Ocean Data Assimilation Research at GFDL

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1. PROJECT SUMMARY

Estimating the state of the Earth System is critical for monitoring our planet's climate and for predicting changes to it on time scales from months to decades. Toward these ends, the vast number of atmospheric observations and the growing number of ocean observations must be combined with model estimates of the state of the Earth System by means of data assimilation systems. This project explores the development of new data assimilation techniques using state-of-the-art ***coupled*** climate models and applies these techniques to detecting climate change, improving forecasts on seasonal to interannual time scales while providing estimates of their uncertainty, and improving our understanding of predictability at decadal time scales in order to provide a foundation for the development of a NOAA capability for decadal forecasts. This capability will provide the Nation's decision and policy makers with the best possible climate information on critical problems such abrupt climate change, changes in hurricane activity, drought, and sea-level rise.

2. ACCOMPLISHMENTS

2.1. Objective analysis of monthly temperature and salinity for the world ocean

Global data management systems (data mirroring and quality control systems) have been continuously maintained and updated (Figure 1). As for the application of Argo profiling data, objective analysis for the world ocean and the basin-scale sea level budget studies have been carried out as well as the investigation of reanalysis data from the GFDL coupled data assimilation system.

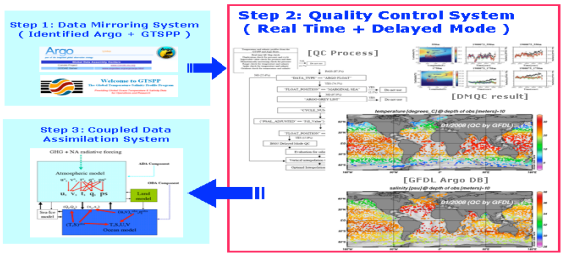

Figure 1. Data process for the GFDL coupled data assimilation system.

A new world ocean atlas of monthly temperature and salinity, based on individual profiles for 2003-2007 (WOA21c), is constructed and compared with the World Ocean Atlas 2001 (WOA01), the World Ocean Atlas 2005 (WOA05) and the data assimilation

analysis from the Coupled Data Assimilation (CDA) system developed by the Geophysical Fluid Dynamics Laboratory (GFDL). First, we established a global data management system for quality control (QC) of oceanic observed data both in real time and delayed mode. Delayed mode QC of Argo floats identified about 8.5% (3%) of the total floats (profiles) up to December 2007 as having a significant salinity offset of more than 0.05. Second, all QCed data were gridded at 1° by 1° horizontal resolution and 23 standard depth levels using six spatial scales (large and small longitudinal, latitudinal, and cross-isobath) and a temporal scale. Analyzed mean temperature in WOA21c is warm with respect to WOA01 and WOA05, while salinity difference is less evident. Consistent differences among WOA01, WOA05, and WOA21c are found both in the fully and sub-sampled dataset, which indicates a large impact of recent observations on the existing climatologies. Root mean square temperature and salinity differences and offsets of the GFDL's CDA results significantly decrease in the order of WOA01, WOA05, and WOA21c in most oceans and depths as well. This result suggests that the WOA21c is of use for the collocated assessment approach especially for high-performance assimilation models on the global scale.

2.2. Basin patterns of global sea level changes

Based on independent observations, we estimate the sea level budget and linear trends for individual ocean basins and the world ocean during 2004-2007. Even though it is confirmed that the seasonal variation of global sea level is balanced by the different sea level components, basin scale sea level budgets show very different characteristics. Sea level budgets over the South Pacific and Antarctic Ocean maintain a good balance both on seasonal to interannual time scales. Meanwhile, only the satellite altimeter data exhibits a large 4-year trend over the South Indian Ocean (Figure 2). This basin significantly impacts the magnitude of the disagreement for the global sea level budget. Large differences among the 3 different gravity fields related to the hydrologic signals in the Atlantic and Indian Ocean could be one of the major causes of the imbalance in the global sea level budget.

