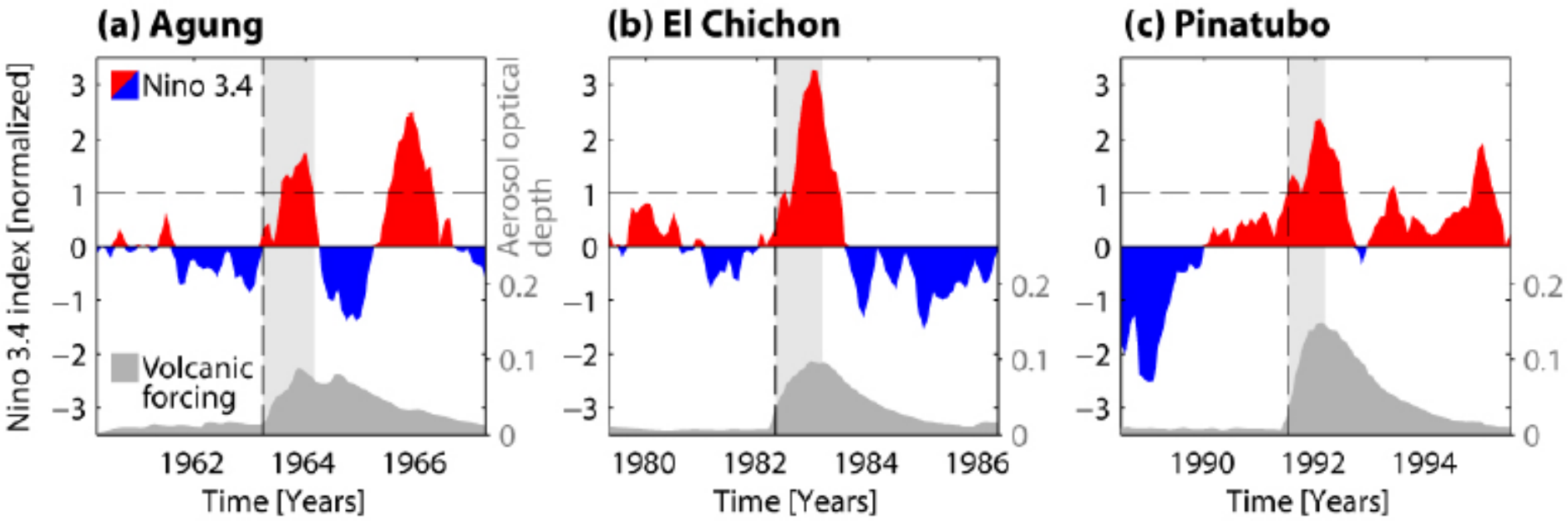
# Comparing the Atmospheric Response to Volcanic Eruptions Against Internal Variability in the NCAR Large Ensemble

Marie C. McGraw
Elizabeth A. Barnes

Atmospheric Science, Colorado State University
Fort Collins, CO

February 9, 2016

# The Problem




Coincidence of volcanic eruptions with El Niño events. From Lehner et al. (*GRL*, submitted).

Is there a robust tropospheric circulation response to volcanic forcing?

# Data Sets

Part 1 (Barnes, Solomon, and Polvani, *J. Climate*, under review):

- 13 CMIP5 models with reasonable responses to volcanic forcing
- Observations from MERRA Reanalysis

Part 2 (McGraw and Barnes, in preparation):

- CESM1 Large Ensemble (42 Ensemble members)
- Pacemaker (10 ensembles): CESM1 with eastern tropical Pacific SST anomalies nudged toward observations

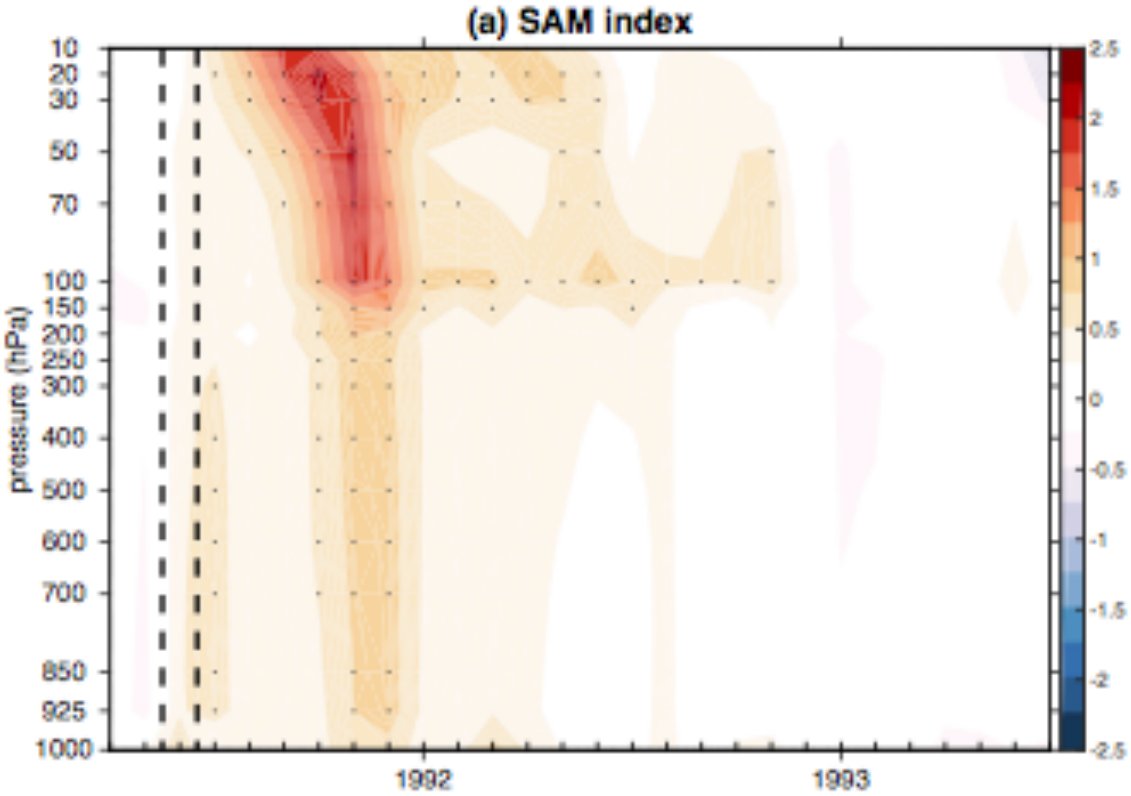
# Caveats

Assuming that the models get things right (aerosols, stratosphere-troposphere coupling, etc.)

Not considering impacts of ocean, land surface, sea ice

Not considering possibly nonlinear impact of ozone climatology

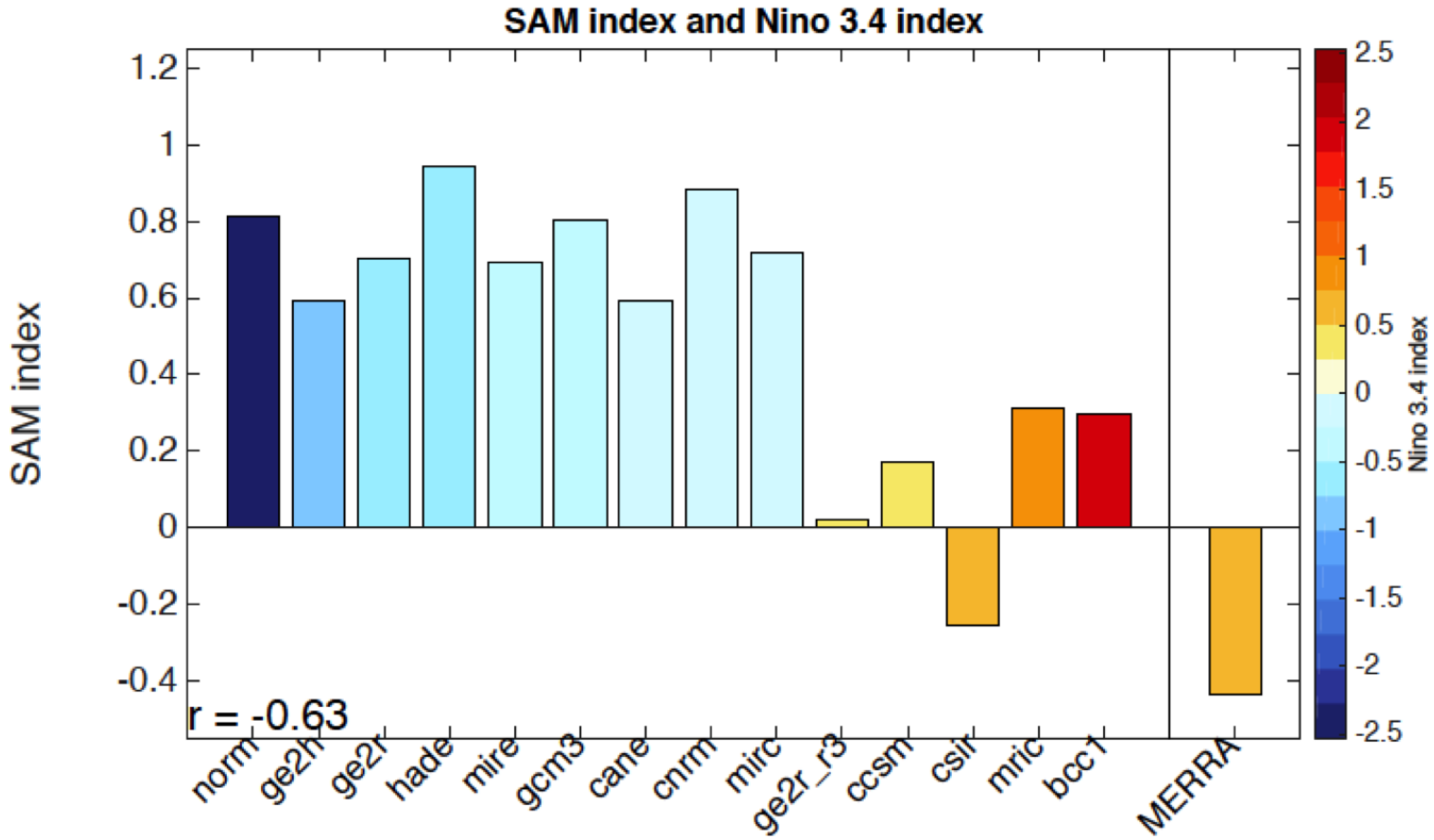
# Part 1: CMIP5 Results




Multi-model mean zonal-wind SAM index after Pinatubo eruption.

