Preliminary Results from Assimilating SMOS-mission Satellite Sea-Surface Salinity Fields in an NCEP Operational Ocean Forecast System

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Recently available satellite sea-surface salinity (SSS) fields provide important global data for assimilating into ocean forecast systems. Although an ocean state variable, previous measurements comprised only *in situ* observations, which were and continue to be extremely sparse in time and space; although, *in situ* salinity observations have notably increased through the Argo float program. The European Space Agency's (ESA) Soil Moisture – Ocean Salinity (SMOS) mission, launched in 2009, began providing the first repeated global higher spatial and temporal resolution coverage of SSS. Here, we present results from assimilating SMOS SSS data into National Oceanic and Atmospheric Administration's (NOAA) operational Modular Ocean Model version 4 (MOM4), the modeling platform of NOAA's Global Ocean Data Assimilation System (GODAS) and the ocean component of NOAA's seasonal-interannual Climate Forecast System (CFS). This study employed SMOS Barcelona Expert Centre (SMOS-BEC) 0.25-degree gridded SSS fields for 2010-2012, averaged over a 3-day rolling window and updated every 3 days. The global NCEP ocean model, spanning 81S-90N and employing 0.5-degree zonal resolution with variable meridional resolution of 0.5 degrees or less, provides a fast and robust platform for analyzing ocean dynamics at greater than eddy-resolving spatial scales. Forcing this model with NOAA's daily Climate Forecast System Reanalysis (CFSR) fluxes, we assimilate the SMOS SSS fields using a relaxation technique, running sensitivity experiments with different relaxation time periods to evaluate the importance of high-frequency (daily to mesoscale) and low-frequency (seasonal) SSS variability on the ocean's overall state. Four SSS fields provide the basis for this assessment: a) SSS.0 - SMOS-BEC SSS data; b) SSS.1 – base line unconstrained model values (no SSS assimilation); c) SSS.2 - model values constrained by SMOS SSS (SSS.0); and (d) SSS.3 - model values constrained by NOAA's 2009 World Ocean Atlas monthly climatological SSS.

To establish robustness, we examine the global signal-to-error ratio for SSS.1 data—the unconstrained ocean model SSS values, divided by the error estimates provided for the SMOS SSS data—to identify the oceanic regions and frequency bands for which the SMOS SSS fields can reliably and significantly improve the oceanic state and initialization of coupled forecast models. We then apply the Empirical Orthogonal Function (EOF) technique to analyze the SSS field's modes of variability in the tropical Pacific, a domain where oceanic dynamics are dominated by El Niño interannual variability in the cold tongue region and by high-frequency precipitation events in the western Pacific warm pool region. We expect that assimilating salinity fields at the sea surface will impact surface circulation and, through changes in baroclinic pressure gradients, the three-dimensional circulation patterns in the upper ocean. Thus, we examine changes in upper-ocean heat content, mixed-layer depths, and velocity in the top 300 m of the water column. It is shown here that assimilating surface salinity fields causes significant seasonal and interannual changes in the three-dimensional circulation patterns of mass, momentum, and heat in model results. Finally, preliminary verification studies are conducted using independent variables, such as sea-surface height (SSH) and velocity, to show that SSS improves ocean state representation. The observations used in this study are global merged satellite SSH fields and daily vertical profiles of scalars (temperature, salinity and velocity) from two fixed-location buoys located in the western Pacific warm pool and eastern Pacific cold tongue regions. Our results show that SMOS SSS fields help improve the simulated ocean state, thus providing better initialization of coupled seasonal and tropical cyclone forecast systems.

Assimilation of Satellite and Glider Data in the Monterey Bay and Hawaiian Regions using the Navy Coastal Ocean Model 4DVAR

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A 4DVAR data assimilation system has recently been developed for the Navy Coastal Ocean Model (NCOM) and has been demonstrated using real ocean observations in this study. The NCOM-4DVAR is formulated for weak-constraint data assimilation based on the in-direct representer method. In this study, satellite data consisting of sea surface temperatures (SSTs) and sea surface height anomalies (SSHAs), as well as in-situ data from Airborne eXpendable BathyThermographs (AXBTs), ARGO floats, and gliders is used to derive optimal corrections to the ocean model background and surface forcing provided by the atmospheric model. Two regional domains have been selected for this study: the first consists of the waters adjacent to Monterey Bay, California during the AOSN-II experiment and the second in a region surrounding Hawaii during the RIMPAC08 experiment. It is shown that the NCOM-4DVAR can correct the model solution via control of the initial conditions and model error terms and produce an improved forecast as a result. Also the NCOM-4DVAR can produce optimal corrections to the atmospheric forcing based on ocean data. These corrections alone can be applied to the specified surface forcing to produce an improved ocean forecast.

Operational Ocean Data Assimilation with Global HYCOM

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A three-dimensional variational ocean data assimilation system has been developed that produces simultaneous analyses of temperature, salinity, and vector velocity. The system is referred to as NCODA (Navy Coupled Ocean Data Assimilation). NCODA 3DVAR is the data assimilation component of the real-time, global, 1/12° resolution HYbrid Coordinate Ocean Model (HYCOM) forecast system operational at the U.S. Naval Oceanographic Office [1]. It makes full use of all sources of the operational ocean observations (both *in situ* and remotely sensed). Observations are assimilated at their measurement times using the first guess appropriate time (FGAT) method. Hourly forecast fields are used in FGAT for surface data types, while daily averaged fields are used at depth to assimilate late receipt profile and altimeter sea level anomaly (SLA) observations (observations received at the center later than the 24-hour update cycle interval).

NCODA is a unified and flexible oceanographic analysis system. The adjoint of the 3DVAR is available and is routinely used to estimate the impact of observations assimilated on reducing HYCOM model forecast error [2]. Satellite sea surface temperature (SST) radiances are directly assimilated using forward and inverse modeling based on radiative transfer. SST radiance assimilation is a true example of coupled data assimilation where observations in one fluid (top-of-the-atmosphere radiances) create innovations in the other fluid (ocean SST). Adaptive data thinning of the high-density satellite SST observations is performed using a water mass classification scheme and covariance length scales that vary with location. This approach maintains adequate data density in dynamic ocean regions while removing data redundancy and reducing correlated errors elsewhere. NCODA performs data consistency checks within the minimization algorithm itself as a form of internal data quality control. Work is underway to assimilate SLA as geostrophic velocity observations estimated from the dynamically important along track slopes of the altimeter data. This method avoids the non-trivial problem of specifying a mean dynamic topography matching that contained in the altimeter data. NCODA has components for computing analysis error covariance and the ensemble transform for generating perturbed ensemble initial conditions. A prototype NCODA 3DVAR-hybrid has been developed that uses ensemble-based covariances to augment the existing multivariate background error covariances. Optimum values for weighting the ensemble and multivariate covariances in the hybrid are determined from a time history of model-data misfits and ensemble variances.

