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Do large tropical volcanic eruptions influence the Southern Annular Mode?

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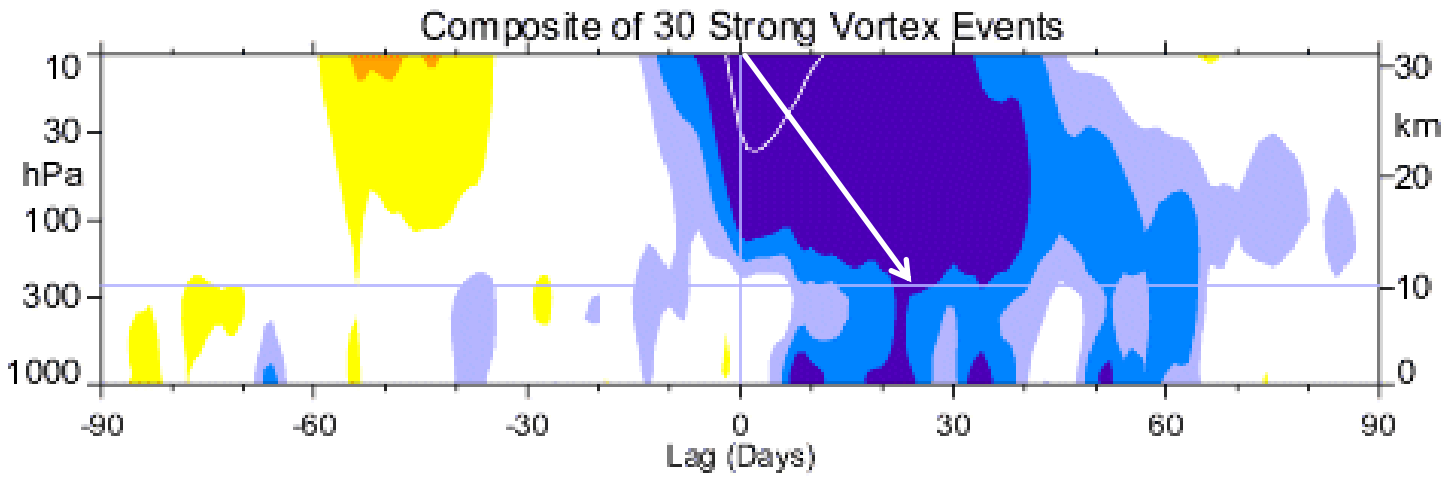
- Motivation
- Volcano-climate modeling
- Conclusions
- Implications

What do we expect after large tropical volcanic eruptions in the SH?

Annular Mode (AM) response during winter

AM_{10hPa} > 1.5

(cold/ strong polar vortex events)



Baldwin and Dunkerton, 2001

→ We would expect a positive Southern Annular Mode (SAM) in the winter stratosphere propagating downward to the surface during winter/ spring.

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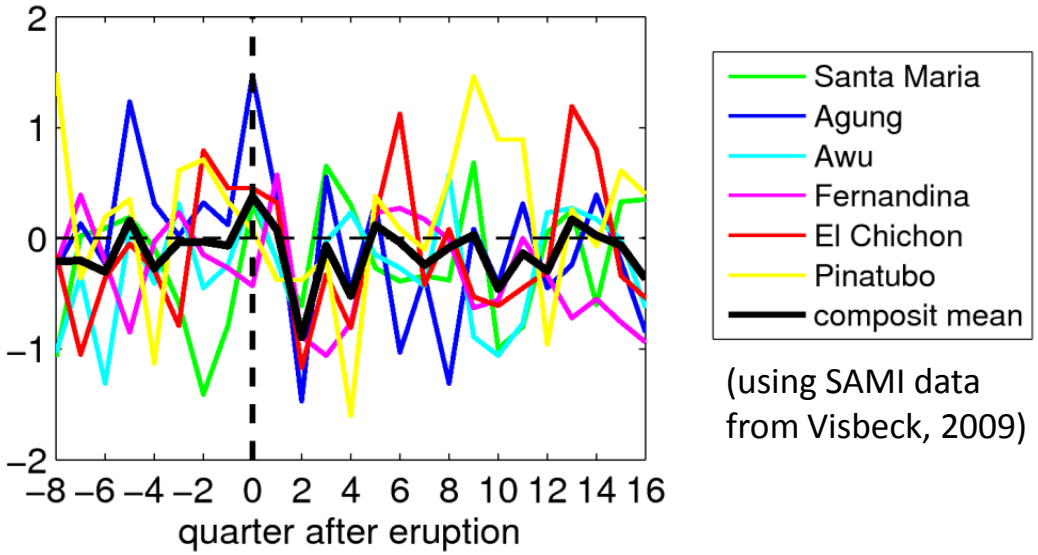
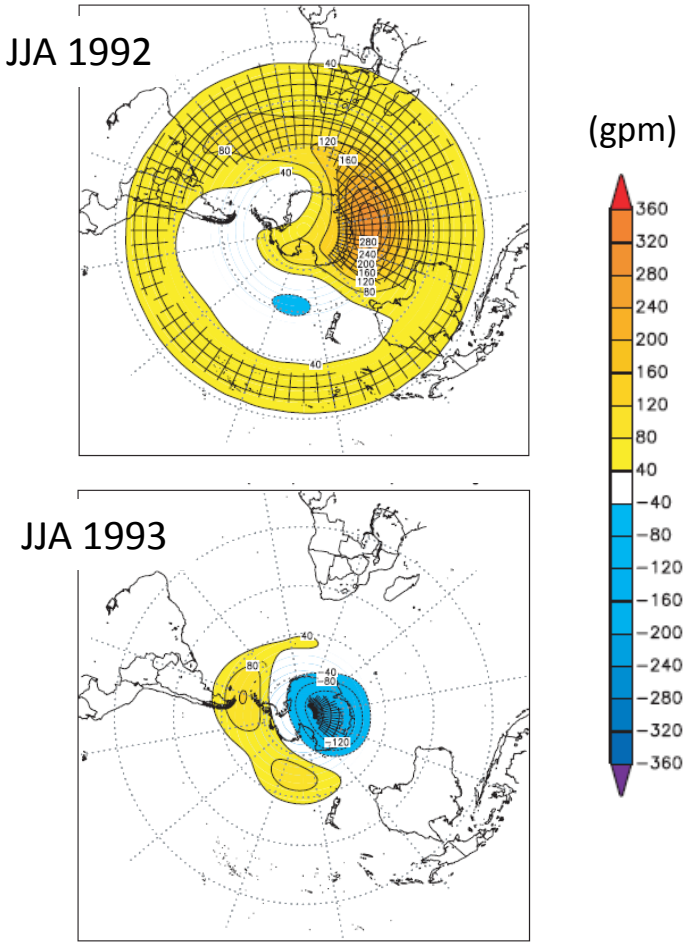
But... SH observations after large tropical VE

