Resolution dependence of deep convections in a global simulation from over 10-kilometer to sub-kilometer grid spacing

*Yoshiyuki Kajikawa[1], Yoshiaki Miyamoto[1], Ryuji Yoshida[1], Tsuyoshi Yamaujra[1], Hisashi Yashiro[1], Hirofumi Tomita[1,2]

1.RIKEN Advanced Institute for Computational Science , 2.Japan Agency for Marine-Earth Science and Technology

The success of sub-kilometer global atmospheric simulation opens the door for resolving deep convections, which are essential elements of cloudy disturbances that drive global circulation. Previous study, Miyamoto et al. (2013), found that the essential change in simulated convection properties occurred at a grid spacing of about 2 km as a global mean. In grid-refinement experiments (14 km - 0.8 km) with a constant vertical resolution by using NICAM (Satoh et al., 2014), we conducted further comprehensive analysis of the global-mean state and the characteristics of deep convection, to clarify the difference of the essential change by location and environment. We found that the essential change in convection properties was different in location and environment for each cloudy disturbance. The convections over the tropics show larger resolution dependence than convections over mid-latitudes, whereas no significant difference was found in convection over land or ocean. Furthermore, convections over cloudy disturbances [(i.e., Madden Julian Oscillation (MJO), tropical cyclones (TC)] show essential change of convection properties at about 1-km grid spacing, suggesting resolution dependence. As a result, convections not categorized as cloudy disturbances make a large contribution to the global-mean convection properties. This implies that convections in disturbances largely affect organization processes, and hence have more horizontal resolution dependence. In contrast, other categorized convections that are not involved in major cloudy disturbances show the essential change at about 2-km grid spacing. This affects the latitude difference of the resolution dependence of convection properties, and hence the zonal mean outgoing long-range radiation (OLR). Despite the diversity of convection properties, most convection is resolved at less than 1-km grid spacing. In the future, longer integration of global atmosphere, to 0.87-km grid spacing, will stimulate significant discussion about the interaction between the convections and cloudy disturbances.

Keywords: deep convection, high resolution, global simulation, resolution dependence

Resolution dependence of diurnal cycle of tropical precipitation in a global high-resolution simulation

*Hisashi Yashiro[1], Kajikawa Kajikawa[1], Yoshiaki Miyamoto[1], Ryuji Yoshida[1], Tsuyoshi Yamaura[1], Hirofumi Tomita[1]

1.RIKEN Advanced Institute for Computational Science

<!--?xml version="1.0" encoding="UTF-8" standalone="no"?-->We carried out the global high-resolution atmospheric simulations with five horizontal resolution from 14km to 0.87km. The Nonhydrostatic Icosahedral Atmospheric Model (NICAM; Satoh et al. 2014) was used for this study and both simulations and anarysis are conducted on the K computer. In the tropical region (15S-15N), the result shows clear resolution dependence of the diurnal precipitation cycle over the land. Relatively weak precipitation peak appeared at late night in the result of the coarse resolution. The peak becomes stronger and its time becomes faster with increasing the horizontal resolution. Theresolution dependence of temporal changes in the averaged environmental variables over the tropical land, such as CAPE, PBL height, cloud base height, and precipitable water, were analyzed. The result shows that the activation of the convections become earlier, especially in the simulations with grid spacing less than 2 km. This result suggests that the difference of convection activity around the noon at the different horizontal resolution affects timing of the peak of the daily precipitation.The early morning peak of tropical precipitation cycle over the ocean was also well reproduced, with lesser resolution dependence.

Keywords: GCM, precipitation, high resolution simulation

Data assimilation experiments of phased array weather radar with 30-second-update ensemble Kalman filter with 100-m resolution

*Masaru Kunii[1,3], Juan Ruiz[2,3], Guo-Yuan Lien[3], Tomoo Ushio[4], Shinsuke Satoh[5], Kotaro Bessho[6], Hiromu Seko[1,3], Takemasa Miyoshi[3]

1.Meteorological Research Institute, 2.University of Buenos Aires, 3.RIKEN Advanced Institute for Computational Science, 4.Osaka University, 5.National Institute of Information and Communications Technology, 6.Meteorological Satellite Center

