11D.1 WRF Model Simulations of tropical cloud systems observed during TWP-ICE

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1 Introduction

The Tropical Warm Pool-International Cloud Experiment (TWP-ICE, May et al. 2008) took place in Darwin, Australia during January and February 2006. It provides an extensive data set describing tropical cloud systems, their evolution and interaction with the larger-scale environment. The experiment included a relatively dense network of ground-based observational systems including a polarimetric weather radar, cloud radar, wind profilers, radiation measurements, a lightning network and a balloon-borne sounding network. Additionally, five research aircraft were operated to measure cloud properties and the state of the atmosphere.

During the experiment four different convective regimes were sampled; these regimes were an active monsoon, a relatively suppressed monsoon, some clear days, and a break period. During the active monsoon a great variety of convective organization occurred, including isolated storms as well as convective lines. This period showed the highest cloud occurrence of the TWP-ICE experiment, and the area-averaged rain rate during the active monsoon period was around 17mm/day. Towards the end of this period a large mesoscale convective system developed, which produced an area-averaged accumulated rainfall of more than 70mm/day. In contrast, the break period was characterized by intense afternoon thunderstorms as well as several squall lines passing through the TWP-ICE domain during the evening and early morning. Due to the relatively transient and localized nature of the convection during the break period, the area-averaged rain rate was only 8 mm/day.

The measurements of these different regimes during TWP-ICE provide a valuable resource for the validation of cloud-scale model simulations under different tropical meteorological situations. In particular, this study focuses on the performance of the Weather Research and Forecasting (WRF) model, and its ability to reproduce the observed cloud structures as well as the model's performance in terms of precipitation.

2 WRF Model Simulations

The WRF model is a compressible nonhydrostatic finite difference model that has a variety of physics options, including explicit moisture processes (see Skamarock, 2005 for details). In this study, WRF is configured to explicitly simulate tropical cloud systems observed during TWP-ICE. The WRF simulations were performed with multi-nested domains with 4 different horizontal resolutions all having 64 levels (see Fig. 1); the inner-most nest, which is centered on Darwin, has a horizontal grid spacing of 1.259 km

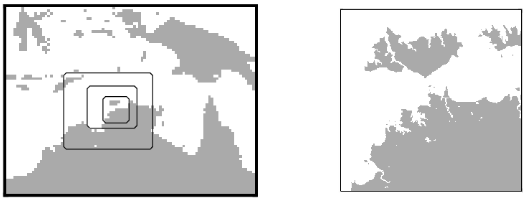

Figure 1: Simulation domain including the nests (left); inner-most nest (right)).

covering an area of 307 km*307 km. The initial and boundary conditions were derived from the NCEP 1°*1° global operational analysis. In all simulations, the model was configured using the longwave Rapid Radiative Transfer Model (RRTM; Mlawer et al., 1997), the shortwave MM5 (Dudhia, 1989) radiation, thermal diffusion surface scheme, and the Purdue Lin microphysical scheme (Chen and Sun, 2002). Sensitivity tests were conducted with two different boundary layer parameterizations: the Yonsei University (YSU) scheme and the Mellor-Yamada-Janjic (MYJ) scheme (Janjic, 2002).

Simulations for two different periods have been performed using version 2.2 of the Advanced Research WRF (ARW). The period from 21-24 January 2006 represents the active monsoon. The second simulation period, 6-9 February 2006, is part of the break period. The simulations and the available observations enable detailed assessments of the WRF model performance in simulating tropical convection, and its regime dependence.

