Large Eddy Simulation of Entire Tropical Cyclone

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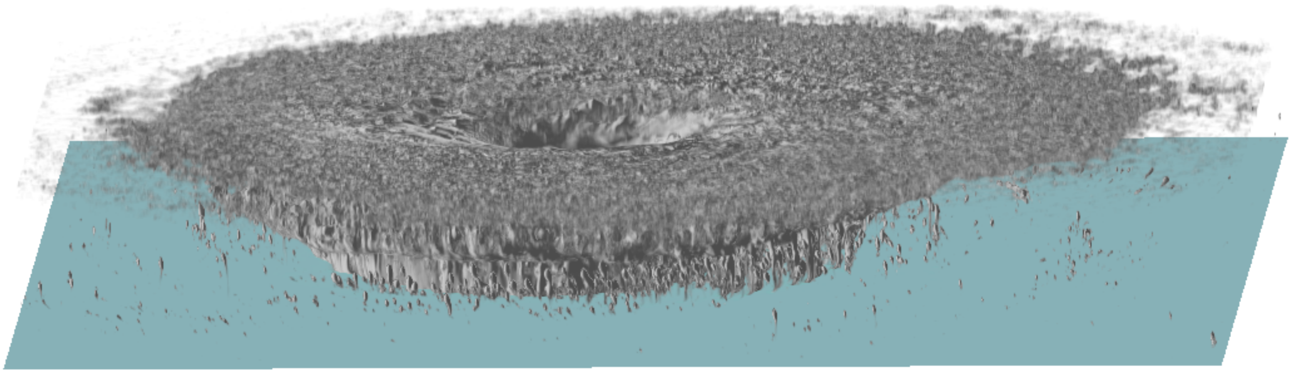
Most numerical models of a tropical cyclone do not have a resolution to explicitly simulate turbulent eddies, but their effects are parameterized. Such parameterizations must introduce significant uncertainties. Large Eddy Simulation (LES) which resolve the eddies can mitigate the uncertainties, while it requires more computational resources.

Taking advantage of the huge computational power of a massive parallel supercomputer (K-supercomputer, AICS, RIKEN), LES of entire tropical cyclones is realized. A regional numerical weather predicition model used in this study is Japan Meteorological Agency's Non-Hydrostatic Model (JMA-NHM). The computational domain covers 2000 km by 2000 km in the horizontal and 23 km in the vertical directions, and horizontal boundary conditions are doubly cyclic. The grid number is 20000 by 20000 in the horizontal directions, and 60 in the vertical direction where grid spacing increases with increasing height. Before starting the LES, a preliminary run with JMA-NHM with dx=2km is made. In this preliminary run, a tropical cyclone develops from a weak initial vortex to a mature stage after 120 hours integration. The grid point values of this mature stage are interpolated to prepare the initial condition for the LES. The time integration of the LES is then performed for 10 hours.

Figure exhibits the cloud amount (mixing ration of hydrometers) of a reproduced tropical cyclone in the LES. The wall cloud around the eye consist of a number of cumulus clouds. Although the fine scale structures are resolved in the LES, the maximum of the near-surface wind changes little from that simulated based on coarse-resolution runs. The boundary layer height is smaller in the LES, and this may shrink the radius of the maximum wind

We explore especially near-surface coherent structures in the TC boundary layer. Three kinds of coherent structures appeared inside the boundary layer: Type-A roll, which is caused by an inflection-point instability of the radial flow and prevails outside the radius of maximum wind. The second is a Type-B roll that also appears to be caused by an inflection-point instability but of both radial and tangential winds. Its roll axis is almost orthogonal to the Type-A roll. The third is a Type-C roll, which occurs inside the radius of maximum wind and only near the surface. It transports horizontal momentum flux in an up-gradient sense and causes the largest gusts.

Keywords: Tropical Cyclone, Large Eddy Simulation, Supercomputer, Turbulence, Regional Weather Prediction Model



Effects of cloud condensate vertical alignment on radiative transfer calculations in deep convective regions

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Effects of cloud condensate vertical alignment on radiative transfer process were investigated using cloud resolv- ing model explicit simulations, which provide a surrogate for subgrid cloud geometry. Diagnostic results showed that the decorrelation length Lcw varies in the vertical dimension, with larger Lcw occurring in convective clouds and smaller Lcw in cirrus clouds. A new parameterization of Lcw is proposed that takes into account such varying features and gives rise to improvements in simulations of cloud radiative forcing (CRF) and radiative heating, i.e., the peak of bias is respectively reduced by 8 W m−2 for SWCF and 2 W m−2 for LWCF in comparison with Lcw = 1 km.

