# Turbulent Heat Fluxes during an Extreme Lake Effect Snow Event: Direct Measurements and Model Ensemble

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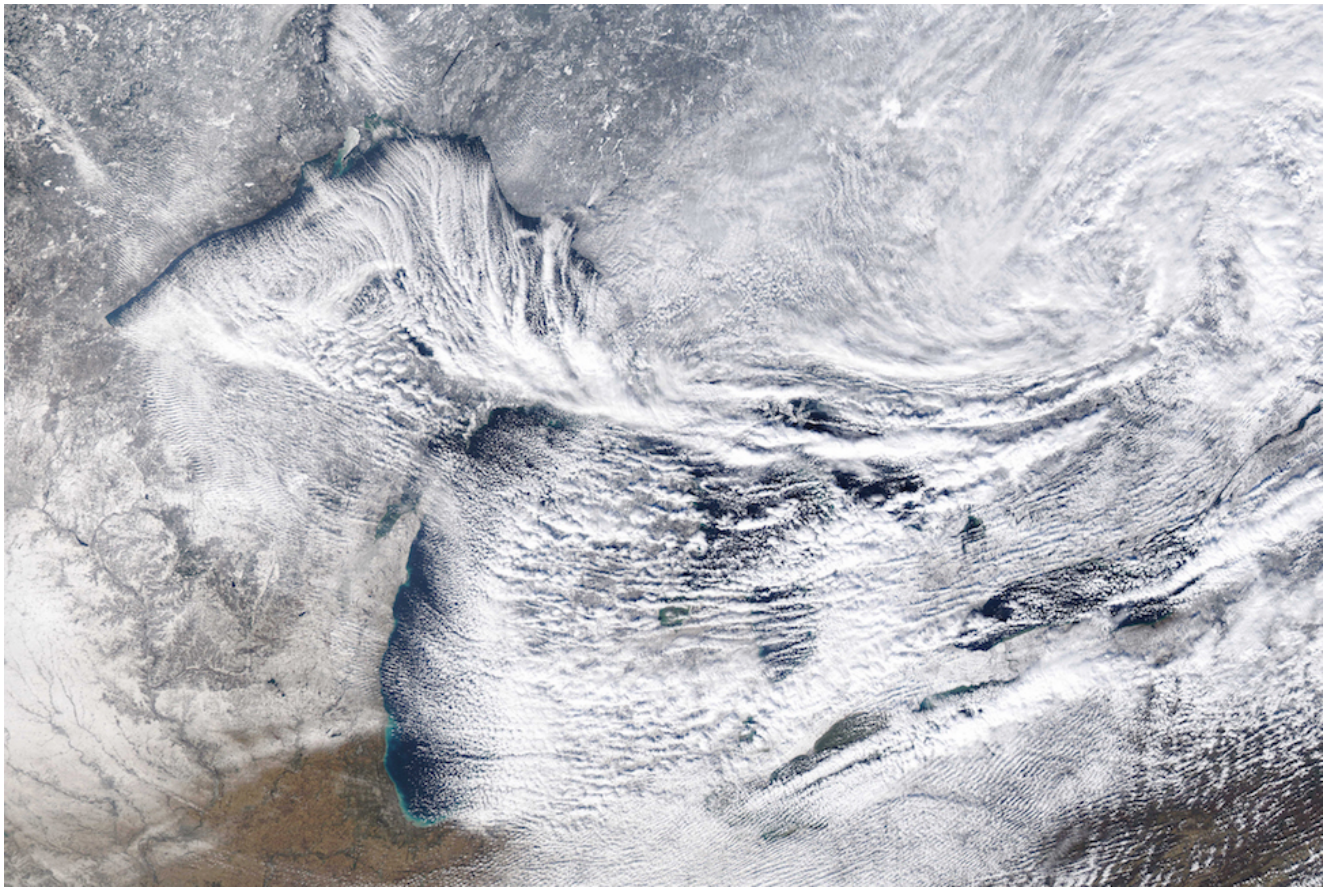
An extreme North American winter storm near eastern Lake Erie in November 2014 triggered the largest lake-effect snowfall event in southwest New York since the 1940s. While the large-scale atmospheric conditions of the southward migrating polar air mass are believed to be responsible for producing the extreme amounts of lake-effect snowfall, there has not yet been an assessment of how state-of-the-art numerical models performed in simulating the turbulent heat fluxes from Lake Erie, which is critical to accurate forecasts of lake-effect snow. To examine the turbulent heat fluxes during the extreme lake-effect snowfall event, this study utilized direct measurements of the turbulent heat fluxes and a suite of numerical weather and lake models that are operationally and experimentally used to provide nowcasts and forecasts of weather and lake conditions. Analysis of the water vapor budget in the weather models showed that lake evaporation accounted for the majority of snow precipitation during the event. Overall, the models captured the sharp rise of the turbulent heat fluxes during the event, while the peak values showed significant variation. In the hydrodynamic model results, the variation of the turbulent heat flux resulted in the range of the 3D-mean water temperature increasing from 9.2-10.1 °C (0.9 °C) to 6.4-8.5 °C (2.1 °C) and in the range of cumulative evaporation increasing from 2-3 cm (1 cm) to 5.5-7 cm (1.5 cm) during the four-day duration of two storm waves. These increased ranges caused by the single extreme event are large enough to impact simulations at longer time scales, including seasonal ice forecast and water balance prediction.