Barnes et. al., *J. Climate*, under review.

# Part 1: CMIP5 Results



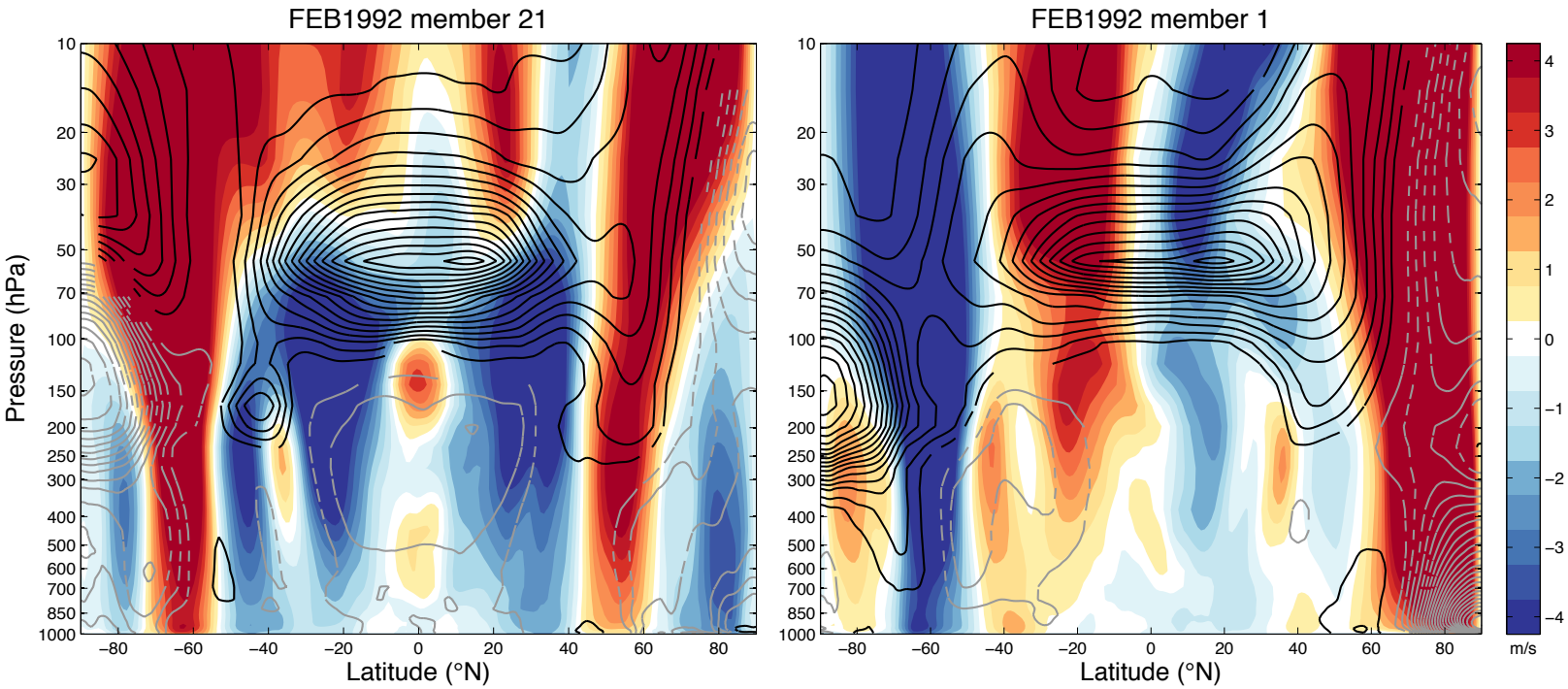

Vertically-averaged SAM index (bars) and Niño 3.4 index (colors) over the year following Pinatubo for CMIP5 models and MERRA reanalysis.

Barnes et. al., *J. Climate*, under review.

# CMIP5 Results: Summary

- Multi-model mean shows **positive** annular mode response
- Magnitude of SAM response may be masked by ENSO state
- Lehner et. al. (*GRL*, submitted) see something similar in global mean surface temperature response

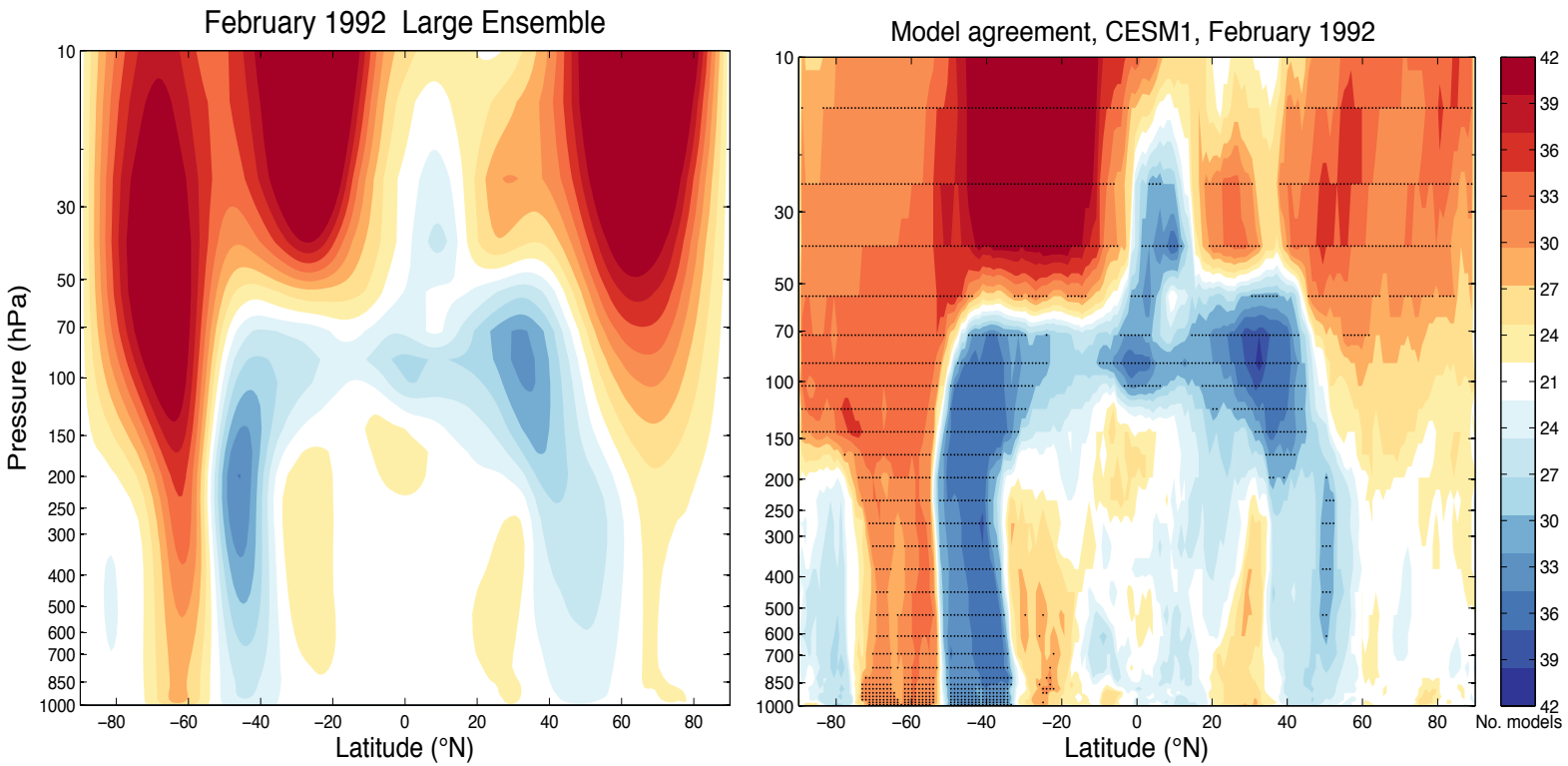
# Part 2: CESM1 Large Ensemble Results




February 1992 multi-model mean zonal wind (shading) and temperature (contours) anomalies for two CESM1 Large Ensemble members.

McGraw and Barnes, in preparation.