The role of Lcw in modulating CRFs is twofold. On the one hand, larger Lcw tends to increase the standard deviation of optical depth $\sigma \tau$, as dense and tenuous parts of the clouds would be increasingly aligned in the vertical dimen- sion, thereby broadening the probability distribution. On the other hand, larger $\sigma \tau$ causes a decrease in the solar albedo and thermal emissivity, as implied in their convex functions on τ. As a result, increasing (decreasing) Lcwleads to decreased (increased) CRFs, as revealed by comparisons among Lcw = 0, Lcw = 1 km andLcw = ∞. It also affects the vertical structure of radiative flux and thus influences the radiative heating. A better representa- tion of $\sigma \tau$ in the vertical dimension yields an improved simulation of radiative heating. Although the importance of vertical alignment of cloud condensate is found to be less than that of cloud cover in regards to their impacts on CRFs, it still has enough of an effect on modulating the cloud radiative transfer process.

Keywords: horizontal inhomogenity, vertical alignment, cloud resolving model

The Impact of Dimensionality on Barotropic Processes during KWAJEX

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In this study, the two-dimensional (2D) and three-dimensional (3D) cloud-resolving model simulations of the Tropical Rainfall Measuring Mission (TRMM) Kwajalein Experiment (KWAJEX) are compared to study the impact of dimensionality on barotropic processes during tropical convective development. Barotropic conversion of perturbation kinetic energy is associated with vertical transport of horizontal momentum under vertical shear of background horizontal winds. The similarities in both model simulations show that (1) vertical wind shear is a necessary condition for barotropic conversion, but it does not control the barotropic conversion; (2) the evolution of barotropic conversion is related to that of the vertical transport of horizontal momentum; (3) the tendency of vertical transport of horizontal momentum is mainly determined by the horizontal transport of cloud hydrometeors. The differences between the 2D and 3D model simulations reveal that (1) the barotropic conversion has shorter time scales and larger amplitudes in the 2D model simulation than in the 3D model simulation; (2) kinetic energy is generally converted from the mean circulations to perturbation circulations in the 3D model simulation. In contrast, more kinetic energy is transferred from perturbation circulations to the mean circulations in the 2D model simulation; (3) there is no statistical relation in barotropic conversion between the 2D and 3D model simulations.. The same large-scale vertical velocity may account for the similarities whereas the inclusion of meridional winds in the 3D model simulation may be responsible for the differences in barotropic conversion between the 2D and 3D model simulations.

Keywords: Cloud-resolving model, barotropic conversion, vertical wind shear

A numerical study of ice nucleation process and crystal habit for Arctic mixed-phase clouds

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In this presentation, the ice nucleation processes and ice crystal habits are investigated numerically for Arctic mixed-phase stratus. Arctic region is well known for its high sensitivity to climate change and the liquid-containing clouds play an important role in the surface energy budgets as well as at TOA. In our previous studies (de Boer et al. 2010, 2013), it was hypothesized that the immersion freezing process is the key self regulating process where the large droplets freeze quickly and fall out of the super-cooled layer. Our 2D LES experiments highlighted the importance of insoluble characteristics of aerosol particles instead of soluble fraction. However, we did not take into account the condensation freezing (or deliquescence freezing) mode. This time we use a classical nucleation theory approach to deal with the ice nucleation modes more rigorously and implement 3D LES experiments.

The dynamic model is UW-NMS (Tripoli 1992) and the cloud microphysical scheme is AMPS (Hashino and Tripoli 2007, 2008, 2011ab). The ice part of AMPS (SHIPS) is particularly unique in that it predicts ice crystal habits explicitly, thus it is suitable to study ice nucleation process for the mixed-phased clouds. The case studies were chosen from SHEBA (Surface Heat Budget of the Arctic Ocean) and ISDAC (Indirect and Semi-Direct Aerosol Campaign) field campaigns. We will discuss the dominant mode of ice nucleation and resulting habits with parcel model settings and LES experiments. Furthermore, to better understand the applicability of the classical nucleation theory approach to cloud-resolving simulations, we will simulate the same cases with larger spatial resolution.