For preventing and mitigating natural disasters caused by local severe rainstorms, precise numerical weather prediction with higher spatial and temporal resolution would be essential. In this study, we developed a 30-second-update data assimilation system based on an ensemble Kalman filter using JMA-NHM with 100-m resolution. In the present setting of the experiments, we assimilated radar reflectivity and radial velocity derived from the every 30-second volume scan of the phased array weather radar (PAWR) at the Osaka University.
The data assimilation experiments were performed to reproduce the local heavy rainfall that had occurred in Kyoto on 13 July 2013. During the data assimilation cycles, the reflectivity patterns in the model became closer to the observations, indicating that the PAWR data were appropriately assimilated. However, the extended forecast showed a rapid error growth in about 10 minutes. This very short limit of predictability would be related to the time scales of convective activities represented by 100-m resolution, and may also be caused by an imbalance in the initial conditions due to 30-second update cycles, or could be related to potential inconsistency with the lateral boundaries. This presentation will include an introduction to the experimental system and the results of the data assimilation experiments.

Keywords: data assimiilation, ensemble Kalman filter, phased array weather radar

Ensemble Data Assimilation of GSMaP precipitation into the nonhydrostatic global atmospheric model NICAM

*Shunji Kotsuki[1], Koji Terasaki[1], Lien Guo-Yuan [1], Takemasa Miyoshi[1,2], Eugenia Kalnay[2]

1.RIKEN Advanced Institute for Computational Science, 2.Department of Atmospheric and Oceanic Science, University of Maryland, USA

It is generally difficult to assimilate precipitation data into numerical models mainly because of non-Gaussianity of precipitation variables and nonlinear precipitation processes. Lien et al. (2013, 2015) proposed to use an ensemble Kalman filter approach to avoid explicit linearization of models, and a Gaussian transformation (GT) method to deal with the non-Gaussianity of precipitation variables. Lien et al. pioneering results show that using an EnKF and GT helps improve the forecasts by assimilating global precipitation data, in both a simulated study using the SPEEDY model, and in a real-world study using the NCEP GFS and TRMM Multi-satellite Precipitation Analysis (TMPA) data.
This study extends the work of Lien et al. by assimilating the JAXA's Global Satellite Mapping of Precipitation (GSMaP) data into the Nonhydrostatic Icosahedral Atmospheric Model (NICAM) at 112-km horizontal resolution. It develops a new method to construct the two GTs (forward and inverse GTs) for observed and forecasted precipitation using the previous 30-day precipitation data. Using this new forward GT, precipitation variables are transformed to Gaussian variables, and assimilating the GSMaP precipitation results in improved forecasts. We also found that using the inverse GT allows to create realistic observation-like precipitation fields from the model forecasts transformed by the observation-based inverse GT. Moreover, we also explore online estimation of model parameters related to precipitation processes using precipitation data. This presentation will include the most recent progress up to the time of the meeting.

Keywords: Data Assimilation, GSMaP, NICAM-LETKF, Gaussian Transformation

Vertical grid spacing necessary for simulating tropical cirrus clouds

*TATSUYA SEIKI[1], Chihiro Kodama[1], Masaki Satoh[2], Tempei Hashino[3], Yuichiro Hagihara[4], Hajime Okamoto[3]

1.Japan Agency for Marine-Earth Science and Technology, 2.Atmosphere and Ocean Research Institute, The University of Tokyo, 3.Research Institute for Applied Mechanics, Kyushu University, 4.Earth Observation Research Center, Japan Aerospace Exploration Agency

The distribution of simulated cirrus clouds over the tropics is affected by the particular model's vertical grid spacing. To examine this effect, we use a high-resolution atmospheric general circulation model NICAM with 28-km and 14-km horizontal meshes. We show that a vertical grid spacing of at least 400 m is necessary to resolve the bulk structure of cirrus clouds. As one reduces the vertical grid spacing below about 1000 m, the visible cirrus cloud fraction decreases, the cloud thins (optically and geometrically), the cloud-top height lowers, and consequently, the OLR increases. These effects are stronger over the tropics. When using a vertical grid spacing of 400 m or less, the vertical profiles of effective radii and ice water content converge toward measurements (CloudSat satellite and Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation).

