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EVALUATION OF THE GLOBAL OCEAN DATA ASSIMILATION SYSTEM AT NCEP: THE PACIFIC OCEAN

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1. INTRODUCTION

The El Nino-Southern Oscillation (ENSO) phenomenon has been forecast reasonably well by both numerical and statistical models at lead times of 6-12 months. As the atmospheric weather system behaves in a chaotic manner beyond timescales of days, it is mainly the ocean that carries the potential for predictability skill up to a year in advance. Therefore, a large amount of effort has been devoted to intialize accurately the oceanic components of coupled ocean-atmospheric models using ocean data assimilation systems (ODAS). The ocean analyses generated by ODAS are being used not only in initializations for coupled ocean-atmospheric models but also in diagnostic studies and real time monitoring of the subsurface oceanic conditions in support of climate prediction activities (e.g. "ENSO Diagnostic Discussion" at Climate Prediction Center of NOAA).

The ODAS developed at the National Centers for Environmental Prediction in 1995 was configured for the Pacific Ocean only. Recently, a new global ocean data assimilation system (GODAS) has been developed at NCEP for initialization of the new global coupled ocean-atmospheric model that will be used for operational ENSO prediction in the future. It is imperative for us to evaluate the GODAS against independent data sets, and compare it with the operational ODAS for the Pacific Ocean, and, eventually, implement the GODAS in the real time monitoring products at CPC.

The GODAS at NCEP was developed using the Geophysical Fluid Dynamics Laboratory Modular Ocean Model version 3 (MOM.v3) and a three-dimensional variational data assimilation scheme. Compared with the operational ODAS developed for the Pacific Ocean (Behringer et al. 1998; referred as RA6 hereafter), the major changes include 1) the extension from the Pacific basin to the quasi-global domain for 75^{O}S-65^{O}N, 2) the model change from MOM.v1 to MOM.v3 that contains more vertical levels, an explicit free surface, the Gent-McWilliams mixing scheme and an improved boundary layer mixing scheme, 3) the forcing change from momentum flux forcing only to momentum flux, heat flux and fresh water flux forcings from the reanalysis 2 (Kanamitsu et al. 2002), and most importantly, 4) the data input change from temperature only to temperature and synthetic salinity that is constructed from temperature and local T-S climatology. The temperature data includes those from XBTs, profiling floats and TAO moorings. The evaluation of the GODAS is focused on the comparison with RA6 for the Pacific Ocean. The temperature fields from GODAS and RA6 are compared with the TAO mooring data to estimate how well the analyses fit to observations. Then the quality of the analyses is evaluated against independent data sets such as tide gauge observations and TOPEX/Poseidon (T/P hereafter) sea level observations, the current data from the TAO moorings and the satellite-derived current analysis.

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2. Data

Both surface and subsurface temperature observations are assimilated in GODAS. The SST is the NCEP's in situ and satellite blended analysis (Reynolds et al. 2002). The subsurface temperature XBT profiles for years 1980-89 have been extracted from the online version of the WOD98 V.2 archive provided by the National Oceanographic Data Center (NODC) (http://www.nodc.noaa.gov/General/temperature.html). The profiles for the years 1990-present have been acquired from the archive of MEDS (ftp://ftp.nodc.noaa.gov/pub/gtspp/best and ftp://ftp.nodc.noaa.gov/pub/gtspp/realtime). The TAO moorings data are obtained from the Pacific Marine Environmental Laboratory (PMEL) (http://www.pmel.noaa.gov/tao). Fig. 1 shows the distribution of temperature profiles for the entire analysis period 1980-2001. It is seen that the number of temperature profiles from XBT drops systematically since the early 1990s, while that of the TAO moorings increases dramatically at the beginning of 1993 and increases slowly afterward. The data from Profiling floats became available in 1998 and have increased gradually since then as more Argo instruments continue to be deployed.

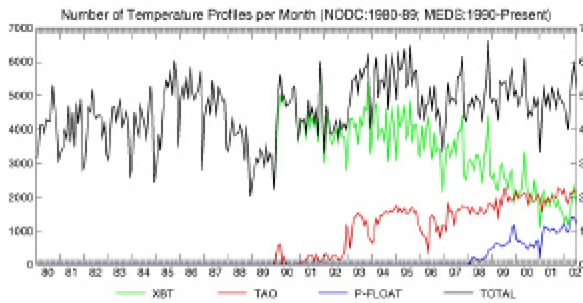

Figure 1. Number of temperature profiles during 1980-2001.

