Topic "Improved Convection and Cloud Parameterization: Towards an India Centric Climate Model (ICCM)"

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Abstract

Although significant efforts have been made in recent decades for improvements in global climate models (GCMs), many important biases still remain, the South Asian Summer Monsoon (SASM) being one of the important areas with a large scope for improvement. In this thesis we have used one of the better performing community models, namely, the NCAR Community Atmosphere Model Version-5 (CAM5), as the base model, and improved its convection and cloud physics parameterization schemes, to improve the simulation of both regional and global climate. To begin with, we used an advanced clustering algorithm to group the CMIP5 models based on biases in their convective precipitation and carried out further analysis to identify some important reasons behind the systematic precipitation biases. We found the convective parameterization scheme, specifically, the closure function and trigger function, play important roles in governing the bias patterns. Next, we focused on improving the closure and trigger functions used in the deep convection parameterization scheme, by formulating and implementing a dynamically computed spatio-temporally varying convective adjustment time-scale, and implementing stochastic entrainment in the NCAR CAM5 model. These changes led to the alleviation of multiple persistent biases in the model. Next, we carried out a detailed sensitivity analysis of 17 parameters used in the cloud parameterization schemes of the model and subsequently tuned them using semi-automatic tuning.

Inter-model similarity studies of the bias structure suggest that the group of models falling within a given group (based on the extent of commonality in bias structure) is somewhat sensitive to the variable used for clustering (total/convective/large-scale precipitation). From the comparative study of CMIP5 and AMIP5 models, the degree of similarity in their bias patterns is found very high if two models have the same atmospheric component as compared to when other components are common but atmospheric components are different. Further analysis led to the finding that similarity in closure assumption and trigger mechanism in the atmospheric model's convection schemes largely govern the similarity in the commonality of convective precipitation biases, and thus highlights the primary role played by atmospheric component in governing the precipitation biases.

Next, a new formulation of the convective adjustment timescale (τ) was carried out by making it a function of cloud depth and updraft vertical velocity, unlike the control version that had fixed prescribed value. The new formulation (DtauCAM5) led to various improvements, such as the improved simulation of total precipitation over peninsular India, maritime continent (MC), leeward side of WG, Himalayan region, eastern equatorial Indian ocean (EIO), and western Pacific ocean (WPO), precipitation annual cycle, and monsoon onset and withdrawal. These improvements are found to be associated with improvements in large-scale dynamical features such as the meridional tropospheric temperature gradient (MTTG), easterly shear in the

zonal wind (ESZW), inter-tropical convergence zone, tropical easterly jet (TEJ), and subtropical westerly jet (STWJ). In addition, there is an improvement in quasi-biweekly oscillation as seen in the improvement of the longstanding bias of slower northward propagation and overestimated maximum amplitude across the west of 100°E in the westward propagation. DtauCAM5 has also improved the underestimated spectral power of MJO, Rossby waves, and Kelvin waves for higher frequencies.

Next, stochastic entrainment is formulated and implemented in the Zhang-McFarlane deep convection scheme, used in NCAR CAM5 (StochCAM5). In the control version, the entrainment rate was prescribed and constant. Compared to the control simulations (DefCAM5), StochCAM5 has benefited in improving the SASM and global climate simulations. The StochCAM5 has significantly alleviated the precipitation biases over central India, northeast India, AS, BoB, Indo-Burmese mountains, and Myanmar, as well as improved monsoon onset and withdrawal. The longstanding bias of the overestimation in the frequency of light precipitation and the underestimation in the frequency of large-to-intense precipitation is reduced and simulated very close to observation in StochCAM5. In addition, the improvement in low-level wind and Somali Jet (SJ) strength along with the improvement in MTTG, ESZW, and ITCZ are found. Interestingly, the overestimated maximum amplitude across the 15-22°N in the northward propagation of quasi-biweekly oscillation in DefCAM5 and DtauCAM5 is relatively alleviated in StochCAM5. The spectral power of MJO and the spectral power of Kelvin waves at higher periodicities that were worsened in DtauCAM5 and overestimated in DefCAM5 are improved greatly in StochCAM5.

Next, a detailed study of parameter sensitivity analysis and parameter tuning of the parameters in cloud microphysics and cloud macrophysics parameterization is carried out. Sensitivity analysis suggests that the threshold relative humidity for low clouds (rhminl), auto-conversion size threshold for ice to snow (dcs), fall speed parameter for snow (as), and fall speed parameter for ice (ai) are very sensitive uncertain parameters, for the simulation of precipitation, shortwave and longwave cloud forcing, and cloud cover over the global and SASM regions. The monotonic decrease in total precipitation is noted with the increase in rhminl and dcs value through its influence on liquid and ice water path and cloud forcings. From further analysis, we noted ai and as work opposite to dcs. Influence of these parameters on the onset, withdrawal, SJ, TEJ, and local Hadley circulation are also found through their influence on MTTG and ESZW. Tuning of these most sensitive parameters yields overall improved simulation of precipitation, cloud forcings, etc. globally and over the SASM region. The improvement in monsoon onset and withdrawal, annual precipitation cycle, ITCZ are also noted along with the improvement in MTTG and ESZW simulation with respect to DefCAM5 simulations. Finally, through the aforementioned development efforts to the NCAR CAM5, we have been able to alleviate many of the persistent biases by varying degrees, however, some important biases still remain and would need further model development, especially to the convection and cloud parameterization schemes.