Keywords: North American Great Lakes, Lake Effect Snow, Hydrodynamic, Ice, and Weather numerical models



# Tornadogenesis as revealed by high-resolution ensemble forecasts for the Tsukuba city supercell tornado on 6 May 2012

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To clarify the environmental conditions for tornadogeneses, we performed ensemble-based analyses using 33-member high-resolution ensemble forecasts of the Tsukuba city supercell tornado on 6 May 2012. The horizontal resolution of the model was 50 m. The initial and boundary conditions were taken from ensemble forecasts with 350-m horizontal resolution started from local ensemble transform Kalman filter analyses with 1875-m horizontal resolution, which assimilated four C-band radars and dense surface data. The results of backward trajectory analyses of parcels that were placed in forecasted near-surface tornado-like vortices showed that the circulation of the vortices can be generated due to both surface friction and baroclinity, but the way the circulation is generated did not appear to be essential for determining whether tornadoes are generated or not. On the other hand, the mesoscale environment such as the strength of low-level mesocyclones at about 1-km height and near-surface humidity had strong correlations with the maximum vertical vorticity of the tornado-like vortices, indicating that these factors seem to be essential for a tornadogenesis.

Acknowledgement:
This work was supported in part by the research project “HPCI Strategic Program for Innovative Research (SPIRE) Field 3,” “Social and Scientific Priority Issues (Theme 4) to Be Tackled by Using Post K Computer of the FLAGSHIP2020 Project,” “Tokyo Metropolitan Area Convection Study for Extreme Weather Resilient Cities (TOMACS),” JSPS KAKENHI Grant Numbers JP24244074 and JP16K17804, and the Cooperative Program (No. 131, 2014; No. 136, 2015; No. 138, 2016) of Atmosphere and Ocean Research Institute, The University of Tokyo. Experiment with 350-m and 50-m horizontal resolution were conducted using the K computer at the RIKEN Advanced Institute for Computational Science through the HPCI System Research Project (Project ID: hp120282, hp130012, hp140220, hp150214, hp150289, hp160229). Observational data were provided from Japan Meteorological Agency and NTT DOCOMO, Inc.