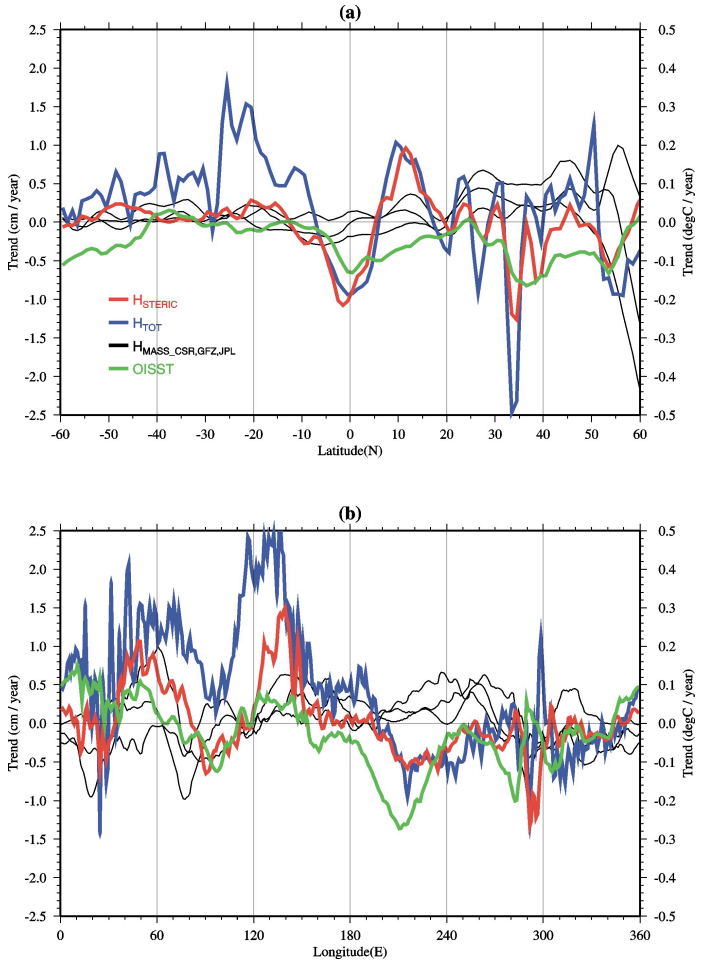

Figure 2. (a) 4-year linear trends of zonally averaged sea level from steric heights (H_{STERIC} in red), altimetric heights (H_{TOT} in blue), 3 different gravity fields (H_{MASS_CSR}, H_{MASS_GFZ}, H_{MASS_JPL} in black), and OISST (green). (b) Lower panel indicates the meridionally averaged results.

2.3. Validation for the GFDL Coupled Data Assimilation (CDA) system

We investigated the monthly mean analyses (SST, SSH, heat contents, zonal wind stress, 850hPa zonal wind speed, surface zonal current, vertical velocity, and sea ice mass) derived from the GFDL's CDA system from January 1979 to December 2008. GFDL's CDA analyses for 30 years are consistent with observation especially for the global temperature related fields. They also depicted the basin scale special features very well (ENSO (Figure 3), PDO, North America western coast upwelling, Atlantic hurricane non local anomalies, Indian Ocean dipole mode, and the Arctic sea ice coverage variation).

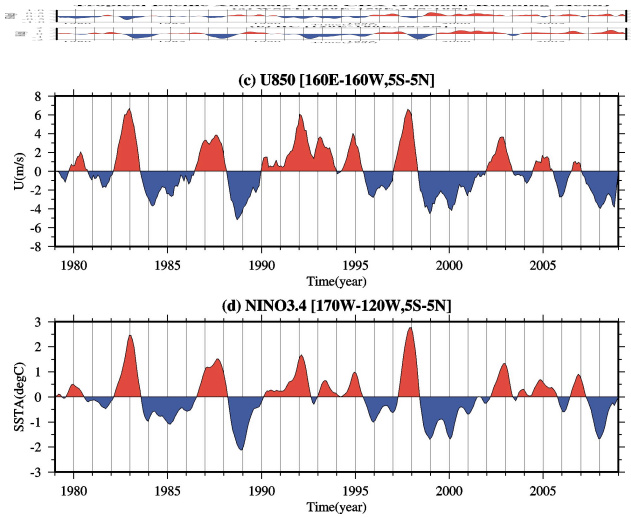

Figure 3. Time series of the equatorial Pacific (a) SST, (b) heat contents (upper 300 m temperature average), (c) zonal wind speed at 850 hPa, and (d) NINO3.4 SST anomalies simulated by the GFDL coupled data assimilation system.