Since the T/P sea level is not assimilated into the model, it is used as an independent data set for the model evaluation. The T/P sea level is obtained from Laboratory for Satellite Altimetry of the National Environmental Satellite, Data, and Information Service (NESDIS) (http://ibis.grdl.noaa.gov/SAT/). Tide gauge observations are also used, and they are obtained from University of Hawaii Sea Level Center (http://uhslc.soest.hawaii.edu/uhslc). The current profiles from the two analyses are compared with the TAO Acoustic Doppler Current Profiles at four longitude locations (165^{o}E, 170^{o}W, 140^{o}W and 110^{o}W). The surface currents of the analyses are compared with the satellite-derived current analysis by the Ocean Surface Current Analyses - Real Time (OSCAR) (http://www.oscar.noaa.gov/). It is important to mention that the OSCAR surface currents are not observations, instead, they are computed from satellite sea level and surface wind analyses using dynamical and statistical methods (Lagerloef et al, 1999).

We analyzed two runs of the GODAS that differ only in the time period coverage, one for the 1992-2001 period and another for the 1979-2001 period. This note concerns the run for the 1992-2001 period. A preliminary study of the 1979-2001 run suggests that there are some positive biases in sea level in the first half period that degraded its overall performance for the whole period 1979-2001. The possible reasons will be discussed briefly in the summary.

3. Evaluation of GODAS

3.1 Salinity

To improve the model's analysis of dynamic height, the T/P sea level have been assimilated in the NCEP's ODAS since 1993 (Behringer et al. 1998). In the assimilation, changes in dynamic height are attributed to changes in temperature only. This assumption can introduce errors in regions where salinity fluctuations contribute significantly to dynamic height variability. This is particularly the case for the western tropical Pacific, where dynamic height errors due to misestimation of salinity reach values of 6 dyn cm (Ji et al. 2000). Since there are few salinity observations, several attempts have been made to infer salinity using temperature and sea level observations. Some use the combined Empirical Orthogonal Functions (EOFs) of temperature, salinity and sea level, and infer salinity from the combined EOF modes (Maes et al. 2000), and others adjust model's sea level by vertically shifting local temperature and salinity profiles (Segschneider et al. 2000). Here we construct a synthetical salinity using the local T-S relationship derived from the Levitus' climatology. This approach, although simple, is guaranteed to give a reasonable representation of the climatological salinity that RA6 poorly represents.

3.2 Sea level

In the current version of GODAS, no sea level observations are assimilated. So both the T/P sea level and tide gauge observations are independent data sets for the evaluation. Fig. 2 shows the root mean square (RMS) differences between the sea level anomalies of GODAS and tide gauge observations at 27 Pacific islands (referred as RMS errors hereafter). The RMS errors are about 3-5 cm in the equatorial belt and 4-6 cm in the subtropics. The RMS errors of GODAS are generally smaller than those of RA6, with the most reduction in the equatorial western Pacific (Fig. 3). This

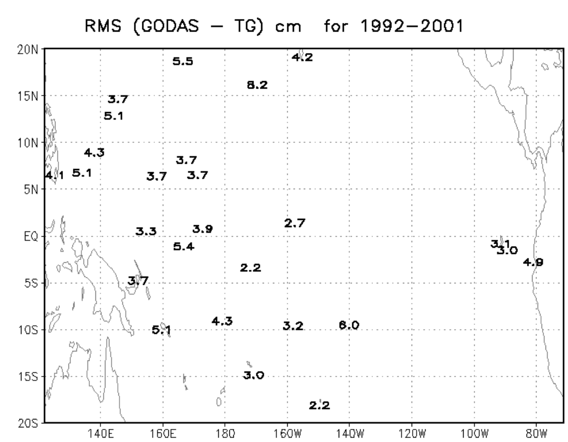

Figure 2. The root mean square (RMS) differences between sea level anomalies of GODAS and tide gauge observations for 1992-2001.

result is a little surprising since the T/P sea level has been assimilated into RA6 but not in GODAS. The improvement in sea level in the equatorial western Pacific is related to the improvement in subsurface temperature there, that will be discussed in next subsection.

