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Coordination to understand and reduce global model biases by US and Chinese Institutions
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Author Comments:	Dear BAMS Editor, We wish to submit a summary of a US-China bilateral workshop on biases in coupled ocean-atmosphere models for publication in BAMS. The summary describes coordinated diagnostics and investigations of climate model biases by the US and Chinese modeling institutions, and bilateral collaboration plan to address these biases. While the US model centers represented at the workshop are widely known in the community, some of the Chinese models are not. These models will all submit results to the CMIP6. We think all of these should be of common interests to the broader community. Thank you for your considerations! Minghua Zhang Professor of Stony Brook University Editor-in-Chief, JGR-Atmospheres On behalf of all co-authors
Suggested Reviewers:	Shaocheng Xie Lawrence Livermore National Laboratory xie2@llnl.gov Represented the US Department of Energy to attend the Workshop
	Tongwen Wu twwu@cma.gov.cn Represented the Beijing Climate Center of the Chinese Meteorological Administration to attend the workshop
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	Ruby Leung PNNL ruby.leung@pnnl.gov Chief Scientist of DOE Climate Model Project who should be able to comment on the value of the submitted meeting summary to the broad community

COORDINATION TO UNDERSTAND AND REDUCE GLOBAL MODEL BIASES BY US AND CHINESE INSTITUTIONS

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A US-CHINA COUPLED MODEL INTERCOMPARISON WORKSHOP

What: The first bilateral workshop to coordinate diagnoses of global climate models and resolution of key biases with 60 attendees from 3 US and 6 Chinese modeling institutions.

When: 23-25 August, 2017

Where: Beijing, China

Systematic biases in coupled ocean-atmosphere climate models and Earth System Models (ESM) impact their fidelity to predict variability and future changes. These biases will affect the simulation results in the upcoming Phase 6 of the Coupled Model Intercomparison Project (CMIP6, Eyring et al. 2016). Complementary to the broad efforts in the international community to confront these biases, there are benefits of focused collaborations by a smaller number of modeling groups to diagnose, understand and investigate specific biases of mutual interests. These collaborations allow for discussions of model development priorities and coordinated process-oriented diagnostics and numerical experiments. Recognizing the benefits of such collaborations, representatives of modeling centers from the United States (US) and China held a joint workshop on biases in coupled models in Beijing. The meeting was jointly organized by the Chinese Academies of Sciences and NOAA, and involved scientists from a number of major US and Chinese modeling institutions participating in the Coupled Model Intercomparison Project - Phase 6 (CMIP-6).

While the US models participating in CMIP6 are widely known, some of the Chinese models are not. The workshop gave scientists in the US, and in other countries through this workshop summary, an opportunity to become better acquainted with the development undertaken by the modeling institutions in China. Most of the Chinese models build-off component models, such as the ocean, atmosphere, land, and sea ice publicly available from institutions in the US or other countries with varying degrees of heritage and similarities. The totality of these models offer unique opportunities to compare and understand biases in coupled models when one or more components are replaced.

Modeling Center Overviews

The workshop was attended by representatives of six Chinese modeling institutions that currently plan to submit simulation results to CMIP6 (Table 1). Representatives from three modeling centers in the US attended the workshop. Several models from China were initiated in recent years as a result of the country's increased investments in Earth science research in general and climate change research in particular. Some other models have had a long history, such as the model at the Institute of Atmospheric Physics (IAP) of the Chinese Academy of Sciences (CAS) that participated in the 1992 Atmospheric Model Intercomparison Project (AMIP, Gates 1992) and each phase of the past CMIP simulations.

Model Biases Motivating Strong Mutual Interests: East Asia Monsoon And US SGP

To the Chinese modeling institutions, simulation of the seasonal north-south migration of the Meiyu front in eastern China—a nearly zonal band of persistent precipitation extending from the eastern periphery of Tibet Plateau to Korea and Japan— is a high priority. Year-to-year variation of the Meiyu precipitation is large (e.g., Huang et al. 2012) and it can have a huge impact on people's lives. For example, along the Yangtze river, the stagnation of the Meiyu front in June for period just one week longer can cause widespread flooding because the water reservoirs and soils are already near capacity and saturation. One the other hand, early departure of the Meiyu front would place the region under longer period of subsidence warming from the western Pacific subtropical high for the summer, causing severe heat waves. Seasonal prediction of the anomalous Meiyu precipitation is therefore of great societal importance because it can be directly used to plan for agriculture, and management of dam and water reservoirs among other things. Sadly, current climate models collectively perform poorly in simulating the mean precipitation in East Asia, not to mention the seasonal phase of the northward progression (Figure 1a). The workshop not only brought this significant model deficiency to the attention of the US modeling centers, but also provided a forum for the Chinese modeling institutions to discuss and plan for coordinated efforts to solve this problem.

