COORDINATION TO UNDERSTAND AND REDUCE GLOBAL MODEL BIASES BY U.S. AND CHINESE INSTITUTIONS

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Systematic biases in coupled ocean–atmosphere models and Earth system models (ESMs) impact their fidelity to predict climate 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 and China held a joint workshop in Beijing, China, on biases in coupled models. The meeting was jointly organized by the Chinese Academy of Sciences and National Oceanic and Atmospheric Administration (NOAA) and involved scientists from major U.S. and Chinese modeling institutions participating in CMIP6.

A U.S.–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 three U.S. and six Chinese modeling institutions.
When: 23–25 August 2017
Where: Beijing, China

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While the U.S. models participating in CMIP6 are widely known, some of the Chinese models are not. The workshop gave scientists in the United States, and in other countries through this workshop summary, an opportunity to become better acquainted with the development undertaken by the modeling institutions in China. Some of the Chinese models build off component models, such as the ocean, atmosphere, land, and sea ice models publicly available from institutions in the United States or other countries, with varying degrees of heritage and similarities. The totality of these models offers 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 and three U.S. modeling institutions that currently plan to submit simulation results to CMIP6 (Table 1—refer to this for modeling centers and model acronyms). 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 Chinese 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 in each phase of the past CMIP simulations.

MODEL BIASES MOTIVATING STRONG MUTUAL INTEREST: EAST ASIA MONSOON AND U.S. SOUTHERN GREAT PLAINS. To the Chinese modeling institutions, simulation of the seasonal north–south migration of the mei-yu front in eastern China—a nearly zonal band of precipitation extending from the eastern periphery of the Tibetan Plateau to Korea and Japan—is a high priority. Year-to-year variation in mei-yu 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 mei-yu front in June for a period just one week longer can cause widespread flooding because the water reservoirs and soils are already near capacity and saturation. On the other hand, early departure of the mei-yu front would place the region under a longer period of subsidence warming from the western Pacific subtropical high for the summer, causing severe heat waves. Seasonal prediction of the anomalous mei-yu 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 [Fig. 1a; the lists of models and observational data are described in the online supplemental material (https://doi.org/10.1175/BAMS-D-17-0301.2)]. The workshop not only brought this significant model deficiency to the attention of the U.S. 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 over the U.S. southern Great Plains (SGP) are of significant concern (Fig. 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 Clouds Above the United States and Errors at the Surface (CAUSES) project among others (Ma et al. 2014). Recent research suggests that this bias may be caused by the lack of

Table 1. Models and modeling institutions from China and the United States represented at the workshop.

Model name	Institutions
CAS Flexible Global Ocean–Atmosphere–Land System Model (CAS-FGOALS) CAS Earth System Model (ESM)	IAP, CAS
Beijing Climate Center (BCC)	BCC, China Meteorological Administration (CMA)
Community Integrated Climate System Model (CICSM)	Center for Earth System Science (CESS), Tsinghua University (THU)
Beijing Normal University (BNU)	BNU
First Institute of Oceanography (FIO)	FIO, State Oceanic Administration (SOA)
Nanjing University of Information Science and Technology (NUIST)	NUIST
GFDL Climate Model (CM) GFDL-ESM	NOAA/GFDL
Community Earth System Model (CESM)	NCAR
Energy Exascale Earth System Model (E3SM)	National Laboratories of the U.S. Department of Energy (DOE)

