Large Eddy Simulation of Entire Tropical Cyclone

*Junshi Ito[1,3], Tsutao OIZUMI[2], Hiroshi Niino[3]

1. Meteorological Research Institute, Japan Meteorological Agency, 2. JAMSTEC, 3. The University of Tokyo

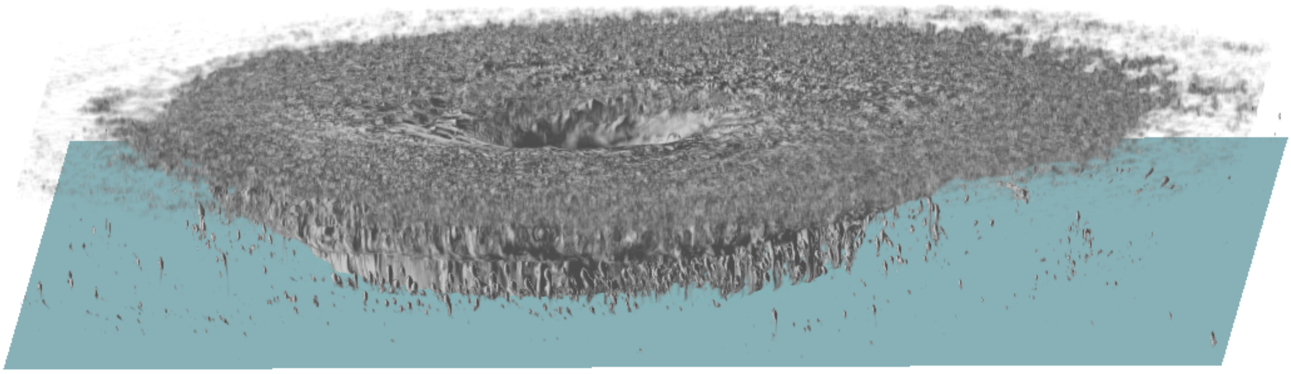
Most numerical models of a tropical cyclone do not have a resolution to explicitly simulate turbulent eddies, but their effects are parameterized. Such parameterizations must introduce significant uncertainties. Large Eddy Simulation (LES) which resolve the eddies can mitigate the uncertainties, while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

*Xiaocong Wang[1]

1. Institute of Atmospheric Physics

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

*Xiaofan Li[1]

1. Zhejiang University

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

*Tempei Hashino[1], Gijs de Boer[2], Hajime Okamoto[1]

1. Kyushu University, 2. Univeristy of Colorado at Boulder

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

*Tatsuya Seiki[1], Chihiro Kodama[1], Masaki Satoh[2], Tempei Hashino[3], Yuichiro Hagihara[4], Hajime Okamoto[3]

1. Japan Agency for Marine-Earth Science and Technology, 2. The University of Tokyo, 3. Kyushu University, 4. Japan Aerospace Exploration Agency

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-

*Yousuke Sato[1], Hiroaki Miura[2], Hisashi Yashiro[1], Daisuke Goto[3], Toshihiko Takemura[4], Takuro Michibata[4], Kentaroh Suzuki[5], Teruyuki Nakajima[6]

1. RIKEN Advanced Institute for Computational Science, 2. Department of Earth and Planetary Science, The University of Tokyo, 3. National Institute for Environmental Studies, 4. Research Institute for Applied Mechanics, Kyushu University, 5. Atmosphere Ocean Research Institute, The University of Tokyo, 6. Earth Observation Research Center, Japan Aerospace Exploration Agency

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

*Andrea Molod[1], Donifan Barahona[1], Nathan Arnold[1]

1. NASA Goddard Space Flight Center

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

*Masaki Satoh[1], Tomoki Ohno[1], Allison Wing[2], Sandrine Bony[3], Bjorn Stevens[4], Kevin Reed[5]

