Roles of wind and precipitation nonlinearities in ENSO asymmetries

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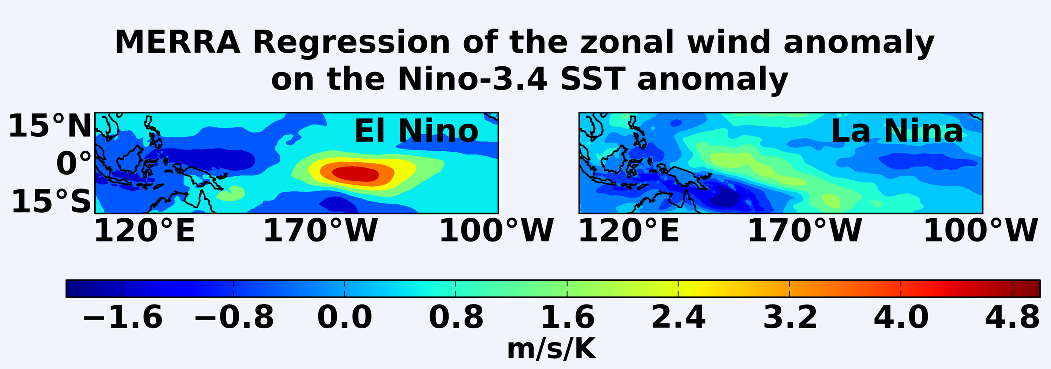
1. Research Questions

- The equatorial zonal wind response is stronger during El Niño than during La Niña. What does this imply for the ENSO life cycle?
- The nonlinear precipitation response drives a nonlinear wind response
  - What characteristics of the precipitation anomaly matter for the nonlinearity?
  - Why do different models simulate the wind response nonlinearity to different extents?

2. Nonlinear wind response

The stronger zonal wind response during El Niño is robust across CMIP5 models and observations.



Measure of nonlinearity:
$$\frac{|\text{El Niño}| - |\text{La Niña}|}{|\text{El Niño}| + |\text{La Niña}|}$$

