Analyzing the ocean with the latest ECCO Ocean State Estimate

*Ichiro Fukumori[1], Ou Wang[1], Ian Fenty[1], Gael Forget[2], Patrick Heimbach[3], Rui M. Ponte[4]

1. Jet Propulsion Laboratory, California Institute of Technology, 2. Massachusetts Institute of Technology, 3. University of Texas at Austin, 4. Atmospheric and Environmental Research, Inc.

Interannual to decadal variations of the ocean are described using the latest estimate from the "Estimating the Circulation and Climate of the Ocean" (ECCO) project. The estimate combines a state-of-the-art ocean general circulation model (MITgcm) with nearly all extant observations of the ocean from 1992 to 2015, including sea level from satellites (e.g., Jason-2), and in situ hydrographic profiles from ships (e.g., WOCE) and floats (e.g., Argo). The model is of moderate spatial resolution (40-100km) but with a domain that is truly global including the Arctic Ocean. The estimate's enhancements from earlier analyses include its longer period (4 additional years), use of new observations (e.g., GRACE ocean bottom pressure and Aquarius sea surface salinity), model improvements (e.g., geothermal heating, sea ice model), and accounting of correlated uncertainties (e.g., forcing bias).

The new analysis has improved agreements with observations than before, allowing a more accurate accounting of processes contributing to their variation. In particular, the ECCO analysis is characterized by its physical consistency in the sense of the estimate's temporal evolution being accounted for explicitly in terms of physical processes resolved by the model. The estimation's infrastructure (e.g., model adjoint) allows analyses that cannot be easily performed from observations or models alone.

The new estimate and its infrastructure will be presented with a focus on sea level variations and associated changes in ocean heat and mass. Regional and vertical distribution of the variable heat and mass fields will be explored and the nature of their evolution will be examined in relation to the ocean circulation.

Keywords: Ocean Circulation, Sea Level, Climate Change, Data Assimilation, Ocean Modeling

On the discretization of the Onsager-Machlup functional

*Nozomi Sugiura[1]

1. Japan Agency for Marine-Earth Science and Technology

When taking the model error into account, one needs to evaluate the prior distribution (the Onsager-Machlup functional), which contains the divergence term difficult to be calculated for large systems. However, the Euler method for time discretization of the functional can eliminate the need for evaluating the divergence term. This property is of use for solving nonlinear data assimilation problems with sampling methods such as the Metropolis-adjusted Langevin algorithm.

Keywords: data assimilation, Markov chain Monte Carlo

Reconditioning the observation error covariance matrix in the local ensemble transform Kalman filter: experiments with the Lorenz-96 model

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

1. RIKEN Advanced Institute for Computational Science

It is natural that the observation errors are correlated if measured with the same instrument, such as radiosondes, radars, and satellite sensors. Radiosonde observations would have the error correlations in the vertical. Satellite radiances would have the horizontal and inter-channel error correlations. However, in the operational data assimilation systems, the observation errors are usually assumed to be uncorrelated for simplicity and computational efficiency.
The condition number of the observation error covariance matrix affects to the convergence efficiency when minimizing the cost function when the observation error correlation is considered in the variational data assimilation methods. However, it is still unknown how the condition number affects in the local ensemble transform Kalman filter (LETKF). In this study, we explore the potential impact of the condition number of the observation error covariance matrix in the LETKF. We performed a series of observing system simulation experiments (OSSEs) to account for the observation error correlations in the LETKF with the simple toy Lorenz-96 model using different observation error covariance matrices of the low and high condition numbers. The results show that the LETKF becomes very unstable when the condition number is large. ‘Reconditioning’ is a method to reduce the condition number of a matrix by slightly modifying the original matrix. The experiments using the ‘reconditioned’ observation error covariance matrix show that the LETKF is significantly stabilized, while the impact on the analysis accuracy is minimal.

Keywords: Data assimilation, Observation error correlation, Condition number, Reconditioning

Toward real forecast of aurora electrojet index using the data assimilation

*Yoshizumi Miyoshi[1], Ryota Yamamoto[1], Daikou Shiota[1], Genta Ueno[2], Masahito Nose[3], Shinobu Machida[1], Yukinaga Miyashita[4]

1. Institute for Space-Earth Environmental Research, Nagoya University, 2. The institute of statistical mathematics, 3. World Data Center for Geomagnetism, Kyoto, 4. KASI

The auroral electrojet indices (AU, AL, AE) are a proxy of substorm as well as auroral activity, so that the forecast of these indices is important for the space weather forecast. In this study, we develop a data assimilation code to estimate the AU index based on Goertz et al. [1993] model. In the data assimilation, the state space model consists of the system model and the observation model. The model of Goertz et al.[1993] is used as the system model, which calculates time variation of the AU index using the electric fields of the solar wind. The state vector includes the AU index and coupling parameters for solar-wind, magnetosphere and ionosphere. The AU index provided from World Data Center for Geomagnetism, Kyoto is used as the observation vector. The sequential data assimilation includes the following three steps; prediction, filtering, and smoothing. We use the particle filter that can apply for non-linear/non-gaussian problems. Furthermore, we use the particle smoother as the smoothing scheme. To apply the real-time forecast of the AU-index, we develop a system that includes hindcast and forecast. The hindcast investigates probable past state using the data assimilation, while the forecast investigates propable future state. Using the estimated coupling parameters at the hindcast, the AU index is predicted by the Goertz model. The test calculation shows that the forecast performance is improved by estimating the coupling parameters with the data assimilation at the hindcast. This system has been coupled with the SUSANOO-SW that simulates the solar wind and IMF at 1 AU for the next 7 days based on the MHD model, and the electric fields of the solar wind provided from the SUSANOO-SW is used as an input for both hindcast and forecast. Our developed system has been operated and provided weekly variations of the AU index.

