Explicit solution of a problem modelling nonlinear Atmosphere dynamics with consideration of heat transfer, humidity and moisture content

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We present a theoretical study of solutions of nonlinear systems of partial differential equations which describe turbulent movement of Atmosphere flows counting with heat transfer, humidity and moisture content.
We investigate the existence and uniqueness of strong solution. We also establish an explicit algorithm for numerical computing of the solution by Galerkin method. The results may find practical application in modelling the Atmosphere dynamics, especially in the clouds, where the introduction of separate functions of humidity and water (moisture) content is justified.

Keywords: dynamics of the Atmosphere, numerical solutions of nonlinear PDE systems, explicit computing algorithm, Galerkin method, existence and uniqueness of solutions of PDE systems

Numerical simulations of Typhoon Haiyan in 2013

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Typhoon Haiyan in 2013 was among the strongest ever observed for tropical cyclones globally. The typhoon is characterized by fast translation, rapid intensification and extremely intense intensity at such a low latitude. To understand the behavior of the typhoon and to improve the intensity prediction, numerical simulations were performed by a regional coupled atmosphere-wave-ocean model with a horizontal resolution of 2 km. The effect of sea spray was included in the regional coupled model. Even using the model with a horizontal resolution of 2 km, it was difficult to reproduce rapid intensification of the typhoon and the maximum intensity without the effect of sea spray. An issue on the impact of horizontal resolution of numerical models on the simulation will be addressed. The effect of sea spray was confined to the near-surface boundary layer and led the typhoon to intensify more rapidly. The effect of Haiyan-induced sea surface cooling on the maximum intensity was 10 hPa at the maximum due to the fast translation. In order to understand the effect of translation speed on sea surface cooling and resultant maximum intensity of a typhoon, numerical simulations were performed for Typhoon Mike in 1990 because the track was similar to Haiyan's track. The regional coupled model also simulated intensity changes of Typhoon Mike in 1990 realistically that underwent moderate intensification with the slow translation and large sea surface cooling.

Keywords: Typhoon, Numerical simulation, Sea surface cooling

High-resolution global atmospheric data assimilation experiments with an ensemble Kalman filter

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It is crucial to develop a numerical weather prediction system including data assimilation in order to predict the extreme weather such as heavy rainfalls and typhoons in the post-K era. We have been developing the NICAM-LETKF system to assimilate the conventional observations, satellite microwave radiances from AMSU-A (Advanced Microwave Sounding Unit-A), and satellite-based global precipitation data GSMaP (Global Satellite Mapping of Precipitation). The NICAM-LETKF may be run at very high resolution, or may provide boundary conditions for even higher resolution systems. Improving the NICAM-LETKF performance is at the center of enhancing mesoscale predictability for better preparedness for severe weather events well in advance.

Data assimilation experiments have been conducted with NICAM-LETKF at 112- and 28-km horizontal resolution with 100 ensemble members. Higher resolution experiment can reproduce the precipitation field well by assimilating precipitation observations. We need to keep improving the physical and computational performances of NICAM-LETKF to increase the resolution and the ensemble size, and to assimilate “Big Data” from the next-generation observations.

Keywords: Data assimilation, NICAM, Satellite Observations, AMSU-A

Convective-scale breeding experiments in WRF simulations at a 100-m resolution

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Recent developments in high-performance computing and advanced observing technologies enable us to step forward to convective-scale data assimilation at a horizontal resolution of O(100) m. On the other hand, previous studies on predictability have been conducted with horizontal resolutions of several kilometers (e.g., Leoncini et al. 2010; Melhauser and Zhang 2012; Keil et al. 2014). Understanding the convective-scale predictability plays an essential role in designing such high-resolution NWP systems. In particular, it would be important to know what would be the effective temporal frequency of data assimilation, whether or not it needs to be the order of seconds. This study performs 30-second breeding cycles at a 100-m resolution using the Weather Research and Forecasting (WRF) model, and explores the convective-scale predictability. Sensitivity to the rescaling interval and threshold is investigated. Breeding experiments at horizontal resolutions of 500 m and 2.5 km are also performed to reveal the resolution dependency of growing modes.

