An Evaluation of ENSO asymmetry in the Community System Models: A view from the Subsurface

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Research objective

- The asymmetry between El Niño and La Niña is a key aspect of ENSO (e.g. ENSO asymmetry is potentially a mechanism for decadal variability (Rodgers et al. 2004; Sun and Yu 2007, submitted to J. Climate), and a cause of the bias in the time-mean background state (Sun and Zhang 2006; Schopf and Burgman 2006)) and needs to be simulated well by models in order to fully capture the role of ENSO in the climate system.

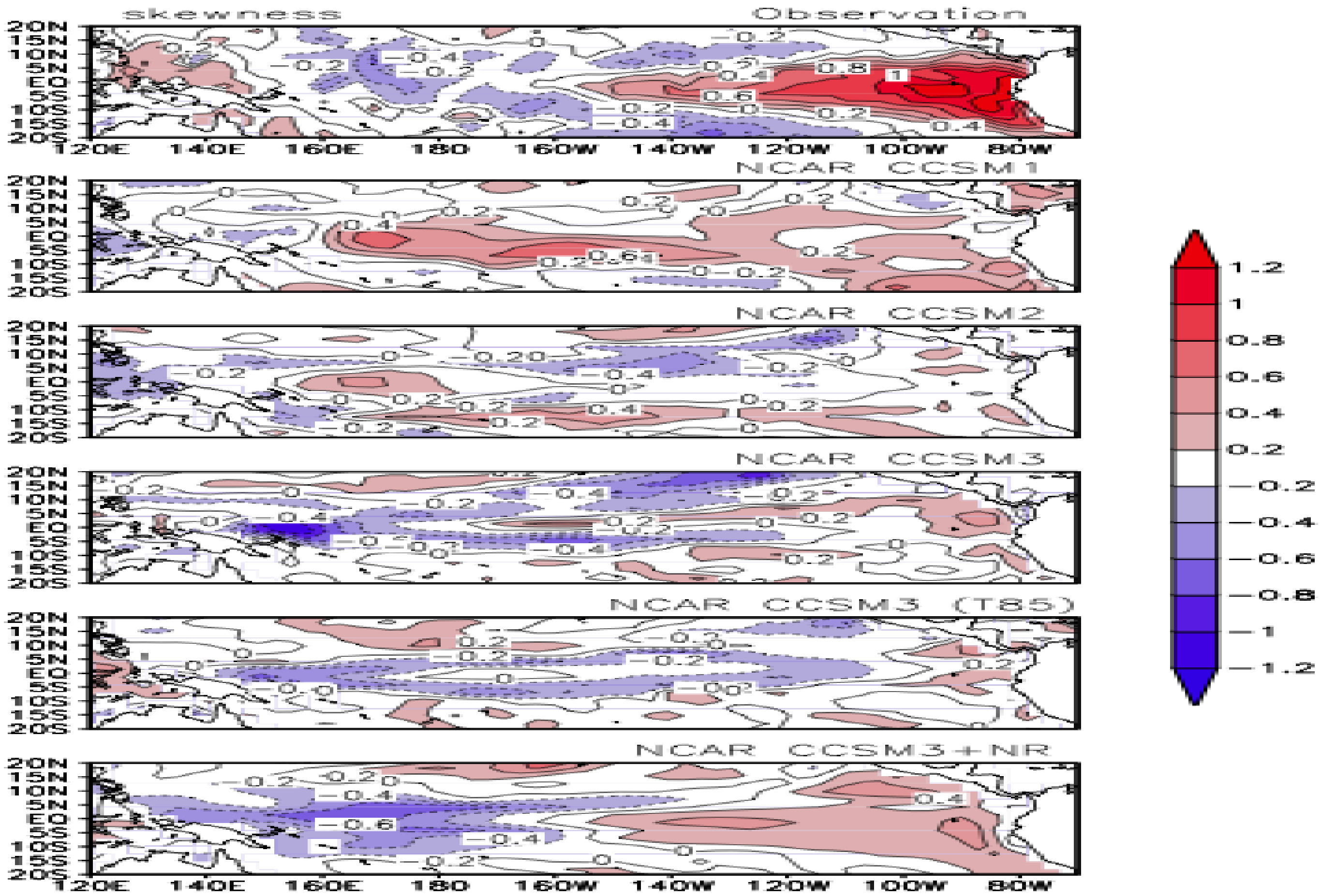
- Different from the previous studies, we not only examine the surface signature of ENSO asymmetry (e.g. investigate the relationship between SST, convection, wind stress, and surface heat flux, particularly the asymmetry in these fields) but also its subsurface signature. We attempt to understand the causes of the ENSO asymmetry by comparing the differences among these models as well as the differences between models and the observations.