1. Atmosphere and Ocean Research Institute, The University of Tokyo, Kashiwa, Japan, 2. Department of Earth, Ocean, and Atmospheric Science, Florida State University, USA, 3. Laboratoire de Météorologie Dynamique, IPSL, CNRS, Paris, France, 4. Max-Planck Institute for Meteorology, Hamburg, Germany, 5. School of Marine and Atmospheric Science, Stony Brook University, NY, USA

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

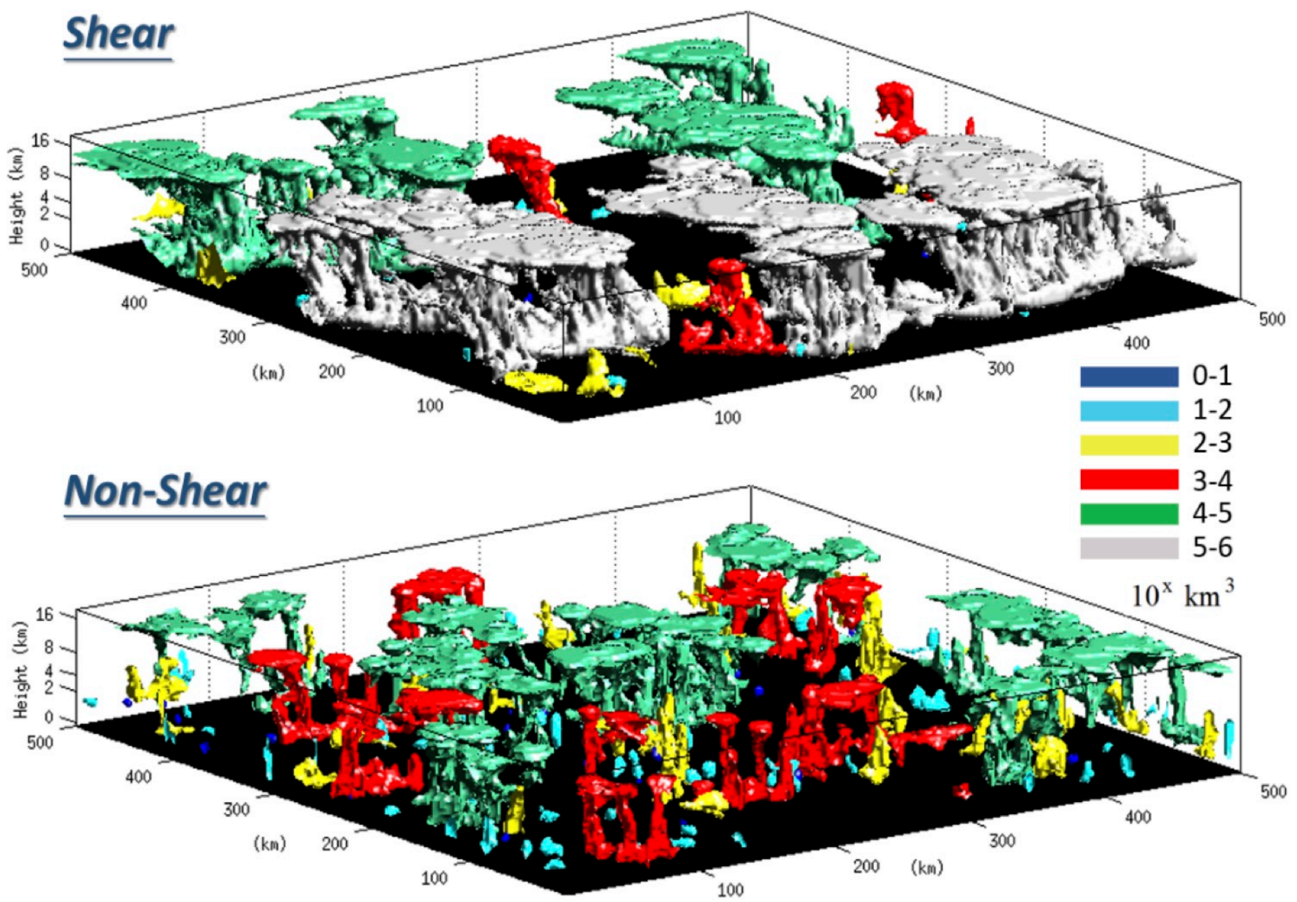
The Environment of Aggregated Deep Convection