Keywords: cumulus convection, breeding, predictability

Simulated Tropical Cyclone Intensity and Structure using high-resolution nonhydrostatic global model

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Tropical cyclone (TC) prediction is important to mitigate a disaster associated with heavy precipitation and high wind. High-resolution global model simulations using three nonhydrostatic models have been conducted to evaluate to what degree TC intensity and structure under JAMSTEC Earth Simulator Strategic Project. Three models are Double Fourier Series (DFS), Multi-Scale Simulator for the Geoenvironment (MSSG), and Nonhydrostatic ICosahedral Atmospheric Model (NICAM). DFS incorporates cumulus parametrization scheme but MSSG and NICAM use explicit microphysics scheme only. SST is given from initial condition in the DFS and MSSG. NICAM uses a simple mixed-layer ocean model. The number of 5-day simulation experiments with 7-km grid spacing is 52, which covers 10 TCs on September-October 2013. All three models simulate TCs stronger than JMA operational global model (approximately 20-km grid spacing). Although three models use almost same horizontal grid spacing, there are significant differences in intensification and structure of TCs. On average, DFS produces TCs with largest intensification rate and compact radius of maximum wind (RMW). A start timing of intensification is the quickest at MSSG among three models and the height of maximum wind by MSSG tends to become a higher than others. In NICAM, the intensification rate is the smallest and the widest variability of RMW among three models. These results will provide scientific knowledge for improving TC intensity and structure prediction.

Keywords: tropical cyclone, nonhydrostatic global model

High cloud size dependency in the applicability of the fixed anvil temperature hypothesis using global non-hydrostatic simulations

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The applicability of the fixed anvil temperature (FAT) hypothesis is examined using data of a global non-hydrostatic model, focusing particularly on high cloud size dependency. Decomposition of outgoing-longwave radiation (OLR) into three components, including cloud-top temperature (T_{CT}), upward cloud emissivity (ε), and clear-sky OLR (F^{CLR}), reveals that the relative contributions of these three components to changes of OLR are highly dependent on cloud size. That is, the FAT hypothesis is applicable only to smaller clouds, because the contribution of T_{CT} by those clouds is small, and $\varepsilon$is more important. In contrast, for larger clouds, the contribution of $\varepsilon$is comparable to that of T_{CT}, and thus, both components are equally important. F^{CLR} slightly reduces OLR, but shows dependence on cloud size.

Keywords: climate change, global nonhydrostatic cloud-resolving simulation, High cloud

Extended-range forecast of tropical cyclogenesis in the western north Pacific using a global nonhydrostatic atmospheric model on the K computer

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Since tropical cyclones (TCs) frequently cause tremendous damage to human lives and property, accurate extended-range forecast of TC genesis is valuable for inhabitants in low latitudes. Nakano et al. (2015, GRL) performed 31 one-month simulations using a global nonhydrostatic atmospheric model, NICAM, initialized at each day of August 2004 and demonstrated that the model can predict TC geneses 2 weeks in advance. August 2004 is the active phase of boreal summer intraseasonal oscillation (BSISO) in the western north Pacific and TC genesis is affected by the BSISO. Therefore predictability of TC genesis in various phases of BSISO has not been clarified. In this study, a total of 248 one-month simulations using 14-km-mesh NICAM initialized at each day of August 2007-2014 which covers various phases of BSISO and predictability of 13 TC genesis which occurred in the latter half of August are examined. The results show that 9 out of 15 TC geneses are predictable about 2 weeks in advance. Generation of 3 TCs which are weak (minimum sea level pressure is higher than 990 hPa) and/or duration is shorter than 3 days are not predicted. The reasons for missed TC geneses of the remains (3) in the model are not clear so far. The large scale circulation in NICAM at phase 7 of BSISO (most favorable phase for TC genesis) from phase 4 are compared with those from operational models (ECMWF, MetOffice) taken from the THORPEX Interactive Grand Global Ensemble (TIGGE). The results shows that eastward extension of monsoon trough is not enough in the ECMWF model. The MetOffice model simulates eastward extension of monsoon trough, but intensity is weak. NICAM well reproduces the monsoon trough in terms of eastward extension, but intensity is overestimate and position is north of observed.

Keywords: tropical cyclone, global nonhydrostatic atmospheric model, extended-range forecast

Impact of ocean coupling on typhoon prediction in high-resolution nonhydrostatic global model

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Accurate prediction of typhoon intensity and track is crucial to mitigate a typhoon disaster. An intercomparison of nonhydrostatic global atmospheric models has been conducted with the aim of improving typhoon prediction under the JAMSTEC Earth Simulator Strategic Project with Special Support. Three models (Double Fourier Series (DFS), Nonhydrostatic ICosahedral Atmospheric Model (NICAM), and Multi-Scale Simulator for Geo-Environment (MSSG)) were configured with a horizontal resolution of 7-km, and 52 forecast experiments during September-October 2013 were performed (see also Sawada et al. in the same session). In addition to that, we performed forecast experiments, where an ocean general circulation model is coupled in the MSSG, to investigate the impact of ocean coupling on typhoon prediction. It was found that the prediction error of typhoon intensity ranged between -10 to 10 hPa at a lead time of up to 60 hours in all models, while the typhoon intensity was under-predicted by 20 hPa in the JMA operational global model (20-km grid spacing). No marked difference was found in the predicted typhoon intensity at a lead time of up to 36 hours between MSSG simulations with and without ocean coupling; however, the predicted typhoon intensity was reduced after a lead time of 36 hours in the case where the ocean is coupled.