To the U.S. modeling centers, the systematic warm and dry biases in the simulated surface temperature and precipitation of over the the Southern Great Plains (SGP) are a significant concern (Figure 1b). These biases have been known for a long time. Only recently, coordinated efforts were made to understand the cause of the biases through projects like CAUSES (Clouds Above the United States and Errors at the Surface) project among others (Ma et a. 2014). Recent study suggests that this bias may be caused by the lack of heavy precipitation associated with mesoscale convective systems in the models whose impact is amplified through land-atmosphere interactions that is unique to this region (Lin et al. 2017). Evidences have been presented that these biases affect the magnitude of future change of precipitation and warming (Cheruy 2014; Lin et al. 2017). Reducing this bias is therefore of both scientific and practical importance. The fact that some models do not have this bias while others do offers opportunities for the modeling groups to diagnose and understand the biases by examining and learning from the differences in the models.

Model Biases of Strong Common Interests: Double ITCZ And Low Clouds

Workshop participants discussed two persistent model biases that are of common interests. One is the double Inter-Tropical Convergence Zone (ITCZ); the other is low clouds in the subtropical eastern oceans.

The double ITCZ bias refers to two bands of annual precipitation on the two sides of the Equator in the central to eastern Pacific. In observations, the climatological ITCZ in the Pacific is between 5-10^{o}N. Only in the boreal spring and in some years, there is a weak precipitation maximum south of the Equator. In coupled models, however, the maximum to the south of the Equator persists throughout most of the year. This bias is often visible in atmospheric models when the Sea Surface Temperature (SST) is prescribed, but it is significantly amplified in coupled ocean-atmospheric models. Several modeling groups reported improvements in reducing the double ITCZ bias, but the reductions are sensitive to specific model parameterizations of convections, and appear to re-occur with moderate changes in other model physics. The double ITCZ bias is always accompanied by the cold tongue bias along the Equator, since more precipitation off the Equator leads to divergence at the equator and more equatorial upwelling, thus colder temperature. The double ITCZ bias is also accompanied by warm SST in the southeastern tropical Pacific along and off the Peru coast (e.g., Zhang et al. 2015). It is not clear whether the SST bias in southeastern tropical Pacific and the double ITCZ are caused by the same error sources or by two separate sources. This bias compromises model’s ability to simulate the spatial distribution and teleconnection of El Nino as well as the biogeochemical cycle along the Equator.

Low clouds have received much attention in the model community in the last twenty years because of their large net impact on the Earth's radiation budget thus the cloud feedback (Bony and Dufresne 2005). The prevalence of low clouds over the eastern oceans in the subtropics is one of the most conspicuous features of any daily global satellite image, with large areas of bright clouds in the visible channels but low-contrast clouds in the infrared channels that are barely distinguishable from SST. These clouds owe their existences to the large-scale conditions of cold SST, subsidence in the free troposphere, and advective forcing of cold and dry air in the trade winds. Despite concentrated efforts in recent years, models still have difficulties in simulating them. Most models underestimate the amount of these clouds. The failure of the models can be attributed to at least two challenges. One is the parameterization of turbulent mixing at the cloud top; the other is the coarse vertical representation of the models to capture the turbulences. Differences in the physical parameterizations of boundary-layer turbulence and shallow convection can lead to either positive or negative climate feedbacks from these clouds in the current generation of models (Zhang et al. 2013). Because cloud feedback is directly linked to climate sensitivity, solution to low cloud biases is of strong common interests to the workshop participants. This is also one of the grand challenges framed by the World Climate Research Program.

Other model biases of common interests include the Atlantic Meridional Overturning Circulation (AMOC) that is two shallow in the models, trade winds and subtropical highs that are too strong, El Nino periods that are too regular and amplitudes too large.

Climate Forcing: Direct and Indirect

Workshop participants shared information on their experiences with climate forcing for the 20th Century to prepare for their CMIP6 simulations. For the direct forcing, two specific issues are noted. One is the change of the prescribed solar forcing from CMIP5 values by a reduction of about 4 W/m^2 (Matthes et al. 2016). Considering an average planetary albedo of 30%, this change is equivalent to about 0.7 W/m^2 when spread to the Earth, which has an impact on the simulated temperature in the control simulations. The other is emission and concentration of aerosols (Stevens et al. 2016). Sensitivity experiments to these changes in the forcing have been carried out in some models and shared with other modeling groups at the workshop. More accurate quantification of forcing uncertainties and their impact on model simulations are identified as necessary steps for future research.

