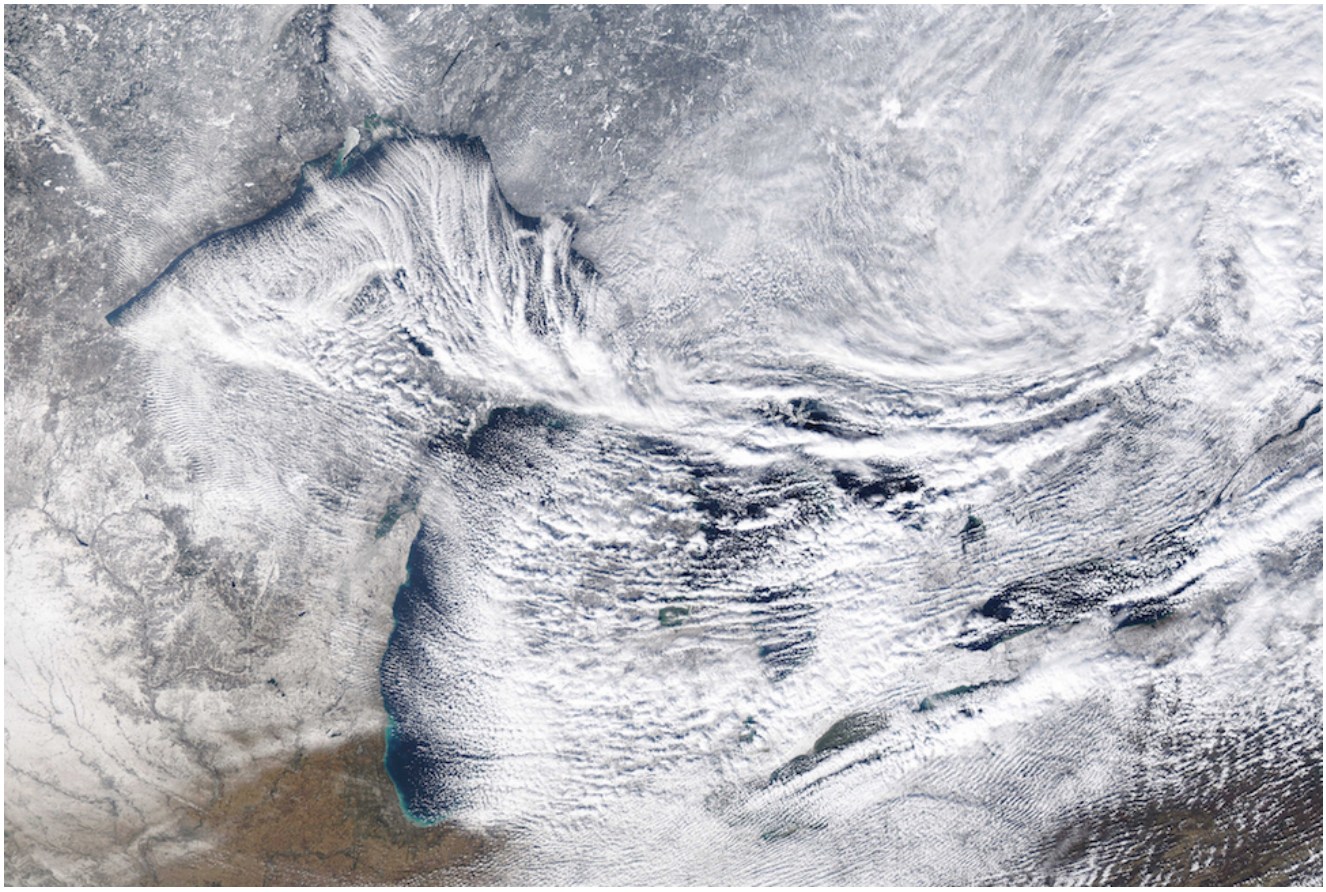
Turbulent Heat Fluxes during an Extreme Lake Effect Snow Event: Direct Measurements and Model Ensemble

*AYUMI Fujisaki-Manome[1], Lindsay E. Fitzpatrick[1], Andrew D. Gronewold[2], Eric J. Anderson[2], Christopher Spence[3], Jiquan Chen[4], Changliang Shao[4], David Wright[1], Chuliang Xiao[1]

1. University of Michigan Ann Arbor, 2. NOAA Great Lakes Environmental Research Laboratory, 3. Environment and Climate Change Canada, 4. Michigan State University

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

*横田 祥[1]、瀬古 弘[1,2]、國井 勝[1]、山内 洋[3,1]、新野 宏[4]
*Sho Yokota[1], Hiromu Seko[1,2], Masaru Kunii[1], Hiroshi Yamauchi[3,1], Hiroshi Niino[4]

