An Evaluation of ENSO Asymmetry in CCSM4

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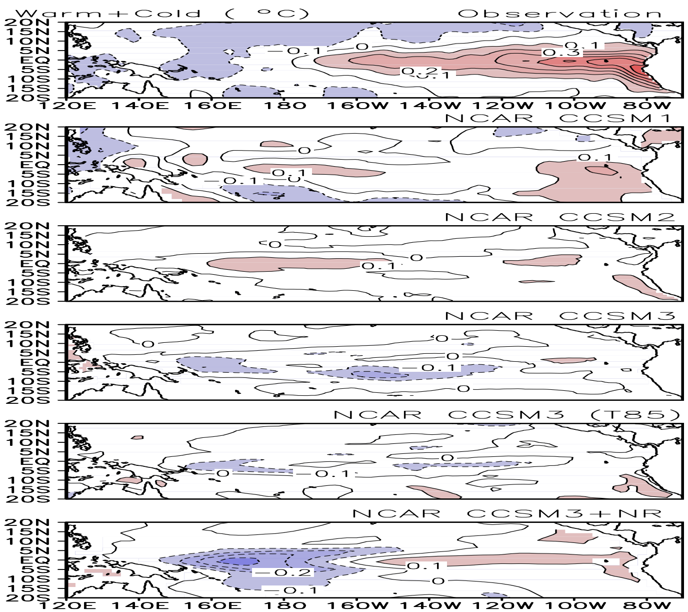
Why it is important to evaluate ENSO asymmetry ?

1) Rectification effect of ENSO events into the mean (Sun and Zhang 2006; Schopf and Burgman 2006, Sun 2010).

2) decadal variability in the tropics and beyond (Rodgers et al. 2004; Sun and Yu 2009, Liang et al. 2011).

What we have done for previous NCAR models?

SST residuals



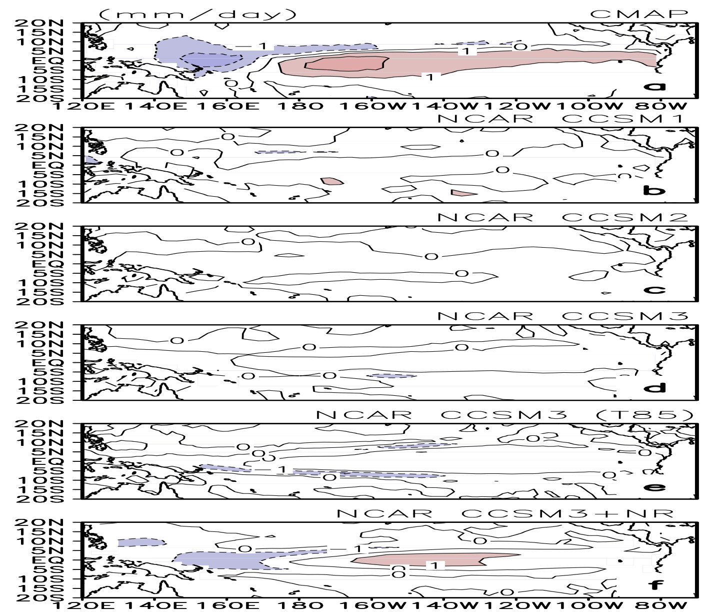
from Zhang et al. (2009), *J. Climate*, 22, 5933-5961.

Precip. residuals

OBS

Coupled runs

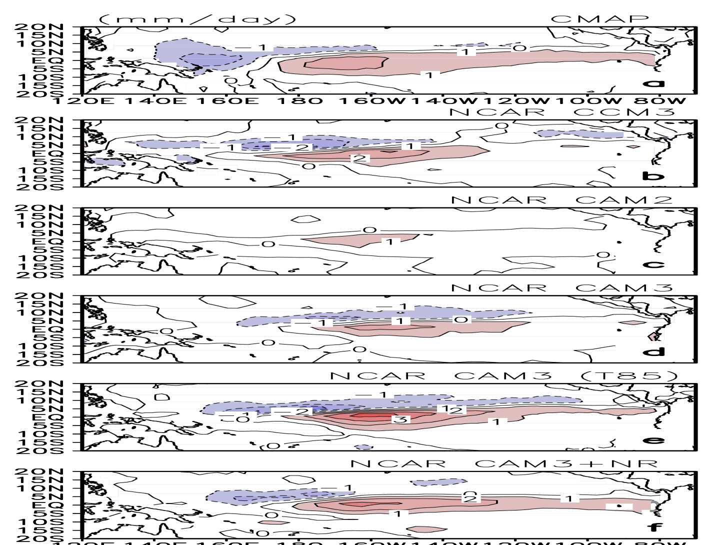
CCSM3+NR



OBS

AMIP runs

CAM3+NR



CCSM3+NR with Neale and Richter scheme is getting closer to the observations than the earlier versions.

What we have concluded from previous NCAR models?

- **All models underestimate the ENSO asymmetry, but CCSM3+NR has significant improvements over the earlier versions**

- **The enhanced nonlinearity in tropical convection appears to be the cause for the improvement.**

Research Objective

- **Evaluate ENSO asymmetry in CCSM4 including its surface and subsurface signatures.**
- **Test the hypothesis developed in previous NCAR models against CCSM4.**
- **Understand the effects of convection scheme and model resolution on the simulation of ENSO asymmetry.**

Model description

1) Main difference between CCSM3+NR (CCSM3.5) and previous CCSM1, 2, 3:

CCSM1, CCSM2, and CCSM3 use Zhang and McFarlane deep convection scheme (Zhang and McFarlane 1995) .

CCSM3+NR : the Neale and Richter convection scheme (Neale et al. 2008; Richter and Rasch 2008) replaces the Zhang and and McFarlane (1995) scheme used in CCSM3.

2) Main difference between CCSM4 and CCSM3+NR (CCSM3.5):

The ocean model component in CCSM4 has 60 vertical levels as opposed to 40 in CCSM3.

Methodology and data

1) Skewness (Burgers and Stephenson 1999)

2) Asymmetricity (variance weighted skewness) analysis (An et al. 2005)

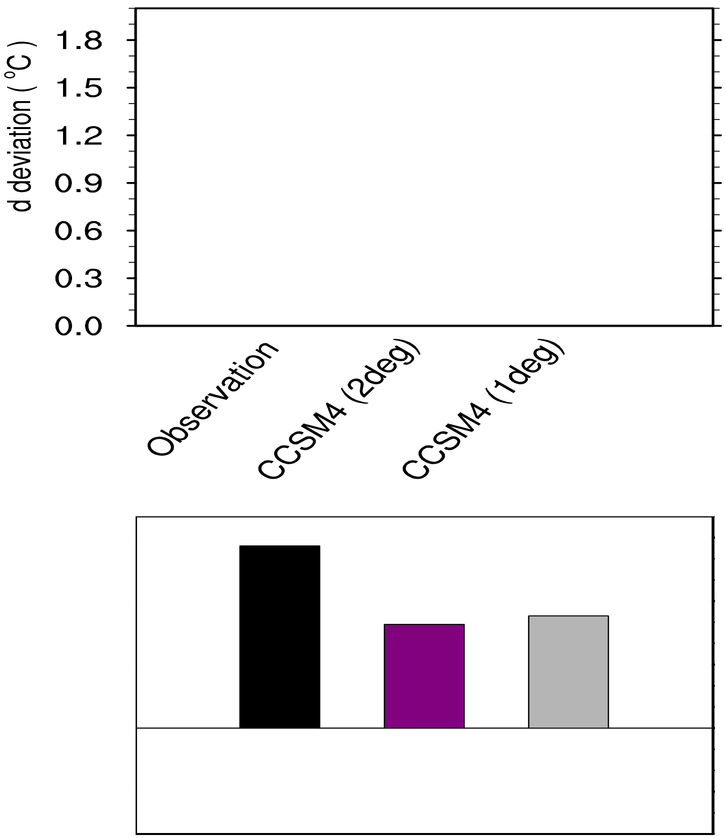
Why? The definition of asymmetricity (variance weighted skewness) can avoid the problem in the definition of skewnes that small variance can cause larger skewness. The asymmetricity results are more consistent with the composite analysis.

