Exploiting large ensembles to understand the continental winter warming following the 1991 Mt. Pinatubo eruption

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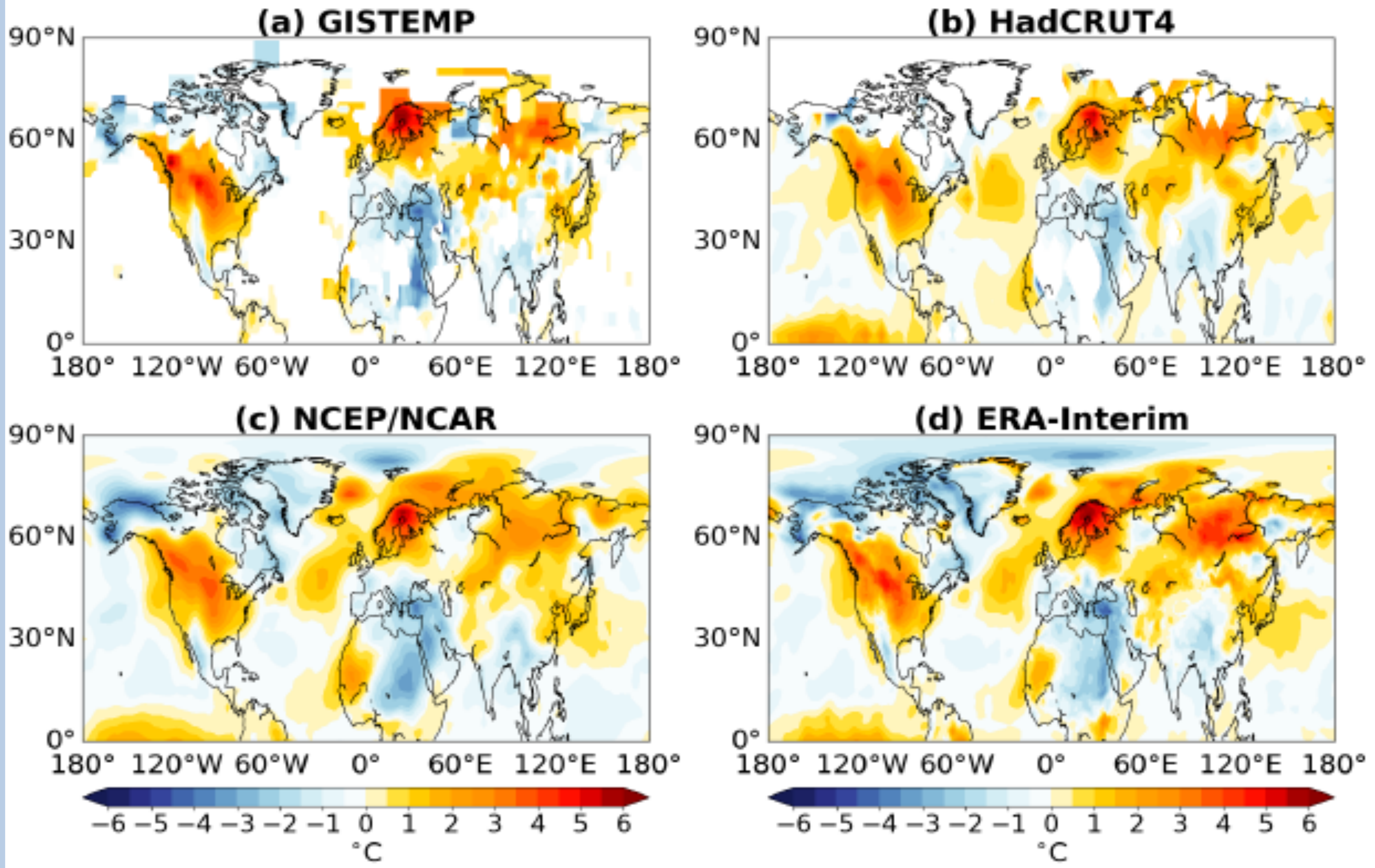
1. Observations