Keywords: Tornado, Ensemble forecast, Data assimilation, Circulation analysis, K-computer

 

# 30-second-cycle LETKF assimilation of phased array weather radar data

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Assimilation of meteorological radar data has been widely studied for short-range numerical weather prediction. Based on the knowledge gained from previous studies, we explore the assimilation of the dense phased array weather radar (PAWR) data, with a high-resolution model and rapid update cycles: The targeted model resolution is 100 meters and the targeted update frequency is every 30 seconds. To achieve this goal, our key investigation includes: 1) development of the high-performance regional data assimilation system capable of performing such big radar data assimilation, 2) studies on the data quality control, superobing, thinning, and localization schemes that are suitable for the dense radar data, 3) better use of both raining and clear-sky reflectivity data to initiate and suppress the convections, and 4) the balance issue for this super rapid-update ensemble data assimilation.
Successful results have been obtained with the 30-second-cycle PAWR data assimilation in a 1-hour cycling analysis period. The 3-dimensional movement of hydrometeors is nicely shown in the model analysis, which is not easily seen with the conventional radar data. Reasonable 30-minute forecast skill has also been attained. We plan to work towards performing longer analysis cycles, so that the potentials and challenges of the operational use of this 30-second-cycle PAWR data assimilation can be investigated.

Keywords: radar assimilation, LETKF, phased array radar, rapid-update cycle

 

# Assimilating All-Sky Himawari-8 Satellite Infrared Radiances: A Case of Heavy Rainfalls and Floods

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To predict heavy rainfalls and floods, it is important to get better initial conditions with accurate moisture transport via data assimilation. To do so, infrared (IR) radiance observations by geostationary satellites can give useful information in a wide area because some IR bands are sensitive to moisture. In particular, the new Japanese geostationary satellite “Himawari-8” can provide high-spatiotemporal resolution observations with many bands. The present study aims to assimilate all-sky IR radiance observations by Himawari-8 and investigate its impact on the analyses and forecasts of a heavy rainfall event in Japan. The results show that northward moisture transport over the ocean south of Japan is enhanced due to Himawari-8 data. The improved analyses give much better precipitation forecasts compared to the control experiment without Himawari-8 IR observations. The improved precipitation forecasts are essential for more accurate river model forecasts.

Keywords: Data assimilation, Himawari-8

 

# Perturbation Methods for Ensemble Data Assimilation

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Ensemble data assimilation methods are widely noticed as the analysis methods suitable for HPC which have potential to improve the accuracy of numerical weather prediction, substituting for or combining with the variational methods. Ensemble data assimilation methods have an advantage in terms of the development cost over the 4-dimensional variational method in that the adjoint models are not necessary, however, their performances are still arguable and likely have room for further improvement.
In ensemble data assimilation, the forecast error, which is necessary in data assimilation, is estimated by perturbations of the ensemble forecast, while characteristics of the ensemble forecast strongly depend on how the initial ensemble was generated. The ensemble transform (ET), eigenvalue decomposition of the analysis error covariance matrix, is widely used as the initial ensemble perturbation generator for the most ensemble data assimilation including ensemble Kalman filter such as LETKF and the ensemble variational method (EnVAR). The ensemble transform has an advantage in that the magnitude of perturbations (initial ensemble spread) can reflect the magnitude of the analysis error, but on the other hand, it is known that the growth of the errors is slower than other methods such as the singular vector method and the BGM method. In the previous studies for the mesoscale ensemble system (e.g., Saito et al.; 2011; 2012), perturbations from LETKF were not necessarily better than other methods as the initial perturbations, which may affect the accuracy of the analysis field. Non-diagonal components in the transform matrix likely contaminate the synoptic scale structure of the bred vectors in the ensemble forecast in the assimilation window when the localization is applied.
We started to tackle this problem, and in the presentation, some preliminary results using SPEEDY-LETKF will be shown, including spatial strucure and power spectrum of ensemble perturbations by diaonal and off-diagonal components of the transform matrix.