Method and model

- 1) skewness analysis following Burgers and Stephenson (1999)
- 2) composite analysis of the anomaly during warm and cold periods

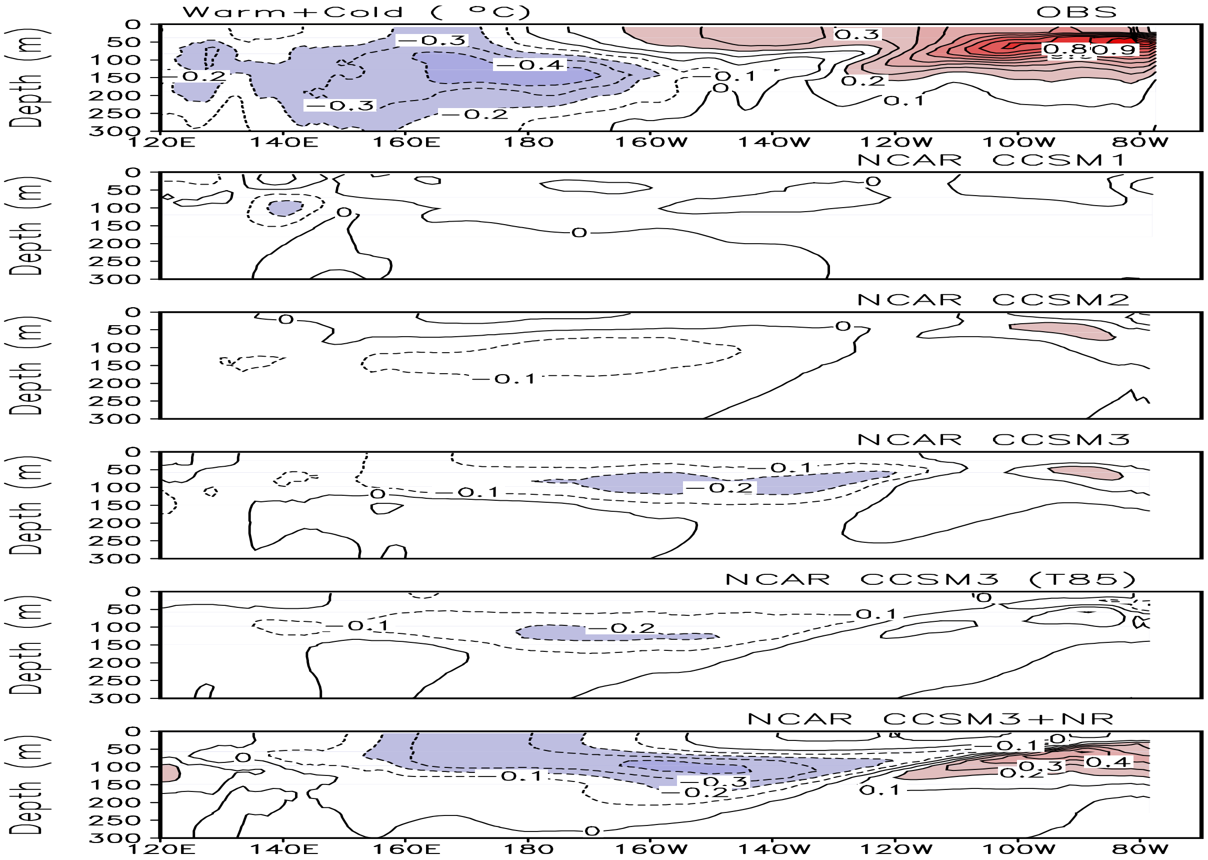
- 3) Coupled run from 5 models (CCSM1, CCSM2, CCSM3 at T42, CCSM3 at T85 with Zhang and McFarlane (1995) convection scheme and the CCSM3+NR with Neale and Richter convection scheme (Neale et al. 2008)

SST Skewness pattern



All the models underestimate the positive SST anomalies over the eastern Pacific, the later version CCSM3+NR with Neale and Richter convection scheme (Neale et al. 2008) shows a significant improvement, but the skewness in the model does not even reach half of the observed value in the eastern Pacific, and has a stronger negative skewness in the western Pacific.

