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

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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

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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.

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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

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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

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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

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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

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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

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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

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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

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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

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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