Keywords: ensemble data assimilation, ensemble transform, perturbation method

 

# Improvement of Hydro-debris2D and It’ s application to Mountain Hazards and Sediment transport

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Hydro-debris2D model has been developed and improved for predicting occurrence of debris flow throughout hydrological regime changes. The model contains three components: (1) Shallow-water based surface flow modules, in order to calculate mountain zone torrential flow regimes, (2) rapid subsurface/interflow in weathered rock, and (3) debris flow and sediment-transport components. The model has been applied into Izu Oshima Island’ s debris flow event in 2013 and to Hiroshima’ s debris flow disaster in 2014. As rainfall was input, we made a comprehensive comparison between observed rainfall station datasets from AMeDAS and High-resolution NHM calculation results. In the case of Izu Oshima, heavy rainfall and extensive surface flow occurred in the western part of the island, together with extreme interflow which may have caused the start of debris flow in the wall. In Hiroshima’ s case, observed rainfall reproduced occurrences of debris flow with better agreement of the disaster due to the slight changes in heavy-rainfall zone. Projected rainfall produced by NHM gave also appropriate results in preparation. The model was also applied to Aso Mountain zone in order to predict possible occurrence of landslides in the zone

Prediction using ensemble rainfall data may be needed in order to increase the accuracy of the occurrence.

Keywords: Hydro-debris 2D, NHM, debris flow

 

# Ekman downwelling from the lower troposphere in the intense tropical cyclones

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The warm-core structure is one of the most important features of tropical cyclones (TCs). As the warm-core structure is related to the tangential wind field and the intensity of the TC, understanding the mechanism controlling the warm-core structure is a fundamental issue. Although the warm-core structures are observed in the troposphere in many studies, several cases of high-level warm core (HWC) located near the tropopause height have been reported in previous studies, particularly of intense TCs. A number of mechanism have been proposed to explain the formation of such HWCs, it seems that no consensus has been reached yet on the formation mechanism.

A mechanism by which the HWCs develop in the development early stage of TCs is proposed on the basis of sensitivity studies using a three-dimensional nonhydrostatic model. We hypothesize that the occurrence of downdraft from the lower stratosphere near the TC center which causes the warming can be explained based on the theory of Ekman layer. According to Ekman layer theory, the vertically integrated ageostrophic mass transport is determined from the stress at the layer boundaries, and the magnitudes of vertical flows which cross the boundaries are proportional to the curl of the stress at the boundaries. When considering a layer near the lower stratosphere, downward flow which crosses the lower boundary can be caused by the turbulent momentum flux through the lower boundary, because the primary circulation of the TC is always cyclonic and decays with height.

This hypothesis was examined by conducting idealized TC simulations which are similar to those examined in the study of Ohno and Satoh (2015, JAS). It was found that suppressing the vertical mixing of momentum above the upper troposphere caused significant impact for the formation of the HWCs. This is consistent with the proposed hypothesis. The present analysis suggests that TCs can be even stronger than those expected by theories in which TC structures are confined in the troposphere (i.e., Emanuel, 1986, JAS). In addition, it is expected that the dynamical processes occurring near the tropopause have impact on the intensification through the imbalance effect near the surface suggested by the previous studies (i.e., Syono and Yamasaki, 1966, JMSJ).

Keywords: Tropical Cyclone

 