Asymmetry in the upper ocean temp.



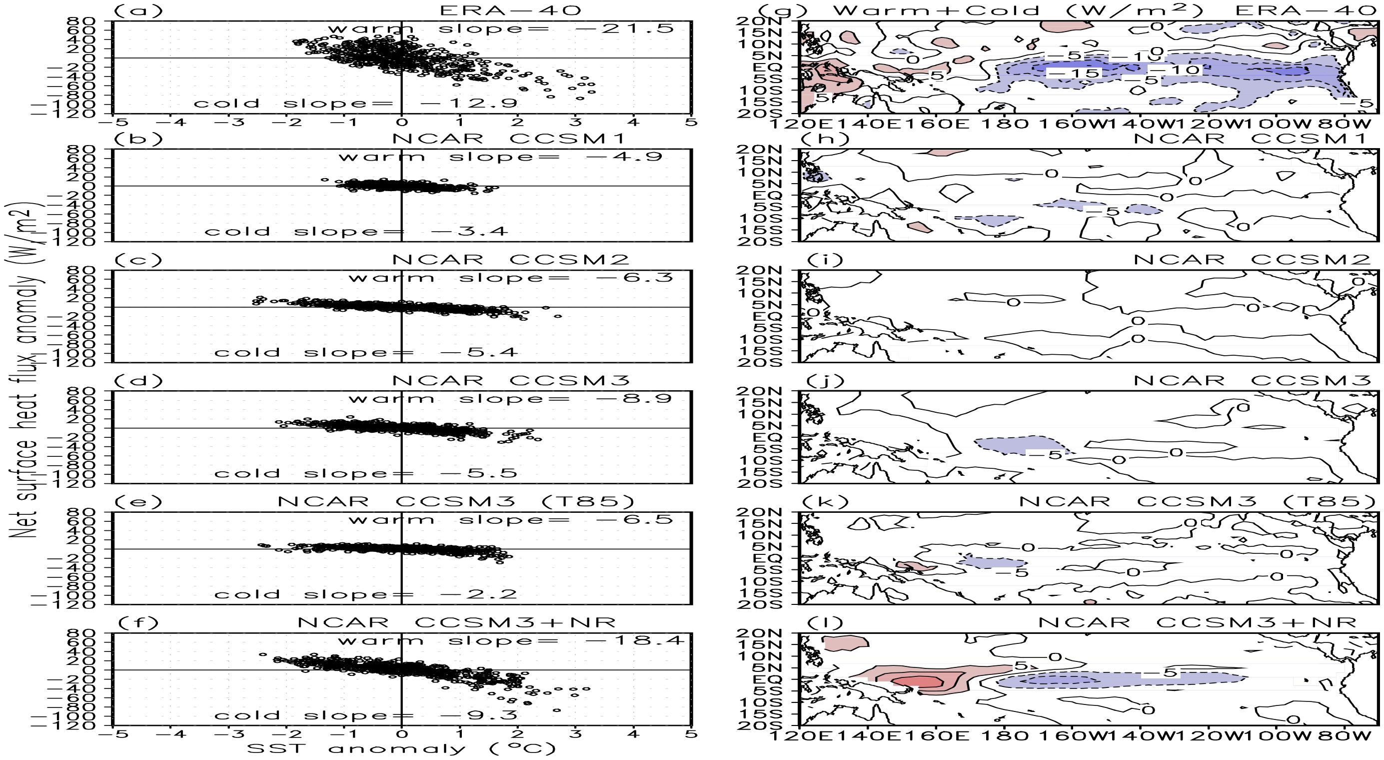
All of the models underestimate the asymmetry in the subsurface temperature. Therefore, the weaker SST asymmetry in the models is likely associated with an underestimate of the asymmetry in subsurface temperature. Again, CCSM3 + NR has an increased positive asymmetry in the subsurface temperature compared to other old versions.