The RMS errors verified against the T/P sea level also suggest that GODAS is closer to observations than

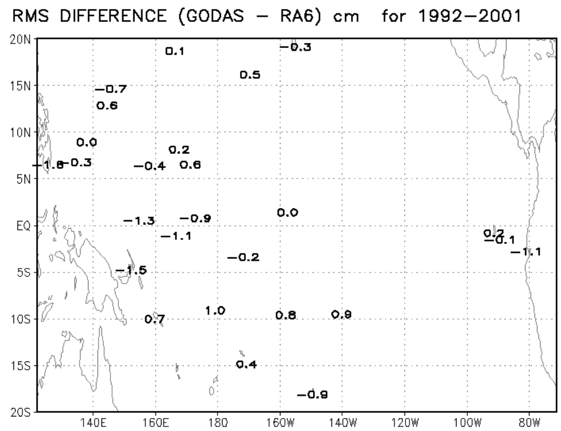

Figure 3 Differences of RMS errors of GODAS and RA6 that are verified against tide gauges.

RA6 in the equatorial western Pacific and the north-western Pacific around 10^{O}N (not shown). However, GODAS has slightly larger RMS errors than RA6 in the north-eastern Pacific around 10^{O}N. The sea level deviations, in which the mean for 1993-2001 has been removed, of the two analyses in the equatorial belt are compared with those of the T/P (Fig. 4 and 5). The figures show that the erroneously high sea level in RA6 in the western Pacific during 2000-2001 are significantly reduced in GODAS.

3.3 Temperature

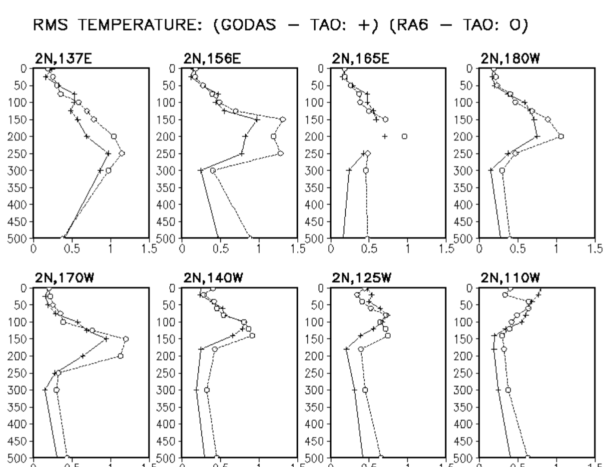

Figure 6. The root mean square (RMS) differences between the temperature fields in GODAS and the TAO moorings along the 2^{O} latitude belt. Unit is degree.

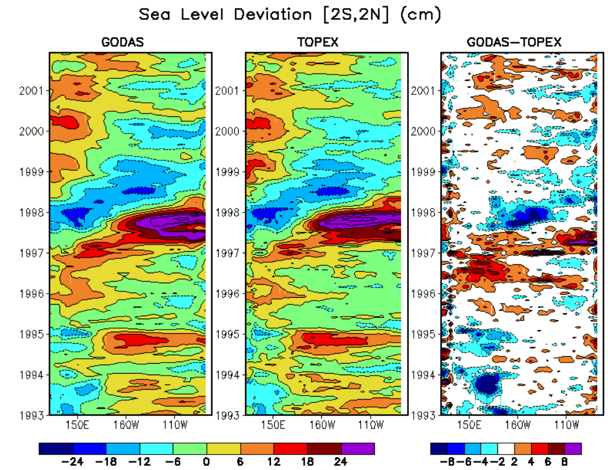

Figure 4. Hovmoeller plots of sea level deviations averaged for 2^{O}S-2^{O}N of GODAS (left), TOPEX (middle), and GODAS minus TOPEX (right).