Southern Annular Mode (SAM) Index at SLP



(using SAMI data from Visbeck, 2009)

G. Height anomalies at 24 km



Robock et al (2007)

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).

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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 SO_2**
- injected at 24 km, 15°N, 269°E
- January eruption: 7 x 5 years

E700: Los Chocoyos simulation

- **VEI 7: 700 Mt SO_2, 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)

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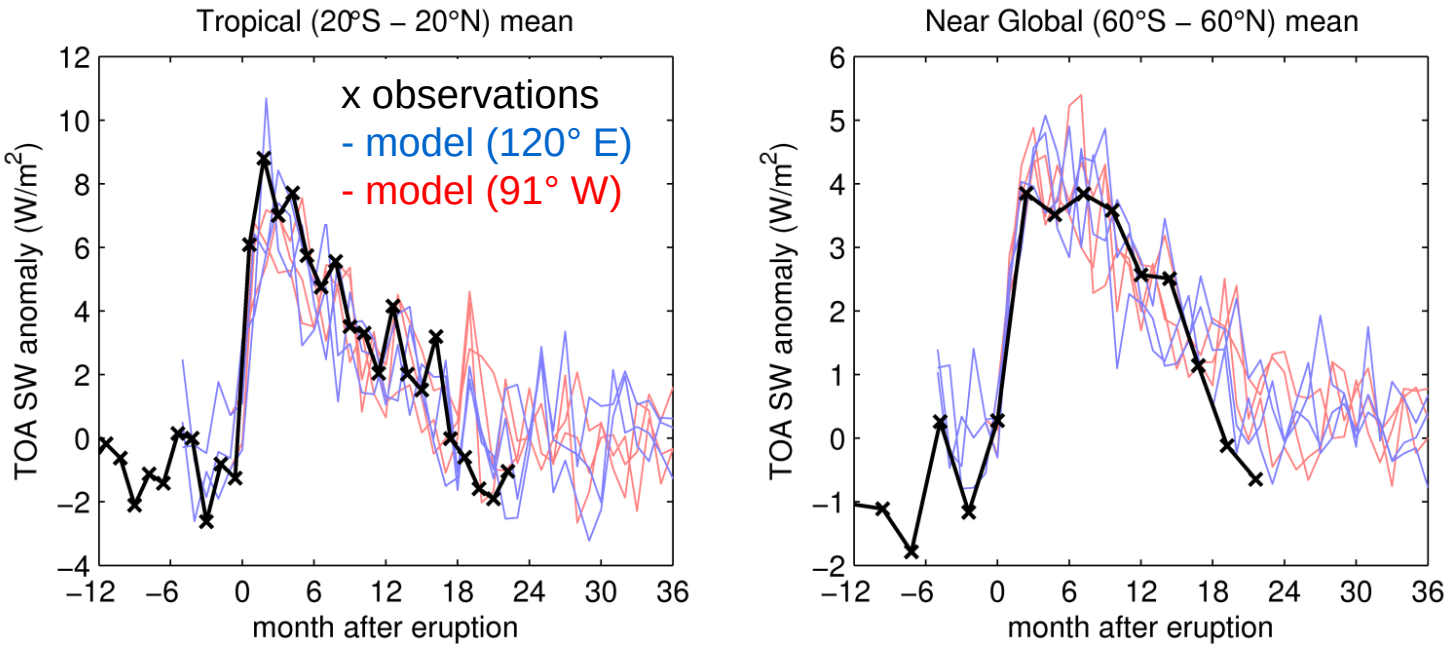
Model validation: Pinatubo eruption



- 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*)

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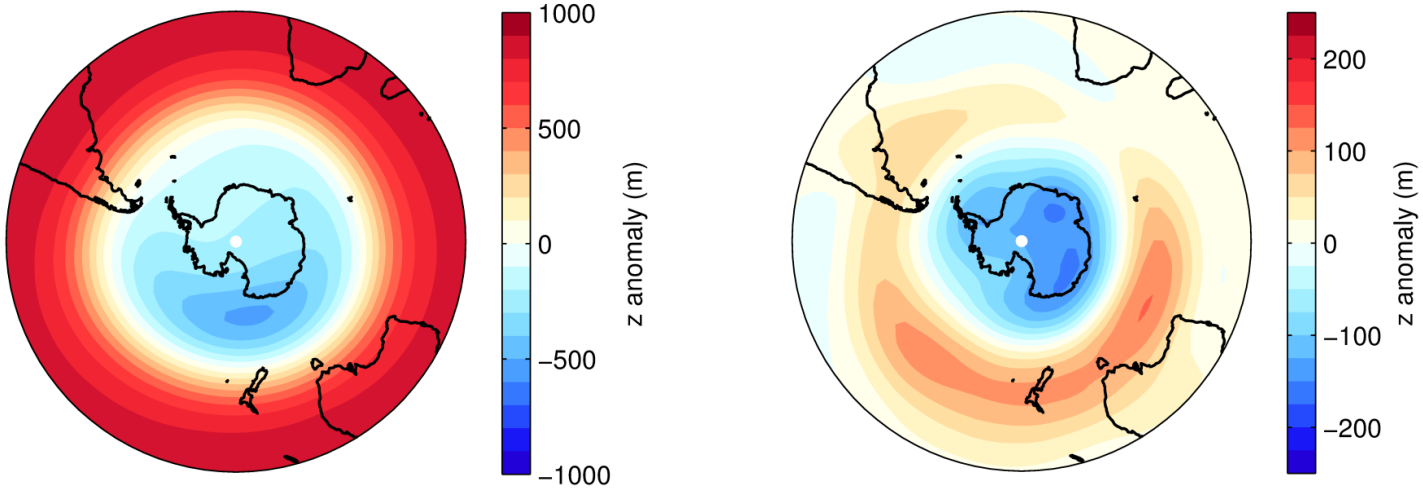
SH Geopotential Height anomalies (JJA)