Possible causes for the weak ENSO asymmetry in the models

1. Role of surface heat flux:

Not the major contributor to weaker ENSO asymmetry in CCSMs

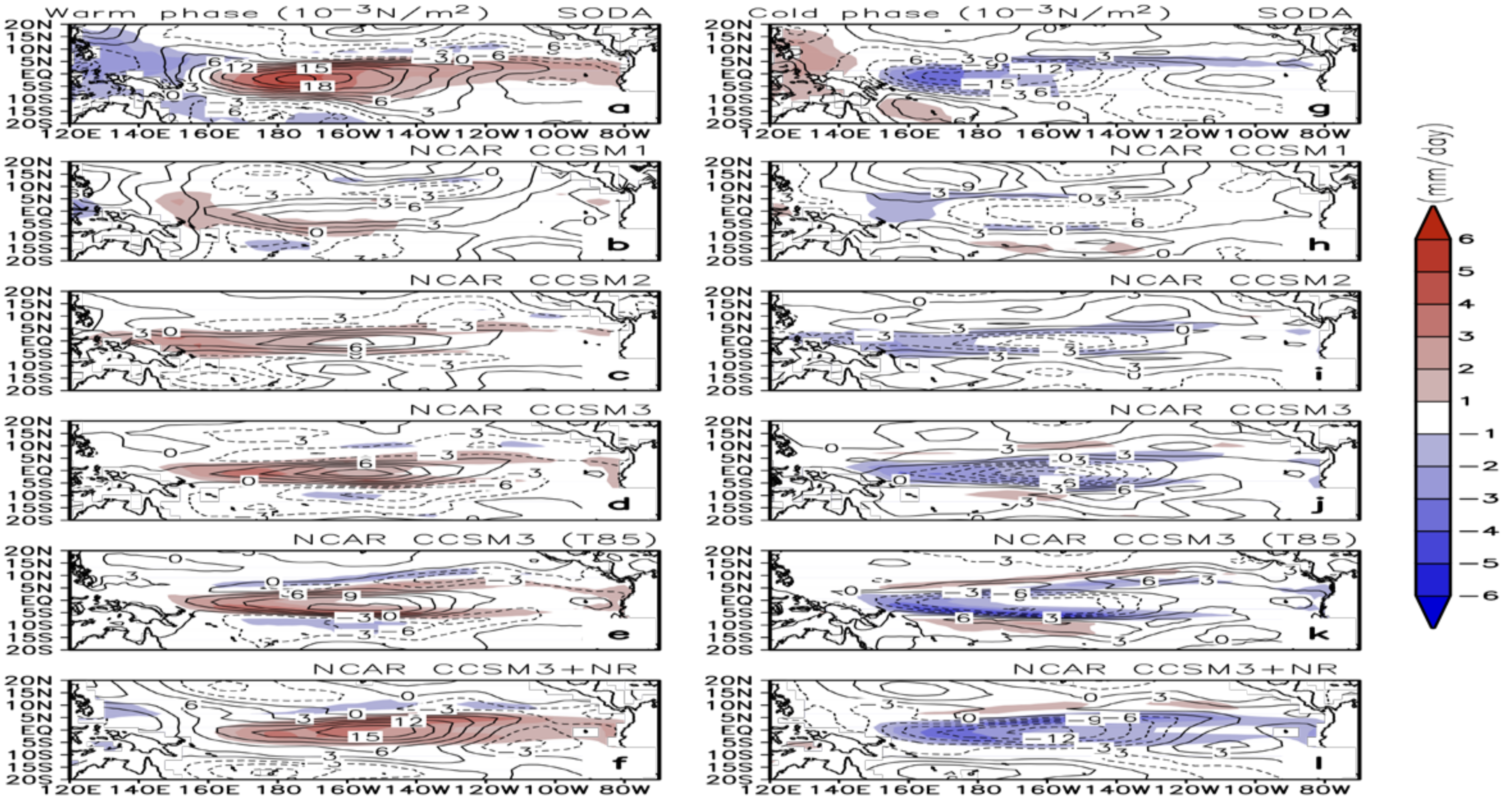
Scatter plot of Fs and SST over Nino3 region and Asymmetry pattern of Fs



The net surface heat flux is found to damp the asymmetry in the SST field in both models and observations, but the damping effect in the models is weaker than in observations, thus excluding a role of the surface heat fluxe in contributing to the weaker asymmetry in the SST anomalies associated with ENSO.