Keywords: Arctic clouds, Ice nucleation, crystal habit

Evaluation of simulated ice clouds using joint CALIPSO and CloudSat satellite observations

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This study developed a new method to evaluate simulated ice clouds using joint CloudSat and CALIPSO satellite observations. This method used joint histogram of cloud optical depth from cloud top and cloud microphysical properties (e.g., ice water content or effective radius) in comparison between simulated results and observations. To examine observed cloud optical depth, we integrated extinction coefficient with 550 nm wave-length observed by the Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP Lidar). Ice cloud microphysical properties were retrieved by using the radar-lidar algorithm developed by Okamoto et al., [2010] with cloud masking and cloud-phase detection techniques [Hagihara et al., 2010; Yoshida et al., 2010]. This method was limited to around cloud top (cloud optical depth smaller than about 2) because the lidar signal was fully attenuated in deeper cloud layers.

This study first evaluated global ice clouds and then focused on ice clouds over major mountain regions (e.g., the Andes). We used a global non-hydrostatic atmospheric model NICAM [Tomita and Satoh, 2005; Satoh et al., 2008; 2014] with a double-moment bulk cloud microphysics scheme [Seiki and Nakajima, 2014; Seiki et al., 2014; 2015] for global simulations. The simulated results were processed by the Joint Simulator for Satellite Sensors package [Hashino et al., 2013; Satoh et al., 2016]. This simulator provided us with consistent radiative signals with those observed by space-borne optical sensors. We performed sensitivity experiments by changing cloud microphysics and model resolutions to optimize uncertain ice cloud microphysics.

We found that cloud optical depth from the cloud top was a good measure to evaluate vertical profile of cloud microphysical properties instead of using altitude as a vertical coordinate. In particular, vertical profiles of cloud microphysical properties in the altitude-coordinate were found to be affected by change in cloud dynamics rather than cloud microphysics. Using this analysis method, we suggested that improvement in cloud microphysics had more impact on reproducing observed vertical profiles of cloud microphysical properties when the model horizontal resolution was finer than 14 km.

Keywords: Cloud Microphysics, Ice Clouds, Climate Modeling

Suggestions from a global cloud system resolving simulation to global climate model -Transportation of black carbon aerosol to the Arctic-

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In this study, we investigated effects of horizontal grid resolution on the transportation of black carbon aerosol (BCA) to the Arctic region. BCA in the Arctic has unique and large impact on the climate system through changing the albedo of snow-covered surface as well as absorbing and scattering sunlight. Despite its profound impact, most of the current generation general circulation models (GCM) underestimate BCA in the Arctic. To clarify the reason of the underestimation, the global aerosol transport simulation with kilometer order resolution (3.5km) was conducted. We also conducted sensitivity experiments with coarsening horizontal grid resolution from 3.5 km to 56 km to investigate the impacts of horizontal grid resolution. Our results indicated that BCA mass concentration in the Arctic increased with fining grid resolution, and the BCA mass concentration in the Arctic simulated with the 3.5-km grid resolution was 4.2 times larger than that simulated with a coarse (56-km) grid resolution. The underestimation of BCA was reduced by fining the grid resolution. Results of this study propose that global simulations using kilometre-order or finer horizontal resolution can lead to more accurate estimations of the distribution of BCA in the Arctic and reduce uncertainties regarding the effects of aerosols on global climate. As well as the BCA, we will introduce the several results of global cloud system resolving simulation coupled with aerosol transport model.

Keywords: Black carbon aerosol, Cloud system resolving model, Aerosol transpot model

Using Global Mesoscale Model Results to inform GEOS GCM Moist Process Parameterizations

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The GEOS Atmospheric General Circulation Model (AGCM) is currently in use in the NASA Global Modeling and Assimilation Office (GMAO) at a wide range of resolutions for a variety of applications including atmospheric analyses and forecasts, coupled atmosphere-ocean simulations and global mesoscale simulations. A global mesoscale simulation at approximately 7-km horizontal resolution was used to examine the subgrid-scale variability of several fields within several coarser-resolution grid sizes. These subgrid scale variances are relevant for informing the parameterization of moist processes in the GEOS GCM, and are the total water, relevant for the cloud macrophysics, the vertical velocity, relevant for the cloud microphysics related to cirrus formation, and the near-surface moist static energy, relevant for the cumulus parameterization. The analysis of the global mesoscale model output also allowed a proper implementation of resolution dependant behavior in the parameterizations. Modification of the parameterizations using the subgrid scale information were implemented in the GCM and the impact on the AGCM simulations will be presented here. The statistics of total water and vertical velocity had a positive impact on the simulations, and the moist static energy impact is still under development.

