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Various Applications on Tropical Convective Systems Using a Cloud Resolving Model (CRM)

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1. INTRODUCTION

The growing usage of cloud resolving model (CRM or cloud ensemble model-CEM) in recent years can be credited to its inclusion of crucial and physically relatively realistic features such as explicit cloud-scale dynamics, sophisticated microphysical processes, and explicit cloud-radiation interaction. On the other hand, impacts of the environmental conditions (for example, the large-scale wind fields, heat and moisture advections, as well as sea surface temperature) on the convective system can also be plausibly investigated using the CRMs with imposed explicit forcing.

In this paper, by basically using a 2D and 3D Goddard Cumulus Ensemble (GCE) model, three various studies on tropical convective systems are briefly presented. Each of these studies serves a special goal as well as uses a different approach. In the first study, which uses more of an idealized approach, the respective impacts of the large-scale horizontal wind shear and surface fluxes on the modeled tropical quasi-equilibrium states of temperature and water vapor are examined. In this 2D study, an interesting relation found between the quasi-equilibrium temperature and water vapor fields based on both model results and observations will be presented. For the second study, a handful of real tropical episodes (TRMM Kwajalein Experiment - KWAJEX, 1999; TRMM South China Sea Monsoon Experiment - SCSMEX, 1998) have been simulated such that several major atmospheric characteristics such as the rainfall amount and its associated stratiform contribution are investigated. In this study, the observed large-scale heat and moisture advections are continuously applied to the 2D and 3D model. The modeled cloud generated from such an approach is termed "continuously forced convection" or "continuous large-scale forced convection". A third study, which focuses on the respective impacts of atmospheric components on upper ocean heat and salt budgets, will be presented in the end. Unlike the two previous studies, this study employs the 3D GCE-simulated diabatic source terms (using TOGA COARE observations) - radiation (longwave and shortwave), surface fluxes (sensible and latent heat, and wind stress), and precipitation as input for the ocean mixed-layer (OML) model.*

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2. MODEL

The 2D or 3D GCE model used in this study is an anelastic, nonhydrostatic model that has been broadly used to study cloud-radiation interaction, cloud-environment interaction, and air-sea interaction. The cloud microphysics include a two-category liquid water scheme (cloud water and rain), and a three-category ice microphysics scheme (cloud ice, snow and hail/graupel). The model also includes solar and longwave radiative transfer processes, and a subgrid-scale turbulence (one-and-a-half order of turbulent kinetic energy) scheme. A stretched vertical coordinate with finer/coarser grid resolution in the lower/upper layers as well as a uniform horizontal coordinate with cyclic boundary conditions is included in the model. The model structure was detailed in Tao and Simpson (1993).

3. RESULTS

In the first study, Figure 1 shows a scatter diagram of domain-averaged water vapor "Q" (mm) vs temperature "T" (K) at the quasi-equilibrium states for the 16 2D GCE modeled simulations (at the end of 25-day of integration). The setups for these 16 (8 pairs) idealized GCE tropical simulated runs (either reaching or near statistically quasi-equilibrium states) are addressed as follows. Three of the 8 pairs are the same as those in Shie et al. (2003) that involve various model setups pertaining to two major components: the vertical wind shear pattern and the minimum surface wind speed used for surface flux computation. These 3 pairs use one same type of sounding setup. One other pair of runs followed the same model setup of "1M" and "1N" (Shie et al. 2003) except for using a different sounding setup. The rest 4 pairs all have a similar model setup with respect to the "controlled" pair of runs "4M" and "4N" (Shie et al. 2003), except that each pair of runs possess an unique setup component, i.e., either in large-scale forcing (constant or variant), surface fluxes (constant or variant), radiations (constant or variant), or sea surface temperature (28.18 or 29.51 C), respectively. Similar to our previous studies (Tao et al. 1999 and Shie et al. 2003), these 16 modeled experiments have also shown an interesting quasi-linear relationship. A slope value of dQ/dT (mm/K), i.e., 4.218 can be obtained by applying a linear regression method to the group of 16 data points (see the dashed line in Figure 1). An idealized equation that has been established based on a simple thermodynamic concept may properly interpret the slope feature of dQ/dT. Detailed discussion will be presented during the meeting.