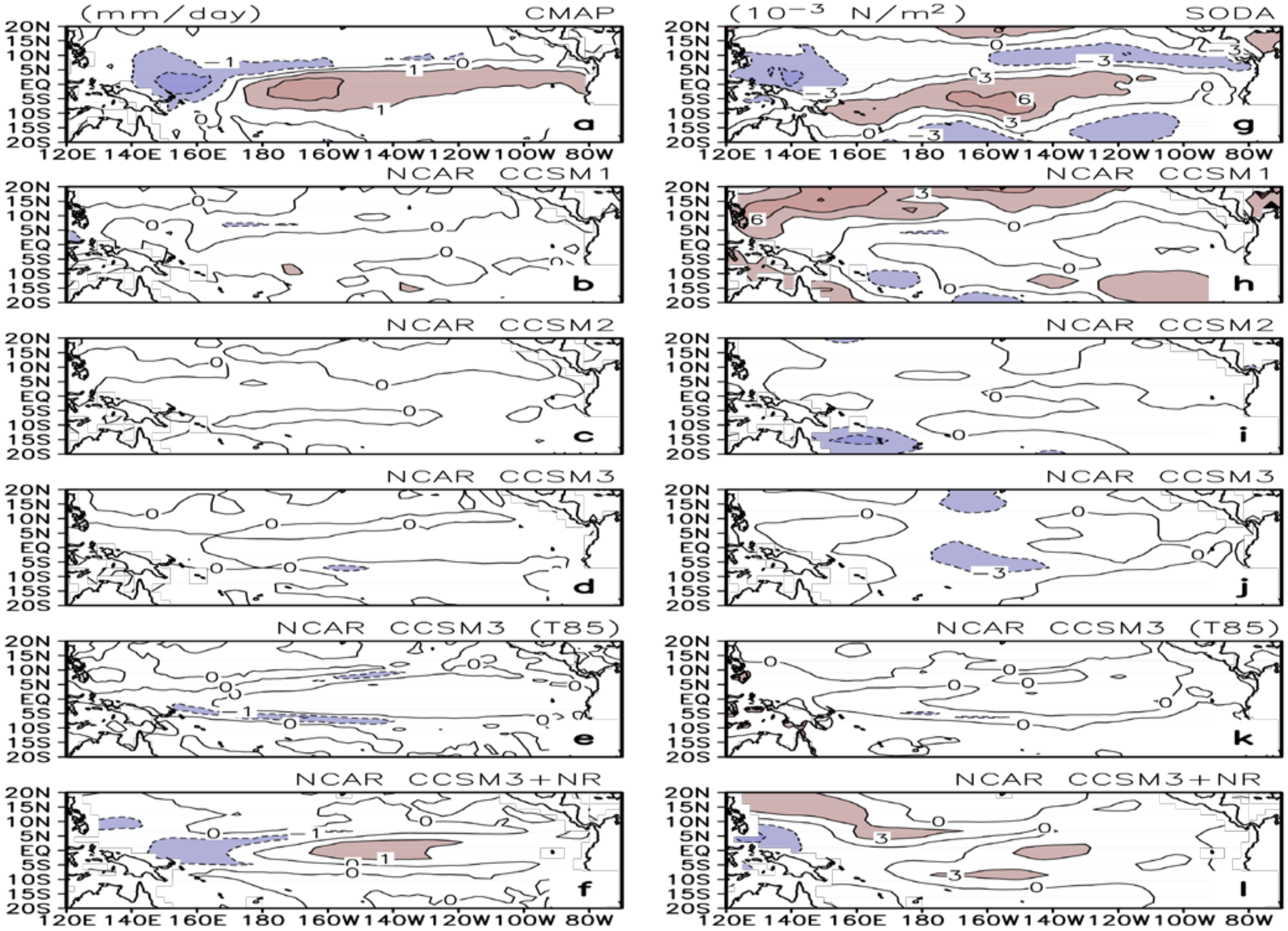
2. **Role of surface winds associated with convection**

Composite precipitation (shaded) & zonal wind stress (contour) anomalies during warm (left) and cold (right) phases



The westward shift of the center of the zonal wind anomalies during the cold phase relative to the warm phase is consistent with the shift in the observed precipitation anomalies. However, models do not simulate well this shift and the wind center shifts eastward relative to observations. CCSM3 + NR is distinctly closer to the observations. It has an improvement not only in simulating the meridional extension of the zonal wind stress anomalies, but also in simulating the magnitude of the zonal wind stress anomalies, due to an increase of precipitation in the warm phase over the central and eastern Pacific.