Surface temperature anomaly in winter 1991/1992 relative to the 1985-1990 average in observations and in reanalyses

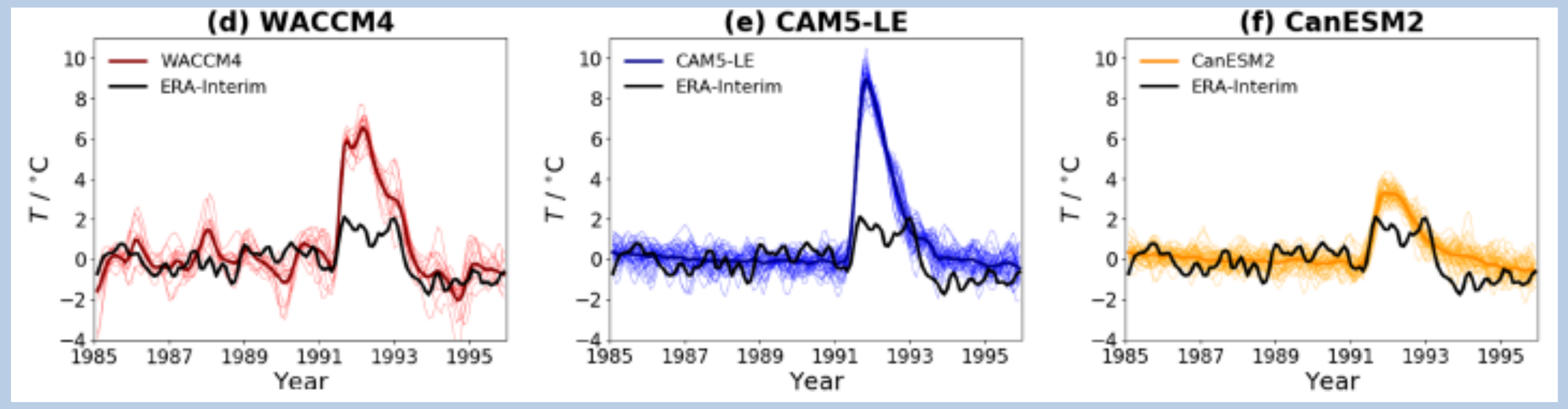
It is claimed that the eruption of Mt. Pinatubo in June 1991 caused anomalous warming over NH continents in the following winter [*Robock,* 2002], and that climate models are unable to capture this phenomenon [e.g. *Driscoll et al.* 2012].

2. Large ensemble simulations

Number of members, and model top, for each ensemble
(historical runs, as per CMIP5, with all forcings included)