# 50-member ensemble simulations for 1997 and 2015 using a global nonhydrostatic model

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El Niño influences tropical cyclone (TC) activity in the western North Pacific. Camargo and Sobel (2005) showed that TC lifetime and the number of intense TCs increase during El Niño. In 2015, strong El Niño event was developed. Wang and Chan (2002) showed that intense TCs tend to be formed over the southeastern part of the western North Pacific during El Niño. According to the Regional Specialized Meteorological Center Tokyo best-track data, in the western North Pacific, 10 intense TCs were formed between June and October in 2015, which was the largest number since 1971. In this study, intense TC is defined as TC whose minimum central pressure reached less than 945 hPa.
To evaluate the influence of El Niño on the number of intense TCs, we conducted 50-member ensemble simulations targeting the summers (June-October) of 2015 and 1997 known as development of extreme El Niño event, using a global nonhydrostatic model called NICAM (Satoh et al. 2014) with a horizontal grid interval of 14 km. Clouds were explicitly calculated using a single-moment bulk microphysics scheme without cumulus convection scheme. The sea surface temperature was nudged toward the OISST data (Reynolds et al. 2002) using a slab ocean model.
In the ensemble simulation of 1997, the ensemble-mean of number of intense TCs is 7.0 which is higher than the model’s climatology (5.8) which is derived from an AMIP-type 30-year simulation (Kodama et al. 2015). Moreover, intense TCs tend to be formed over the southeastern part of the western North Pacific and have longer lifetime. Those results indicate that the model response of TC activity to El Niño in 1997 agree with observed response (Wang and Chan 2002; Camargo and Sobel 2005).On the other hand, in the ensemble simulation of 2015, ensemble mean of the number of intense TCs is almost equal to the model’s climatology. Whereas intense TCs simulated in the members with 7 or more intense TCs tend to be formed over the southeastern part of the western North Pacific and have longer lifetime, this feature are not obvious in the other members. These results indicate that the number of intense TCs is not determined only by development of El Nino-type sea surface temperature pattern but is influenced by the internal variation of the atmosphere induced by differences in the sea surface temperature distribution between 1997 and 2015.

Keywords: tropical cyclone, El Nino, high-resolution global nonhydrostatic model

 

# Status and outlook of a high-resolution climate simulation using NICAM toward CMIP6 HighResMIP

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Climate simulation using a global model with a mesh size of *O* (10 km) becomes more common than ever thanks to the rapid advancement in high performance computer. Such a fine-mesh global climate simulation represents atmospheric multi-scale phenomena ranging from large-scale circulation to meso-scale features associated with convection, front, severe rainfall, atmospheric gravity wave and so on in a seamless manner. Tropical cyclone is an excellent example of multi-scale interactions. Its generation, development and track are strongly influenced by larger-scale mean state and disturbances. To this end, we have performed a first-ever AMIP-type climate simulation using a 14-km mesh non-hydrostatic global atmospheric model, NICAM, without convection scheme and shown a good performance in the simulated climatology of tropical cyclone as well as a wide variety of atmospheric phenomena including tropical wave and precipitation (Kodama et al. 2015). We have also found some significant climate biases which might hinder a reliable projection of future climate.
Here we will present a status and an outlook of a high-resolution climate simulation using the latest version of NICAM. A series of new climate simulations under a framework of CMIP6 HighResMIP (High Resolution Model Intercomparison Project) and DynVAR (Dynamics and Variability Model Intercomparison Project) are planned. An impact of the horizontal resolution on weather and climate phenomena will be investigated by preforming the model with a mesh sizes of 14, 28 and 56 km. Physics schemes including cloud microphysics, gravity wave drag, aerosol and land model are under updating and/or tuning to improve the simulated climatology. As an example, a better performance in the simulated top-of-the-atmosphere radiation balances is found in the latest version of NICAM with a new cloud microphysics scheme, which was validated by a satellite measurement with a focus on cloud-precipitation processes (Roh and Satoh 2014). In addition, some fresh results from a series of short-term sensitivity experiments will be presented and discussed in this talk.

Keywords: high-resolution climate simulation, CMIP6 HighResMIP, sensitivity experiments, climate bias, tropical cyclone

 

# Assimilating satellite radiances without vertical localization using the local ensemble transform Kalman filter with up to 1280 ensemble members

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Covariance localization plays an essential role in the ensemble Kalman filter (EnKF) to avoid bad influence of spurious covariance from sampling errors when the ensemble size is limited. In our previous study, we performed 10240-member ensemble data assimilation experiments with the global atmospheric model NICAM (Nonhydrostatic Icosahedral Atmospheric Model) to investigate horizontal and vertical error correlations. As a result, we found that roughly 1000 ensemble members would be large enough to avoid vertical covariance localization for satellite radiance data. In this study, we perform the Local Ensemble Transform Kalman Filter (LETKF) experiments with NICAM using the ensemble sizes from 20 to 1280. We compare the results with and without vertical localization for satellite radiance data.