*Chien-Ming Wu[1], Wei-Ming Tsai[1]

1. Department of Atmospheric Sciences, National Taiwan University

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

*Shuhei Matsugishi[1], Hiroaki Miura[1]

1. Department of Earth and Planetary Science, Graduate School of Science, The University of Tokyo

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

*Marat Khairoutdinov[1]

1. Stony Brook University

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

*Wei-Kuo Tao[1]

1. NASA Goddard Space Flight Center

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

Torrential Rainfall Responses of Typhoon Fitow (2013) to Radiative Processes: A Three-Dimensional WRF Modeling Study

*Huiyan Xu[1]

1. Zhejiang University

The three-dimensional Weather Research and Forecasting (WRF) model is used to conduct sensitivity experiments of Typhoon Fitow in 2013 during its landfall. Surface rainfall and heat budgets as well as the vertical profiles of stability and vertical velocity are analyzed to examine physical processes responsible for radiative effects on rainfall. The inclusion of radiative effects of liquid clouds suppresses radiative cooling in liquid cloud layers via reducing outgoing radiation to ice cloud layers, whereas it enhances radiative cooling in ice cloud layers through trapping less radiation from liquid cloud layers. The enhanced radiative cooling decreases from ice cloud layers to liquid cloud layers. The suppressed stability and vertical mass convergence increase. Thus, heat divergence is weakened to warm the atmosphere, which reduces net condensation and rainfall. The inclusion of radiative effects of ice clouds suppressed radiative cooling by reducing outgoing radiation. The suppressed radiative cooling reduces from ice cloud layers to liquid cloud layers and the suppressed instability and vertical mass convergence decreases when radiative effects of liquid clouds are present. As a result, heat divergence is strengthened to cool the atmosphere, which increases net condensation and rainfall. The suppressed radiative cooling increases temperature and reduces net condensation and rainfall when radiative effects of liquid clouds are absent.

Keywords: Radiative effects, cloud and heat budget

Convective-Stratiform Rainfall Separation: A Three-Dimensional WRF Modeling Study

*Guoqing Zhai[1]

1. Zhejiang University

In this study, convective-stratiform rainfall separation scheme is developed based on a three-dimensional surface precipitation budget equation using the WRF model simulation of Typhoon Fitow (2013). The results show that water vapor convergence moistens local atmosphere and support hydrometeor divergence, and maximum rainfall corresponds to water vapor and hydrometeor convergence and local atmospheric drying. The separation results are verified by analyzing vertical velocity and cloud microphysical budgets. Mean ascending motions are prevailing throughout the troposphere over convective rainfall regions, whereas mean descending motions occur below 5 km and mean ascending motion occur above over stratiform rainfall regions. The frequency distribution of vertical velocity shows that vertical velocity has a wide distribution with the maximum values up to 13 m s^{-1} over convective regions, whereas it has a narrow distribution with absolute values confined within 7 m s^{-1} over stratiform region. Liquid cloud microphysics is dominant over convective regions whereas ice cloud microphysics is dominant over stratiform regions. The physical characteristics of the convective-stratiform rainfall in the three-dimensional framework conform generally to those from the two-dimensional framework.