WACCM4	13	high top
CAM5-LE	42	low top
CanESM2	50	low top

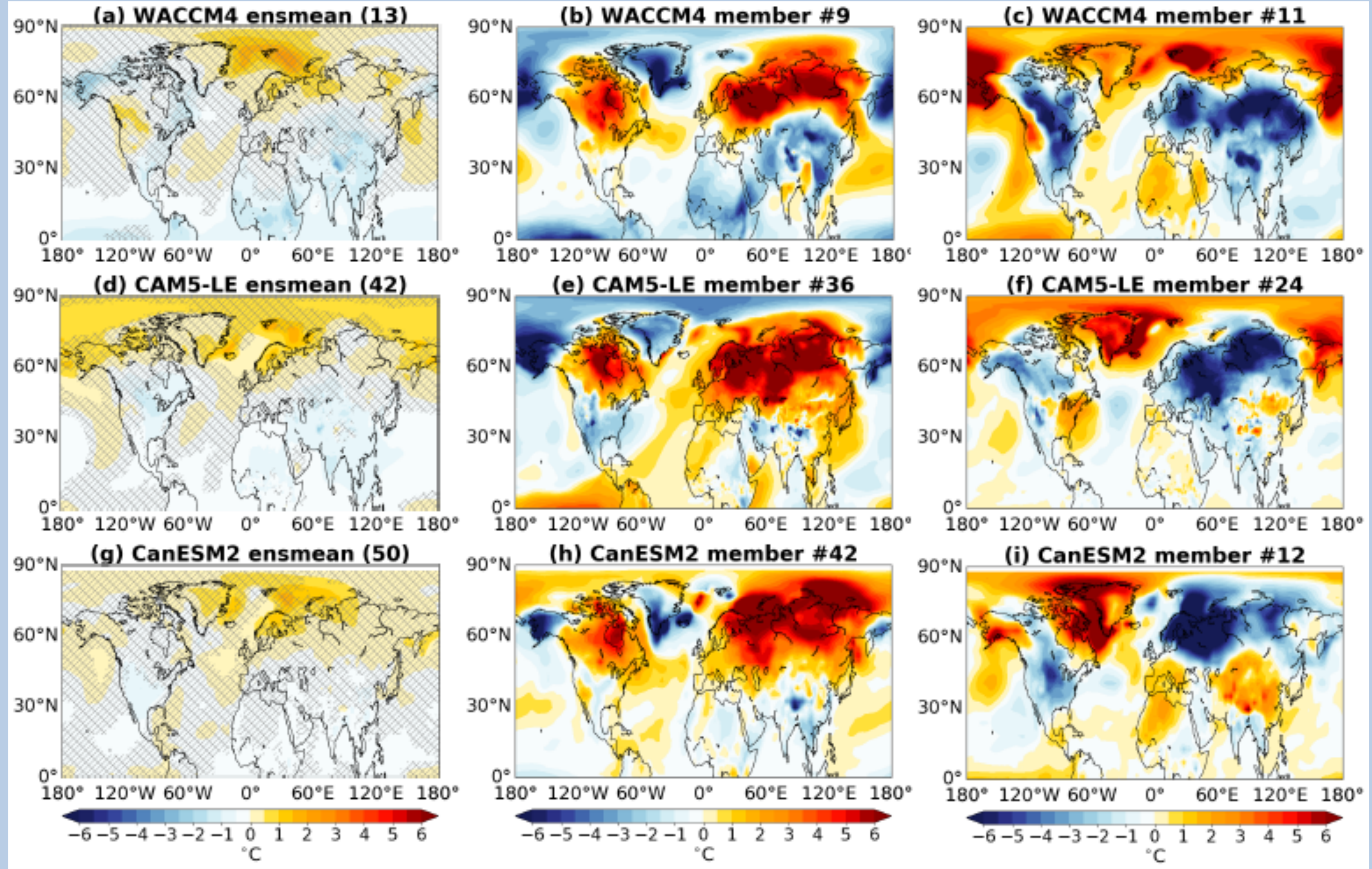
Within each ensemble all members are forced identically; members only differ in their atmospheric initial conditions.