In this presentation development and evaluation of the NCODA 3DVAR data assimilation system is described. Special emphasis is placed on documenting the new capabilities listed above (adjoint-based data impacts; SST radiance assimilation; altimeter velocity assimilation; 3DVAR-hybrid) in the global system.

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THE INTERPLAY BETWEEN OCEAN DATA SCARCITY AND OCEAN STORM SURGES IN WEST AFRICA COAST: A CASE IN NIGERIA.

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ABSTRACT

Over thirty occurrence of Ocean storm surges events over the Nigerian coastline were recorded between 1994-2012 and each with its devastating consequences resulting from the massive coastal flooding and erosion. It revealed that all Ocean storm surges apart from the surges of march 2002 were experienced in summer months of April to October, but more frequent in August.

Some evidences in the West Africa coast have been observed that Ocean data scarcity as it relate to Ocean storm surges, is one of the major factors slowing down the process of understanding the variation of ocean-atmospheric systems especially in the developing countries in West Africa like Nigeria.

The paper talked on the scarcity of real time data in situ hindered validation of both ocean and atmospheric models. Further more we have no access of extracting these data(Ocean storm surges records, information etc).

This paper conclude with an attempt to investigate and show how the Nigerian Meteorological Agency(NIMET),intends to increase Ocean observation network for better understanding of ocean dynamics, thus support of the international scientific community to come onboard to improve sea observation network is crucial.

Keywords: Marine Environment, Nigeria, Coastal degradation, Climate data. Ocean storm surges.

An Ensemble of Ocean Reanalyses for Climate Studies

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An 18 member ensemble of ocean reanalyses spanning the period from 1871 through 2010 is conducted using the SODA methodology. The ensemble reanalyses use forcing the ensemble members of the 20th Century reanalysis project. Ocean sea surface temperature data from ICOADS 2.5 is assimilated, but with a bias correction as implemented for HadISST (the bucket correction).

The reanalysis is used to explore climate variability in the tropical Pacific Ocean. The results show that there is a broad range of variability in all of the characteristics. The reanalysis shows that the location of ENSO is normally distributed about a single mean value, suggesting that there are not different types of ENSO based on location. The distributions of strength and duration are not obviously normal, so that it is possible that there are different types based on these characteristics. All of the ENSO characteristics have some manifestation of decadal variability, however none of the characteristics have a trend that can shown to be significantly different than zero. However, given the large variance of ENSO characteristics, even 150 years does not contain enough ENSO Events to accurately determine if ENSO has changed. The reanalysis results are largely supported by both the SST reconstructions and CMIP5 historical runs. After the 1950s the ENSO in the reconstructions is similar to ENSO in the reanalysis. Before The 1950s, the timing of ENSO Events is similar between the various products, but the amplitude of events can be different. The CMIP5 models show a wide range of characteristics, with ENSO events that range from too far in the west to too far in the east, and from some models showing very weak ENSO While some models have quite realistic strength. None of the models appear to have different types of ENSO, in agreement with the reanalysis and the reconstructions.

Comparison of 4DVAR and EnKF state estimates and forecasts in the Gulf of Mexico

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Experiments were conducted to compare the performances of four-dimensional variational (4DVAR) and ensemble Kalman filter (EnKF) assimilation in the Gulf of Mexico (GoM) using the Massachusetts Institute of Technology general circulation model (MITgcm). The quality of the ocean state estimates and forecasts using both methods were compared including the contribution of ensemble prediction. The MITgcm-Estimating the Circulation and Climate of the Ocean (MITgcm-ECCO) 4DVAR and the MITgcm-Data Assimilation Research Testbed (MITgcm-DART) EnKF systems were used to obtain two month hindcasts by assimilating satellite-derived along-track sea-surface height (SSH) and gridded sea-surface temperature (SST) observations. The model analysis from each method was used to initialize a forecast for two months from the end of the hindcast period. The forecasts provide a cross-validation test of the state estimate by comparing it to independent future observations and are evaluated against analyses for practical Loop Current (LC) predictability. The model forecast was tested for Loop Current Eddy (LCE) separation events, including Eddy Franklin (Eddy-F) in May 2010 during the Deepwater Horizon (DwH) oil spill in the GoM. The model performance was evaluated by computing model-observation root-mean-square-difference (*rmsd*) during both the hindcast and forecast periods. Both methods outperformed persistence (keeping the initial state fixed), although forecasts initialized from the HYCOM $(1/12)^0$ global analysis using Navy Coupled Ocean Data Assimilation (NCODA) also produced competitive forecasts. The 4DVAR has better long-term (longer than 1 month) predictability and lower *rmsd* compared to EnKF, while EnkF is better than 4DVAR for short-term forecasts (less than 1 month). The EnKF short-term predictability can be enhanced by decreasing the localization length scale (i.e. increasing localization) which enables a better fit with the data. The EnKF also showed enhanced predictability by increasing the number of ensemble members from 25 to 50 and to 100 with identical localization radius and covariance inflation parameters. It is hypothesized that increased long-term forecast performance reflects better initialization, and that this results from retaining more information in the hindcasts, whether by increasing the ensemble size in the EnKF or by using 4DVAR, which is not limited to a subspace of the model control space.

Impact of Data Assimilation on ECCO2 Equatorial Currents

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A component of the Estimating the Circulation and Climate of the Ocean (ECCO) consortium [1] is called ECCO2 [2], which introduced sea ice, the Arctic Ocean, and a 19-km horizontal grid that permits eddying motions in the global ECCO ocean circulation estimates. We use ECCO2 adjoint-method solutions over five years (2004, 2005, 2009-2011) to examine the impact of assimilation of in-situ observations on the Equatorial Undercurrent (EUC) and North Equatorial Countercurrent (NECC). ECCO2 solutions had nineteen 10- to 20-m layer thicknesses in uppermost 400 m and archived estimates with 3-day averages. In the equatorial central Pacific Ocean at 150°W where April and October are maximum and minimum times of the annual cycle of upper-ocean currents, the impacts of data assimilation were negligible for the EUC transport and slightly modest for the NECC transport. For example, the Optimized (with data assimilation) – minus – Baseline (with no data assimilation) difference (in absolute percentage value, |(Optimized-Baseline)/(Optimized+Baseline)/2)|) in EUC volume transports for 12-14 April 2004 and 12-14 October 2004 were -1.4 (or 2.5%) and 0.0 (or 0.0%) Sverdrups, respectively. One Sverdrup (Sv) equals 10^6 m^3 s^{-1}. Similarity of ECCO2 currents and National Oceanic and Atmospheric Administration in-situ measurements of upper-ocean currents on the equator at 147°E, 165°E, 170°W, 140°W, and 110°W will be discussed. For NECC transports, the 12-14 April and 12-14 October 2004 differences were -0.4 (2.7%) and -5.4 (or 17.9%) Sv, respectively. Throughout 2004, the largest such 3-day averaged differences between Optimized and Baseline solutions for EUC and NECC transports at 150°W were -12.0 (or 18.2%) and -17.6 (or 52.9%) Sv, respectively.