Keywords: Aurora, Data assimilation, Space Weather

Utilization of fisherman-logging data for enhancement of the coastal ocean monitoring network in Japan

*Yasumasa Miyazawa[1], Tsutomu Tokeshi[2], Sergey Varlamov[1], Toru Miyama[1], Tsutomu Hihara[1], Xinyu Guo[3], Yushi Morioka[1]

1. Japan Agency for Marine-Earth Science and Technology, 2. Miyazaki Prefectural Fisheries Research Institute, 3. Ehime University

An operational ocean observing system around Japan is mainly composed of satellite observation, ARGO floats, and repeated section surveys by central and local governmental research agencies. The data from the observing system are conveyed to operational ocean forecast systems based on data-assimilative ocean general circulation models in near real-time basis. Here we examine impacts of fisherman-logging Conductivity, Temperature, Depth sensor (FCTD) data on the ocean observing system using an operational ocean forecasting system JCOPE2. Additional assimilation of the FCTD data provided from Miyazaki prefectural fisheries research institute is effective for modifying representation of oceanic conditions for a period from April to August 2016 in nearshore region southeast of the Kyushu Island. The Kuroshio front position averaged for the period moves to nearshore side as observed by the additional assimilation. In particular, the FCTD assimilation leads to finer representation of a subsurface warm water tongue varying with a few days time scale, which is never detected by the satellite remote sensing and existing in-situ monitoring data, demonstrating a potential key role of FCTD for enhancement of the coastal ocean monitoring network in Japan.

Keywords: data assimilation, ocean observing system, fisherman-CTD

4DVAR with ensemble background error covariance estimation in a coastal ocean model

*Ivo Pasmans[1], Alexander Kurapov[1]

1. Oregon State University

Traditionally 4DVAR implementations for ocean forecasting proceed in a series of relatively short time windows and assume that the model background error covariance is static in time. Offshore Oregon/Washington (USA west coast) this static assumption on the background error covariance is unlikely to hold as the outflow of the Columbia River creates a fresh water plume of which the location and extent vary depending on wind direction and river outflow. To better capture the natural variability in the system we have implemented E4DVAR data assimilation in Oregon State University's ocean forecasting system. In this system the initial conditions at the beginning of each 3-day window are corrected by combining the previous 3-day model forecast from a 2-km ROMS (Regional Ocean Modeling System) model with observations of GOES sea-surface temperatures, high-frequency radar surface current observations and Jason satellite altimetry using 4DVAR. For the tangent linear and adjoint parts of the 4DVAR algorithm the system uses the in-house developed AVRORA codes. The background error covariance is estimated by localizing, using a new Monte-Carlo localization scheme, the sample covariance of a 50-member ensemble. The members of this ensemble are generated by running the system using different wind fields and perturbed observations. Results show that the new system provides better forecasts for the subsurface temperature and salinity fields and a more accurate representation of the temperature-salinity relationship. However, the surface salinity in the new system turned out to be overly sensitive to observation errors in sea-surface temperature. Interestingly, introduction of approximate salinity conservation in the assimilation scheme has been shown to suppress unrealistically large sea-surface salinity corrections and additionally modify the shape of the river plume. This indicates that implementation of data assimilation in models with tracers is non-trivial and should be handled with care.

Keywords: data assimilation, 4DVAR, coastal ocean, localization, river plume

Estimation of a posterior error covariance using a linear quasi-Newton method and its application to an inversion of CO_2 sources and sinks

*Yosuke Niwa[1], Yosuke Fujii[1]

1. Meteorological Research Institute

Data assimilation and inversion methods are widely used in earth science problems to estimate optimal initial/boundary conditions or parameters of a numerical model from given limited observations. A four-dimensional variational method (4D-Var), one of prominent data assimilation/inversion methods, is attractive in that it estimates optimal model variables in a high-resolution without explicitly dealing with a model operator matrix whose size is too large to store in a memory or storage. However, a conventional 4D-Var does not estimate a posterior error covariance owing to its deterministic nature based on the maximum likelihood estimation. A posterior error covariance could provide valuable information not only of uncertainties of estimated variables but also of observation impacts, which is beneficial, for instance, for designing observation networks. In this study, we have developed a new method to estimate a posterior error covariance in a 4D-Var framework. The descent scheme of the 4D-Var method is based on Preconditioned Optimizing Utility for Large-dimensional analyses (POpULar: Fujii, 2005), which employs a quasi-Newton method with Broyden–Fletcher–Goldfarb–Shanno (BFGS) algorithm. One prominent feature of POpULar is that it does not require difficult decomposition of a prior error covariance matrix. In iterative calculations of the BFGS formula, an inverse Hessian is approximated and then used to determine a next search direction. If accurately approximated, this inverse Hessian can be considered as the posterior error covariance. Although the developed method assumes the model linearity and the perfect forward-adjoint relationship, it successfully calculates an accurate inverse Hessian. Furthermore, the convergence speed of the estimation of the inverse Hessian can be efficiently accelerated by ensemble calculations. Applying this method to a linear problem of CO_2 sources/sinks inversion with a system named NICAM-TM 4D-Var (Niwa et al., 2016a,b), we demonstrate its validity and practical utility.

