10D.6 SIMULATED CONVECTIVE SYSTEMS USING A CLOUD RESOLVING MODEL: IMPACT OF LARGE-SCALE TEMPERATURE AND MOISTURE FORCING USING OBSERVATIONS AND GEOS-3 REANALYSIS

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1. INTRODUCTION

As the chosen CRM (Cloud Resolving Model) for a NASA Interdisciplinary Science (IDS) Project, the GCE (Goddard Cumulus Ensemble) model has recently been successfully upgraded into an MPI (Message Passing Interface) version with which great improvement has been achieved in computational efficiency, scalability, and portability [*Juang et al*., 2005]. By basically using the large-scale temperature and moisture advective forcing, as well as the temperature, water vapor and wind fields obtained from TRMM (Tropical Rainfall Measuring Mission) field campaigns such as SCSMEX (South China Sea Monsoon Experiment, 1998) and KWAJEX (Kwajalein Experiment, 1999), our recent 2-D and 3-D GCE simulations were able to capture detailed convective systems typical of the targeted (simulated) regions. The GEOS-3 [Goddard EOS (Earth Observing System) Version-3] reanalysis data (Hou et al. 2001) have also been proposed and successfully implemented for usage in the proposed/performed GCE long-term simulations (i.e., aiming at producing massive simulated cloud data -- "Cloud Library") in compensating the scarcity of real field campaign data in both time and space (location).

There are three major objectives served in this study. The first objective is to investigate and verify the GEOS-3 data quality by comparing several paired model simulations using the field campaign sounding observations (e.g., SCSMEX and KWAJEX) and the corresponding GEOS-3 reanalysis data. The large-scale advective temperature and moisture forcing acquired from these two different resources has been considered as a critical factor in determining modeled results. The second objective of this study is, therefore, to investigate and present such an impact by large-scale forcing on various modeled quantities such as hydrometeors, rainfall, and reflectivity. To validate the overall GCE model performance by comparing the numerical results with sounding observations, as well as available satellite data serves as a third objective*.

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2. MODEL

The GCE (2-D or 3-D) 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). The 3-D GCE/MPI model has recently been further developed into an integrated version of multi-functions/purposes that it can run (1) for either an anelastic or a compressible physical/dynamical system, (2) with either open or cyclic lateral boundary conditions, (3) with imposed either one sounding, large-scale advective forcing, or non-uniform initial condition, (4) with several options in microphysical schemes such as a) warm rain only, b) 2-ICE, c) 3-ICE with graupel, or d) 3-ICE with hail, (5) with either coupling or decoupling to the Goddard Land Process Model PLACE (Parameterization for Land-Atmosphere-Cloud Exchange), and LIS (Land Information System).

3. RESULTS

The 2-D and 3-D GCE simulated results using the respective field campaign observations and GEOS-3 data generally show good qualitative agreement, yet with some quantitative discrepancy. The time-averaged large-scale temperature and moisture forcing obtained from sounding network and GEOS-3 reanalysis, which are used for simulating the SCSMEX May 18-26 convective episode (i.e., prior to and during the onset of the monsoon) are shown in Fig. 1a and Fig. 1b, respectively. The time-averaged GEOS-3 reanalysis forcing data are generally cooler (dashed line in Fig. 1a) and drier (dashed line in Fig. 1b) than those from the sounding derivations (solid line in Fig. 1a and Fig. 1b), while the former also demonstrates a smoother vertical distribution. Fig. 2 shows the time-averaged bias/discrepancy of the simulated temperature and water vapor (i.e., the simulated field subtracted by the original field from the respective sounding observation or GEOS-3 reanalysis). As for the modeled temperature field (Fig. 2a), a cold bias is found throughout the vertical domain for the simulation using sounding forcing (solid line), which is a quite common finding among CRM simulations. However, such a cold bias is further enhanced for the simulation using GEOS-3 forcing (dashed line). We attribute this stronger cold bias to the cooler temperature forcing of GEOS-3 compared to the sounding counterpart (as discussed earlier in Fig. 1a). The modeled water vapor (Fig. 2b) using the GEOS-3 forcing (dashed line) is found carrying a drier bias than the simulated moisture using the sounding forcing (solid line) particularly near the surface layer, which is consistent to that the GEOS-3 moisture forcing is much drier than the sounding forcing in the lower atmosphere (Fig. 1b).

