A MITgcm/DART Ocean Analysis and Prediction System with Application to the Gulf of Mexico

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Introduction

The ECCO system is a new generation of ocean assimilation systems based on the Massachusetts Institute of Technology general circulation model (MITgcm) and its adjoint. The system has been used to produce the first global 1º ocean state estimates (Köhl et al., 2006 and Wunsch and Heimbach, 2008). It is now also used for regional and coastal MITgcm applications (Hoteit et al., 2005; Gebbie et al., 2006; Hoteit et al., 2008). To improve the predictive capabilities of the ECCO system, the Data Assimilation Research Testbed (DART), which is an ensemble Kalman filter (EnKF)-based data assimilation package, has been recently integrated to the ECCO system. DART is a portable software facility employing different (stochastic and deterministic) EnKFs. It has been developed at the National Center of Atmospheric Research (NCAR) and is now used for different operational weather forecasting problems. This contribution describes the integration of DART with the MITgcm, and discusses how this ensemble-based system can complement the existing adjoint-based assimilation system. An example of a 1/10º MITgcm/DART application for predicting the evolution of the loop current in the Gulf of Mexico is presented.

MITgcm

The MITgcm solves the Boussinesq form of the Navier-Stokes equations for an incompressible fluid, hydrostatic or fully non-hydrostatic, in a curvilinear framework (Marshall et al., 1997). The model equations are written in z-coordinates and discretized using a staggered Arakawa C-grid. The horizontal assembly of the finite volume grid cells is based on a domain decomposition to enable efficient parallelization across a variety of high performance compute (HPC) architectures. The model is endowed with state-of-the art physical parameterization schemes for sub-gridscale horizontal and vertical mixing of momentum and tracer properties, as well as a sophisticated dynamic/thermodynamic sea-ice model, plus atmospheric boundary layer scheme over the open ocean. The model is continuously undergoing vigorous development to incorporate novel physics, numerical schemes and approaches for treating the horizontal and vertical grid, e.g. Adcroft et al. (2004). The numerical code is further designed to allow for the construction of the adjoint model using the automatic differentiation tool TAF.

DART

The Data Assimilation Research Testbed (DART) is a community software facility designed for implementation of stochastic and deterministic Ensemble Kalman Filtering (EnKF) techniques with large dynamical models. DART further employs advanced inflation/localization schemes essential for a good behavior of an EnKF (Anderson, 2003). The distributed code includes many models with various levels of complexity, various sets of observations, and skeleton code to guide users in adding their own models or new observation types. The DART algorithms are designed so that incorporating new models and new observation types requires minimal coding of a small set of interface routines, and does not require modification of the existing model code. The expected scaling of the DART parallel algorithm is independent of the forecast model. The reader is referred to "http://www.image.ucar.edu/DAReS/DART/" for further information about DART.

The MITgcm/DART Assimilation System

The MITgcm and DART run separately and no modifications are needed for each code. An interface was built to exchange the information between the two codes. It is mainly composed of routines that handle inputs/outputs needed to run each code.

The state vector, composed of all the variables required for the initialization of the numerical model, needs first to be defined. In the MITgcm, the state variables are temperature, salinity, horizontal velocities, and sea surface height.

The system starts from an initial ensemble of state vectors that supposedly describes the uncertainties around the initial state estimate. The MITgcm is the forecast model and is used to integrate the ensemble of state vectors forward in time. Once the new observations are available, the interface transforms the 'forecast' ensemble, outputs of the MITgcm, into DART format. DART wakes up, uploads the forecast ensemble and the observations, updates and writes out the 'analyzed' ensemble, then goes to sleep. The interface reads DART outputs, transforms them into MITgcm format (as initial conditions) and then launches the model for a new round of prediction.

The MITgcm/DART system is now enabled for assimilation of most ocean data sets.

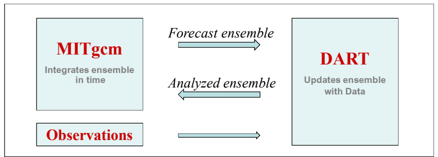

Fig. 1 *A schematic description of the MITgcm/DART assimilation system.*

Application to the Prediction of the Loop Current in the Gulf of Mexico

MITgcm Configuration in the Gulf of Mexico

The MITgcm was implemented in the Gulf of Mexico basin between 8.5ºS - 31ºN and 262ºE – 287.5ºE on a 1/10º×1/10º Mercator grid and 50 vertical layers. The vertical resolution is spaced at 5m from the surface to 300m in depth. The maximum depth is at 6000m. In this configuration, the model operates in a hydrostatic mode with an implicit free surface. No-slip conditions are imposed at the lateral boundaries with quadratic bottom friction. The sub-grid scale physics is a tracer diffusive operator of second order on the vertical, the eddy coefficients being parameterized by the KPP mixed layer model. Horizontally, diffusive and viscous operators are of second or fourth order. Eastern and Northern open boundaries are prescribed by the ECCO 1º global state analysis (Köhl et al., 2007). The model is forced with NCEP atmospheric forcing. This includes air temperature, specific humidity, wind speed, precipitation, and short and long wave radiative fluxes. A monthly river input (freshwater) is also prescribed in the model. Surface salinity is relaxed towards monthly climatology with a 30-day time-scale.