Keywords: inversion, posterior error, quasi-Newton method

The development of data assimilation in the ionospheric space weather

*Chia-Hung Chen[1], Charles Lin[1], Tomoko Matsuo[2,3], Jann-Yenq Liu[4,5]

1. Department of Earth Sciences, National Cheng Kung University, Taiwan, 2. Cooperative Institute for Research in Environmental Sciences, University of Colorado Boulder, Boulder, Colorado, USA, 3. Space Weather Prediction Center, National Oceanic and Atmospheric Administration, Boulder, Colorado, USA, 4. Institute of Space Science, National Central University, Chung-Li, Taiwan, 5. Center for Space and Remote Sensing Research, National Central University, Chung-Li, Taiwan

An ionospheric data assimilation forecast model has been developed by ensemble Kalman filter (EnKF) to adjust ionospheric observations into a thermosphere-ionosphere-electrodynamics general circulation model (TIEGCM). Using this assimilation model, the performances of ionospheric forecast during the geomagnetic storm conditions are further evaluated in this study. Results suggest a rapid assimilation-forecast cycling (10-min in this study) can greatly improve the quality of the model forecast. Furthermore, updating the thermospheric state variables in the coupled thermosphere-ionosphere forecast model in the assimilation step is an important factor in improving the trajectory of model forecasting. Different high-latitude ionospheric convection models, Heelis and Weimer, are further evaluated in different latitude regions. Results show the better forecast in the electron density at the low-latitude region during the storm main phase and the recovery phase. The well reproduced eastward electric field at the low-latitude region by the assimilation model reveals that the electric fields may be an important factor to have the contributions on the accuracy of ionospheric forecast.

Keywords: data assimilation, ionospheric forecast model, geomagnetic storm

Data assimilation for real-time prediction of earthquake ground shaking: “Numerical shake prediction” for Earthquake Early Warning

*Mitsuyuki Hoshiba[1]

1. Meteorological Research Institute

Real-time prediction of earthquake ground shaking is a strong tool for prevention/mitigation of earthquake disaster, and it has been applied for earthquake early warning (EEW). EEW has been operated for general public in Japan since 2007 and in Mexico since early 1990s, and possible use of such systems has been investigated in the United States, Taiwan, EU, Turkey, and other countries. Many of the present EEW systems first quickly determine the earthquake hypocenter and magnitude, and then they predict the strengths of ground shaking at various locations using the hypocenter distance and magnitude. The 2011 Tohoku earthquake (M_w 9.0), however, revealed some technical issues with such methods: under-prediction at large distances due to the large extent of the fault rupture, and over-prediction because the system was confused by multiple aftershocks that occurred simultaneously. To address these issues, we propose a new concept for EEW, in which the distribution of the present wavefield is estimated precisely in real time (real-time shake mapping) by applying a data assimilation technique, and then the future wavefield is predicted time-evolutionally by simulation of seismic wave propagation. We call this method, in which physical processes are simulated from the precisely estimated present condition, “numerical shake prediction” by analogy to “numerical weather prediction” in meteorology. By applying the proposed method to the 2011 Tohoku Earthquake and the 2016 Kumamoto Earthquake (M_w 7.0), we show that numerical shake prediction can precisely and rapidly predict ground shaking in real time manner.
Real-time prediction of earthquake ground shaking is a strong tool for prevention/mitigation of earthquake disaster, and it has been applied for earthquake early warning (EEW). EEW has been operated for general public in Japan since 2007 and in Mexico since early 1990s, and possible use of such systems has been investigated in the United States, Taiwan, EU, Turkey, and other countries. Many of the present EEW systems first quickly determine the earthquake hypocenter and magnitude, and then they predict the strengths of ground shaking at various locations using the hypocenter distance and magnitude. The 2011 Tohoku earthquake (M_w 9.0), however, revealed some technical issues with such methods: under-prediction at large distances due to the large extent of the fault rupture, and over-prediction because the system was confused by multiple aftershocks that occurred simultaneously. To address these issues, we propose a new concept for EEW, in which the distribution of the present wavefield is estimated precisely in real time (real-time shake mapping) by applying a data assimilation technique, and then the future wavefield is predicted time-evolutionally by simulation of seismic wave propagation. We call this method, in which physical processes are simulated from the precisely estimated present condition, “numerical shake prediction” by analogy to “numerical weather prediction” in meteorology. By applying the proposed method to the 2011 Tohoku Earthquake and the 2016 Kumamoto Earthquake (M_w 7.0), we show that numerical shake prediction can precisely and rapidly predict ground shaking in real time manner.