2.4. Assimilation with Multi-Model Ensembles

Some new and exciting work has begun on a multi-model ensemble assimilation scheme. Both GFDL's CM2.0 and CM2.1 coupled models are used in a unified ensemble system in which the filtering process is based on the error statistics from both models' ensemble integrations. The system construction is complete but the analysis is ongoing. The idea here is that often the ensemble forecasts tend to look more like each other than reality. The goal is that the ensemble spread should span the possible solution space and to include the true solution. Some initial OSSE imperfect twin studies using this system uncovered some inconsistent constrains in the upper and deep ocean due to model biases and the nature of the low frequency of the deep ocean circulation. Although this issue may not be important for seasonal initialization it will most likely be for decadal initialization.

The impact of the ensemble circulation-dependent inflation filter (EcdiF) on oceanic climate detection is examined in 'biased' oceanic data assimilation (ODA) perfect model experiments. Two coupled GCM's CM2.0 and CM2.1 are used. Synthetic-observations are produced by projecting the CM2.0's simulation onto the ARGO network and they are then assimilated into the CM2.1 model. Because of the model bias and limitation of finite ensemble's representing the low frequency variability of the deep ocean, a standard ensemble filter fails to construct the proper watermass structure and develops spurious velocities. An EcdiF uses a pre-computed anomaly's variance to inflate the covariance for improving the consistency of the upper/deep ocean's data constraints.

2.5. Detection of Multi-Decadal Oceanic Variability

The impact of oceanic observing systems, external radiative forcing and oceanic initial conditions on the long time variability of oceanic heat content and salinity has been studied by the assimilation of synthetic oceanic "observations" in the context of a "perfect" IPCC AR4model. The 20th-century temperature (XBT) and 21st-century

temperature and salinity (Argo) "observations" are drawn from the model projection on the 20th-century historical greenhouse gas and natural aerosol (GHGNA). These model observations are assimilated into the coupled model based on temporally-varying and fixed-year GHGNA records and different oceanic initial conditions. Both the 20th-century XBT and 21st-century Argo observations adequately capture basin scale heat content variability. Argo salinity observations appear to be necessary to reproduce the North Atlantic thermohaline variability. The addition of historical radiative forcing does not make a significant contribution to the detection skill. The initial conditions spun up from the temporally-varying GHGNA radiative effects produce better detection skill than the ones spun up from a fixed-year GHGNA value due to the relaxed assimilation shocks for the deep oceans that have been forced by the historical changes in radiative forcing. These results suggest that the 20th-century temperature observations be sufficient for the state estimate of the tropical ocean due to the strong TS relationship from air-sea interactions. Argo salinity observations are very important for global state estimation, particularly in high latitudes. An assimilation adequately spun up by external radiative forcing may reduce the error of the state of the art that combines a coupled model and observed data.

3. PUBLICATIONS

Chang, Y.S., A.Rosati, S.Zhang, and M.J. Harrison, 2009: Objective analysis of monthly temperature and salinity for the world ocean in the 21st century: Comparison with World Ocean Atlas and application to assimilation validation, *J. Geophys. Res.*, 114, C02014, doi:10.1029/2008JC004970.

Chang, Y.S., A. Rosati, and G.A. Vecchi, 2008: Basin Patterns of Global Sea Level Changes for 2004-2007. *GRL*, submitted.

Zhang, S., A. Rosati and M.J. Harrison, 2007: Detection of Multi-Decadal Oceanic Variability by Ocean Data Assimilation System in the Context of a "Perfect" Coupled Model. *JGR Oceans*, in press.

Zhang, S. and A. Rosati, 2008: Impact of an Ensemble Circulation-Dependent Inflation Filter on Oceanic Climate Detection within "Biased" Coupled GCMs. *Journal of Climate*, submitted.