Summary of the Tropical Bias Workshop
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A Quick Run Down of What Occurred during the Workshop

Day 1 was devoted to presentations from major modeling centers and groups. We learned about the latest developments on coupled climate models as well as the history of model biases in individual models. Many centers have recently undergone a major revision of their coupled climate models. For example, in addition to the new models developed at CCSM and GFDL, Hadley Centre has updated its coupled model from HadCM3 to HadGEM1 which consists of a higher resolution ocean (1x0.3 x40) and a higher vertical resolution atmosphere (L 38), MPI has updated its coupled model which is now based on ECHAM5 (AGCM) and a higher resolution version of the HOPE model. Despite the considerable effort that has gone into improving the component models, all the new models show little improvement in tropical biases. In fact, in some cases, such as the new Hadley Centre model and the new MPI model, the bias problems in the tropics have become more severe than before.

In terms of strategies and parameterization improvements that have proven effective in reducing tropical biases, no single unique solution has been found. Some solutions found to be effective at one center/group, but did not turn out so at other centers/groups. For example, GFDL has found that increase in cumulus friction appears to be very effective in reducing double ITCZ biases in its atmospheric model. Experiments with NCAR/CAM2 show that this effect is less dramatic, unless there is a factor of 10 increase in cumulus friction. The NSIPP atmospheric model shows even negative sensitivity, i.e., an increase in cumulus friction leads to a more severe double ITCZ problem. On the other hand, the NSIPP model shows that the double ITCZ bias is greatly reduced, particularly during JJA, by increasing the re-evaporation efficiency. The other models show little or no sensitivity to this parameter. The NSIPP model also finds that the advective transport of water vapor above the PBL seems to play a role in eliminating double ITCZ biases. The Hadley Centre has been focused on biases in surface wind stresses. The trade wind strength is apparently overestimated by the new atmospheric component of HadGEM1, which leads to a strong cold bias in the tropical Pacific. By artificially decreasing the trade wind strength in the coupled model, the cold bias problem is much reduced. The COLA coupled model, which has a warm bias in the tropical Pacific, attributes the problem to the surface heat flux. By experimenting with different combinations of surface wind stresses and surface heat fluxes from COLA and CAM2 AGCMs, it is shown that a combination of COLA AGCM winds and CAM2 surface heat flux gives a much improved simulation of the tropical mean state.

There is also no consensus on the effect of enhanced model resolution on systematic biases. While NCAR/CAM2 shows an improved simulation of ITCZ structure and the southeasterly trades winds along the coast of South America when model resolution is increased from T42 to T85 and T170, the experience with the GFDL/AM2 does not concur with these findings regarding enhanced model resolution. The experiments performed by INGV using ECHAM4 at three different resolution T30, T42 and T106 coupled to the same Ocean GCM (OPA) show that the spatial and temporal structures of the simulated ENSO cycle have improved steadily as the resolution increases, but the double ITCZ biases remain largely unchanged. The CCSR coupled GCM from the University of Tokyo shows an improved ENSO simulation by reducing mixing coefficients of the ocean GCM. One interesting finding from the MPI coupled model experiments is that when the atmospheric model resolution matches the resolution of the ocean model; the cold tongue bias in the equatorial Pacific seems to be reduced

One observation based on all the presentations from different modeling centers/groups is that some atmospheric GCMs have very small double ITCZ biases when forced with observed SST compared to others. These include the old version of the Hadley Centre atmospheric GCM, the BMRC AGCM and CCSR AGCM from the University Tokyo. This may call for a further inter-model comparison study to understand the cause of the biases in the atmospheric GCMs.

During the group discussion, the ocean modeling group focused its discussion on the problem of the excessive cold tongue along the equator. A number of ocean processes are listed as potential candidates for the problems. These include the "deep cycle turbulence", the lateral mixing associated with inertial instability, and meridional heat transport associated instability waves. The current OGCMs are not able to transport turbulence energy deep enough below the mixed layer, as indicated by the micro-structure measurement. Additionally, the lateral processes represented by the current OGCMs seem to be deficient in taking into account the common heat exchange between equatorial and off-equatorial water. There are some discussions on the diffused thermocline being a problem to all the OGCMs. This may be linked to the insufficient vertical resolution. As for the warm bias along the coast of South America and Africa, many felt that this problem is more likely to have its origin in the atmosphere. On the issue of penetrative solar radiation and the role of biological feedbacks, many felt that this is not the leading cause of the bias problem.