Lower stratosphere (20 km)

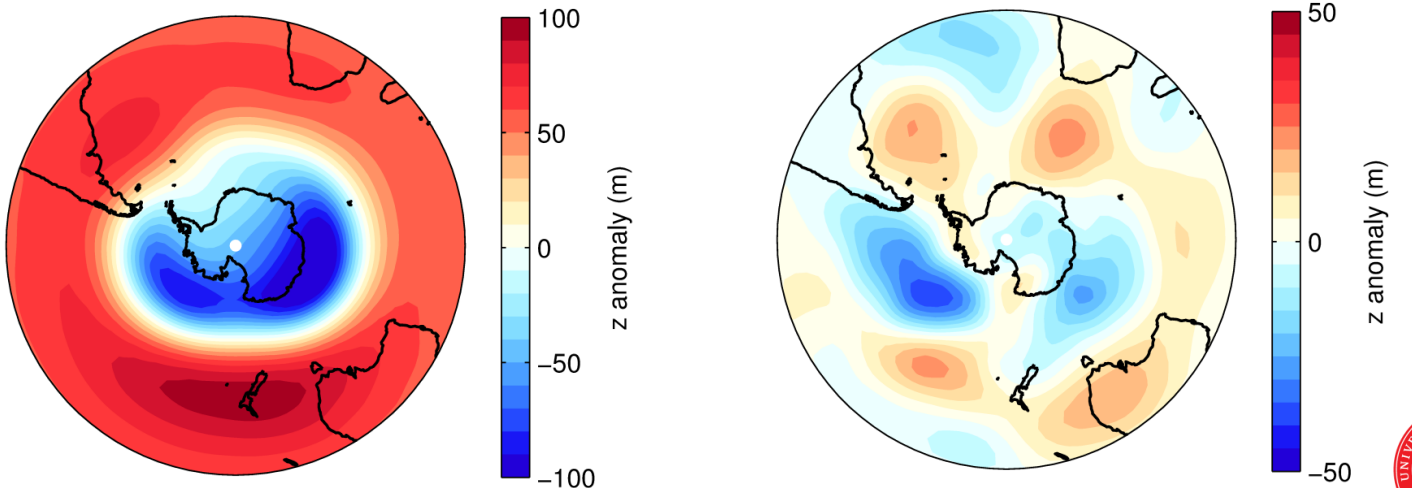
Free troposphere (5 km)

E700



Note different scales between E700 and E17!

E17



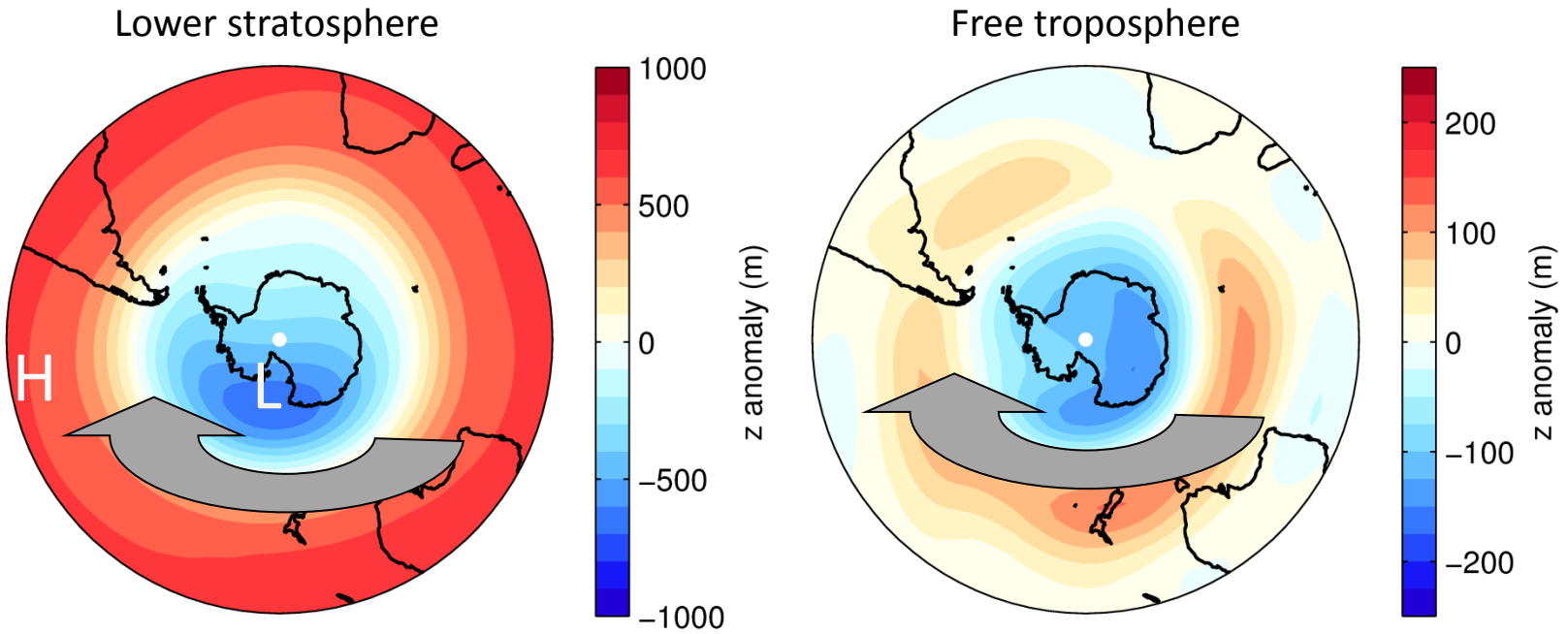
20-90°S

20-90°S

Positive Southern Annular Mode (SAM)

Geopotential Height anomalies [gpm] (SON)

E700



The increased meridional pressure gradient leads to stronger circumpolar westerly winds from the stratosphere to the surface!