The ECCO2 methodology assimilated a vast quantity of observations [1], including satellite measurements of ocean surface topography, sea surface temperature, and ocean mass, and in-situ measurements of vertical profiles of temperature and salinity. No ocean current observations were assimilated. Unlike the satellite component of the observing system, the in-situ component had continuous spatial and temporal variations in data quantity and quality, which sometimes were substantial. To test the spatial-temporal impact of in-situ assimilated data on ECCO2 equatorial currents, the longitudinal distribution (including Atlantic and Indian oceans) of EUC and NECC transport differences between Optimized and Baseline solutions will be described relative to the quantity and quality of types of assimilated data. The 5-year ECCO2 time period encompassed a substantial reduction (increase) of measurements recorded in the equatorial Pacific (Indian) Ocean. The impact of data assimilation over a longer period from 1992 to the present will be examined with other ECCO products.

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Coastal Ocean Data Assimilation and Forecasting Using a Multi-Scale Three-Dimensional Variational Data Assimilation Scheme

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Coastal ocean flows are often characterized by multiple spatial and temporal scales, and mesoscale and sub-mesoscale features, such as eddies and filaments, are energetic. A multi-scale three-dimensional variational data assimilation (MS-3DVAR) scheme has been formulated for high resolution coastal ocean models that represent a wide range of spatial scales, and implemented in real-time forecasting systems in support of a few operational coastal ocean observing systems and field campaigns. This MS-3DVAR scheme uses partitioned cost functions and thus background error covariances of multi-decorrelation length scales. MS-3DVAR improves the effectiveness of the assimilation of both very sparse and high resolution observations. A variety of data assimilation experiments, known as Observing System Experiments (OSEs), is performed to illustrate MS-3DVAR. These OSEs are also used to assess the relative impacts of different types of observations. The observations assimilated primarily includes satellite altimetry data and sea surface temperatures, High Frequency (HF) radar surface velocities, and vertical profiles of temperature/salinity (T/S) measured by ships, moorings, Autonomous Underwater Vehicles and gliders. The combination of high resolution HF radar surface velocities and sparse T/S profiles allows representing meso-scale systems and producing analyses and forecasts with skill. It is suggested that a potentially promising observing network may be based on satellite altimetry data and SSTs along with sparse T/S profiles, but future satellite SSHs with wide swath coverage and higher resolution may be needed.

A Regional Ocean Data Assimilation for the Ocean Component in a Hurricane Weather Research and Forecast (HWRF) System

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Traditional data assimilation for the ocean component in a coupled atmosphere-ocean hurricane forecast system is targeted to obtain best estimates of the upper ocean conditions - sea surface temperature (SST), mixed layer and upper pycnocline, over hurricane footprint before and during the storm. Atmospheric fluxes are assumed to be about right in the environment around the hurricane and corrections to atmospheric fluxes due to the presence of the hurricane are mostly related to observed hurricane path and intensity. In an operational hurricane forecast system, it is desirable to include sequentially and in a robust manner improvements in the ocean state variables and also in the atmospheric fluxes. In this presentation we start from a parallel setup to the operational NCEP hurricane forecast (HWRF) system, employing HYCOM as a numerical ocean model. We examine the effects of introducing ocean data assimilation to the regional ocean model and substantial improvements in the representation of atmospheric fluxes as seen by the ocean component in the system.

The assimilated data in near real time include remotely sensed SST and sea surface height, vertical profiles of temperature and other in situ observations. The observation operator includes updates of temperature and salinity congruent with correlation derived from historical data, static stability and the current state of the model.

Experiments with Satellite Ocean Color Fields in an NCEP OperationalOcean Forecast System

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Solar shortwave heating of the the upper layers of the ocean is dependent on the wavelength of the incoming radiation and the optical properties of the water column. Chlorophyll concentration has been found to correlate to the optical properties of the water column. In this study, we use satellite ocean color fields obtained from NASA to study the impact of different ocean color datasets on ocean model simulations. The various data sets used in this study are the 9-km mapped fields of varying temporal resolution from the Sea-viewing Wide Field-of-view Sensor (SeaWiFS), Moderate Resolution Imaging Spectroradiometer on board the Aqua (MODIS-Aqua), and Visible/Infrared Imaging Radiometer Suite (VIIRS) missions. These simulations are carried out on the National Oceanic and Atmospheric Administration (NOAA) National Center for Environmental Prediction (NCEP) Modular Ocean Model version 4 (MOM4), which spans 81S-90N and employs 0.5-degree zonal resolution with variable meridional resolution of 0.5 degrees or less, and provides a fast and robust platform for analyzing ocean dynamics at greater than eddy-resolving spatial scales. For these simulations, the model is forced with NOAA's daily Climate Forecast System Reanalysis (CFSR) fluxes, and relaxation techniques are employed to assimilate daily satellite sea surface temperature fields and climatological monthly sea surface salinity fields from NOAA's 2009 World Ocean Atlas. The ocean color fields modulate the absorption of solar insolation in the upper ocean. Through changes in the density profiles, the differential heating patterns cause baroclinic pressure gradients, which in turn, impact the three-dimensional circulation patterns in the upper ocean. Thus, we examine changes in upper-ocean heat content, mixed-layer depths, and velocity in the top 300 m of the water column. Anomalous buildup of Equatorial Pacific ocean heat content is an important variable for the recharge-discharge oscillator theory for the evolution of El Nino events. Here, we show that the different specifications of ocean color data inputs cause significant changes in the ocean heat content anomalies in the tropical Pacific. Thus, it is important for seasonal predictions that we study the impact that the choice of ocean color data sets has on the ocean forecasts. Finally, in addition to inter-comparisons of the different simulations, we conduct preliminary verification studies between model simulations and independent (i.e, non-assimilated) observations, such as satellite sea-surface height (SSH) fields, vertical profiles of prognostic variables from *in situ* observations, and ocean heat content and mixed-layer depths from CFSR ocean analyses.

Estimating Atmospheric Forcing Errors in Ocean Data Assimilation using the Representer Method of 4DVAR

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In this study, a weak constraint assimilation is carried out using the Navy Coastal Ocean Model 4DVAR to fit the ocean observations collected in the Monterey Bay, California region while minimizing/estimating the errors in both the initial conditions and atmospheric forcing fields. The cost function is minimized through the representer algorithm, which expresses the optimal assimilation solution as a first guess plus a finite linear combination of representer functions, one per datum. The method allows the control of both initial conditions and model errors while minimizing the cost function in the observations space. Retrieved corrections to the atmospheric forcing are validated by adding them to the prior estimates and integrating the nonlinear model, and comparing the resulting solution to independent and non-assimilated observations. Examples of numerical experiments will be shown.