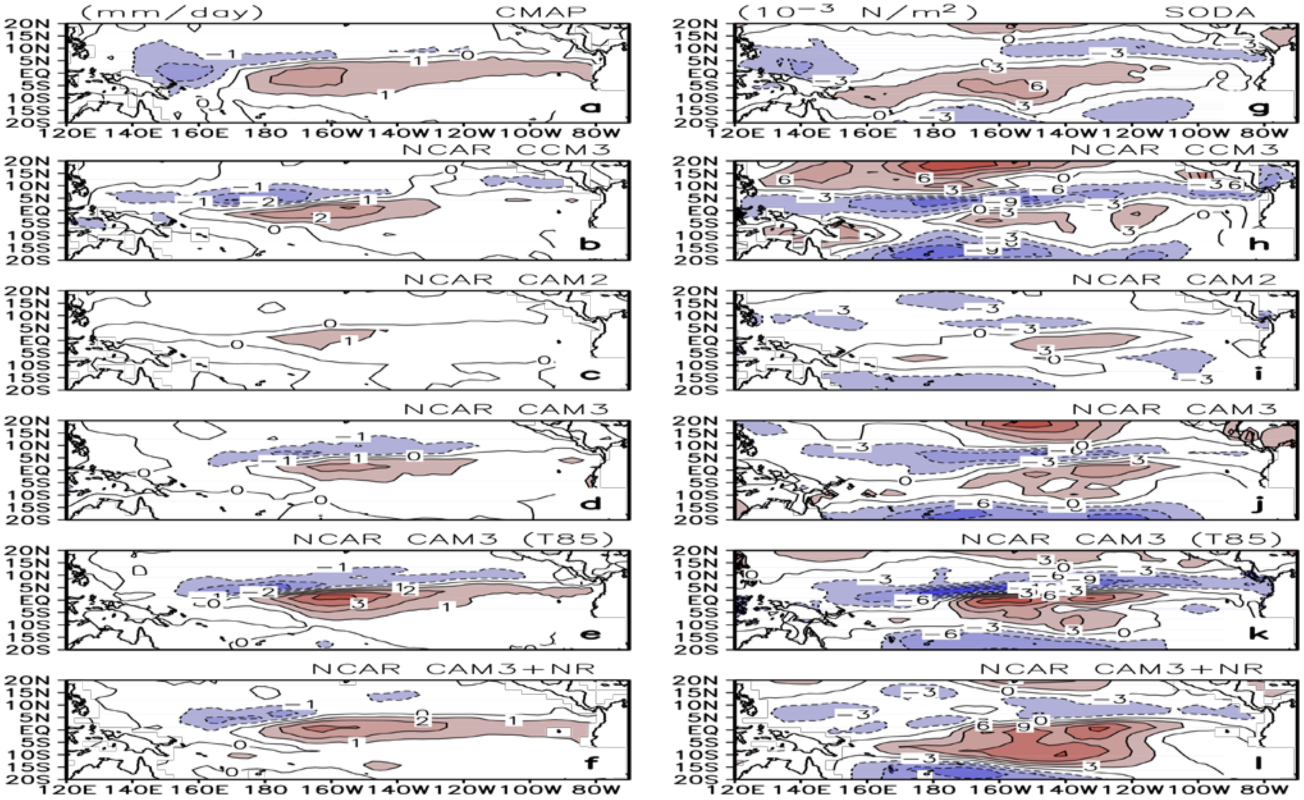
Asymmetry pattern of precipitation (left) and zonal wind stress (right)



a strong positive asymmetry in the central and eastern Pacific and a strong negative asymmetry in the western Pacific is noted in observed precipitation. With the exception of CCSM3 + NR, such an asymmetry does not exist in the models. The underestimate of the asymmetry in the precipitation anomalies in the four old versions is due to the lack of convection in the warm phase. An increase of precipitation in the warm phase over the central and eastern Pacific in the latest CCSM3 + NR improves the asymmetry of precipitation. Consistent with the weak asymmetry in the precipitation anomalies, the asymmetry in the zonal wind stress anomalies is also weak in the NCAR models. The new version CCSM3 + NR has an improved asymmetry pattern of zonal wind stress anomalies because of the improvement in simulating the asymmetry in the precipitation anomalies.

Is the weak asymmetry in precip. and surface winds a consequence of the weak asymmetry in the corresponding SST fields or the cause of the latter?