Keywords: General Circulation Model, Climate, Cirrus

High Cloud Responses to Global Warming Simulated by Two Different Cloud Microphysics Schemes Implemented in the Nonhydrostatic Icosahedral Atmospheric Model (NICAM)

*Ying-Wen Chen[1], TATSUYA SEIKI[1], Chihiro Kodama[1], Masaki Satoh[1,2], Akira Noda[1], Yohei Yamada[1,2]

1.Japan Agency for Marine-Earth Science and Technology, 2.Atmosphere and Ocean Research Institute, The University of Tokyo

This study examines cloud responses to global warming using a global nonhydrostatic model with two different cloud microphysics schemes. The cloud microphysics schemes tested here are the single- and double-moment schemes with six water categories: these schemes are referred to as NSW6 and NDW6, respectively. Simulations of one year for NSW6 and one boreal summer for NDW6 are performed using the nonhydrostatic icosahedral atmospheric model with a mesh size of approximately 14 km. NSW6 and NDW6 exhibit similar changes in the visible cloud fraction under conditions of global warming. The longwave (LW) cloud radiative feedbacks in NSW6 and NDW6 are larger than the average LW cloud radiative feedbacks in the Coupled Model Intercomparison Project Phase 5 (CMIP5)/Cloud Feedback Model Intercomparison Project 2 (CFMIP2). The LW cloud radiative feedbacks are mainly attributed to cirrus clouds, which prevail more in the tropics under global warming conditions. For NDW6, the LW cloud radiative feedbacks from cirrus clouds also extend to mid-latitudes. The changes in cirrus clouds and their effects on LW cloud radiative forcing (LWCRF) are assessed based on changes in the effective radii of ice hydrometeors (R_{ei}) and the cloud fraction. We determined that an increase in R_{ei} has a non-negligible impact on LWCRF compared with an increase in cloud fraction.

Keywords: Cloud Feedback

Achievements and future subjects of the 'Ultra-high Precision Mesoscale Weather Prediction' in SPIRE Field 3

*Kazuo Saito[1,3], Hiromu Seko[1,3], Tadashi Tsuyuki[2,1], Kozo Nakamuara[3], Le Duc[3,1], Tsutao OIZUMI[3,1], Kosuke Ito[4,1], Tohru Kuroda[3,1], Akihiro Hashimoto[1], Junshi Ito[1], Seiji Origuchi[1], Masaru Kunii[1], Wataru Mashiko[1], Sho Yokota[1], Kenichiro Kobayashi[5], Yosuke Yamashiki[6], Kazuhisa Tsuboki[7], Guixing Chen[8]

1.Meteorological Research Institute, 2.Meteorological College, 3.Japan Agency for Marine-Earth Science and Technology, 4.University of the Ryukyus, 5.Kobe University, 6.Kyoto University, 7.Nagoya University, 8.Sun Yat-sen University

A research project on super high-resolution mesoscale numerical weather prediction with the High Performance Computing using the K-computer was conducted from FY 2011 to FY 2015 (March 2016). This research was one of the five fields of the MEXT-funded national research project in Japan, the HPCI Strategic Programs for Innovative Research (SPIRE). Following three subjects were performed to show the feasibility of precise prediction of local high impact weather phenomena using the K-computer: 1) Development of cloud resolving 4-dimensional data assimilation systems, 2) Development and validation of a cloud resolving ensemble analysis and forecast system, and 3) Basic research with very high resolution atmospheric models.
In the presentation, achievements in the five year projects including development of advanced data assimilation methods, high-resolution data assimilation/ensemble experiments and super high resolution experiments for mesoscale high impact weathers (torrential rains, tropical cyclones, and tornados) are presented, and remaining subjects are addressed.

