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 results of 2016 financial year will be presented.

An Ultra-high Resolution Numerical Weather Prediction with a Large Domain: Case Study of the Izu Oshima Heavy Rainfall Event in October 2013

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This study aims to examine whether an ultra-high resolution numerical weather prediction (NWP) model with a large model domain is able to produce a more accurate forecast. A heavy rain event induced massive debris flow in Izu Oshima, October 2013 was simulated with “K” computer.
The following five factors of the NWP model were investigated. (1) grid spacing (2 km and 500, 250 m), (2) boundary layer physics (Mellor-Yamada-Nakanishi-Niino [MYNN] level 3, and Deardorff [DD]), (3) model domain size, (4) lateral boundary conditions (LBCs), and (5) terrain data
The turbulence closure models greatly influenced on the position of the rainband. The experiments with DD simulated the rainband at the similar position to the observation than that of the experiment with MYNN. The sensitivity experiments on the domain size and LBCs, in Izu Oshima case showed the importance of having the large domain and the inclusion of cloud microphysical quantities in the LBCs. The finer grid model with the accurate terrain representation improved the precipitation distribution in the island.
These results demonstrate that the very high-resolution NWP model with the large domain has the ability to better predict the meso scale rain band and associated precipitation.

Keywords: heavy rainfall, high-resolution, JMA-NHM, K computer

Multi-scale Structure of A Meso-beta-scale Vortex that Caused Sudden Gusty Winds Over the Sea of Japan: A Case Study on 1 September 2015

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A sudden gusty wind accompanied by a meso-beta-scale vortex of about 30km diameter occurred in the Tsushima Strait at the southwest part of the Sea of Japan between 0300 and 0400 JST (Japan Standard Time) on 1 September 2015. It upset 6 fishery boats, causing 5 fatalities and 1 missing people. Some of the survived fishermen reported that they were hit by a waterspout. The meso-beta-scale vortex was located near the warm front about 300 km northeast of the center of a meso-alpha-scale cyclone. The structure and evolution of the meso-beta-scale vortex are examined using a numerical simulation.

A numerical simulation using JMA non-hydrostatic model (JMA-NHM) with horizontal resolution of 2km and 50 vertical levels successfully reproduced the meso-beta-scale vortex. The simulated vortex had a diameter of about 30-50 km, and was formed in the northeast quadrant of the meso-alpha-scale cyclone at around 0400 JST. The vortex developed between 0400 and 0430 JST and the associated wind exceeded 20 m s^{-1} near the surface. To examine the development process of the vortex, a vorticity budget analysis is performed. The vorticity and each term of a vorticity equation are averaged over 60 km around the vortex center. The vorticity developed through tilting and stretching terms at 1000-1500 km height in the early developing stage. Subsequently, the vortex was intensified near the surface thorough the stretching term.

An additional numerical simulation with horizontal resolution of 50 m and 100 vertical levels has been performed to clarify more detailed structure and evolution of the meso-beta vortex and to reproduce small-scale features that caused the damaging gusty wind. In the simulation, micro-scale vortices with horizontal scale less than 1km were simulated within the meso-beta-scale vortex. It is suggested that these vortices formed with shear instability. The maximum of vorticity and wind speed occasionally exceeds 50 m s^{-1} and 1 s^{-1}, respectively, during the simulation.

Keywords: Gusty wind, Vortex, Cyclone

A 4DEnVAR data assimilation system without vertical localization using the K computer

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Like the ensemble Kalman filter, the ensemble variational method (EnVAR) uses localization to remove unrealistic correlations between distant points due to a limited number of ensemble members. This also helps to increase the rank of background error covariances, thus maintaining stability of data assimilation systems. However, localization results in imbalance in analysis fields, which degrades forecast quality especially in the cases like heavy rainfall events or tropical cyclones where strong vertical correlations are expected.

Localization is employed by introducing a predefined function to taper correlations at distant points to zero, and usually separated into horizontal and vertical localization. Here the same localization function is applied for all grid points without considering physical processes there, e.g. no differentiation between intense rain and no rain. Thus, vertical localization is clearly the main source for imbalance in analysis fields. This can be avoided if the number of ensemble members is in the order of 1000, which can be achieved using the K computer.

When vertical localization is not employed into EnVAR, the same weight is applied for all grid points in each vertical column to determine analysis increments. This reduces the computational cost by a factor of the number of vertical levels (about 40) compared to the case using vertical localization. Since the number of ensemble members increases from the order of 100 to the order of 1000, the computational cost increases by a factor of 10-20. That means EnVAR without vertical localization in fact consumes less computational cost than EnVAR with vertical localization. Thus, when not employing vertical localization, all computational resources are almost used for integrating ensemble members and generating analysis perturbations.

