Project: Nonlinearity of the Tropical Convection and the Asymmetry of the El Niño Southern Oscillation

PIs: Tao Zhang and De-Zheng Sun

Final Report

Results and Accomplishments:

(1) Participated in writing an overview paper as members of CMIP5 task force and provided material for the ENSO asymmetry subsection

As part of the CMIP5 Task Force, we participated in writing an overview paper on the simulations by CMIP5 models (Sheffield and Coauthors 2013). In particular, we contributed to the material on ENSO asymmetry. We show that an underestimate of the ENSO asymmetry remains a common bias in CMIP5 models and that a stronger variability of ENSO (measured by variance) does not guarantee a stronger ENSO asymmetry (measured by skewness) (see Figure 1).

(2) Investigating the causes of the weaker ENSO asymmetry in the CMIP5 coupled models.

The underestimate of the asymmetry also shows up in zonal wind stress, precipitation and subsurface temperature. The weaker ENSO asymmetry in the models primarily results from a weaker SST warm anomaly over the eastern Pacific and a westward shift of the center of the anomaly. In contrast, SST anomalies for the La Niña phase are close to observations.

Corresponding Atmospheric Model Intercomparison Project (AMIP) runs are analyzed to understand the causes of the underestimate of ENSO asymmetry in coupled models. The analysis reveals that during the warm phase, precipitation anomalies are weaker over the eastern Pacific, and westerly wind anomalies are confined more to the west in most models. The time-mean zonal winds are stronger over the equatorial central and eastern Pacific for most models. Wind-forced ocean GCM experiments suggest that the stronger time-mean zonal winds and weaker asymmetry in the interannual anomalies of the zonal winds in AMIP models can both be a contributing factor to a weaker ENSO asymmetry in the corresponding coupled models, but the former appears to be a more fundamental factor, possibly through its impact on the mean state (see Table 1). The study suggests that the underestimate of ENSO asymmetry in the CMIP5 coupled models is at least in part of atmospheric origin.

A paper summarizing the above results has been published by J. Climate (Zhang and Sun 2014).

(3) Exploring the physics responsible for the observed stronger asymmetry in ENSO teleconnections

A large asymmetric component (El Niño + La Niña) of El Niño–Southern Oscillation (ENSO)-related teleconnections over North America is found during 1984–2009 that is comparable in strength to the commonly studied symmetric component (El Niño – La Niña). Climate reforecasts spanning this period are diagnosed in order to understand the processes responsible for the observed asymmetry. It is confirmed that an asymmetric component is indeed a fundamental property of atmospheric responses to recent ENSO forcing. Each and every composite of a 16-member reforecast ensemble has appreciable asymmetry in tropical Pacific rainfall, upper tropospheric Pacific-North American circulation patterns, and contiguous U.S. surface temperatures. There is considerable sampling variability in the magnitude of this asymmetric component among individual reforecast composites (Figure 2). We argue therefore that the true sea surface temperature boundary-forced signal of ENSO teleconnections is likely composed of a symmetric component having greater magnitude than its asymmetric component, though the latter is an important property of how ENSO affects North American climate.

A paper summarizing the above results has been published by GRL (Zhang et al. 2014).

4) Rectification of El Nino-Southern Oscillation into Climate Anomalies of Decadal and Longer Time-Scales

To better understand the causes of climate change in the tropical Pacific on the decadal and longer time scales, the rectification effect of ENSO events is delineated by contrasting the time-mean state of two forced ocean GCM experiments. In one of them, the long-term mean surface wind stress of 1950–2011 is applied, while in the other, the surface wind stress used is the long-term mean surface wind stress of 1950–2011 plus the interannual monthly anomalies over the period. Thus, the long-term means of the surface wind stress in the two runs are identical. The two experiments also use the same relaxation boundary conditions, that is, the SST is restored to the same prescribed values. The two runs, however, are found to yield significantly different mean climate for the tropical Pacific. The mean state of the run with interannual fluctuations in the surface winds is found to have a cooler warm pool, warmer thermocline water, and warmer eastern surface Pacific than the run without interannual fluctuations in the surface winds.

The warming of the eastern Pacific has a pattern that resembles the observed decadal warming. In particular, the pattern features an off-equator maximum as the observed decadal warming. The spatial pattern of the time-mean upper-ocean temperature differences between the two experiments is shown to resemble that of the differences in the nonlinear dynamic heating, underscoring the role of the nonlinear ocean dynamics in the rectification. The study strengthens the suggestion that rectification of ENSO can be a viable mechanism for climate change of decadal and longer time scales.

