The Impact of a Proposed Geo-engineering Scheme on Troposphere and Stratosphere

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The Impact of a Geo-engineered Sulfate Aerosols on Troposphere and Stratosphere

Overview

- Impact of sulfate aerosol particles on polar ozone chemistry, estimates are based on observations
- Impact of sulfate aerosol particles on the entire atmosphere, with focus on the stratosphere, a model study between 2020-2050
- Comparison of observational estimates and model results.
Idea of Using Geo-Engineered Aerosols to Cool the Earth’s Climate

Injection of Stratospheric Sulfate Aerosols:
Natural Experiment: for example 1991 Mt Pinatubo eruption cools the Earth’s surface
Geo-engineering: for example injection of 10 TgS per year = one million flights per year with a payload of 10 metric tons of aerosol (Rasch et al, 2008).

Possible Impacts on
- Local Temperatures
- Precipitation patterns
- Changes of the Stratospheric Chemistry

Impact on Ozone and UV radiation
Chemical Ozone Loss in Polar Regions

Depends on:
1. The amount of halogen compounds
2. The surface for chlorine activation
3. The temperature

Heterogeneous Chemistry
Chlorine Activation

Activation Temperature \(\sim 195K\)
Ozone Depletion Depends on the Amount of Halogen Loading in the Stratosphere

Equivalent Effective Stratospheric Chlorine

Newman et. al, 2006

2068: ‘Recovery’ to 1980 values
2100: Still enhanced values of EESC!!!
Ozone Depletion Depends on the Amount of Halogen Loading in the Stratosphere!

Equivalent Effective Stratospheric Chlorine

Newman et al, 2006

2068: ‘Recovery’ to 1980 values
2100: Still enhanced values of EECl!!!
-> 2050 ozone depletion ~ 80 DU
Temperature Dependence of Ozone Depletion

Arctic

Chlorine activation: effective around 195 K, Temperatures where PSCs can form ($T_{\text{NAT}}$).

**PSC Formation Potential** (*Tilmes et al.*, 2006): Fraction of the vortex where the temperature is below the threshold temperature for PSC existence (*initiated by Rex et al.*, 2004).

Linear relationship between Ozone loss and PSC Formation Potential, excluding the years after the volcanic eruption in 1991.
Sensitivity of the Activation Temperature

Curtsy Katja Drdla

Threshold Temperature for PSCs: $T_{\text{NAT}}$
Activation temperature: $T_{\text{ACL}}$

Enhanced SAD result in a larger volume, where chlorine activation is possible.

Chlorine Activation Temperature: $T_{\text{ACL}}$
Function of SAD, H$_2$O and altitude

Enhanced SAD result in a larger volume, where chlorine activation is possible.
Potential of Activated Chlorine (PACl)

**PSC Formation Potential**
Fraction of the vortex where the temperature is below the threshold temperature for PSC existence.

**Potential of activated chlorine (PACl)**
Fraction of the vortex where the temperature is below the activation Temperature $T_{ACL}$ times the normalized EESC, *Tilmes et al., 2008*

Arctic Ozone Loss in March between 350-550K. HALOE and Aircraft observations, 1991-2005
Relation between Ozone loss and PACl in Arctic and Antarctica

PACl depends on halogen loading, temperature and sulfur burden.
-> Tool to quantify the impact of Geo-engineering on ozone depletion
Relation between Ozone loss and PACl in Arctic and Antarctica

PACl depends on halogen loading, temperature and sulfur burden.

-> Tool to quantify the impact of Geo-engineering on ozone depletion
Projection of PACl and Chemical Ozone Loss for Different Geo-Engineering Scenarios and Future Halogen Condition:

Generic assessment of the impact of geo-engineered aerosol particles on future polar ozone. Any other starting date can be chosen.
Projection of PACl and Chemical Ozone Loss for Different Geo-Engineering Scenarios and Future Halogen Condition:

Observations

- **Very cold Arctic Winter**
- **Moderately cold Arctic Winter**

Volcanic sized aerosols

Small aerosols
Antarctica

Paci

Usual Antarctic Winter

Background SAD
Extension of chemical ozone loss in lower altitudes (below 14km) results in a longer delay of the ozone hole up to 70 years.
## Whole Atmosphere Community Climate Model (WACCM3)