Keywords: data assimilation, Assimilating satellite radiances, Ensemble Kalman Filter

 

# A high-resolution global atmospheric composition data assimilation of multiple satellite measurements during NASA's KORUS-AQ aircraft campaign

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Ozone ($O_3$) and its precursors ($NO_x$, CO, and VOCs) in the atmosphere are important for human health, ecosystems, and climate. Chemical transport models (CTMs) have been used to study controlling processes of variations of $O_3$ and related species (e.g., Sekiya and Sudo, 2012). However, current CTMs still have large uncertainties in representing variations of $O_3$ and related species, including large uncertainties in bottom-up emission inventories used in the simulations. We have developed a global chemical data assimilation system based on an ensemble Kalman filter to combine multiple-species observations from multiple-satellite sensors, including OMI, TES, MLS, MOPITT, GOME-2, and SCIAMACHY, with a global CTM (CHASER) (Miyazaki et al., 2017). High-resolution modeling is considered to be important for improving data assimilation performance, by improving the general model performance, reducing spatial and temporal gaps between the simulation and observations, and improving resolving small-scale processes. By conducting forward calculations, we have found that an increase of horizontal model resolution from 2.8˚ to 1.1˚ substantially improved the forecast model performance (Sekiya et al., in preparation).

In this study, we demonstrate the performance of high-resolution data assimilation during the NASA's KORUS-AQ aircraft observation campaign conducted over South Korea in May 2016. The tropospheric $NO_2$ column bias in the data assimilation compared to OMI satellite retrievals is reduced by 57% over South Korea and by 43% over central Japan, by increasing horizontal model resolution from 2.8˚ to 1.1˚. The 1.1˚ analysis also led to improved agreements with vertical profiles by DC-8 aircraft measurements. Surface $NO_x$ emissions derived from the data assimilation also differed by 17% over South Korea and by 4% over central Japan by changing the model resolution, with substantial differences over many megacities in Asia. Data assimilation performance could further be improved using a model with horizontal resolution higher than 1.1˚. Based on sensitivity calculations conducted under the post-K project, we will discuss the potential benefit of using a 0.5˚ resolution model in chemical data assimilation, in reproducing the spatio-temporal variations of major pollutants over Asia.

Reference

Miyazaki et al. (2017), Atmos. Chem. Phys., 17, 807–837.
Sekiya and Sudo (2012), J. Geophys. Res., 117, D18303.

Keywords: atmospheric chemistry, atmospheric environment, data assimilation

 

# Towards an extreme scale global data assimilation on the post-K supercomputer: development of a throughput-aware framework for ensemble data assimilation

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The weather/climate simulation models and the data assimilation (DA) systems are placed as the important applications in the development of post-K supercomputer system. In a cyclic operation of the DA system, the simulation model and the DA system are executed cooperatively. In recent years, the horizontal resolution of the simulation model increases, and the ensemble size increases, too. In such situation, data movement between the two applications becomes a more significant issue.
We proposed an ensemble DA framework with a "throughput-aware" design that maintains data locality and maximizes the throughput of file I/O between the simulation model and the ensemble DA system. This framework is implemented to a DA system, which is used a local ensemble transform Kalman filter (LETKF) and a Non-hydrostatic Icosahedral Atmospheric Model (NICAM) (NICAM-LETKF, Terasaki et al., 2015). The results of benchmark test on the K computer showed a reduction in a total executed time and a better scalability up to 10,000 nodes in comparison with the current system. Our new concept is effective for the speedup of the workflow and enables to expand the computational scale of the DA system.

Keywords: High Performance Computing (HPC), data assimilation, global cloud resolving simulation

 

# 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

 