Keywords: GCM, Moist Processes, Parameterization

RCEMIP: Radiative Convective Equilibrium Model Inter-comparison Project

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Radiative Convective Equilibrium Model Inter-comparison Project (RCEMIP) is proposed.
Radiative-convective equilibrium (RCE) is referred to as atmospheric quasi statistical balance between convection and radiation processes (Manabe and Strickler 1964). Historically, RCE has been argued mainly with one-dimensional models, but in recent years more computationally intensive numerical calculations of RCE have been conducted with three-dimensional numerical models with explicitly resolved convection and domain lengths of 100-1000 km. A simple horizontally uniform boundary condition is prescribed with a constant sea surface temperature (SST) or a slab ocean model with uniform solar insolation. Since clouds are a most ambiguous part of climate models, the simple framework of RCE is suitable for understanding how clouds are simulated in numerical models. RCE is also useful to clarify the sensitivities of clouds to the details of cloud schemes implemented in numerical models (e.g., Satoh and Matsuda 2008). A number of RCE numerical studies have been conducted until recently with their own various configurations. One category is RCE on the sphere either with or without a cumulus parameterization scheme (e.g., Popke et al., 2013; Arnold and Randall, 2015; Reed et al., 2015; Bony et al., 2016; Satoh et al., 2016; Ohno and Satoh, 2016). The other category is RCE with regional models in an arbitrary domain size , primarily with explicitly resolved convection (e.g., Wing and Cronin 2016; Silvers et al. 2016). In order to systematically understand differences or similarities of various model results, a more coordinated framework for RCE numerical studies is demanded as "RCEMIP". Possible choices for experimental settings of RCE are listed as follows:
Geometry: sphere / plane (square or channel)
Domain size: Earth radius R / length=40,000 km ×factor (e.g., 0.1–1.0)
Horizontal resolution: Δx = 1–10 km for explicit convection, or coarser resolution (1–2 degree) with a cumulus parameterization
Boundary condition: fixed SST (e.g., 296, 300, 304K) or a slab ocean
CO_2: a current value or increased (e.g., 4×CO_2)
Physics dependency: cloud microphysics, turbulence, radiation,; switch on/off of cumulus parameterization
Interactive radiation or non-interactive, with/without clouds
With or without diurnal cycle
Without rotation, or with rotation
Among a lot of varieties listed above, we will discuss the experimental design of RCEMIP, scientific targets, and how to proceed. One strength of RCEMIP is the numerous scientific questions that could be explored, such as better understanding of uncertainties of climate sensitivities and changes in clouds and circulations, or convective aggregation, associated with global warming.

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Keywords: radiative convective equilibium, cloud resolving model, general circulation model, model intercomparison project, RCEMIP