GLOBAL EDDY-PERMITTING OCEAN REANALYSES and SIMULATIONS of the PERIOD 1992 to PRESENT

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The GLORYS (Global Ocean reanalysis and Simulation) Project is motivated by the need of a realistic description of the ocean state and variability over the recent decades, at the global scale, and at the scale of the ocean basins and regional seas (https://reanalyses.org/ocean/overview-current-reanalyses). The French research community (CNRS), the operational ocean forecasting center MERCATOR-Ocean (http://www.mercator-ocean.fr) and the CORIOLIS data center (http://www.coriolis.eu.org/), have gathered their skills and expertise in physical oceanography, ocean modeling and data assimilation, to carry out global ocean reanalyses at eddy scale resolution for the period 1992 to present. This reanalysis effort is part of the project MyOcean granted by the European Commission within the GMES Program (7th Framework Program, http://www.myocean.eu/).

This paper will present the GLORYS reanalysis system relies on the ORCA025 global model configuration developed by the DRAKKAR consortium (http://www.drakkar-ocean.eu/), on the basis of the NEMO3 ocean/sea-ice general circulation model (http://www.nemo-ocean.eu/). ORCA025 uses a horizontal grid resolution of 1/4° and 75 vertical levels, which permits the growth of mesoscale eddies. The data assimilation scheme developed for the operational forecasting systems of Mercator Océan is used in this reanalysis system. It is based on a reduced order Kalman filter (SEEK formulation) and an incremental analysis update, in conjunction with a bias correction scheme for temperature and salinity. AVHRR Sea Surface Temperature, along track Sea Level Anomalies and in situ Temperature and Salinity profile data are assimilated for the ocean component. In parallel, Sea Ice Concentration data (CERSAT, http://cersat.ifremer.fr/) are assimilated to constrain the LIM sea ice model. At the surface, the GLORYS reanalyses are forced with atmospheric surface variables from ERA-INTERIM atmospheric reanalysis (http://www.ecmwf.int/research/era/do/get/era-interim) at high frequency (3 hours). In parallel, a control experiment with no observation assimilated is integrated, to estimate the benefit of data assimilation.

The paper will present assessments and measures of the quality of GLORYS products obtained from a validation protocol based on recommended GODAE (https://www.godae-oceanview.org/) and CLIVAR-GSOP reanalysis diagnostics, and from a comparison with the control simulation. The scientific value of the GLORYS reanalysis products will be illustrated with results from independent scientific studies obtained in a wide range of areas such as climate, seaice, mesoscale processes, mixed layer processes, etc.

Role of Ocean Data Assimilation in improving NCEP-CFS based monsoon forecast

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The Indian summer monsoon (from June to September) rainfall is of great importance to India's agriculture and economy as 60-90% of annual rainfall is received during this season. Severe flood and drought conditions over the Indian subcontinent are the result of intraseasonal oscillations within the monsoon period. The fundamental driving mechanism of the monsoon cycle is the thermal contrast between land and ocean, sea surface temperature (SST) and moisture are crucial factors for its evolution and intensity [Cherchi et al., 2007]. Recent studies highlight the role of tropical Pacific and Indian Ocean SST in Indian summer monsoon and its interannual variability.

National Centers for Environmental Prediction (NCEP) Coupled Forecast System (CFS) is selected to play a lead role for monsoon research (seasonal prediction, extended range prediction, climate prediction, etc.) in the ambitious Monsoon Mission project of Government of India [Samir et al., 2013]. Global Ocean Data Assimilation (GODAS) is the ocean data assimilation model for the Modular Ocean Model (ocean component of CFS).

It is important to note that improvement in ocean initial state and an improved SST analysis will lead to better monsoon forecast with the coupled forecast system. The present study investigates the role of ocean data assimilation in improving the CFS- based monsoon forecast. The GODAS assimilation method is the 3DVAR scheme [Derber and Rosati, 1989]. Surface and subsurface ocean data (temperature and salinity) from different observational platforms like ARGO, RAMA etc are assimilated to prepare the ocean analysis. To quantize the role of ocean data assimilation, a control run is also carried out without assimilating observations to MOM4. The results indicate that ocean data assimilation provides improved SST analysis (by improving the SST up to ~2°C) compared to control run and leads to better monsoon forecast. The data assimilations resulted better ocean dynamics and represent the thermocline structure well. The improvement in the monsoon rainfall forecast is mainly due to the evolution of better SST in the coupled model. The role of ocean data assimilation in capturing interannual monsoon variability is also examined.

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The Impact of Velocity Data Assimilation from Drifters Using the Navy Coupled Ocean 3D Variational Data Assimilation System (NCODA-VAR)

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The Navy Coupled Ocean 3D Variational Data Assimilation (NCODA-VAR) system is one of the primary tools that the Navy uses operationally to ingest, process, quality and control, and assimilate ocean observations in near-real time in order to regularly update and improve the forecast skill of several different operational ocean prediction systems. One of the deficiencies of NCODA, however, is its inability to accurately resolve small-scale features. This is primarily because the two predominant sources of data for NCODA are SST and SSH. The spatial resolution of SSH data is typically too coarse to resolve smaller eddies, and SST data lacks the vertical correlation with the subsurface to steer the analysis towards these types of features.

The capability to assimilate velocity observations has been added to NCODA, which included constructing and implementing additional error covariances to cross-correlate velocity observation with temperature and salinity throughout the water column. This was needed so that the resulting analysis from velocity assimilation has dynamically balanced increments of velocity, temperature and salinity. The construction of the new error covariances stems from a historical database of temperature and salinity; and their relation to velocity is achieved using the equation of state (to calculate the covariance of geopotential) and the geostrophic balance (to correlate geopotential to velocity).

Results of an experiment will be presented that demonstrate that the inclusion of velocity data assimilation improves NCODA's ability to resolve eddies. This experiment used velocity data that were inferred and assimilated from 100s of surface drifters that were released during the summer of 2012 in the Northeastern Gulf of Mexico as part of the GoMRI CARTHE drifter experiment. The resulting analyses are compared with independent observations from altimetry, and temperature and salinity profiles.

Representativeness Error of Velocity Assimilation in the Regional Navy Coastal Ocean Model and Prediction System

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A regional Navy Coastal Ocean Model (RNCOM) of the Gulf of Mexico (GoM) was used in real-time support of the GoM Grand Lagrangian Deployment (GLAD) that took place in July and August 2012. The GLAD experiment deployed over 300 near-surface drifters in the Northern GoM in the proximity of the De Soto Canyon. NCOM output was provided to GLAD researchers for dispersion and particle trajectories prediction studies and for forecast of ocean state during the experiment. RNCOM was used to generate two simulations of GoM. One simulation had 3 km horizontal spatial resolution and the other had 1 km. RNCOM produced 3-hourly forecasts out to 72 hours for each simulation.