Keywords: data assimilation, earthquake early warning, real-time prediction of ground shaking

Potential of assimilating river discharge observations into the atmosphere by strongly coupled data assimilation: Hydrometeorology as an inversion problem

*Yohei Sawada[1], Toshiyuki Nakaegawa[2], Takemasa Miyoshi[1]

1. RIKEN Advanced Institute for Computational Science, 2. Meteorological Research Institute, Japan Meteorological Agency

We examine the potential of assimilating river discharge observations into the atmosphere by strongly coupled data assimilation. The Japan Meteorological Agency Non-Hydrostatic atmospheric Model (JMA-NHM) is first coupled with the simple rainfall-runoff model. Next, the Local Ensemble Transform Kalman Filter (LETKF) is used for this coupled model to assimilate the observations of the rainfall-runoff model variables into the JMA-NHM model variables. This system enables to do hydrometeorology backward, i.e., to inversely estimate atmospheric conditions from the information of a flood on land surfaces. We will present our recent progress of an Observing System Simulation Experiment (OSSE) to evaluate how the assimilation of river discharge observations improves the skill of forecasting severe rainfalls and floods.

Keywords: Coupled Data Assimilation, Floods

Applycation of data assimilation to paleoclimate

*Atsushi Okazaki[1], Kei Yoshimura[2], Takemasa Miyoshi[1]

1. RIKEN Advanced Institute for Computational Science, 2. The University of Tokyo

Knowledge of past climate conditions is crucial to understand the climate system and to predict the future. Historically, two approaches have been used to reconstruct paleoclimate: one based on the empirical evidence contained in proxy data, and the other based on simulation with physically-based climate models. Here, proxies are not the direct record of climate variables such as temperature, winds and pressure, but natural records representing climate such as tree-ring width and isotopic composition in ice sheets. Recently, an approach combining proxy data and climate simulations through data assimilation (DA) has emerged. DA has long been used for forecasting weather and is a well-established method. However, the DA algorithms used for weather forecasts cannot be directly applied to paleoclimate due to the different temporal resolution, spatial extent, and type of information contained within the observation data. The temporal resolution and spatial distribution of proxy data are significantly lower (seasonal at best) and sparser than the present-day observations used for weather forecasts. Therefore, DA applied to paleoclimate is only loosely linked to the methods used in the more mature field of weather forecasting. Several DA methods have been proposed for paleoclimate reconstruction, and paleoclimate studies using DA have successfully determined the mechanisms behind the past climate changes. In the previous studies, the variables used for DA have been data reconstructed from proxies (e.g., surface air temperature) because physical models for proxies have not been readily available. Recently, proxy modelers have developed and evaluated several forward models for stable water isotopic proxies. In this study, we attempted to assimilate proxy data directly for the first time, and demonstrated that the new method can reconstruct paleoclimate more skillfully.

Keywords: data assimilation, paleoclimate, stable water isotope

Data assimilation for massive autonomous systems based on a second-order adjoint method

Shin-ichi Ito[1], *Hiromichi Nagao[1,2], Akinori Yamanaka[3], Yuhki Tsukada[4], Toshiyuki Koyama[4], Masayuki Kano[1], Junya Inoue[5]

1. Earthquake Research Institute, The University of Tokyo, 2. Graduate School of Information Science and Technology, The University of Tokyo, 3. Graduate School of Mechanical Systems Engineering, Tokyo University of Agriculture and Technology, 4. Graduate School of Engineering, Nagoya University, 5. Research Center for Advanced Science and Technology

We propose an adjoint-based data assimilation method for massive autonomous models that produces optimum estimates and their uncertainties within reasonable computation time and resource constraints. The uncertainties are given as several diagonal elements of an inverse Hessian matrix, which is the covariance matrix of a normal distribution that approximates the target posterior probability density function in the neighborhood of the optimum. Conventional algorithms for deriving the inverse Hessian matrix require $O(CN^2+N^3)$ computations and $O(N^2)$ memory, where N is the number of degrees of freedom of a given autonomous system and C is the number of computations needed to simulate time series of suitable length. The proposed method using a second-order adjoint method allows us to directly evaluate the diagonal elements of the inverse Hessian matrix without computing all of its elements. This drastically reduces the number of computations to $O(C)$ and the amount of memory to $O(N)$ for each diagonal element. The proposed method is validated through numerical tests using a massive two-dimensional Kobayashi phase-field model. We confirm that the proposed method correctly reproduces the parameter and initial state assumed in advance, and successfully evaluates the uncertainty of the parameter.