SAM Index (Gong&Wang, 1999): GH gradient between 40°S and 65°S

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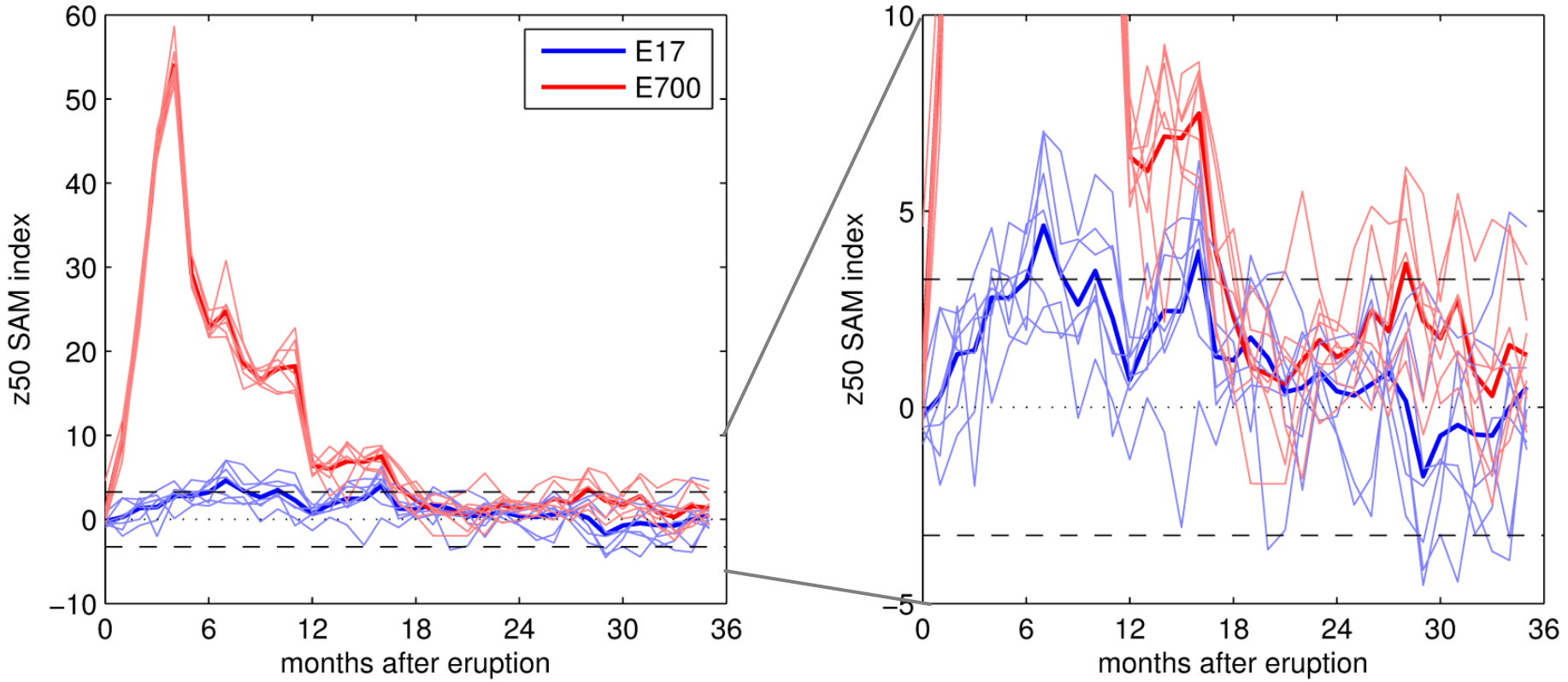
SAM Index: lower stratosphere



E700: A **significant, strong positive SAM** is simulated, lasting up to 18 months.

E17: **Hardly any significant signal** is found in good agreement with Mt. Pinatubo observations (Robock et al., 2007; Karpechko et al., 2010).