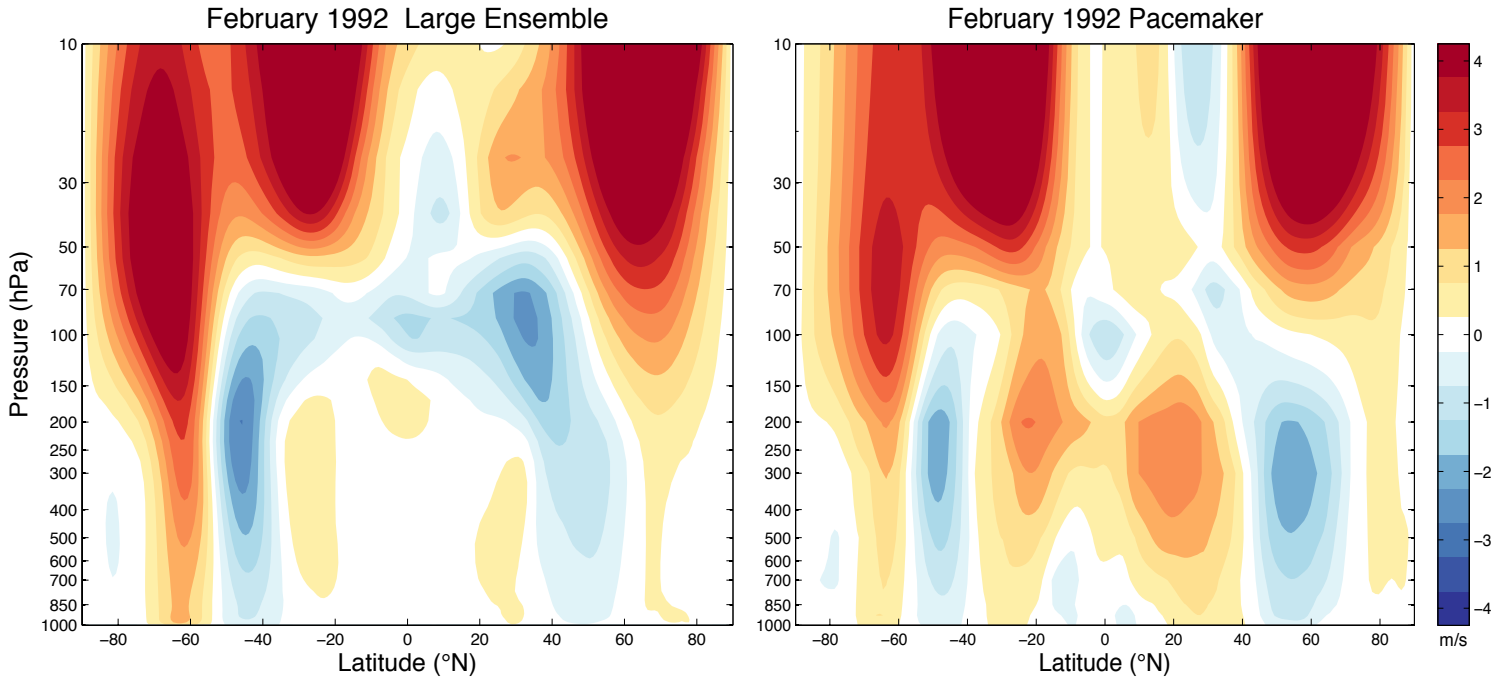
# Part 2: CESM1 Large Ensemble Results




(left) February 1992 multi-model mean zonal wind anomalies for two CESM1 Large Ensemble members. (right) CESM1 Large Ensemble model agreement on zonal wind anomalies. Red (blue) indicates positive (negative) anomalies. Stippling indicates agreement at 95% confidence.

McGraw and Barnes, in preparation.

# Part 2: CESM1 Large Ensemble Results

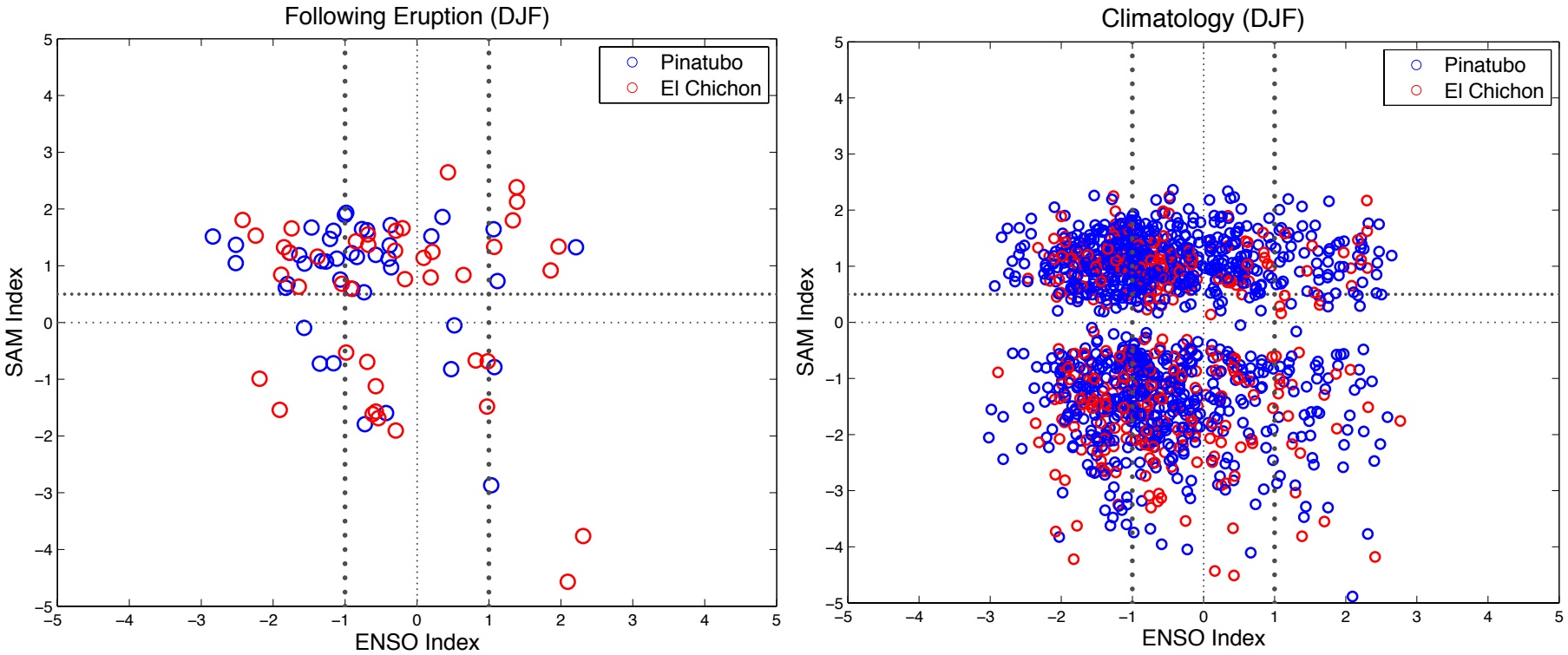



February 1992 multi-model mean zonal wind anomalies for the (left) CESM1 Large Ensemble and (right) Pacemaker.

McGraw and Barnes, in preparation.

When ENSO is neutral ($\leq \pm 1$), is a positive SAM response ($\geq +0.5$) significantly more likely after a volcanic eruption than in climatology?

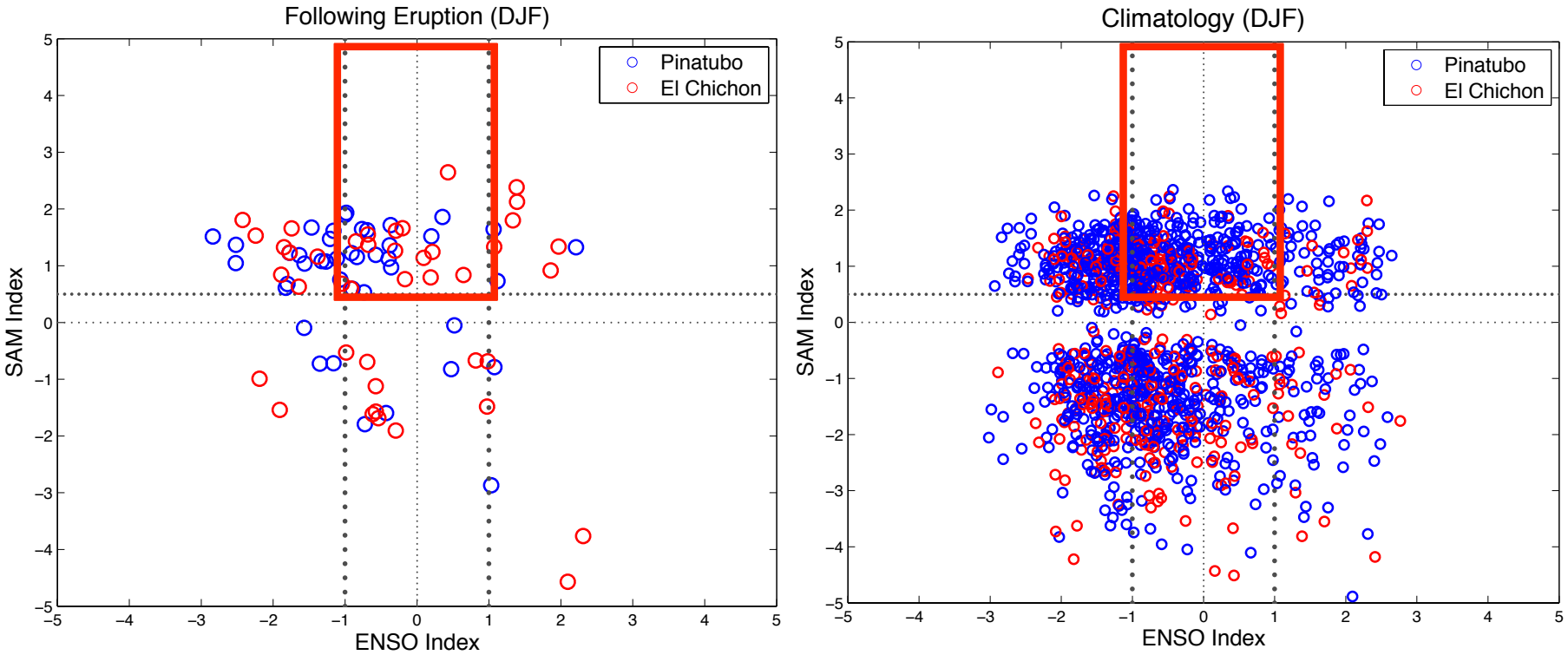
# Part 2: CESM1 Large Ensemble Results




SAM index versus ENSO index for each ensemble for DJF (a) after volcanic eruption and (b) 25 years surrounding eruption.

McGraw and Barnes, in preparation.

