Data Assimilation and Ocean Data Quality Control Upgrades in SWAFS

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LONG-TERM GOALS

The goal of this project is to improve the forecast performance of shallow-water and limited-area ocean forecast systems through improvement in ocean data analysis and assimilation techniques.

OBJECTIVES

The Shallow Water Analysis and Forecast System (SWAFS) is the operational ocean nowcast/forecast system at the Naval Oceanographic Office (NAVOCEANO). The objective of this project is to improve the forecast skill of SWAFS by integrating into the NAVOCEANO system the ocean data assimilation component developed for the Coupled Ocean Atmosphere Mesoscale Prediction System (COAMPS). The ocean data quality control, analysis, and assimilation components of SWAFS will be upgraded.

APPROACH

SWAFS is an operational nowcast/forecast system used at NAVOCEANO for predicting the three-dimensional current and thermohaline structure of the ocean. Presently, SWAFS produces forecasts for sixteen areas including the Persian Gulf, Arabian Sea, Mediterranean Sea, and Baltic. The modeling system uses a 3D primitive equation numerical circulation model as its dynamical core. The model is an upgraded version of the Princeton Ocean Model that has been converted to MPI code, has updated code for correction of the error from the pressure gradient truncation, and includes Lagrangian trajectory simulation companion codes. SWAFS routinely applies tidal forcing, in addition to using Navy forecasts of surface winds, air temperature, and vapor pressure to calculate air-sea momentum and thermal fluxes.

The ocean data assimilation package developed for COAMPS (NCODA) improves on the univariate optimum interpolation (OI) approach currently used in SWAFS with a fully multivariate, three-dimensional OI ocean data analysis capability (3DMVOI). The NCODA and accompanying data quality control software use operationally available data types to produce 3D analyses of temperature,

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salinity, geopotential, and u-v velocity components. MODAS synthetic profiles can also be included in the NCODA analysis. The synthetic profiles are generated in areas where the measured changes in sea surface height anomaly (SSHA) from the background field are considered significant. The NCODA analysis code can be cycled on itself, when it uses a previous analysis for the background, or it can be cycled with a dynamical model and use a model forecast as the first guess field.

3DMVOI has several distinct advantages to the more traditional univariate 2D OI analysis systems. The fully three-dimensional analysis permits direct assimilation of single level point or threaded data, such as observations from AUVs or SSTs, which cannot be easily interpolated to the analysis depths. In addition, the multivariate method allows adjustments to the ocean mass field to be correlated with adjustments to the ocean current field, thereby providing balanced initial conditions for the ocean forecast model. An ocean data quality control (QC) system has been developed as an integral part of NCODA. As the analysis capability is extended to assimilate multiple variable types from a number of different sources, new QC techniques must be developed for those observations. The QC system can be customized for the SWAFS data flow with a look forward to new data streams that are coming on line (e.g., microwave SSTs).

The expected improvements from the NCODA upgrade to the SWAFS data assimilation component are the following:

1) allows the use of in situ surface observations (ships, fixed and drifting buoys) in the SWAFS SST analysis;
2) provides full-depth temperature and salinity analyses performed in 3D with velocity increments consistent with the mass field updates;
3) improves the diagnostic information on the performance of the analysis and of the forecast model;
4) permits users to adjust the performance of the analysis with simple changes via namelist variables;
5) improves the quality control of the ocean observations assimilated in SWAFS.

To achieve these improvements, the following technical approach is being implemented.

Implement developmental copy of SWAFS and synchronize configuration management: The initial beta system is the operational Northwest Pacific SWAFS nest. The beta system runs on the same NAVOCEANO MSRC platform using observational data from the QC system, and boundary condition and forcing fields archived from the operational run. The system will be extended to additional SWAFS areas in the third year.

Develop diagnostic and validation tools: Tools for validating the skill of the SWAFS model and for evaluating the quality of the analysis are being developed with a goal towards establishing the accuracy of the forecasts issued from the analysis. Measures of forecast skill include case-by-case and statistical comparisons with observations not yet assimilated, bulk statistics that measure improvements over persistence for the data used in the analysis (e.g., RMS error, correlation), and subjective evaluations of whether the forecasts are physically reasonable. The forecast skill estimates will also include data types not used in the analysis, for example special data collected by NAVO as available, and comparison of simulated drifter tracks with drifting buoy positions.

