Evaluation of CRM Intercomparison Simulations Using TWP-ICE Observations, Part 1

Research Highlight

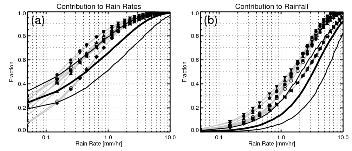
A large source of uncertainty in general circulation model (GCM) predictability is representation of tropical convective cloud systems, including their thermodynamic and radiative impacts, as well as their relationship to environmental properties. Because of their use with single-column models and super-parameterization in improving GCMs, high resolution cloud-resolving models (CRMs) need to be critically evaluated against observations to ultimately improve parameterizations. This study compares observed convective and stratiform structural properties of Tropical Warm Pool – International Cloud Experiment (TWP-ICE) monsoonal convective cloud systems to those within nine different 3D CRM simulations, all having horizontal resolution of ~1 km. All simulations use an idealized oceanic lower boundary and periodic horizontal boundary conditions. Three-hourly output is compared to radar and satellite observations over an area equivalently covering approximately 176 km by 176 km for the six days of observed active monsoonal conditions from 19 to 25 January 2006. The model forcing is derived using a variational analysis including observations such as three-hourly soundings at five domain boundary sites and radar-derived rain rates.

While all simulations reasonably reproduce the six-day time series of rainfall, convective rainfall is too high and balanced by stratiform rainfall that is too low. The high convective rainfall is a symptom of over-prediction of convective area by 20% or more, while the low stratiform rainfall is due to very low rain rates despite over-prediction of stratiform area by up to 65%. While all models reproduce the convective radar reflectivity distribution shape in the rain region, they fail to reproduce the distribution shape at upper levels where observations show a sharply peaked distribution at all levels. Whereas graupel is the only cause for high biases in simulated convective radar reflectivity of simulations that use 1-moment microphysics schemes, snow also leads to high biases in simulations that use 2-moment microphysics schemes. In all regions, observed radar reflectivity aloft decreases much more gradually with height than in simulations, where reflectivity decreases much more sharply near storm echo top.

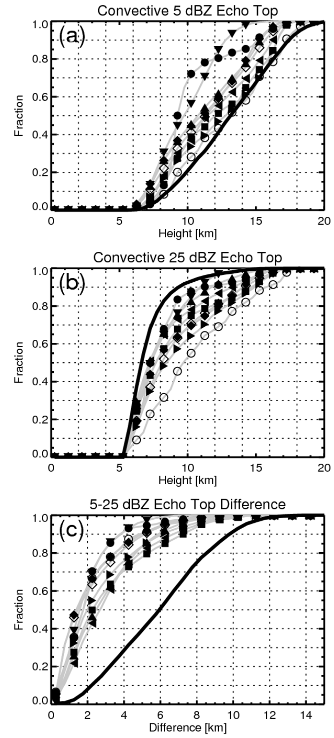
Radar reflectivity differences between models are not highly correlated to simulated top-of-atmosphere 10.8-micron infrared brightness temperature (IR Tb) differences between models. There is substantial spread in simulated IR Tb distributions with a few that come very close to the observed normalized cumulative distribution. Two sensitivity simulations, in which the thermodynamic profiles were nudged toward observations, have warmer brightness temperatures than their non-nudged counterpart simulations. This is consistent with their closer to observed stratiform area, leading to the hypothesis that the method in which the CRMs are forced may lead to excessive cloudiness and light precipitation.

Distributions of simulated ice water content, number concentration, and mass mean melted diameter for both graupel and snow show that varying the intercept and shape parameters of the assumed gamma distributions have much larger effects on radar reflectivity than varying the ice water content. Non-spherical mass-dimension relationships for precipitation-sized ice also heavily influence the radar reflectivity distribution.

Despite the large spread of simulated precipitation structure, no one simulation substantially stands out among the rest. Simulations that used 2-moment microphysics schemes did not clearly perform better than simulations with 1-moment microphysics schemes, although the superior ability of 2-moment schemes is evident. It appears that a gamma distribution shape parameter greater than zero, a variable



(a) The 2.5 km stratiform rain rate normalized cumulative distribution, with models represented by symbols (see Table1 in paper) and observations represented by the thick black line. Thin black lines show the observational error bounds. (b) The cumulative contribution of stratiform rain rates to total stratiform rainfall. Observations are derived from the scanning C-band radar (CPOL).



Observed and simulated convective radar reflectivity echo top normalized cumulative distributions for (a) 5 dBZ and (b) 25 dBZ. (c) The cumulative distributions of the difference between 5 dBZ and 25 dBZ echo tops. Samples are limited to columns that have at least a 25 dBZ echo at 5.5 km or higher. Models are represented by symbols (see Table 1 in paper), and the thick black lines represent observations from the scanning C-band radar (CPOL). Similar results are seen in stratiform regions.

size intercept parameter, and certain non-spherical mass-dimension relationships in which hydrometeor density is allowed to vary lead to radar reflectivity distributions closest to observed. No combination, however, leads to the proper decrease in radar reflectivity with height in both convective and stratiform regions. For simulations that overestimate convective radar reflectivity aloft, graupel is the cause in 1-moment schemes, but snow is often the cause in 2-moment schemes, suggesting excessive aggregation may be occurring in those schemes. The most important finding may be that all simulations had an excessive amount of low stratiform rain rates, which may be expected for some 1-moment schemes, but not for all schemes. Sensitivity simulations in which the thermodynamic profile is nudged toward observations bring the excessive simulated stratiform area more in line with observations, but do not fix the rain rates. This indicates that the idealized model forcing may lead to excessive cloudiness and light stratiform rain, but that the light nature of the rain rates is likely due to other mechanisms.

Reference(s)

Varble AC, AM Fridlind, EJ Zipser, AS Ackerman, J Chaboureau, J Fan, A Hill, SA McFarlane, J Pinty, and B Shipway. 2011. "Evaluation of cloud-resolving model intercomparison simulations using TWP-ICE observations: Precipitation and cloud structure." Journal of Geophysical Research – Atmospheres, 116, 10.1029/2010JD015180.

Contributors

Adam Varble, *University of Utah*

Working Group(s)

Cloud Life Cycle