A new and improved coherent, prescribed parameterization of stratospheric aerosol for all flavors of CESM

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and thanks to L. Thomason, J.P. Vernier, B. Luo, F. Arfeuille and T. Peter
Motivation

CMIP5 Global Annual Mean Surface Temperature Anomaly

Year

Anomaly (referenced to 1961-1990, °C)

-0.6 -0.4 -0.2 0 0.2 0.4 0.6 0.8 1


HadCRUT4 GISTEMP NCDC
Motivation: Bad and Ugly Volcanoes

CMIP5 Global Annual Mean Surface Temperature Anomaly

- Bezymianny
- Agung
- St. Helens
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Volcanic
Eruptions
Motivation: “The Hiatus”

CMIP5 Global Annual Mean Surface Temperature Anomaly

Anomaly (referenced to 1961-1990, °C)

Year

Motivation: Why are there Discrepancies?
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CMIP5 Global Annual Mean Surface Temperature Anomaly

DO YOU HATE YOUR VOLCANOES?

YOU SHOULD!
Overview of Stratospheric Aerosols

- Meteoritic Smoke
- Stratospheric Aerosol Layer

Mesosphere

Stratosphere

Troposphere

Surface

Volcanic
Terrestrial
Biomass Burning
Anthropogenic
Marine

SO$_2$
OCS
SO$_2$
OCS
SO$_2$
OCS
DMS

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Problems with Stratospheric AOD Forcing

Mauna Loa (19.5N) AOD Comparison

Ammann et al. (2003)
Sato et al. (1993)
Problems with Stratospheric AOD Forcing

Mauna Loa (19.5N) AOD Comparison

What are the best constraints for volcanic aerosol forcing?
How can we make a better forcing file?
A New Dataset for CCMI for 1960-2013

1960-1978

Photometer

Ground photometers: Optical depths at 550 nm.

1979-2005

SAGE I, SAM II, SAGE II

(1) SAGE I: 1979-1980, extinction coefficients at 1020 nm

(2) SAM II: 1981-1984, extinction coefficients at 1020 nm

(3) SAGE II: 1984-2005, extinction coefficients at 1020, 525, 452 and 386 nm.

2006-2011

CALIOP

CALIOP: Backscatter and extinction coefficients at 532 nm.

For more details see: Arfeuille, F., and B.-P. Luo (2013), Uncertainties in modeling the stratospheric warming following Mt. Pinatubo eruption, ACP
A New Dataset for CCMI: Strat. AOD

RESULTS (IX)

PINATUBO

1991

eruption

RESULTS (V)

1991–2011

Sato V2012 (with OSIRIS since 2002)

AOD 15–35 km 50°N–50°S

End of SAGE II

0.100

0.030

0.010

0.003

0.001

0.100

0.030

0.010

0.003

0.001

1991 93 95 97 99 01 03 05 07 09 11

AOD @ 525 nm

Courtesy of Jean-Paul Vernier
A New Dataset for CCMI: Strat. AOD

Fixes Overshoot of Large Volcanoes

AOD 15-35 km 50°N-50°S

- - - Sato-V2012 (with OSIRIS since 2002)

Combined SAGE II – GOMOS – CALIOP

End of SAGE II

Courtesy of Jean-Paul Vernier
A New Dataset for CCMI: Strat. AOD

RESULTS

PINATUBO

1991 eruption

RESULTS

1991–2011

Sato V2012 (with OSIRIS since 2002)

Combined SAGE II – GOMOS – CALIOP

More Accurately Accounts for Moderate Volcanoes

AOD 15-35 km 50°N-50°S

SAGE II – CALIOP

End of SAGE II

 Courtesy of Jean-Paul Vernier

Overlap of instruments allows to test SAGE II – CALIPSO transition

Important differences to Sato-GISS data

More Accurately Accounts for Moderate Volcanoes
A New Dataset for CCMI: SAD

Results

- SAD in broad agreement with newest SAD estimates (Thomason et al., 2008).
- During volcanic periods, SAGE_4l SAD tends to be smaller than OPC measurements.