To demonstrate the benefit of EnVAR without vertical localization, a four dimensional EnVAR system using 1600 ensemble members has been developed in the K computer. The system was built around the operational limited area model NHM of Japan Meteorological Agency (JMA). The deterministic EnKF method combined with the block GMRES method was used to generate analysis perturbations. This ensures consistency between analyses and analysis perturbations when the same Kalman gain is used in both cases. The system was applied for prediction of several heavy rainfall events in Japan. The forecast results are shown to outperform those of the operational 4DVAR system of JMA.

Keywords: EnVAR, vertical localization, K computer

Data assimilation of dense precipitation radar observations: a simulation study

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Precipitation radar observations have been playing an important role in meteorology through providing valuable information, such as precipitation nowcast. Recently, a new radar system known as the phased array radar, which can scan the three-dimensional structure of precipitation much faster than the conventional parabolic type radar, has been developed. The advancement can also be seen in the spaceborne precipitation radar. The GPM core satellite, the successor of the TRMM satellite, has the newly-developed dual-frequency precipitation radar (DPR). Precipitation radars keep advancing and tend to provide denser and more frequent observations. With these in mind, it would be essential to develop methods to effectively use the radar reflectivity data for numerical weather prediction through data assimilation. Previous studies showed some success in data assimilation of radar reflectivity for convective-scale and tropical cyclone analyses. Nevertheless, it is still difficult to build a general approach to data assimilation of radar reflectivity due to various factors such as the non-diagonal observation error covariance matrix, complex observation operator, and strong nonlinearity and model errors in the moist physical processes. In this study, we aim to develop an effective data assimilation method which can fully exploit the radar reflectivity data. We perform an observing system simulation experiment, in which we assume that reflectivity data are available at all model grid points. As the first step, we focus on the case of Typhoon Soudelor (2015), which was the strongest typhoon in the West Pacific in 2015. In the presentation, we will report the impact of dense radar observations on the analyses and forecasts of Typhoon Soudelor.

Keywords: data assimilation, precipitation radar

Impacts of dense surface observations on predicting torrential rainfalls on September 9, 2015 around Tochigi and Ibaraki prefectures

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To investigate the impact of dense surface observations on a severe rainfall event occurred on September 9, 2015 around Tochigi and Ibaraki prefectures, we perform a series of data assimilation (DA) experiments using the Local Ensemble Transform Kalman Filter (LETKF) with the SCALE regional NWP model. In this event, an active rainband was maintained for an extended period and caused torrential rainfalls over 500 mm/day with catastrophic flooding.
Two DA experiments were performed: the control experiment (CTRL) at 4-km resolution with only conventional observations (NCEP PREPBUFR), and the other with additional every minute surface observation data (TEST). CTRL showed general agreement with the observed rainfall patterns, although the intensity was smaller, and rainfall area was shifted westward. By contrast, TEST showed stronger rainfall intensity, better matching with the observed precipitation. Dense surface DA contributed to improve the moisture field in the lower layer, leading to intensified rainfall amount. The results suggest that the dense surface DA have a potential to improve the forecast accuracy for severe rainfall events.

Keywords: Data Assimilation, Surface weather observation

Two-year analysis experiments with NICAM-LETKF

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We applied the Local Ensemble Transform Kalman Filter (LETKF) to the Non-hydrostatic ICosahedral Atmospheric Model (NICAM). Observation operators to assimilate the conventional observations, satellite-borne Atmospheric Microwave Sounder Unit-A (AMSU-A), and the Global Satellite Mapping of Precipitation (GSMaP) data were developed. The purpose of this study is to verify the long-term stability of the NICAM-LETKF system. We performed experiments to assimilate all observations for two years and two months from June 2014 to July 2016.
The first experiment was not successful. We found that the NICAM-LETKF system became unstable due to an extreme outlier of the 100-member ensemble. Therefore, we applied the relaxation to prior spread (RTPS) instead of the default setting of an adaptive multiplicative inflation method, and found that the NICAM-LETKF system was stable for more than two years. The analyzed atmospheric fields were largely improved by assimilating the AMSU-A radiances. The humidity bias is also improved by assimilating the GSMaP data while the NICAM is known to have a dry bias, especially over land.
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Keywords: Data assimilation, NICAM, Satellite observation

The multi-resolution estimation of stratosphere-troposphere exchange simulated with the K computer