Evaluate the operational system: A key ingredient to the success of a 3DMVOI analysis is proper specification of the various statistical input parameters that are required a priori by the technique. It is expected that the prior statistical parameters will be both region and time dependent, and perhaps depth

dependent. Horizontal and vertical correlation length scales will be calculated from a time history of the innovations (observation-minus-forecast) using the innovation correlation method. This method also provides domain-averaged estimates of the observation and forecast error variances. The consistency of the error variances with the innovations will be checked using an a posteriori chi-square test. The chi square test will indicate if the prescribed error covariances in a region, or for a given observing system, are very different from what has been assumed. This technique avoids the use of ad hoc methods in the evaluation of the priors used in NCODA. Finally, the spatial correlation of the residuals (observation-minus-analysis) will be computed. Any positive spatial correlation remaining at spatial lags greater than zero represents information that has not been extracted by the analysis.

Install the QC system: The ocean data QC routines have been installed on NAVOCEANO MSRC computers. NAVOCEANO operational data feeds for the QC have been established for all primary ocean data sources, including in situ and remotely sensed observations. The NCODA QC uses static (GDEM) and dynamic (MODAS) climatologies as well as previous analysis and forecast fields to determine the validity of the data. A 2D global NCODA analysis of surface temperature and sea ice concentration is run daily to support the QC system. The QC system updates the observation data files that are in turn read by the NCODA software.

Optimize the data assimilation method: An incremental updating technique will be implemented as one potential approach to SWAFS ocean data assimilation. This technique has been applied successfully in regional NCOM and global POP model runs at NRL Monterey. A second approach will use the existing SWAFS relaxation technique. Here, model mass fields are nudged towards the analysis value, thereby allowing the velocity fields to adjust as to any other forcing term. The relaxation time scale is an adjustable parameter. In SWAFS, it is a function of the expected error of the analysis and the depth. The degree to which model characteristics determine the success of the incremental updating technique is not known; consequently the SWAFS/NCODA system will be evaluated using both methods.

WORK COMPLETED

The NCODA analysis - derived from serial/vector code – was designed to take advantage of shared memory parallelization techniques using Cray/SGI/OpenMP directives. In order to support the grid sizes used in the SWAFS nests, on existing and planned NAVOCEANO computational resources, a major restructuring of the analysis code was undertaken. First, the analysis code was divided into preprocessing, analysis, and post-processing steps. Next, the analysis step – the core of the analysis and the more computationally demanding portion - was coded to use message-passing techniques (MPI) suitable for the distributed-memory platforms available for SWAFS operational use at NAVOCEANO MSRC. The pre- and post-processing steps can still take advantage of shared-memory parallelization as available. This code has been installed and tested on the large IBM SP4 at NAVOCEANO, which is the platform used for the largest SWAFS nests. The system scripts/code to perform analysis/forecast cycles with the western North Pacific SWAFS and the NCODA analysis have been developed on the NRLMRY development platform, and are being tested on the NAVOCEANO platform. The analysis and QC codes have been installed and tested at NAVOCEANO, and operational data streams are being processed through the QC system in real time. In addition, several coordination meetings have been held with NAVOCEANO personnel to discuss project plans and progress. In particular, the validation test plan is being developed in close communication with NAVOCEANO to ensure a successful transition. NAVOCEANO has requested that the validation test be completed by 2QFY04.

RESULTS

We continue to archive SWAFS operational model output for use in model evaluation and comparison, and update weekly composite SST forecast statistics validated against MCSST observations for several of the SWAFS domains. The ocean data QC process is being executed daily at NAVOCEANO, and QC results are being monitored to verify that the data streams are being processed correctly (Fig. 1). The MPI version of analysis code has been tested on the target platform at the NAVOCEANO MSRC and produces results identical to those obtained on the developmental platform ay NRLMRY (Fig. 2).