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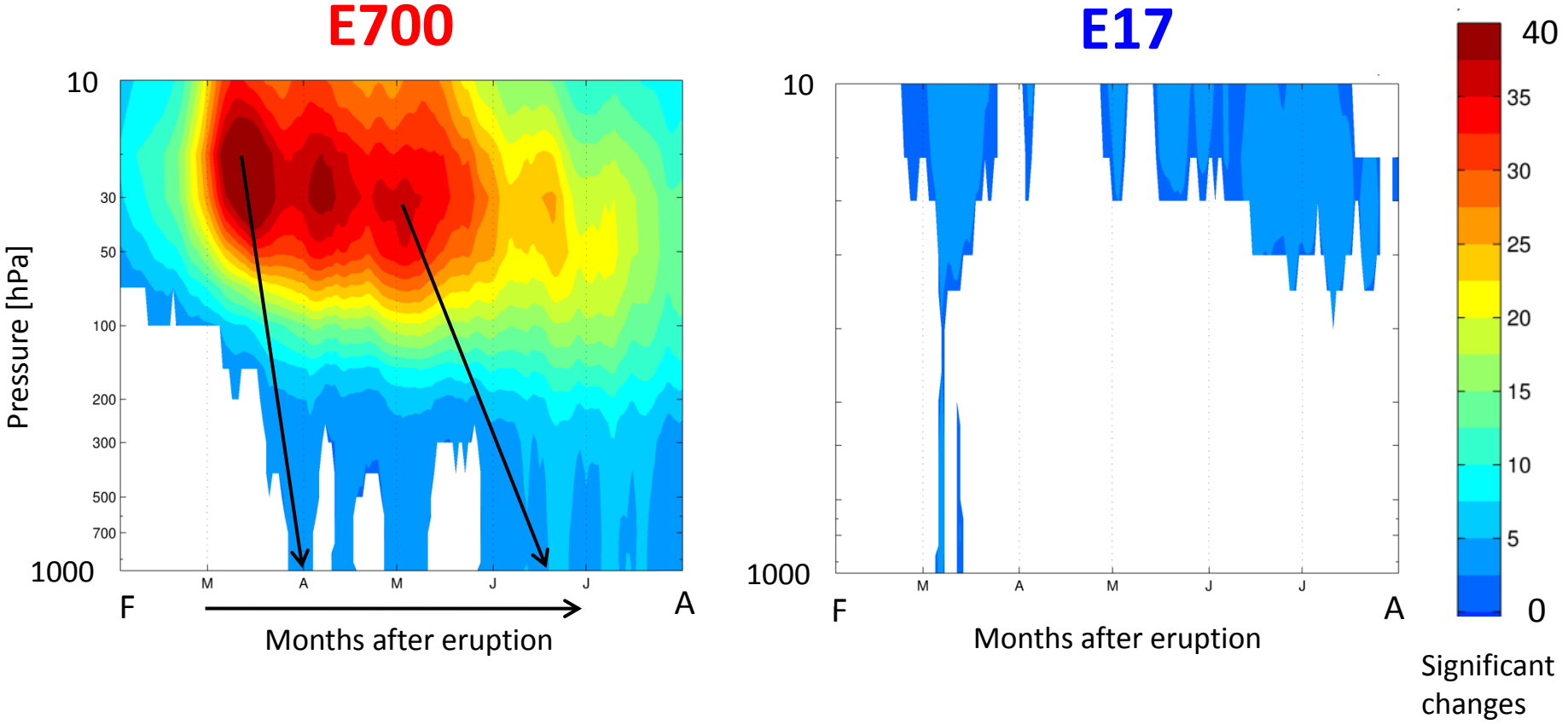
Does this signal propagate downward?

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.

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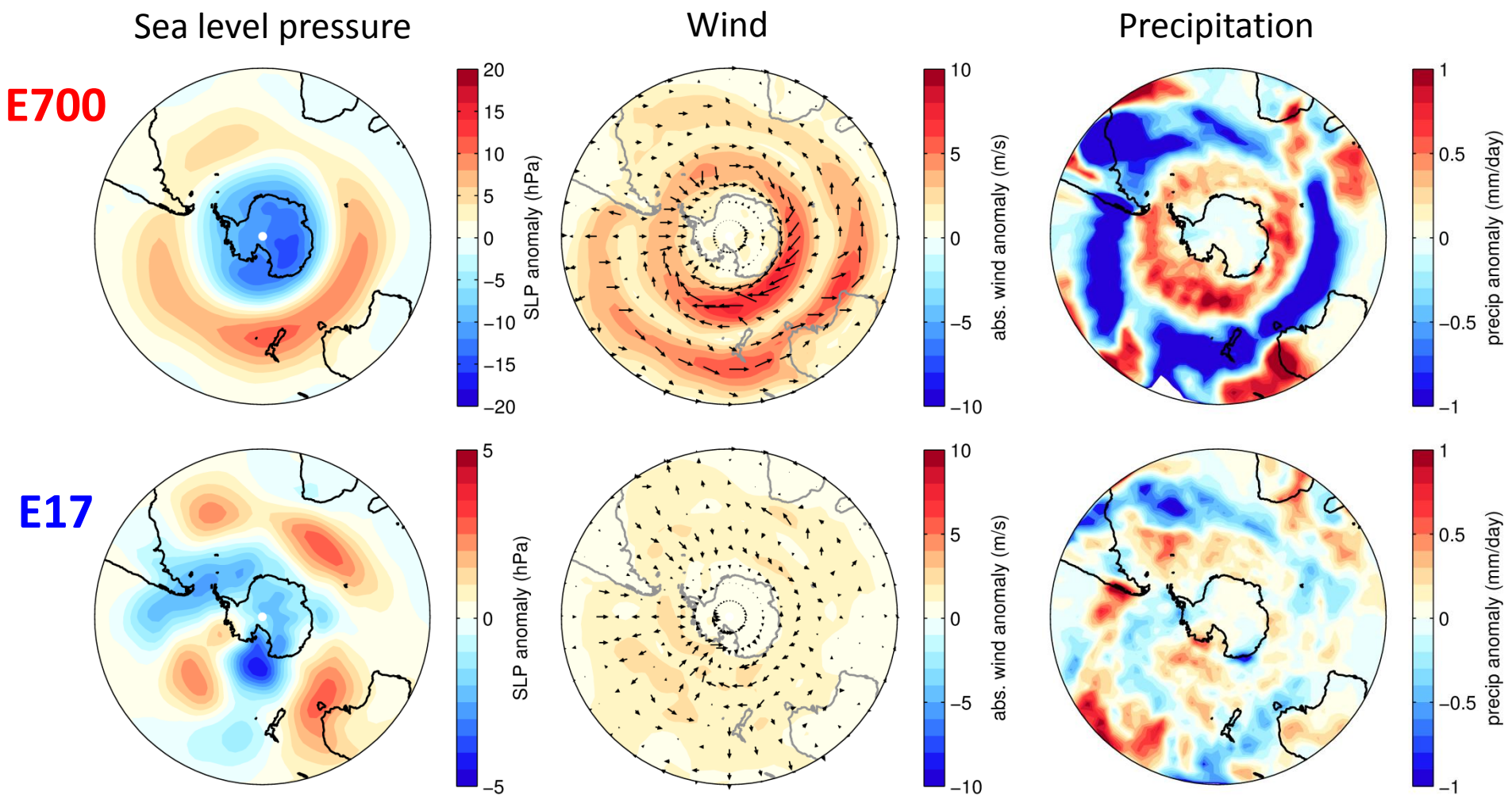
Surface anomalies (SON)