Keywords: High Performance Computing, K-computer, Mesoscale Numerical Weather Prediction

Mesoscale hybrid data assimilation system based on JMA nonhydrostatic model

*Kosuke Ito[1,2], Masaru Kunii[2], Takuya Kawabata[2], Kazuo Saito[2,3], Le Duc[3,2]

1.University of the Ryukyus, 2.Meteorological Research Institute, 3.JAMSTEC

This presentation discusses the benefits of using a hybrid ensemble Kalman filter and four-dimensional variational (4D-Var) data assimilation (DA) system rather than a 4D-Var system employing the National Meteorological Center (NMC)-method to predict severe weather events. This hybrid system is an adjoint-based 4D-Var system that uses a background error covariance matrix **B** constructed from the NMC method and perturbations in a local ensemble transform Kalman filter (LETKF) system. To reduce the sampling noise, two types of implementation (the spatial localization and neighboring ensemble approaches) were tested. Both the 4D-Var and LETKF systems are based on the Japan Meteorological Agency's nonhydrostatic model. The assimilation of a pseudo-single-observation of sea-level pressure located at a tropical cyclone (TC) center yielded wind and potential temperature increments physically consistent with what is expected of a mature TC in both hybrid systems at the beginning of the assimilation window, whereas analogous experiments performed using the NMC-based **B** (4D-Var-Bnmc) were not. At the end of the assimilation window, the structures of the increments became similar to each other among 4D-Var-based methodologies, while the analysis increment by the 4D-Var-Bnmc system was broad in the horizontal direction. Realistic DA experiments showed that the hybrid systems provided initial conditions that yielded more accurate TC intensity and track forecasts than those achievable by the 4D-Var-Bnmc system. The hybrid systems also yielded some statistically significant improvements in forecasting a local heavy rainfall event in terms of fraction skill scores when a 160 km ×160 km window size was used.

Keywords: Data Assimilation, Tropical Cyclone, Heavy Rainfall Event

Inter-comparison of the hybrid variational-ensemble methods

*Le Duc[1], Kazuo Saito[2]

1.Department of Seamless Environmental Prediction Research, Japan Agency for Marine-Earth Science and Technology, 2.Meteorological Research Institute, Japan Meteorological Agency

Variational (VAR) and ensemble Kalman filter (EnKF) methods are two dominant approaches in data assimilation for large-scale problems. VAR estimates the mode of the posterior distribution, leading to minimize a cost function. This cost function depends on the second moment of the prior distribution which cannot be produced by VAR itself. Therefore the climatological background covariance is used instead of the true “errors of the day”. This second moment is available into EnKF by sampling the prior distribution with a number of ensemble members. However, with a limited number of ensemble members, only a subspace of the error space can be represented. This means partial “errors of the day” are considered in EnKF. To introduce “errors of the day” into assimilation as in EnKF but can still explore the full error space as in VAR, some hybrid methods have been proposed.
In a hybrid method a specific operator is taken as a linear combination from the corresponding operators in the variational part and the ensemble part. If this operator is the background covariance we have the hybrid covariance method (hybrid B). In case the Kalman gain is chosen we have the hybrid gain method (hybrid K). In some variants of the hybrid covariance method, the operators in the factor form of the background covariance can be used. That means we can take a linear combination between background variances (hybrid V) or background correlations.
In the Strategic Programs for Innovative Research (SPIRE) Field 3, besides the traditional methods like 4DVAR and EnKF, hybrid methods have been implemented in the K Computer under a unified hybrid assimilation system for the Japan Meteorological Agency (JMA) limited-area operational model NHM. The system consisted of two components: the variational one 4DVAR and the ensemble one 4D-LETKF. The variational part was adopted from the JNoVA system developed at JMA. The ensemble part was based on the NHM-LETKF system developed at JMA. There is a two-way interaction between two sub-systems.
Real observation experiments were carried out for the August in 2014. This month was characterized by abnormal rainfall over the western Japan with two tropical cyclones and several heavy rainfall events. To verify performance of three hybrid methods (Hybrid B, Hybrid V, and Hybrid K) the same 50-50 weights were used in all hybrid experiments. In addition to the hybrid experiments, JNoVA and NHM-LETKF were run over the same period. Verification shows that all hybrid methods and JNoVA outperformed NHM-LETKF. Using JNoVA as the control method, Hybrid B and Hybrid K were slightly better than JNoVA. Hybrid V can beat JNoVA at some pressure level but in general Hybrid V was slightly worse than JNoVA. Hybrid B and Hybrid K were comparable in predicting atmospheric variables. Further verification against rainfall analyses points out that Hybrid K was comparable to JNoVA, whereas Hybrid B was better than JNoVA significantly in predicting precipitation especially for rainfall thresholds greater than 20 mm.

