Final Progress Report

Using ARM Measurements to Understand and Reduce the Double ITCZ Biases in the Community Atmospheric Model (ER65442-0018467)

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Under the support of this grant, we have made progress in two areas of research about the Intertropical Convergence Zone (ITCZ) in the equatorial eastern Pacific. One is in the understanding of the observed ITCZ variability in the eastern equatorial Pacific. The other is in the understanding of double ITCZ in climate models and improvement of parametrerization schemes.

1. Understanding of the observed variability of ITCZ in the equatorial eastern Pacific.

The annual mean precipitation in the eastern Pacific has a maximum zonal band north of the equator in the ITCZ where the maximum SST is located. During the boreal spring (referring to February, March, and April throughout the present paper), because of the accumulated solar radiation heating and oceanic heat transport, a secondary maximum of SST exists in the southeastern equatorial Pacific. Associated with this warm SST is also a seasonal transitional maximum of precipitation in the same region in boreal spring, exhibited as a weak double ITCZ pattern in the equatorial eastern Pacific. This climatological seasonal variation, however, varies greatly from year to year: double ITCZ in the boreal spring occurs in some years but not in other years; when there a single ITCZ, it can appear either north, south or at the equator. Understanding this observed variability is critical to find the ultimate cause of the double ITCZ in climate models.

<u>Seasonal variation of ITCZ south of the eastern equatorial Pacific</u>

By analyzing data from satellites, field measurements and atmospheric reanalysis, we have found that in the region where spurious ITCZ in models occurs, there is a "seasonal cloud transition" — from stratocumulus to shallow cumulus and eventually to deep convection —in the South Equatorial Pacific (SEP) from September to April that is similar to the spatial cloud transition from the California coast to the equator. This seasonal transition is associated with increasing sea surface temperature (SST), decreasing lower tropospheric stability and large-scale subsidence. This finding of seasonal cloud transition points to the same source of model errors in the ITCZ simulations as in simulation of stratocumulus-cumulus-deep convection transition. It provides a test for climate models to simulate the relationships between clouds and large-scale atmospheric fields in a region that features a spurious double Inter-tropical Convergence Zone (ITCZ) in most models. This work is recently published in Yu et al. (2016):

Yu, H., Zhang, M., Lin, W. and Zhang, X. (2016), Cloud transitions: comparison of temporal variation in the southeastern Pacific with the spatial variation in the northeastern Pacific at low latitudes. Int. J. Climatol.. doi:10.1002/joc.4889

Interannual variation of ITCZ south of the eastern equatorial Pacific

By analyzing data from satellites, field measurements and atmospheric reanalysis, we have characterized the interannual variation of boreal spring precipitation in the eastern tropical Pacific and found the cause of the observed interannual variability. We have shown that ITCZ in this region can occur as a single ITCZ along the Equator, single ITCZ north of the Equator, single ITCZ south of the Equator, and double ITCZ on both sides of the Equator. We have found that convective instability only plays a secondary role in the ITCZ interannual variability. Instead, the remote impact of the Pacific basin-wide SST on the horizontal gradient of surface pressure and wind convergence is the primary driver of this interannual variability. Results point to the need to include moisture convergence in convection schemes to improve the simulation of precipitation in the eastern tropical Pacific. This result has been recently submitted for publication (Yu and Zhang 2016):

Yu, Haiyang and Minghua Zhang, 2016: Explaining the Hemispheric Asymmetry in the Interannual Variation of ITCZ over the Eastern Pacific. Submitted.

2. Improvement of model parameterizations to reduce the double ITCZ bias

We analyzed the current status of climate model performance in simulating precipitation in the equatorial Pacific. We have found that the double ITCZ bias has not been reduced in CMIP5 models relative to CMIP4 models. We have characterized the dynamic structure of the common bias by using precipitation, sea surface temperature, surface winds and sea-level. Results are published in Zhang et al. (2015):

Zhang, X., H. Liu, and M. Zhang (2015), Double ITCZ in Coupled Ocean-Atmosphere Models: From CMIP3 to CMIP5, Geophys. Res. Lett., 42, 8651–8659, doi:10.1002/2015GL065973.

Since cumulus convection plays a significant role in the double ITCZ behavior in models, we have used measurements from ARM and other sources to carry out a systematic analysis of the roles of shallow and deep convection in the CAM. We found that in both CAM4 and CAM5, when the intensity of deep convection decreases as a result of parameterization change, the intensity of shallow convection increases, leading to very different changes in precipitation partitions but little change in the total precipitation. The different precipitation partition however can manifest themselves in other measures of model performances including temperature and humidity. This study points to the need to treat model physical parameterizations as integrated system rather than individual components. Results from this study are published in Wang and Zhang (2013):

Wang, Xiaocong and Minghua Zhang, 2013: An analysis of parameterization interactions and sensitivity of single-column model simulations to convection schemes in CAM4 and CAM5. J. Geophys. Res., DOI: 10.1002/jgrd.50690.

Since shallow convection interacts with the deep convection scheme and surface turbulence to trigger the double ITCZ, we studied methods to improve the shallow convection scheme in climate models. We investigated the bulk budgets of the vertical velocity and its parameterization in convective cores, convective updrafts, and clouds by using large-eddy simulation (LES) of four shallow convection cases including one from ARM. We proposed optimal forms of the Simpson and Wiggert equation to calculate the vertical velocity in bulk mass flux convection schemes for convective cores, convective updrafts, and convective clouds as parameterization schemes. The new scheme is published in Wang and Zhang (2014):

Wang, X., and M. Zhang (2014), Vertical velocity in shallow convection for different plume types, J. Adv. Model. Earth Syst., 06, doi:10.1002/2014MS000318.

By using long-term radar-based ground measurements from ARM, we derived a scale-aware inhomogeneity parameterization of cloud liquid water in climate models. We found a relationship between the inhomogeneity parameter and the model grid size as well as atmospheric stability. This relationship is implemented in the CESM to describe the subgrid-scale cloud inhomogeneity. Relative to the default CESM with the finite-volume dynamic core at 2-degree resolution, the new parameterization leads to smaller cloud inhomogeneity and larger cloud liquid-water path in high latitudes, and the opposite effect in low latitudes, with the regional impact on shortwave cloud radiation effect of up to 10 W/m2. This is due to both the smaller (larger) grid size in high (low) latitudes in the longitude-latitude grid setting of CESM and the more stable (unstable) atmosphere. This parameterization is expected lead to more realistic simulation of tropical precipitation in high-resolution models. Results from this study are reported in Xie and Zhang (2015):

Xie, X., and M. Zhang (2015), Scale-aware parameterization of liquid cloud inhomogeneity and its impact on simulated climate in CESM, J. Geophys. Res. Atmos., 120, 8359–8371, doi:10.1002/2015JD023565.