# Enhanced Ocean Climate Products from NCEP

David W. Behringer PI, Hendrik Tolman co-PI
NOAA National Weather Service NCWP, College Park, MD

## Table of Contents

1. Project Summary ..... 1
2. Scientific and Observing System Accomplishments ..... 2
3. Outreach and Education ..... 5
4. Publications and Reports ..... 5
   4.1. Publications by Principal Investigators ..... 5

## 1. Project Summary

The Global Ocean Data Assimilation System (GODAS) at the National Centers for Environmental Prediction (NCEP) uses a statistics based algorithm to combine a numerical ocean model with ocean observations to provide a global estimate of the ocean state (the three dimensional fields of temperature, salinity, velocity, plus sea surface height). In effect, the GODAS uses the model ocean dynamics to interpolate in time and space between the locations of individual observations and to compute those parts of the ocean state that may not be directly observed. For example, there are currently many more observations of temperature and salinity in the ocean than there are of velocity. Assimilation of these data adjusts the model temperature and salinity fields to be in accord with the observations (within specified statistical bounds) and the model then computes a velocity field in balance with the distribution of mass established by the temperature and salinity. The GODAS assimilates temperature profile observations from eXpendable BathyThermographs (XBTs), fixed moorings, and autonomous Argo floats, salinity profiles from Argo floats and synthetic salinity profiles from temperature observations and the observed correlation between temperature and salinity, and sea surface altimetry observations from TOPEX/Poseidon, Jason-1 and Jason-2 satellite missions. NASA's Aquarius instrument was successfully launched in June, 2011, and a "first look" image of the global sea surface salinity has been released. These data look very promising and we expect to begin experimenting with them as well as the SMOS data soon. Tide gauge and velocity observations are reserved for validation.

The work covered by this project is the construction, maintenance and development of the NCEP GODAS. The GODAS uses the Modular Ocean Model (MOM) developed over the last several decades at NOAA's Geophysical Fluid Dynamic Laboratory (GFDL). The current uncoupled operational GODAS uses the MOM version 3 (GODAS/MOM3), while the new version of the GODAS incorporated into version 2 of the operational coupled Climate Forecast System (CFSv2) uses the MOM version 4 (GODAS/MOM4). The assimilation algorithm is a sequential 3-Dimensional Variational (3DVAR) method that estimates the ocean state through minimization of a cost function that balances statistically weighted contributions from the model and from the observations. The original purpose of the GODAS was to provide initial conditions for the ocean component of the coupled CFS used for operational seasonal to interannual (S-I) prediction At

NCEP. S-I prediction has a well-established social benefit and it remains the primary rationale for the maintenance and further development of the GODAS. The GODAS has a second important use as a means for monitoring the changing ocean state, which derives from its operational, near real-time, 3D synthesis of global ocean observations. Within NCEP the CFSv2 and the GODAS are fundamental tools used by the Climate Prediction Center (CPC) to prepare the official seasonal outlooks disseminated by the National Weather Service. Internationally the GODAS is an established member of an ensemble of ocean analyses produced by governmental and academic institutions worldwide that provides researchers with the means to study the evolution of the ocean state over past decades, including a measure of the uncertainty associated with the observed evolution.

NCEP/CFC maintains an interactive web site (http://www.cpc.ncep.noaa.gov/products/GODAS/) that allows the visitor to view GODAS output in a variety of ways. The same site provides links for acquiring the GODAS output data.

## 2. Scientific and Observing System Accomplishments

As stated above ocean state estimation is fundamental to forecasting and monitoring climate variability. Maintaining and improving GODAS at NCEP is a top priority.

The main task during this past year has been the porting of operational codes to NCEP's next generation of super computer and ensuring their stable performance in operations. With regard to GODAS this has meant transitioning the uncoupled GODAS/MOM3 and the version of GODAS/MOM4 that provides ocean initial conditions to the CFSv2. While both computers are IBM products, the change in the underlying architecture is significant, from a system based on the IBM proprietary Power 6 processor to one based on the Intel Sandy Bridge processor. This work has, consequently, taken up most of our time and effort during this past year. We are now at the stage of monitoring the performance of GODAS and CFSv2 on the new system and we believe we are ready for the day when the current system is switched off later this summer. The transition between computers has meant that operational applications are frozen for the duration. For that reason an upgrade to the uncoupled GODAS/MOM3 remains on hold. Nevertheless we have moved forward with other projects.