The time-mean simulated relative humidity discrepancy and total cloudiness are shown in Fig. 3. A positive/negative bias of relative humidity is found at lower/higher levels (i.e., below/above around 7 km) for simulation using sounding forcing (solid line in Fig. 3a), while a stronger positive/weaker negative bias appears at lower/higher levels (i.e., below/above around 9.5 km) for simulation using GEOS-3 forcing (dashed line in Fig. 3a). Overall, the simulation using GEOS-3 generates a relative "overestimation" of relative humidity than the simulation using sounding, which is particularly dominant between heights 2 to 9 km. This overall "overestimation" of relative humidity between the simulations using GEOS-3 and sounding forcing may be attributed to a combined effect that a moderately larger dry bias of GEOS-3 than sounding (shown in Fig. 2b, particularly between 2 to 9 km) is, however, overcompensated by a much stronger cold bias of GEOS-3 than sounding (Fig. 2a). However, near the surface the simulation using sounding possesses a slightly larger overestimation of relative humidity than the simulation using GEOS-3 because the dry bias of the latter becomes much stronger, as well as dominates its moderate cold bias near the surface. As a result, the simulation using GEOS-3 forcing, which produces a relative "overestimation" of relative humidity than the simulation using sounding generates an overall larger cloudiness than its counterpart simulation (Fig. 3b). The higher cloudiness near the surface for the simulation using GEOS-3 might be due to a stronger vertical velocity of GEOS-3 than that of sounding (i.e., actually throughout the entire vertical domain, yet not shown here) even the former has a smaller overestimation in relative humidity than the latter.

As one of the three aforementioned objectives to this study, the impact of large-scale forcing on the modeled rainfall will be brief discussed here. A time sequence of the GCE 3-D simulated domain-averaged surface rainfall rate for the SCSMEX 2-11 June, 1998 convective episode (i.e., post onset of the monsoon) using large-scale temperature and moisture forcing from sounding observations and GEOS-3 reanalysis are shown in Fig. 4, along with a calculated quantity of correlation between the respective large-scale temperature and moisture forcing. The correlation between large-sale temperature and moisture forcing is attained by vertically integrating the product of these two forcing quantities obtained at each vertical level, which is computed with a simple formula detailed as follows. A positive correlation value is obtained for a product with a negative (cold) temperature and positive (moist) moisture forcing, while a negative value is given to a product with a positive (warm) temperature and negative (dry) moisture forcing. A correlation value of zero is assigned for a product with the rest types of combination. The model simulated surface rainfall using the sounding forcing (curve with open triangle) and that using the GEOS-3 forcing (curve with solid triangle) generally resemble each other in a temporal evolution, yet with some quantitative discrepancy, which may be primarily attributed to the imposed different large-scale forcing. The large-scale temperature and moisture forcing based on sounding (curve with open circle) and GEOS-3 reanalysis (curve with solid circle) correlate fairly well with their corresponding rainfall time series not only temporally but also quantitatively. For example, the simulated surface rainfall using sounding/GEOS-3 forcing (open/solid triangle) is almost perfectly in phase with the respective forcing correlation (open/solid circle). It is also obvious that the generally larger simulated rainfall amount using sounding forcing than that using GEOS-3 forcing is consistent to a larger correlation shown in sounding forcing than GEOS-3 forcing. We believe that an improved quantitative proportion between the simulated rainfall and the large-scale forcing correlation may be attained should the current forcing correlation be also weighted by an air density during the vertical integral.

4. SUMMARY

Meanwhile, the 3-D GCE/MPI model has been continually utilized for simulating the targeted cloud systems at different geographic locations (Tropics and subtropics; marine and continent) by applying the GEOS-analyzed or observational data. In addition to a few targeted episodes (e.g., SCSMEX monsoon and KEAJEX convective system) performed in an earlier stage, a few more long-term episodes (i.e., the CRYSTAL-FACE study [Cirrus Regional Study of Tropical Anvils and Cirrus layers – Florida Area Cumulus Experiment] and ARM study [Atmospheric Radiation Measurement Program]) have also been completed recently. More simulated results, along with the available observations will be discussed and presented during the conference meeting.