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Baseline Run:
- IPCC scenario A1b 2010-2050
- Secular increase of greenhouse gases (CO$_2$)
- Changing halogen loading
- Background SAD from SAGE aerosols

Geo-engineering using Volcanic Sized Aerosols:
- As baseline run 2020-2050 but with geo-engineered aerosols
- Injection of 2Tg S/yr (from CAM: Rasch et al., 2007)
- Fixed 'Volcanic like' aerosols (2020-2050):
  radius of 0.37 microns, effective radius about 0.43 microns
Aerosol Distribution: Basic Run and Volcanic Run

Surface Area Density for Sulfate Aerosol Particles SAD (μm²/cm³)

Baseline Run

Geo-engineering Run

Global distribution of particles only possible if injection is located at or above 25 km in the Tropics.
Global Annually Averaged Temperature Response Between 2010-2020 and 2040-2050

Hatched areas are not significant at 95% level
Global Annually Averaged Temperature Response Between Geo-eng. and Baseline Runs 2040-2050

- ~5 year adjustment of temperatures
- Constant temperature offset
- The fixed amount of sulfur cools the Earth’s surface by ~0.9 K,
  
  -> Delay of global warming by ~ 40 years
  
  -> Still climate change
Ozone Changes With Increasing Greenhouse Gases and Geo-Engineered Sulfate Aerosol Particles

Ozone changes (2040-2050) – (2010-2020)

Baseline Run

Altitude (km)

Column Ozone (DU)

latitude

2040-2050

2010-2020
Ozone Changes With Increasing Greenhouse Gases and Geo-Engineered Sulfate Aerosol Particles

Ozone changes (2040-2050) – (2010-2020)

Baseline Run

Geo-eng. Run

Altitude (km)

Column Ozone (DU)

latitude

2040-2050

2010-2020
Ozone Difference Between Geo-Engineering and Baseline 2040-2050

Annually averaged difference in Ozone
Difference Between Geo-engineering and Baseline 2040-2050, Tropics

Changes of ozone due to chemical Loss

Increase of heterogeneous reactions

- decrease of the NO\textsubscript{x}/NO\textsubscript{y} equilibrium (Fahey et al., 1993)

1. \(\text{N}_2\text{O}_5 + \text{H}_2\text{O} \rightarrow 2\text{HNO}_3\)

2. \(\text{ClONO}_2 + \text{H}_2\text{O} \rightarrow \text{HOCl} + \text{HNO}_3\) \hspace{1cm} T < 200 K as important as (1)

- increase in the ClO\textsubscript{x} and HO\textsubscript{x}
Difference Difference Between Geo-engineering and Baseline 2040-2050, Tropics

Importance of dynamical changes:
- significant decrease of ozone around 25 km in the Tropics
- significant increase of ozone below 22 km in the Tropics
Difference in Ozone Between Geo-engineering and Baseline 2040-2050, Polar Regions

September/October/November

January/February/March

Changes of ozone due to chemical Loss
Polar Ozone Loss: Arctic

2-4 times increase in Ozone Loss
- Stronger polar vortex
- Colder temperatures
- Enhanced heterogeneous reactions

April 2018

April 2021
Polar Ozone Loss: Arctic Model Results vs. Observational Estimates

Observational estimate for a moderately warm winter.

Agreement between model and observation estimates for warm and moderately warm winters.
Polar Ozone Loss: Arctic

Observational estimate for a moderately warm and a very cold winter.

Impact of geo-engineering in case of very cold winters could not be simulated.
Polar Ozone Loss: Antarctica
Polar Ozone Loss: Antarctica

Antarctic ozone hole:
• 20-30 years delay of the recovery (model)
• Increase of ozone of ~20 DU
Summary

Geo-engineered Aerosols in the Stratosphere result in:

- Cooling of the surface, delay of global climate change by 40 years
- Changes in climate due to changes in horizontal and vertical temperature gradient -> indication of changes in the precipitation pattern
- Minor changes of column ozone in low and mid latitudes
- Significant decrease of the depth of the ozone layer, especially in high northern latitudes
- Recovery of the Antarctic ozone loss delayed by 30-70 years

Open Issues following directly from this study
- Impact of more realistic ozone depletion in the NH on atmosphere and biosphere
- Air-quality? Deposition processes (UTLS exchange)
- Injection scenarios and particle size/distribution