Asymmetry in precip.(left) and zonal wind stress (right) from AMIP run

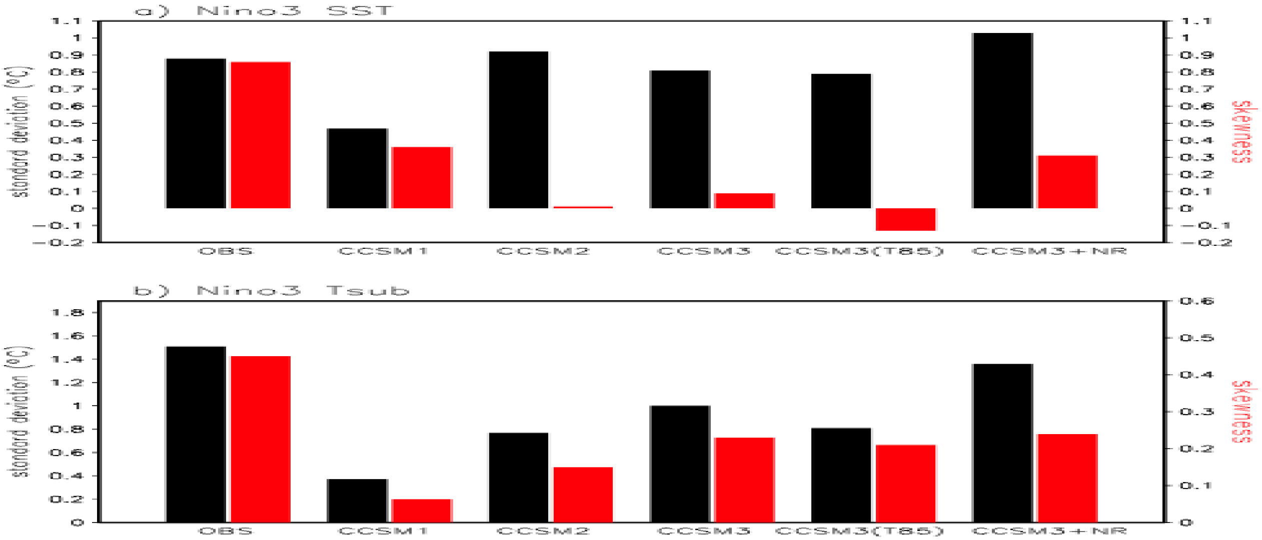


The results from AMIP runs suggest that the weak asymmetry in SST is likely due to a weaker asymmetry in precipitation response to SST forcing. In observations, there is a significant westward shift in the maximum response in the precipitation from the warm phase to the cold phase. However, models do not simulate this shift. With the exception of the latest version, the precipitation response in the eastern Pacific during the warm phase also tends to be too weak. These biases are then reflected in the zonal wind stress, causing a weaker asymmetry in zonal wind stress. Such a bias is then reinforced in the coupled models because the resulting weaker asymmetry in the zonal wind stress causes a weaker asymmetry in the SST through the subsurface dynamics. The latter then in turn generates an even weaker asymmetry in the precipitation, and thereby an even weaker asymmetry in the zonal wind stress.

Although the SSTs now are the same as those observed, the asymmetry in precipitation over the eastern Pacific in the three old versions is notably weaker. The positive asymmetry in precipitation in T85 CAM3 and CAM3 + NR in the central and eastern equatorial Pacific is more comparable to the observations, but the corresponding negative asymmetry in the western Pacific is weaker than observations. Substantially weak negative zonal wind stress asymmetry in the equatorial western Pacific in all of the models, and the weak positive zonal wind stress asymmetry in the central and eastern Pacific in CCM3, CAM2, and T42 CAM3.