A paper summarizing the above results has been published by J. Climate (Sun et al. 2014)

5) Assessing water vapor and cloud feedbacks during the ENSO cycle in CMIP5 models.

Previous evaluations of model simulations of the cloud and water vapor feedbacks in response to El Niño warming have singled out two common biases in the Phase 3 of Coupled Model Inter-comparison Project (CMIP3) models: an underestimate of the negative feedback from the shortwave radiation forcing of clouds (SWCRF) and an overestimate of the positive feedback from the greenhouse effect of water vapor. Here we check whether these two biases are alleviated in the Phase 5 of Coupled Model Inter-comparison Project (CMIP5) models. While encouraging improvements are found, particularly in the simulation of the negative SWCRF feedback, the biases in the simulation of these two feedbacks remain prevalent and significant. It is shown that bias in the SWCRF feedback correlates well with biases in the corresponding feedbacks from precipitation, large-scale circulation and long-wave radiation forcing of clouds (LWCRF). By dividing CMIP5 models into two categories—high score models (HSM) and low score models (LSM)—based on their individual skills of simulating the SWCRF feedback, we further find that ocean-atmosphere coupling generally lowers the score of the simulated feedbacks of water vapor and clouds, but the LSM is more affected by the coupling than the HSM. We also find that the SWCRF feedback is simulated better in the models that have a more realistic zonal extent of the equatorial cold tongue, suggesting that the continuing existence of an excessive cold tongue is a key factor behind the persistence of the feedback biases in models.

A paper summarizing the above results has been published in J. Climate and will appear in the special issue with the overview paper by the CMIP5 task force (Chen et al. 2013).

Highlights of Accomplishments

- Underestimate of the ENSO asymmetry has been found to be a common bias in the CMIP5 models.

- Analysis of the AMIP runs of these coupled models trace the error to the atmospheric origins—in particular the mean tropical winds. Forced ocean GCM experiments show that biases in the AMIP total winds can cause a weaker ENSO asymmetry.

- The study utilizing the large ensemble of the retrospective forecasts from the Climate Forecast System (CFS) version 2 (CFSRR) revealed that the asymmetry in ENSO teleconnections is a robust feature of atmospheric responses to recent ENSO. Strong observed asymmetry in ENSO teleconnections is from sampling variability. True ENSO symmetric component is likely greater than asymmetric component.

- Forced ocean GCM experiments have delineated the spatial pattern of the time-mean effect of ENSO. The pattern is found to have significant differences from the asymmetry pattern of ENSO.

- Cloud and water vapor feedbacks during ENSO cycle in the CMIP5 models have significant improvements than in the CMIP3 models, but the underestimate of the cloud albedo feedback and the overestimate of the water vapor greenhouse effect feedback remain to be a common problem.

Publications from the Project:

Chen, L., Y. Yu, and D.-Z. Sun, 2013: Cloud and Water Vapor Feedbacks To El Nino Warming: Are They Still Biased in CMIP5 Models? *J. Climate*, **26**, 4947–4961.

Sheffield, J., S.J. Camargo, R. Fu, Q. Hu, X. Jiang, N. Johnson, K.B. Karnauskas, J. Kinter, S. Kumar, B. Langenbrunner, E. Maloney, A.a Mariotti, J. E. Meyerson, D. Neelin, Z. Pan, A. Ruiz-Barradas, R Seager; Y. L Serra, D.-Z. Sun, C. Wang, S.-P. Xie, J.Y. Yu, T. Zhang, M. Zhao, 2013: North American Climate in CMIP5 Experiments. Part II: Evaluation of Historical Simulations of Intraseasonal to Decadal Variability. *J. Climate*, **26**, 9247–9290.

Sun, D.-Z., T. Zhang, Y. Sun, and Y. Yu, 2014: Rectification of El Nino-Southern Oscillation into Climate Anomalies of Decadal and Longer Time-scales: Results From Forced Ocean GCM Experiments. *J. Climate*, **27**, 2545-2561, doi:10.1175/JCLI-D-13-00390.1.

Zhang, T., and D.-Z. Sun, 2014: ENSO Asymmetry in CMIP5 Models. *J. Climate*, **27**, 4070-4093, doi:10.1175/JCLI-D-13-00454.1.