Observational data is assimilated into RNCOM via the Navy Coupled Ocean Data Assimilation System (NCODA). NCODA assimilates quality controlled remotely sensed sea surface temperature (SST) and sea surface height anomaly (SSHA), as well as in situ observations such as temperature and salinity profiles from ships, buoys, and Argo floats. Data are assimilated into RNCOM over a 24 hour hindcast period ending at 00 UTC each day. In situ subsurface observations are supplemented with synthetic subsurface profiles of temperature and salinity using SST and SSHA via the Modular Ocean Data Assimilation System. Observations assimilated in these models was provided by the Naval Oceanographic Office (NAVOCEANO) and introduced into NCODA via its real-time ocean data quality control process. Initial (start of simulation) and lateral boundary conditions come from the operational global ocean model (NCOM, running at NAVOCEANO) Global Ocean Forecast System (GOFS 2.6). Forcing on the upper boundary (air/sea interface) comes from the 0.2° Coupled Ocean/Atmosphere Mesoscale Prediction System (from 0 to 48 hour forecast) and from the 0.5° Navy Operational Global Atmospheric Prediction System (from 48 to 72 hour forecast).

During GLAD, RNCOM did not assimilate velocity observations because there was no balance operator in place between the velocity field and the density (temperature and salinity (T&S)) field within NCODA. Further, enforcing geostrophic balance between the velocity field and the T&S fields is undesirable for areas and events where ageostrophic flow dominates. Ageostrophy can increase temporally, during high wind stress (increasing surface currents), and spatially, in areas of shallow water (coastal and shelf regions) where frictional forces are dominant. High current shear, such as outer edges of the Loop Current in the GoM, also increases ageostrophy. In this study, modeled velocities from the GoM simulations and observed currents will be compared to geostrophic currents computed from the SST and SSHA fields from the model output. Modeled currents, geostrophic currents from modeled density field, and observational currents will be correlated with respect to wind speed and to bathymetry (depth; distance from land) as well as directly compared. Observed surface currents will come from the GLAD drifters and High Frequency Radar. Subsurface observational currents will come from shipboard Acoustic Doppler Current Profilers (ADCP) and ADCP attached to oil rigs in the GoM. The representativeness error plus model error (difference between the observed and model-derived-geostrophic currents) will be quantified. The objective is to compute and assign a representativeness error to each velocity observation to allow for velocity assimilation into the current version of RNCOM.

Coupled 4D-variational physical and biological data assimilation in the California Current System

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Coupled physical and biological data assimilation is performed within the California Current System. The initial condition of physical and biological variables is estimated using the four-dimensional variational (4DVar) method under the Gaussian and lognormal error distributions assumption, respectively. Errors are assumed to be independent, yet variables are coupled by assimilation through adjoint model dynamics. Using a nutrient- phytoplankton-zooplankton-detritus (NPZD) model coupled to an ocean circulation model (the Regional Ocean Modeling System, ROMS), the coupled data assimilation procedure is evaluated in a twin experiment setting and compared to two related experiments, assimilating physical data only and biological data only. Independent assimilation of physical (biological) data reduces the root-mean-squared error of physical (biological) state variables by more than 56% (43%) on average. However, the improvement in biological (physical) state variables is less than 7% (13%). In contrast, the coupled data assimilation shows improvement in both physical and biological components by 57% and 49%, respectively, illustrating the superior performance of the coupled assimilation approach. The coupled data assimilation also recovers the coupled modes between surface physical-biological variables, while other two assimilation runs do not.

A Hybrid Ensemble-Variational Approach for Coastal Ocean Application

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The potential for combining ensemble and variational methods for coastal ocean application is investigated off the Bonney Coast in southern Australia. The tangent linear and adjoint code developed for the ROMS ocean model is applied to the output of another coastal ocean model to derive an improved initial condition by assimilating satellite SST data. The Assimilation is done using the Advanced Variational Regional Ocean Representer Analyzer (AVRORA) [1,2], a set of stand-alone codes that are dynamically consistent with ROMS.

The results show that the tangent linear and adjoint code from AVRORA could be successfully applied to SHOC (Sparse Hydrodynamic Ocean Code) [3] model output to obtain an initial condition that is closer to the observations and improve forecast. The representers derived from the ensemble OI [4] and AVRORA demonstrate similarities but also differences, with the ensemble OI-derived representers capturing the general patterns of coastal upwelling, and the AVRORA representers capturing the flow-dependent ocean states. One possibility to take advantage of both systems is therefore to initialize the covariances in AVRORA with the covariances derived from ensemble OI. Results from experiments on sensitivity and applicability of such a hybrid system will be presented.

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A Robust Ensemble-Based Kalman Filter for Data Assimilation into a 3D Ecosystem Model of the Cretan Sea (Eastern Mediterranean)

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An application of the robust filtering approach with an ensemble square-root Kalman filter for data assimilation into an ecosystem model of the Cretan Sea (Eastern Mediterranean) is presented and discussed.
The ecosystem system comprises two on-line coupled sub-models: the three-dimensional Princeton Ocean Model and the European Regional Seas Ecosystem Model (ERSEM) [1]. The ecosystem model is under hydrodynamic control, in winter and spring when mixing events significantly influence the biology by transporting nutrients from below the thermocline into the euphotic zone and organic matter passes to the benthos. For the remainder of the year it is under ecological control. Accounting for model deficiencies remain a significant problem for any EnKF assimilation, as they limit the accuracy of the estimated background covariance crucial for proper weighting of the model prediction in the assimilation. Additionally, poor behavior of KFs during ecosystem bloom periods is now acknowledged as a common difficulty. A KF is indeed generally quite inefficient with highly intermittent and fast varying processes having probability distributions not well characterized by means and variances. This contribution addresses these difficulties through an assimilation scheme that is based on the Singular Evolutive Interpolated Kalman (SEIK) [2] filter implemented with a time-local H_infinity filtering strategy to enhance robustness and performances during periods of strong ecosystem variability [3]. It is shown that robustness can be achieved in the SEIK filter by introducing an adaptive inflation scheme of the modes of the filter error covariance matrix.
Twin-experiments are performed to evaluate the performance of the assimilation system and to study the benefits of using robust filtering in and ensemble-filtering framework. Pseudo-observations of surface chlorophyll extracted from a model reference run for the year 2003 were assimilated every two days to correct the ecosystem model predictions. Simulation results suggest that the adaptive inflation scheme significantly improves the behavior of the SEIK filter during periods of strong ecosystem variability.

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Impact of the Assimilation of Aquarius Sea Surface Salinity Data in the GEOS System

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We present a methodology to correct the biases and errors of along track Aquarius level 2 sea surface salinity (SSS) data (version 2.0). Observed SSS retrievals are mapped into bulk salinity and the bulk salinity data are assimilated into the GEOS iODAS system. The assimilation significantly reduces the bias and RMS observation minus forecast differences at Argo in-situ locations, especially in the tropical and Southern oceans.

