Evaluating UKESM stratospheric composition using satellite datasets

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Outline

Using Satellite data to understand:
I. Low NOy bias, hence positive ozone bias
II. Volcanic aerosol forcing using interactive aerosol module

1860 1880 1900 1920 1940 1960 1980 2000

60°S-60°N

TCO [DU]

The Krakatoa eruption in 1883 is visible as a peak in the TCO [Dobson units] data. Courtesy of James Keeble.
Tracer-tracer Correlation Analysis

CH₄ oxidation → 2H₂O

CH₄ loss correct but too humid stratosphere

SPARC (7.0-2.0 x CH₄) model (7.3-1.0 x CH₄)

ACE (6.8-1.75 x CH₄)

MIPAS (8.0-2.4 x CH₄)

NCEO data

N₂O loss → NOy

N₂O loss correct but NOy produced then lost too rapidly

Archibald et al., GMD (2020)

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• Fast-Jx photolysis scheme- $J_{NO}$ scaled to 0.6
• Corrected BrONO$_2$ cross section
• Updated O$_2$, O$_3$, Cl$_2$O$_2$, BrCl, ClONO$_2$, SO$_3$ cross sections using JPL2015
• Some other minor corrections
• 4-year simulation for present day shows improvements in NOy

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Improvements in Pre-industrial Ozone in UKESM

➔ New simulation with photolysis rate correction (Luke Abraham)
➔ Significant improvements in total column and ozone profile
➔ Pre-industrial ozone is largely controlled by NOx and HOx cycles
➔ Model still shows high bias against other models
Stratospheric Aerosol Scheme in the UKESM
Stratospheric Aerosol Module in the UKESM

**Particle phase**
- 4 Modes
  - Coarse
  - Accumulation
  - Aitken

**Gas phase**
- H$_2$SO$_4$ vapour pressure with Kelvin Effect
- H$_2$O
- OH, O$_3$
- O, NO$_3$, OH

**Nucleation** (Vehkamaki)

**Sedimentation**

- Climate models without aerosol module use external forcing datasets that are constructed with observations and models
- UKESM simulation for CMIP6 does not include interactive aerosol model for volcanos
- Large uncertainties about SO$_2$ emitted during each eruption

Dhomse et al., (2014)
Dhomse et al., (2020)
Set-Up for Mt. Pinatubo Simulation

- Interactive strat-trop aerosol configuration of UM-UKCA for aerosol properties across stratosphere & troposphere (nb \( \text{H}_2\text{SO}_4 \) (aq) particles evaporate to gas phase \( z>30\text{km} \)).

- Free-running transient atmos-only simulations in high-top (80 km) version of v8.4 UM-UKCA (GA4) GCM with time-varying prescribed SSTs & sea ice as AMIP2.

- UKCA stratospheric-troposphere chemistry scheme (Abraham et al., 2016) extended with sulphur chemistry.

- For each eruption, control-run spun-up to GHG, ODSs, then 3-member ensemble from different initial fields with common specified QBO-transition for \( \text{SO}_2 \) emission at a) mid-pt, b) upper bound, c) lower bound.

**Pinatubo:** a) 14, b) 20, c) 10 Tg \( \text{SO}_2 \) at 21-23 km 1990 GHGs & ODSs, June eruption with easterly QBO
Pinatubo Evaluation (Stratospheric AOD)

- Simulations with 10 Tg and 14 Tg SO\(_2\) injection show reasonable agreement with most of the observational data sets.


- Large difference in volcanic forcing data set.

- Created and tested microphysically consistent off-line (easy aerosol) forcing data set for three largest volcanic eruptions (Mt Pinatubo (1991), El Chichon (1982) and Mt Agung (1983)) over last century.

- Model simulations suggest much lower SO\(_2\) amount is needed to simulate past volcanic eruption possibly indicating missing removal mechanism (e.g. co-emitted volcanic ash).
Pinatubo - Extinction at 550nm (SAGE II)

- 10 to 14 Tg seems to show better agreement
- CMIP6 data show plateau in tropical extinction
Radiative Forcing and Lower Stratospheric Heating

TOA rad. changes [60S-60N]

SW

LW


SW/LW ano. [W/m²]

dT

Pressure [hPa]


Pressure [hPa]
Summary

• Updated photolysis data in the UKESM. Updated simulation shows increase in stratospheric NOy, but model still shows more ozone and less NOy than observations.

• Simulated stratospheric aerosol properties following Mt. Pinatubo eruption have been evaluated against a range of observational data sets.

• Smaller amount of SO$_2$ injection is needed to simulate changes in stratospheric aerosol following past eruptions suggesting (probable) missing mechanism.

• Microphysically consistent volcanic forcing data has been created for Mt Pinatubo, El Chichon and Mt Agung eruptions.
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