1. 気象庁気象研究所、2. 海洋研究開発機構、3. 気象庁観測部、4. 東京大学大気海洋研究所
1. Meteorological Research Institute, Japan Meteorological Agency, 2. Japan Agency for Marine-Earth Science and Technology, 3. Observations Department, Japan Meteorological Agency, 4. Atmosphere and Ocean Research Institute, The University of Tokyo

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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キーワード：竜巻、アンサンブル予報、データ同化、循環解析、京コンピュータ
Keywords: Tornado, Ensemble forecast, Data assimilation, Circulation analysis, K-computer

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

*Guo-Yuan Lien[1], Takemasa Miyoshi[1], Juan Ruiz[2]

1. RIKEN AICS, 2. CIMA, Univ. Buenos Aires, Argentina

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

*本田 匠[1]、Lien Guo-Yuan[1]、小槻 峻司[1]、前島 康光[1]、岡本 幸三[2,1]、三好 建正[1]
*Takumi Honda[1], Guo-Yuan Lien[1], Shunji Kotsuki[1], Yasumitsu Maejima[1], Kozo OKAMOTO[2,1], Takemasa Miyoshi[1]

1. 理化学研究所計算科学研究機構、2. 気象研究所
1. RIKEN Advanced Institute for Computational Science, 2. Meteorological Research Institute

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.

キーワード：データ同化、ひまわり８号
Keywords: Data assimilation, Himawari-8

アンサンブルデータ同化のための摂動手法について

Perturbation Methods for Ensemble Data Assimilation

*斉藤 和雄[1,2]、國井 勝[1]、Le Duc[2,1]、栗花 卓弥[3]
*Kazuo Saito[1,2], Masaru Kunii[1], Duc Le[2,1], Takuya Kurihana[3]

1. 気象研究所、2. 海洋研究開発機構、3. 筑波大学
1. Meteorological Research Institute, 2. Japan Agency for Marine-Earth Science and Technology, 3. University of Tsukuba

近年アンサンブルカルマンフィルタなどアンサンブル予報を用いるデータ同化手法が、ハイパフォーマンスコンピューティングの環境下において変分法に代わる、もしくは変分法と組み合わせて解析精度を改善させることが期待出来る手法として注目されている。4次元変分法などに比べ開発コストが少なく、アンサンブル予報が同時に行える、などの利点がある一方で、精度比較では4次元変分法など既存の手法を凌駕出来ないという報告も多い。アンサンブルデータ同化ではアンサンブル予報が張る空間でアンサンブル平均場からの差からデータ同化に必要な予報誤差を見積もるが、アンサンブル予報場の特性はどのようにアンサンブルメンバーを生成させるかに強く依存する。既存の摂動手法の特徴や問題点を把握しておく必要がある。

現在LETKF（やアンサンブル変分同化法）などでは摂動手法として、「アンサンブル変換」と呼ばれる方法が広く用いられている。アンサンブル変換法の利点として、摂動振幅に解析誤差が反映すること、摂動場の直交性がある程度保証されるということが挙げられる。一方で、LETKFの摂動は、BGM法や特異ベクトル法などの他の摂動手法に比べて成長が遅く、アンサンブル予報の初期摂動として用いた場合のアンサンブル平均の精度やアンサンブル予報の検証スコアで必ずしも良くないことが講演者らのこれまでの調査（Saito et al. 2011; 2012: Tellus)で示されている。LETKFによる摂動の成長が遅い原因の一つとして変換行列に非対角成分が含まれる場合の非線形効果の影響が考えられるが、より影響が大きい問題として、アンサンブル変換を局所化と組み合わせた場合、局所化スケールよりも大きな大域的な場の構造が摂動場に反映されないということが懸念される。

講演では初期的な調査としてSPEEDY-LETKFを実行し、変換行列の係数を実際に出力するとともに、変換行列の対角成分や非対角成分の重ね合わせによる摂動ベクトルの空間的な構造やパワースペトルを調べたのでその結果を示す。

キーワード：アンサンブルデータ同化、アンサンブル変換、摂動手法
Keywords: ensemble data assimilation, ensemble transform, perturbation method

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

*山敷 庸亮[1]、大泉 伝[2]、黒木 竜介[1]
*Yosuke Yamashiki[1], Tsutao OIZUMI[2], Ryusuke Kuroki[1]

1. 京都大学大学院総合生存学館、2. 海洋研究開発機構
1. Global Water Resources Assessment Laboratory - Yamashiki Laboratory Graduate School of Advanced Integrated Studies in Human Survivability Kyoto University, 2. Japan Agency for Marine-Earth Science and Technology

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.