Keywords: data assmilation, adjoint method, phase-field model, uncertainty quantification, Bayesian statistics

Data assimilation for optimal estimation of frictional parameters and prediction of afterslip in the 2003 Tokachi-oki earthquake

*Masayuki Kano[1], SHINICHI MIYAZAKI[2], Yoichi Ishikawa[3], Kosuke Ito[4], Kazuro Hirahara[2]

1. Earthquake Research Institute, The University of Tokyo, 2. Department of Geophysics, Graduate School of Science, Kyoto University, 3. Japan Agency for Marine-Earth Science and Technology, 4. Faculty of Science, University of the Ryukyus

A wide variety of fault slips at plate subduction zones are considered to reflect the spatial heterogeneities of frictional parameters. Thus, it is important to estimate the frictional parameters from geophysical observations. In addition, these estimated frictional parameters contribute to compute a realistic spatio-temporal evolution of fault slips. For this purpose, we have developed a technique to optimize frictional parameters and to predict a spatio-temporal evolution of slip based on an adjoint data assimilation method [Kano et al. 2010; 2013] and applied to the afterslip data in the 2003 Tokachi-oki earthquake [Kano et al. 2015]. In this presentation, we review these studies, and discuss the problems and the future plan for challenges of earthquake forecasting.

Keywords: Data assimilation, Afterslip, Frictional parameters, GNSS

Observation impact on the medium and the long-term range forecast on an eddy-resolving ocean forecast system based on ROMS

*Takashi Setou[1], Hiroshi Kuroda[5], Daisuke Takahashi[5], Tomonori Azumaya[5], Takeshi Okunishi[2], Daisuke Hasegawa[2], Shigeho Kakehi[2], Hitoshi Kaneko[2], Yugo Shimizu[1], Kiyotaka Hidaka[1], Yutaka HIroe[1], Keiichi Yamazaki[1], Takahiko Kameda[1], kazuhiro aoki[1], Takeshi Taneda[3], Kenji Morinaga[4], Makoto Okazaki[4], Masachika Masujima[4], Atsushi Nishimoto[1]

1. National Research Institute of Fisheries Science, Japan Fisheries Research and Education Agency, 2. Tohoku National Fisheries Research Institute, Japan Fisheries Research and Education Agency, 3. Seikai National Fisheries Research Institute, Japan Fisheries Research and Education Agency, 4. National Research Institute of Far Seas Fisheries, Japan Fisheries Research and Education Agency, 5. Hokkaido National Fisheries Research Institute, Japan Fisheries Research and Education Agency

Japan domestic fisheries research institutions constitute a horizontally close-arranged monitoring system around the coastal and the offshore region of Japan in the western North Pacific. Most of these hydrographic data (hereafter FRDATA) have been introduced for an eddy-resolving ocean forecast system, named by the FRA-ROMS (Kuroda et al. 2016, Ishii et al., 2016, Kodama et al. 2015), which developed by Japan Fisheries Research and Education Agency and is based on ROMS (Regional Ocean Modeling System) assimilated with satellite SSH/SST and hydrographic data such as GTSPP and FRDATA. The assimilation scheme, which is founded on the MOVE system developed by the Japan Meteorological Research Institute, is characterized by the following three steps; (1) minimizing the nonlinear cost functions by using a pre-conditioning method, (2) analyzing temperature-salinity profiles by using vertical coupled EOF modes, and (3) assimilating the data analyzed into an ocean model, namely, making reliable reanalysis data by using the Incremental Analysis Updates method. We assessed the relative impact of FRDATA by comparing modeled fields with assimilated and withheld FRDATA. The coastal FRDATA enabled to finely represent hydrographic structures in the coastal region and to remarkably improve the coastal forecast on the medium range forecast (about 1-month). On the other hand, the offshore FRDATA contributed to improve the accuracy not only on the long-term forecast (about 2-months) of some synoptic phenomena (e.g. the Kuroshio) but also of some coastal changes caused by such the phenomena.

Development of an operational system for monitoring and forecasting coastal and open ocean states around Japan.

*Nariaki Hirose[1], Norihisa Usui[1], Takahiro Toyoda[1], Yosuke Fujii[1], Yasushi Takatsuki[1], Kei Sakamoto[1], Hiroyuki Tsujino[1]