Figure 1 : Regression coefficient of zonal wind anomaly on Niño-3.4 index

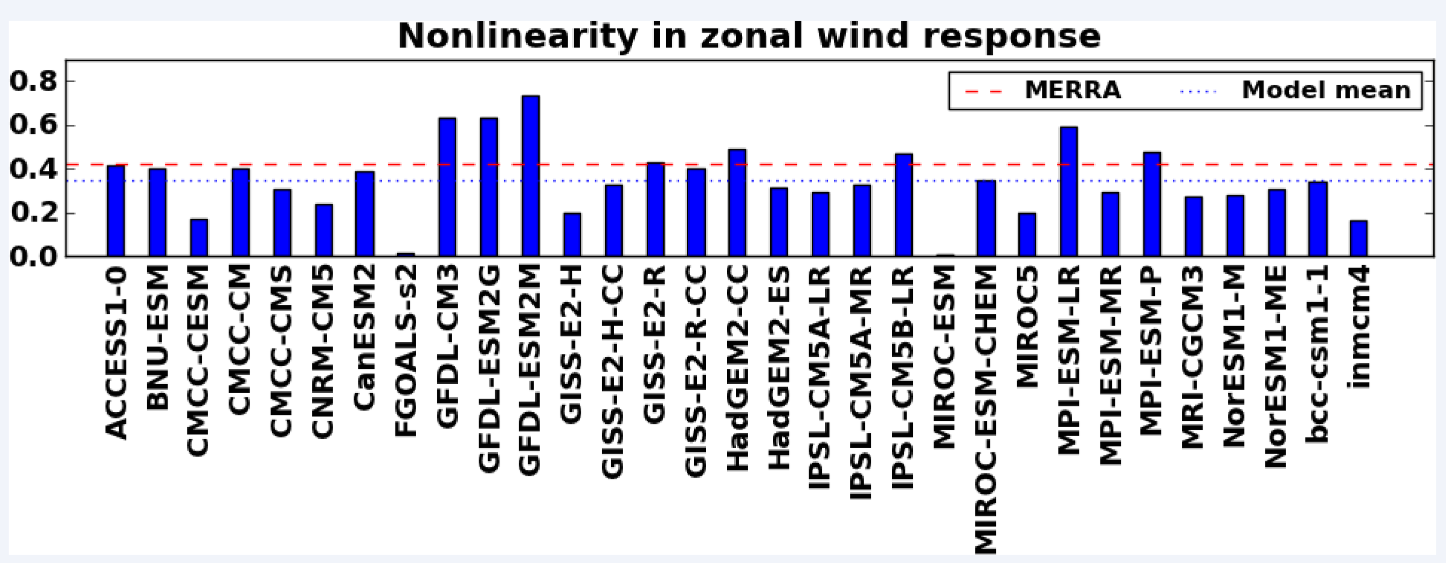


Figure 2 : Nonlinearity in zonal wind response to ENSO for CMIP5 models. Maximum zonal wind anomaly after a 40-degree longitude running mean over the 140E-260E, 5S-5N region is used. Positive indicates stronger wind response during El Niño.

3. ENSO Asymmetry

Three aspects of asymmetry are quantified.

Amplitude: Skewness. Positive means El Niño is stronger
Duration: Duration of La Niña − Duration of El Niño
Transition: Probability(El-Niño-to-La-Niña-transitions) −Probability(La-Niña-to-El-Niño-transitions)