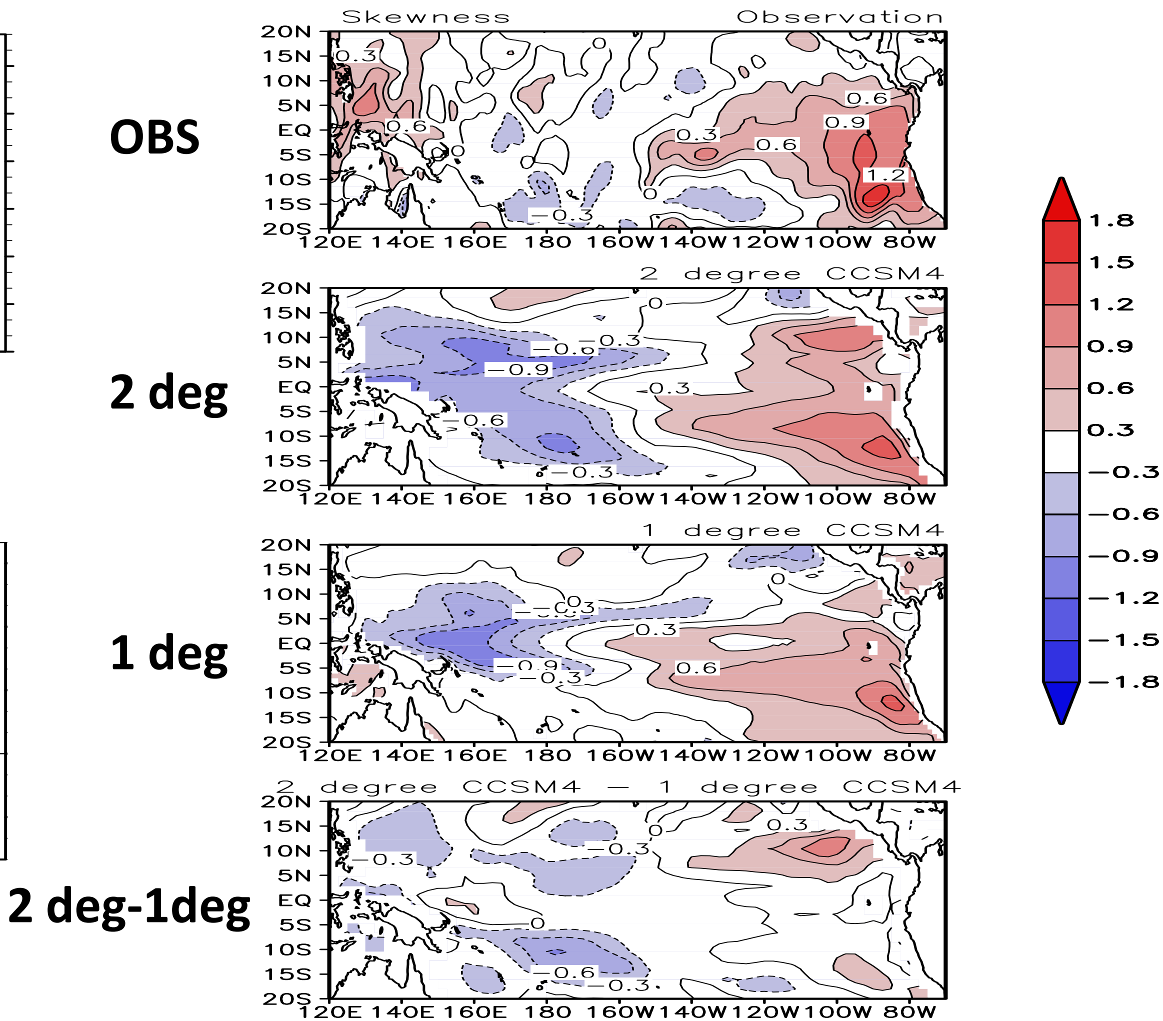
3) composite analysis of the anomaly during warm and cold periods (Zhang et al. 2009)

4) forced experiments with NCAR basin model (Sun and Zhang 2006).

5) Coupled runs from two versions (1 deg and 2 deg) of CCSM4 and corresponding AMIP runs.

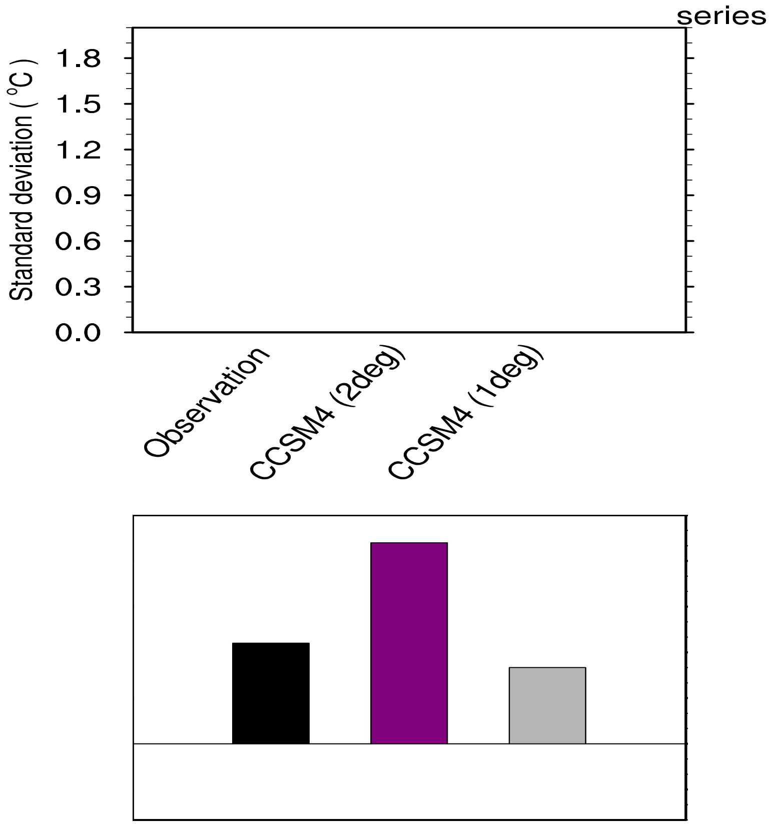
Standard deviation and Skewness of Nino3 SSTA





2 deg CCSM4 has a much larger variability of Nino3 SSTA, but the skewness in 2 deg version is even slightly smaller than that in 1 deg version. The observed skewness is underestimated in both models.