1. Meteorological Research Institute, Japan Meteorological Agency

MOVE/MRI.COM-JPN is the next operational system for monitoring and forecasting ocean state around Japan, and is currently under development at the Meteorological Research Institute (MRI) of the Japan Meteorological Agency (JMA). This system is scheduled to be operated in the JMA in a few years later to provide information not only for monitoring and forecasting ocean state but also for preventing coastal disasters such as abnormal sea level and storm surges. The whole system consists of three versions of the Ocean General Circulation Models (OGCM) for the global ocean (GLB), the North Pacific (NP) and the seas around Japan (JPN) and a four-dimensional variational (4DVAR) assimilation system used for the North Pacific Ocean model and its adjoint model (NP-4DVAR).
All the OGCMs used in the system are built based on the Meteorological Research Institute Community Ocean Model (MRI.COM). The domain of the JPN model extends from 117˚E to 160˚E zonally and from 20˚N to 52˚N meridionally. The horizontal resolution is about 2 km: 1/33˚ in the zonal direction and 1/50˚ in the meridional direction. The model has 60 levels in the vertical direction, with the layer thickness increasing from 2 m at surface to 700m at 6500-m depth. The z* vertical coordinate in the latest version of MRI.COM (ver.4.0) allows the models to set the minimum of the bottom depth to 8 m. A two-way on-line double-nesting method is used for downscaling from GLB to NP and from NP to JPN. The surface forcing of the wind stress and heat fluxes is subtracted from JRA55-do, calibrated dataset for driving ocean circulation based on the Japanese 55-year Reanalysis (JRA-55). The explicit tidal forcing and depression/suction by sea level pressure are incorporated into MRI.COM-JPN.
NP-4DVAR uses MOVE-4DVAR, which is extended from a multivariate three-dimensional variational (3DVAR) analysis scheme using vertical coupled temperature and salinity EOF modes for the background covariance matrix, MOVE. In-situ temperature and salinity profiles above 2000m-depth, satellite-based sea surface temperature (SST) and sea surface height (SSH) data are assimilated in NP-4DVAR. Incremental analysis updates (IAU) are applied for initializing temperature and salinity fields in NP-4DVAR for the first 3 days during the 10-days assimilation window. Both JPN and NP models are initialized by IAU based on the temperature and salinity analysis fields derived from NP-4DVAR.
The experiment in 2009 is carried out by using MOVE/MRI.COM-JPN. To evaluate the reproduction of sea level variability in MOVE/MRI.COM-JPN, we use the independent tide gauge data around the coastal area in Japan. We compare the daily-mean time series of sea level among MOVE/MRI.COM-JPN, free run simulation using the MRI.COM-JPN (JPN-free) and tide gauge data processed by a tide killer filter. These data include the variability caused by sea level pressure. The sea level variability in MOVE/MRI.COM-JPN well captured the variability of the tide gauge data from weekly to monthly time scales. This is attributed to the improvement of the synoptic scale variability through the inclusion of explicit sea level pressure representation and the mesoscale variability (such as eddies) by the initialization of NP-4DVAR. The correlation (root-mean-square difference) of sea level time series between MOVE/MRI.COM-JPN and tide gauge data are higher (smaller) than those between JPN-free and tide gauge data, indicating that MOVE/MRI.COM-JPN has the high potential of forecasting phenomena in the coastal seas.

Keywords: operational system, coastal model, data assimilation

Analysis error estimation in a 4-dimensional variational ocean data assimilation system using a quasi-Newton method

*Yosuke Fujii[1], Yosuke Niwa[1], Norihisa Usui[1]

1. Meteorological Research Institute, Japan Meteorological Agency

JMA/MRI has developed MOVE-WNP-4DVAR, an ocean data assimilation system of the western North Pacific using a four-dimensional variational (4DVAR) method, for monitoring and forecasting of the coastal and open ocean state around Japan. This system has generated the 4DVAR Ocean Reanalysis for the western North Pacific over 30 years (FORA-WNP30), which is now freely provided from JAMSTEC basically for research activities. It is valuable to estimate the analysis errors for assessing the reliability of assimilation fields, or reanalysis data, generated by data assimilation systems. In this study, we tried to estimate analysis errors using the information of the Hessian matrix which are used in a quasi-Newton method for minimizing the cost function in the 4DVAR analysis. We also use an ensemble approach in order to improve the estimation. The results indicate that the data assimilation reduces errors of the ocean fields in the Kuroshio Extension region, the Kuroshio-Oyashio mixed water region, south of Japan where Kuroshio meanders are often developed, and the south-west Japan Sea around the exit of the Tsushima Strait. The errors seem to be reduced effectively in the area where unstable physical modes exist. In addition, we confirm that increasing ensemble members is essential for improving the accuracy of the error estimation.

Keywords: 4DVAR, analysis error, quasi-newton method, ocean data assimilation system, ocean reanalysis

A Reanalysis Experiment using a Coupled Atmosphere-Ocean Data Assimilation System in JMA/MRI

*Yosuke Fujii[1], Toshiyuki Ishibashi[1], Tamaki Yasuda[2], Yuhei Takaya[1], Takeshi Iriguchi[1], Nariaki Saito[1], Yoshiaki Takeuchi[1]

1. Meteorological Research Institute, Japan Meteorological Agency, 2. Japan Meteorological Agency

JMA/MRI have developed a coupled Data Assimilation (DA) system, MRI-CDA1, based on JMA’s operational systems. The system adopts so-called weakly-coupled data assimilation procedure in which a coupled atmosphere-ocean model simulates the time-evolutions of the atmosphere and ocean fields while separated analysis routines generate analysis increments of the atmosphere and the ocean for modification of the coupled model fields. MRI-CDA1 is composed of the global atmosphere DA system for numerical weather predictions, NAPEX, the global ocean DA system for seasonal predictions, MOVE-G2, and the coupled atmosphere-ocean model for seasonal predictions, JMA/MRI-CGCM2.

MRI-CDA1 is applied to a coupled reanalysis experiment for the period from November 2013 to December 2015. Comparison of the reanalysis result with Japanese 55-year Reanalysis (JRA-55) indicates that the overestimation of the sea surface latent heat flux found in JRA-55 disappears in the reanalysis of MRI-CDA1. Consequently, the coupled system improved the global ocean heat budget. MRI-CDA1 also effectively suppresses the excess rainfall in the tropics in JRA-55, particularly in the Intertropcal Convergence Zone (ITCZ) in the Pacific. Anomaly correlation coefficients of precipitation in MRI-CDA1 with observation-based datasets (CMAP and GPCP) have quite similar distributions with the distribution for JRA-55, but decreases in a few areas. Although the sea surface temperature field is well reproduced by MRI-CDA1, the equatorial Pacific thermocline is shallower and the Pacific Equatorial Undercurrent is weaker than those in an uncoupled ocean reanalysis generated by MOVE-G2. These differences are likely to stem from difference of the bulk formula of the wind stress fields which force the ocean model.

