Enhanced Ocean Climate Products from NCEP

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1. Abstract

The Global Ocean Data Assimilation System (GODAS) combines global ocean observations with a numerical ocean model to produce an estimate of the ocean state. The operational version of the GODAS is used to initialize the ocean component of the coupled Climate Forecast System (CFS) used for seasonal to interannual prediction at NCEP. The GODAS analyses are also a means for monitoring the state of the ocean climate. In FY2008 a new version of the GODAS was developed, incorporating GFDL's Modular Ocean Model, version 4. In FY2009 a 30-year (1979-2008) analysis was completed and used for validating the performance of the new version of the GODAS. The new GODAS-M4 was also part of the new CFS Reanalysis (CFSR) in FY2009.

2. 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 (fully three dimensional fields of temperature, salinity, velocity, and 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 from Argo floats and synthetic salinity 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. 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 operational GODAS uses the MOM version 3, while the current developmental GODAS uses the MOM version 4. 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 Climate Forecast System (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. The Climate Prediction Center (CPC) of NCEP 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.

3. Scientific Accomplishments

In FY2008 we completed the conversion of the GODAS to MOMv4 and we reported on its implementation as part of the CFS Reanalysis and Reforecast (CFSRR). The reanalysis portion of that effort was completed in FY2009 and is currently being analyzed. Also in FY2009 we completed a stand-alone 29 year reanalysis using the GODAS-M4 forced by surface flux fields from the NCEP-DOE Reanalysis 2 (R2). The purpose was to compare its performance with the current operational GODAS-M3. Figure 1 compares monthly sea surface height from GODAS-M4 (red), GODAS-M3 (blue), TOPEX-Jason1 altimetry (green) and tide gauges (triangles) at islands in the Pacific Ocean. Neither altimetry data nor tide gauge data was assimilated by GODAS in these particular experiments. Islands within 2° of the equator are on the left and those beyond 7° of the equator are on the right. The RMS differences and correlations between the different time-series are listed in Table 1. The largest correlations and smallest RMS differences are between the two versions of GODAS.

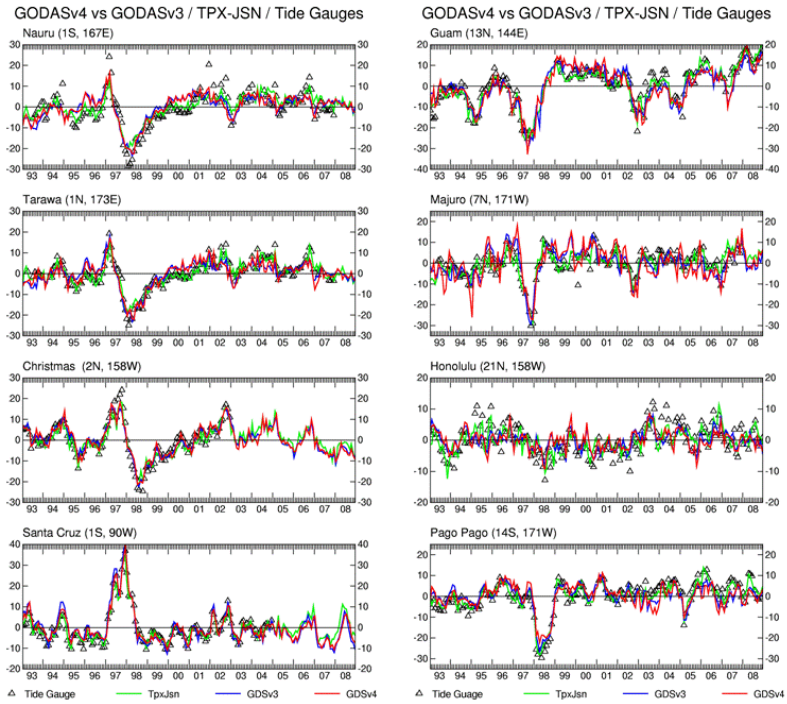

Figure 1. Sea surface height in cm at Pacific island sites. GODAS-M4(red), GODAS-M3(blue), TOPEX-Jason1(green), tide gauges(triangles).

The models are closer to the observations for the sites nearest the equator, but the RMS differences are on the order of only a few centimeters at all sites. The GODAS-M3 tracks the observations slightly better than the GODAS-M4 at off-equatorial sites, which may be the

Table 1: RMS differences in cm and correlations in parentheses

	Naru	Tarawa	Xmas	S. Cruz	Guam	Majuro	Honolulu	PagoPago
G4 v G3	1.5 (0.97)	1.9 (0.96)	1.7 (0.97)	1.7 (0.98)	2.8 (0.95)	4.3 (0.85)	1.5 (0.88)	2.2 (0.94)
G3 v TG	4.7 (0.82)	3.8 (0.87)	2.6 (0.97)	2.7 (0.96)	4.0 (0.90)	4.7 (0.77)	3.6 (0.61)	3.8 (0.86)
G4 v TG	4.6 (0.84)	3.5 (0.88)	2.9 (0.95)	2.2 (0.97)	4.4 (0.89)	6.2 (0.67)	3.8 (0.56)	4.6 (0.79)
G3 v TJ	3.4 (0.85)	3.5 (0.84)	2.2 (0.95)	3.1 (0.94)	3.7 (0.92)	4.5 (0.78)	3.0 (0.60)	3.0 (0.90)
G4 v TJ	3.3 (0.86)	3.5 (0.84)	2.8 (0.92)	2.7 (0.94)	4.0 (0.90)	6.0 (0.68)	3.4 (0.51)	3.8 (0.82)

result of greater variability in GODAS-M4 which has twice the resolution of GODAS-M3. Along the equator, where the oceanic scales of motion are larger, GODAS-M4 appears to have a slight edge on GODAS-M3.