Standard deviation and asymmetricity of Nino3 SSTA

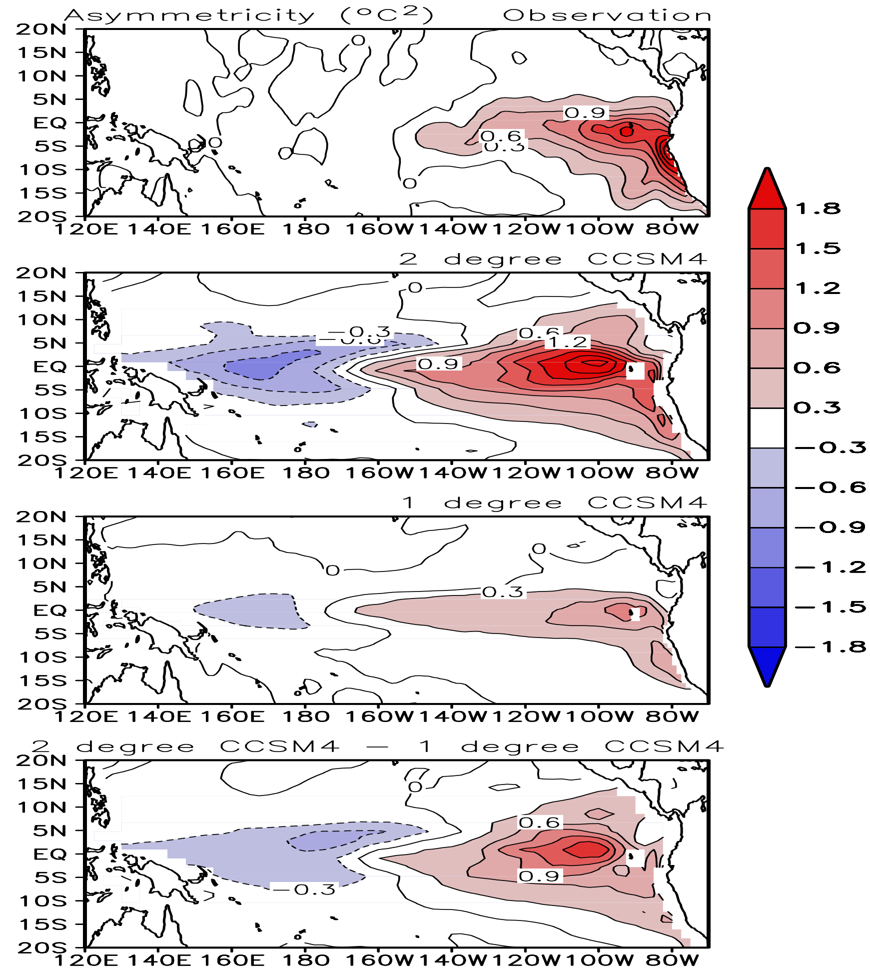


OBS

2 deg

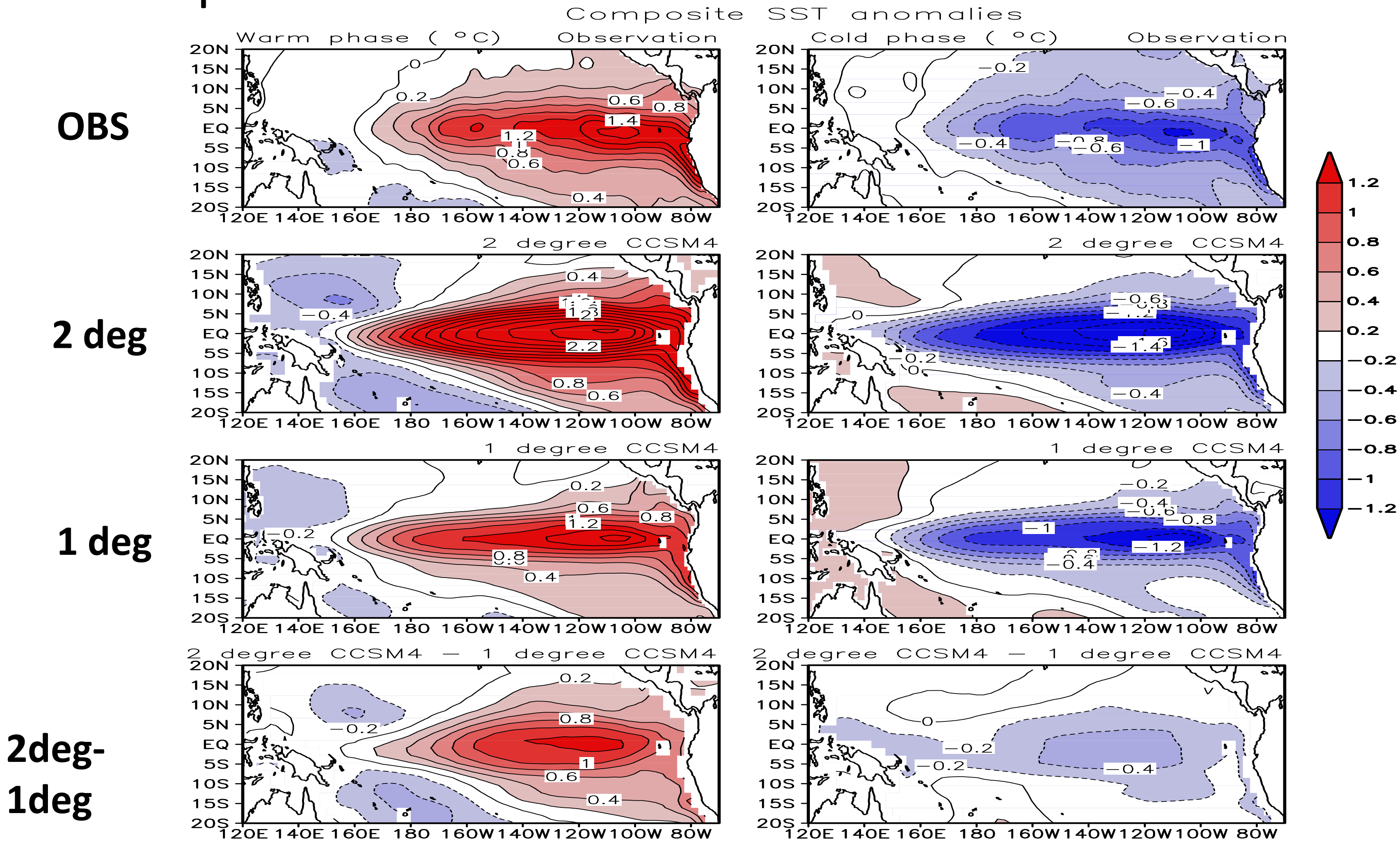
1 deg

2 deg-1deg



The definition of asymmetricity (variance weighted skewness) can avoid the problem in the definition of skewnes that small variance can cause larger skewness. The asymmetricity results are consistent with the composite analysis. 2 deg CCSM4 has a larger positive asymmetricity over eastern Pacific and a larger negative value over western Pacific, in contrast to 1 deg CCSM4.

Composite SST warm and cold anomalies from CCSM4



2 deg CCSM4 has a stronger positive SSTA than 1 deg CSM4 during warm phase, and warm bias can reach 1.2 C. The difference in cold phase is relatively small.

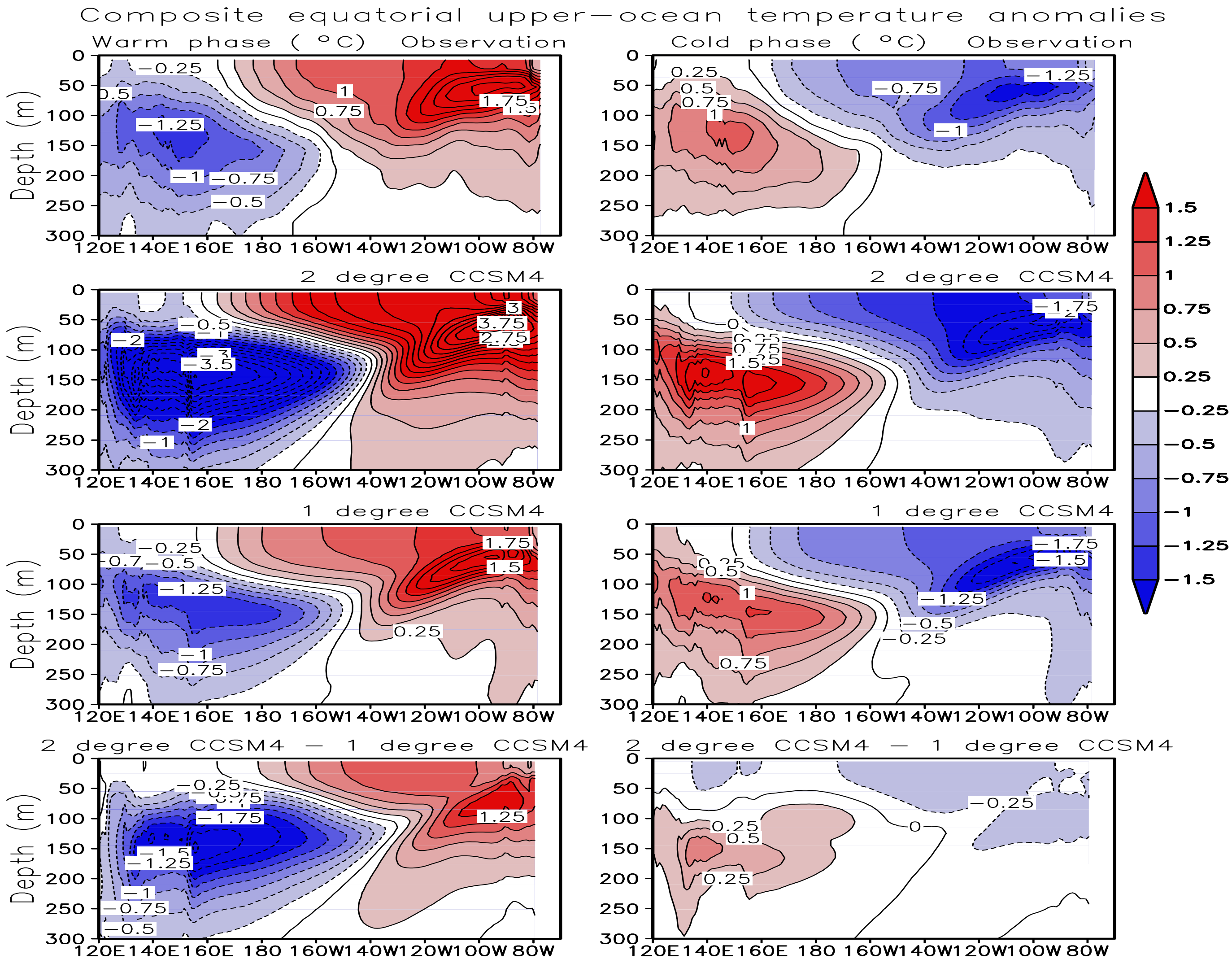
Composite subsurface temp. warm and cold anomalies from CCSM4