Keywords: Coupled Data Assimilation , Reanalysis, Precipitation, Global Ocean Heat Budget

Numerical Weather Prediction Experiments using a Coupled Atmosphere-Ocean Data Assimilation System in JMA/MRI

*Toshiyuki ISHIBASHI[1], Takeshi Iriguchi[1], Yosuke Fujii[1], Tamaki Yasuda[2], Yuhei Takaya[1], Naoaki Saito[1], Yoshiaki Takeuchi[1]

1. Meteorological Research Institute, 2. Japan Meteorological Agency

An atmosphere-ocean coupled data assimilation system (CDAS) has been developed at the JMA/MRI to investigate feasibility of a CDAS as a future DAS for seamless numerical prediction including both numerical weather prediction (NWP) and numerical seasonal climate prediction (NCP), and for reanalysis of the atmosphere-ocean. Our CDAS (**MRI-CDA1**) has two features.
1) It composed of the JMA operational systems, the global atmospheric DAS (MRI-NAPEX) based on 4D-Var, the global ocean DAS (MOVE-G2) based on 3D-Var, and the atmosphere- ocean coupled global forecast model (CGCM: JMA/MRI-CGCM2).
2) Coupling strategy is “weak coupling” with two different data assimilation window lengths for the atmosphere and ocean. Here, “weak coupling” denotes the approximation that ignores correlations of atmosphere and ocean background forecast errors.

In this paper, we report basic property of MRI-CDA1 in NWP such as analysis increment structure and short range forecast accuracy. We have conducted single data assimilation experiments and one month cycle experiments using MRI-CDA1. Results of the single assimilation experiments show that information of assimilated ocean (atmosphere) observation data flow into the atmosphere (ocean) in short range forecasts by the outer CGCM. Results of the cycle experiments show that accuracy of forecasts with a non-coupled atmosphere model started from coupled analyses generally degrade forecast accuracy in comparison with those from uncoupled analyses. However, forecast root mean square errors (RMSEs) of temperature in a planetary boundary layer, and forecast biases of sea surface pressure are significantly improved. Verification results of forecasts with the CGCM and another basic property of CDAS such as impacts of each observation data type, also will be presented in our presentation.

Keywords: data assimilation, atmosphere-ocean coupled data assimilation, numerical weather prediction

Towards assimilation of aerosol data from an imager of GOSAT into the aerosol transport model SPRINTARS

*Nakamura Haruna[1], Akihide Kamei[2], Tatsuya Yokota[2], Masataka Ajiro[2]

1. Fujitsu FIP Corporation, 2. National Institute for Environmental Studies

Cloud and Aerosol Imager (CAI) mounted on “IBUKI” (Greenhouse gases Observing SATellite: GOSAT) observes Cloud and Aerosol Image. The GOSAT project in the National Institute for Environmental Studies calculated CAI L2 Aerosol Property products (Fukuda et al. 2010) from CAI L1 data and distributed for researchers. In this study, we investigated the applicability of these CAI L2 Aerosol Property products as the aerosol input data to aerosol transport model Assimilation SPRINTARS (Schutgens et al. 2010). Assimilation SPRINTARS assimilates Aerosol Optical Thickness (AOT) using ensemble Kalman filter. For example, Assimilation SPRINTARS can assimilate MODIS aerosol data provided by Naval Research Laboratory (NRL). In order to assimilate CAI L2 AOT using this assimilation system, we created 6 hourly 1 degree gridded data (same format as MODIS NRL) from CAI L2 AOT and compared with MODIS NRL.
The data used in this study are 550nm AOT of GOSAT CAI L2 Aerosol Property product V02.00 (CAI L2 AOT) based on GOSAT CAI L1A V130.131 data, and AERONET (AErosol RObotic NETwork) Lev2.0 data as observation data.
Using the method of making MODIS NRL (Zhang and Reid 2006, Shi et al. 2010, Hyer et al. 2010), we created the plan to prepare input data for Assimilation SPRINTARS by the following procedure. (1) Create a matchup for AERONET and CAI L2 AOT for one year. (2) Examine the screening method of CAI L2 AOT using the result of (1). (3) The screening method determined in (2) is applied to CAI L2 AOT and the average value of 1 degree grid of CAI L2 AOT after the screening is adopted as a representative value. In this report, the results of (1) and (2) are shown.
As for the matchup result of AERONET and CAI L2 AOT, there was a tendency that CAI L2 AOT data are larger than AERONET data. As a whole the correlation between these data was low.
We tried the following two types of criteria as screening. (a) CAI L2 AOT is calculated in more than one-third of the circle with a radius of 10 km centered on the AERONET observation point. Also, the standard deviation of derived CAI L2 AOT is 0.08 or less. (b) There are 3 or more AERONET observations within 30 minutes before and after GOSAT CAI observation time. Also, the standard deviation of these AERONET data is 0.08 or less. Creating the scatter diagram, we found that the data after passing these two screening were distributed densely around the line of y=x and around the area where AERONET AOT equaled 0.1. For the latter, there was a possibility that cirrus clouds were treated as aerosol. This feature was clearly seen in the sea data.
Using the screening results, we compared the correlations between AERONET and CAI L2 AOT among AERONET observation points. After screening, the slopes and correlation coefficients of the regression lines were generally improved, but the R square value was less than 0.6 even for the best observation point. By screening, in some AERONET observation points data with larger CAI L2 AOT than AERONET drastically decreased, and the distributions of the data were concentrated more prominently around the line of y = x.
To proceed to (3), we need to investigate the method to exclude CAI L2 AOT with low correlation with AERONET.