Keywords: Convective-stratiform rainfall, cloud budget, vertical velocity

Polarimetric Radar Characteristics of Simulated and Observed Convective Cores Between Continental and Maritime Environment

*Toshi Matsui[1]

1. NASA GSFC & ESSIC UMD

Previous observational and simulation studies have suggested that dry surface turbulent heat fluxes, deeper boundary layers, and elevated lifting condensation levels likely generate continental convective vigor in association with enhanced cold-precipitation processes and stronger mesoscale dynamics. This study presents polarimetric radar characteristics of intense convective cores derived from observations as well as a polarimetric-radar simulator from cloud-resolving model (CRM) simulations from both a continental (MC3E: Midlatitude Continental Convective Clouds Experiment) and a maritime (TWP-ICE: Tropical Warm Pool-International Cloud Experiment) field campaign.

The **POLArimetric Radar Retrieval and Instrument Simulator (POLARRIS)** is a state-of-art Tmatrix-Mueller-Matrix-based polarimetric radar simulator that can generate synthetic polarimetric radar signals (reflectivity, differential reflectivity, specific differential phase, co-polar correlation) as well as synthetic radar retrievals (precipitation, hydrometeor type, updraft velocity) through the consistent treatment of cloud microphysics and dynamics from CRMs. The Weather Research and Forecasting (WRF) model is configured to simulate continental and maritime severe storms over the MC3E (continental) and TWP-ICE (maritime) domains with the Godddard bulk 4ICE single-moment microphysics and HUCM spectra-bin microphysics. Continental and maritime background thermodynamics in pre-storm environment are compared and various statistical diagrams of polarimetric radar signals, hydrometeor types, updraft velocity, and precipitation intensity are investigated with a focus on contrasting convective cores in continental-maritime environments.

Keywords: cloud-resolving model, polarimetric radar, precipitation

Comparison between bulk and bin cloud microphysical schemes for warm rain

*Naomi Kuba[1], Kentaroh Suzuki[1], Woosub Roh[1], Tatsuya Seiki[2], Masaki Satoh[1,2]

1. Atmosphere and Ocean Research Institute, The University of Tokyo , 2. Japan Agency for Marine-Earth Science and Technology

Two-moment bin and two-moment bulk cloud microphysical schemes were compared using a two-dimensional kinematic driver model and a forward simulator of satellite measurements. The conversion process from cloud droplets to raindrops was focused. From numerical experiments, the following results were found. The bulk and bin schemes studied in this paper show the effect of cloud droplet number on precipitation sufficiently, and the difference in rainfall amount between these schemes was small in contrast to previous studies. The vertical distributions of mass of rain water and number of raindrops in these schemes are quite different. It can be caused by overestimation of falling velocity of rainwater and underestimation of self-collection process (or overestimation of collisional breakup process) of raindrops in the bulk scheme. Time evolutions and patterns of the relationships between horizontally averaged reflectivity and optical depth from cloud top were similar between these schemes. The slope factor of this relationships (changing rate of horizontally averaged reflectivity for optical depth from cloud top) near the cloud top in a later stage of cloud lifetime is smaller in bulk scheme than bin scheme. Previous studies showed that the slope factor relates to bulk collection efficiency. However, it was shown that bulk collection efficiency assumed in this bulk scheme is almost same as that estimated in the bin scheme, and that overestimated falling velocity of raindrops leads to the smaller slope factor in this bulk scheme.

Keywords: Cloud microphysical scheme, satellite simulator, two-moment bin scheme, two-moment bulk scheme

Numerical simulation of heavy rainfall events in the Tokyo metropolitan area

*Naoko Seino[1], Ryoko Oda[2], Hirofumi Sugawara[3], Toshinori Aoyagi[1]