OBS

2 deg

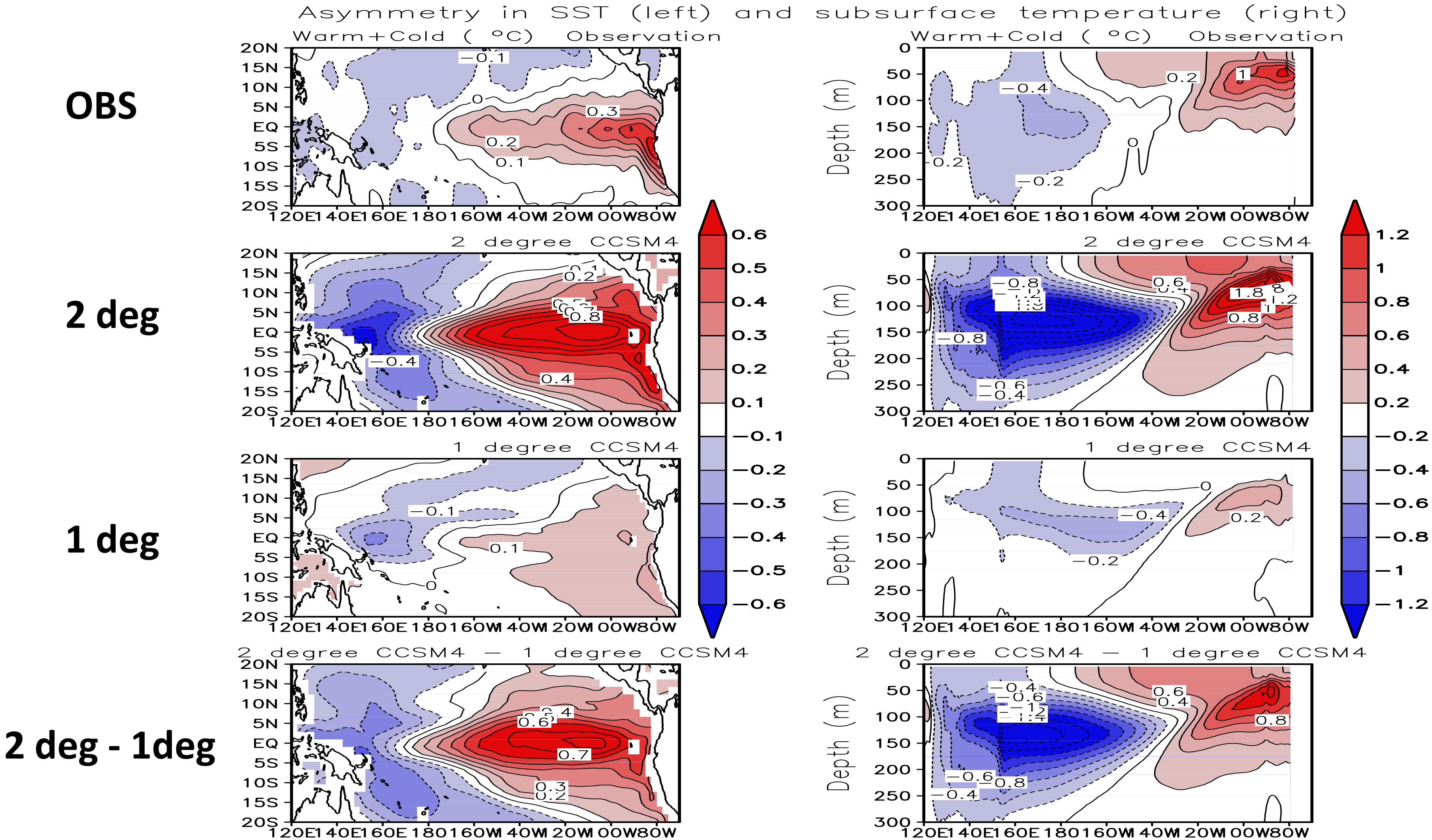
1 deg

2 deg – 1deg



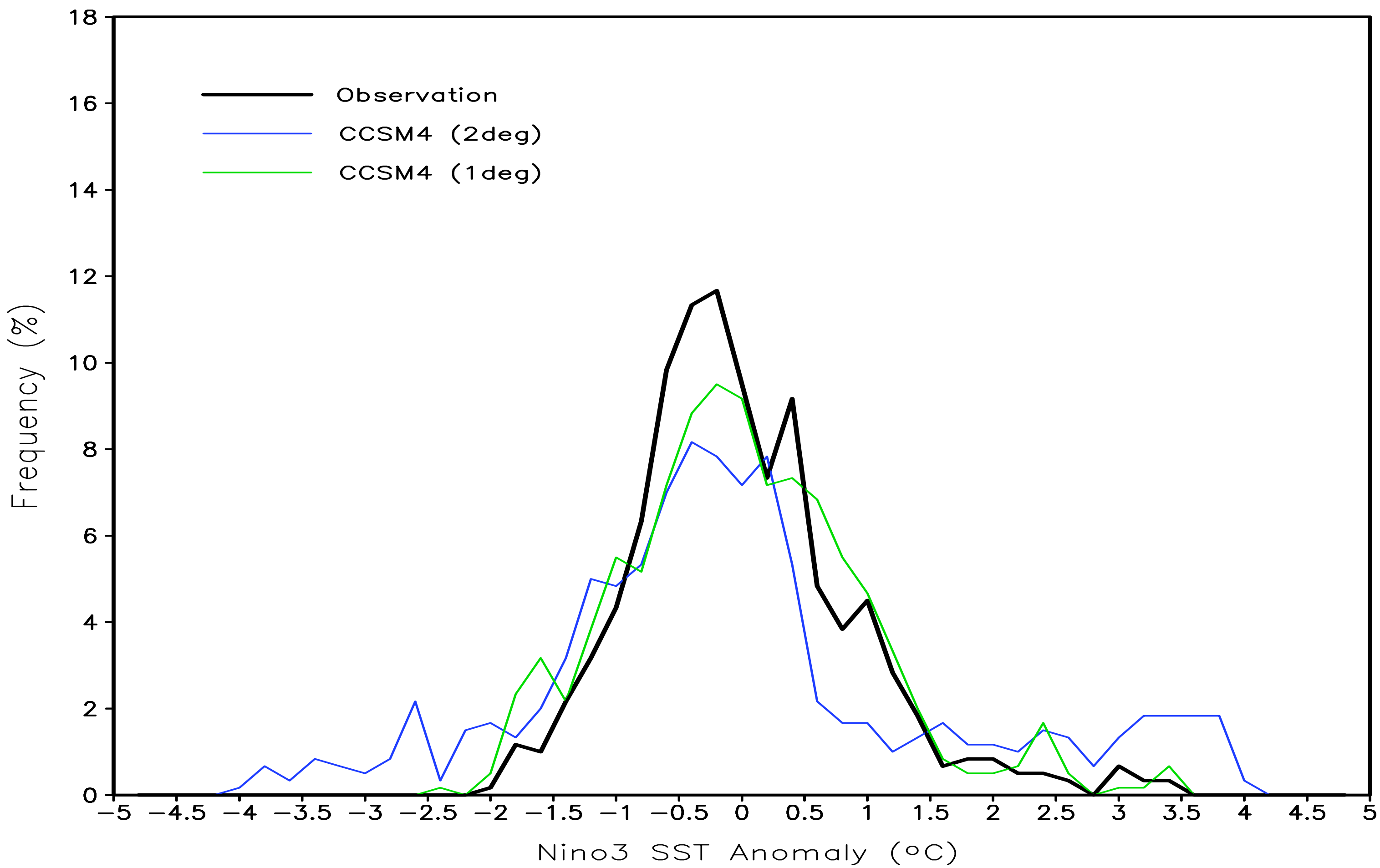
Consistent with SST bias, the bias in subsurface temp. between two versions mainly comes from the warm phase. The positive subsurface temp. anomaly over EP and negative anomaly over WP are overestimated by 1.5 C and 2 C in 2 deg CCSM4 in contrast to 1 deg version.

SST and subsurface temp. residuals (warm+cold) from CCSM4



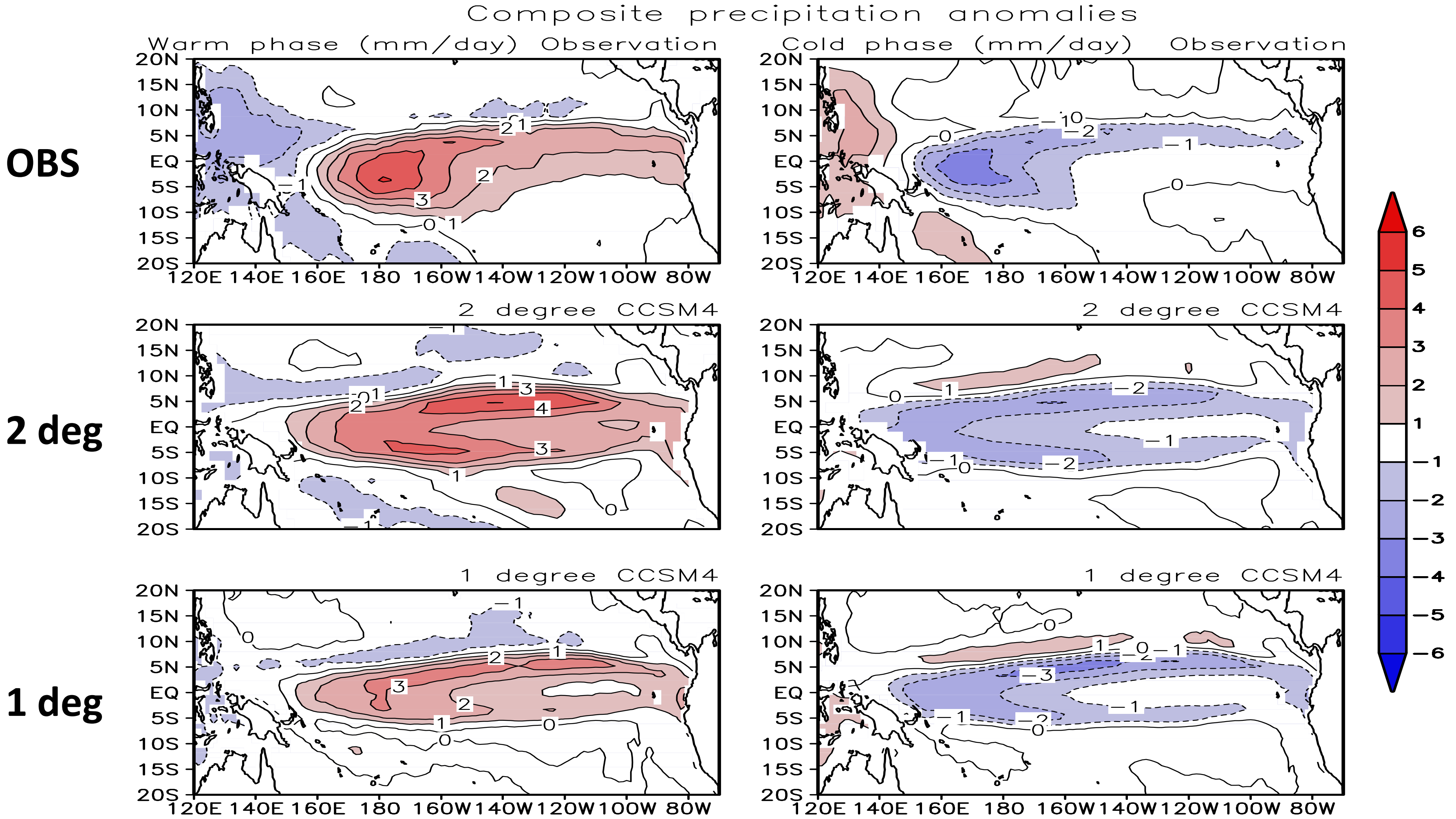
The difference in SST residual is more consistent with the difference in SST asymmetricity pattern rather than skewness pattern.