Keywords: variational data assimilation, ensemble Kalman filter, hybrid covariance, hybrid gain

Issues regarding the high-performance computing associated with the rapid-update-cycle ensemble data assimilation

*Guo-Yuan Lien[1], Takemasa Miyoshi[1], Seiya Nishizawa[1], Ryuji Yoshida[1], Hisashi Yashiro[1], Takumi Honda[1], Hirofumi Tomita[1]

1.RIKEN Advanced Institute for Computational Science

We have developed the SCALE-LETKF system, utilizing the Scalable Computing for Advanced Library and Environment (SCALE)-LES model and the Local Ensemble Transform Kalman Filter (LETKF), aiming to conduct ensemble data assimilation with very high resolution and rapid update cycle. The system has been used for several different studies, including the assimilation of the phased array weather radar (PAWR) and the Himawari-8 satellite radiance data. Although the peak computational speed of the K computer is powerful enough to run a very large problem, but the early version of the SCALE-LETKF system showed several issues to cause poor computational performance and low parallelization efficiency, or even to inhibit us from running a big problem. These issues include the memory overflow with huge observation files, heavy disk I/O and inter-process communication, and the load imbalance among processes. Some issues have been solved by the improvement of the code design, and the others are being investigated. We will discuss the issues and solutions up to the time of the presentation.

Keywords: LETKF, SCALE, High-performance computing

Non-Gaussian statics and data assimilation in the global atmospheric dynamics with 10240-member ensemble Kalman filter

*KEIICHI KONDO[1], Takemasa Miyoshi[1]

1.RIKEN Advanced Institute for Computational Science

In our previous work, impacts of removing covariance localization are investigated by increasing the ensemble size up to 10240, with an intermediate AGCM known as the SPEEDY (T30/L7) model and an ensemble Kalman filter (EnKF). The analysis accuracy without localization was greatly improved, and we found that the long range covariance structures up to several thousand km helped to extract information from distant observations. By contrast, the improvement in the tropical regions was relatively small. In this study, we hypothesize that this little improvements be related to the non-Gaussianity of the error statistics due to highly-nonlinear processes of convections. Actually, we found that strong non-Gaussianity such as bimodal distributions frequently appears in the tropical regions, and the spatial patterns of the occurrences of the non-Gaussian error statistics correspond well to that of the analysis error. We test some ideas to partly account for non-Gaussianity in the EnKF framework. We will present the results up to the time of the workshop.

Keywords: data assimilation, numerical weather prediction, non-Gaussianity

Improvement of Hydro-debris2D&3D model and It's application to Mountain Hazards and Sediment Disaster Prediction

*Yosuke Yamashiki[1], TSUTAO OIZUMI[2]

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 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. Prediction using ensemble rainfall results may be needed in order to increase the accuracy of the occurrence.
Hydro-debris 3D has been developed in order to simulate flow-particle interaction in the debris flow using Euler-lagrangean coupling numerical simulation. By precisely routing particle segregation, the mechanism of "Inverse grading" in debris flow observed in steep slope channel experiment in large eddies of debris flow is being reproduced by the model.

Keywords: Hydro-debris2D, Debris Flow, Heavy Rain, Euler-lagrangean coupling model

Impacts of dense and frequent surface observations on a sudden severe rainstorm forecast: A case of an isolated convective system

*Yasumitsu Maejima[1], Masaru Kunii[2], Juan J. Ruiz[3], Hirotaka Kure[4], Kae Sato[4], Takemasa Miyoshi[1]

1.RIKEN Advanced Institute for Computational Science, 2.Forecast Research Department, Meteorological Research Institute, 3.University of Buenos Aires, 4.Meisei Electoric Co. Ltd