Courtesy of Arfeuille, F., and B.-P. Luo (2013, CCMI Meeting)
Implementation in CESM(All Flavors)

- New mass, radius and SAD inputs based on CCMI reanalysis
- Improved optical lookup tables for CAMRT and RRTMG
- Coherent treatment of input for radiation and chemistry parameterizations

Test Setup:
- Focus on Pinatubo (June, 1991)
- Ensemble of 5 each for the Old, New, and Background
Changes in Stratospheric AOD

New/CCMI
CAM4: New Volcanoes – Background, AEROD$_V$

Old/CCSM4
CAM4: Old Volcanoes – Background, AEROD$_V$

Latitude

Year

Latitude
0 20 40 60 80

0 0.05 0.1 0.15 0.2 0.25

AOD

Changes in Stratospheric AOD

New/CCMI
CAM4: New Volcanoes – Background, AEROD$_V$

Old/CCSM4
CAM4: Old Volcanoes – Background, AEROD$_V$

Latitude

Year

Latitude
0 20 40 60 80

0 0.05 0.1 0.15 0.2 0.25

AOD
Changes in MLO Stratospheric AOD

Mauna Loa (19.5N) AOD Comparison

Visible AOD vs Year

- MLO PFR AOD
- Ammann et al. (2003)
- Sato et al. (1993)
- CAM4 with CCMI
Implementation in CESM (All Flavors)

Global Annual Mean Surface Temperature
(Mean of 5 Ensemble Members using CAM4/CCSM4)

Year
Anomaly (Referenced to 1990, °C)

-0.4 -0.3 -0.2 -0.1 0 0.1 0.2 0.3 0.4

GISS Land–Ocean Index
Old Volcanoes
Background
New Volcanoes
Upper Atmosphere Warming

Temperature Difference at 50hpa

- Red: WACCM
- Blue: CAM
- Black dashed: Obs
- Pink: CCSM4

ΔT

Month (Jan 1991)
Changes in Stratospheric Heating

**New/CCMI**

CAM4: New Volcanoes – Background, Tropical T

**Old/CCSM4**

CAM4: Old Volcanoes – Background, Tropical T
Conclusion

A New Parameterization of Stratospheric Aerosol has been implemented in CESM

Tested in WACCM, CAM4, CAM5, CCMI and CCSM4

Method has also been applied to creations of Paleo and GeoMIP scenarios
Next Steps... What about Prior 1960?
What about Prognostics Stratospheric Aerosols?
Questions?
The Role of Moderate Volcanoes and the ‘Hiatus’

Greenhouse gas forcing increased continuously throughout period. Stratospheric aerosol only slowed increase by ~0.2 W/m²

Adapted from Solomon et al. (2011), The Persistently Variable “Background” Stratospheric Aerosol Layer and Global Climate Change, Science.
Impacts on global temperature

Temperature Change

Ignoring the moderate volcanoes from 2000 to 2010 may lead to an underestimate of global temperature of \(\sim 0.1^\circ\text{C}\) in 2010.
Remaining Questions: Why is the Response so Variable?

Global Annual Mean Surface Temperature
(Mean and 5 Ensemble Members using CAM4/CCSM4)
Changes in Stratospheric AOD

CAM4: New Volcanoes – Old Volcanoes, AEROD₀

New/CCMI minus Old/CCSM4
Where is the Change in AOD Coming From?
AOD

CAM4: New Volcanoes – Background, AEROD

CAM4: Background – No Stratospheric Aerosol, AEROD

CAM4: Old Volcanoes – Background, AEROD

CAM4: New Volcanoes – Old Volcanoes, AEROD
FSNSC

CAM4: New Volcanoes – Background, FSNSC

CAM4: New Volcanoes – Old Volcanoes, FSNSC

CAM4: Old Volcanoes – Background, FSNSC
Tropical T (20S-20N)

CAM4: New Volcanoes – Background, Tropical T

CAM4: New Volcanoes – Old Volcanoes, Tropical T

CAM4: Old Volcanoes – Background, Tropical T
Old, New, Background, None, New Mass Old Optics, Old Mass with New Optics, GISS

Global Annual Mean TREFHT

Year

Temperature (K)
Scale

<table>
<thead>
<tr>
<th>VEI</th>
<th>Volume of erupted tephra</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.00001 km³</td>
<td>Mono-Inyo Craters past 5,000 years</td>
</tr>
<tr>
<td>1</td>
<td>0.001 km³</td>
<td>Mount St. Helens May 18, 1980 (~1 km³)</td>
</tr>
<tr>
<td>2</td>
<td>0.01 km³</td>
<td>Pinatubo, 1991 (~10 km³)</td>
</tr>
<tr>
<td>3</td>
<td>0.1 km³</td>
<td>Tambora, 1815 (&gt; 100 km³)</td>
</tr>
<tr>
<td>4</td>
<td>1 km³</td>
<td>Yellowstone Caldera 600,000 years ago (~1,000 km³, not depicted)</td>
</tr>
<tr>
<td>5</td>
<td>10 km³</td>
<td></td>
</tr>
<tr>
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<td></td>
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<tr>
<td>7</td>
<td>1,000 km³</td>
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</table>
Volcanic Eruptions from 2000 to 2010

Maximum Observed Injection Height and Total Column SO$_2$

Circles represent relative amount of sulfur emitted.