Temperature anomaly at 50hPa, tropical average

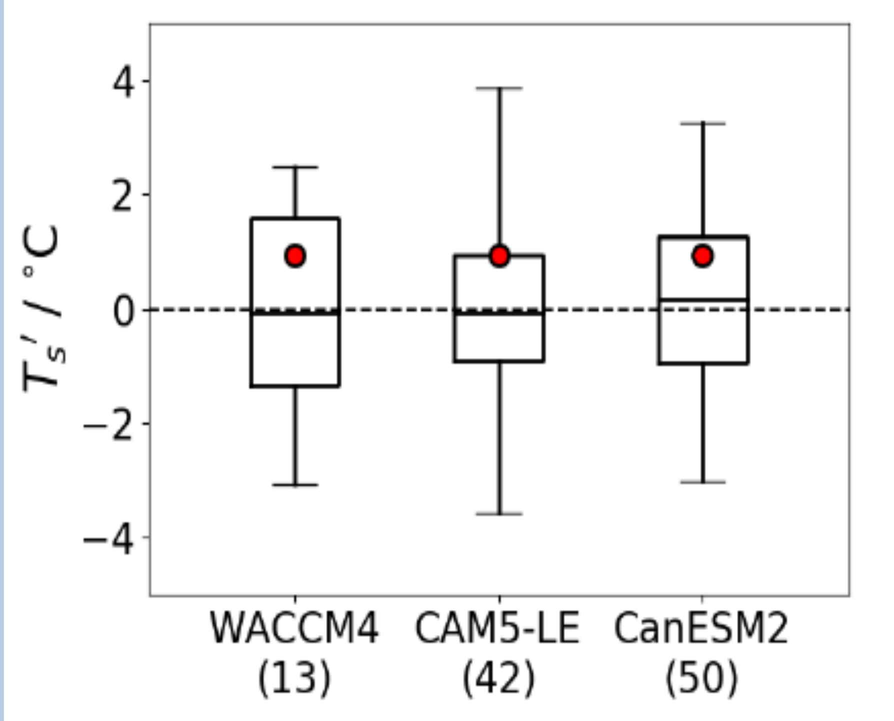
Models show ***greater*** forcing (heating from sulfate aerosols) than in the reanalyses. This is a well-known model bias.

3. Modeled responses



Surface temperature anomaly in winter 1991/1992 in models' ensemble mean (left) and individual members

The ensemble mean response is not statistically significant. However, one should not compare the observation with the ensemble mean since that is only the ***forced*** response. Individual members, and hence the models, are perfectly capable of capturing the observed warming.

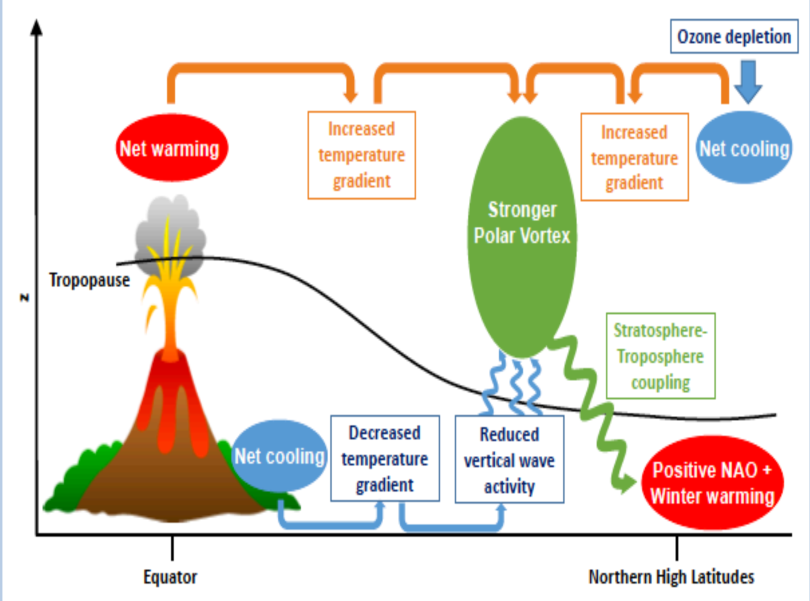


We find no forced winter warming in the models (distributions are centred around zero) with a large spread due to internal variability. The observed warming falls well within the distributions, hence can be simply attributed to internal variability.