In the second study that involves simulations of tropical field experiments, the GCE modeled results have shown promising features for both 2D and 3D. For example, the temporal variation of both 2D and 3D modeled rainfall has agreed fairly well with the observation that was diagnostically estimated from the combined radar and raingauge data. Such a good agreement, we believe, is mainly attributed to the driving forcing -- the sounding derived large-scale temperature and moisture tendencies that were implemented into the model. However, both 2D and 3D simulated rainfalls have quantitatively shown a slight wet bias in all three episodes. Overall, the 3D model has a slightly better performance than the 2D model in simulating both temporal evolution and total amount of rainfall. It is also found that the 2D model generates more stratiform-type rainfall, while the 3D model significantly favors convective-type rainfall. Moreover, based on the 3D model results, the clouds and cloud systems are generally unorganized and short lived in the KWAJEX episodes. This numerical finding has further been validated by radar observations that will be presented in the meeting. Evolutions of the 2D modeled domain-averaged apparent heat source (Q1) and moisture sink (Q2), as well as the sounding estimate for the three KWAJEX convective episodes will also be presented. The modeled Q1 and Q2 have reasonably captured the observed typical vertical structures. In a budget analysis, the large-scale forcing and net condensation (sum of condensation, deposition, evaporation, sublimation, freezing, and melting of cloud) are found the two major physical processes that account for the evolution of the temperature and moisture budgets. Quantitative budget differences between 2D and 3D as well as between various episodes will be further discussed in the meeting.

In the third study, 3D GCE modeled surface quantities for three convective episodes during TOGA-COARE have been used as input forcing to drive the OML model. TOGA-COARE observations are used as initial and boundary conditions for the coupled model as well as to validate the model results. The three episodes studied are episode 1, December 10-17, 1992; episode 2, December 19-27, 1992; and episode 3, February 9-13, 1993. Episode 1 is prevailed by easterly, while episodes 2 and 3 evolve in the system mainly associated with strong westerlies. A series of sensitivity simulations have been performed for each episode to study the impact by the individual input forcing on upper ocean heat and salt budgets. A series of time evolution of horizontal mean mixed layer temperature (T), depth (h), and 3-m salinity (S) for the three episodes will be presented in the meeting.

4. SUMMARY

The three distinct studies presented in this paper have clearly demonstrated that a multiple-functioned GCE model has been successfully applied to tackle various tropical atmospheric and oceanic issues. In each of these three studies (i.e., an idealized approach, a real atmospheric simulation, as well as an air-sea interaction study), the respective modeled result has well captured the observed features.

5. REFERENCES

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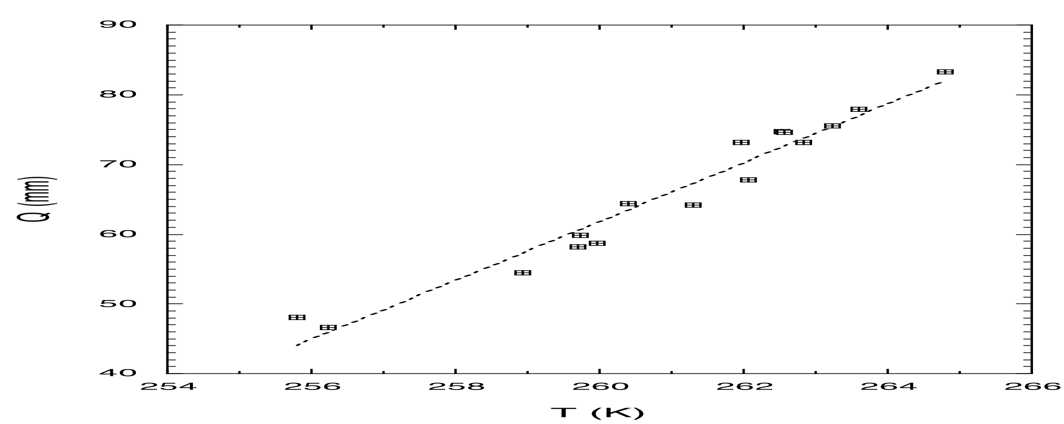

Figure 1. Scatter diagram of domain-averaged water vapor vs temperature at the quasi-equilibrium states (at the end of 25 days of integration) for 16 numerical simulations. A slope value of 4.218 is obtained as a built-in linear regression method in the "KaleidaGraph" plotting package (used to generate this diagram) has been applied to the group of 16 data points (see the dashed line).