To investigate the predictability at 1-km resolution for a sudden severe rainstorm event occurred on September 11, 2014 around Kobe city, we perform a series of data assimilation (DA) experiments using the Local Ensemble Transform Kalman Filter (LETKF) with the JMA-NHM (NHM-LETKF). In this event, a cumulonimbus generated suddenly near the Kobe city center around 0800 JST. It developed rapidly within 10-minutes, and brought heavy rainfalls over 50 mm h^{-1} from 0830 JST to 0930 JST, affecting people's morning activities.
The control run (CTRL) was performed with only reflectivity and radial velocity data from the Phased Array Weather Radar (PAWR) in Osaka University. We installed the automated weather stations Meisei "POTEKA II" at 8 locations in Kobe city, and have been observing surface data every 30 seconds. We performed DA experiments with the additional temperature and relative humidity data from the surface stations. Since we found that the surface station data had significant biases, a bias correction method has been developed with the Kobe observatory data as the unbiased ground truth. Two DA experiments with the raw data (NOBC) and the bias corrected data (BC) have been performed.
CTRL showed strong echoes and surface rainfalls, although the rainfall intensity is smaller than the JMA analyzed precipitation based on the radar and gauge networks. NOBC showed a significant decrease in surface relative humidity because of the dry biases of the surface station data, and consequently, showed decreased surface rainfalls. By contrast, BC showed stronger rainfall intensity, better matching with the JMA analyzed precipitation. The results suggest that the dense and frequent surface DA have a potential to improve the forecast accuracy for sudden severe rainstorms.

Keywords: Data assimilation, Sudden severe rainstorm forecast, An isolated convective system

Assimilating Himawari-8 Brightness Temperature: A Case Study on Typhoon Soudelor (2015)

*Takumi Honda[1], Guo-Yuan Lien[1], Seiya Nishizawa[1], Ryuji Yoshida[1], Sachiho Adachi[1], Koji Terasaki[1], Kozo Okamoto[2,1], Hirofumi Tomita[1], Kotaro Bessho[3], Takemasa Miyoshi[1]

1.RIKEN Advanced Institute for Computational Science, 2.Meteorological Research Institute, 3.Meteorological Satellite Center

The Japan Meteorological Agency started full operations of the new geostationary meteorological satellite “Himawari-8” in July 2015. Himawari-8 is the first of a series of the third-generation geostationary meteorological satellites including NOAA's GOES-R (planned for launch in 2016), producing about 50 times more data with more channels and 3 times more observing frequency than the previous generation. In August 2015, Himawari-8 successfully captured rapid intensification of Typhoon Soudelor (2015), the strongest northwestern Pacific typhoon in the summer of 2015 with minimum central pressure of 900 hPa. In this study, we assimilate brightness temperature from Himawari-8 using our new ensemble data assimilation system called “SCALE-LETKF” and investigate its impact on the analyses and forecasts of Soudelor.

Response of tropical cyclone activity and structure to a global warming in a high-resolution global nonhydrostatic model

*Yohei Yamada[1], Masaki Satoh[2], Masato Sugi[3], Chihiro Kodama[1], Akira T Noda[1], Masuo Nakano[1], Tomoe Nasuno[1]

1.Japan Agency for Marine-Earth Science and Technology, 2.Atmosphere and Ocean Research Institute, The University of Tokyo, 3.Meteorological Research Institute

Recently, the present-day and global warming simulations are conducted by using Nonhydrostatic ICosahedral Atmospheric Model (NICAM) without cumulus convective scheme. These simulations span 30-years. Horizontal grid interval is 14-km. The authors investigate response of tropical cyclone (TC) activities to global warming by using those outputs. The model projects reduction in the global TC formation, and a rise in rate of intense TC formation to the total TC. These findings are consistent with the previous studies.
NICAM reproduces the TC primary and secondary circulations. In particular, updrafts along eyewall cloud exhibits outward slope with height, which was documented by observational studies. Horizontal size of TC modulates the scale of natural disaster by tropical cyclone as well as its genesis number and intensity. The authors investigate a future change in the radius of maximum wind at the same life time maximum intensity. The global warming simulation projects a decrease in sea-level pressure under eyewall cloud, and an increase in TC frequency with large radius of maximum wind for TC developing to deeper than 980 hPa.
This change is related to the elevation of tropopause due to global warming. The elevation of tropopause induces upward extension of eyewall cloud, and increase in diabatic heating related to the extension. The heating decreases sea level pressure underneath the heating area mainly from hydrostatic adjustment. The change in sea level pressure distribution enhances tangential wind under and outward of eyewall cloud. The Outward slope of updrafts with height plays a key role in this mechanism.