1. Meteorological Research Institute, 2. Chiba Institute of Technology, 3. National Defense Academy

Heavy rainfall in metropolitan area often draws public attention because of the large social impact. Better understanding of mesoscale and microscale processes, improved forecast, and sophisticated warning system of the severe weather are required for disaster resilience in urban areas. We investigated formation and development processes of an extremely developed thunderstorm on 26 August 2011 (Case 1) and a moderately developed thunderstorm on 18 July 2013 (Case 2) in the Tokyo metropolitan area. Numerical simulations were carried out using the Non-Hydrostatic Model (NHM) of the Japan Meteorological Agency (JMA) incorporating the Square Prism Urban Canopy (SPUC) scheme. Model results fairly represented spatial distribution and amounts of the rainfall. The lower LFC and the thicker easterly flow layer characterized the mesoscale environment in Case 1. Formation of the distinct convergence zone between easterly and southerly flow is likely to trigger active convective systems at around Tokyo in Case 1. Urban impact on precipitation was also examined in comparative experiments using realistic built-up urban condition (CRNT experiment) and less urbanized condition (LURB experiment). Greater amounts of precipitation in the CRNT experiment than in the LURB experiment were simulated in the central urban area. Comparison of the meteorological fields between the two experiments suggests that the intensified convergence and ascending motion in Tokyo due to urban temperature rise can cause precipitation increase at around the central urban area.

Keywords: heavy rain, urban effect, NHM

Numerical weather prediction experiment over the United Arab Emirates using JMA-NHM

*Akihiro Hashimoto[1], Masataka Murakami[1,2], Shigenori Haginoya[1]

1. Meteorological Research Institute, Japan Meteorological Agency, 2. Institute for Space-Earth Environmental Research, Nagoya University

Japan Meteorological Agency Non-Hydrostatic Model (JMA-NHM) is applied to meteorological simulations that partly cover the Middle East including the arid and semi-arid regions in the United Arab Emirates (UAE) in order to predict cloud and precipitation properties for supporting the cloud seeding field experiment planned in the summer of 2017. At first, one-year (from February 2015 to January 2016) hindcast experiment was performed with 5 km horizontal resolution to examine the performance of the model for reproducing clouds and precipitation in the UAE and to adjust the model configuration to the UAE’ s environment, which is much drier than Japanese environment. With the original configuration, the model failed to reproduce daytime high surface air temperature, because of unrealistically large evaporation of soil water and low sensitivity of land surface temperature to solar radiation, which gave adverse effect to reproducibility of clouds and precipitation. We changed the soil and land surface parameters such as heat capacity, heat conductivity, roughness length, soil water content, etc, so as to be more representative for the arid and semi-arid environments. With the new configuration, the model clearly showed much better agreements with observations in terms of the diurnal variation of land surface temperature and surface air temperature, and formation of clouds and precipitation. In addition, we performed another hindcast experiment through the same period with 1 km horizontal resolution to examine a dependency of simulation result on a horizontal resolution. The finer horizontal resolution enhanced thermal convections over the arid and semi-arid regions, and consequently increased cloud formation, which further improved the skill of the model.

Acknowledgement
This study was conducted as a part of the project “Advanced Study on Precipitation Enhancement in Arid and Semi-Arid Regions.” that is supported by the UAE Research Program for Rain Enhancement Science, an initiative of the Ministry of Presidential Affairs, under the management of the National Center of Meteorology and Seismology.

Keywords: Land surface temperature, Non-hydrostatic regional model , Arid and semi-arid region, Rain enhancement, UAEREP

Sensitivity studies of cloud responses on SSTs in RCE experiments using a high-resolution global nonhydrostatic model

*Tomoki Ohno[1]

1. Atmosphere and Ocean Research Institute, The University of Tokyo

As the variation in climate sensitivity among global climate models (GCM) is largely attributable to differences in cloud feedback, better understanding of the response of clouds to climate changes provides important insights into climate science. The radiative-convective equilibrium (RCE) is one of key ingredients in order to understand the role of moist convection in the atmosphere. To reduce the uncertainties of the response of clouds to climate changes, simulations with RCE configurations are examined using a high-resolution nonhydrostatic global circulation model (the Nonhydrostatic Icosahedral Atmospheric Model; NICAM; Satoh et al., 2014). The configurations with fixed SSTs, explicit microphysics parameterizations, and no cumulus parameterization are used. Especially, the sensitivity of the high clouds, liquid water path, and ice water path to vertical grid spacings are studied using fixed SST configurations, as previous studies showed high clouds responses are different between NICAM and other coarse resolution climate models. In addition, it was found that vertical grid spacings of 400 m or less are necessary to resolve the bulk structure of cirrus clouds, we also examine sensitivities to vertical resolutions (Seiki et al., 2015).