Zhang, T., J. Perlwitz, and M. P. Hoerling, 2014: What is Responsible for the Strong Observed Asymmetry in Teleconnections Between El Nino and La Nina? *Geophys. Res. Lett.*, **41**, 1019-1025, doi:10.1002/2013GL058964.

PIs Contact Information

Lead PI:
Tao Zhang, NOAA/ESRL/PSD, 325 Broadway, R/PSD1, Boulder, CO 80305. Phone: 303-497-4340, email: tao.zhang@noaa.gov
CO-PI:
De-Zheng Sun, NOAA/ESRL/PSD, 325 Broadway, R/PSD1, Boulder, CO 80305. Phone: 303-497-6272, email: Dezheng.Sun@noaa.gov

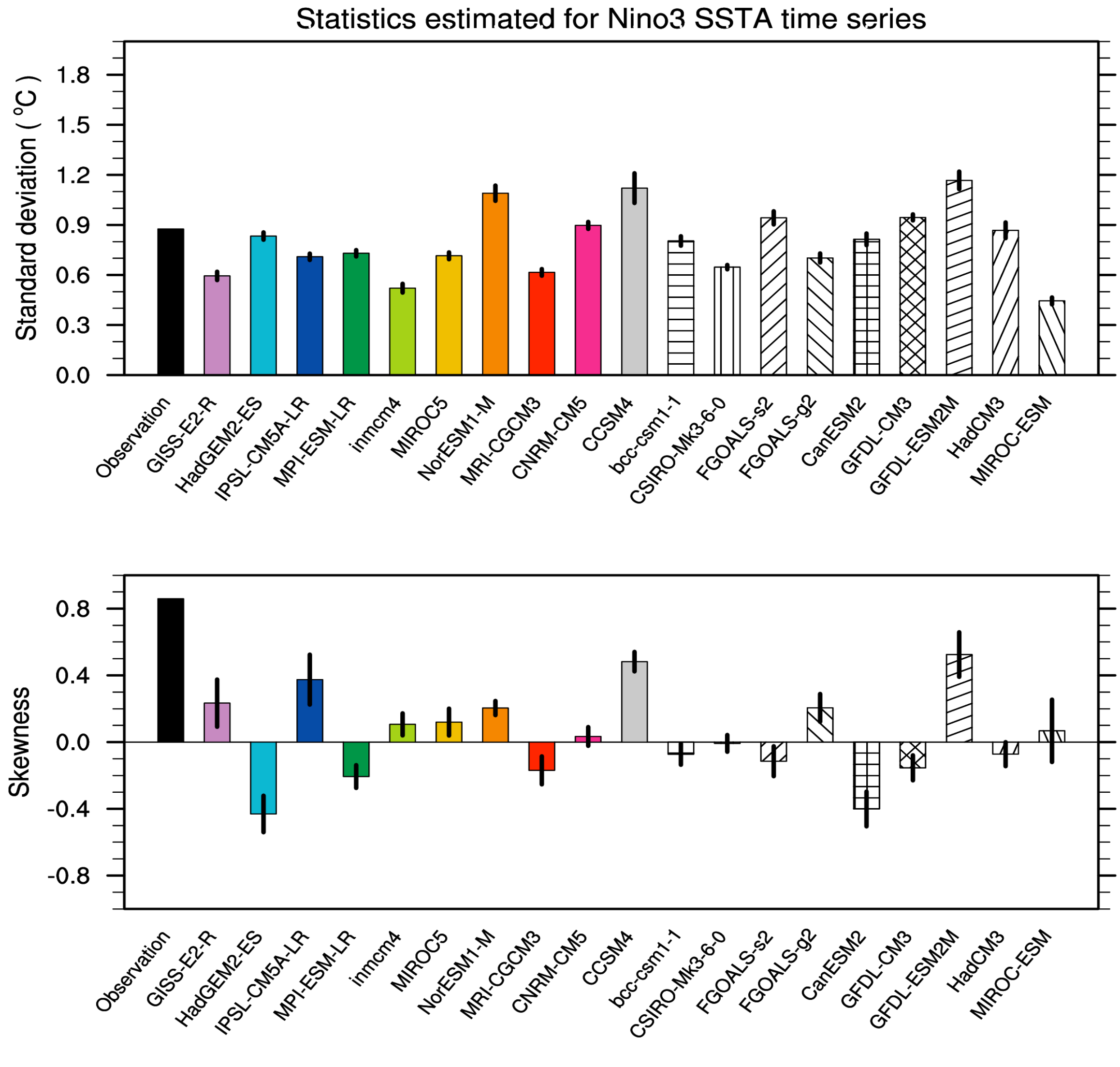

Figure 1: The (top) standard deviation and (bottom) skewness of monthly Niño-3 SST anomalies from observations and CMIP5 model simulations. The length of data for computing the standard deviation and skewness is 50 yr for the observations (1950–99). For the model, the standard deviation and skewness were calculated for a 50-yr moving window over 100 yr of the model run for a total of 601 samples. The figure shows the mean of the samples and the standard deviation across the samples.