In collaboration with Arun Kumar's group in the Climate Prediction Center (CPC) we are working on an OSE experiment to evaluate the impact of profile observing systems on seasonal forecasts made with the coupled ocean-atmosphere model used in the CFS. The experiments are being conducted for the years 2000-2012. The initial set of experiments include a control that assimilates no data, an experiment that assimilates "all" profile data (TAO, PIRATA, RAMA, Argo and XBTs), another that omits only the Argo data, and the last that omits only the tropical moorings (TAO, PIRATA and RAMA). The analyses that provide the ocean initialization for the forecasts with the CFS have been completed. Jason-X SSH has not been assimilated in these experiments, so as a validation of the experiments, Figure 1 shows the RMS of the difference between the GODAS SSH and the JASON-X SSH expressed as a percentage of the RMS of the JASON-X SSH. In each panel the RMS difference is less than 50% within the gray area and less than 30% within the contour lines. In the top panel GODAS assimilates all of the profile observations, in the middle panel the Argo profiles are excluded and in the bottom panel the

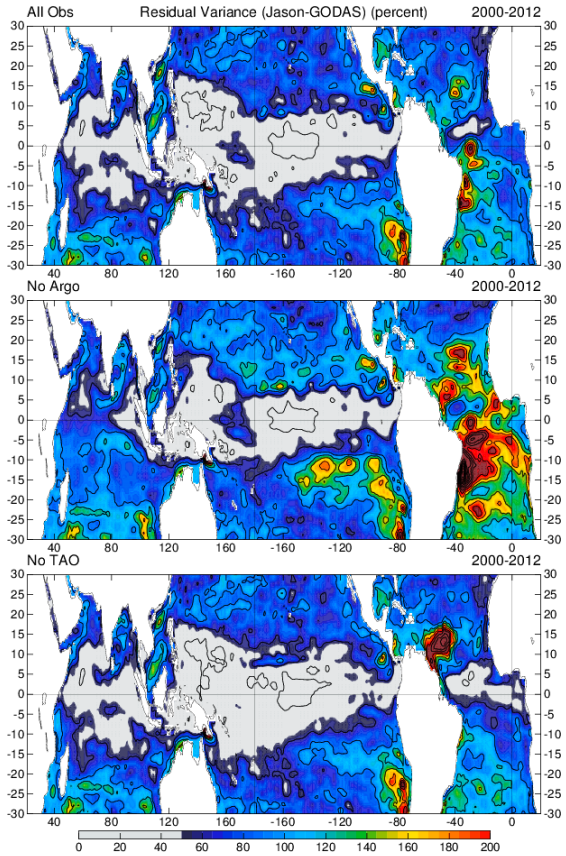


Figure 1. SSH RMS (GODAS-Jason) shown as a percentage of RMS (Jason). Top:All Obs, Mid: No Argo, Bot.: No Moorings

As illustrated by the examples given here, the sensitivity of GODAS to gross changes in the date set being assimilated is significant. The sensitivity of the CFS to these changes will be known when forecasts, currently being run by Arun Kumar's group, are completed.

These experiments should be regarded as preliminary in that entire data sets are removed for each denial experiment. The goal here is to establish the baseline sensitivity for each of the systems, i.e. are the forecast systems sensitive enough to detect the loss of an entire subset of the observing system. If such is the case, subsequent experiments will explore the impact of losing more limited parts of the observing system.

The conclusions which can be drawn from an OSE which has been done with a particular analysis/forecast system will be, to a greater or lesser extent, specific to that system. To mitigate TAO and other tropical moorings are excluded. Comparing the three panels, it is clear that Argo is responsible for reducing the SSH error outside of the equatorial Pacific, most notably in the Atlantic and Indian Oceans. In all of the panels the largest errors in the GODAS SSH occur off the NE, SE and SW coasts of South America. This is particularly evident in the middle panel where the Argo data is not assimilated.

Figure 2 shows time-series of GODAS temperature minus TAO temperature at 110$^{o}$W. The top panel in which GODAS assimilates all profiles and the middle panel in which Argo is excluded are most similar. Without Argo the GODAS experiences only a slight loss of accuracy. The bottom panel in which GODAS does not assimilate TAO, the loss of accuracy in GODAS greatest as would be expected. However, it is interesting that, beginning in 2006 as the number of Argo profiles available to GODAS increases, the error in GODAS sharply decreases. The same effect is seen at 95$^{o}$W and to a lesser extent at 125$^{o}$W (not shown), but it is not seen farther to the west.