The results demonstrate the complementarity of in-situ (Argo) and Aquarius SSS observations and highlight problems that arise during the assimilation of the Aquarius data.

Evaluation of the ECMWF Ensemble of Ocean Reanalyses using Assimilation Diagnostics

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A new operational global ocean reanalysis system (ORAS4) has been implemented at ECMWF, spanning 1958 to present ([1], [4]). ORAS4 consists of five ensemble members: one unperturbed member and four additional members obtained by randomly perturbing the surface wind-stress forcing, the initial conditions at the start of the reanalysis period, and the observation rejection criterion. The ensembles have been used to provide information about the uncertainty in the reanalysis but have not been used interactively to specify the background-error (bge) covariance matrix. ORAS4 has been evaluated using various metrics, including comparisons with non-assimilated observations, impact on seasonal forecast skill, and robustness of prominent climate signals ([1], [2]). Observation-space assimilation diagnostics provide an additional metric. This presentation describes results from a statistical analysis of the innovations and analysis residuals in ORAS4. The objectives of this work are to assess: 1) the quality of the model fit to the assimilated observations; 2) the statistical consistency of the bge and observation-error (obe) covariance specifications ([3]); and 3) the adequacy of the ensemble spread.

Results show that the fit to temperature and salinity data in the forecast cycle of the reanalysis is systematically improved with ORAS4 compared to a control experiment defined as an ensemble of forced simulations with no data assimilation. The specified bge variances are reasonably consistent with the diagnosed bge variances, especially for temperature, and notably are able to capture seasonal variations by using a flow-dependent parameterization in terms of the background state. The parameterized bge variances are independent of the observing network, however, and this limitation manifests itself as an increasing discrepancy between specified and diagnosed bge variances with time. The specified obe variances are generally much larger than the diagnosed obe variances for all data types (temperature and salinity profiles, as well as altimeter data), which can be mainly attributed to the deliberate inflation of the specified obe variances near continental boundaries to account for representativeness error. As expected, comparisons with ORAS4 and the control illustrate that data assimilation has a significant damping effect on the ensemble spread, particularly in the last half of the reanalysis period. Compared to the diagnosed bge standard deviations, the ensemble spread in ORAS4 is too small suggesting that variance inflation and/or improvements in the ensemble generation strategy will be necessary in order to use the ensemble perturbations effectively for defining flow-dependent bge covariances in the variational assimilation system.

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An analysis system for diurnal Sea Surface Temperature

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Diurnal variations in skin Sea Surface Temperature (SST), which can be as large as 6 degrees, play an important role in determining the heat flux between the ocean and atmosphere. At the UK Met Office we are engaged in a program to produce an analysis of the diurnal cycle of SST. This analysis will assimilate satellite measurements of SST into a diurnal model of the instantaneous skin temperature.

We present results from an analysis of the quality and coverage of the diurnal cycle by satellite SST data, both from low orbiting and geostationary satellites. Using data from the SEVIRI instrument we show the particular importance of using data from geostationary satellites in any diurnal study.

While still in the development stage, we present results from the current version of our diurnal SST analysis system. In this system we use a diurnal model based on the ECMWF's warm layer model coupled to the Artale model of the cool skin. To complete the analysis the warm layer is constrained by using a 4DVar method to assimilate available satellite data. To fully control the system the assimilation constrains not only the initial temperature, but also the applied heat and wind forcing. The system has been tested in twin experiments as the model and observation errors are adjusted; results from these tests are presented. We also present preliminary results from the system when it is tested in a global setting with realistic data.

Ocean Data Assimilation in the Indian and Pacific Oceans

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The ocean data assimilation system is developed in the Indian and Pacific oceans. An ensemble-based method is used to assimilate various types of observations including in-situ temperature and salinity profiles (MBT, XBT, ARGO, TAO, CTD and other stations), remotely-sensed sea surface temperature and altimetry sea level anomaly into the HYbrid Coordinate Ocean Model (HYCOM). The assimilation of temperature and salinity profiles is performed by a different method [Xie and Zhu, 2010]. Instead of temperature and salinity profiles, the pseudo-observations of layerthickness calculated from temperature and salinity observations are firstly assimilated to adjust model layerthickness and current fields. Then, the temperature or salinity observations are assimilated separately. The assimilation experiment is performed in the Indian and Pacific oceans. The assimilation results are evaluated by the comparison to climatology observations, independent ARGO observations, independent TAO current, drifters and tide gauge observations. The assimilation experiment shows a good agreement with observations. Additionally some comparisons with reanalysis products such as SODA, ECCO are carried out.

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Pacific Sub-tropical Cells Variability in CMCC Ocean reanalysis and SODA 2.2.6 from 1979 to 2009

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Variability of the Pacific Sub-tropical Cells (STCs) from 1979 to 2009 is analyzed in this study by using the CMCC global ocean reanalysis system (C-GLORS) and ensemble runs of Simple Ocean Data Assimilation (SODA 2.2.6). C-GLORS, which covers the period from 1979 to 2011, consists of a weekly three-dimensional variational analysis (3DVAR), followed by a 1-week integration of the Ocean General Circulation Model NEMO coupled with the LIM2 sea-ice model. The resolution of the model is 0.5 degree on the horizontal with 50 vertical levels. The atmospheric forcing is provided by the ECMWF ERA-Interim atmospheric reanalysis, with a further correction of precipitation and radiative fluxes by using the climatology of Remss/PMWC and GEWEX/SRB data, respectively. All the hydrographic data (XBT, CTD, moorings and Argo floats) and sea-level altimetric observations (1992 - onwards) are assimilated into C-GLORS.

SODA 2.2.6 covers the period from 1871 to 2009 and the ocean model is based on the Parallel Ocean Program (POP) ocean model with a horizontal resolution that is on average 0.4^{o} x 0.25^{o} and with 40 levels in the vertical. The ocean model surface boundary conditions are provided from eight ensemble members from atmospheric reanalysis 20th century reanalysis version 2 (20CRv2). SST observations from ICOADS 2.5 are assimilated using the SODA software package. Hydrographic data is not assimilated in SODA 2.2.6, but is assimilated in C-GLORS.

We calculated the transport at 9°S/9°N to analyze the interannual variability of the STC. The STCs consist of equatorial upwelling, Ekman transport, extra-tropical subduction and pycnocline transport from the subtropical to the tropical region. The change of the STC may affect tropical Pacific SST, especially ENSO variability. The correlation between transports of the STC and tropical Pacific SST is calculated. Variability of tropical Pacific wind stress, subsurface temperature and the equatorial undercurrent (EUC) are also analyzed to help understand the change of the STC. The comparison of the variability of the STC between C-GLORS and SODA 2.2.6 is conducted in order to verify the influence of different assimilation schemes, atmospheric forcing and the impact of hydrographic data versus SST only.