The Environment of Aggregated Deep Convection

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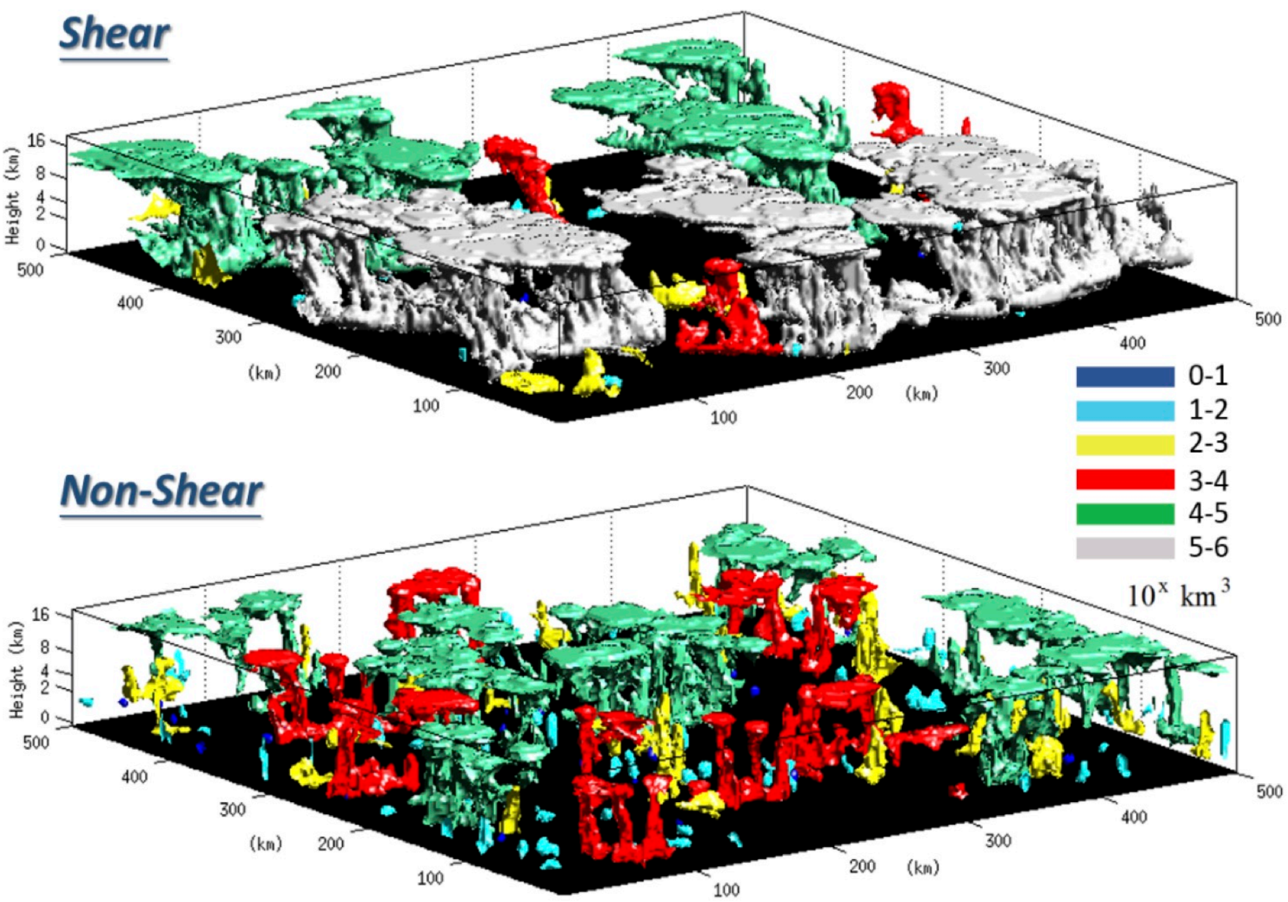
In this study, the environment of aggregated deep convection is investigated using a vector vorticity equation cloud-resolving model (VVM). Idealized experiments are performed under various environmental moisture with or without imposed vertical wind shear. Convective aggregation is then evaluated through diagnosing the 3-D size of an individual cloud from the model output using a six-connected segmentation method.
The aggregated convection is recognized by a distinct mode with larger size in the cloud size distribution. The results suggest that aggregated convection tends to develop when column relative humidity (CRH) is larger than 80% (67%) in non-shear (shear) cases. In addition, the degree of aggregation further increases with the increase of CRH. This aggregation process may be caused by an increasing probability of multi-cellular cloud structure under a moister environment. The results suggest that there are at least 5 core-updrafts of such system. Analyses of precipitation distribution suggest that that the probability of extreme precipitation increases with the increase of aggregated convection. The favorable environment of aggregated convection can be used to improve convective parameterizations in large-scale models.

Keywords: cloud-resolving model, aggregated convection, extreme precipitation



Change in the horizontal scales of convection due to the self-aggregation of clouds under the radiative convective equilibrium