5. REFERENCES

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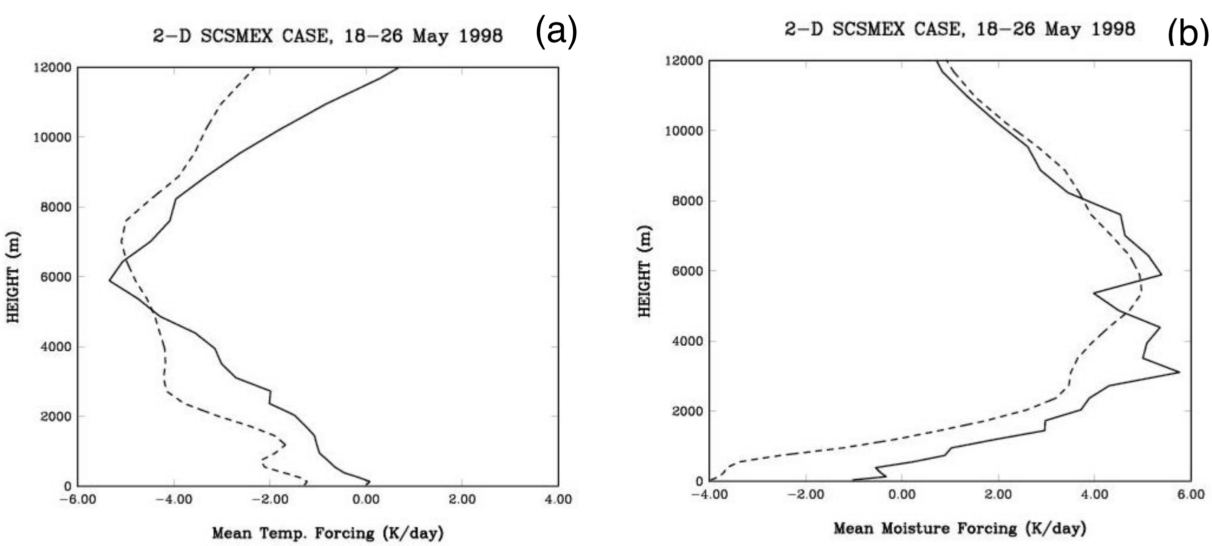

Fig. 1: Time-averaged (SCSMEX 18-26 May, 1998) large-scale (a) temperature forcing (K/day) and (b) moisture forcing (K/day) derived from sounding network observation (solid line) and GEOS-3 reanalysis (dashed line).