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The stratosphere-troposphere exchange (STE) of atmospheric mass is important to understand the oxidizing capability of troposphere as well as the atmospheric chemistry and climate interaction, since the lower stratospheric ozone is efficiently transported to the troposphere with the synoptic- and small-scale mechanisms of the STE, especially in early spring (March). This study identifies the mass flux of STE from the outputs of the multi-resolution simulations of the Nonhydrostatic Icosahedral Atmospheric Model (NICAM) using K computer, compering with the results of the CCSR/NIES-MIROC3.2 Chemistry-climate model simulations (T42 horizontal resolution with 34 vertical layers from surface to mesopause, the single simulation with the NIES supercomputer system). We perform the 3 horizontal resolutions and 2 vertical resolutions of the NICAM. The horizontal resolutions of the NICAM are about 220 km (GL05), 56 km (GL07), and 14 km (GL09), and the vertical resolutions around tropopause are about 0.7–1.5 km for 40 layers and about 0.4 km for 78 layers (upper limits of the model are about 40 km for 40 layers and 50 km for 78 layers). The results show that the March average of the STE flux is large in magnitude for the coarse vertical resolutions and for the high horizontal resolutions. In addition, we find the spiral structure of the STE around the cutoff cyclones from the high horizontal and high vertical resolution simulations. These results imply that the resolution dependency of the STE is possibly related to the oxidizing capability of troposphere, which will be simulated with the chemistry interactive version of the NICAM.

Keywords: stratosphere-troposphere exchange, Nonhydrostatic Icosahedral Atmospheric Model (NICAM)

Optimum numerical calculation with mixed precision floating point number for a regional shallow-water model

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We investigate the impact of numerical errors of floating point numbers (FPNs) to the equilibrium and instability condition experiments, using a regional shallow-water model with mixed precision FPN by a reduced precision emulator. To express the numerical errors quantitatively, we define the reproducibility index that is the mean ratio of root-mean-square-error to standard deviation of prognostic variables. The results of the ideal experiments are listed as follows: (1) Higher spatial resolution requires larger size of significand bit width. (2) Preparing a reference value, which is made from horizontal mean of a variable before time integration, is effective in reducing loss of significand digits. (3) Reducing accuracy of FPN before making the reference value of geopotential may induce large loss of significand digits, while that of velocity is relatively small contribution to the loss. (4) A careful summation algorithm for a large number of grids can avoid loss of trailing digits that induces low accuracy of the reference value. (5) The time evolution of numerical errors can be expressed as an exponential function form. Therefore, reducing initial numerical errors is crucial for preserving high reproducibility with time evolution. Following the above results, we construct an optimum shallow-water model that uses single precision FPN to dynamics kernel. The optimum model can obtain the results with slight numerical errors, compared with the shallow-water model fully using double precision FPN. In contrast, execution time of the optimum model is comparable to that of the shallow-water model fully using single precision FPN. The results of this work suggest the base of dynamics kernel with high cost-performance, which can be also applied for the dynamics kernel in a numerical weather prediction model on a high-performance computer.

Keywords: shallow water equation, optimization

Simulation skills of the Unified Model 3.0 (UM3.0) for heavy rainfall over South Korea

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As the computational abilities improve, resolution of numerical weather prediction (NWP) model has been steadily increasing. Compared with a lower resolution model, a higher resolution model can simulate more detailed atmospheric phenomena related with precipitation. Therefore, a higher resolution prediction model is commonly used for short-term weather forecast and developing a higher resolution model is one of the important issue for improving weather forecast. In the same vein, the Korean Meteorological Administration (KMA) is operating the Unified Model(UM), the numerical prediction model, which is introduced from the United Kingdom Meteorological Office (UKMO). Through the operation of the UM, the KMA is providing various weather prediction information such as Global Data Assimilation and Prediction System (GDAPS), Regional Data Assimilation and Prediction System (RDAPS), Local Data Assimilation and Prediction System (LDAPS), UM3.0 and so on. Among them, UM3.0 has been using for medium-term forecast by the KMA. The UM3.0 has 3km of spatial resolution and 1-hour time resolution providing 7days prediction information from the beginning point of prediction time. In this study, we aimed to evaluate the predictability of the UM 3.0. As the UM 3.0 provides the data for medium-term forecast, we focused on the evaluation of typhoon events with heavy rainfall during 2014 and 2015. For the study, preprocessed QCF (Quality Control by Fuzzy method) radar data which have same grid-point were used and we used three statistics such as root mean square error (RMSE), correlation coefficient, and bias to quantify the temporal and spatial accuracy of the model.

Keywords: UM3.0, numerical weather prediction model, simulation skill

Some advances in the upwind hybridized discontinuous Galerkin method for dynamical cores

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We will present new developments on the emerging Hybridized Discontinuous Galerkin (HDG) method targeting at large-scale and parallel simulation of the dynamical core. In particular, we will present an iterative HDG (iHDG) method that exploits current and future multi-threaded computing system with massive concurrencies. We provide both theoretical justification and numerical results to support the iHDG idea. Furthermore, we also present fast and scalable preconditioning strategies for HDG method that potentially make the HDG approach competitive with the existing methods. Several test cases and models for the dynamical core will be presented to demonstrate the potential of the HDG approach.

Keywords: hybridizable Discontinuous Galerkin method, Discontinuous Galerkin method, non-hydrostatic model, dynamical core, parallelization