CCSM4 Nino3 SSTA PDF (Probability Distribution Function)



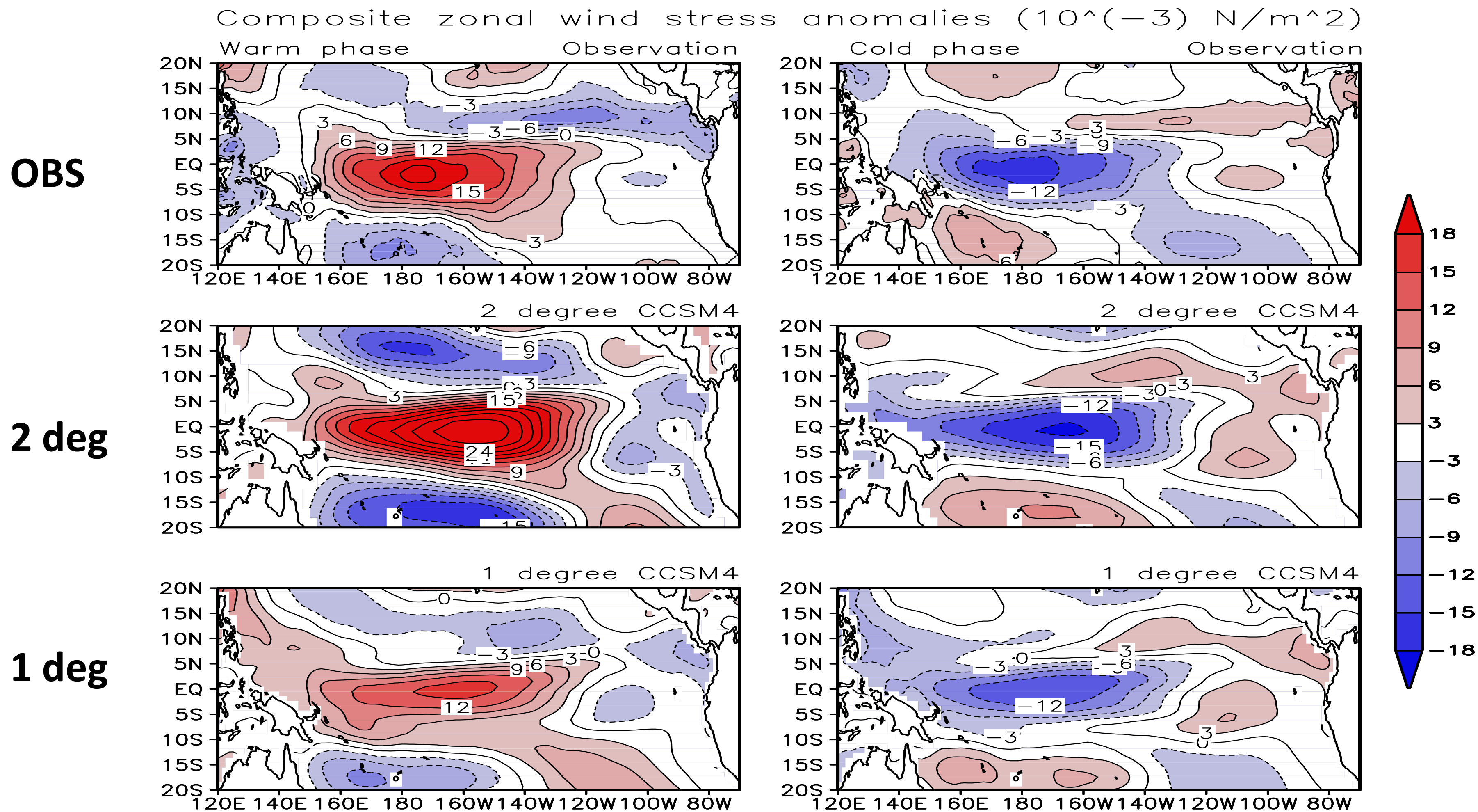
2 deg CCSM4 has a longer tail on both sides. The maximum positive (negative) anomaly can reach 4 C (-4 C) and the stronger positive anomaly is dominant. The PDF in 1 deg CCSM4 is more close to OBS in positive anomaly while negative anomaly in 1 deg is somewhat overestimated.

Composite precip. warm and cold anomalies from coupled CCSM4



Maximum positive precip. anomaly center shifts eastwards by about 30 degree in two models, and the magnitude is stronger in 2 deg CCSM4 during warm phase. There is also an eastward shift in negative precip. Center during cold phase but the difference is small between two versions.

Composite zonal wind warm and cold anomalies from coupled CCSM4



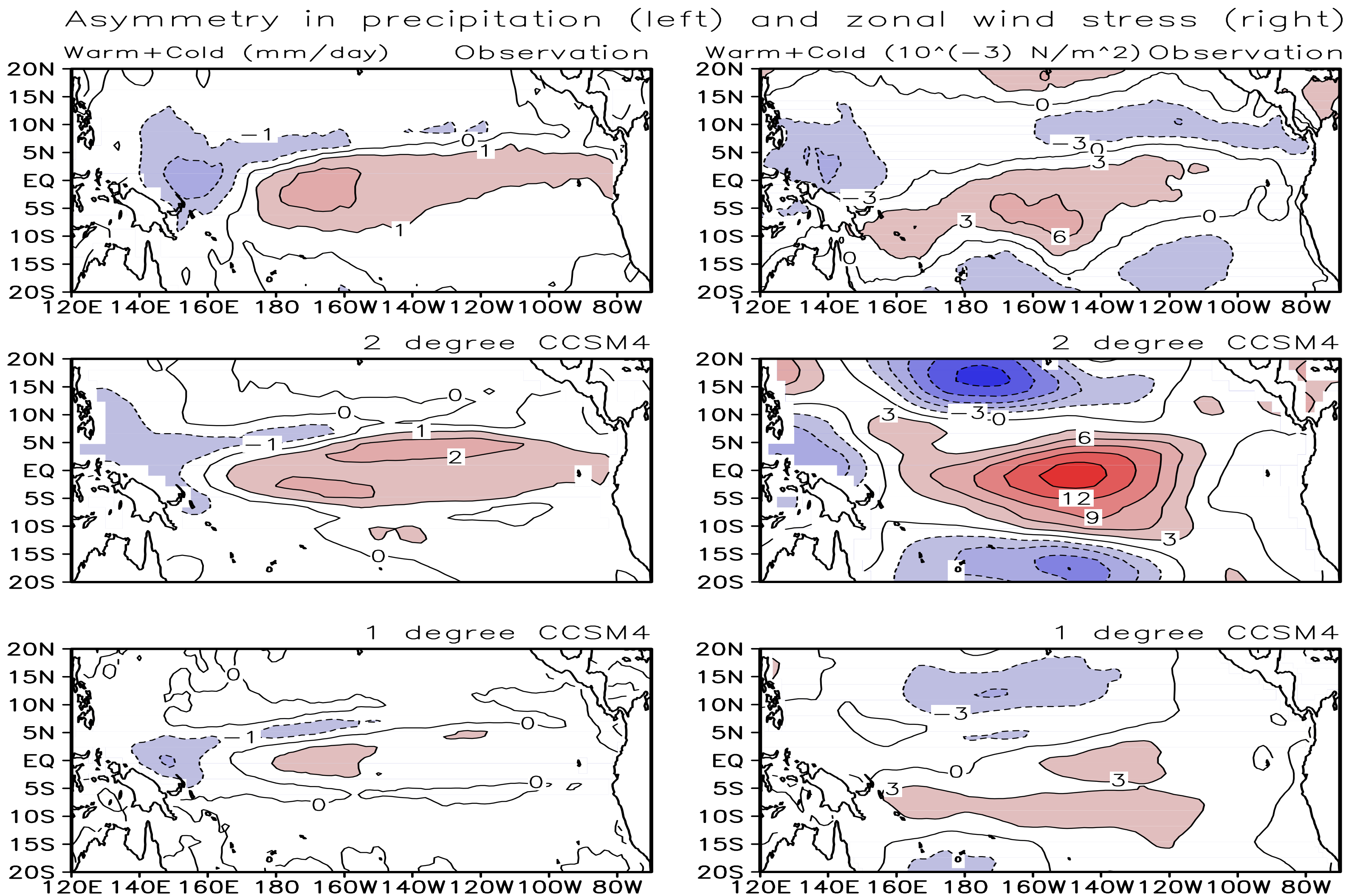
Consistent with the eastward shift in precip., the zonal wind stress also shift eastwards in two models during two phases of ENSO. The magnitude of zonal wind warm anomaly in 2 deg CCSM4 is two times as large as that in 1 deg version because of the increase in precip. over central and eastern Pacific.