Keywords: tropical cyclone, global warming

Future projection of extratropical cyclone simulated by a 14 km mesh global atmospheric model

*Chihiro Kodama[1,2], Bjorn Stevens[2], Thorsten Mauritsen[2]

1.Japan Agency for Marine-Earth Science and Technology, 2.Max Planck Institute for Meteorology

Changes in the extratropical cyclones due to global warming were investigated using 14 km mesh global non-hydrostatic atmospheric model. Present and future climate runs were performed for 30 years each with cloud microphysics scheme instead of convection scheme. Detection and tracking algorithms were applied to the model output as well as reanalysis data to obtain statistics of the extratropical cyclones. Structural changes of the extratropical cyclones were analyzed by compositing each variable at the cyclone center.

The model simulates statistics and mean structure of the extratropical cyclones including histograms of mean sea level pressure (MSLP), wind speed and precipitation and dynamical structure. Geographical distribution of storm-track is captured, though significant positional bias exists, especially over the north Pacific.

The model projects poleward shift of the storm-track and slight reduction of the number of extratropical cyclones. Though MSLP does not change significantly, precipitation and Southern Hemispheric low-level wind speed around the extratropical cyclone are enhanced due to global warming. The magnitudes of changes in precipitation and low-level wind speed tend to be greater for the cyclones with lower synoptic-filtered MSLP. Both liquid and ice water paths are increased, and it seems to be linked to the increased temperature and the enhanced upward motion around the extratropical cyclones. Such thermodynamical and dynamical factors will be discussed in our talk.

Keywords: extratropical cyclone, future projection, high-resolution global atmospheric model

Month-long forecasts using a global non-hydrostatic model in boreal summer season

*Tomoe Nasuno[1], Masuo Nakano[1], Masahiro Sawada[2]

1.Japan Agency for Marine-Earth Science and Technology, 2.Meteorological Research Institute

Month-long forecasts using a global non-hydrostatic model (Nonhydrostatic Icosahedral Atmospheric Model, NICAM) have been routinely run (once a week) during boreal summer season in 2014 and 2015. The model was initialized using NCEP final analysis and free run was conducted with prescribed sea surface temperature. Horizontal mesh size of 14-km was globally used with explicit representation of moist convection. In both years, El Nino was developing and successive formation of tropical cyclones took place in the western North Pacific during the active periods of intraseasonal oscillation (ISO). The model generally captured the large-scale variability associated with the ISO, such as the eastward and northward extension of lower tropospheric equatorial westerlies and convective activity at the lead time of approximately two weeks. These results support the arguments of previous studies based on NICAM ensemble simulations using the K-computer. Some common biases were noted, such as northward displacement of monsoonal circulation and earlier growth of convectively coupled vorticity disturbances. By fixing these biases, extension of predictability is highly expected. The simulation results also suggest that better prediction of major convective systems, such as tropical cyclones, leads to better forecast skills in large-scale fields.

Keywords: Global nonhydrostatic model, Tropical Cyclogenesis, Boreal Summer Intraseasonal Oscillation

Current status of subseasonal simulations using ocean coupled NICAM (NICOCO)

*Tomoki Miyakawa[1]

1.Atmosphere and Ocean Research Institute, The University of Tokyo

NICAM has demonstrated its potential as an atmospheric model in producing realistic MJOs in terms of eastward propagation speed and spatial precipitation patterns (Miura et al. 2007, Miyakawa et al. 2014). Ocean-surface boundary conditions for NICAM had been either prescribed SSTs or mixed-layer 1D ocean model in these studies. Recently we developed a coupler that connects the Icosahedral grid-system of NICAM with a Tri-polar grid system applied in an ocean model COCO, which has been used extensively as the ocean component of MIROC. The ultimate target of the ocean coupling is to enable long-term climate predictions, which require additional effort for adjustment and verification along with a large amount of computational resource. However in the short term, we seek to utilize the ocean coupled NICAM (NICOCO) to improve sub-seasonal to seasonal predictions, and deepen our understandings in the interactions between MJO and ocean. The pilot study of NICOCO includes the evaluation of ocean coupling impacts on 1) interaction between MJO and ENSO, 2) interactions between MJO and oceanic waves and/or through flows in the Maritime continent warm pool regions, and 3) Australian monsoon onset. Model features and preliminary results will be introduced.