It is found that amounts of high cloud increase as associated with the increase of SST in the simulations with different cloud microphysics schemes, although the heights of high clouds and detrainment speeds near the convective region depend on microphysics schemes used. The responses of the amount of high cloud are consistent with those of the tropical cloud of the study of Satoh et al. (2012) based on the global simulations. However, the response of the amount of high cloud in simulations with higher vertical resolutions vary with cloud microphysics schemes, although the heights of high clouds and detrainment speeds near the convective region are similar to those of simulations with relatively lower vertical resolutions. These results indicate that differences of properties of clouds such as effective radii of hydrometeors and their dependencies for the vertical resolution are possible cause of variations of the response of clouds to climate changes. In addition, they suggest the possible existence of uncertainties of the results of studies based on the simulations with conventional GCMs which do not consider the microphysical properties.

Keywords: radiative-convective equilibrium

Microphysics and cumulus parameterization sensitivity of the WRF Model to extreme rainfall in tropical Island - Evaluation of the 2016 May flood event of Sri Lanka

*Suranjith Bandara Koralegedara[1,2,3], Chuan Yao Lin[1,2], Yang Fan Sheng[2]

1. Earth System Science Program, Taiwan International Graduate Program, Academia Sinica, Taipei, Taiwan, 2. Research Center for Environmental Changes, Academia Sinica, Taipei, Taiwan, 3. Institute of Atmospheric Physics, College of Earth Science, National Central University, Zhongli, Taiwan

This study uses the Advanced Research Weather Research and Forecasting model (WRF-ARW) 3.6.1 to improve the simulation of the features associated with an extreme rainfall and flood event over Sri Lanka on 14th to 20th May 2016. Several sensitivity experiments were conducted to examine the model performances with respect to different combinations of cloud microphysics schemes and cumulus parameterizations. The model domain consists of one domain with 3 km horizontal grid resolution and the National Centers for Environmental Prediction Climate Forecast System version 2 (NCEP-CFSv2) data at 0.5 degrees and 45 vertical levels were used as initial and lateral boundary conditions. Three different microphysical schemes (namely - Lin, WSM6, Morrison) and four cumulus parameterization scheme options (namely - Kain-Fritsch, Betts-Miller-Janjic, Grell-Freitas ensemble, Explicit Convection) were tested for their performance in simulating the event. Hourly rainfall and the accumulated rainfall of the event were compared with the observation data obtained from the Department of Meteorology, Sri Lanka, and the CMORPH (the climate prediction center morphing algorithm) data. All the parametrization combinations were able to simulate the extreme event initiation, development, and accumulated rainfall nearly well. In particular, the combination of Lin microphysics scheme with Yonsei University PBL scheme and Kain-Fritsch cumulus parameterization scheme provides the optimal combination of physical parameterization schemes in the simulation of this extreme rainfall and flood event over Sri Lanka. The study also emphasizes the need for a comprehensive, multi-observational platform observational campaign to improve the parameterizations of the cloud microphysics and cumulus convection for the numerical weather simulations over Sri Lanka. Moreover, suggesting WRF has a potential for operational use in numerical weather prediction in Sri Lanka and these parametrizations would serve as reference in future numerical weather forecasting or simulation in similar extreme events

Keywords: Model sensitivity, Atmospheric dynamics, Microphysics, Cumulus convection, WRF model

The radiative impact of precipitating ice in a global nonhydrostatic model

*Ying-Wen Chen[1], Tatsuya Seiki[1], Chihiro Kodama[1], Masaki Satoh[2,1], Akira T. Noda[1]

1. Japan Agency for Marine-Earth Science and Technology, 2. Atmosphere and Ocean Research Institute, The University of Tokyo