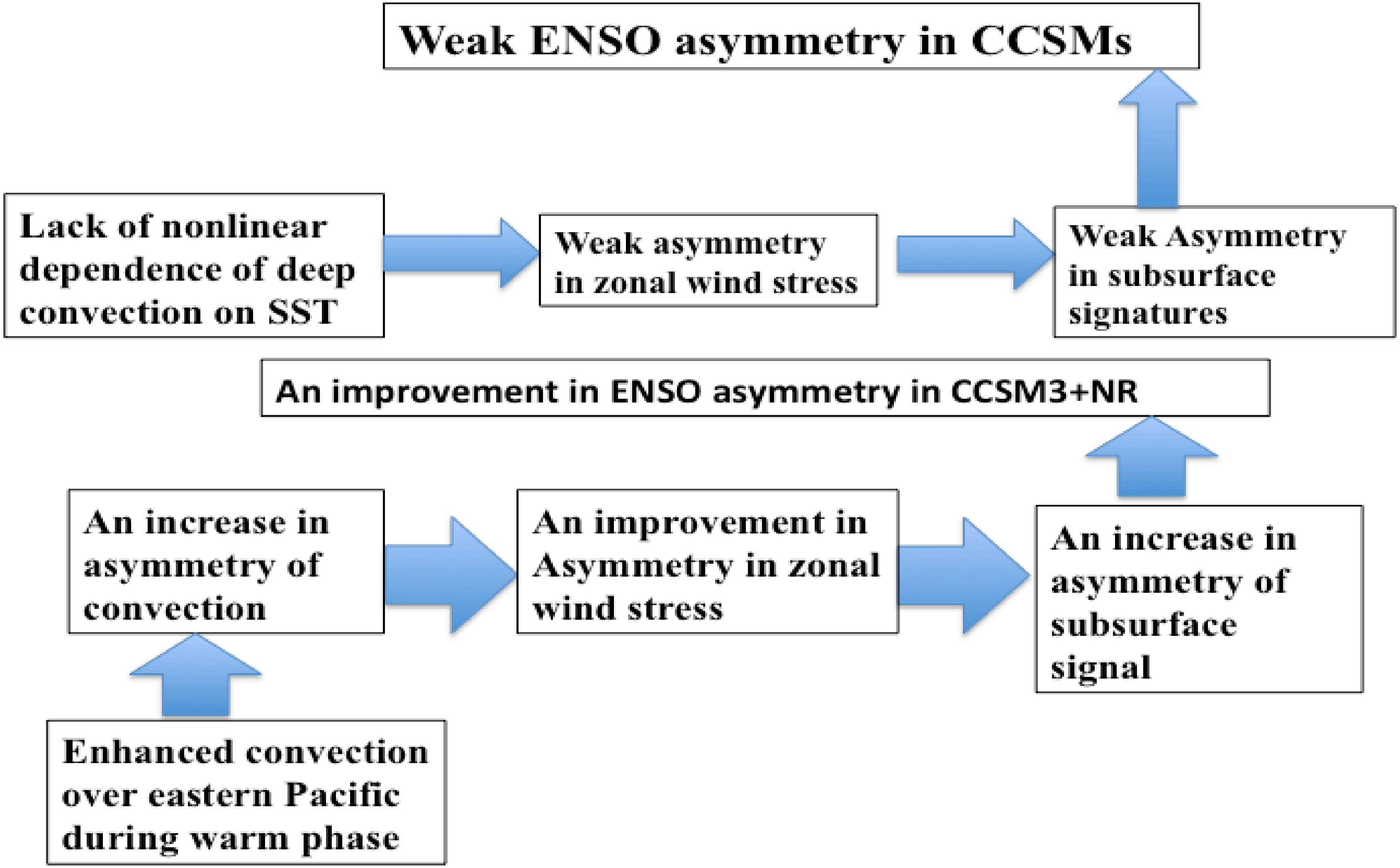
Summary

1) An underestimate of ENSO asymmetry is noted in all the models. Examining the subsurface signatures of ENSO reveals the same bias—the asymmetry in the models is weaker than in the observations. But the latest version with the Neale and Richter scheme (CCSM3+NR) is getting much closer to the observations than the earlier versions. The subsurface temperature anomalies may be a good proxy as a measure of the relationship between ENSO variability and asymmetry, because no correlation between SST variance and SST skewness is found in the surface.



2) The net surface heat flux is found to damp the asymmetry in the SST field in both models and observations, but the damping effect in the models is weaker than in observations, thus excluding a role of the surface heat fluxe in contributing to the weaker asymmetry in the SST anomalies associated with ENSO.

3) **The cause for the weak ENSO asymmetry in CCSMs**



Weak ENSO asymmetry in CCSMs

Lack of nonlinear dependence of deep convection on SST

Weak asymmetry in zonal wind stress

Weak Asymmetry in subsurface signatures

An improvement in ENSO asymmetry in CCSM3+NR

An increase in asymmetry of convection

An improvement in Asymmetry in zonal wind stress

An increase in asymmetry of subsurface signal

Enhanced convection over eastern Pacific during warm phase