Japan Geoscience Union Meeting 2014
(28 April - 02 May 2014 at Pacifico YOKOHAMA, Kanagawa, Japan)

AAS02-01 Room:314 Time:April 29 09:00-09:30

Entropic Balance Theory and Variational Field Lagrangian Formalism

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The entropic balance theory has been applied with outstanding results to explain many important aspects of tornadic phenomena. The entropic balance theory was originally developed in variational formalism with Lagrangian appropriate for supercell storm and tornadic phenomena. The entropic balance theory shares the same foundation as, symbolically called with keywords, "variational field Lagrangian formalism" in short "variational formalism". It is broadly used in inmodern physics, not only in classical mechanics, with Lagrangian density and action designed for each physical problem properly. The Clebsch transformation (equation) was developed in the classical variational formalism, but has not been used because of the unobservable and non-meteorological Lagrange multiplier.

The Lagrange multipliers appeared in the Clebsch transformation are analogous to the mathematical vector potential (and gauge field) of the theoretically found Aharonov-Bohm effect . Its experimental verification has been difficult and has not been made until two decades later. The Lagrange multipliers in the Clebsch transformation seem similar to the vector potential and gauge of electromagnetic field and in advanced physics disciplines.

The entropic balance condition is thus developed from the Clebsch transformation, changing the unobservable non-meteorological Lagrange multiplier to observable meteorological rotational flow velocity with entropy and making it applicable to tornadic phenomena.

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AAS02-02 Room:314 Time:April 29 09:30-09:45

Deterministic predictability of the most probable state and reformulation of variational data assimilation

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Four-dimensional variational data assimilation (4DVar) and ensemble Kalman filter (EnKF) have been widely used for data assimilation in meteorology and oceanography. Since prior probability density functions (PDFs) used in 4DVar and EnKF are usually assumed to be Gaussian, those two methods may not work well for a strongly nonlinear system. Thus data assimilation with nonlinear systems or non-Gaussian PDFs is a challenge in geophysics. Theoretical study of the two methods for nonlinear systems may be expected to provide insight for further advancement of data assimilation. The present study addresses this issue by reformulating variational data assimilation.

A necessary condition for deterministic predictability may be that the forecast state starting from the most probable state at an initial time remains close to the most probable state at a forecast time. It is found from the Liouville equation that if the trace of the Jacobian matrix of a deterministic nonlinear system does not depend on the state variables (hereafter referred to as the trace condition), the mode of a PDF of the state variables evolves according to the governing equations of the system. A condition for the forecast state to be close to the mode of the PDF is derived under an assumption of small prediction error for general deterministic nonlinear systems. This condition depends on the sensitivity of the trace to an initial condition, the size of initial condition error, and the length of forecast lead time.

Since the dynamical cores of numerical models of the atmosphere and the ocean are based on fluid dynamics, it is interesting to examine whether the governing equations of fluid dynamics satisfy the trace condition. The trace of the Jacobian matrix is calculated for finite-dimensional analogs of several Eulerian equations of ideal fluids. It is readily found that the trace condition generally holds for unbounded fluids under periodic boundary conditions. It is shown that the trace condition also holds for the quasigeostrophic equations with rigid boundaries, the Boussinesq approximation with rigid boundaries, and the shallow water equations on a sphere, by expanding the state variables in eigenfunctions of the Laplacian operator or the curl operator. The shallow water equations in a channel and compressible fluid with top and bottom boundaries do not satisfy the trace condition due to divergence at the boundaries.

A new formulation of variational data assimilation is presented for deterministic nonlinear systems that satisfy the trace condition. Though the cost function in the new formulation takes the same form as the conventional one, it makes clear an advantage of 4DVar over EnKF. If the trace condition holds, the forecast state starting from the mode of the posterior PDF at the last analysis time is the mode of the prior PDF. In the new formulation, the logarithm of the prior PDF is expanded around the forecast state, and covariance globalization is introduced to take into account the global distribution of the prior PDF that may be non-Gaussian. A feasible method for the covariance globalization may be to replace the local covariance matrix at the mode with a forecast error covariance matrix taken from EnKF. It is proved that a non-Gaussian prior PDF that evolves according to the Liouville equation is implicitly used for assimilating observational data in 4DVar. Results from an assimilation experiment with a toy model suggest that 4DVar thus formulated outperforms EnKF if the global minimum of the cost function is found.

Finally, it is pointed out that enough observational data are necessary for variational data assimilation to work well for a deterministic nonlinear system that does not satisfy the trace condition. Otherwise, EnKF and ensemble prediction may be a better choice for data assimilation and prediction of the system.