4D-LETKF Data Assimilation in a WAVEWATCH III® Wave Model Ensemble

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Challenges in wave data assimilation into models are diverse. The evolution of wave energy spectra under wind forcing quickly loses memory of initial conditions [1]. The aim of this work is to build a system that efficiently performs a wave height assimilation cycle in a global wave model ensemble, including the joint use of wave and wind observations, and an improved sea surface wind analysis. The most widely available wave data provide a measure of total energy. Global data coverage is provided by satellite altimeters, which small number and lack of swath conspire against an even spatial distribution. We explore here how flow-dependent uncertainties contribute to overcome this drawback. Conventional wave observations from buoys are usually too near the coast to be relevant in global assimilation. They are used here as an independent source of information for validation.

The NOAA/NCEP GEFS fields drive a global WAVEWATCH III© [2] wave model ensemble. We get observed significant wave heights from satellite altimeters on Jason 1 and Jason 2 and vector winds from the ASCAT scatterometer on MetOp-A. A 4D-LETKF assimilation system based on T. Miyoshi's code [3] produces analyzed significant wave height and surface wind fields. The latter enhance the driving wind fields in the wave hindcasts, while the significant wave height analyses scale the initial wave energy spectra in the wave model, with no further considerations.

We developed an object-oriented system to handle observations, which main skill is to easily add new sources of data. Following current trends, we worked with phyton, an updated and versatile language, with friendly graphics, date management, encoding/decoding libraries (matplotlib, matplotlib.basemap, datetime, netcdf4-python). We succeeded in implementing an efficient and feasible in computing time, wave data assimilation system.

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Using Ocean Data Assimilation for Observing System Studies with a Focus on the Tropical Pacific

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Data assimilation systems provide a mechanism for evaluating the impact of observing systems for specialized applications, such as weather or climate forecasts. Typically, this is done through data denial experiments. Here we use the Goddard Earth Observing System integrated Ocean Data Assimilation System (GEOS iODAS) to study the impact of ocean observing systems in the tropical Pacific. In particular, the experiments consider the relative impact of TAO and Argo on estimates of temperature and salinity across the equatorial Pacific. Three experiments are conducted from 1993-2012, all assimilating sea-surface temperature (SST) and sea-level anomaly (SLA) data, but with perturbations in the use of TAO and Argo:

1. EXP_Argo (assimilating Argo or synthetic Argo data, but not TAO).
2. EXP_TAO (assimilating TAO data, but not Argo)
3. EXP_ALL (assimilating TAO, Argo, and other in-situ data)

Whereas the three analyses are very close in terms of heat and salt content in the upper 300 m, significant differences are evident in the thermocline region. Differences are largest in the eastern Pacific where the mean difference reaches ~ 1°C and RMS differences are up to ~ 1.5 °C at about 100 m at 125°W. In comparison with TAO temperature data at that location and depth, the analysis from experiment EXP_Argo (EXP-TAO) has an RMS difference of 2.9°C (2.0°C) and correlation of 0.75 (0.78). We will present a comparison and evaluation of the different experiments as well as their impacts on seasonal-to-interannual forecasts using the GMAO GEOS-5 Forecasting System.

Assimilating NOAA's SST data and *in situ* T, S profiles into BSH operational circulation model for the North and Baltic Seas

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The operational circulation model of the German Federal Maritime and Hydrographic Agency (BSH) has been augmented by a data assimilation (DA) system in order to improve the hydrography forecast of the North and Baltic Seas. The DA system has been developed based on the Singular Evolution Interpolated Kalman (SEIK) filter algorithm [1] coded within the Parallel Data Assimilation Framework [2], [3].

The quality of the forecast has been previously improved by assimilating sea surface temperature (SST) measurements obtained with the Advanced Very High Resolution Radiometer (AVHRR) aboard polar orbiting NOAA's satellites [4]. We investigate possible further improvements using *in situ* observational temperature and salinity data: MARNET time series and CTD and Scanfish measurements. The study addresses the problem of the local SEIK analysis accounting for the data within a certain radius. The localisation radius is considered spatially variable and dependent on the system local dynamics. As such, we define the radius of the data influence based on the energy superposition of the baroclinic and barotropic flows.

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A Variational Data Assimilation Algorithm to Estimate Salinity in the Berre Lagoon with Telemac3D

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The Berre lagoon is a receptacle of 1000Mm3 where salty water from the Mediterranean Sea meets fresh water discharged by the hydroelectric plant at Saint-Chamas and by natural tributaries (Arc and Touloubre rivers). The Laboratoire National d'Hydraulique et d'Environnement (LNHE) aims at optimizing the operation of the hydroelectric production while preserving the lagoon ecosystem. To achieve this objective, improving the quality of the simulation and more specifically the description of the salinity state are essential. The hydrodynamics of the lagoon is modelled with a 3D resolution of the shallow water equations using the TELEMAC software (http://www.telemac.org) developed at Electricité De France (EDF R&D). In collaboration with CERFACS, a data assimilation (DA) algorithm is being implemented, using the Open-Palm coupler, to exploit continuous (every 15 min) in-situ salinity measurements at four locations in the lagoon. Preliminary studies were carried out to quantify the difference between a reference simulation and the observations on a test period. It was shown that the model is able to represent reasonably well the evolution of the salinity field at the observing stations, given some adjustments on the observed forcing near Caronte. Nevertheless, discrepancies up to several g/l remain and could be corrected with the DA algorithm.

Similarly to the meteorological and oceanographic approaches, the observations are used sequentially to update the hydrodynamic state. More specifically, a 3D-FGAT algorithm is used to correct the salinity state. This variational assimilation algorithm relies on the hypothesis that corrections to the model state are approximately constant over a chosen time window. Sensitivity experiments show that in order to cope with this constraint, the analysis time window should be at most 3h. As the number of observations over an assimilation window is significantly smaller than the size of the model state vector (70,000 cells approximately), the minimization is performed in a space spanned by vectors of the size of the observation vector. This allows us to reduce both memory usage and computational cost [1]. An inhomogeneous and anisotropic formulation of the background error covariance matrix for salinity is modelled using a diffusion operator [2] using a stochastic estimate of the horizontal and vertical correlation length scales. Preliminary results from the 3D-FGAT system will be presented and the impact of the sequential salinity correction on the model forecast will be quantified.

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Development of a high-resolution coastal forecasting system with a 4DVAR assimilation scheme

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We have been developing a high-resolution coastal forecasting system with a horizontal resolution of about 2km, which aims to be a next generation coastal forecasting system in Japan Meteorological Agency (JMA). The coastal model (model-CST) covers western part of the Japanese coastal region and is nested into a western North Pacific model (model-WNP) with a horizontal resolution of 10km. Initialization of the model-CST is performed by Incremental Analysis Updates (IAU) using assimilated fields of the model-WNP.