Keywords: typhoon, ocean coupling, nonhydrostatic global model

The statistical analysis of the explosively developing extratropical cyclone in northern Japan and Atmospheric blocking

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The explosively developing extratropical cyclone (bombs) is one of the most important meteorological phenomena in natural disaster protection, especially over the northwest Pacific and Atlantic (Sanders and Gyakum, 1980, Roebber 1984). Over east Asia, explosive cyclogenesis occurred most frequently in cold season peaked in December to February (Chen and Kuo, 1992). In mid-December 2014, a storm surge induced by explosive cyclone attacked Nemuro, a city located in Hokkaido, Northern Japan, causing great economic loss due to abnormal tides (Saruwatari and Lima, 2015). On 16 December, extratropical cyclones located off Kyusyu island and the Sea of Japan were rapidly intensified when it moved toward northeast and merged with each other. The minimum central pressure reached 946 hPa (Kitano and Yamada, 2016). On 17 December, a blocking high over western Russia and a cut-off low over the Sea of Okhotsk were observed and explosive cyclone stagnated off the coast of Nemuro city about 28 hours. The aim of this study is to estimate the deepening rate after the merger statistically and to reveal the relationship between the stagnant of explosive cyclones and atmospheric blocking.

We used the 40-yr ECMWF Re-Analysis (ERA-40; Uppala et al. 2005), with the full horizontal resolution of 1.125°, available every 6 hours for the period 1960-1999. The subject region in this study extends over the northwestern Pacific region from 20° to 65°N and from 100°E to 180°. Definition of explosively developing extratropical cyclone follows the tracking algorithm proposed by Yoshida and Asuma (2003). Here, merger is defined as the situation in which more than two cyclone trajectories overlap each other. Blocking is diagnosed by a two-dimensional (2D) blocking index derived from daily 500-hPa geopotential gradient according the method of Masato et al. (2012, 2013).

The results show that 1775 explosive cyclones were detected. After the merger, deepening rate becomes the maximum and it is 5.37 [hPa / 6 hour] statistically. The higher latitude explosive cyclones merge in, the higher the deepening rate is. The results indicate that merger often occurs over the Sea of Japan and off the Pacific coast of Kanto region. Furthermore, about 40 % of explosive cyclones are located on southern part of blocking when the velocity of explosive cyclone becomes slowest.

Keywords: explosively developing extratropical cyclone, atmospheric blocking, disaster protection

Innovative numerical weather predictions and advanced weather disaster prevention based on damage-level estimation

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In the project of 'Innovative numerical weather predictions and advanced weather disaster prevention based on damage-level estimation' of Fields 4: 'Advancement of meteorological and global environmental predictions utilizing observation', the studies which increase the leading time of severe weathers such as local heavy rainfalls and Typhoons will be conducted by using the next generation super computer 'K' and 'Post K' and Big observation data (e.g. Himawari-8 and the Phased array radar data). In the presentation, the objects and results of this project will be presented.

An Ultra-high Resolution Numerical Weather Prediction with a Large Domain Using the K Computer

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In Japan, heavy rainfalls occasionally cause disasters such as debris flows and floods that induce severe damage to society. The high resolution numerical weather prediction (NWP) model has found to be important for this kind of disaster mitigation.
Accuracy of numerical prediction models depends on several factors such as resolution, domain size, dynamics and physical processes. Especially, finer grid spacing contributes to improving the representation of deep moist convection, reducing discretization errors, and expressing more realistic topography. However, little studies have conducted ultra-high resolution simulations (100 m scale) with a large model domain. Such a high resolution, large domain experiment needs a very large computational resource such as the K computer.
The authors have conducted ultra-high resolution experiments of heavy rain events with K computer and the Japan Meteorological Agency nonhydrostatic model (JMA-NHM). The case studies are the heavy rain events in Izu Ohshima on October 2013 and Hiroshima on August 2014.
The objectives of this study are to examine whether an ultra-high resolution NWP model with a large domain is able to produce more accurate forecast and to elucidate its reason. The four factors of the NWP model were investigated: (1) grid spacing (up to 250 m), (2) turbulence closure model (Mellor-Yamada-Nakanishi-Niino [MYNN] level 2.5 and 3, and Deardorff [DD]), (3) model domain (1600× 1100 km, and 200 km square), and (4) terrain data.
One of the main findings is the 250-m grid model with the finest terrain representation showed the best performance in both case studies. The results of this study demonsrate that the very high resolution NWP model with the large domain has the potential ability to better predict the meso-beta scale rain.

Keywords: K computer, Ultra-high Resolution Numerical Weather Prediction, JMA-NHM