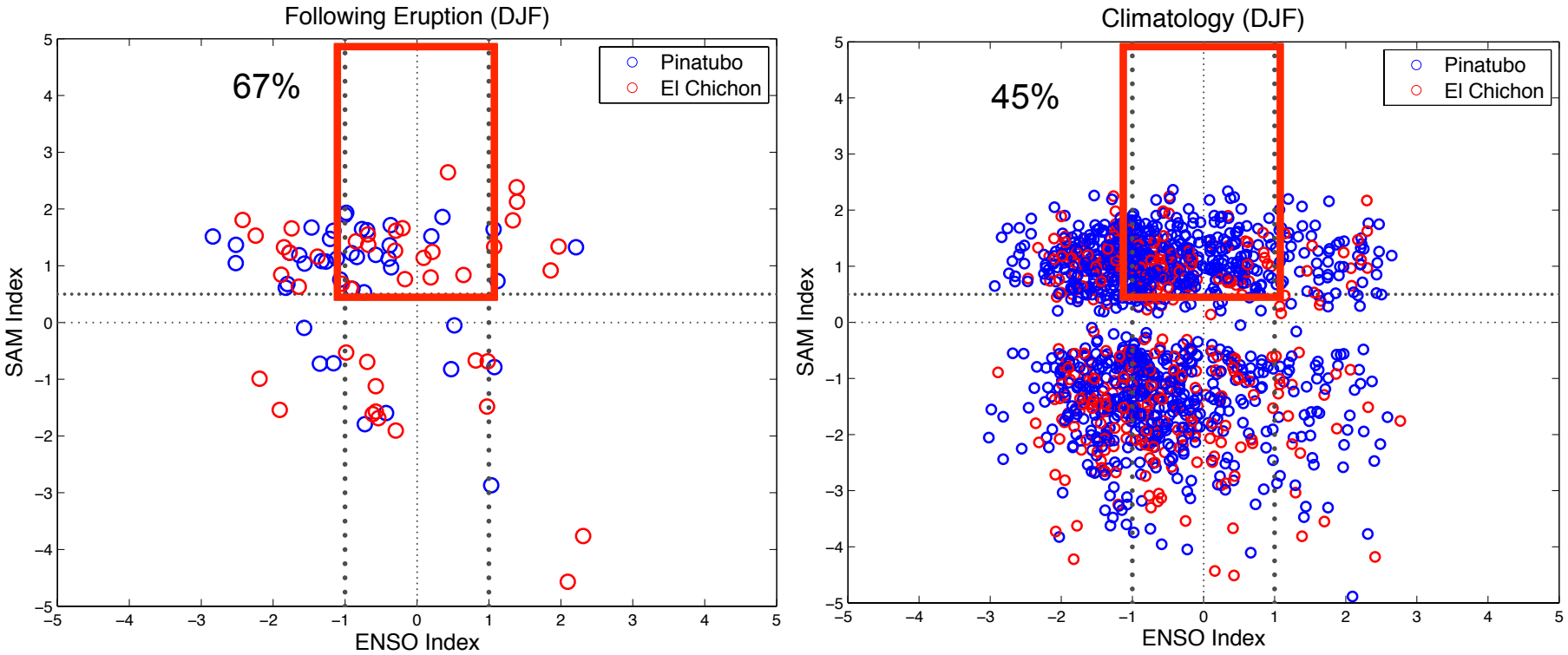
# Part 2: CESM1 Large Ensemble Results




SAM index versus ENSO index for each ensemble for DJF (a) after volcanic eruption and (b) 25 years surrounding eruption.

McGraw and Barnes, in preparation.

# Part 2: CESM1 Large Ensemble Results




SAM index versus ENSO index for each ensemble for DJF (a) after volcanic eruption and (b) 25 years surrounding eruption.

McGraw and Barnes, in preparation.

# Part 2: CESM1 Large Ensemble Results

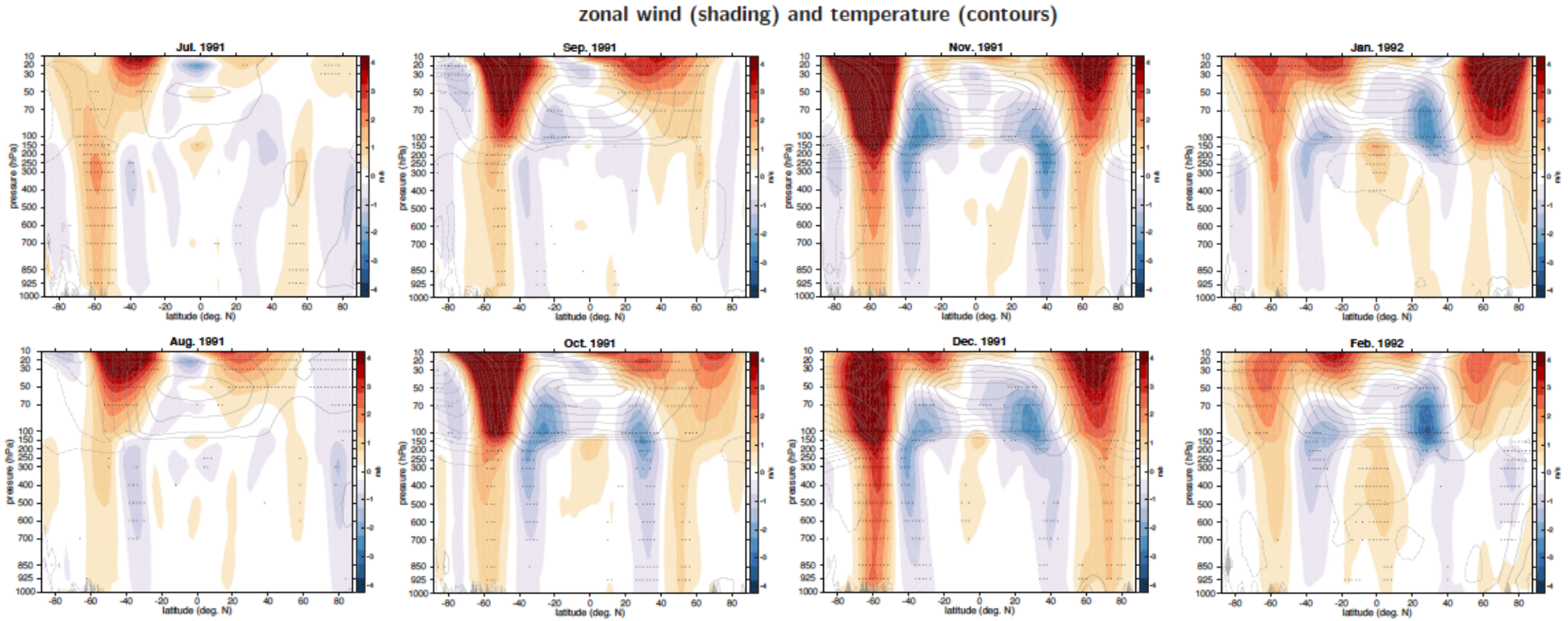
- **Robust positive** annular mode-like response to volcanic forcing in SH
- Model agreement on NH response is lower . . . need to look at N. Atlantic and N. Pacific separately?
- ENSO variability is important, but there is still other variability

# References

Barnes, E. A., S. Solomon, and L. M. Polvani: Robust wind and precipitation responses to the Mount Pinatubo eruption, as simulated in the CMIP5 models. *J. Climate,* revisions submitted 01/2016.

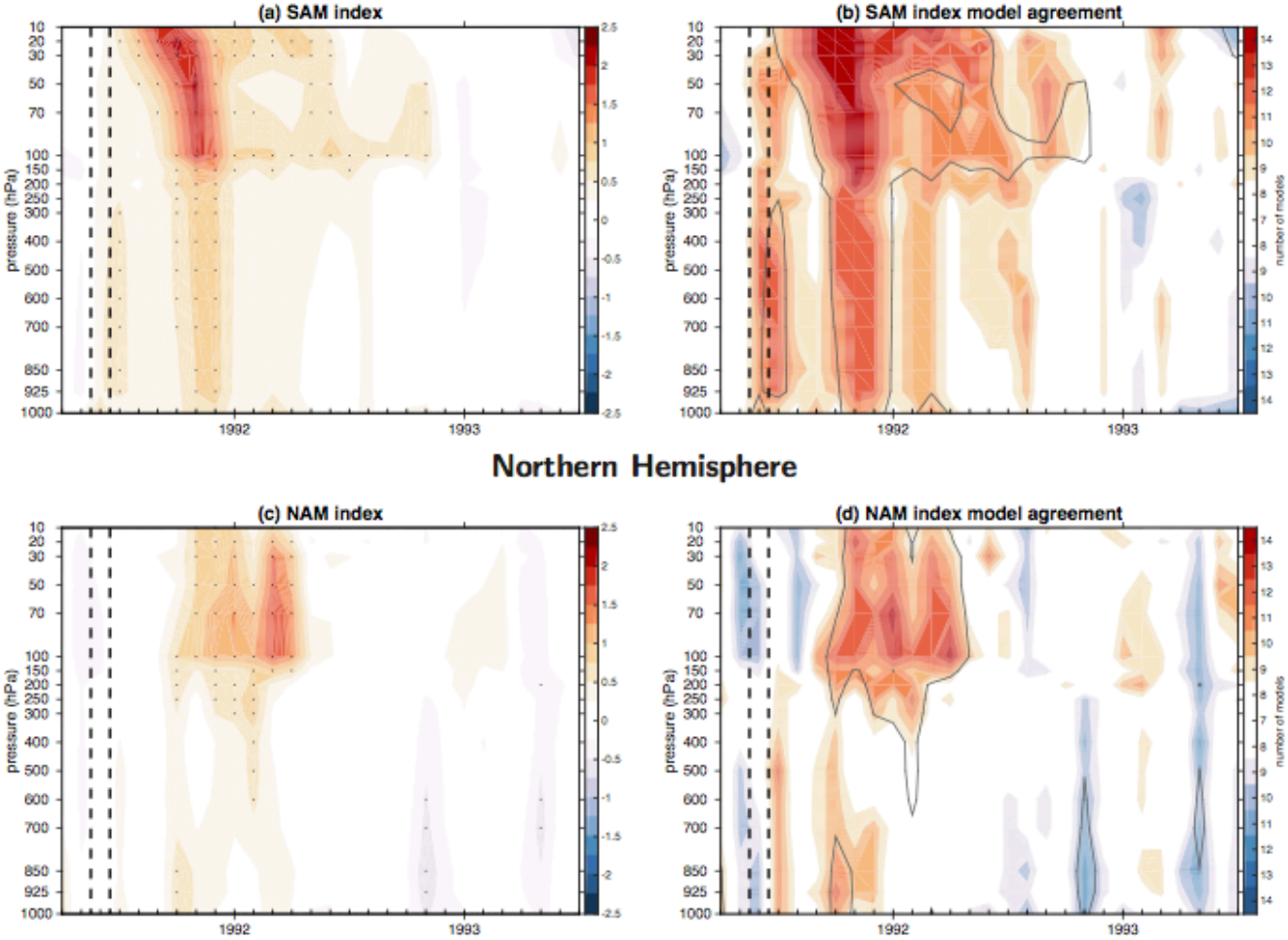
Lehner, F., A. P. Schurer, G. C. Hegerl, C. Deser, and T. L. Frölicher: The importance of ENSO phase during volcanic eruptions for detection and attribution. *Geophys. Res. Lett.,* submitted.