A Four-Dimensional Variational (4DVAR) scheme is employed for the assimilation system with the model-WNP. In this scheme, amplitudes of vertical coupled Temperature and Salinity (T-S) EOF modes are used as control variables, which compose the vertical correlation matrix of the background errors. This method is based on the same strategy as that used in the present operational 3DVAR assimilation system in JMA. In addition, the 4DVAR system adopts the IAU scheme for initializing the forward model in order to filter out high-frequency noises. Because the IAU scheme works as an Incremental Digital Filtering (IDF) during backward integration of the adjoint model, high frequency noises in the adjoint variables can also be filtered out.

In the presentation, improvements in assimilation results using the 4DVAR scheme and their impacts on coastal sea level variability will be shown.

SST data assimilation in the UK Met Office's shelf sea models.

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The UK Met Office has two operational shelf seas models, the AMM7 model of the north west European shelf and the PGM4 model of the Persian gulf. In recent years we have begun to assimilate Sea Surface Temperature data into these models, and have witnessed a corresponding reduction in Temperature errors. Recently we have updated the data assimilation system used in the shelf sea models from an old analysis correction scheme to a new 3D-Var system that uses the NEMOVAR assimilation code. This poster presents the results from this upgrade

Our data assimilation system ingests observations from in-situ sources and the NOAA-AVHRR, METOP-AVHRR, TMI (PGM4 only) and SEVIRI satellite instruments; historically we have also used data from AMSR-E and AATSR. A 3DVar technique is used to calculate increments to the models surface temperature, which are then applied down to the base of the instantaneous mixed layer. Details of the method are given in this poster, with particular focus given to recent improvements in the data assimilation system. These improvements include the switch to 3DVar and also new error covariance specifications. In particular we present results from recent investigations into parameterising error covariances based upon the daily model state.

We present results showing the impact that our assimilation system has on the SST errors in hindcasts from both the PGM4 and AMM7 models. In both runs RMS and mean SST errors in one day forecasts are reduced. Impacts on other model parameters are also discussed.

Data Assimilation Experiments using the Back and Forth Nudging and NEMO OGCM

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We present Data Assimilation experiments under the OSSE framework using NEMO ocean model and the Back and Forth Nudging (BFN). This algorithm consists in initially solving the forward equations with a nudging term (forcing term proportional to the difference between the model state and the observations), and then, using the final state as an initial condition, in solving the same equations in a backward direction with a feedback term (with the opposite sign compared to the feedback term of forward nudging). This process is then repeated iteratively until convergence. The implementation of the BFN algorithm has been shown to be very easy, and its convergence very fast, compared to other data assimilation methods [1].

However, several theoretical and numerical studies showed that it was difficult to deal with diffusion processes during backward integrations, leading to instabilities or explosion of the numerical solutions [2]. We propose here an improved Back and Forth Nudging algorithm in the context of meteorology and oceanography. In these applications, the theoretical equations are usually diffusive free, or diffusion is small (e.g. Euler's equation for meteorological processes). But then, in a numerical framework, a diffusive term is often added to the equations (or a diffusive scheme is used), in order to both stabilize the numerical integration of the equations, and take into consideration some subscale phenomena. In such situations, it is physically coherent to change the sign of the diffusion term in the backward integrations, in order to keep the stabilizing role of the diffusion term in both directions in time.

In our experiments on NEMO, two sets of observations are used: either sea-surface height at all grid points and available every day or sea-surface height taken at the satellite (Jason-1) track. We compare the BFN results with results obtained using the NEMOVAR system (4D-Var). Also we tested a "hybrid" method which combines the iterative character of the BFN with a correction step similar to the one used in Kalman Filters (KF). In this case, the resulting algorithm can be seen as a smoother, as long as we use future observations to estimate the initial condition of the system [3].

Our results show that in the case of experiments using sea surface height observations at all grid points, the BFN converges after 10 iterations and performs better than the 4D-Var, when we considered the same computational power for both methods. When we allowed the 4D-Var to do a hundred iterations it performed better in the sense of the mean squared error, but with a cost about one hundred times larger than the BFN cost. Under a more realistic observation network, the performances of both algorithms are close, but the computation cost of BFN is much smaller. The results produced by the hybrid BFN-KF will be compared with the 4D-Var and a smoother.

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The Representer Method: Theory and Applications to Ocean Data Assimilation

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The representer method is a data assimilation or generalized inverse technique that allows both strong and weak constraints formulations and minimizes the cost function in observations space. This is particularly suitable to ocean data assimilation where observations are sparse and regional models, especially in coastal applications, suffer from significant error levels in atmospheric forcing fields due to poor resolution of the atmospheric models. The theoretical background will be presented, as well as numerical results from applications with the Navy coastal ocean model.

Impact of non-linearities on an incremental 4D-VAR data assimilation method in a high resolution numerical ocean model

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A current stake for numerical ocean models is to adequately represent meso- and small-scale activity, in order to simulate its crucial role in the general ocean circulation and energy budget. It is therefore also a challenge for data assimilation (DA) methods to control these scales. However this small-scale activity is strongly linked to the nonlinear character of the flow, whereas DA methods are generally much less efficient in such contexts than in (almost) linear ones.

The purpose of this poster is to address this problem specifically, by exploring the behavior of an incremental 4D-VAR DA method in a non-linear ocean model, based on NEMO and NEMOVAR modeling frameworks. A series of experiments assimilating simulated altimeter data in an idealized Gulf Stream-like configuration of the NEMO model at increasing resolutions (which is a proxy for increasing nonlinearity) are analyzed.

We present in particular results characterizing scales and structures of the analysis error along the assimilation process, as well as tentative links with small scale activity. In order to study qualitatively and quantitatively the convergence of the algorithm and the structure of analysis and forecast errors, a wide spectrum of diagnostics has been employed: classical spatial and temporal RMSE, cost function characteristics, projection of error fields on model EOFs, characterization of the validity of the tangent linear hypothesis, etc.

In our experiments, it appears that the incremental 4DVAR algorithm is mainly sensitive to two factors: the length of the assimilation window and the number of inner loops during the minimization process. If both parameters are overestimated, increments produced by the DA algorithm are of excessive amplitude, which leads to the degradation of the validity of the linear tangent hypothesis. An optimally tuned eddy-permitting experiment, with two-month assimilation windows, is presented, which gives quite good results in terms of analysis and forecast error reduction.

Moreover we investigate some particular strategies for DA in such nonlinear contexts, with the aim of reducing the analysis and forecast errors. First we present the performance of quasi-static incremental 4DVAR for improving the algorithm convergence for long assimilation windows. Second we present preliminary experiments on observations filtering techniques based on model characteristics (*e.g.* EOF), to take into account the representativeness error in our DA process.