3 Results

The overall model performance during the two convective regimes is evaluated using radiosonde data. Figure 2 shows time-height cross-sections of the relative humidity with respect to water. Shown are WRF results using the YSU boundary layer scheme, the MYJ boundary layer scheme, and radiosonde measurements

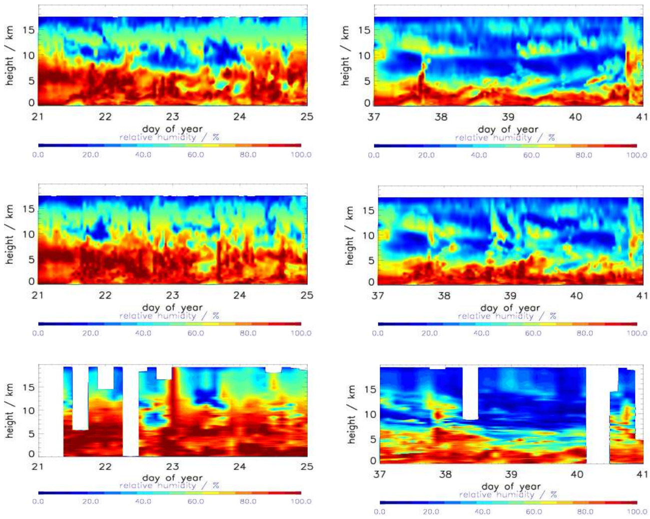

Figure 2: Time height cross-section of relative humidity (with respect to water) from WRF (YSU PBL scheme (top) and Mellor-Yamada-Janjic PBL scheme (middle)) and measured by radiosondes at Point Stuart (bottom) for the active monsoon (left) and the break period (right).

for both simulation periods. The radiosonde site chosen for this comparison was only operating during TWP-ICE and the measurements from those radiosondes haven't been included in the NCEP analysis and thus don't have an influence on the WRF simulations. Hence the radiosondes are an independent source for comparisons.

Figure 2 shows that during the active monsoon the observed and simulated relative humidity below 10 km is relatively large; in comparison the break period is relatively dry. Overall there is a good agreement between the simulations and the measurements, but there are important sensitivities to the choice of boundary layer schemes. The YSU scheme produces a diurnal cycle in relative humidity that is too strong, and during the day the simulated boundary layer is much drier than observed by the radiosondes. The use of the MYJ scheme mostly remediates these problems, and the simulated boundary layer structure more closely resembles that observed.

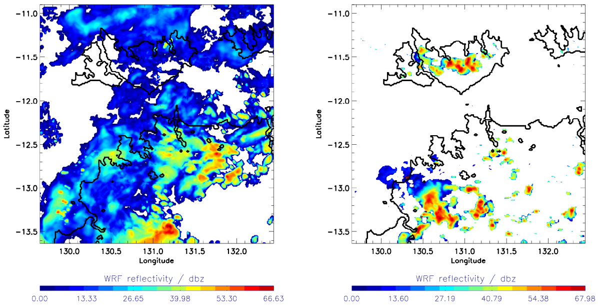

Figure 3: Examples of WRF reflectivities for the active monsoon (left) and the break period (right).

This improvement is true for both the active monsoon and the break period.

Figure 3 shows an example of simulated radar reflectivities derived from the WRF model. During the active monsoon the convection was very wide-spread, in contrast to the scattered and localized convection during the break period. In general, during the break period individual convective cells attained higher values of reflectivity than in the active monsoon.

The 4-day simulation of the active monsoon has an average cloud fraction between 0.7 at low levels and 0.5 in upper levels. In contrast, the break period reaches values of 0.1 at low levels and 0.05 at upper levels. This is in good agreement with cloud frequencies observed with radar (not shown, see May et al. 2008). Even for a perfect simulation of cloud distribution, the cloud fraction from the model domain shouldn't necessarily be the same as that derived from a single point observation within the domain. Nevertheless, the observed cloud frequencies provide a source of model validation. The observed cloud frequencies for the break period are higher in upper levels, reaching 0.15 compared to 0.1 in lower levels. In the active monsoon period the cloud frequencies are around 0.5 throughout the lower 5 km, whereas the simulations show a peak of about 0.7 at 5 km and