Robock, A., 2000: Volcanic eruptions and climate. *Rev. Geophys.,* **38,** 191-219.



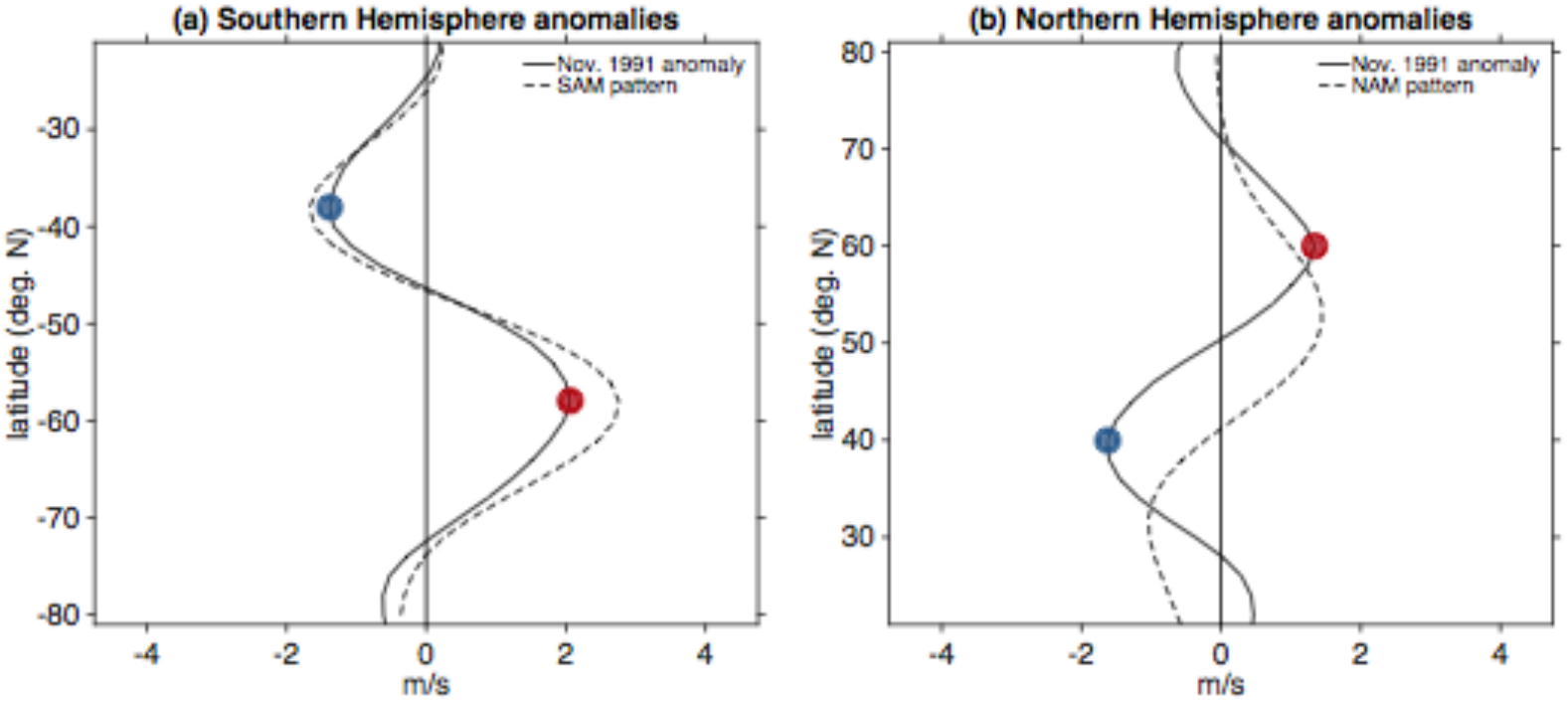

CMIP5 multi-model mean zonal wind (shading) and temperature (contours) anomalies, July 1991-February 1992.

Barnes et. al., *J. Climate*, under review.



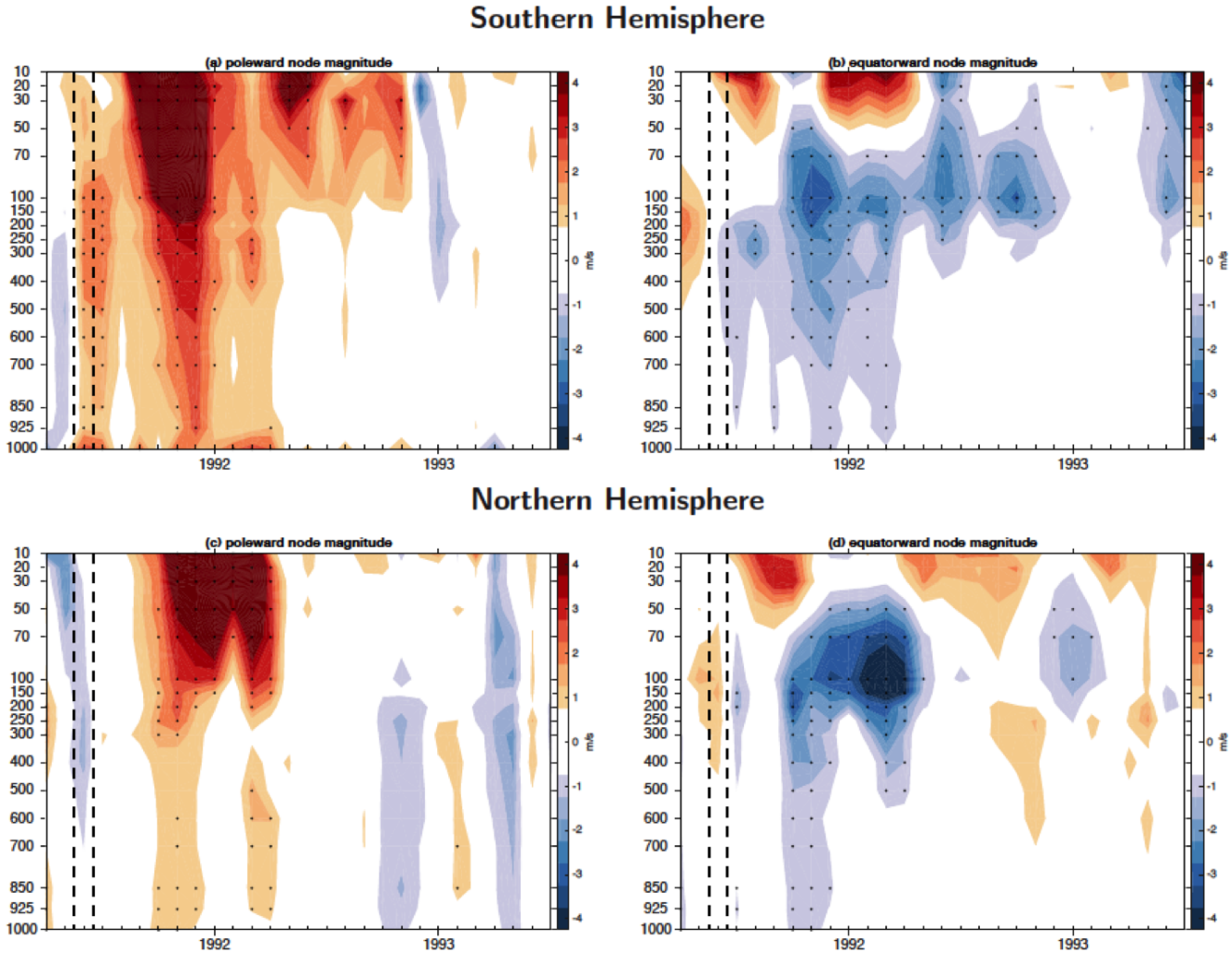

Zonal mean CMIP5 SAM (top left) and NAM (bottom left) indices, and SAM (top right) and NAM (bottom right) model agreement after Pinatubo eruption.

Barnes et. al., *J. Climate,* under review.