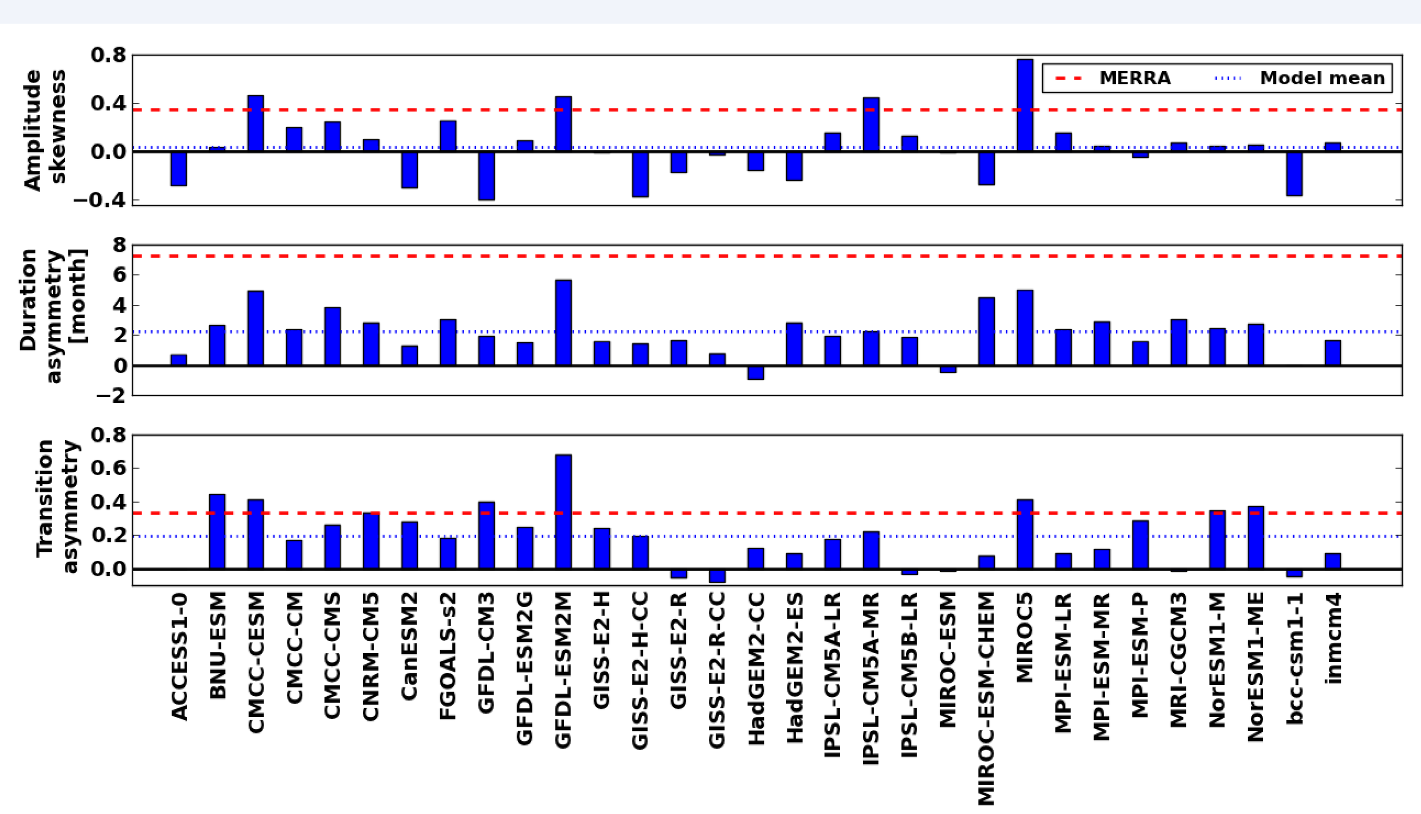


Figure 3 : Amplitude, duration and transition asymmetries of ENSO in CMIP5 models.

4. Conceptual ENSO model setup

The conceptual ENSO model simulates the rate of change of the eastern Pacific SST anomaly T:

$$\frac{dT}{dt} = -bT + c\tau(t - t_1) - d\tau(t - t_2) \quad (1)$$

Damping Positive feedback Delayed negative feedback

The nonlinear wind response is included as follows:

$$\tau = \begin{cases} \gamma(1 + r)T, & T > 0 \\ \gamma(1 - r)T, & T < 0. \end{cases} \quad (2)$$

5. Conceptual model result

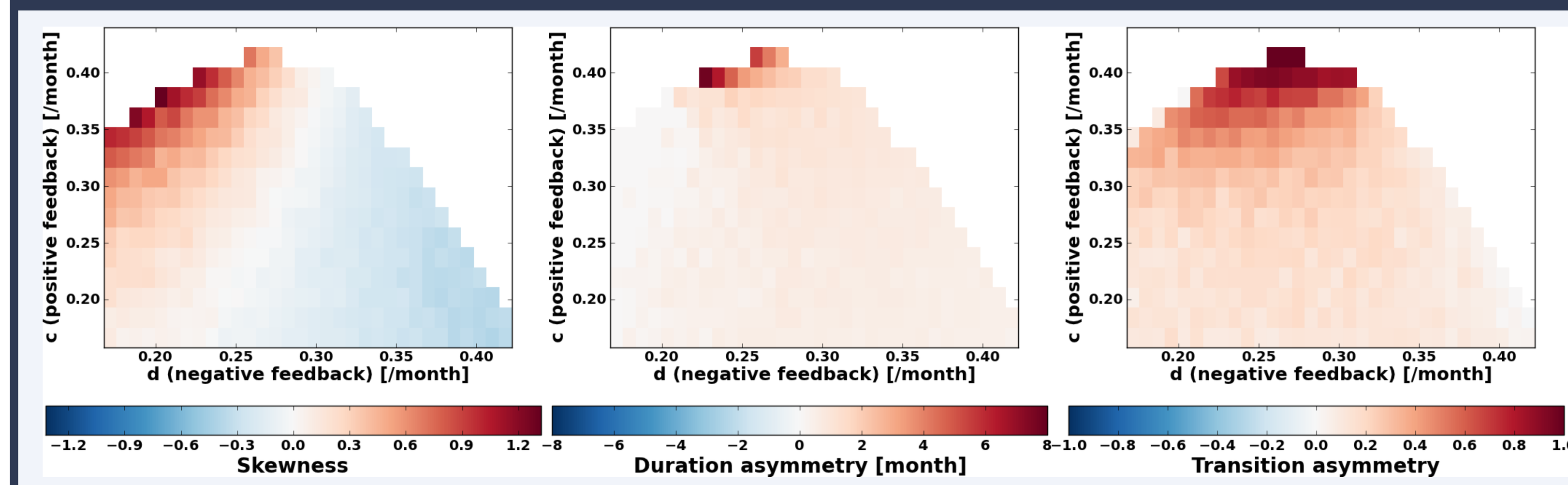


Figure 4 : ENSO asymmetry in the conceptual model with $r = 0.4$, $b = 0.2$, $\gamma = 1$.

