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Theme 4: Data Assimilation

Session 1: Variational, ensemble and hybrid methods in ocean data assimilation I

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Development of regional high-resolution assimilation systems based on four-dimensional variational method at JMA/MRI

Usui, Norihisa[1], Hirose, Nariaki[1], Fujii, Yosuke[1], Toyoda, Takahiro[1], Kohno, Nadao[1], Kuragano, Tsurane[1]
[1]Meteorological Research Institute, Tsukuba, Japan nusui@mri-jma.go.jp

Meteorological Research Institute (MRI) of Japan Meteorological Agency (JMA) has been developing MRI Multivariate Ocean Variational Estimation (MOVE) system, which includes both three- and four-dimensional variational (3DVAR and 4DVAR) methods. The 4DVAR scheme was first applied to a western North Pacific system with an eddy-resolving ocean model (WNP-4DVAR), which has been implemented as a part of a coastal system covering the western part of Japan and has been in a quasi-operational phase at JMA since 2016. WNP-4DVAR was used to construct a high-resolution (10km) long-term (1982-2016) ocean reanalysis data for the western North Pacific (FORA-WNP30), which is the first-ever dataset covering the western North Pacific over three decades at eddy-resolving resolution. It was shown that 4DVAR significantly improve mesoscale features compared to 3DVAR. To upgrade the coastal system, JMA/MRI has developed a new data assimilation system, which consists of two separate models. One is a forecast model based on a 2km model for the seas around Japan, which incorporates explicit tidal forcing and realistic river discharge to represent coastal circulation. The other is an analysis model covering the North Pacific with 10km resolution, to which 4DVAR is applied. The forecast model is initialized with analysis model results through the Incremental Analysis Update (IAU). In this presentation, detail information of the 4DVAR scheme as well as recent improvements of the assimilation scheme such as observation operator for the satellite altimeter and IAU initialization for the forecast model will also be shown.

Keywords: DA - Variational data assimilation, DA - Shelf-seas and coastal data assimilation, Systems - Ocean reanalysis, ,

Presenter:
Norihisa Usui
Meteorological Research Institute
Tsukuba, Japan
nusui@mri-jma.go.jp

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Hindcasting the subsurface oil plume after the Deepwater Horizon disaster in the Gulf of Mexico

Yu, Liuqian[1], Fennel, Katja[1], Wang, Bin[1], Laurent, Arnaud[1], Thompson, Keith[1], Shay, Lynn[2] [1]Department of Oceanography, Dalhousie University, Halifax, Canada [2]Rosenstiel School of Marine and Atmospheric Science, University of Miami, Miami, USA liuqian.yu@dal.ca

The 2010 Deepwater Horizon (DwH) oil spill released an unprecedented quantity of crude oil into the Gulf of Mexico (GOM). The neutrally buoyant fraction of the oil formed deep-water hydrocarbon-enriched plumes at depths between 1,000 and 1,200 m where significant microbial drawdown of dissolved oxygen was observed. For a rapid and appropriate response to such an event, accurate information on the circulation at depth is crucial. Toward that objective, we implemented a deterministic Ensemble Kalman Filter (DEnKF) in a 3D physical-hydrocarbon model of the GOM (with a horizontal resolution of 5 km) to assess whether assimilating observations improves the simulated circulation and oil distribution at depth. Assimilation experiments in both, a fraternal twin framework and a realistic configuration using satellite and in situ profile observations, show that the assimilation greatly improves the dominant circulation features (i.e., the Loop Current and associated mesoscale eddies) in the open GOM, but submesoscale features near the DwH spill site are not significantly improved through the assimilation. Identical twin experiments further show that the improvements in circulation near the spill site due to assimilation yield only modest improvements in the distribution of the deep-water hydrocarbon plume. During the DwH spill, shipboard measurements of oxygen profiles were used to map the deep-water hydrocarbon distribution and estimate its mass, but the uncertainty of these estimates is large because of insufficient observations. Motivated by the need for a better sampling strategy, we used the physical-hydrocarbon model to conduct a series of Observing System Simulation Experiments (OSSEs), where synthetic Lagrangian floats were released with different sampling schemes to determine the optimal strategy for tracking the movement of the hydrocarbon plume and estimating its mass.