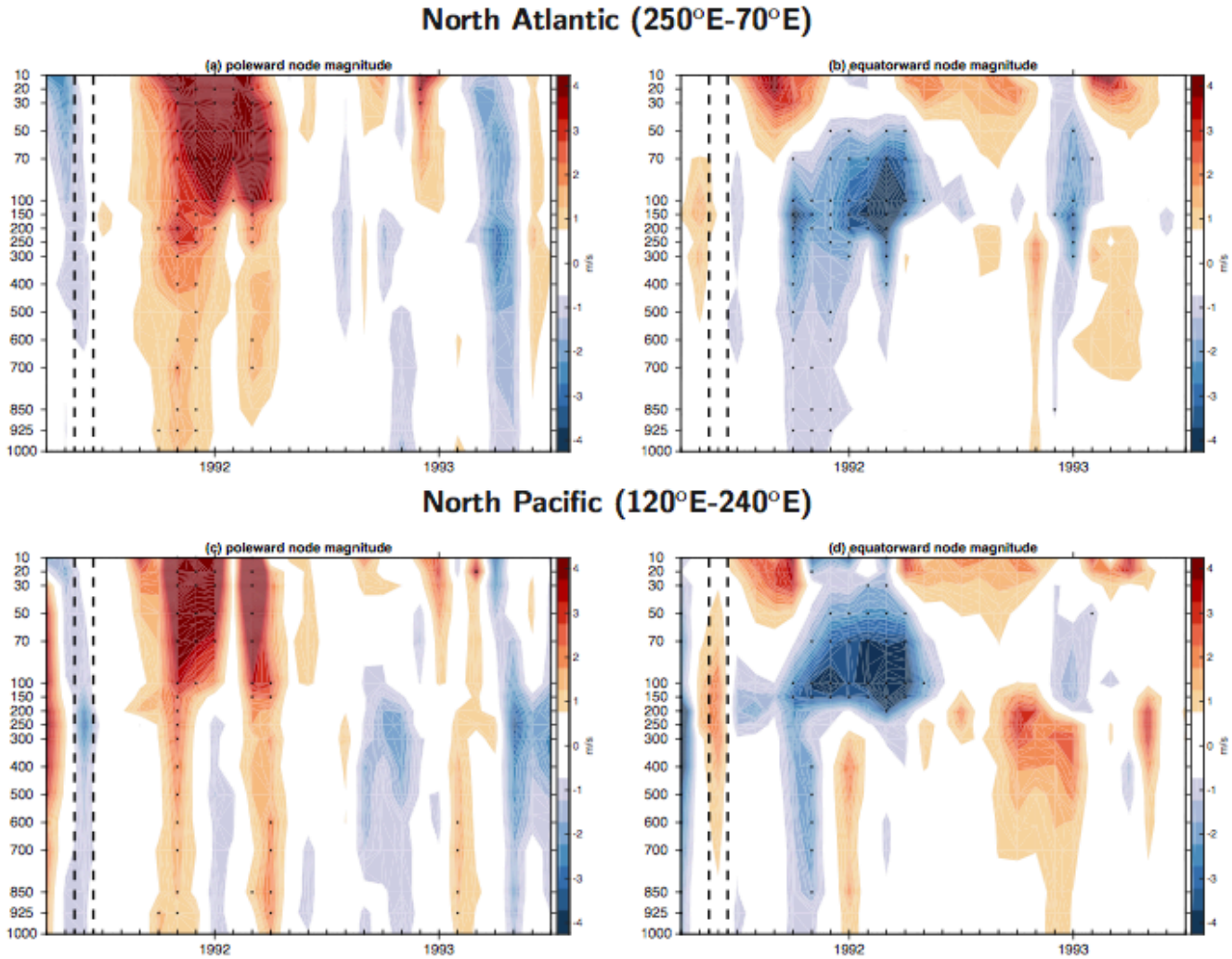

CMIP5 November 1991 multi-model mean 500 hPa zonal wind anomalies for Southern Hemisphere (left) and Northern Hemisphere (right) compared to canonical SAM/NAM patterns (dashed lines). Red (blue) dots indicate poleward (equatorward) nodes.

Barnes et. al., *J. Climate*, under review.



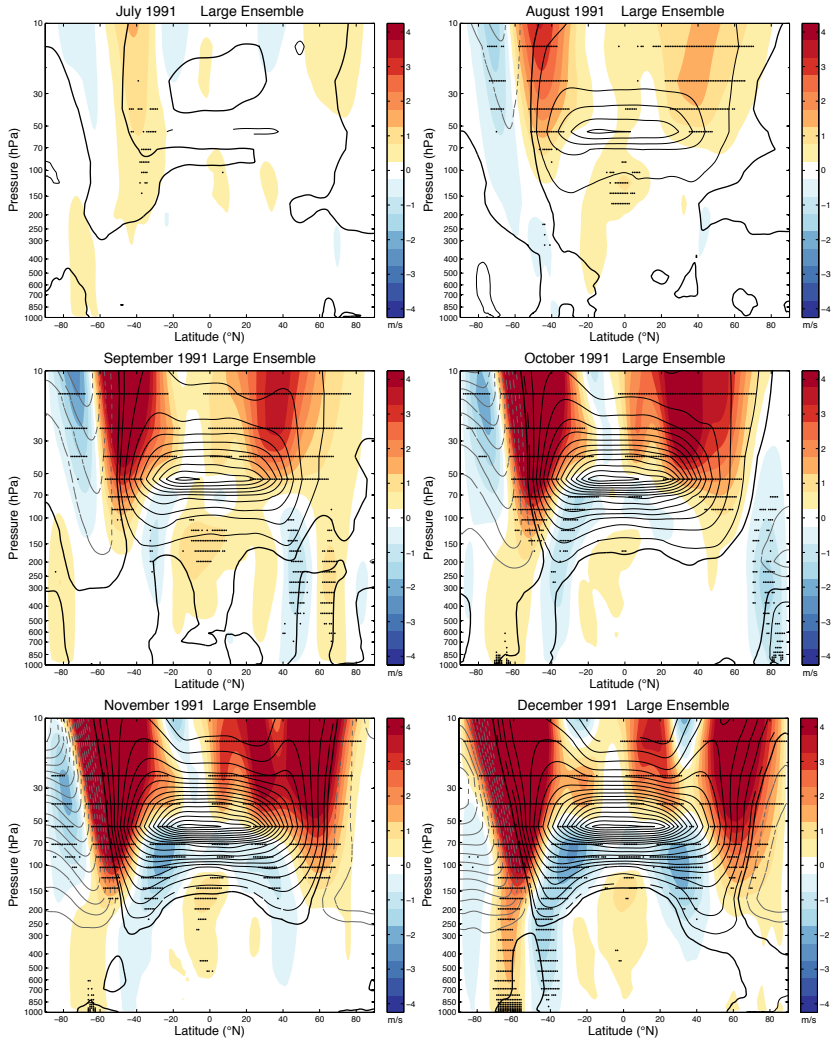

CMIP5 multi-model mean zonal wind anomalies of the poleward (left) and equatorward (right) nodes after Pinatubo eruption (dashed lines).

Barnes et. al., *J. Climate*, under review.



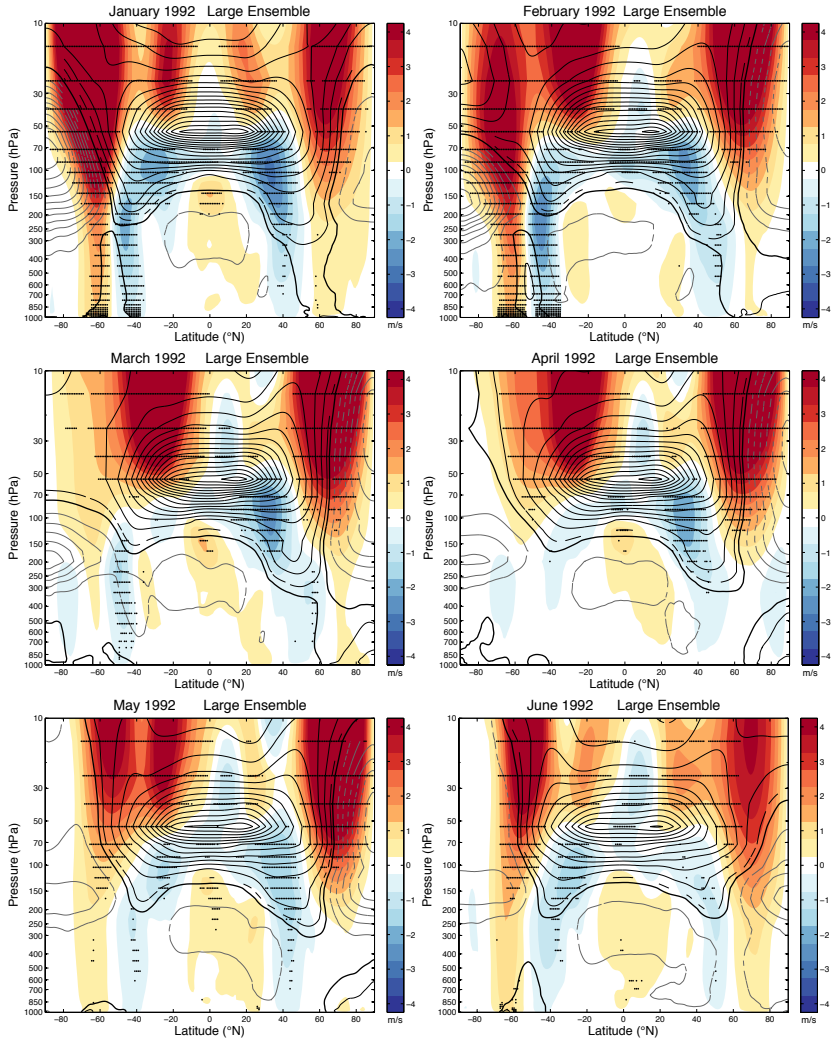

CMIP5 multi-model mean zonal wind anomalies after Pinatubo for the North Atlantic (top) and North Pacific (bottom).

Barnes et. al., *J. Climate*, under review.



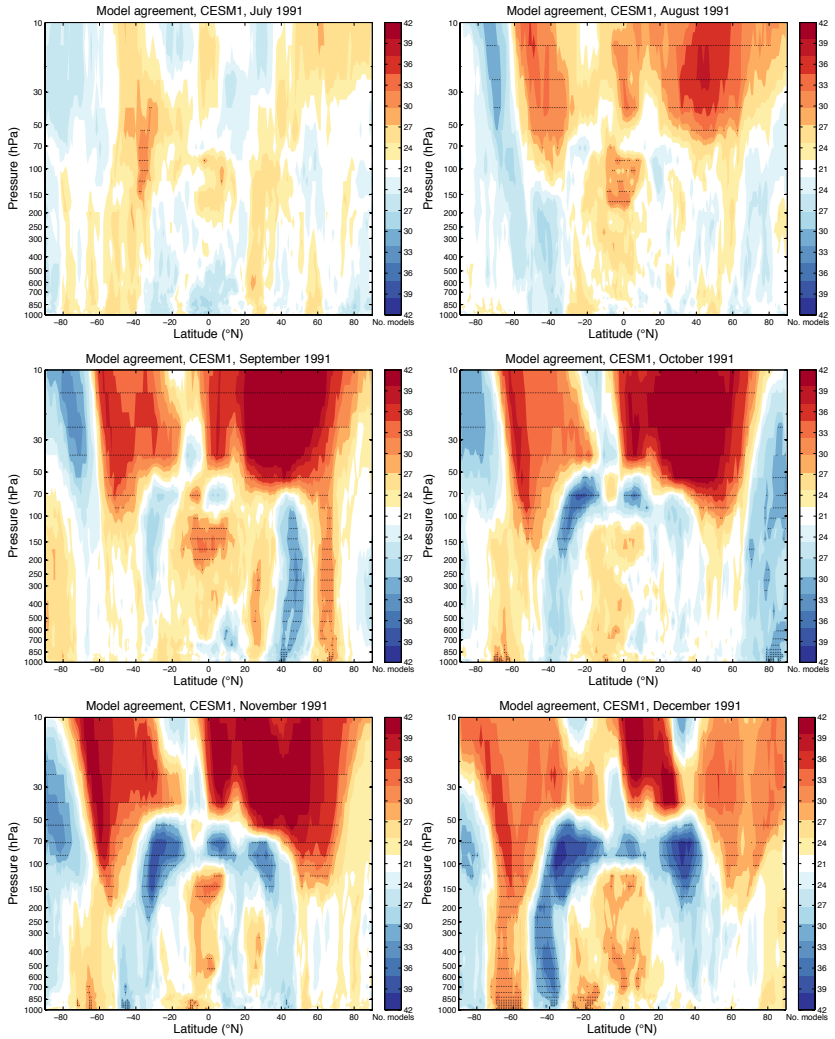

CESM1 Large Ensemble multi-model mean zonal wind (shading) and temperature (contours) anomalies, July 1991-December 1991.