キーワード：水文土石流モデル、NHM、土石流
Keywords: Hydro-debris 2D, NHM, debris flow

Ekman downwelling from the lower troposphere in the intense tropical cyclones

*大野 知紀[1]
*Tomoki Ohno[1]

1. 東京大学大気海洋研究所
1. Atmosphere and Ocean Research Institute, The University of Tokyo

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).

キーワード：熱帯低気圧
Keywords: Tropical Cyclone

全球非静力学モデルを用いた1997年と2015年の50メンバーアンサンブル実験
50-member ensemble simulations for 1997 and 2015 using a global nonhydrostatic model

*山田 洋平[1]、小玉 知央[1]、佐藤 正樹[2,1]、中野 満寿男[1]、那須野 智江[1]、杉 正人[3]
*Yohei Yamada[1], Chihiro Kodama[1], Masaki Satoh[2,1], Masuo Nakano[1], Tomoe Nasuno[1], Masato Sugi[3]

1. 海洋研究開発機構、2. 東京大学大気海洋研究所、3. 気象庁気象研究所
1. Japan Agency for Marine-Earth Science and Technology, 2. Atmosphere and Ocean Research Institute, The University of Tokyo, 3. Meteorological Research Institute, Japan Meteorological Agency

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.

キーワード：熱帯低気圧、エルニーニョ、高解像度全球非静力学モデル
Keywords: tropical cyclone, El Nino, high-resolution global nonhydrostatic model

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

*小玉 知央[1]、大野 知紀[2]、野田 暁[1]、八代 尚[3]、山田 洋平[1]、中野 満寿男[1]、清木 達也[1]、那須野 智江[1]、Chen Ying-Wen[1]、宮川 知己[2]、佐藤 正樹[1,2]、杉 正人[4]
*Chihiro Kodama[1], Tomoki Ohno[2], Akita T Noda[1], Hisashi Yashiro[3], Yohei Yamada[1], Masuo Nakano[1], Tatsuya Seiki[1], Tomoe Nasuno[1], Ying-Wen Chen[1], Tomoki Miyakawa[2], Masaki Satoh[1,2], Masato Sugi[4]

1. 独立行政法人海洋研究開発機構、2. 東京大学大気海洋研究所、3. 理化学研究所計算科学研究機構、4. 気象研究所
1. Japan Agency for Marine-Earth Science and Technology, 2. Atmosphere and Ocean Research Institute, the University of Tokyo, 3. RIKEN Advanced Institute for Computational Science, 4. Meteorological Research Institute

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.

キーワード：高解像度気候シミュレーション、CMIP6 HighResMIP、感度実験、気候バイアス、台風
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

*近藤 圭一[1]、寺崎 康児[1]、三好 建正[1]
*KEIICHI KONDO[1], Koji Terasaki[1], Takemasa Miyoshi[1]

1. 国立研究開発法人 理化学研究所 計算科学研究機構
1. RIKEN Advanced Institute for Computational Science

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.

キーワード：データ同化、衛星観測同化、アンサンブルカルマンフィルタ
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

*関谷 高志[1]、宮崎 和幸[1,2]、大越智 幸司[1]、須藤 健悟[3,1]、滝川 雅之[1]
*Takashi Sekiya[1], Kazuyuki Miyazaki[1,2], Koji Ogochi[1], Kengo Sudo[3,1], Masayuki Takigawa[1]

1. 海洋研究開発機構、2. ジェット推進研究所/カリフォルニア工科大学、3. 名古屋大学 大学院環境学研究科
1. Japan Agency for Marine-Earth Science and Technology, 2. Jet Propulsion Laboratory-California Institute of Technology, 3. Graduate School of Environmental Studies, Nagoya University

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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キーワード：大気化学、大気環境、データ同化
Keywords: atmospheric chemistry, atmospheric environment, data assimilation

ポスト京コンピュータにおける超高解像度全球データ同化への挑戦：データスループット性能に着目したアンサンブル同化システムの開発
Towards an extreme scale global data assimilation on the post-K supercomputer: development of a throughput-aware framework for ensemble data assimilation

*八代 尚[1]、寺崎 康児[1]、三好 建正[1]、冨田 浩文[1]
*Hisashi Yashiro[1], Koji Terasaki[1], Takemasa Miyoshi[1], Hirofumi Tomita[1]

1. 国立研究開発法人理化学研究所　計算科学研究機構
1. RIKEN Advanced Institute for Computational Science

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.

キーワード：ハイパフォーマンスコンピューティング、データ同化、全球雲解像シミュレーション
Keywords: High Performance Computing (HPC), data assimilation, global cloud resolving simulation