Keywords: variational data assimilation, deterministic predictability, non-Gaussianity

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Modal analysis of near-bank velocity profiles in a tidal river.

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We apply two decompositions to long-beam velocities of a 600 kHz 3-beam Horizontal Acoustic Doppler Current Profiler (HADCP) at West Point on the Hudson River Estuary, so as to efficiently characterize the spatiotemporal variation of near-bank velocity. One main motivation is to test statistical tools with which to benchmark computations. The HADCP is deployed next to the USGS gauging station at West Point, some 100 km upriver from Manhattan, on the inner bank downstream of a sharp bend and its associated 40 m deep trough. We analyzed a time series of 1-minute averages from October 2011, out to 80 meters from the bank with 1 m bins.

The first decomposition we apply is Principal Component Analysis. The PCA generates an optimally convergent set of spatial eigenfunctions or "principal components" (PC), with which are associated temporally-varying amplitudes called "temporal coefficients". The first principal component captures more than 96.3% of the variance in velocity measured along the three HADCP beams, while the second PC captures about 2%. There appears an asymmetry between ebb and flood, as seen clearly from a phase plot of the temporal coefficient of the first PC versus that of the second.

The second is Fourier-based Koopman Mode Decomposition, i.e. decomposition into harmonic averages of the measurement vector. KMD associates a spatial structure with each of a series of temporal frequencies. For Oct 2011, the semidiurnal mode captured 74.33% of the variance. KMD also quantifies the phase lags at different distances from the river bank (and between normal and tangential velocity). Phase lags of tangential velocity between 10 and 80 m from the bank were about 1 hour for the semidiurnal mode, and 2 hours for the first (with a period of about 6 hours.), and this difference grew to a factor of four when considering flow within 10 m.

Keywords: principal component analysis, Koopman mode decomposition, ebb-flood asymmetry

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AAS02-04 Room:314 Time:April 29 10:00-10:15

Pathways of the North Pacific Intermediate Water identified through the tangent linear and adjoint codes of an OGCM

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We develops a strategy of tracing a target water mass, and applies it for analyzing the pathway of the North Pacific Intermediate Water (NPIW) from the subarctic gyre to the northwestern part of the subtropical gyre south of Japan in a simulation of an ocean general circulation model. This strategy estimates the pathway of the water mass that travels from an origin to a destination area during a specific period using a conservation property concerning tangent linear and adjoint models. In our analysis, a large fraction of the low salinity origin water mass of NPIW initially comes from the Okhotsk and Bering Seas, meets at the southeastern side of the Kuril Islands, and is advected to the Mixed Water Region (MWR) by the Oyashio current. It then enters into the Kuroshio Extension (KE) around the first KE ridge, and is advected eastward by the KE current. It, however, deviates southward from the KE axis around 158E over the Shatsky Rise, or around 170E on the western side of the Emperor Seamount Chain, and enters into the subtropical gyre. It is finally transported westward by the recirculation flow. This pathway corresponds well to the shortcut route of NPIW from MWR to the region south of Japan inferred from the analysis of the long-term freshening trend of NPIW observation.

Keywords: Adjoint, Sensitivity analysis, North Pacific Intermediate Water, Kuroshio Extension, Oyashio

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AAS02-05 Room:314 Time:April 29 10:15-10:30

Optimization of nested ocean circulation model by four dimensional variational data assimilation system

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Optimization of a regional ocean circulation model by a data assimilation system is achieved by estimating optimal initial condition and external forcing terms which include boundary values. In a nested regional data assimilation system, extracting maximum information from optimized outer model through these control variables is crucial to obtain optimal performance of the nested regional data assimilation system and many schemes were proposed in the atmospheric and oceanic data assimilation studies. In this presentation, the optimization schemes of a nested atmosphere and ocean circulation model by four dimensional variation data assimilation system are summarized in a unified framework. Their performance will be analyzed using observability matrix of a variational data assimilation system constructed on regional ocean circulation model surrounding Japan islands.