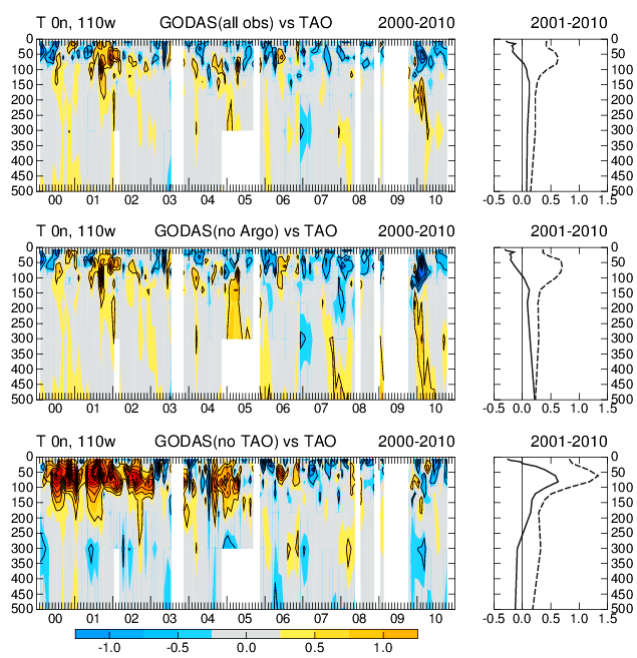


Figure 2. Temperature (GODAS-TAO) on the equator at 110W, Top:All Obs, Mid: No Argo, Bot.: No Moorings. At right: Mean: solid and RMS: dashed

that shortcoming a little bit, we are conducting the project in collaboration with researchers from GFDL who are performing the same experiments with their own analogous forecast system.

We have also begun to develop the code to evaluate routinely the impact of observations on the GODAS analysis. The basic idea is illustrated by the schematic in Figure 3. The model trajectory, $X_b$, is initialized by an analysis at time t=-20 days. A second analysis is done at t=-10 days, with the available assimilation observations and $X_b$ as the forecast or first guess. The new analysis is used to initialize a second trajectory, $X_a$, while $X_b$ continues without being re-initialized. At t=0 an evaluation of the $X_a$ and $X_b$ forecast errors are done against the validation data, $X_0$. Any difference in the forecast errors, $\varepsilon_a$ and $\varepsilon_b$, will be solely due to the set of observations assimilated at t=-10 days. A test experiment was done for January 2006 using GODAS/MOM4 at $1/2^o$ resolution (increasing to $1/4^o$ in the meridional direction at the equator) and forced by fluxes from NCEP's Reanalysis 2. The profiles that are assimilated are drawn from a window extending 5 days on either side of the analysis date. The trajectory, $X_b$, was initialized on January 11, and $X_a$ was initialized on January 12; the validation was done on January 31. Figure 4 shows the reduction in the forecast error in the average temperature of the upper 300 m of $X_a$ due to observations assimilated on January 21. The validation was made against the analysis for January 31. Figure 5 shows another measure of the reduction in the forecast error for T300 in $X_a$, but in this case the validation was done against the profile data from the window around January 31. The pattern is similar to that in Figure 4 because most of the observations come from fixed moorings and Argo floats which don't travel far over ten day intervals. Where the patterns differ, for example, in the tropical Atlantic or off the southwest corner of Australia, it is due to segments of XBT transects present in the observations centered on January 21, but absent from those centered on January 31. The negative (blue) values in these figures suggest that in this short test the assimilated observations have almost everywhere reduced the forecast error in the model. If positive values persisted over time, it could indicate a problem with the model or a faulty observing platform not caught by the QC. We will automate this analysis so that it can be included in the operational GODAS. We

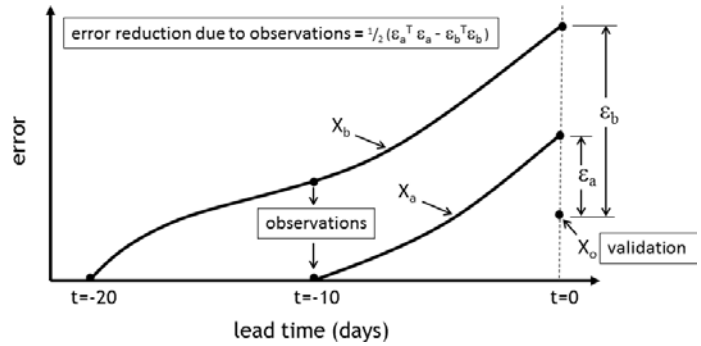


Figure 3. A schematic of a method to evaluate observation impacts.