Keywords: GOSAT, Aerosol, Data Assimilation

Multi-scale localization with NICAM-LETKF using real observations

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

1. RIKEN Advanced Institute for Computational Science

Covariance localization plays an essential role in the ensemble Kalman filter (EnKF) with a limited ensemble size. Localization limits the influence of observations and reduces the impact of sampling errors. To enhance localization, our previous studies proposed and investigated a multi-scale localization method named the “dual localization” method which coupled two separate localization scales using an intermediate AGCM under the perfect model scenario. The results showed consistent improvement over a traditional single localization approach. In this study, we further extended the previous study to use the real-world observations with the non-hydrostatic icosahedoral atmospheric model (NICAM) and to investigate how well the dual localization method captures the multi-scale covariance structures. The results showed that the dual-localization method produced generally better spatial correlation patterns. We will present the newest results up to the time of the meeting.

Keywords: data assimilation, Multi-scale data assimilation, Ensemble Kalman Filter

Implicit thinning and localization of dense observation data in the LETKF: A case of phased array weather radar

*Guo-Yuan Lien[1], Takemasa Miyoshi[1]

1. RIKEN AICS

Observation data from advanced remote-sensing platforms are getting bigger and bigger. Past studies have shown that, to effectively assimilate dense observations, a proper thinning or superobing method to reduce the data density is usually necessary. In general, these techniques have been employed to deal with various factors such as observation error correlations, representativeness errors, and computational costs. However, they also unavoidably decrease the resolution of data, which is contradictory to the pursuit of high-resolution observing systems and numerical models.
We point out that, when using an ensemble data assimilation method, another important, but likely neglected reason to thin the data is to stay in the range that all observations can be effectively assimilated by the limited ensemble size. This issue has been usually addressed by covariance localization methods, but probably not in an optimal way. Recently, the LETKF systems at European Centre for Medium-Range Weather Forecasts (ECMWF) and Deutscher Wetterdienst (DWD) have adopted an “implicit localization” method that significantly reduces the assimilated observation numbers while preserving high-resolution information, by selecting N nearest neighbors of observations from the analyzed grid point. We demonstrate the usefulness of this method on the assimilation of very dense phased array weather radar data, and explain it as an ideal combination of thinning and localization.

Keywords: localization, thinning, LETKF, dense observation, radar assimilation

Data assimilation experiment for reproducing the temporal evolution of the inner-magnetospheric environment

*Shin'ya Nakano[1], Pontus Brandt[2], Mei-Ching Fok[3]

1. The Institute of Statistical Mathematics, 2. The Johns Hopkins University Applied Physics Laboratory, 3. NASA Goddard Space Flight Center

The plasmasphere is the inner part of the magnetosphere where cold plasma is densely concentrated. The ring current is typically located just outside of the plasmasphere and it consists of high energy ions of tens of keV. Both the plasmasphere and the ring current play important roles in various physical processes in the inner magnetosphere. Although it is normally difficult to observe the global structures of the plasmasphere and the ring current, remote imaging observation from the IMAGE satellite provided the information on the global structures of the plasmasphere and the ring current. We are developing a data assimilation system for estimating temporal evolution of the plasmasphere and the ring current by exploiting the EUV and ENA imaging data from the IMAGE satellite. We have conducted a preliminary experiment using a synthetic data set. The result shows that the spatial distributions of the plasmasphere and the ring current were successfully estimated. The electric potential distribution which controls the distributions of the plasmasphere and the ring current was also well reproduced. This demonstrates that the data assimilation of the EUV and ENA imaging data is a useful tool for reproducing the global temporal evolution of the inner magnetosphere.

Keywords: ring current, plasmasphere, data assimilation, ensemble Kalman filter

Use of kernel regression in ensemble Kalman filters

*Shin'ya Nakano[1]

1. The Institute of Statistical Mathematics

The ensemble Kalman filters are now widely used for data assimilation in nonlinear systems in various field. In the ensemble Kalman filters, the uncertainty in a system is represented by a set of possible scenarios called ensemble. An estimate of the system state is produced by a linear combination of the ensemble members. This procedure of the ensemble Kalman filters can be rewritten in a form of the kernel regression approach. A formulation based on the kernel regression approach enables us to allow a nonlinear relationship between the state and the observation. In this study, a formulation of the ensemble Kalman filters based on the kernel regression approach is introduced and some extentions of the ensemble Kalman filters are discussed.

Keywords: ensemble Kalman filter, kernel regression