This study examines the impact of precipitating ice (snow and graupel) on the longwave (LW) radiative flux by evaluating the output data from a global cloud-system resolving model. An offline radiation model based on the radiation transfer code, MSTRNX (Sekiguchi and Nakajima 2008) is employed, and the precipitating ice data, simulation results from a nonhydrostatic icosahedral model (NICAM, Satoh et al. 2014) with a double-moment cloud microphysics scheme with six-water categories (rain, cloud waver, cloud ice, snow, and graupel; Seiki and Nakajima 2014), are used. The horizontal resolution of model output data is approximately 14-km, the cloud process is solved explicitly, and the analyzed period is one boreal summer. Results show that the LW radiative flux in the tropical region is sensitive to the ice hydrometeor properties, and the snow contributing impact reaches a maximum about 2 W m^{-2} in the Indian Ocean region, while the average is 1.2 W m^{-2} in the tropics. Though there is a gap between our estimation and satellite borne estimations (5-10 W m^{-2}; Waliser et al. 2011, Li et al. 2014), both suggest that the LW radiative impact by precipitating ice ignored in most general circulation models, is non-negligible. Specifically, the positive bias in the LW radiative flux in the tropical region appears in GCMs can be reduced by taking the interaction between the precipitating ice and the radiation field into account.

Keywords: simulated precipitating ice in a high resolution model, longwave radiative impact by precipitating ice

Severe Hailstorm in Nepal: Two case studies

*Deepak Aryal[1]

1. Tribhuvan University

Two severe hailstorms that took place in Nepal during the pre-monsoon months of May are investigated in this study. One storm occurred close to midnight on May 3, 2001 at Thori, 215m asl, a small village on the border with India. Giant 1kg hailstones destroyed 800 dwellings, most of the villagers' livestock (over 500 oxen and goats) and 200 hectare of crops. The second storm occurred at Pokhara, 800m asl, in Central Nepal on May 18, 2005, during the middle of the afternoon. The storm lasted 15 to 20 minutes and produced 1kg hail stones that destroyed 1000 vehicles, crops, property and caused many injuries. During the pre-monsoon months in Nepal, severe thunder and hailstorms cause significant property and agricultural damage in addition to loss of life from lightening. Forecasting thunderstorm severity remains a challenge even in wealthy, developed countries that have modern meteorological data gathering infrastructure, such as Doppler Radar. This study attempts to isolate the specific and unique characteristics of the two hailstorms that not only might explain their severity, but also suggest forecasting techniques for future forecasting in Nepal. The primary data sources for this investigation included Infrared Satellite images, which illustrated the sequences of convective activity, and original archived ESRL India and China upper air data, which were used for synoptic and mesoscale analyses.

The Thori hailstorm had its origins in a topographically induced lee-side convergence area in the deserts of Pakistan on May 2, 2001, from where it propagated eastwards into India and evolved into an eastwards travelling Mesoscale Convective Complex reaching Thori near midnight on May 3. Atmospheric instability over the Gangetic Plains, fueled by a very active surface heat low, cold temperatures and dynamic lifting mechanisms aloft, created a synoptic and mesoscale environment capable of generating a dangerous thunderstorm. Thori is known for frequent, severe hailstorms, owing to moisture convergence caused by the nature of its surroundings; an abnormally ample supply of moisture resulted in giant 1kg hailstones near midnight on May 3.

At Pokhara, late afternoon thunderstorms often accompanied by hail, are an almost daily occurrence during May. The hailstorm severity at Pokhara on May 18 was the result of enhanced convection from a sudden intrusion of extremely cold air aloft, originating over the Tibetan Plateau, to the lee-side of the Annapurna Region.

This study calculated CAPE values exceeding 7000J/kg for both hailstorms resulting in intense updraft speeds capable of sustaining giant hail growth.

