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

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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

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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

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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

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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

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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

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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

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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

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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

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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

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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

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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

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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