- Positive (negative) skewness is implied if the positive feedback is relatively stronger (weaker) than the negative feedback.
- La Niña tends to last longer than El Niño
- El Niño is more readily followed by La Niña than vice versa.

6. Understanding the nonlinear wind response

- Nonlinearity in the equatorial wind is strongly correlated with the nonlinearity in the zonal variations of the equatorial precipitation anomaly

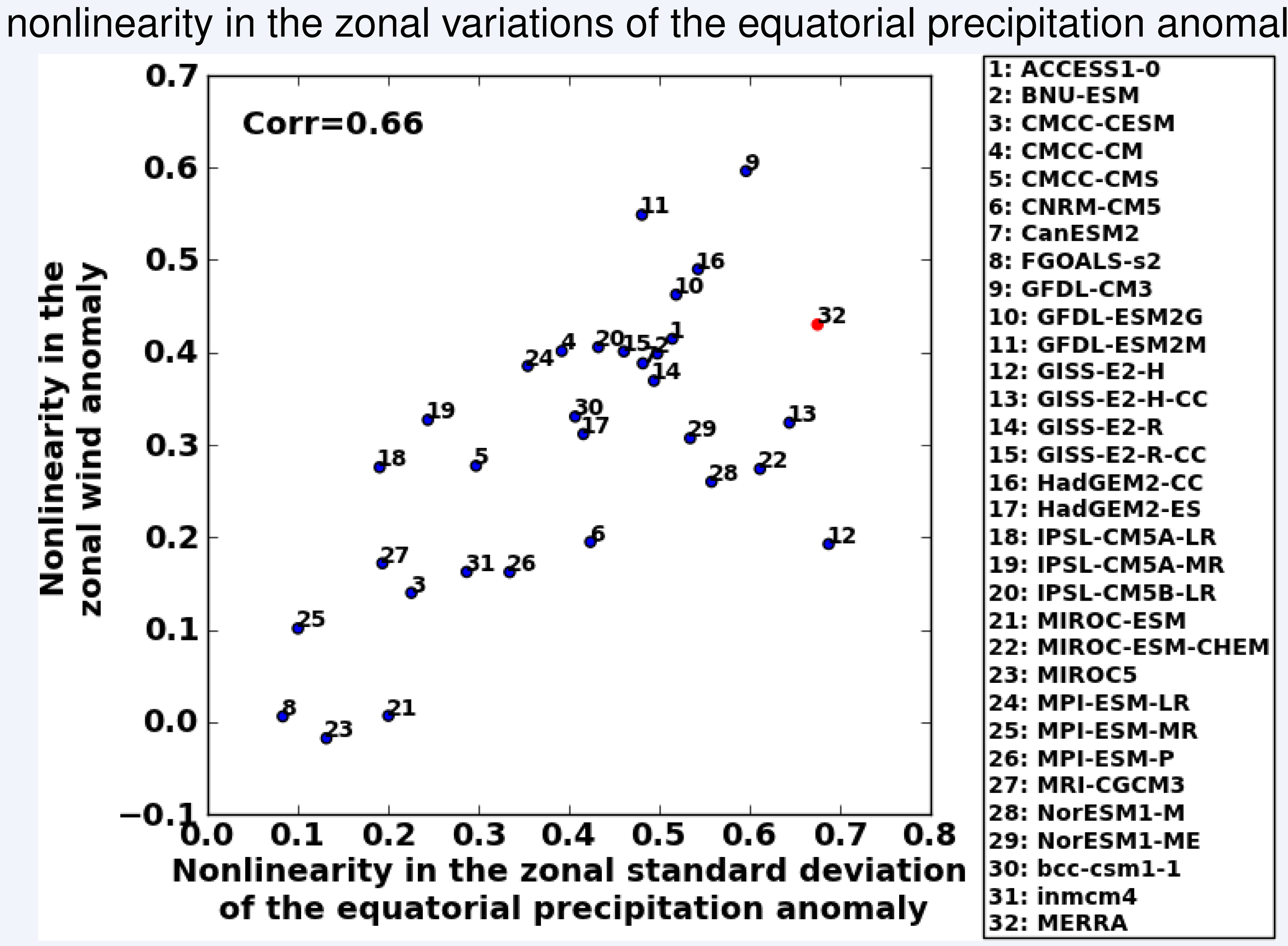


Figure 5 : The zonal wind anomaly refers to its maximum after a 40-degree longitude,4-degree latitude running mean over 120E-260E, 5S-5N. The zonal standard deviation of the equatorial precipitation is computed for the same region for CMIP5 models and MERRA.

- Driving a linear shallow water model with the nonlinear precipitation response reproduces the nonlinear wind response (see Figure 7)