Keywords: CAPE, Lifting Index, hailstorm, radiosonde, geopotential height

Simulation study of the nearshore convective system on 26 July 2011 in Korea

*Jung-Tae Lee[1], Dong-In Lee[1], Shingo Shimizu[3], Sang-Min Jang[2]

1. Division of Earth Environmental System Sciences, Pukyong National University, Korea, 2. Climate Application Team, Climate Application Department, APEC climate center, Korea, 3. Storm, Flood, and Land-Slide Research Department, NIED, Japan

The coastal zones belong to the most populated habitats worldwide, and the weather phenomena near the coast are immediately related to human life. The coastal weather phenomena are associated with sharp changes in heat, moisture, and momentum transfers between land and water. Those dramatic changes cause an unequilibrated state on the low-level flow, and transfers energy to the upper-side. It is quite crucial for prediction heavy rainfall to consider the effect of the surface, so that the transferring energy to upper-side provides a source of the convection. Especially, in a case of the coastal region has to be a meridional direction in the mid latitude such as the Korean Peninsula, the coast could be an important factor to trigger or enhance a convection of the precipitation system.
The rainfall case on 26 July 2011 caused over 150 mm of accumulated rainfall over 15 hours (26th 1500 to 27th 0600 LST) at wide regions. The narrow distributed heavy rainfall region skewed by over 300 mm to the coast, and the rain was one of the reasons for landslide and flash-floods. The precipitated core skewed to the coast is frequent rainfall pattern in the middle of the Korea.
Cloud Resolving Storms Simulator (CReSS) is implemented to simulate the heavy rainfall. The initial background to run storm simulator is the results of Meso-Scale Model (MSM) forecasted every 3 hours, and were resolved into the nested domain (Δx, y = 1 km). The successfully simulated results show similarly distributed rainfall compared with observation. The amount of rainfall concentrated on nearshore indicates that the simulated environment is sensitive to changed surface condition. The new cells were continuously generated by forced outflow of the pre-existing cell, sustained at nearshore. The cooled surface by the sustained outflow was the major role to propagate convergent region at low layer. On the other hand, the experiment which the land of the Korean Peninsula is assumed to be the sea does not simulate much precipitation and consequent cold pool.

Keywords: nearshore precipitation, surface change, cold pool

Evaluations of clouds in NICAM using CALIPSO and Joint simulator

*Woosub Roh[1], Masaki Satoh[1], Tempei Hashino[2], Hajime Okamoto[2]

1. AORI, the university of Tokyo, 2. RIAM, Kyushu university

The evaluation of cloud and precipitation is important in high-resolution models such as a Nonhydrostatic ICosahedral Atmospheric Model (NICAM, Satoh et al. 2014). These models are generally defined as nonhydrostatic models with horizontal grid spacing sufficiently fine to be able to explicitly simulate individual cloud systems. For clouds, NICAM more realistically represents microphysical processes, such as the consistent treatment of precipitating hydrometeors, compared with general circulation models (GCMs), and they calculate the time evolution, structure, and life cycle of cloud systems.
We evaluate thermodynamic phases of clouds in a NICAM using Joint simulator and a Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) lidar. For the evaluation, we developed the simulator of depolarization ratio in Joint simulator (J-simulator). We compare and analyze two simulations using two microphysics schemes such as NICAM Single-moment Water 6 (NSW6, Tomita 2008b) and the modified NSW6 (Roh and Satoh 2014).
Especially, we focus on the characteristics of ice clouds such as effects of backscatters distribution and temperature dependencies. We investigate the effects of ice clouds with 2D plate’s shape (2D plates) on cloud optical properties such as radar reflectivities and backscattering coefficients using CALIPSO data. A merged dataset for CloudSat radar and CALIPSO lidar (Hagihara et al. 2010) and DARDAR (Delanoë, J., and R. J. Hogan, 2010) data are used. We introduce the parameterization of 2D plates using temperature and relative humidity with respect ice for J-simulator.

Keywords: Microphysics, CALIPSO, Satellite simulator