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Keywords: NICAM, Ocean coupled model, global nonhydrostatic model

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

*andrei giniatoulline[1]

1.Department of Mathematics, Los Andes University, Bogota, Colombia, South America

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

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

Numerical simulations of Typhoon Haiyan in 2013

*Akiyoshi Wada[1], Masahiro Sawada[1]

1.Typhoon Research Department Meteorological Research Institute

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

Keywords: Typhoon, Numerical simulation, Sea surface cooling

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

*Koji Terasaki[1], Shunji Kotsuki[1], Takemasa Miyoshi[1]

1.RIKEN Advanced Institute for Computational Science

It is crucial to develop a numerical weather prediction system including data assimilation in order to predict the extreme weather such as heavy rainfalls and typhoons in the post-K era. We have been developing the NICAM-LETKF system to assimilate the conventional observations, satellite microwave radiances from AMSU-A (Advanced Microwave Sounding Unit-A), and satellite-based global precipitation data GSMaP (Global Satellite Mapping of Precipitation). The NICAM-LETKF may be run at very high resolution, or may provide boundary conditions for even higher resolution systems. Improving the NICAM-LETKF performance is at the center of enhancing mesoscale predictability for better preparedness for severe weather events well in advance.
Data assimilation experiments have been conducted with NICAM-LETKF at 112- and 28-km horizontal resolution with 100 ensemble members. Higher resolution experiment can reproduce the precipitation field well by assimilating precipitation observations. We need to keep improving the physical and computational performances of NICAM-LETKF to increase the resolution and the ensemble size, and to assimilate “Big Data” from the next-generation observations.

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

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

*Shigenori Otsuka[1], Takemasa Miyoshi[1]

1.RIKEN Advanced Institute for Computational Science

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

Keywords: cumulus convection, breeding, predictability

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

*Masahiro Sawada[1], Akiyoshi Wada[1], Hiromasa Yoshimura[1], Masuo Nakano[2], Ryo Onishi[2], Shintaro Kawahara[1], Hideaki Kawai[1], Eiki Shindo[1], Takeshi Iriguchi[1], Munehiko Yamaguchi[1], Masato Sugi[1], Tomoe Nasuno[2], Wataru Sasaki[2], Hiromitsu Fuchigami[3], Yoshiaki Takeuchi[1]

1.Meteorological Research Institute, 2.Japan Agency for Marine-Earth Science and Technology, 3.NEC Informatec Systems, Ltd.

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

Keywords: tropical cyclone, nonhydrostatic global model

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

*Akira Noda[1], Tatsuya Seiki[1], Masaki Satoh[1], Yohei Yamada[1]

1.Japan Agency for Marine-Earth Science and Technology

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

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

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

*Masuo Nakano[1], Tomoe Nasuno[1], Masaki Satoh[2,1]

1.JAMSTEC, 2.U. Tokyo/AORI

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

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

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

*Wataru Sasaki[1], Ryo Onishi[1], Hiromitsu Fuchigami[2]

1.JAMSTEC Japan Agency for Marine-Earth Science and Technology, 2.NEC Informatec Systems, Ltd.

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

Keywords: typhoon, ocean coupling, nonhydrostatic global model

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

*Yoshikazu Kitano[1], Tomohito J. Yamada[1]

1.Hokkaido University

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

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

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

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

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

*Hiromu Seko[2,1], Takemasa Miyoshi[3], Kazuo Saito[1,2], Hiroshi Niino[4], Tetsurou Tamura[5], Masaru Kunii[1]

1.Meteorological Research Institute, 2.Japan Agency for Marine-Earth Science and Technology, 3.RIKEN Advanced Institute for Computational Science, 4.Atmosphere and Ocean Research Institute, The University of Tokyo, 5.Tokyo Institute of Technology

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

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

*TSUTAO OIZUMI[1,2], Kazuo SAITO[2,1], Junshi ITO[2], Le DUC[1,2]

1.Japan Agency for Marine-Earth Science and Technology, 2.Meteorological Research Institute

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

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