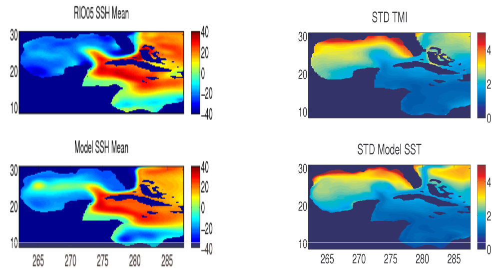

Fig. 2 *Comparison of model SSH mean from a 50 year run between 1950 and 2000 with RIO05 data and model SST standard deviation with TMI data. The model SSH mean is about right, but the variability of the shedding eddies from the loop current extends unrealistically to the east. The variability of the model SST is in good agreement with TMI data.*

Experiments Design

The ensemble adjustment Kalman filter (Anderson, 2001) was used in this study. It was implemented with 50 and 100 ensemble members, an inflation factor of 1.2 and a localization radius of 250 km.

Along-track AVISO anomalies and TMI sea surface temperature were assimilated weekly with a nominal accuracy of 5 cm and 0.5ºC, respectively. The RIO05 sea surface height mean was added to the AVISO anomalies to produce an absolute height.

Assimilation runs were performed over a 6-month period during a strong loop current event in 1999 between May and October.

Assimilation Results – RMS

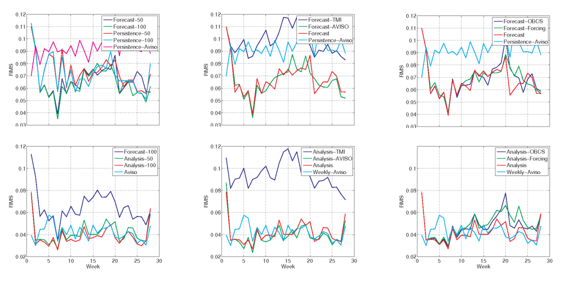

Fig.5 Relative mean square (RMS) misfits between along track AVISO anomalies and assimilation solution (prediction and analysis), and weekly AVISO SSH products. Forecast skill is compared to RMS misfits with persistence from assimilation and weekly AVISO product. In the legends, '100' and '50' refer to runs with 100 and 50 members, 'TMI' and 'AVISO' refer to runs assimilating only TMI and AVISO data, and 'OBCS' and 'Forcing' refer to run with perturbed open boundaries conditions and forcing from 1998.

Assimilation Solution

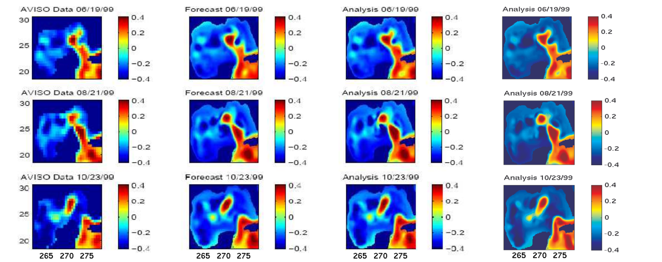

Fig.4 *Weekly SSH forecasts and analysis as estimated by the assimilation with 100 ensemble members compared to AVISO products. The range of times was selected to highlight an eddy separation event. Also shown in the right column is the analysis from a run with 50 ensemble members.*

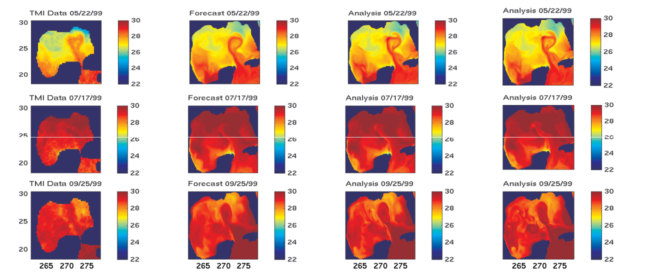

Fig.5 *Same as Fig.4 for weekly SST compared to TMI products.*

Discussion and Future Work

- Assimilation of altimetry and TMI produces a realistic evolution of the loop current.
- AEKF analysis is in better agreement with along track AVISO data than the weekly AVISO products. It further reproduces realistic features of the loop current not present in the TMI mapped products.
- Weak sensitivity to forcing and open boundaries.
- The newly implemented ensemble Kalman filtering package – DART – will complement the ECCO adjoint-based system, providing a dynamically evolving background covariance matrix and schemes less sensitive to the strong nonlinearities of high resolution configurations.
- Future work will mainly focus on improving the forecast skill of the system. It includes:
  - Tune data errors and assimilate data over shorter periods.
  - Test adaptive inflation and localization and run an ensemble Kalman smoother.
  - Develop and test hybrid adjoint/EnKF schemes.

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