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?**

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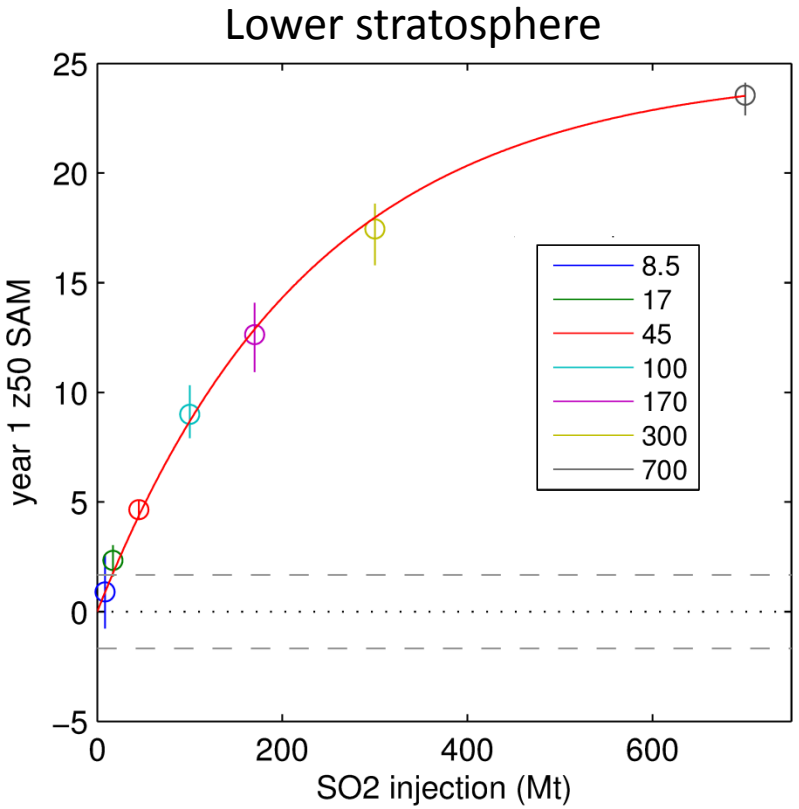
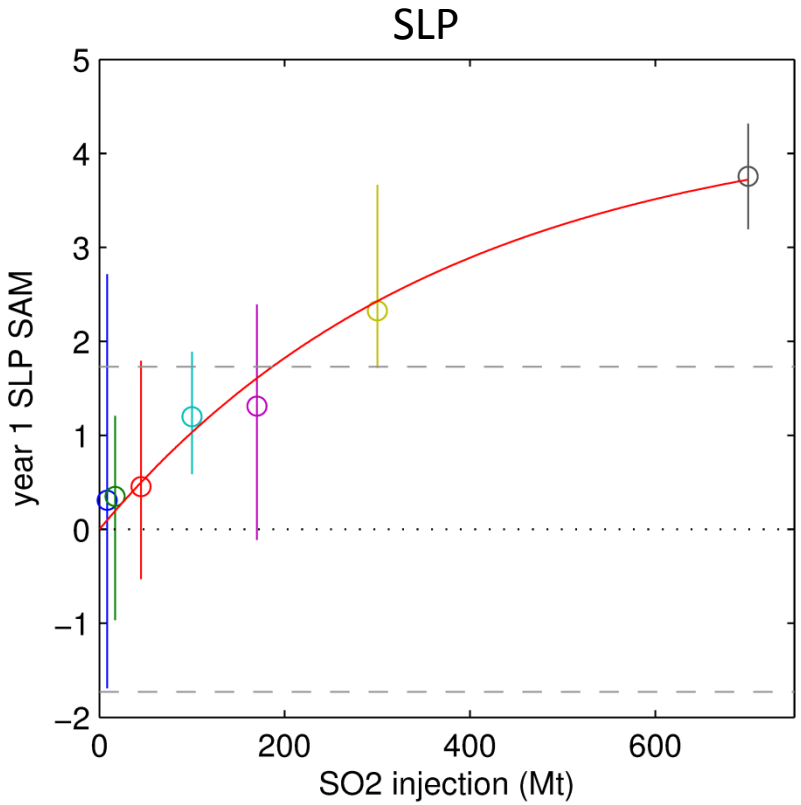
SO_2 – SAM relationship

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*

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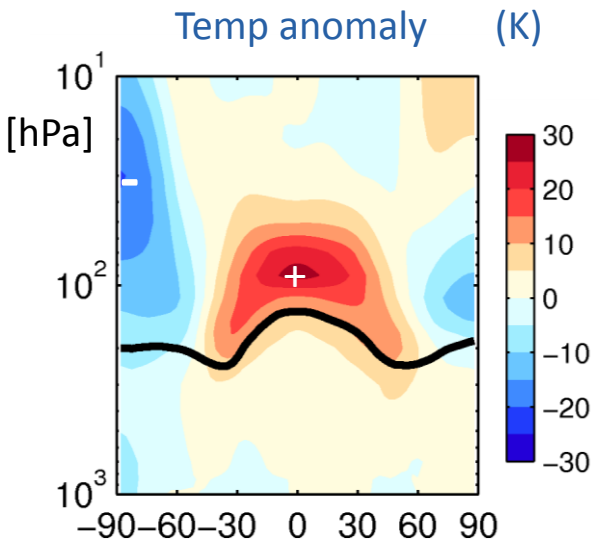
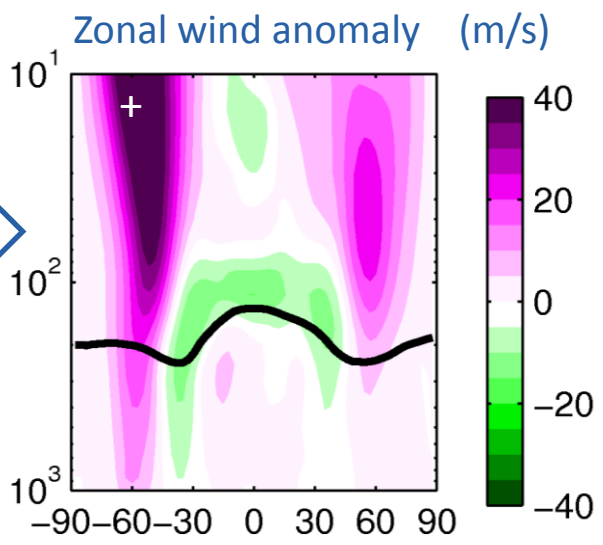
Very large tropical volcanic eruptions cause a positive SAM