Eurasian average surface temperature anomalies
ERA-I: red circles. Model: boxes

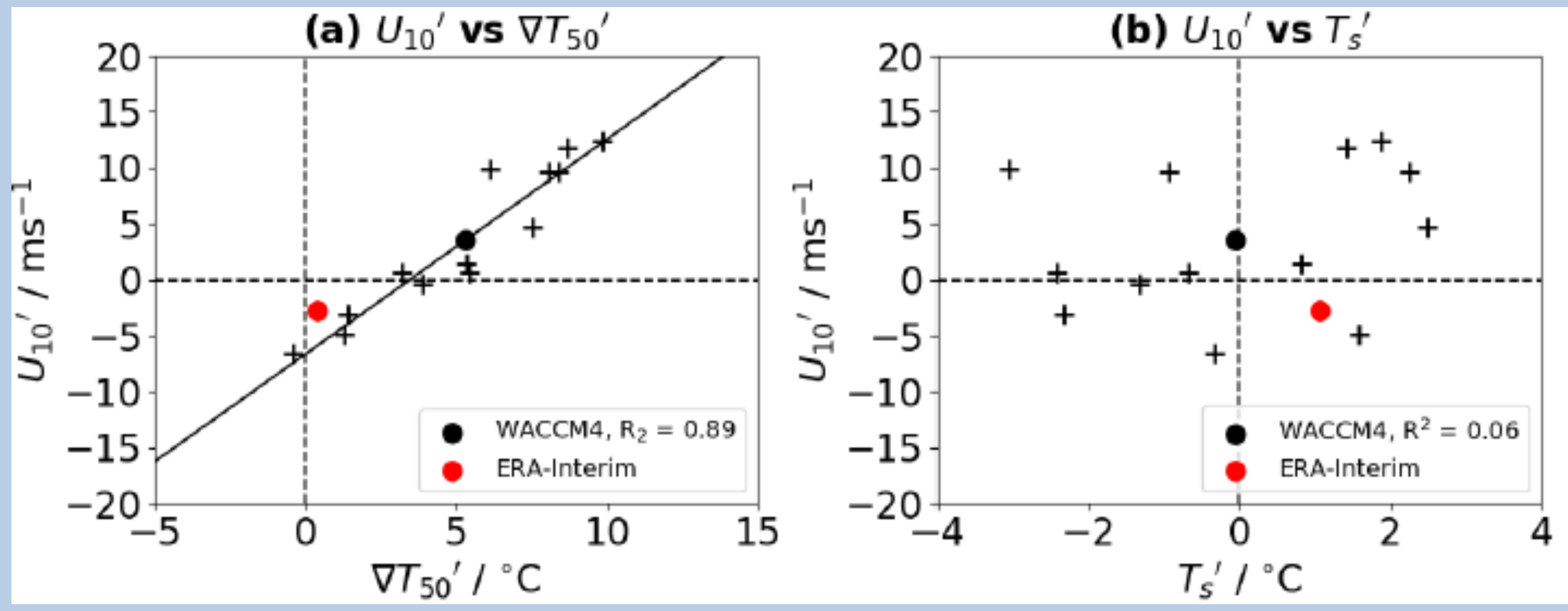
Robock, A. and Mao, J.: Winter warming from large volcanic eruptions, Geophys. Res. Lett., 19, 2405–2408, 1992.
Graf, H., Kirchner, I., Robock, A., and Schult, I.: Pinatubo eruption winter climate effects: Model versus observations, Clim. Dyn., 9, 81–93, 1993.
Kodera, K.: Influence of volcanic eruptions on the troposphere through stratospheric dynamical processes in the northern hemisphere winter, J. Geophys. Res.-Atmos., 99, 1273–1282, 1994.
Robock, A.: Pinatubo Eruption: The climatic aftermath, Science, 295, 1242-1244, 2002.
Driscoll, S. et al.: Coupled Model Intercomparison Project 5 (CMIP5) simulations of climate following volcanic eruptions, J. Geophys. Res., 117, D17105, 2012.
Bittner, M.: On the discrepancy between observed and simulated dynamical responses of Northern Hemisphere winter climate to large tropical volcanic eruptions, Ph.D. thesis, Univerisity of Hamburg, Reports on Earth System Science, 2015.
This work: Polvani, L. M., Banerjee, A., and Schmidt, A.: Northern Hemisphere continental winter warming following the 1991 Mt. Pinatubo eruption: Reconciling models and observations, Atmos. Chem. Phys., *in press*, 2019.