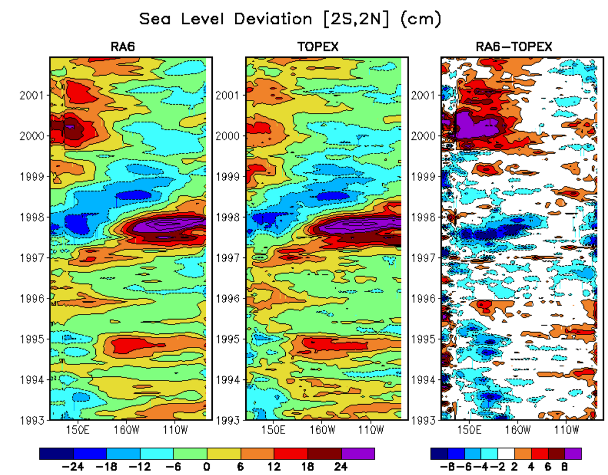

Figure 5. Hovmoeller plots of sea level deviations averaged for 2^{O}S-2^{O}N of RA6 (left), TOPEX (middle), and RA6 minus TOPEX (right).

The temperature fields in GODAS and RA6 are compared with the temperature profiles at 64 TAO moorings located between 8^{O}S and 8^{O}N in the tropical Pacific. The RMS differences between the analyses and TAO data measure how well the analyses fit to the observations. The RMS differences show that the temperature field in GODAS is generally closer to observations than is the temperature field in RA6. The improvement is significant in the western Pacific and in the deep ocean, which is probably attributable to the increased vertical resolution in GODAS relative to that in RA6. However, above the thermocline in the extreme eastern Pacific GODAS has larger RMS errors than RA6 does (Fig. 6).

3.4 Current

The current profiles of the analyses are compared with the TAO Acoustic Doppler Current Profiles at four longitude locations along the equator. Fig. 7 shows that the mean Equatorial Undercurrent is similar in GODAS and RA6. Compared with the TAO data, both do well at 170°W, 140°W, and 110°W, getting the core depth right, but being slightly weak at 110°W. Neither does well at 165°E, where GODAS has a better defined core depth, but has worse amplitude than RA6 at the surface. The mean meridional currents are generally much weaker than the mean zonal currents, and both GODAS and RA6 compare poorly with the TAO data.

For the zonal currents, the RMS errors in GODAS are smaller than those in RA6 at all depths at all four TAO sites with the exception of the near surface at 165°E (Fig. 8). It is interesting that the RMS errors do not maximize at the core depth of the Equatorial Undercurrent, instead, they peak at depths of 50-70 meters. For the meridional currents, the RMS errors are similar in the two analyses.

We compare the model's surface currents with the satellite-derived surface current analysis (OSCAR) for its uniform spatial coverage. Fig. 9 shows that both GODAS and RA6 have large discrepancies (30 cm/s) when compared with the OSCAR data. The Equatorial Counter Currents in the two analyses are all too strong, while the differences between the analyses and OSCAR show changes of sign along the equator. These large errors of surface currents potentially influence the forecast skill of coupled models since zonal advection of SST by surface currents is shown to be important for ENSO development. We are trying to figure out the origins for

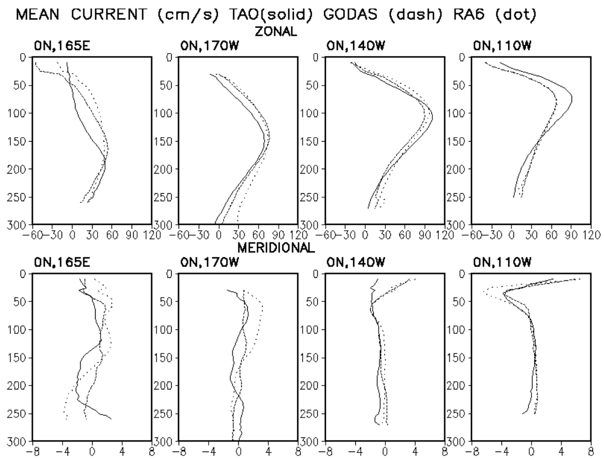

Figure 7. Comparisons of the mean zonal (upper) and meridional (lower) currents in GODAS (dash), RA6(dot), and TAO Acoustic Doppler Current Profiles at four longitude locations indicated in the figure.