Keywords: data assimilation, regional ocean circulation model

Japan Geoscience Union Meeting 2014
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AAS02-06 Room:314 Time:April 29 10:30-10:45

Estimated State of Ocean for Climate Research by Using a 4 Dimensional Variatinal approach

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[1]JAMSTEC

A 4-dimensional variational data assimilation system has been used to better define the 50-year global ocean state estimation for climate research. The synthesis of available observations and general circulation model with a pelagic ecosystem model based on nitrogen cycle yields a dynamically self-consistent dataset. Obtained ocean state estimation possibly has greater information than do models or data alone. In our 4D-VAR approach, optimized 4-dimensional analysis fields are sought by minimizing a cost function on the basis of adjoint method for physical parameters and Green's function approach for biogeochemical ones. The assimilated elements are temperature and salinity based on EN3 dataset provided by Met Office Hadley Centre, sea surface height anomaly form AVISO, nitrate from WOA05, and chlorophyll-a from WOA98 and SeaWiFS. We here present the properties of the analysis fields and some results of climate study by using this state estimation named ESTOC. This report implies that our synthesis scheme as a dynamical interpolation for sparse observations including bio-geochemical parameters is possibly promising and useful for " Integrated Earth System Analyses ".

Keywords: data assimilation, ocean, climate change

AAS02-07 Room:314 Time:April 29 11:00-11:20

Data assimilation for ocean and climate study

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The data assimilation systems have been developed for the initialization of the numerical weather forecasting, and applied for other fields in recent studies. In the area of ocean and climate research, there are several interesting studies to utilize the advantage of the many aspects of the data assimilation, in addition to the ”ocean weather forecasting”.

The atmosphere-ocean coupled data assimilation system using variational adjoint method is one of the unique systems, which is developed in JAMSTEC. The target of this system is the variability of seasonal to inter-annual scale so that the integrated dataset of the observation both in atmosphere and ocean are derived using variational adjoint method. The remarkable feature of the system is that the bulk coefficients are estimated as well as the initial condition of the oceanic fields since the lower boundary condition of the atmospheric model are very important for seasonal to inter-annual time scale. Recently, the marine ecosystem model are embedded into this system and seasonal forecasting not only for physical fields but also for biogeochemical fields are carried out.

For oceanic long-term reanalysis dataset, the interesting data assimilation systems are developed using variational adjoint method (Masuda et al., 2010). In this data assimilation system, strong constraint conditions are applied for entire assimilation period over 50 years, so that the derived dataset are consistent with the dynamics in ocean general circulation model. This means that the derived dataset satisfies the conservation rules and suitable for the 4-dimensional analysis of the heat and water fluxes. This advantage is also suitable for the analysis of the oceanic tracers and useful for the biogeochemical studies.

The data assimilation system for the marine ecosystem model is also notable issues. Since it is difficult to identify the optimal parameters in the marine ecosystem model, the parameter estimation studies are widely used. The realistic fields of the biogeochemical variables are successfully obtained by parameter estimation (Toyoda et al., 2013).

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AAS02-08 Room:314 Time:April 29 11:20-11:35

Development of an ensemble-based data assimilation system with a coupled atmosphere-ocean GCM

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To enhance the capability of the local ensemble transform Kalman filter (LETKF) with the Atmospheric general circulation model (GCM) for the Earth Simulator (AFES), a new system has been developed by replacing AFES with the Coupled atmosphere-ocean GCM for the Earth Simulator (CFES). An initial test of the prototype of the CFES-LETKF system has been completed successfully, assimilating atmospheric observational data (NCEP PREPBUFR archived at UCAR) every 6 hours to update the atmospheric variables, whereas the oceanic variables are kept unchanged throughout the assimilation procedure.

An experimental retrospective analysis-forecast cycle with the coupled system (CLERA-A) starts on August 1, 2008, and the atmospheric initial conditions (63 members) are taken from the second generation of AFES-LETKF experimental ensemble reanalysis (ALERA2). The ALERA2 analyses are also used as forcing of stand-alone 63-member ensemble simulations with the Ocean GCM for the Earth Simulator (EnOFES), from which the oceanic initial conditions for the CLERA-A are taken.

The ensemble spread of SST is larger in CLERA-A than in EnOFES, suggesting positive feedback between the ocean and the atmosphere. Although SST in CLERA-A suffers from the common biases among many coupled GCMs, the ensemble spreads of air temperature and specific humidity in the lower troposphere are larger in CLERA-A than in ALERA2. Thus replacement of AFES with CFES successfully contributes to mitigate an underestimation of the ensemble spread near the surface resulting from the single boundary condition for all ensemble members and the lack of atmosphere-ocean interaction.

In addition, the basin-scale structure of surface and subsurface ocean temperature in the tropical Pacific is well reconstructed from the ensemble correlation in CLERA-A but not in EnOFES. This suggests that use of a coupled GCM rather than an oceanic GCM could be important even for oceanic analysis with an ensemble-based data assimilation system.