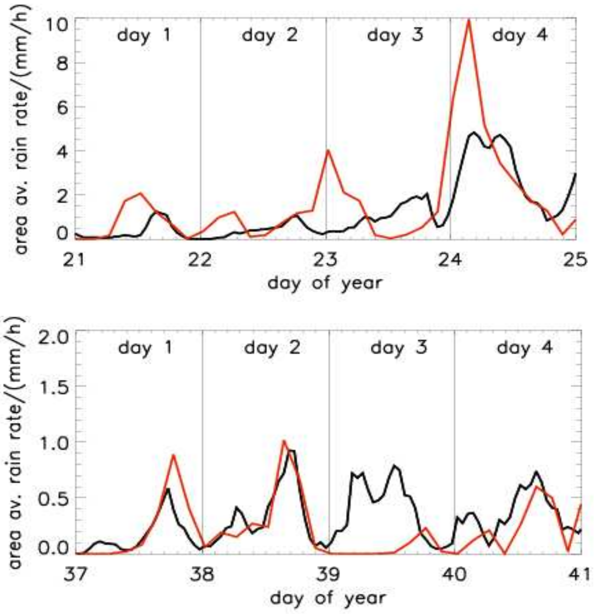

Figure 4: Area averaged rain rates from the polarimetric radar (red) and WRF simulations (black), for the active monsoon (top) and break period (bottom).

decreasing cloud fraction at lower levels. In both periods, active monsoon as well as break period, the simulated clouds reach higher than observed with radar.

A time series of area averaged rain rates during the two different periods are shown in Fig. 4. Despite the great intensity of the individual thunderstorms during the break period, area-mean rainfall during this period was low due to their relatively small coverage (in space and time) compared to the active monsoon conditions. Figure 4 shows excellent agreement between simulated and measured rainfall for the break period on day 1, 2 and 4, but the model overestimates the rainfall on day 3. In fact, this metric suggests that the simulation produced erroneous convective initiation on day 3.

During the active monsoon the observed and simulated area averaged rain rates are higher than during the break period (note different scale in Fig. 4). Daily precipitation totals are approximately reproduced by the WRF model on days 1-3, except the temporal variability of the rainfall is poorly represented. On day 4, the WRF model does reproduce the development of the large MCS but the simulated rainfall is less than observed.

Further, the localized rain rates simulated by the model are in good agreement with measurements by radar and rain gauges, for both the active monsoon and the break period (not shown). This agreement suggests that the WRF simulations are producing convection with approximately the correct intensity.

4 Conclusions and Future Work

WRF model simulations have been performed for two different periods during TWP-ICE, the active monsoon and the break period. These simulations utilize multiple nested domains, allowing convection to be explicitly resolved on the finest grid, which had horizontal grid spacing of 1.259 km. The performance of the WRF model during the two simulation periods is assessed primarily using radar observations; these comparisons show that many aspects of the simulated convection shows good agreement with the properties of the observed convection.

Further comparisons between vertical profiles of relative humidity from radiosondes measurements and the WRF model also show good overall model performance. However, the simulated boundary layer humidity is poorly represented when the YSU boundary layer parameterization is used instead of the Mellor-Yamada-Janjic scheme. The YSU scheme overestimates the diurnal cycle of the low level moisture, whereas the MYJ scheme is in good agreement with the measurements.

The model's performance in terms of precipitation has also been evaluated using radar observations as well as rain gauge measurements. There is correspondence between observed and simulated local rain rates as well as area averaged precipitation. Nevertheless, the model's performance in terms of precipitation is regime dependent. The agreement between simulated and observed rainfall is much better for the break period, where the convection is more strongly forced by the diurnal cycle. The WRF simulation of precipitation is excellent for three of the four days during the break period. During the active monsoon period the simulated daily rainfall accumulations are in good agreement for the four days. However, the WRF model fails to produce the right amount of precipitation for a large mesoscale convective system on day 4, and does not accurately represent the temporal variability of the monsoon precipitation.

Ongoing research is underway to investigate the reasons for the poor performance of the WRF simulations on day 3 of the break period, and day 4 of the monsoon period. Also, further investigations examining the processes controlling the temporal variability of the convection during the active monsoon period are continuing.

Acknowledgments

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