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Idealized explicit convection simulations in radiative convective equilibrium (RCE) has been applied to research on tropical convection. Recent studies using three-dimensional cloud-resolving model in RCE conditions show convection can aggregate into a single region, when the domain is sufficiently large and the sea surface temperature (SST) is warm enough. The phenomenon is called as 'self-aggregation'. Convective organization modifies the mean vertical profiles of temperature, water vapor, and radiative fluxes. The mean climate change into dry and warm after self-aggregation occurs. Self-aggregation is sensitive to the SST, domain size, and horizontal resolution. Previous studies show aggregations favor relatively high SST and large domain size. However, these dependency is not clearly understood. In this study, we are attempt to determine the sizes of a moist region after aggregated and research the SST dependency of them.
We use SCALE-RM model which is non-hydrostatic cloud resolving model developed by RIKEN AICS. The horizontal spacing is 4 km, with 80 vertical levels. Simulations have a domain size of 512 km X 512 km with doubly periodic lateral boundaries, fixed incoming solar radiation. These were conducted in which SST was changed from 292 K to 310 K every 2 K. Self-aggregation occurs in SST over 304 K. The horizontal length scale is determined spatial autocorrelation is larger than 1/e about various two-dimensional variables. Horizontal scales about perceptible water, OLR lowest model level water vape mixing ratio (Qv) are about 200 km when aggregation occurs (SST is larger than 304K) in this study at all aggregate case. However, these about 35m (lowest model level) temperature decrease with increasing SST. In no aggregate cases, the same trend is observed. In these cases, scales of Qv are about 30 km, but these of T are 30~100 km. Self-aggregation seems to be selected when Qv and T scale are same. Furthermore, simulations with water vapor nudging with horizontal mean water vapor shows low troposphere humidity anomaly is important for self-aggregation. Furthermore, simulations with water vapor nudging with horizontal mean water vapor shows low troposphere humidity anomaly is important for self-aggregation. These results show self-aggregation depends on low troposphere and boundary layer process.

Keywords: Self-aggregation, RCE, deep convection

Statistics of Clusters of Tropical Convection as Simulated by a Global Cloud-Resolving Model

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Representation of moist convection on global scale remains challenging for global climate models (GCMs), which typically resolve scales much larger than individual clouds or even cloud clusters. With rapid progress in the supercomputer technology, several global cloud-resolving models have emerged over the past decade or so, with the premise to advance our understanding of the role of moist convection in regulating the Earth’s climate system. A global version of a widely used cloud-resolving model (CRM), the System for Atmospheric Modeling (SAM), has recently been developed. The time and cost of development have been minimized by preserving most features and numerics of the SAM's existing anelastic non-hydrostatic dynamical core while generalizing it from rectangular to latitude-longitude grid. The main software challenge has been the development of efficient and highly scalable hybrid FFT-multigrid solver for elliptic equation for pressure. The model uses a single-moment bulk microphysics, comprehensive radiation transfer module, the Simplified Land Model (SLM) with 16 IGBP land types, single layer of vegetation, multilayered interactive soil, and a block representation of topography in the height coordinates. The preliminary results of multi-month global cloud-resolving simulations with a 4 km horizontal grid spacing at the equator will be presented. In particular, the statistics of convective clusters in the simulated Tropics and the diurnal cycle of precipitation over land and ocean will be discussed.

Keywords: global cloud-resolving model, convection, large-scale organization of clouds

The impact of simulated mesoscale convective systems on global precipitation and its characteristics

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The importance of precipitating mesoscale convective systems (MCSs) has been quantified from TRMM precipitation radar and microwave imager retrievals. MCSs generate more than 50% of the rainfall in most tropical regions. Typical MCSs usually have horizontal scales of a few hundred kilometers (km); therefore, a large domain with several hundred km and high resolution are required for realistic simulations of MCSs in cloud-resolving models (CRMs). Almost all traditional global and climate models do not have adequate parameterizations to represent MCSs. Typical multi-scale modeling frameworks (MMFs) with 32 CRM grid points and 4 km grid spacing may also lack the resolution (4 km grid spacing) and domain size (128 km) to realistically simulate MCSs.

In this study, the impact of MCSs on precipitation is examined by conducting model simulations using Goddard Cumulus Ensemble (GCE) model, and Goddard MMF (GMMF). The results indicate that both models can realistically simulate MCSs with more grid points (i.e., 128 and 256) and higher resolutions (1 or 2 km) compared to those simulations with less grid points (i.e., 32 and 64) and low resolution (4 km). The modeling results also show the strengths of the Hadley circulations, mean zonal and regional vertical velocities, surface evaporation, and amount of surface rainfall are weaker or reduced in the GMMF when using more CRM grid points and higher CRM resolution. In addition, the results indicate that large-scale surface evaporation and wind feed back are key processes for determining the surface rainfall amount in the GMMF. Sensitivity tests with sea surface temperatures (reduced or coupled with ocan model) will be presented at meeting.

Keywords: Global Precipitation, Cloud resolving model, Multi-scale modeling framework, Mesoscale convective system