To further understand how the nonlinear precipitation may lead to the nonlinear wind response, we need to investigate which characteristics of the precipitation response matter.

7. Decomposing the precipitation response

Most of the precipitation anomalies are associated with the redistributions of the climatological precipitation: zonal redistribution and meridional redistribution.

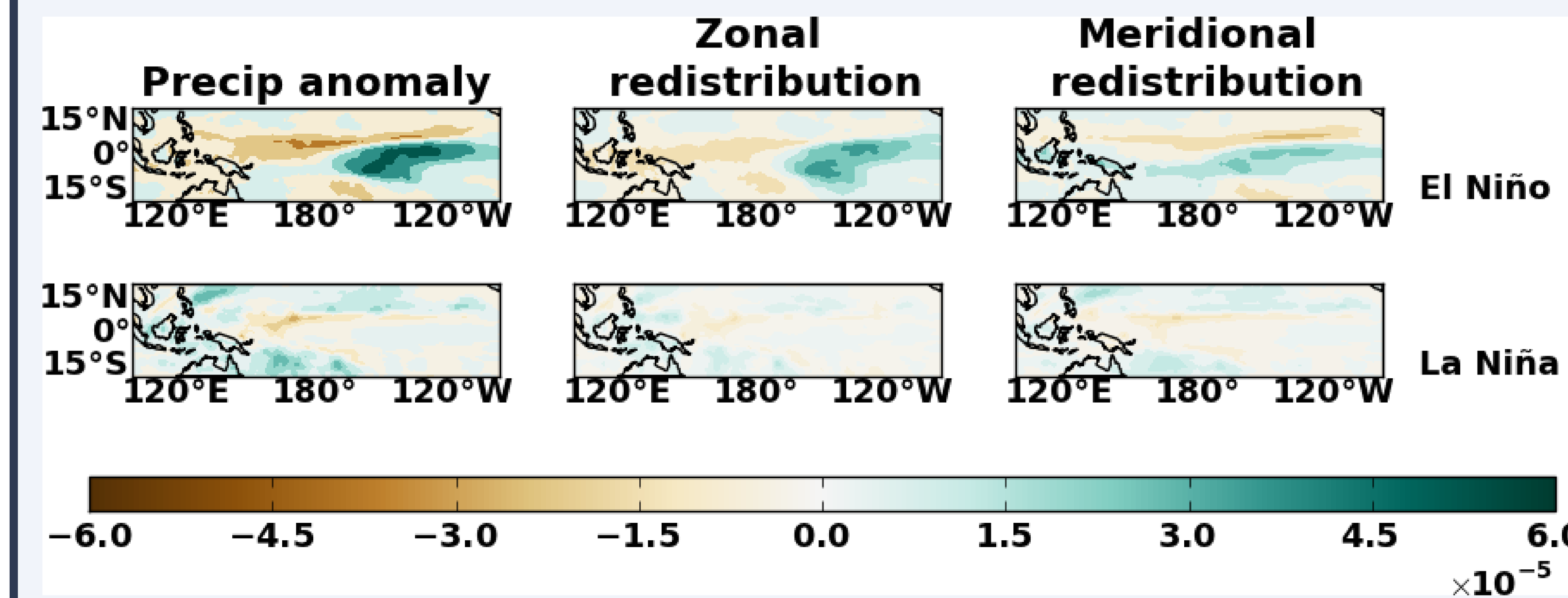


Figure 6 : Precipitation anomaly components for MERRA during El Niño (top) and La Niña (bottom). The sum of the zonal (middle) and meridional (right) redistribution anomalies almost recover the total precipitation (left) anomaly except for a residual component which is two orders of magnitude smaller and is not shown.