The atmospheric modeling group focused its discussion on two key hypotheses regarding atmospheric aspects of the double-ITCZ problem: (1) Small-scale wind structures, not yet resolved by even the finest-resolution models, are important to modeling the ITCZ. (2) Even if these wind structures could be resolved, cumulus (and other physical) parameterizations in AGCMs may not be adequate for modeling the ITCZ. Detailed points regarding the second hypothesis included: (1) Cumulus closures may be responsible. A common element of AGCMs with double ITCZ is the use of CAPE-based closures. Vertical distribution of cumulus heating and drying could also be important. (2) More examination of field data to examine closures and other aspects of cumulus convection was recommended. The possibility that parameterized cumulus precipitation is too closely linked to moisture convergence was mentioned. (3) The temporal and spatial coherence of cumulus activity is likely to be important. (4) Surface fluxes, shallow convection, large-scale, and mesoscale clouds may also play roles. (5) Cumulus momentum transport played varying roles in different GCMs (NCAR, GFDL, NASA) discussed at the workshop. Approaches ranged from treating it diffusively to highly non-locally. Considerable research on cumulus momentum transport moving beyond these approaches has been completed during the last decade and should be used in AGCM experiments. Finally, it was also suggested that perturbation experiments in AGCMs and the study of natural situations where double ITCZ nearly develops (northern spring) be undertaken,

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Day 2 was devoted to the issues, such as, how important is observational uncertainty in creating current biases or process errors? Are there important processes that can be identified as the leading cause of the bias problems? To what extent do mean and seasonal biases impact our ability to forecast ENSO and ENSO related variability on SI timescales? An analysis based on in situ flux measurements in the tropical Pacific and tropical Atlantic shows that there are significant biases in the component surface heat fluxes of the ECMWF and NCEP reanalysis products. Interestingly, some of these biases in each component tend to cancel each other, so that the bias in the net surface heat flux is not as large as those in the individual component. Several studies presented at the workshop focused on exploration of process errors in the eastern Pacific region. Using observations from EPIC field program in 2001, a number of hypotheses on the processes that cause deep convection were tested using relatively simple linear regression analyses. The results indicate that deep convection in the eastern Pacific ITCZ region is largely controlled by the surface heat fluxes and the marine cloud layer entropy. In contrast, surface-based CAPE seemed to have little relationship to the deep convection in this region. These results should provide useful guidance for testing the convective parameterization of atmospheric GCMs. NCAR and GFDL reported results from a series of climate process experiments. The finding of these experiments suggests that the warm bias along the coast of South America was largely attributed to the error in the winds that are unrealistically weak in the atmospheric model so that the intensity of the coastal upwelling is severely underestimated. Replacing the model winds with the observed winds in the region significantly reduced the warm bias. UCLA coupled model experiments focused on the effect of marine stratocumulus on the warm bias. The results show that the coupled model tends to underestimate the amount of stratocumulus in the eastern equatorial Pacific. By inserting "observed" cloud cover into the model, the simulated annual cycle is much improved. The UCLA study also shows the importance of correctly simulating the annual variation of marine stratocumulus in the region. A different approach was taken by IPRC in an investigation of the effects of stratocumulus clouds, coastal winds and the steep Andes. Using a regional atmospheric model coupled to an OGCM, IPRC investigators show that although the regional atmospheric model was able to capture some realistic features of the circulation pattern off the coast of South America when forced with observed SST at the bottom boundary and with reanalysis data along the lateral boundaries, the coupled model drifts considerably away from observations, suggesting feedback errors in the model. Finally, a couple of AGCM studies were presented where a super-parameterization was used to examine the behavior of the simulated convective features under both idealized and realistic conditions. The results of these experiments show that the high-frequency behavior (intra seasonal and diurnal variability) of the convective activity is sensitive to the convective parameterization and the super-parameterization generally gives a more realistic simulation of MJO. However, it is not obvious that the super- parameterization improves the double ITCZ biases in the AGCM.

With regard to the issue of to what extent mean and seasonal biases impact our ability to forecast ENSO and ENSO related variability on SI timescales, results presented at the workshop were somewhat inconsistent. On the one hand, prediction experiments using a number of different atmospheric GCMs coupled to a common ocean GCM show comparable predictive skills, despite the fact that the coupled models have different systematic tropical biases. On the other hand, the ocean-alone simulations with mean biases in the subsurface ocean thermal structures corrected showed notable improvement in the simulation of interannual temperature variability in the tropical oceans, suggesting that the biases in the mean state do have an impact on models' ability to simulate and forecast ENSO.