Residuals in precip. and zonal wind (warm+cold) from coupled CCSM4

OBS

2 deg

1 deg



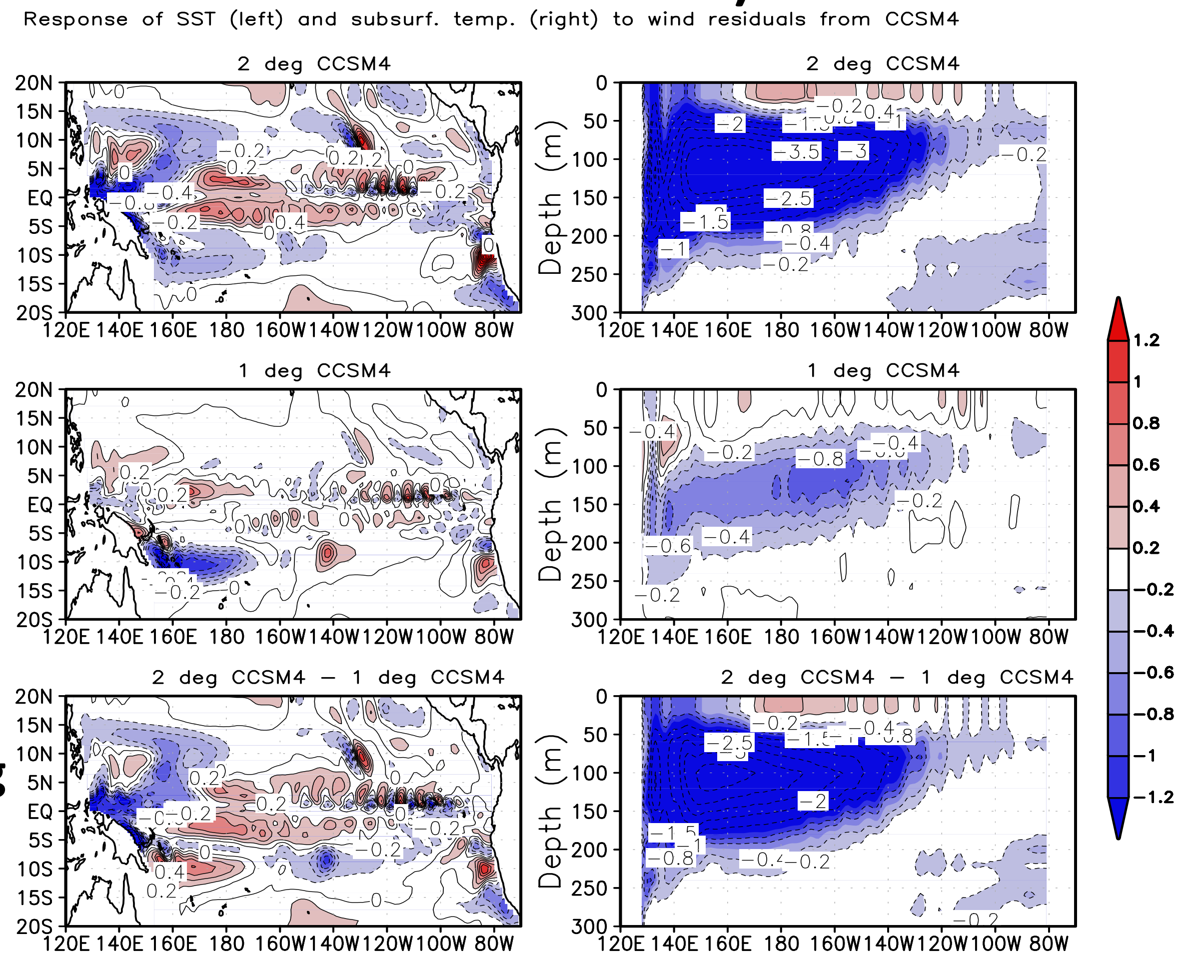
Compared to 1 deg CCSM4, 2 deg CCSM4 has a stronger asymmetry in precip. and zonal wind stress.

Response of SST and equatorial subsurface temperature to the residual winds from CCSM4 by NCAR Basin model (Sun and Zhang 2006)

2 deg

1 deg

2 deg -1deg



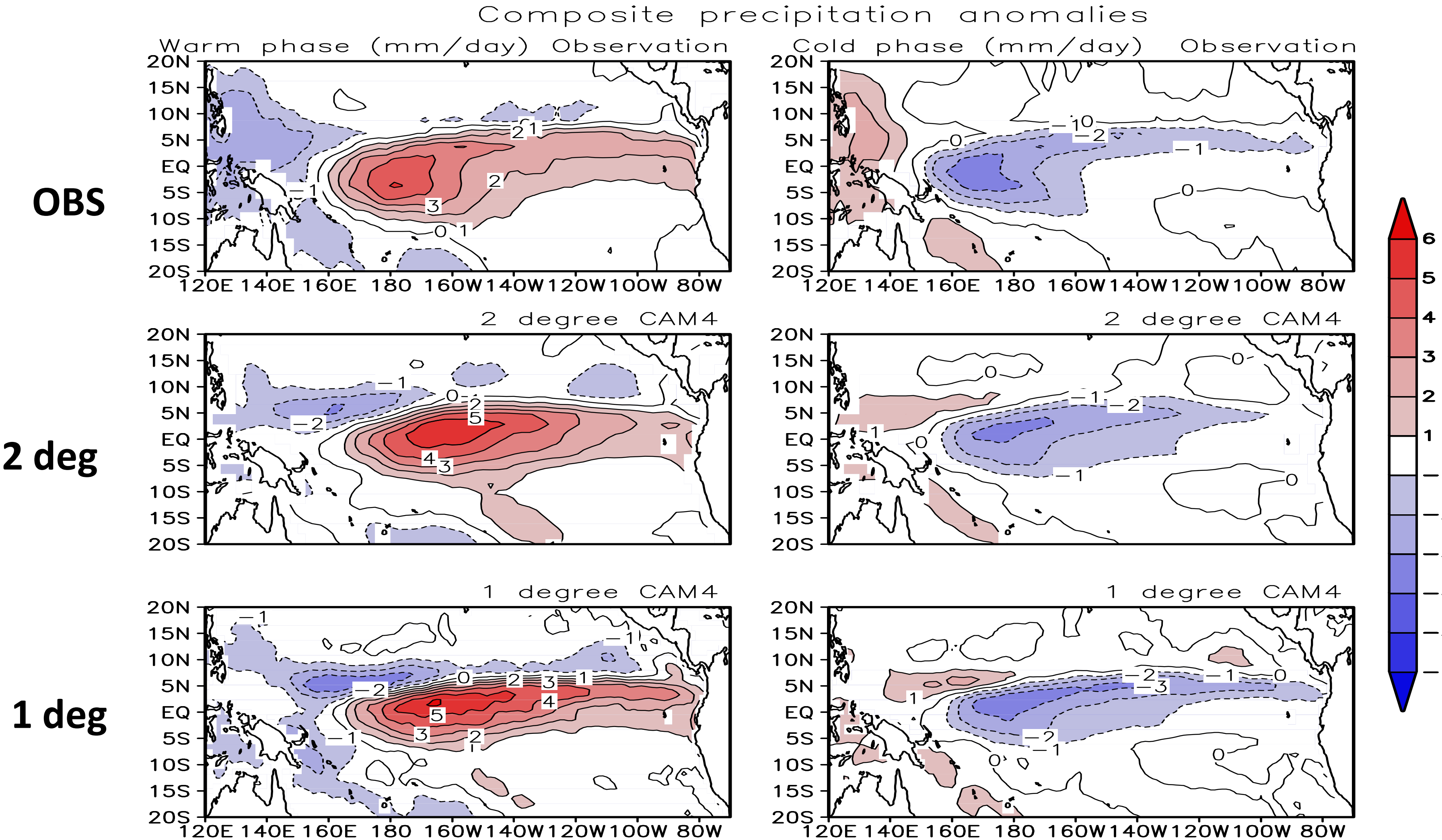
The model:
the NCAR Pacific basin model [Gent and Cane, 1989] as its ocean component.

Control run: observed annual wind stress

Perturbed run: CCSM4 wind residual + observed annual wind stress

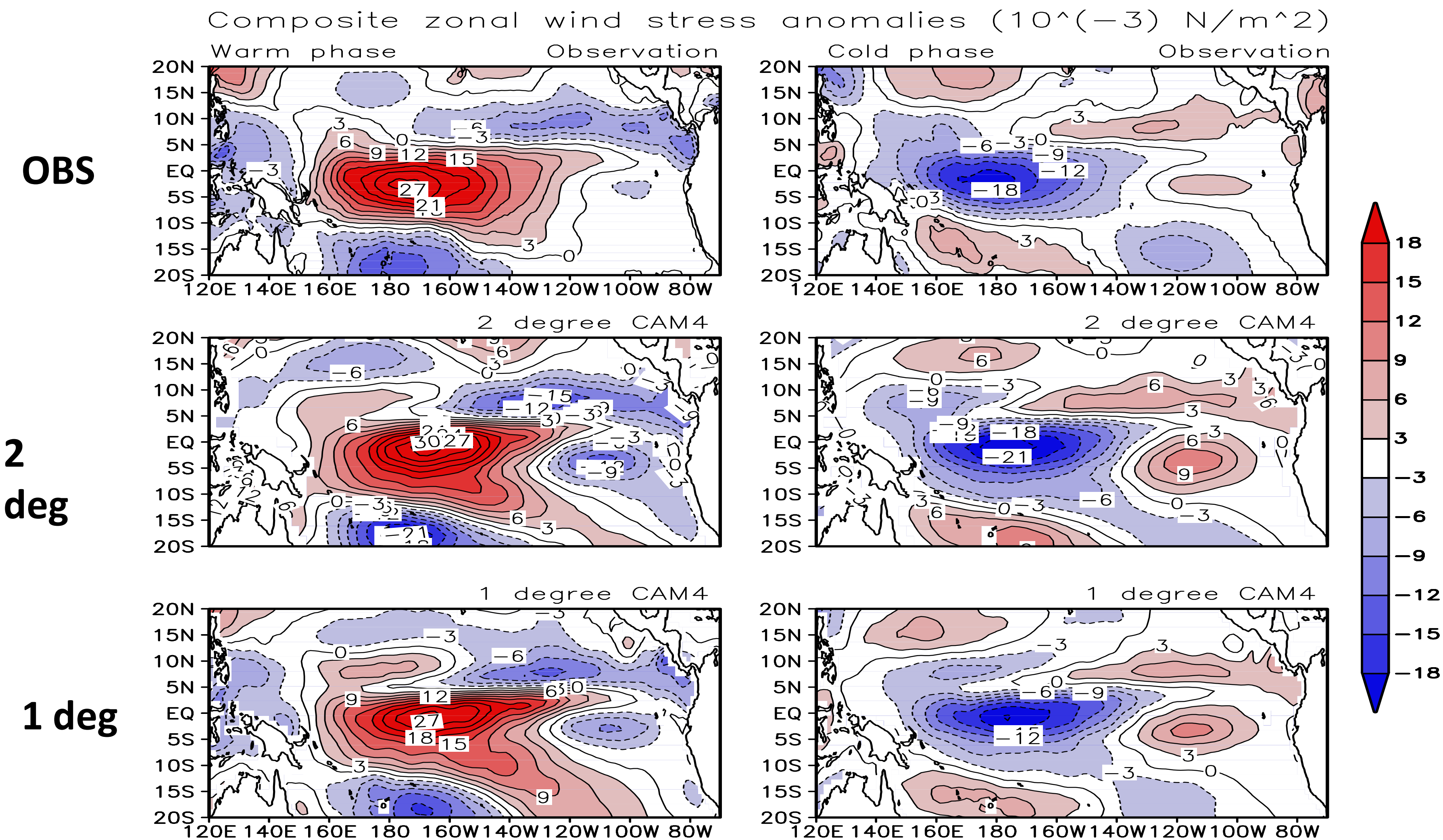
Wind residual from 2 deg CCSM4 can cause a stronger cooling over western Pacific and a stronger warming over central and eastern Pacific, similar to the residual pattern in SST and subsurface temp.