Table 1: Standard deviation and skewness of the interannual variability in Niño-3 SST from forced ocean model experiments. The mean as well as the anomaly part of the surface winds used in these experiments are listed.

Experiment ID (label in figures)	Surface wind stress		Statistics of Nino3 SSTA	
	Climatology	Anomaly	Skewness	Standard deviation(^{0}C)
Experiment I	Observation	Observation	1.16	0.75
Experiment II	CMIP5 amip ensemble	Observation	0.92	0.73
Experiment III	CMIP5 amip ensemble	CMIP5 amip ensemble	0.70	0.63
Experiment IV	Observation	CMIP5 amip ensemble	1.18	0.64

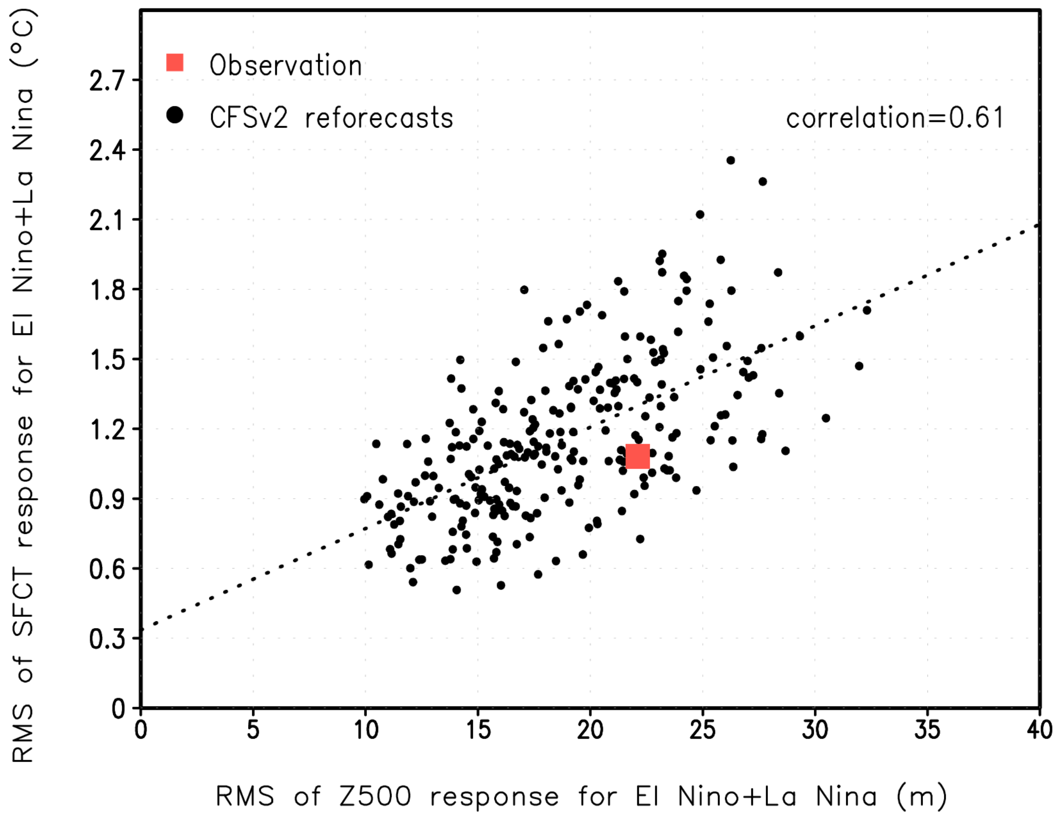

Figure 2: The relationship between the root mean square (RMS) of the asymmetry in DJF 500 hPa height over the Pacific-North America region (120°E-60°W, 30°N-75°N) and the root mean square of the asymmetry in DJF land surface temperature over the North America (130°W-60°W, 20°N-60°N). The closed circles correspond to 256 members of the CFSv2 reforecasts. The observational values are indicated by the red square. Inset value is for the correlation based on 256-member CFSv2 reforecasts.