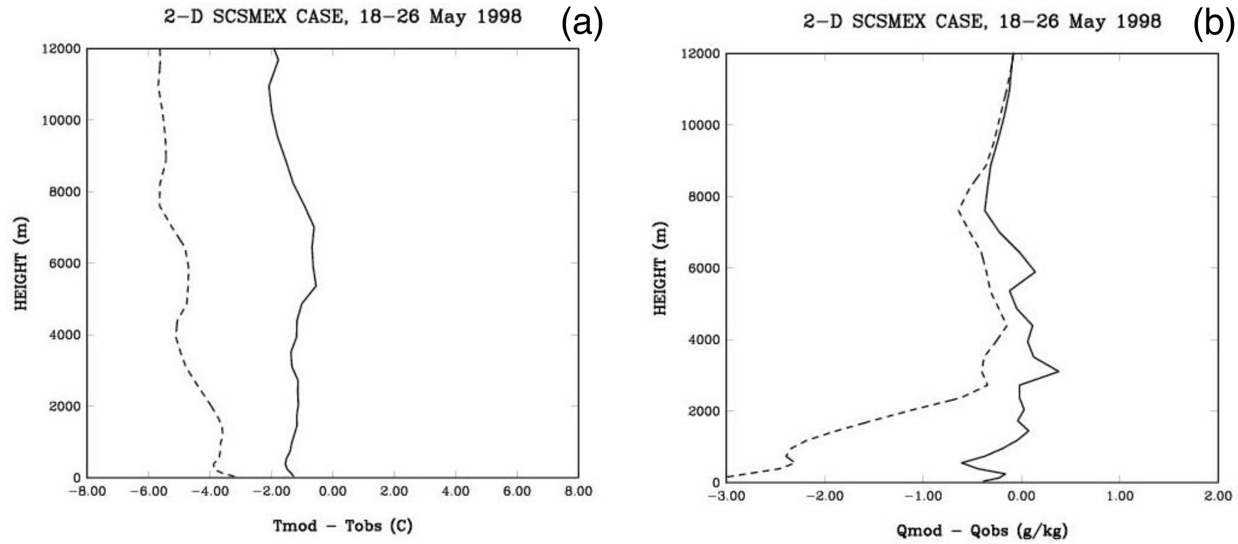

Fig. 2: Time-averaged (SCSMEX 18-26 May, 1998) discrepancy for the simulated (a) temperature (^{0}C) and (b) water vapor (g/kg) for the simulation using sounding network observation (solid line) and GEOS-3 reanalysis (dashed line).

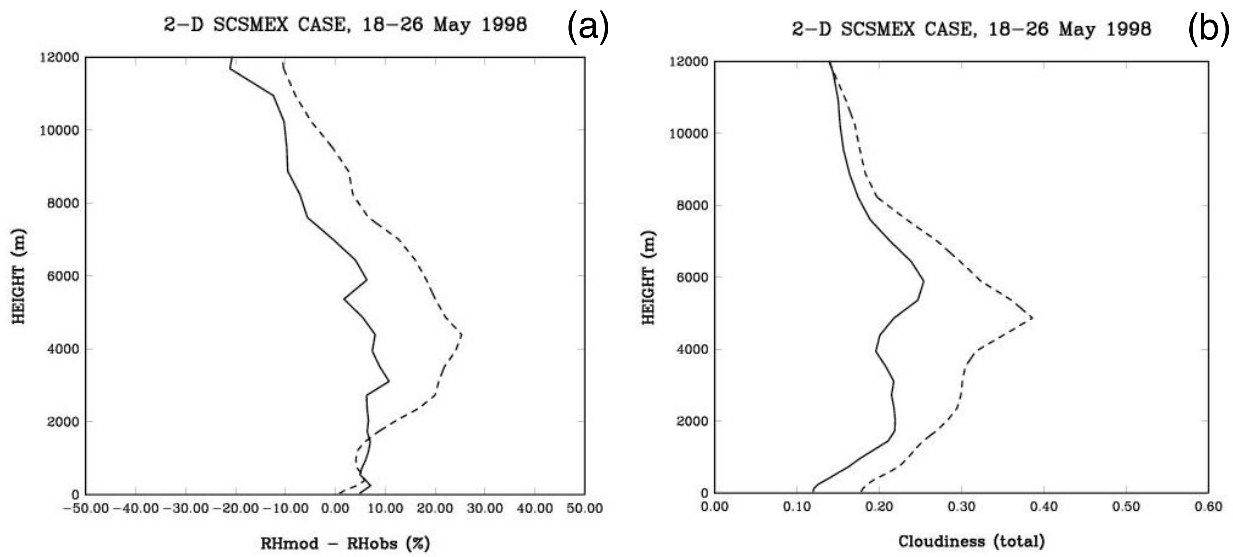

Fig. 3: Time-averaged (SCSMEX 18-26 May, 1998) (a) discrepancy of simulated relative humidity (%) and (b) simulated total cloudiness for the simulation using sounding network observation (solid line) and GEOS-3 reanalysis (dashed line).