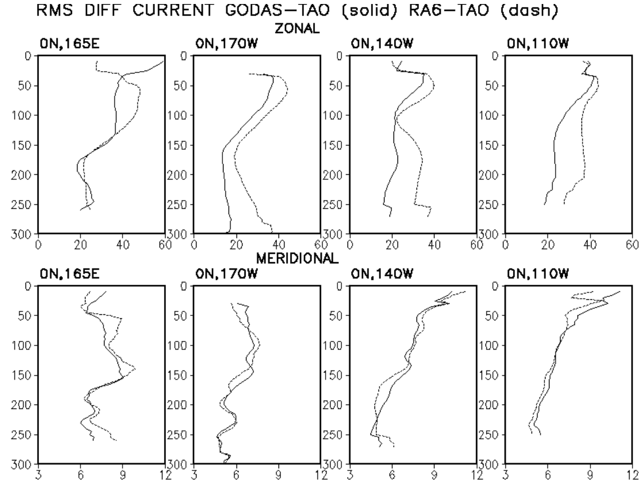

Figure 8. The root mean square (RMS) differences of zonal (upper) and meridional (lower) currents in GODAS (solid) and RA6 (dash) from the TAO currents at four longitude locations indicated in the figure.

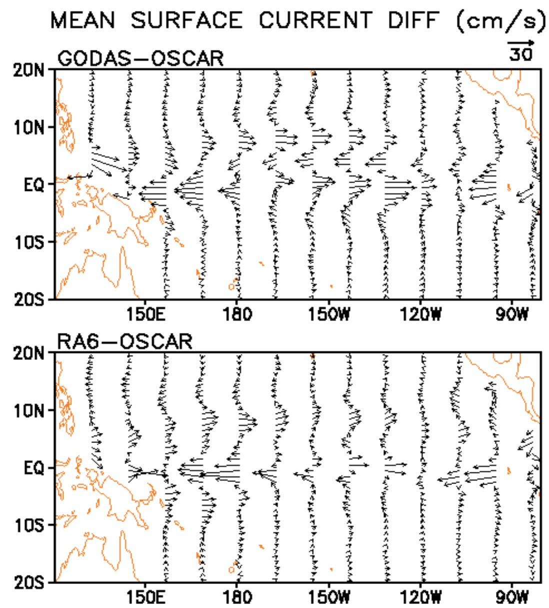

Figure 9. Mean surface current differences of GODAS (upper) and RA6 (lower) from the OSCAR surface current analysis for 1993-99.

the errors. Potential sources of errors are wind forcing errors, model errors, and errors introduced by data assimilation procedures.

4. SUMMARY

Recently, a new global ocean data assimilation system (GODAS) has been developed at NCEP for initialization of the oceanic component of the new global coupled ocean-atmospheric model. The purpose of this paper is to evaluate the quality of the GODAS in a comparison with the operational ODAS for the Pacific Ocean.

We found that the temperature field in GODAS is generally closer to observations than is the temperature field in RA6. GODAS is most improved below the thermocline and in the western Pacific. The poor representation of salinity in RA6 has been corrected in GODAS by assimilating a synthetical salinity that is constructed with the local T-S relationship of the Levitus's climatology.

GODAS does as well as or better than RA6 in comparisons with the T/P sea level, even though this version of GODAS does not assimilate the T/P sea level while RA6 does. The improvement is most significant in the equatorial western Pacific and north-western Pacific around 10^{O}N. The result suggests that the data assimilation procedure that includes a simple salinity estimation by using the climatological T-S relationship (GODAS) can give a comparable or better estimation of sea level than the one that assimilates sea level observations directly (RA6). However, the better estimation of sea level is also attributable to the fact that the ocean model used in GODAS is more advanced than that in RA6.

Both GODAS and RA6 simulate the mean Equatorial Undercurrent well except in the far western Pacific. Compared with the TAO current, GODAS has a smaller RMS error than RA6 has at all depths except near the surface. Both surface currents in GODAS and RA6 remain a problem, and have errors about 30 cm/s compared with the satellite-derived surface current analysis.