IMPACT/APPLICATIONS

The results of this effort will affect most directly the operational SWAFS system, but advances in the data analysis 3D MVOI methodology and the data assimilation techniques will apply to other nowcast forecast systems under development. In addition, the analysis and forecast diagnostics developed as part of this project can be applied to other analysis systems at NRL SSC and NAVOCEANO.
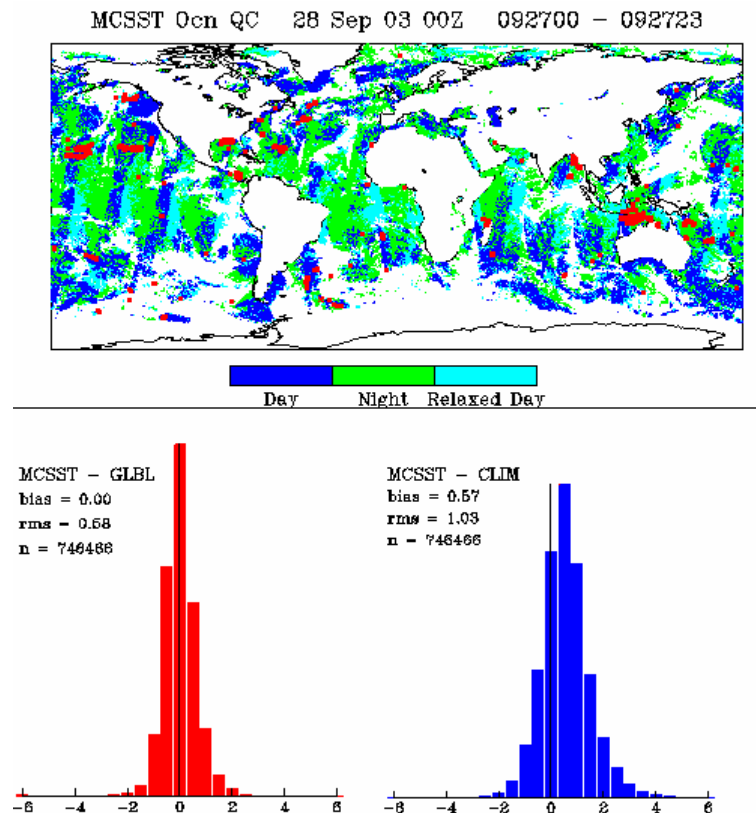
Figure 1. An example of the ocean data quality control process for multi-channel sea surface temperature (MCSST) observations taken 28 Sep 2003. The upper panel shows the spatial distribution of observations by type (day, night, and relaxed day) with suspect observations indicated by red points. The lower panel shows the histogram distribution of the observed deviations from the 00Z 27 Sep 2003 SST analysis (left) and climatological SST (right).
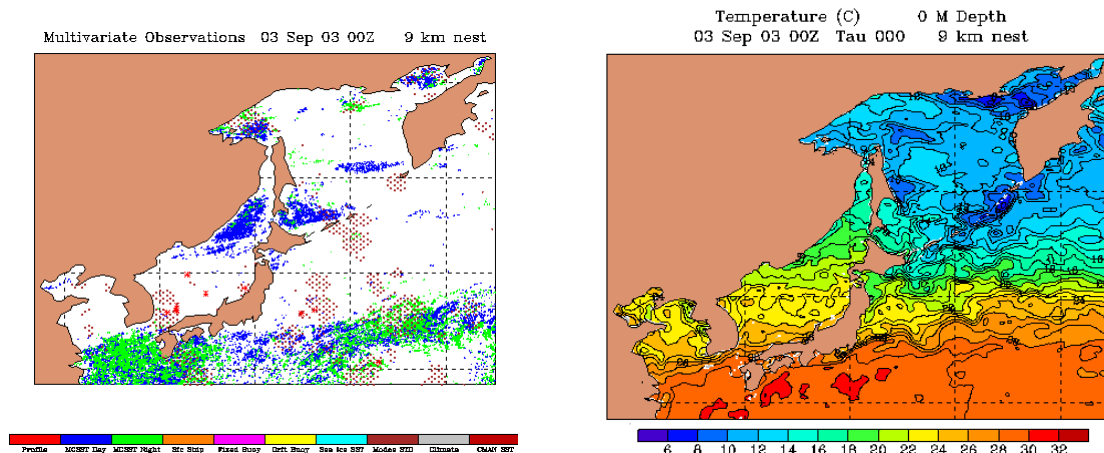
Figure 2. (left panel) The spatial distribution of observations used in the new MPI-version NCODA PACNEST 3D MVOI temperature analysis for 00 UTC 03 Sep 2003, at day 64 of an analysis-only cycle. The MODAS synthetic profiles used as observations are generated in areas where a significant surface height anomaly change is detected. (right panel) The resulting temperature analysis at 0 m depth.

TRANSITIONS

Under SPAWAR co-sponsorship of this project, the upgraded SWAFS system will be transitioned for use at NAVOCEANO, where it will continue to be the operational regional and limited-area ocean nowcast/forecast system. The transition products include the ocean data QC code, the upgraded SWAFS code with the NCODA, diagnostic software, and documentation. The ocean data quality control software will have broad application to other analysis and forecast systems at NAVOCEANO. The results from optimizing the data assimilation method will be of interest to the global and regional NCOM developers.

RELATED PROJECTS

This work is related to the ocean analysis development for COAMPS (ONR 6.2 and SPAWAR 6.4), MODAS Improvements (ONR 6.2), and global NCOM development (SPAWAR 6.4) efforts.