The largest sources of forcing uncertainties presented by the modeling groups are associated with the aerosol-indirect effects (IPCC WGI, 2013). Participants showed at least four factors that contribute to the differences in the simulated aerosol-indirect forcing: how aerosol emissions or concentrations (including dusts) are specified in the model, how cloud particles are nucleated, how microphysical processes of cloud particles are formulated, and the associated radiative forcing. Parameterizations of the sink terms of cloud hydrometers, especially the auto conversion rates in bulk schemes, are shown to have large impact of cloud indirect effect. This suggests that the effects of aerosols in models, including both direct and indirect, have a significant knowledge gap and leaves, a large room for future improvements.

Discussion of Diagnostics Coordination

Meeting presentations during the first two days of the meeting highlighted key long-standing biases common to most coupled models. Meeting participants agreed on the opportunity for some coordinated CMIP-6 model outputs diagnostic evaluations between the U.S. and Chinese modeling institutions present at the meeting, as means to accelerate the understanding and resolution. This bilateral coordination was considered as a useful complementary approach to the established CMIP framework for international coordination, one that would contribute to augment the CMIP6 activities already in place.

While the discussions considered the broad range of model issues that need to be tackled, participants agreed to narrow the focus of initial collaboration to two priorities: biases in low clouds and uncertainties in climate forcing. Other issues such as Asian monsoon, biases over the US Southern Great Plains, arctic sea ice, snow-albedo feedback, permafrost biogeochemistry, Indian Ocean Dipole (IOD), and other land and ocean biases were also considered important, but the decision was to address them in future discussions.

For the two collaboration priorities on low clouds and aerosol climate forcing, GFDL and CAS/IAP offered to lead the development of hypothesis on low cloud biases in climate models, diagnoses of model variables and processes, and recommendations of coordinated evaluations, potential experiments, metrics, and possible solutions to the problem. NCAR, GFDL, and CAS instead offered to take the lead on the aerosol climate forcing issue, providing a similar approach. Most of these efforts would be part of the modeling groups' participation in the CMIP6 project, with few others to be specifically designed to address model biases discussed at the workshop. A tentative timeline for coordination on these issues was discussed, with progress assessed in one year to inform future activities, such as the desirability of future bilateral workshops.

ACKNOWLEGEMENTS: We wish to thank all those who attended the meeting. The meeting as made possible by the generous support of the Chinese Academy of Sciences and the National Science Foundation of China who offered to host the meeting, and the NOAA Modeling, Analysis, Prediction and Projections (MAPP) program.

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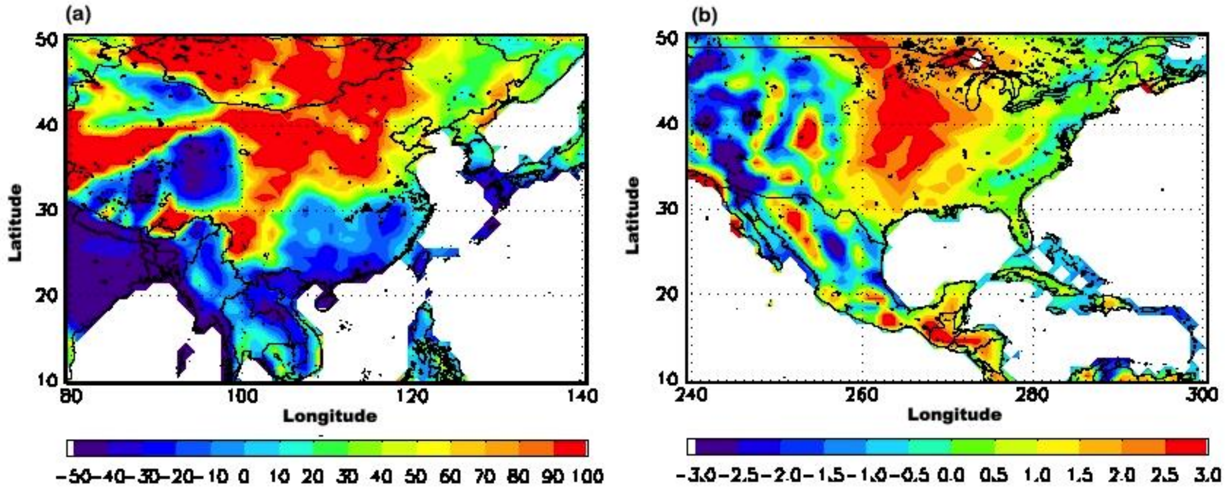
Table and Figure

Table 1. Modeling institutions from the China and the US that attended the workshop.