Although the majority of the discussion during the workshop was focused on the biases in the tropical Pacific, there were some discussion of the bias problem in the tropical Atlantic. It was noted that to a certain degree the biases in the tropical Atlantic sector are more severe than those in the tropical Pacific. With regard to the cause of the large biases in the tropical Atlantic, in addition to the leading candidates that have already been suggested, including the regional feedbacks between stratocumulus clouds, surface winds, upwelling, coastal currents and SST along the coast of off the coast of Angola and Namibia, experiments with the NCAR CCSM models also suggest that the errors in 1) ocean heat transport and 2) cloud-radiative forcing may contribute to the dipole-like SST bias (too cold (warm) in the north (south) tropical Atlantic). One other intriguing result from these model experiments is that the large systematic bias in the tropical Atlantic can have a remote influence on the coupled annual cycle in the tropical Pacific. In particular, they contribute to the double ITCZ bias in the tropical Pacific by enhancing the cold SST bias in the equatorial Pacific. If this assessment is accurate, then the significance of the remote impact of the tropical Atlantic biases cannot be ignored. This means that any effort on reducing coupled model biases in tropical Pacific should take into the consideration not only the local processes, but also the remote influence.

During the general discussion session, it was pointed out that there is a need for compiling an observational data set based on EPIC and other field work, so that a detailed validation of models against observations can be made. In particular, it will be very useful to perform the relatively simple linear regression analyses using the model data as those have been done using the observed data sets. This type of analyses can provide insight into issues, such as whether the CAPE-based closures commonly used by the current generation of AGCM could be partially responsible for the double ITCZ bias, and how different are the processes that control the deep convection in the eastern Pacific ITCZ region between the model and reality. As for recommending new long-term observations that are particularly useful for solving the bias problem, no concrete suggestions were made.

Day 3 was devoted to idealized or reduced physics model studies and useful diagnostic studies related to tropical biases. The model studies presented included results from constant-SST aquaplanet simulations using the Cloud-Resolving Convection Parameterization (CRCP, a.k.a. super-parameterization) and from idealized simulations on the effect of boundary-layer structure on axisymmetric moist circulations. The former suggests that the moisture-convection feedback is crucial for both the development and maintenance of MJO-like coherent structures, while the latter argues that a double ITCZ could result from the cross-equatorial flow being too weak because the model PBL is too shallow. On the diagnostic side, the simple linear regression analyses among various variables that are relevant to tropical convection, such as SWCF vs. precip, precip intensity vs. surface heat flux and marine cloud layer entropy, were argued to be very effective in identifying potential problems in convective parameterizations of atmospheric GCMs, particularly when used intelligently with simple tropical models. Other diagnostic studies included an inter-model comparison study of the feedback between shortwave cloud-radiative forcing and SST which suggests that all the models seem to underestimate the strength of the negative feedback. The ocean model studies included an estimation of energy dissipation rates in the tropical ocean using a reduced physics model as well as an ocean GCM, the role of midlatitude processes in controlling the equatorial thermocline and role of biological feedbacks in the coupled system.

During the final discussion session of the workshop, the issue of the key defining features of the ITCZ was discussed. It was noted that the ITCZ can be defined in terms of precipitation distribution, the wind field, the zonality of the SPCZ, SSTs, and the dry zone along the equator. Geographically, the biases in the tropical Pacific can be divided into a western and an eastern manifestation. In the western Pacific warm pool, the double ITCZ in the model is marked by the dry zone coupled with an excessive cold water tongue extending too far westward along the equator. In the eastern Pacific cold tongue, the double ITCZ in model is marked by warm bias off the coast of South America. Although these features are related, different processes may be important for the problems of atmospheric response and ocean coupling. For example, the bias in the west may be initiated by the error in the convection parameterization, while the bias in the east may be determined more by the regional feedbacks between stratocumulus clouds, surface winds, upwelling, coastal currents and SST. On the other hand, the biases in the different regions may be related via remote influences. For example, the model studies suggest that the warm biases off the coast of South America and Africa can have a remote influence on the biases in the western tropical Pacific.

More refined diagnostic studies are clearly needed to further isolate the cause of the biases. One particularly useful diagnostic study will be to take a further look at the atmosphere-only simulations. It was noted that the degree to which atmosphere-only models produce double ITCZ varies from model to model. Some of the models, like the old version of the Hadley Centre atmospheric GCM, the BMRC AGCM and CCSR AGCM from the University Tokyo, have smaller double ITCZ biases than others. It will therefore be instructive to make an inter-model comparison study by analyzing those which have small double ITCZ biases vs those which have relatively large biases. The goal is to understand how similar or different these two groups of atmospheric models are and whether there are common features in one group of models versus the other.

Observational advances are clearly required for the details of the wind field and stresses. However, there is no specific recommendation on what types of new observations are most useful for fixing the bias problems.

Idealized models were nominated as hypothesis generators for the double ITCZ problem. Sample causes for the double ITCZ suggested by such models are boundary-layer depth, ocean biology variations, and ocean mixing.

As for the organized plan or recommendations for CLIVAR activities to fellow, there were not many suggestions except for the recommendation of a more detailed inter-model comparison project based on the MINI-CMIP project for the workshop. Based on this recommendation, it was announced that Chris Bretherton will lead such an effort, and he will be working with Ping Chang and PCMDI scientists during the summer to make a full detailed inter-model comparison study.