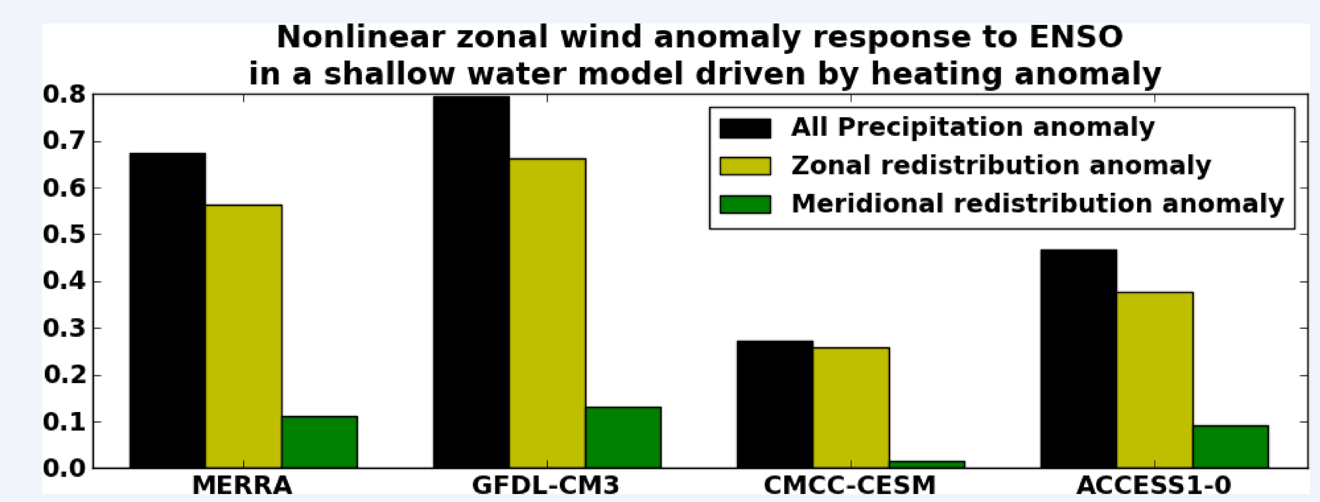


Figure 7 : Nonlinearity in the zonal wind response to the total precipitation anomalies, zonal redistribution and meridional redistribution precipitation anomalies where the precipitation anomalies are prescribed as heating anomalies in a shallow water model.

Although the precipitation anomalies due to meridional redistributions contribute significantly to the total precipitation anomaly, it is the anomalies due to zonal redistributions that are responsible for the nonlinear zonal wind response.

Take-home points

- Equatorial zonal wind anomaly is stronger during El Niño than during La Niña.
- Most CMIP5 models agree with the observations that La Niña tends to last longer and El Niño is more readily followed by La Niña.
  - A conceptual ENSO model with a stronger air-sea coupling efficiency during El Niño reproduces this
- The CMIP5 models exhibit a wide range of amplitude asymmetries, with most underestimating the observed positive asymmetry.
  - The conceptual model suggests that the sign of the amplitude asymmetry depends on the relative strengths of the positive and negative feedback.
- The different zonal wind response to ENSO across CMIP5 models is highly correlated with the different zonal structure of the precipitation anomaly in the models.

References

Choi, Kit-Yan, Gabriel A. Vecchi, Andrew T. Wittenberg (2013): ENSO transition, duration and amplitude asymmetries: Role of the nonlinear wind stress coupling in a conceptual model. *J. Clim.*, **26**, 9462-9476. doi: 10.1175/JCLI-D-13-00045.1

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