4. Mechanism



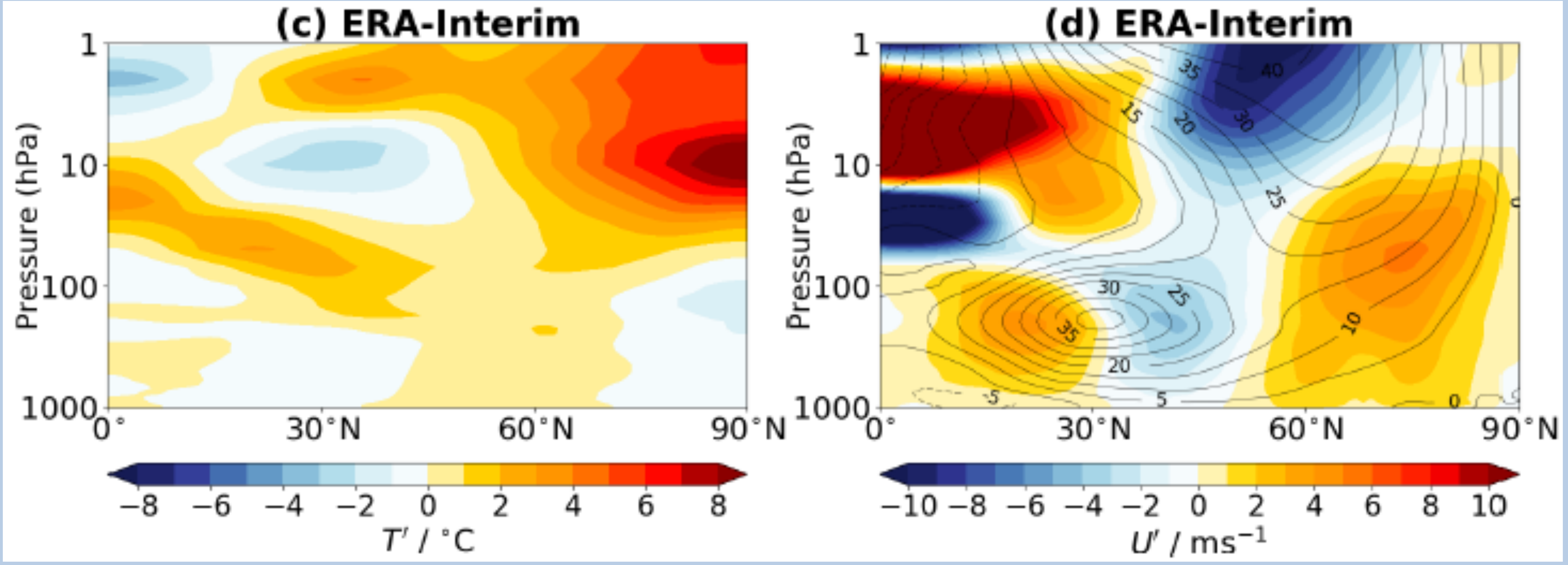
Early studies *[Robock and Mao, 1992; Graf et al. 1993; Kodera, 1994]* proposed the existence of a "stratospheric pathway", with the eruption causing a strengthening of the stratospheric polar vortex.

Figure taken from Bittner [2015]



U (10hPa) vs. T (tropical average, 50hPa) anomalies — *U (10hPa) vs. Surface T (Eurasian average) anomalies*

Models show that vortex strengthening due to Pinatubo is small, and overwhelmed by internal variability at the surface.



T anomaly (latitude-height cross section) — *U anomaly (latitude-height cross section)*

The vortex was actually ***weaker*** in the winter following the eruption, not stronger, thus invalidating the mechanism.

5. Conclusions

(1) Climate models *are* able to capture winter warming, and

(2) the post-Pinatubo NH warming was very likely due to *internal variability*, not due to the eruption.