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AAS02-09 Room:314 Time:April 29 11:35-11:50

Data assimilation experiment of water vapor data derived from a hyper-dense GNSS network using a nested LETKF system

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Data assimilation of observation data with high spatial and temporal resolutions within a numerical weather prediction model is important, in order to provide it with accurate and detailed initial conditions, which generally result in improved forecast accuracy for localized heavy rainfall. Assimilation of water vapor data is especially important because water vapor has a powerful effect on the initiation and development of cumulonimbus clouds. Many assimilation studies reported on the significant and positive impact of assimilating GNSS (Global Navigation Satellite System) derived PWV (Precipitable Water Vapor) data, i.e. the vertically integrated water vapor amount, on the modification of the initial distributions of water vapor, as well as on the forecast accuracy of localized heavy rainfall. The Japan Meteorological Agency (JMA) routinely assimilates PWV data derived from the nationwide GNSS observation network (GEONET) operated by the Geospatial Information Authority of Japan (GSI), which has a horizontal resolution of about 20 km. It is expected, however, that the assimilation of PWV data with higher spatial resolution will be needed as the horizontal resolution of numerical models becomes higher. Therefore, we investigated the assimilation impact of high resolution PWV observations derived from a hyper-dense GNSS network with a horizontal resolution of about 1 km, which we installed near Uji campus of Kyoto University (Sato et al., 2013).

The data assimilation carried out in this report is based on a two-way nested Local Ensemble Transform Kalman Filter (LETKF) system (Seko et al., 2013). Experiments were performed involving a heavy rainfall event that occurred on 14 August 2012, which brought about 260 mm of accumulated rain amount in 6 hours. First, GEONET-derived PWV data were assimilated into an outer model, with horizontal resolution of 15 km. The analysis window and assimilation interval of this first experiment were 6 hours and 1 hour, respectively. Next, PWV data derived from the hyper-dense GNSS network were assimilated into an inner model, with horizontal resolution of 1.875 km. The analysis window and assimilation interval of this second experiment were 1 hour and 10 minutes, respectively. Surface observations and upper atmospheric sounding data used in operational analyses by JMA were also assimilated in both the experiments.

In an experiment without assimilation of any PWV data, the location of the reproduced rainfall region was shifted, and the precipitation intensity was lower, compared with the observation result. When GEONET-derived PWV were assimilated into the outer model and no PWV data were assimilated into the inner model, the location of the simulated rainfall system was improved, although there was no modification in precipitation intensity. When PWV derived from the hyper-dense GNSS network was assimilated into the inner model together with the assimilation of GEONET-derived PWV into the outer model, the precipitation intensity was also modified in addition to the modification of rainfall system location.

These results suggest the usefulness of assimilating high spatial resolution PWV data for heavy rainfall forecast. In the future, we are planning to investigate how the assimilation impact of high resolution PWV data will change depending on the number of observation points of the hyper-dense GNSS network. In this talk, assimilation results of slant water vapor data will also be reported, which is the accumulated water vapor amount along ray paths of radio signals from a receiver to GNSS satellites.

Keywords: Data assimilation, local heavy rainfall, Hyper-dense GNSS observation, nested LETKF

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Data assimilation experiments of tropical cyclones with the NHM-LETKF

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Intensity forecast of tropical cyclones (TCs) has still been a challenging task whereas TC track forecasts have constantly improved over the past several decades owing to advances in numerical weather prediction models as well as observational capabilities. This is partly due to the difficulties in TC initialization because TCs occur and remain almost throughout their existence over the ocean, where observational data have generally been scarce. In this study, TCVital observations are assimilated with an ensemble Kalman filtering, and their impacts are estimated by comparing with the conventional bogus assimilation scheme.

Keywords: data assimilation, ensemble Kalman ffilter, tropical cyclone

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AAS02-11 Room:314 Time:April 29 12:05-12:20

