Final Progress Report

Project Title

Improved Atmosphere-Ocean Coupled Modeling in the Tropics for Climate Prediction

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1. Understanding the initial cause of the double ITCZ in CCSM

We investigated the initial development of the double ITCZ in the Community Climate System Model (CCSM Version 3) in the central Pacific. Starting from a resting initial condition of the ocean in January, the model developed a warm bias of sea-surface temperature (SST) in the central Pacific from 5°S to 10°S in the first three months. We found this initial bias to be caused by excessive surface shortwave radiation that is also present in the standalone atmospheric model. The initial bias is further amplified by biases in both surface latent heat flux and horizontal heat transport in the upper ocean. These biases are caused by the responses of surface winds to SST bias and the thermocline structure to surface wind curls. We also showed that the warming biases in surface solar radiation and latent heat fluxes are seasonally offset by cooling biases from reduced solar radiation after the austral summer due to cloud responses and in the austral fall due to enhanced evaporation when the maximum SST is closest to the equator. The warming biases from the dynamic heat transport by ocean currents however stay throughout all seasons once they are developed, which are eventually balanced by enhanced energy exchange and penetration of solar radiation below the mixed layer. Our results also showed that the equatorial cold tongue develops after the warm biases in the south central Pacific, and the overestimation of surface shortwave radiation recurs in the austral summer in each year.

The above results have been published in the Journal of Climate.

2. Analyzing the heat budget of the upper ocean in the double ITCZ region

To constrain the coupled model in the region of double ITCZ, we used multiple datasets to derive the mixed layer heat budget in the region from 5°S to 10°S and 170°E to 150°W. Seven data sets of objectively analyzed surface energy fluxes and four ocean assimilation products are first evaluated. It was shown that these datasets differ greatly in their net downward surface energy flux in this region, but they fall broadly into two categories: one with net downward heat flux of about 30 W/m^2, and the other around 10 W/m^2. Measurements from the adjacent Manus and Nauru sites of the Atmospheric Radiation

Measurement (ARM) program, the Tropical Atmosphere-Ocean (TAO) buoy, as well as TOGA-COARE, are then used to show that the smaller value is more plausible. An energy balance of the mixed layer is finally presented for the region as primarily between warming from surface heat flux of 7 W/m^2 and horizontal advective cooling in the zonal direction of about 5 W/m^2, with smaller contributions from meridional and vertical advections, heat storage, and subgrid scale mixing.

3. Evaluation of the upper ocean heat budget in the reanalysis in the double ITCZ region

The recently available reanalysis from a *coupled* model system of the NCEP Climate Forecast System Reanalysis (CFSR) data is a potential benchmark for climate models in the double ITCZ region. Its suitability for model evaluation and validation however needs to be established. We examined the mixed layer heat budget and the ocean surface currents – key factors to the SST control in the double ITCZ in the central Pacific – from 5^oS to 10^oS and 170^oE to 150^oW. Two independent approaches are used. The first approach is through comparison of CSFR data with collocated station observations from field experiments; the second is through the residual analysis of the heat budget of the mixed layer. We show that the CFSR overestimates the net surface flux in this region by 23 W/m^2. The overestimated net surface flux is mainly due to an even larger overestimation of shortwave radiation by 44 W/m^2, which is compensated by an overestimated surface latent heat flux by 14 W/m^2. However, the quality of surface currents and the associated oceanic heat transport in CFSR are not compromised by the surface flux biases, and they agree with the best available estimates.

Publications:

1. Liu, Hailong, Minghua Zhang, Wuyin Lin, 2012: An Investigation of the Initial Development of the Double-ITCZ Warm SST Biases in the CCSM. *J. Climate*, 25, 140–155. doi: http://dx.doi.org/10.1175/2011JCLI4001.1

2. Liu, Hailong; Liu, Xiangcui; Zhang, Minghua, Wuyin Lin, 2011: A critical evaluation of the upper ocean heat budget in the Climate Forecast System Reanalysis data for the south central equatorial Pacific ENVIRONMENTAL RESEARCH LETTERS Volume: 6 Issue: 3, Article Number: 034022 DOI: 10.1088/1748-9326/6/3/034022 Published: JUL-SEP 2011.

3. Gent P. R., G. Danabasoglu, L. Donner, M. Holland, E. Hunke, S. Jayne, D. Lawrence, R. Neale, P. Rasch, M. Vertenstein, P. Worley, Z-L. Yang, and M. Zhang, 2011: The Community Climate System Model version 4. *J. Climate*, 24, 4973–4991. doi: http://dx.doi.org/10.1175/2011JCLI4083.1