Composite precip. warm and cold anomalies from AMIP runs of CCSM4



To understand whether stronger asymmetry in precip. And winess in 2 deg CCSM4 are a consequence of the stronger asymmetry in the corresponding SST or the cause of the latter? We perform the composite analysis from AMIP runs. In general, 2 deg CCSM4 has a stronger positive precip. anomaly over the central and eastern Pacific during warm phase even forced with observed forcing. The eastward shift bias is already obvious in AMIP runs.

Composite zonal wind warm and cold anomalies from AMIP runs of CCSM4



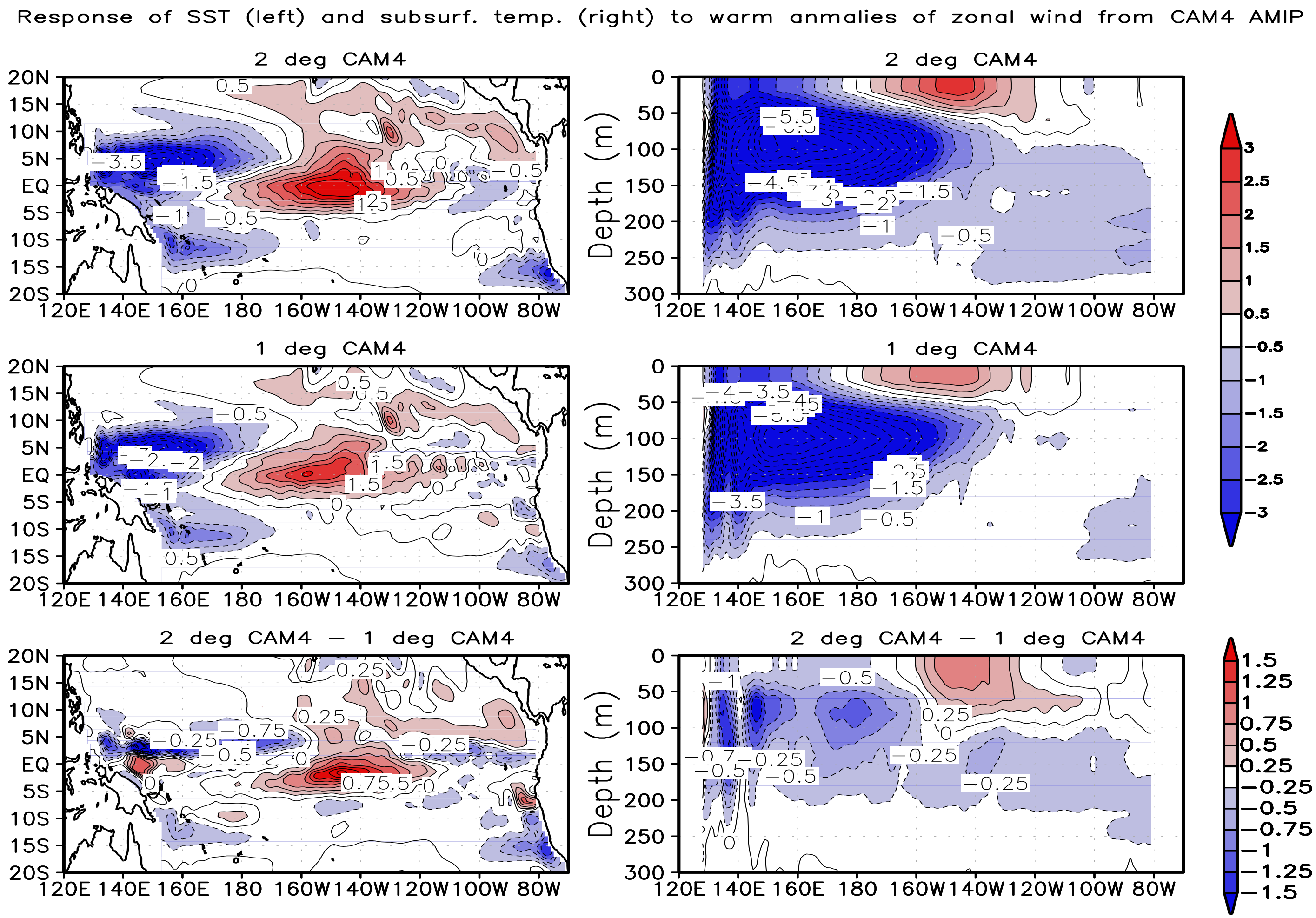
Consistent with the stronger precip. Over the central Pacific during warm phase, the positive zonal wind stress is also somewhat stronger in 2 deg CCSM4.

Response of SST (left) and subsurface temp. (right) to warm anomalies of zonal wind from CAM4 AMIP runs

2 deg

1 deg

2 deg-1deg



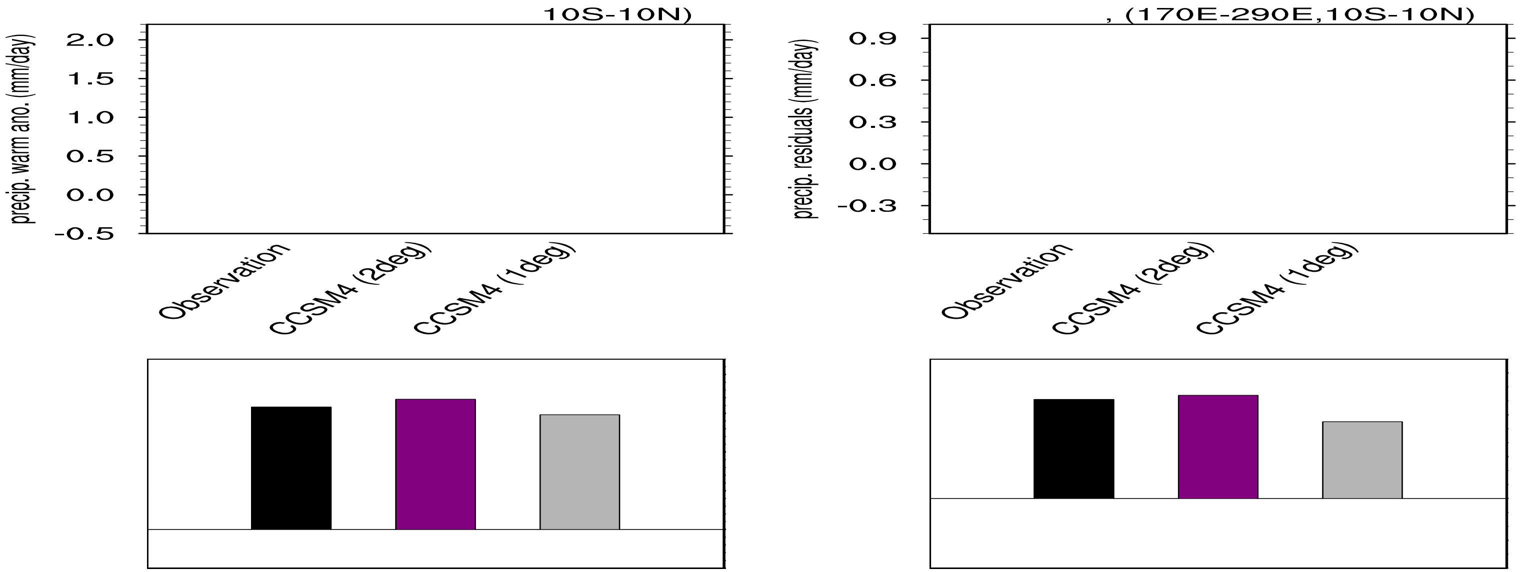
Numerical exp. Suggests that the warm bias in coupled model stems from the bias in AMIP run (about 1~1.5C) during warm phase.