Tropical cyclone forecast using a hybrid EnKF-4DVar system

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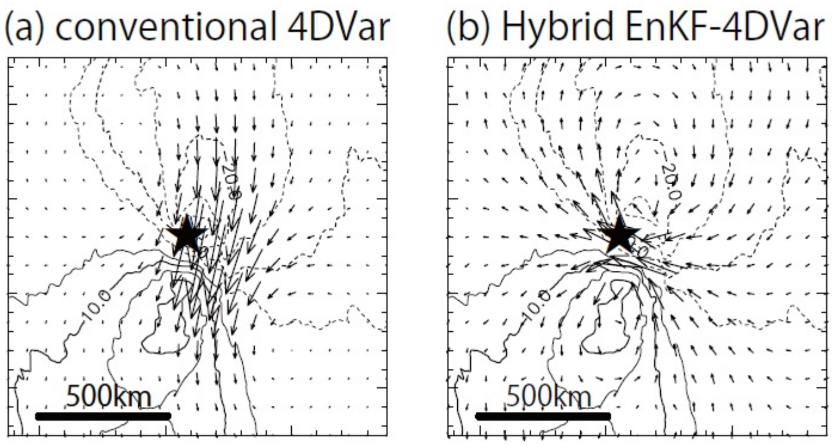
Analysis increment is dependent on the prescribed background error covariance **B** in addition to innovation and model dynamics that describes the development of perturbations. Traditionally, **B** is assumed to be static in time according to so-called NMC method. Following this method, the differences between pairs of forecasts valid at the same time, but having different lead times, are taken to represent the background error. While **B** in NMC method approximates the climatological background error covariance, recent studies have shown that the forecast skill of 4DVar is further enhanced by making flow-dependent **B** out of the perturbations in the ensemble-Kalman filter (EnKF) (Buehner et al. 2010). This system is referred to as Hybrid EnKF-4DVar. We have developed the meso Hybrid-4DVar system based on the meso 4DVar system (JNoVA) in the Japan Meteorological Agency since the improvements is thought to be more pronounced for severe impact weather such as tropical cyclones and heavy rainfall. In this presentation, we present a preliminary result for a forecast of tropical cyclone Talas (2011). Figure 1 shows the analysis increment of horizontal wind in the conventional 4DVar and hybrid EnKF-4DVar. The first guess of the zonal wind is overplotted. It shows a pseudo observation of wind field near the center of the tropical cyclone yields the analysis increment of a pair of cyclonic and anti-cyclonic circulations. It corresponds to a vortex displacement in the hybrid EnKF-4DVar system. In contrast, the analysis increment does not fit the structure of the tropical cyclone when using **B** based on the NMC method. It suggests that the hybrid EnKF-4DVar system reproduces the reasonable analysis increment with a little information.

Keywords: data assimilation, tropical cyclone, 4DVar, ensemble Kalman filter



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AAS02-12 Room:314 Time:April 29 12:20-12:35

Dual-Scale Neighboring Ensemble Variational Assimilation for a Cloud-Resolving Model

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1. Introduction

The purpose of the present study is to develop an Ensemble-based Variational Assimilation (EnVA) scheme with sampling error damping method for the Cloud-Resolving Model (CRM). This is because, in ensemble-based assimilation schemes for CRMs, sampling error is serious, in particular, for precipitation-related variables (precipitation rate, vertical wind speed) because they are confined in rainy areas.

2. Dual-Scale Neighboring Ensemble Variational Assimilation method

Based on the CRM ensemble forecast error analyses for various precipitation cases, we developed the sampling error damping method that consisted of a Neighboring Ensemble (NE) method and a dual scale separation of NE. The NE method approximated the forecast error correlation using NE members within a reduced-grid box (5 x 5 grids in the present study) based on the spectral localization assumption. In the dual scale separation, we divided the NE forecast error into large-scale portions (13 x 13 grid averages in the present study) and small-scale deviations so as to reflect the horizontal scale differences in forecast error between precipitation-related variables and others.

In order to introduce the sampling error damping method to the three-dimensional EnVA, we assumed that the EnVA analysis increments were subject to the dual scale NE forecast error subspace. In addition, we introduced a vertical reduce approximation using the primary Singular Value Decomposition (SVD) modes of the vertical cross correlation of the dual scale NE forecast error. Since the SVD modes were mutually independent, the three-dimensional cost function of EnVA resulted in that for the horizontal component of the analysis increment of the each SVD mode. Then, we horizontally diagonalized the background term of the cost function using the horizontal correlation of the NE forecast error. We used the conjugate gradient scheme to solve the nonlinear minimization of the cost function, and obtained the optimal analysis increment for the ensemble mean. Then, we calculated the analysis increments for ensemble members with the analysis error covariance at the reduced grids.

3. Results of OSSEs

In order to examine the EnVA scheme, we performed OSSEs for several meteorological disturbance cases. The results show that the NE method was successful in producing plausible analyses of precipitation-related variables from the simulated surface precipitation even for grid points where less than 20 % of the ensemble members forecasted precipitation, and that the dual scale separation of NE made spatial scale changes in analysis increments in correspondence with precipitation rates. The EnVA scheme was also successful in retrieving precipitation flags and precipitation profiles from the simulated multi-channel microwave brightness temperatures that were non-linear functions of various precipitation-related variables.

Keywords: Ensemble-based variational data assimilation, Neighboring ensemble, Dual-scale separation, GPM, GCOM, microwave imager