McGraw and Barnes, in preparation.



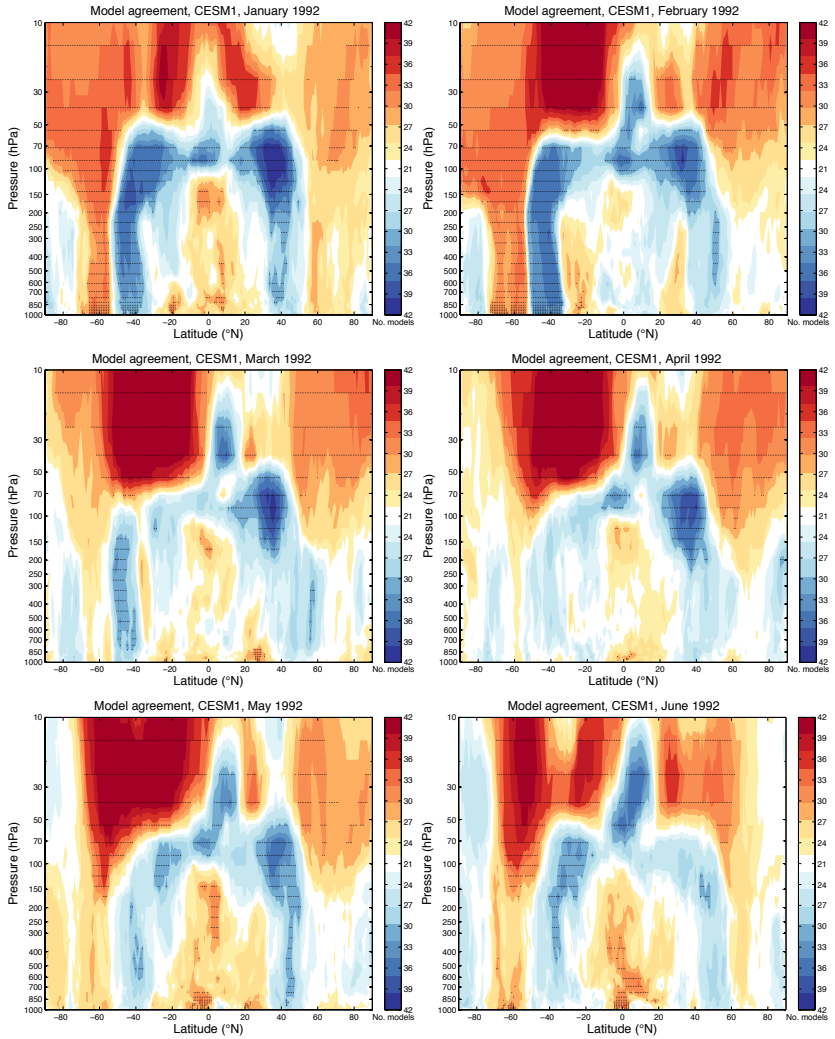

CESM1 Large Ensemble multi-model mean zonal wind (shading) and temperature (contours) anomalies, January 1992-June 1992.

McGraw and Barnes, in preparation.



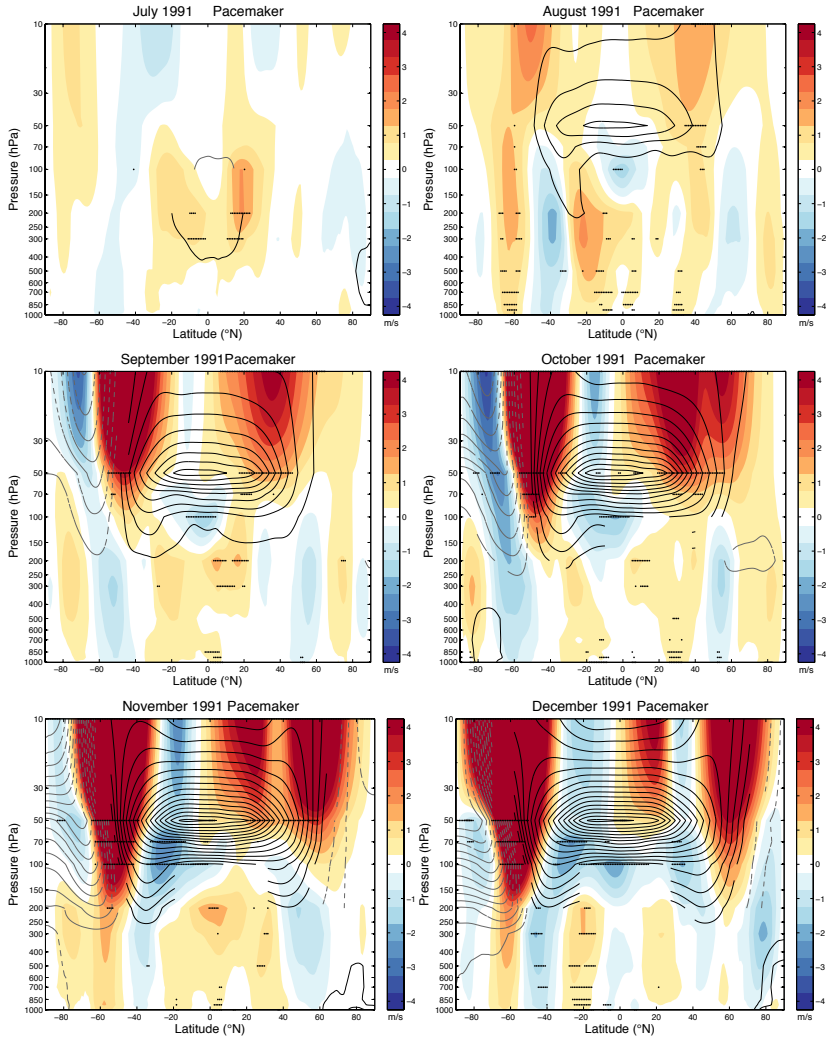

CESM1 Large Ensemble model agreement, zonal wind anomalies, July 1991-December 1991. Red (blue) indicates positive (negative) anomalies. Stippling indicates agreement at 95% confidence.

McGraw and Barnes, in preparation.



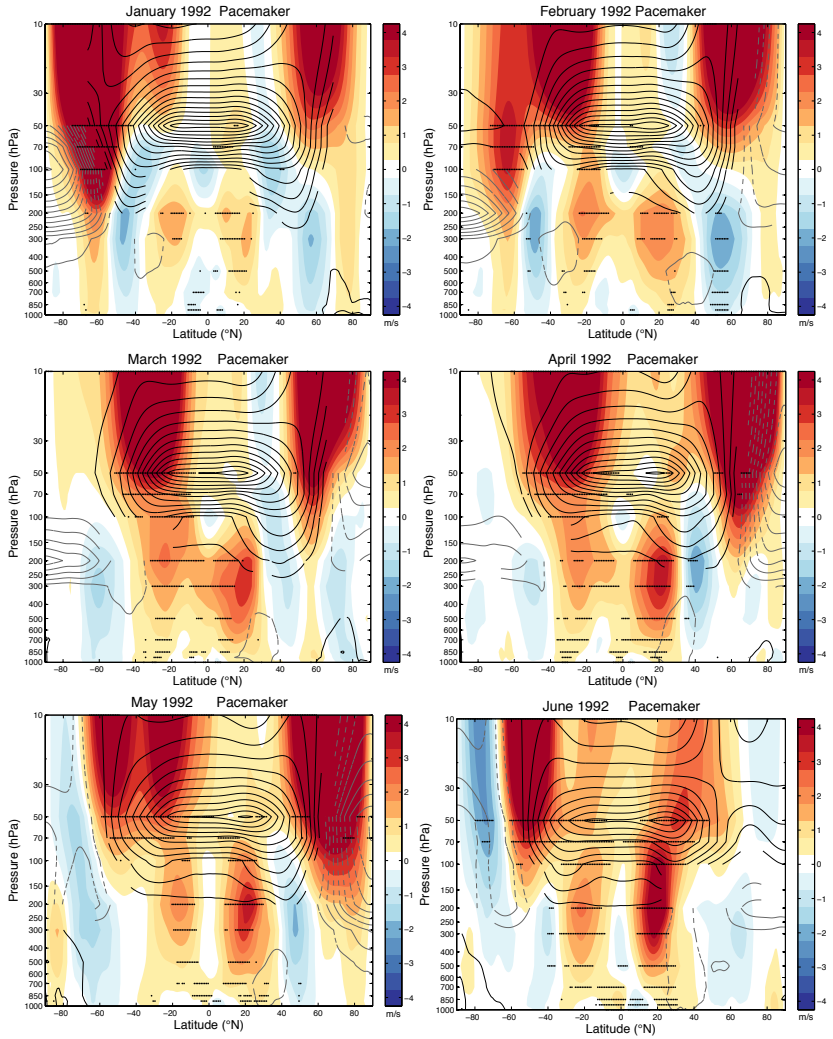

CESM1 Large Ensemble model agreement, zonal wind anomalies, January 1992-June 1992. Red (blue) indicates positive (negative) anomalies. Stippling indicates agreement at 95% confidence.

McGraw and Barnes, in preparation.