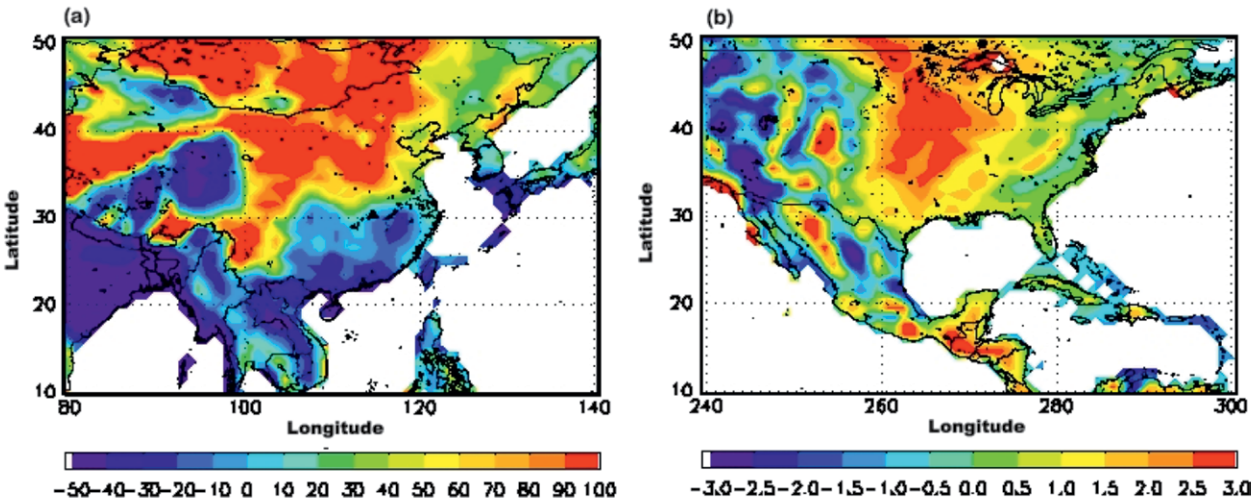

Fig. 1. CMIP5 ensemble model biases averaged over 20 years from 1986 to 2005: (a) Apr–Jun precipitation percentage bias (%) over China and East Asia and (b) Jun–Aug surface temperature bias (K) over the United States.

heavy precipitation associated with mesoscale convective systems in the models whose impact is amplified through land–atmosphere interactions that are unique to this region (Lin et al. 2017). Evidence has been presented that these biases affect the magnitude of future change of precipitation and warming (Cheruy et al. 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 INTEREST: DOUBLE ITCZ AND LOW CLOUDS. Workshop participants discussed two persistent model biases that are of common interest. One is the double intertropical 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° and 10°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 convection and appear to reoccur with moderate changes in other model physics. The double ITCZ bias is always accompanied by cold tongue bias along the equator, since more precipitation off the equator leads to divergence at the equator and more equatorial upwelling and thus colder temperature. The double ITCZ bias is also accompanied by warm SSTs in the southeastern tropical Pacific along and off the coast of Peru (e.g., Zhang et al. 2015). It is not clear whether the SST bias in the southeastern tropical Pacific and the double ITCZ are caused by the same error sources or by two separate sources. This bias compromises the model's ability to simulate the spatial distribution and teleconnection of El Niño as well as nutrient upwelling in the ocean along the equator.

Low clouds have received much attention in the model community in the last 20 years because of their large net impact on Earth's radiation budget–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 SSTs. These clouds owe their existence to the large-scale conditions of cold SSTs, 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, a solution to low cloud biases is of strong common interest to the workshop participants. This is also one of the grand challenges framed by the World Climate Research Programme.

Other model biases of common interest include the Atlantic meridional overturning circulation (AMOC) that is too shallow in the models, trade winds and subtropical highs that are too strong, and El Niño 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 twentieth century to prepare for their CMIP6 simulations. For direct forcing, two specific issues are noted. One is the change in prescribed solar forcing from CMIP5 values by a reduction of about 4 W m^{-2} (Matthes et al. 2017). Considering an average planetary albedo of 30%, this change is equivalent to about 0.7 W m^{-2} when spread to Earth, which has an impact on the simulated temperature in the control simulations. The other is emission and concentration of aerosols (Stevens et al. 2017). Sensitivity experiments on 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 aerosol-indirect effects. Participants showed at least four factors that contribute to the differences in 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 autoconversion rates in bulk schemes, are shown to have large impact on cloud indirect effect. This suggests that there is a significant knowledge gap regarding the effects of aerosols in models, including both direct and indirect, and thus there is much 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 CMIP6 model output diagnostic evaluations between the U.S. and Chinese modeling institutions present at the meeting as a means to accelerate understanding and resolution. This bilateral coordination was considered a useful complementary approach to the established CMIP framework for international coordination, one that would contribute to the augmentation of CMIP6 activities already in place.

While 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 the Asian monsoon, biases over the SGP, Arctic sea ice, snow–albedo feedback, permafrost biogeochemistry, the 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, Geophysical Fluid Dynamics Laboratory (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. National Center for Atmospheric Research (NCAR), GFDL, and CAS 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 a 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. It is hoped that these collaboration priorities will also motivate other modeling centers to participate in research into the key uncertainties and biases identified here.

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