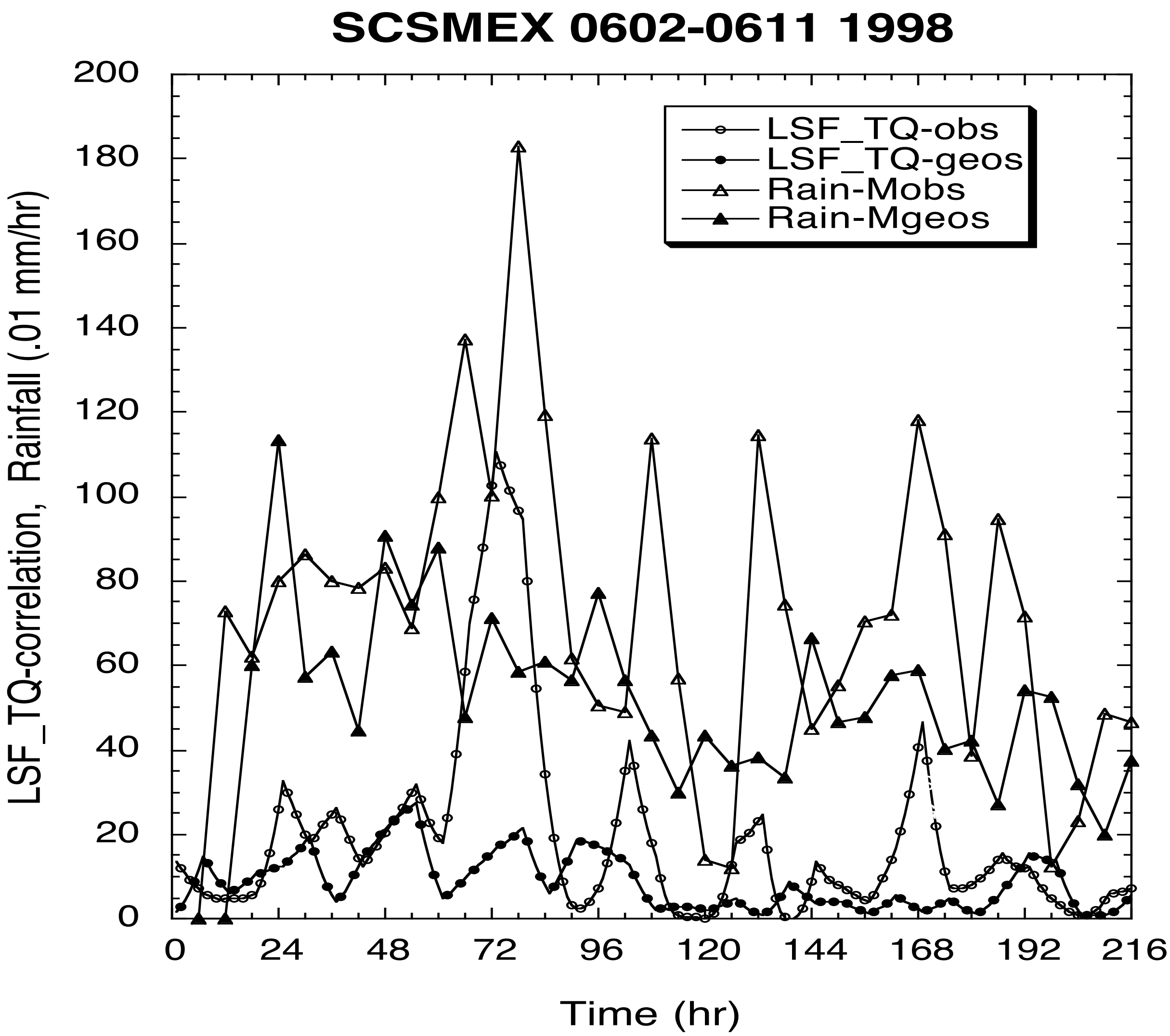

Fig. 4: Time sequence of the GCE 3-D model-simulated domain-mean surface rainfall rate (0.01 mm/hr) for the SCSMEX 2-11 June, 1998 episode using the temperature and moisture large-scale forcing based on either sounding observations (curve with open triangle), or the GEOS-3 [Goddard EOS (Earth Observing System) Version-3] reanalysis data (curve with solid triangle). The correlation between large-scale temperature and moisture forcing based on sounding observations (curve with open circle) and the GEOS-3 reanalysis data (curve with solid circle) is also shown (i.e., the two relatively lower curves among the four curves). Details for attaining the correlation value is described in the main text.