Keywords: DA - Data assimilation applications, DA - Ensemble data assimilation, Observations - Observing system assessments and design, Observations - Observation impacts,

Presenter:
Katja Fennel
Department of Oceanography, Dalhousie University
Halifax, Canada
Katja.Fennel@dal.ca

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A Multi-Scale Approach to High Resolution Observations within a 4DVAR Analysis System

Carrier, Matthew[1], Osborne, John[2], Ngodock, Hans[1], Smith, Scott[1], Souopgui, Innocent[3], D'Addezio, Joseph[4] [1]US Naval Research Lab, Stennis Space Ctr., USA [2]The American Society for Engineering Education (ASEE), Washington, DC, USA [3]The University of New Orleans, New Orleans, USA [4]The University of Southern Mississippi, Stennis Space Ctr., USA matthew.carrier@nrlssc.navy.mil

All data assimilation methods make assumptions or approximations regarding the background error correlation length scales. If more than one observation of the same type are within an error correlation length from one another, these data are considered redundant and either spatially averaged (e.g. super observations of sea surface temperature) or removed (e.g. underwater glider observations). This procedure eliminates many observations from the analysis step and can reduce the effectiveness of a particular observation platform. Simply including these observations is not an option as doing so would produce unrealistic analysis increments in the vicinity of the dense observations. An approach, presented here, aims to treat the observations in terms of the spatial scales the data reflects. A two-stage assimilation paradigm is adopted: stage one attempts to constrain the large-scale features by assimilating a set of super observations with appropriate background error correlation scales and variances; stage two attempts to constrain the small-scale by assimilating the full observations set with shorter background error correlation scales and lower error variances (using the analysis from stage one as the new background). Results using a real high-density observation set from underwater gliders collected during the 2017 Nordic Recognized Environmental Picture (NREP17) experiment will be shown using the Navy Coastal Ocean Model 4DVAR (NCOM-4DVAR). Experiments include (1) subset of the glider observations in a standard 4DVAR assimilation, and (2) all the gliders using the two-step assimilation treatment with the 4DVAR. Comparisons between results will be presented with evaluation on the quality of the analysis and resulting 24- hr forecasts shown.

Keywords: DA - Variational data assimilation, DA - Fundamentals and methodologies of data assimilation, DA - Data assimilation applications, Observations - Observation operators, DA - Background and observation error covariances

Presenter:
Matthew Carrier
US Naval Research Lab
Stennis Space Ctr., USA
matthew.carrier@nrlssc.navy.mil

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Two simple ways for creating model-independent biogeochemical tangent linear and adjoint code

Mattern, Jann Paul[1], Edwards, Christopher[1] [1]UC Santa Cruz, Santa Cruz, US jmattern@ucsc.edu

Variational data assimilation has shown to yield large improvements in model state estimates for coupled physical-biogeochemical models. Yet, techniques like 4D-Var rely on tangent linear and adjoint models which must be constructed from the original, nonlinear model. If done manually, tangent linear and adjoint models are time-consuming to construct and maintain, and have hence not been developed for many biogeochemical models. We present two techniques that accurately create tangent linear and adjoint models for biogeochemical data assimilation applications using only evaluations of the nonlinear model. This approach is model-independent, in that it can easily be implemented for any biogeochemical model, and it eliminates the need to make changes to the tangent linear and adjoint code whenever the modifications are made to the nonlinear code. Of the two techniques, one is based on a finite difference-approximation, the second relies on dual numbers (similar to complex numbers) to evaluate the tangent linear model automatically. We introduce both techniques and evaluate them in terms of their accuracy, cost of implementation, and computer runtime.

Keywords: DA - Variational data assimilation, DA - Biogeochemical data assimilation, DA - Fundamentals and methodologies of data assimilation, DA - Performance and cost of data assimilation, Models - Ecosystem/BGC modelling

Presenter:
Jann Paul Mattern
UC Santa Cruz
Santa Cruz, US
jmattern@ucsc.edu

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A method for estimating the analysis error covariance with 4DVar

Ngodok, Hans[1], Carrier, Matthew[1], Smith, Scott[1], Souopgui, Innocent[2] [1]US Naval Research Laboratory, Stennis Space Center, USA [2]University of New Orleans, New Orleans, USA hans.ngodock@nrlssc.navy.mil

The traditional formulation of 4dvar does not provide the analysis error covariance. Bennett (2002) introduced a Monte-Carlo approach for estimating the posterior error covariance, but it requires a large number of samples (solutions of the tangent linear model). Recently, Moore et al. (2012) proposed a method to estimate analysis and forecast error variances using the adjoint of the 4dvar system, based on the premise of perturbing the observations and background fields. A new method is proposed here, that consists of an ensemble of perturbations of the optimal adjoint solution, instead of an ensemble of 4dvar analyses, e.g. Bonavita et al. (2012). We hypothesize that carrying out an ensemble of 4dvar solutions amounts to computing an ensemble of optimal adjoint solutions, since the forward nonlinear or linearized dynamics are not changed, and neither is the minimization process of the 4dvar system itself. Note that perturbing the optimal adjoint is equivalent to perturbing the innovation vector (on which the adjoint linearly depend), and the innovation vector itself depends on the observations and the background.

Keywords: DA - Data assimilation diagnostics, DA - Estimates of probabilities, , ,

Presenter:
Hans Ngodok
US Naval Research Laboratory
Stennis Space Center, USA
hans.ngodock@nrlssc.navy.mil