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

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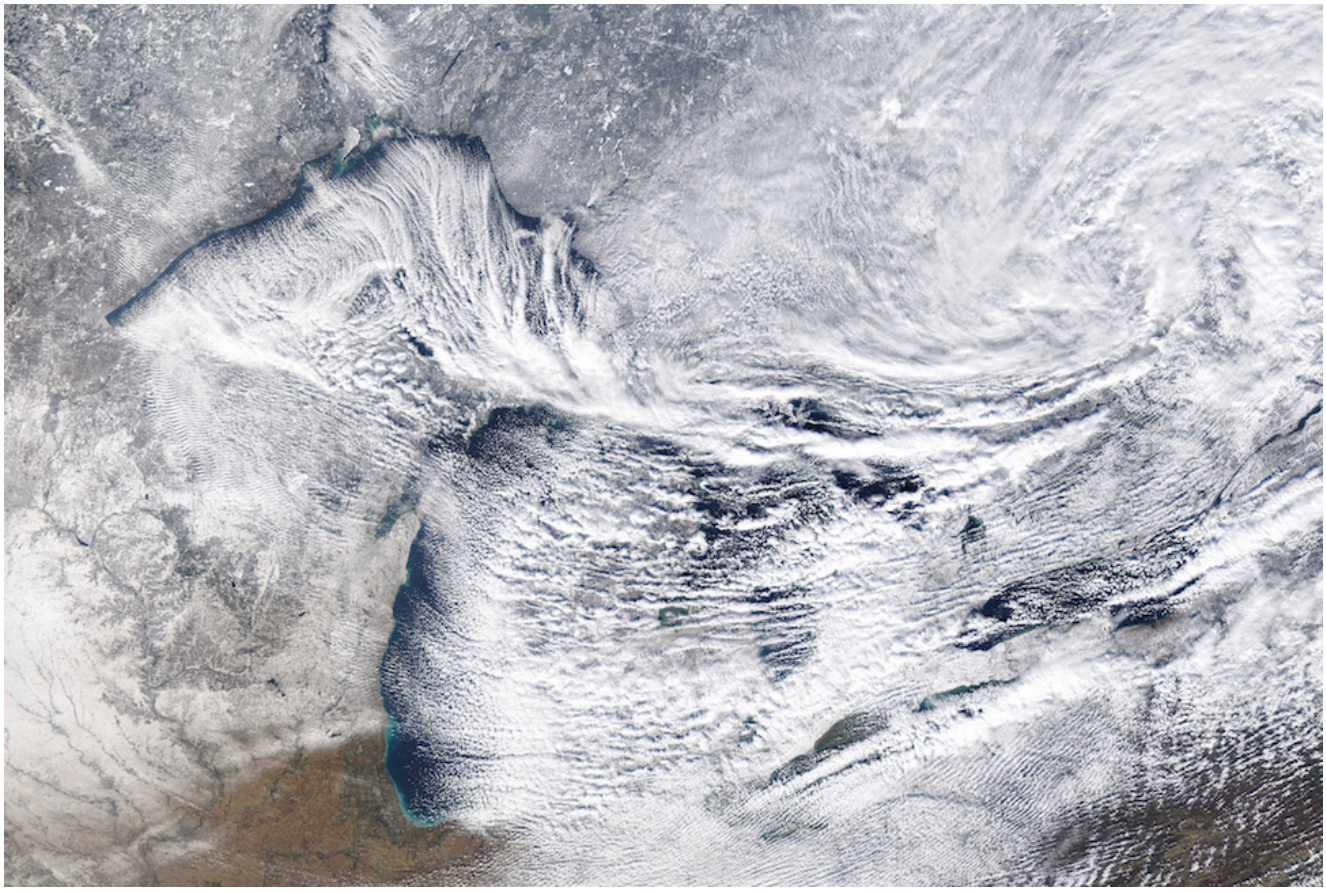
An extreme North American winter storm near eastern Lake Erie in November 2014 triggered the largest lake-effect snowfall event in southwest New York since the 1940s. While the large-scale atmospheric conditions of the southward migrating polar air mass are believed to be responsible for producing the 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.

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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

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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