Very large eruptions

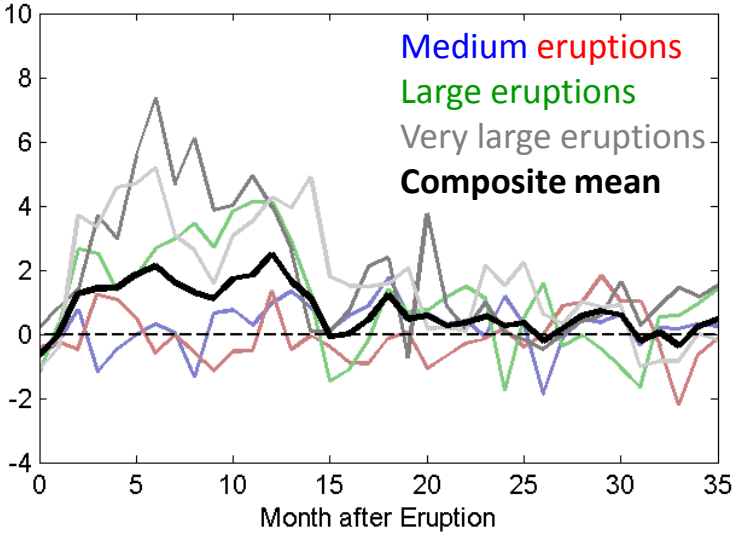




Implications for e.g.:

- Southern Ocean
- Sulfate deposition in Antarctica

SAM Index (SLP): Modelled volcano comp.



Positive SAM ✓
increased westerlies

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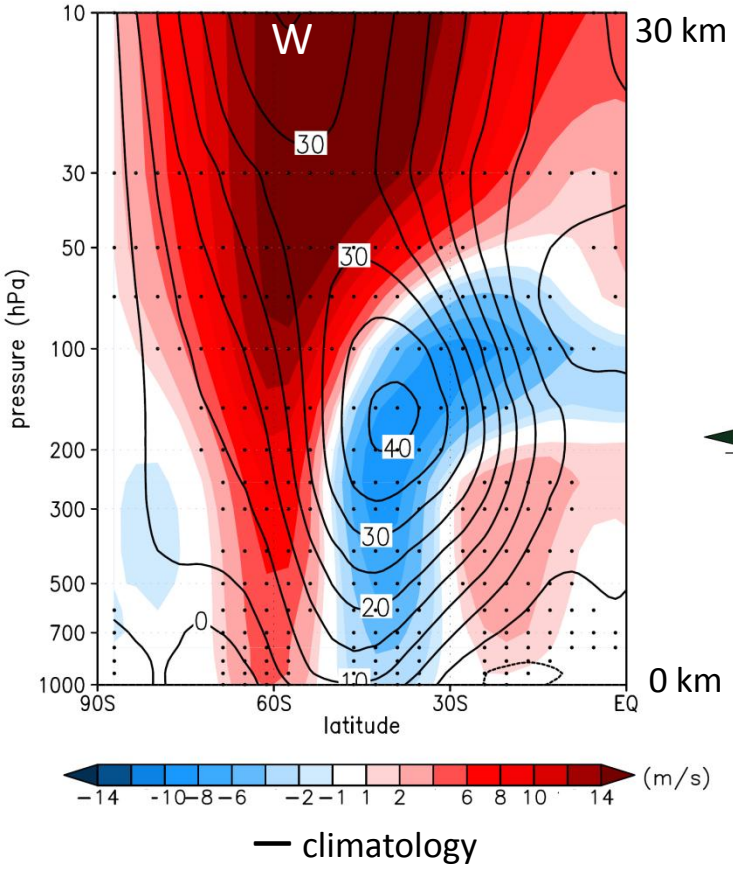
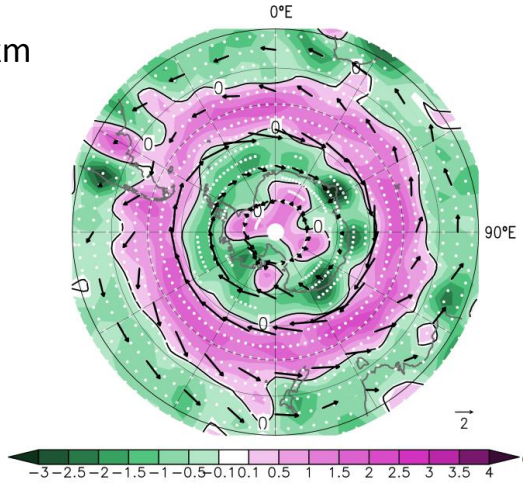
Southern Ocean response: 700 Mt SO_2 VE

ECHAM5/MPIOM simulations (+1yr)

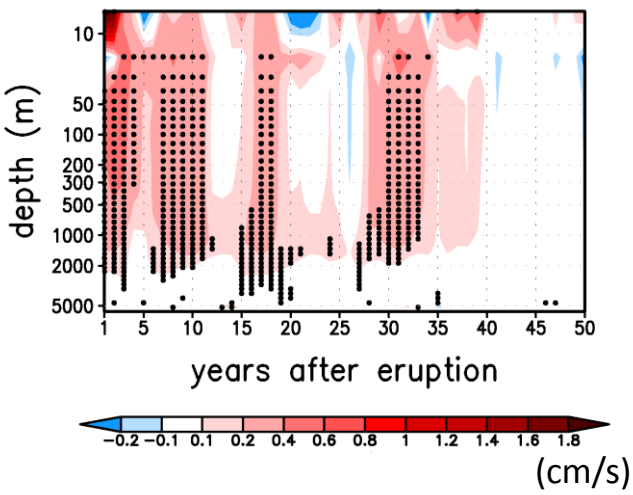
zonal wind changes (m/s)



surface wind stress (N/m²)



zonmean zonal velo 60S



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.