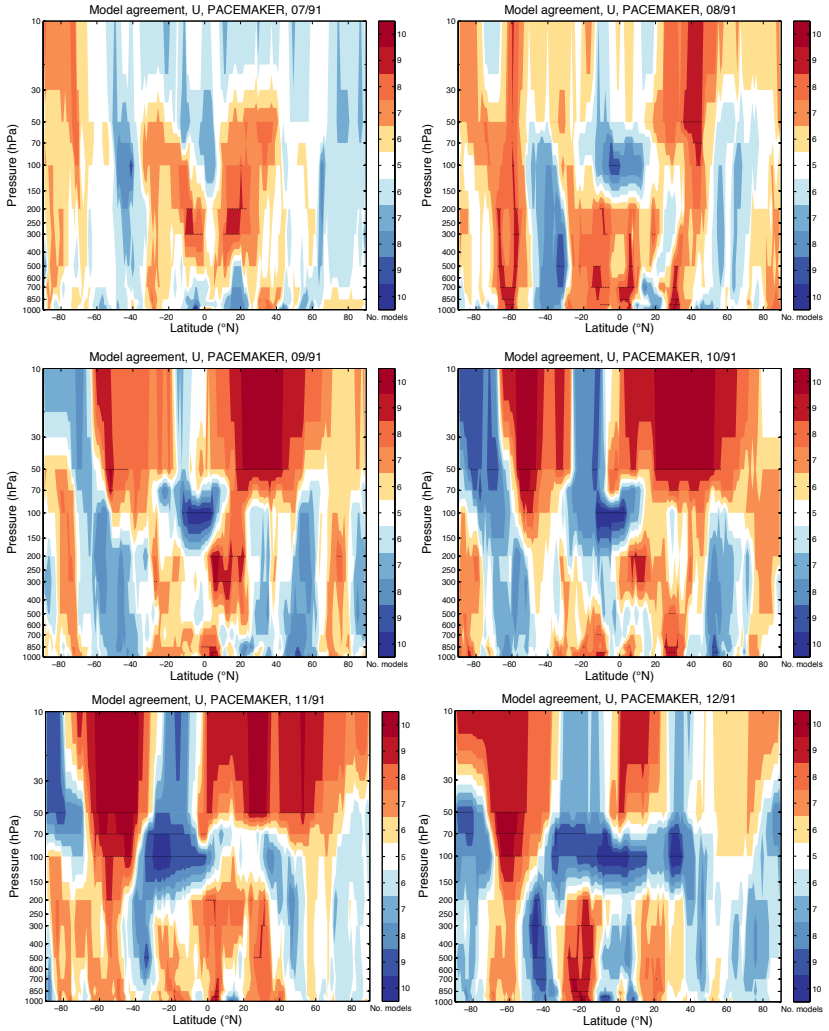

Pacemaker multi-model mean zonal wind (shading) and temperature (contours) anomalies, July 1991-December 1991.

McGraw and Barnes, in preparation.



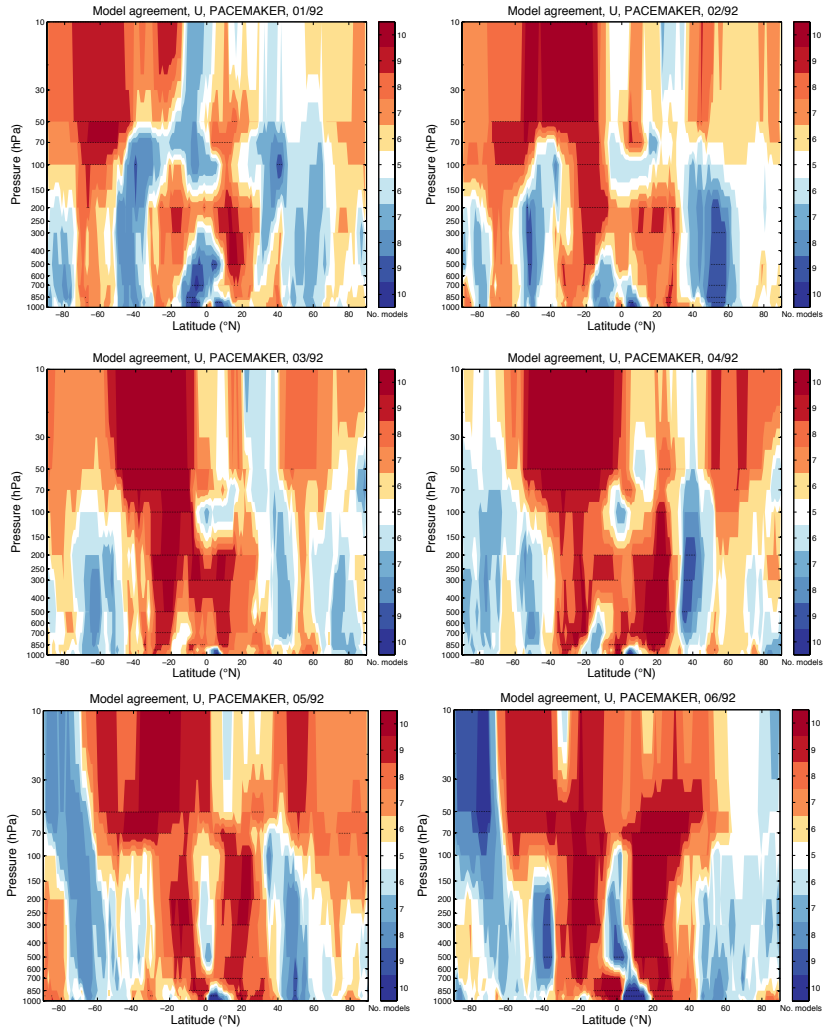

Pacemaker multi-model mean zonal wind (shading) and temperature (contours) anomalies, January 1992-June 1992.

McGraw and Barnes, in preparation.



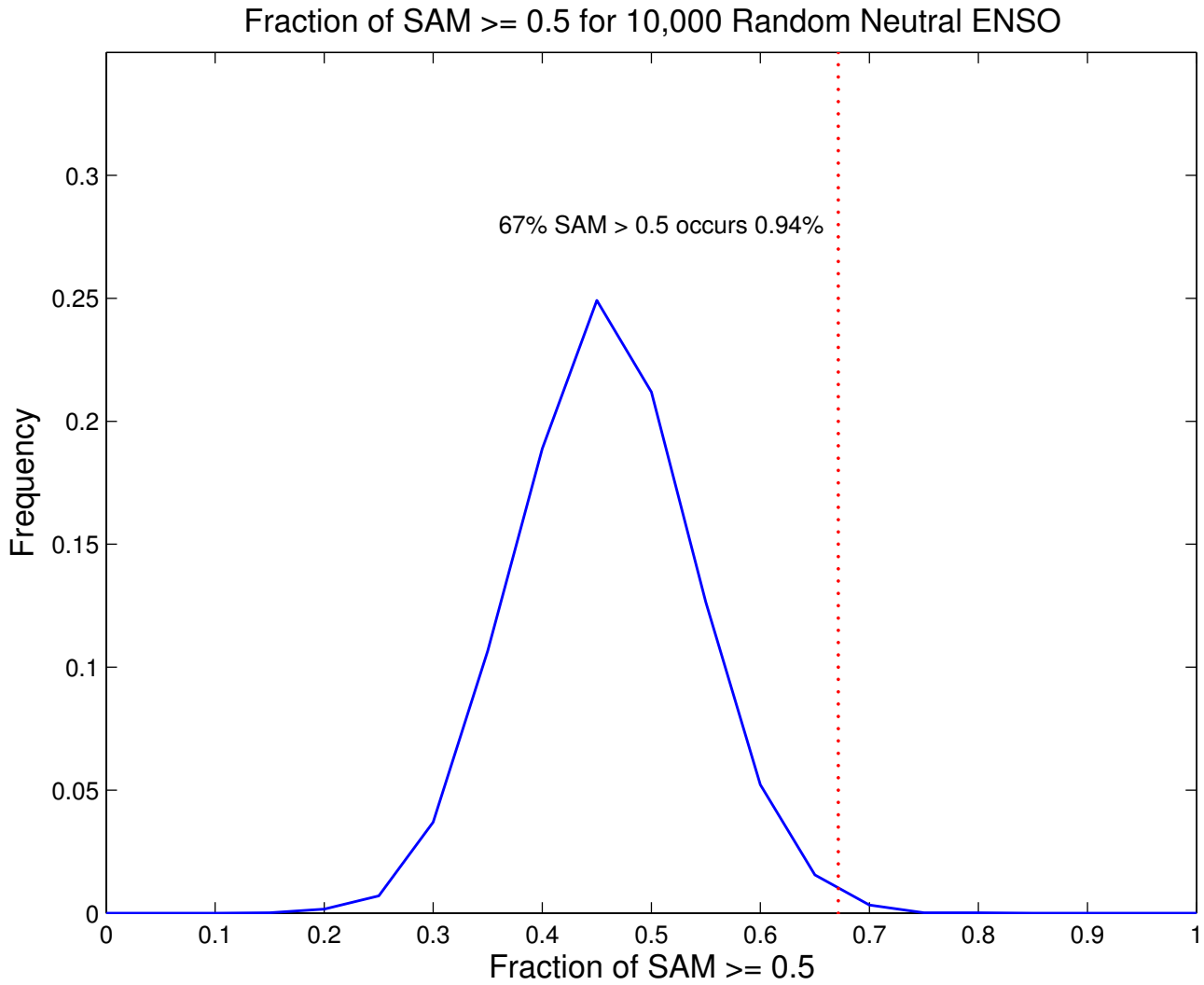

Pacemaker model agreement, zonal wind anomalies, January 1992-June 1992. Red (blue) indicates positive (negative) anomalies. Stippling indicates agreement at 95% confidence.

McGraw and Barnes, in preparation.




Pacemaker model agreement, zonal wind anomalies, January 1992-June 1992. Red (blue) indicates positive (negative) anomalies. Stippling indicates agreement at 95% confidence.

McGraw and Barnes, in preparation.




Probability of obtaining 67% positive SAM responses ($\geq +0.5$) during neutral ENSO state.

McGraw and Barnes, in preparation.