Figure 2 shows a comparison of mean surface velocity components from GODAS-M4, GODAS-M3 and climatology constructed from surface lagrangian drifter data by Lumpkin and Garraffo (2005, *J. Atmos. Oceanic Techn.*). The similarity between the model fields on the one hand and the drifter-derived fields on the other is remarkable, given that they are the result of very different computations based on very different kinds of data. The Antarctic Circumpolar Current appears stronger in the drifter representation than in either version of the GODAS, but this is a region of relatively sparse observations which will affect both model and drifter computations. A more significant difference is the westward current just north of the equator in the western Indian Ocean that can be seen in both GODAS maps but is absent in the drifter version. This is again a region where drifter observations are relatively sparse, but it is well observed by Argo floats, leading to the speculation that the GODAS maps may be more accurate here than the drifter map.

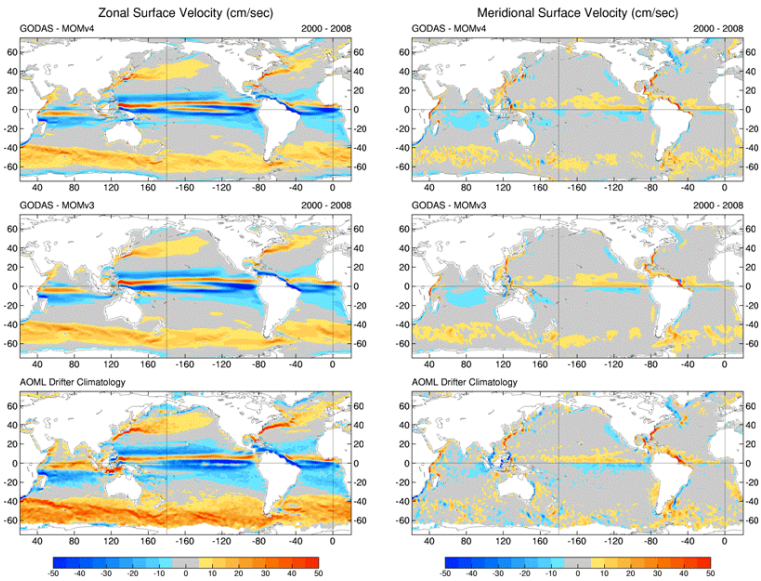

Figure 2. Surface current velocities in cm/sec, zonal on the left and meridional on the right. Shown are 2000-2008 averages from GODAS-MOM4 (top) and GODAS-MOM3 (center) and a drifter-based climatology (bottom).

The comparisons described here establish that in making the transition from MOMv3 to MOMv4 we have maintained the level of performance

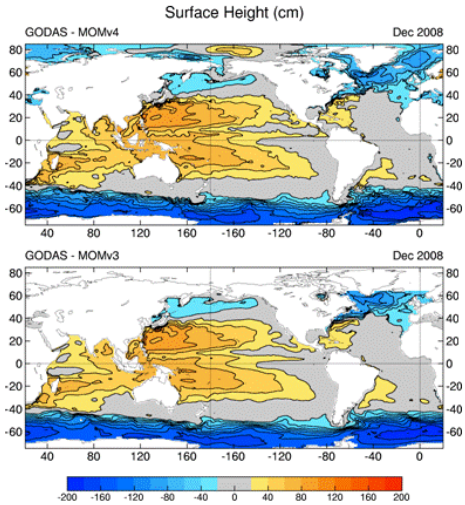

Figure 3. Sea surface height in cm for December 2008. Shown are GODAS-MOM4 (top) and GODAS-MOM3

established by the earlier version. Figure 3, showing the average sea surface height for December 2008, illustrates some advantages of the new version. The improved resolution of the GODAS-M4 (0.5^o globally / 0.25^o in the tropics) versus the GODAS-M3 (1° / 0.33^o) allows a better representation of the complex region between Indonesia, New Guinea and Australia. There is also an improved interaction between the Mediterranean Sea and the Atlantic Ocean. Finally and perhaps most importantly, the GODAS-M4 is truly global where the GODAS-M3 was truncated at 65^oN. The transition to MOMv4 and to the GODAS-M4 also means that the new CFS is fully global in all its components.

4. Education and Outreach

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/NOAAReanalysis/cfsrr

5. Publications and Reports

Huang, B., Y. Xue, and D. W. Behringer, 2008: Impacts of Argo salinity in NCEP Global Ocean Data Assimilation System: The tropical Indian Ocean. *J. Geophys. Res.*, **113**, C08002, doi:10.1029/2007JC004388.

Nadiga, S. and D. Behringer, 2009: The diurnal cycle of SST in CFSR. 34th Climate Diagnostics and Prediction Workshop, Monterey, CA, NOAA.