Do large tropical volcanic eruptions influence the Southern Annular Mode?

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- Motivation
- Volcano-climate modeling
- Conclusions
- Implications
What do we expect after large tropical volcanic eruptions in the SH?

Annular Mode (AM) response during winter

\[ \text{AM}_{10\text{hPa}} > 1.5 \]  
(cold/ strong polar vortex events)

\[ \Rightarrow \text{We would expect a positive Southern Annular Mode (SAM) in the winter stratosphere propagating downward to the surface during winter/ spring.} \]
But... SH observations after large tropical VE

Negative, non-significant changes in the SAM Index are observed after large tropical volcanic eruptions of the past (see also Robock et al., 2007; Karpechko et al., 2010).

No clear SAM signal in CMIP3 and CMIP5 models (i.e., Karpechko et al., 2010; Driscoll et al., 2012; Charlton-Perez et al., 2013; Gillet and Fyve, 2013).
Modelling SH climate effects of volcanic eruptions

MAECHAM5-HAM (T42/ L39) (Giorgetta et al., 2006; Niemeier et al., 2009; Timmreck et al., 2010)

General circulation model, interactive aerosol/ microphysics/ sulfur chemistry (HAM), high top model, climatological SSTs

E17: Pinatubo size simulation (at Los Chocoyos location)
- VEI 5: 17 Mt SO₂
- injected at 24 km, 15°N, 269°E
- January eruption: 7 x 5 years

E700: Los Chocoyos simulation
- VEI 7: 700 Mt SO₂, 84 ka, Guatemala
  (Metzner et al., 2012)
- injected at 24 km, 15°N, 269°E
- January eruption: 7 x 5 years

Atitlán caldera (host of Los Chocoyos)
Model validation: Pinatubo eruption

- ECHAM5-HAM simulations of 17 Mt eruption, June 15, 15.3°N
- Excellent agreement with ERBE top of the atmosphere (TOA) satellite short wave flux anomalies observed after Pinatubo.
- Little to no dependence on eruption longitude.

Toohey et al (2011, ACP)
SH Geopotential Height anomalies (JJA)

Lower stratosphere (20 km)  Free troposphere (5 km)

Note different scales between E700 and E17!
The increased meridional pressure gradient leads to stronger circumpolar westerly winds from the stratosphere to the surface!

**Positive Southern Annular Mode (SAM)**

**Geopotential Height anomalies [gpm] (SON)**

- **Lower stratosphere**
  - **E700**
  - **H**
  - **L**

- **Free troposphere**
  - **z anomaly (m)**

**SAM Index (Gong&Wang, 1999):** GH gradient between 40°S and 65°S
A significant, strong positive SAM is simulated, lasting up to 18 months.

Hardly any significant signal is found in good agreement with Mt. Pinatubo observations (Robock et al., 2007; Karpechko et al., 2010).
Does this signal propagate downward?

daily SAM Index

Only for E700 a positive significant signal propagates downward, reaching the surface within 15 to 45 days; ongoing up to at least 1 year.
The surface (SON) is still affected, showing stronger meridional pressure gradient, stronger westerly wind, poleward shift of the storm tracks and a drier Antarctica for E700.
Conclusions

The SH surface is impacted by tropical volcanic eruptions through direct radiative and indirect dynamical effects (stronger westerlies, shift of the storm tracks, colder and drier Antarctica).

For a Pinatubo size eruption (E17, VEI 5) we find no significant SAM signal at the surface, which is in good correspondence with observations for the Mt. Pinatubo eruption in June 1991 (Robock et al 2007; Karpechko et al 2010).

However, for Los Chocoyos (E700, VEI 7) a significant, positive up to 10x stronger SAM phase is simulated compared to a Pinatubo size eruption.

→ How large has a tropical volcanic eruption to be to force a positive SAM phase and significant Stratosphere-Troposphere coupling?
SO$_2$ – SAM relationship for tropical volcanic eruptions of different strength

> 15 Mt injected SO$_2$: significantly increased SAM Index in the lower stratosphere (50hPa)

> 190 Mt injected SO$_2$: significantly increased SAM Index at the surface (sea level pressure)

Krüger and Toohey to be submitted
Very large tropical volcanic eruptions cause a positive SAM

Very large eruptions

Implications for e.g.:
- Southern Ocean
- Sulfate deposition in Antarctica

Positive SAM increased westerlies

SAM Index (SLP): Modelled volcano comp.
Increased Westerlies >50°S down to the surface → positive SAM → increase in surface wind stress → acceleration of zonal current in the ocean at 60°S.
Bi-polar sulfate deposition

SO$_4$ flux (kg/km$^2$): Greenland-Antarctic

Eruptions < 170 Mt SO$_2$

+ Jan model
+ Jul model
○ ice cores

All eruptions

Toohey et al (2013, JGR)
Thanks for your attention!

Relevant references


