{ μm} \)

Aerosol radiative effects not coupled, but het chem is
5 year simulations; 5th year analyzed
Five SO$_2$ injection schemes (50 mb, 8N-8S, all longitudes)

1) 0 Tg (baseline)
2) 1.3 Tg S / yr
3) 2.6 Tg S / yr
4) 6.5 Tg S / yr
5) 13 Tg S / yr
1) 0 Tg (baseline)
2) 1.3 Tg S / yr
3) 2.6 Tg S / yr
4) 6.5 Tg S / yr
5) 13 Tg S / yr

Surface area increases up to 100x

Zonal mean surface area density (um² cm⁻³)
Geoeng. Particles are ~4x larger than Pinatubo

Predicted size is consistent with Heckendorn et al.

Particles are ~4x larger than Pinatubo
Microphysical simulations predict lower burden (shorter lifetime) than simulations with prescribed size distributions.
Geoeng. may decrease ozone in some locations, but large inter-annual variability at high latitudes

Courtesy S. Tilmes
These WACCM-CARMA simulations suggest:

- Stratospheric sulfur injection aerosols peak at 1 µm*, ~4 times larger than Pinatubo
- These large sizes fall out of the stratosphere much faster than previously assumed, esp. at higher injection rates*
- Geoeng. simulations predict some ozone loss, but high variability due to coarse resolution
- Stratospheric sulfur injection geo-engineering may have a limited efficacy (~2 W m⁻² ?)*

*in agreement with Heckendorn et. al
Higher injection altitude $\rightarrow$ increased efficacy

3d sim finds increased SW effect (Niemeier et al., 2010)
Next Steps

• Calculate RF using WACCM/CARMA
• Study Polar Injections also
• WACCM/CARMA remains the most comprehensive model available for stratospheric study:
  – 3D
  – 66 vertical levels
  – Full chemistry
  – Sectional (not modal)
  – Full microphysics
13 Tg perturbation has smaller polar vortex (1-yr comparison)

Baseline 13 Tg/yr

March

October

Courtesy S. Tilmes
Figure 5. Annual mean differential number density $dN/d \log r$ in cm$^{-3}$ at the equator at 39 hPa (first column), 55 hPa (second column) and 90 hPa (third column). (a)–(c) Continuous S injection into the lower stratosphere of 0, 1, 2, 5 and 10 Mt/a (GEO0–GEO10). (d)–(f) Continuous and pulsed emission of 5 Mt/a S emissions (GEO5, GEO5p12, GEO5p2) and annual mean aerosol size distribution for PIN10 from June 1991 to May 1992. (g)–(i) GEO5, GEO5-cond with reduced condensation rates and GEO5-coag with reduced coagulation rates.