Precip. warm anomalies (left panel) and residuals (right panel) over the central and eastern Pacific (170E-290E, 10S-10N)

Warm Phase | Residuals(warm+cold)

Coupled run

AMIP run



Reduction in atmospheric model resolution → Increases in Convection during warm phase in AMIP run → Increases in zonal wind stress during warm phase in AMIP run → Increases in subsurface signals during warm → Increases in warm SST anomalies → Increases in ENSO asymmetry

Summary

1) 1^o CCSM4 underestimates the observed ENSO asymmetry while 2^o CCSM4 shows a much stronger ENSO asymmetry associated with a stronger asymmetry in subsurface signals, suggesting that the increase in the horizontal resolution in the atmosphere model is found to weaken the ENSO asymmetry as noted in two CCSM4 models.

2) The examination of the corresponding AMIP runs along with the coupled runs in CCSM4 supports the previous findings of Zhang et al. (2009) that the nonlinearity in tropical convection is an important cause of the asymmetry in ENSO.

Summary (continued)

3) Specifically, mainly suffering from stronger convection over central and eastern Pacific during warm phase, the low resolution CCSM4 has a relatively larger wind anomalies during warm phase in AMIP run forced by the observed SST forcing. When coupled to the ocean, the bias in wind stress will cause a warm bias in subsurface and thus in SST. These biases will be amplified further in the coupling process through the feedbacks among SST, convection and winds.

4) Numerical experiments with forced winds support the arguments that the bias in ENSO asymmetry in CCSM4 mainly stems from the bias in convection and the associated zonal wind in the atmosphere model, especially during the warm phase.

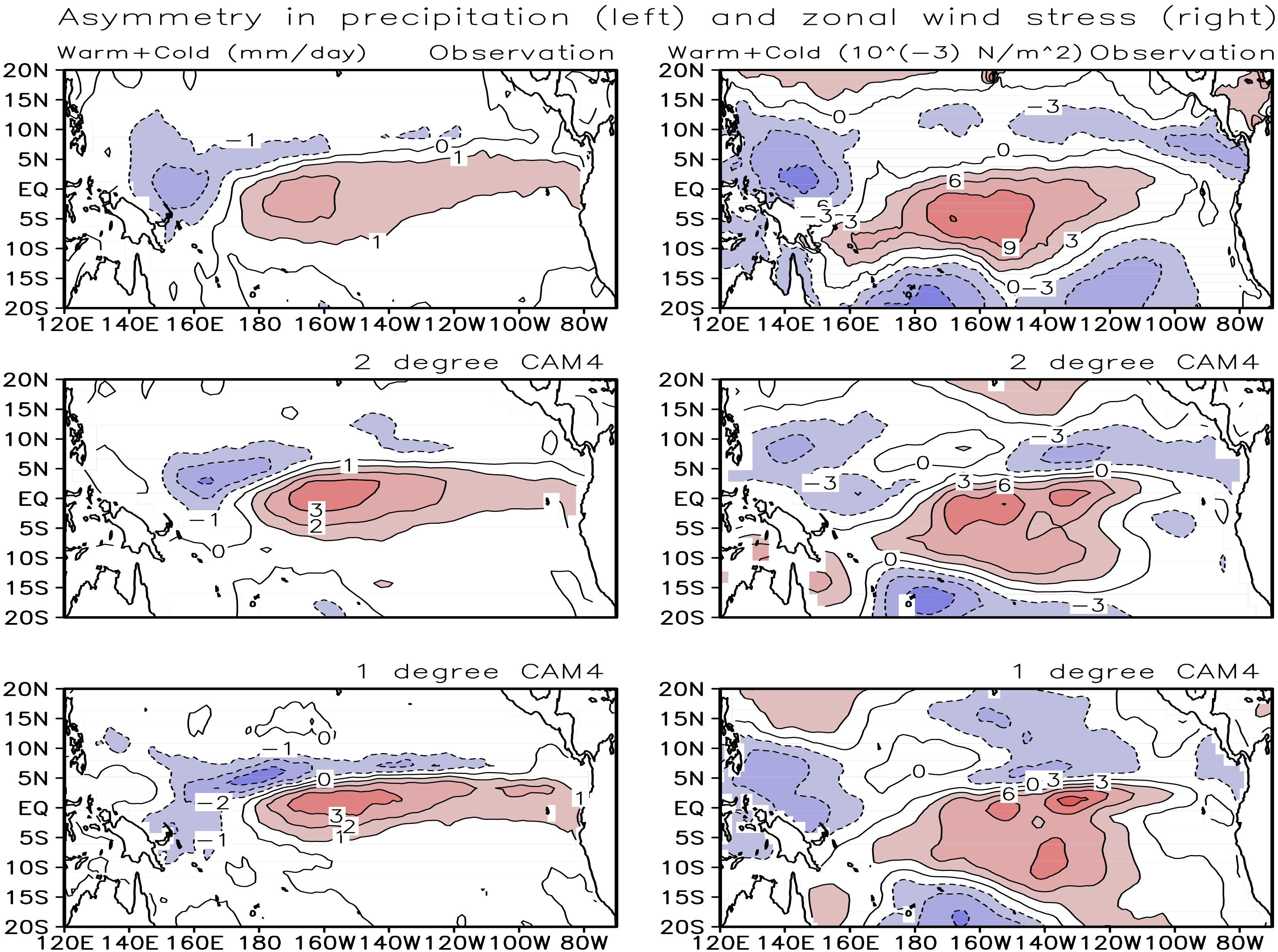
Plan to do next

1) CAM4 runs forced by symmetric SST forcing to check the nonlinearity of tropical convection and winds.

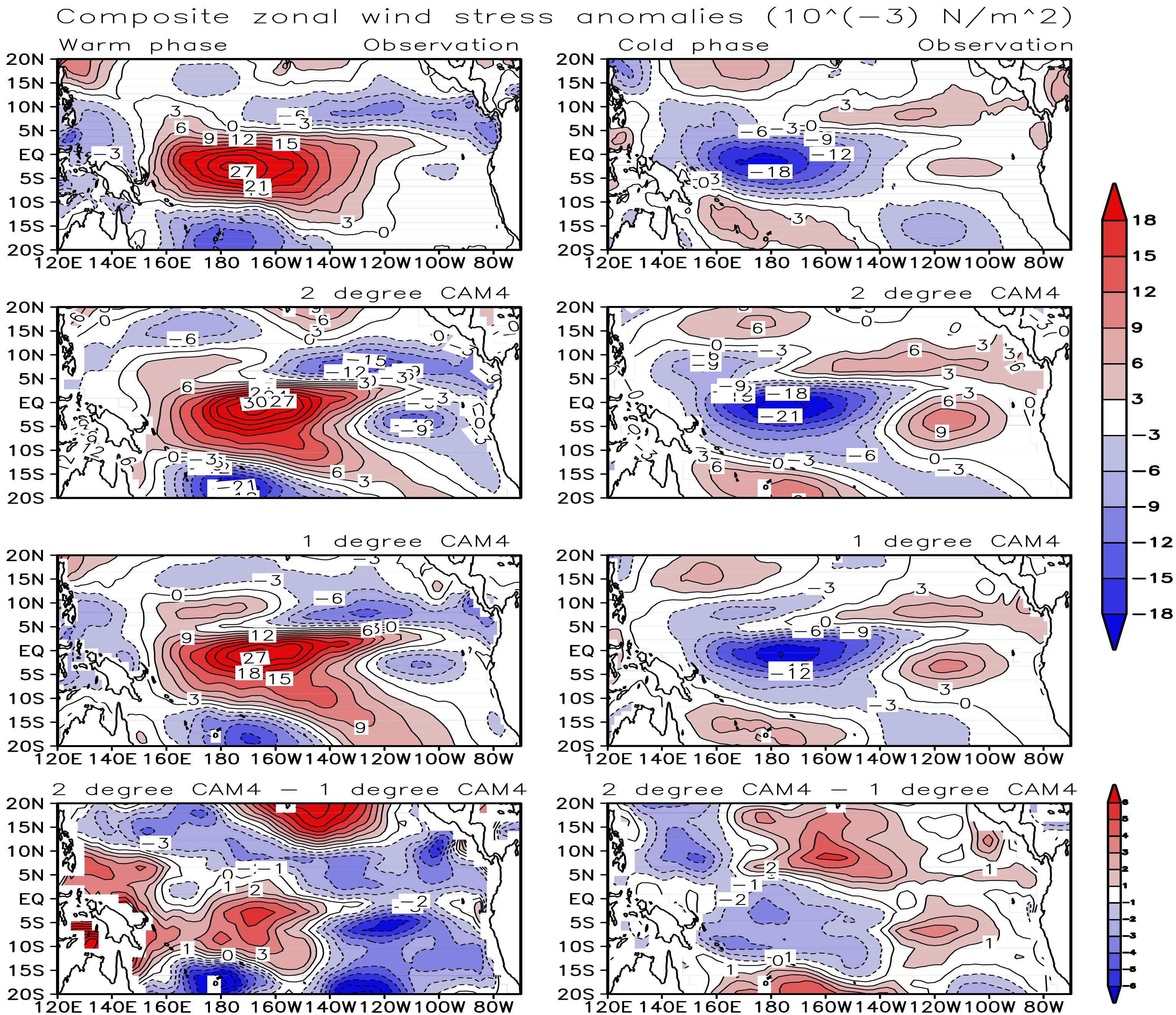
2) Using POP2 ocean model to perform the forced wind runs

3) Examination of the effect of model resolution and convection scheme on ENSO asymmetry in CESM1

Asymmetry in precip. and zonal wind (warm+cold) from AMIP runs of CCSM4



Composite zonal wind stress anomalies from AMIP runs of CCSM4



Response of SST (left) and subsurface temp. (right) to warm anomalies of zonal wind and the wind difference from CAM4 AMIP runs