D. Metzner PhD thesis

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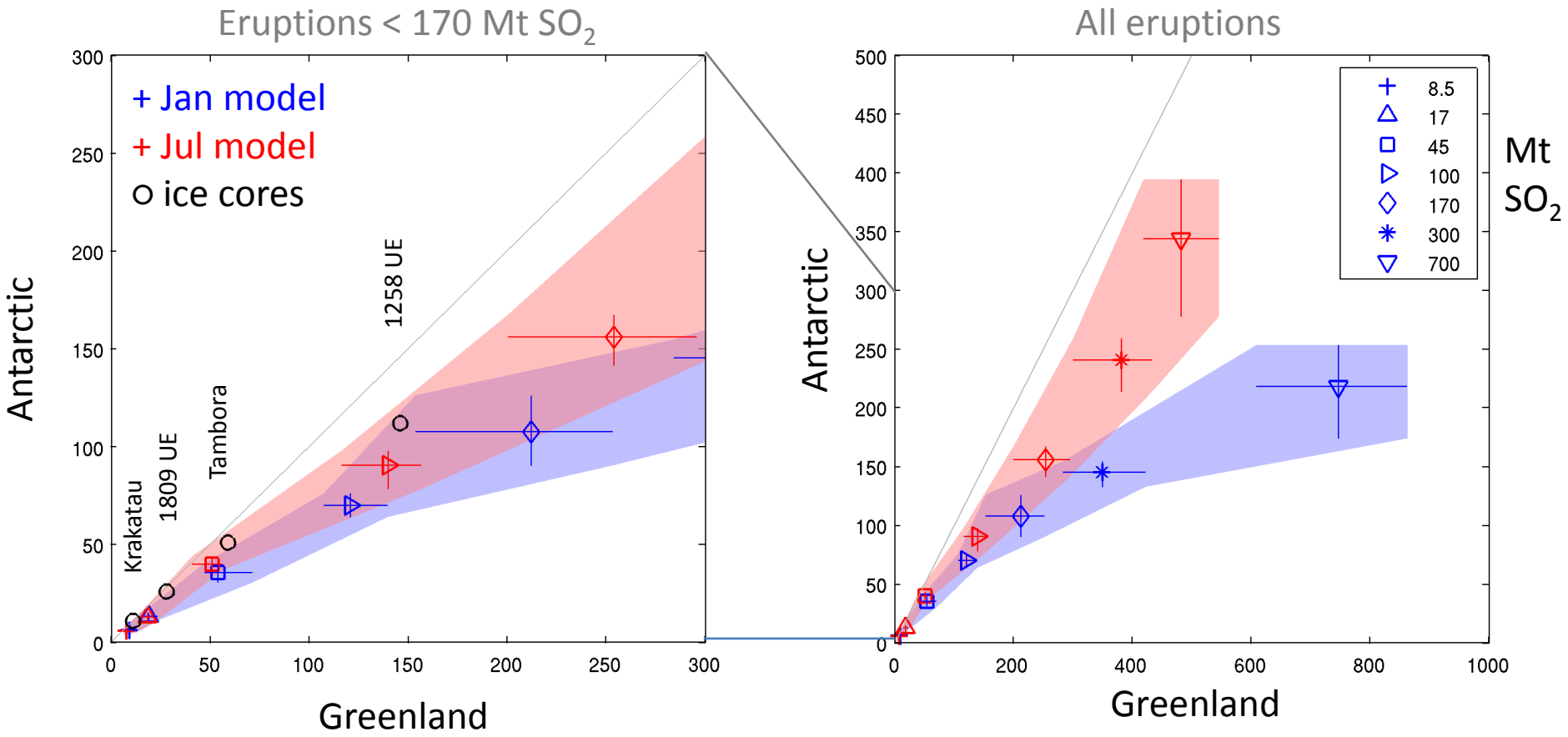
Bi-polar sulfate deposition

SO_4 flux (kg/km^2): Greenland-Antarctic



Toohey et al (2013, *JGR*)

Thanks for your attention!

SFB 574 team, Lübeck, May 2012

Relevant references

Metzner, D., S. Kutterolf, M. Toohey, C. Timmreck, U. Niemeier, A. Freundt, K. Krüger, Radiative forcing and climate impact resulting from SO2 injections based on a 200,000 year record of Plinian eruptions along the Central American Volcanic Arc, *Int J Earth Sci (Geol Rundsch)*, 2012.

Timmreck C et al., Aerosol size confines climate response to volcanic super-eruptions. Geophys Res Lett., 2010.

Timmreck, C., H. Graf, D. Zanchettin, S. Hagemann, T. Kleinen, K. Krüger, Climate response to the Toba super-eruption: regional changes, *Quarternary International,* 2011.

Toohey, M., K. Krüger, U. Niemeyer, C. Timmreck, The influence of eruption season on the global aerosol evolution and radiative impact of tropical volcanic eruptions, *Atmos. Chem. Phys.*, 2011.

Toohey, M., K. Krüger, C. Timmreck, Volcanic sulfate deposition to Greenland and Antarctica: a modeling sensitivity study, *JGR special issue, 2013.*