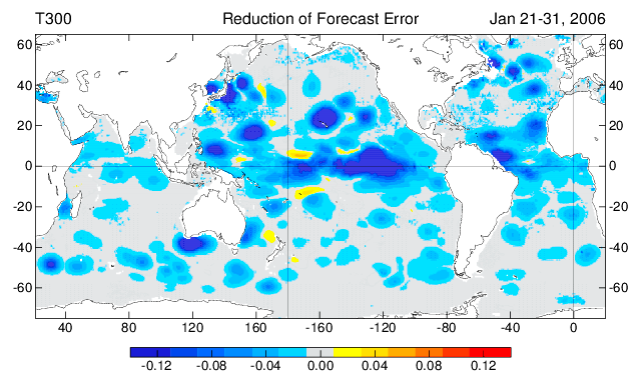


Figure 4. Reduction of forecast error in temperature averaged over the top 300m as validated against subsequent analysis.

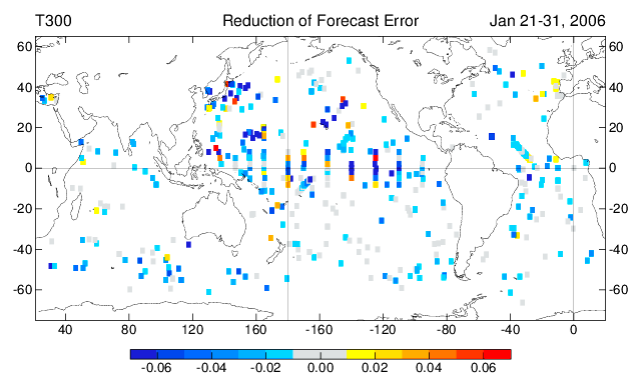


Figure 5. Reduction of forecast error in temperature averaged over the top 300m as validated against profile observations.

will also extend the analysis with an adaption of the method of Langland and Baker (Tellus, 2004) to evaluate the contribution of individual platforms in reducing the forecast error. The result of that analysis would look somewhat like Figure 5, but the reductions would be everywhere weighted by the model's sensitivity to changes in the observations.

A basic part of maintaining operational data assimilation systems is incorporating new observations as they become available. Satellite sea surface salinity (SSS) in from SMOS and Aquarius are current examples and we are continuing work on preparations to assimilate them into GODAS. We are currently working with monthly averaged, gridded level 3 (L3) SSS data from SMOS and Aquarius. These data are research products and at this stage we are using them for development purposes only. Before using these data in GODAS it is necessary to understand fully differences between them and near surface in situ observations from Argo.

## 3. Outreach and Education

The outreach associated with the GODAS takes the form of an interactive, public web page (http://www.cpc.ncep.noaa.gov/products/GODAS/) developed and maintained by NCEP's Climate Prediction Center. Users can select views of the GODAS analyses with interactive tools available on the site. The site also provides links for downloading the data.

Data from the CFSR is available at http://nomads.ncdc.noaa.gov/

## 4. Publications and Reports

### *4.1. Publications by Principal Investigators*

Ravichandran, M., D. Behringer, S. Sivareddy, M. S. Girishkumar, Neethu Chacko, and R. Harikumar, 2012: Evaluation of the Global Ocean Data Assimilation System at INCOIS: The Tropical Indian Ocean. *Ocean Modeling*, (in press)

Saha, S., S. Moorthi, X. Wu, J. Wang, S. Nadiga, P. Tripp, D. Behringer, Y. T. Hou, H. Chuang, M. Iredell, M. Ek, J. Meng, R. Yang, M. Peña Mendez, H. van den Dool, Q. Zhang, W. Wang, M. Chenand, and E. Becker, 2013: The NCEP Climate Forecast System Version 2. *J. Climate* (accepted)