Figure 1: CMIP5 ensemble model biases averaged over 20 years from 1986-2005: (a) April-June precipitation percentage bias (%) over China, (b) June-August temperature bias (K) over the US. The lists of models and observational data are described in the supplemental materials.

Table 1. Modeling institutions from the China and the US that attended the workshop

Model Name	Institutions
CAS-FGOALS **CAS-ESM**	Institute of Atmospheric Physics (IAP)/Chinese Academy of Sciences (CAS)
BCC	Beijing Climate Center (BCC) / China Meteorological Administration (CMA)
CICSM	Center for Earth System Science (CESS)/Tsinghua University (THU)
BNU	Beijing Normal University (BNU)
FIO	First Institute of Oceanography (FIO) / State Oceanic Administration (SOA)
NUIST	Nanjing University of Information Science and Technology (NUIST)
GFDL-CM **GFDL-ESM**	Geophysical Fluid Dynamics Laboratory (GFDL)/NOAA
CESM	National Center for Atmospheric Research (NCAR)
E3SM	National Laboratories of the U. S. Department of Energy (DOE)



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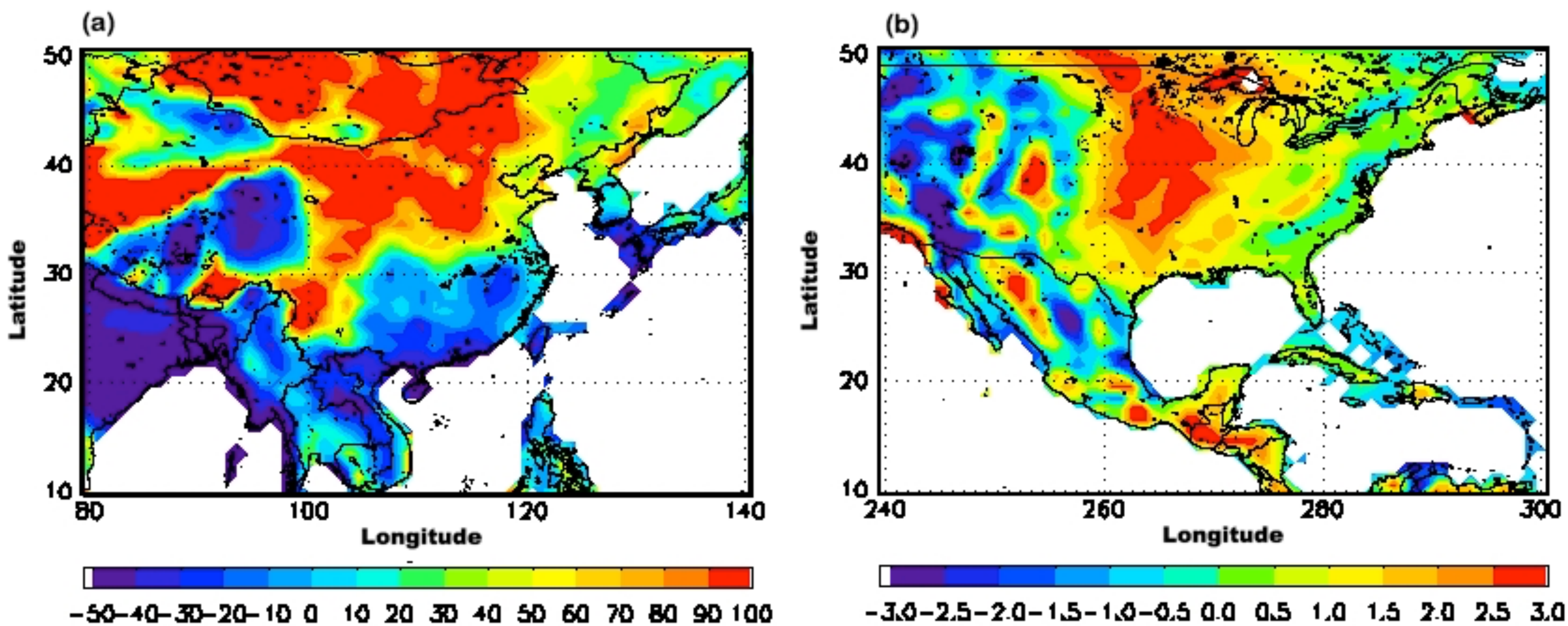

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