We also compared the long GODAS run with RA6 in their common period 1980-2001. The RMS errors of sea level in GODAS are generally larger than those in RA6. This is because the GODAS sea level have positive biases in the first half period. We suspect the positive biases are related to the large positive biases of mean sea level in the simulation run that is the same as GODAS except no data are assimilated (Fig. 10). Compared with GODAS, the mean thermoclines in the simulation run are too deep and diffused, which results in temperature errors in the thermoclines as large as 3^{O}C in the equatorial belt, and 6^{O}C in the north-western Pacific. When the mean sea level for the 1992-2001 period is removed (called sea level deviation), both GODAS and RA6 compare well with the tide gauges from earlier 1990s to 2001, but have positive biases in 1980-1990. However, the sea level deviation in the simulation run differs significantly from the tide gauges from earlier 1990s to 2001, and have positive biases in 1980-1990 that are comparable to the positive biases of mean sea level (10 cm) that is measured by the mean sea level differences between the simulation and GODAS (Fig. 10). Therefore, the data assimilation scheme has to correct the positive biases in both the mean and deviation of sea level in 1980-1990. So it is not surprising that some of the positive biases remain even after data assimilation. A possible explanation for the residual positive biases is that there are not enough data to constrain the analysis in the earlier period. We plan to reduce the mean positive biases in the simulation run by modifying the climatological wind forcings, and then tune the model's error covariance functions to constrain the model further towards observations.

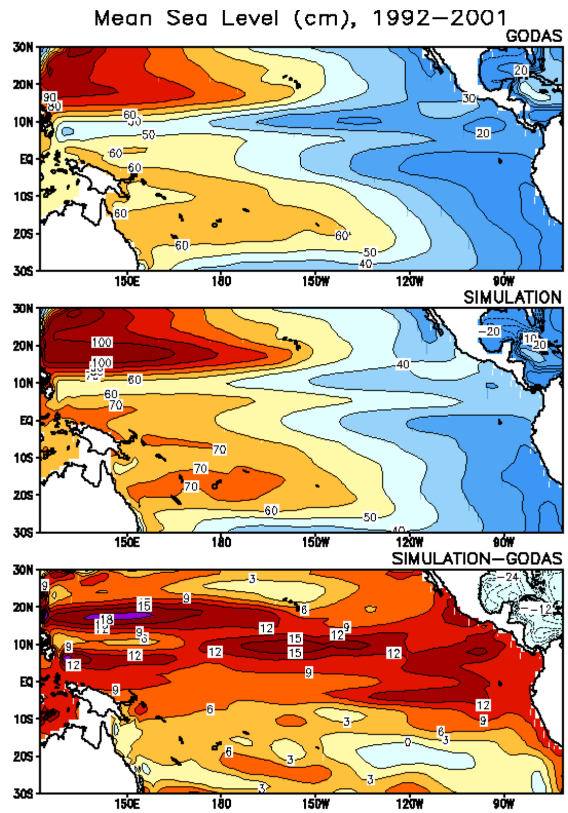

Figure 10. Mean sea level of GODAS (upper), simulation (middle), and simulation minus GODAS (lower) for 1992-2001.

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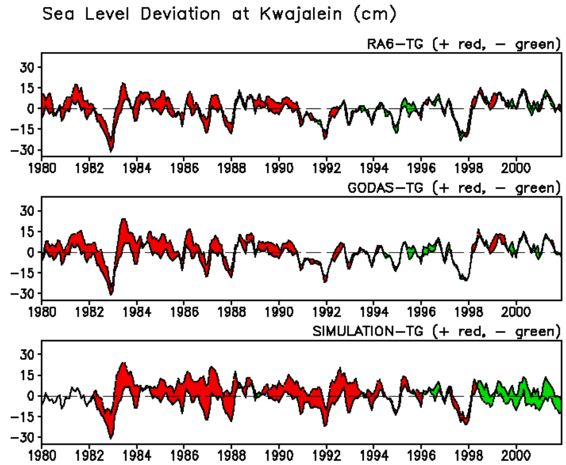

Figure 11. Comparisons of sea level deviations of RA6 (upper), GODAS (middle), and simulation (lower) from sea level deviations of tide gauge observations at Kwajalein (168°W, 8.7°N) . Note red (green) shades indicate model sea level are higher (lower) than tide gauges.