Data Assimilation for the Real Time Ocean Forecast System

Zulema D. Garraffo[1], James A Cummings[1], Ilya Rivin[1], Shastri Paturi[1], Yan Hao[1], Todd Spindler[1], Avichal Mehra[2]
(1)IMSG at NOAA/NWS/NCEP/EMC, College Park, MD, USA; (2)NOAA/NWS/NCEP/EMC, College Park MD, USA.
Email: zulema.garraffo@noaa.gov; phone: 301-683-3744

Introduction

Global high resolution data assimilation simulations were produced as a step towards building the RTOFS-DA (Real Time Ocean Forecast System with Data Assimilation). RTOFS-DA is based on the Navy Coupled Ocean Data Assimilation (NCODA) system (Cummings and Smedstad, 2013). The current operational RTOFS, version 1.1.4, produces forecasts starting from daily analyses provided by the HYCOM based Global Ocean Forecast System, version 3.1, operational at the U.S. Naval Oceanographic Office (Metzger et al., 2014). Instead, analyses will be produced through RTOFS-DA when in operations. RTOFS and RTOFS-DA use the HYbrid Coordinates Ocean Model (HYCOM, Bleck 2002) at 1/12° resolution and 41 vertical hybrid layers coupled with Los Alamos Community Ice CodE (CICE).

Simulations

We present results from simulations with 2017 historical data, and discuss the setup for a near real time simulation being started in 2019. All simulations are performed on the tri-polar global 1/12° horizontal resolution domain with 41 vertical hybrid layers, and are forced with atmospheric analysis fields from the NOAA/NCEP Global Data Assimilation System (GDAS).

Externally produced quality controlled data are used for the 2017 simulations. The observational data consist of the following: sea surface height (SSH) from the CryoSat, Jason, Sentinel, Altika altimeters; sea surface temperature (SST) retrievals from NOAA (18, 19), and METOP (A, B); surface temperature from in-situ measurements (fixed and drifting buoys, ships); subsurface profiles of temperature and salinity from Argo, XBT, CTD, and glider data; and sea ice coverage from SSMI/S and AMSR2. With the exception of SSH, all data are obtained from the Global Ocean Data Assimilation Experiment (GODAE) server. SSH observations are obtained directly from the Altimeter Processing System (ALPS) at the Naval Oceanographic Office.

The 3D-VAR analysis is performed using a 24-hour update cycle with the analysis time centered on the update cycle interval. The observations are pre-processed as follows; SST observations are averaged to form super-observations to remove data redundancies using local correlation length scales; background error variances are computed from a 15-day history of forecast differences using forecasts separated by a 48-hour time interval (twice the analysis update cycle). The 3D-VAR analysis is performed directly on the HYCOM global horizontal grid, and uses hybrid vertical coordinates valid at the analysis time. The global ice coverage analysis is incorporated through the CICE model. The 3D-VAR analysis increments for temperature, salinity, velocity, and layer thickness are incorporated into the forecast model using an incremental analysis update procedure where the corrections are inserted into the ocean model starting 3 hours earlier than the analysis time. The forecast is then issued from this balanced initial state.

For a first historical simulation covering one year, February 2017-January 2018, altimeter SSH is incorporated using bi-monthly climatological relationships between SSH (dynamic height) and temperature and salinity at depth in the form of synthetic temperature and salinity profiles (MODAS, Fox et al., 2002). MODAS assimilates SSH anomalies (SSHA) from a long term mean. A strong limitation with using MODAS is that the synthetic profiles do not incorporate any information from the forecast model. In addition, a shorter simulation covering the period October-December 2017 was performed by assimilating altimetry SSH observations in the form of Absolute Dynamic Topography (ADT). Here, the ADT measurements are referenced to the model forecast SSH. The observed difference is then used to directly adjust the HYCOM temperature, salinity, and layer structure so the model forecast SSH now matches the altimeter ADT. A modified version of the Cooper and Haines (1996) method is used. The modifications include constraining the solution with updated estimates of SST, SSS, and model mixed layer depth. Work continues to improve the method by developing multivariate constraints between the ADT innovations and the barotropic stream function in HYCOM, which should improve the use of altimeter data in mid to high latitudes.

Results

For the long-term simulation with MODAS profiles, the total temperature verification averaged across the grid results in very small biases (not shown) during the length of the simulation. A few days after initialization, the global total temperature verification RMS error reaches a stable value of 0.5°C, with a slight increase during the Northern Hemisphere summer. The Argo temperature verification RMS error is 0.8°C, with a seasonal cycle similar to that of the total RMS temperature. The Argo temperature mean bias is 0.1°C.

Vertical sections for verification of total, Argo and MODAS temperature show very small residuals (Observations minus Analysis, Figs. 1a, b, c lower panel, respectively), implying that the observations are effectively analyzed. The section for total temperature bias for innovations (Observations minus 24-hour Forecast) shown in the Fig. 1a upper panel closely follows the MODAS bias (Fig. 1c upper panel). The model 24-hour forecasts of Argo temperature are consistently cold-biased below 100m, and are relatively unbiased near the surface due to the simultaneous assimilation of satellite SST (Fig. 1b upper panel). The similarity of the total and MODAS biases indicates that the lack of skill in forecasting Argo temperature at depth is likely due to the assimilation of MODAS synthetics.

A 3-month (Oct-Dec, 2017) simulation employing assimilation of ADT altimetry shows improved subsurface temperature forecast of Argo profiles. HYCOM forecasts the ADT observations very well with SSH innovations on the order of 10 cm or less away from western boundary currents, where model corrections can be large due to errors in the positions of ocean fronts. There is a consistent ~0.5 m difference between the HYCOM and ADT SSH across all satellite altimeters and ocean basins that is easily corrected. ADT observations are more accurate because the data incorporate geoid information instead of a model-based reference mean dynamic topography. Whole ocean averages of total temperature and Argo temperature RMS error for the ADT simulation result in similar values compared to the MODAS simulation (0.5°C and 0.8°C respectively).

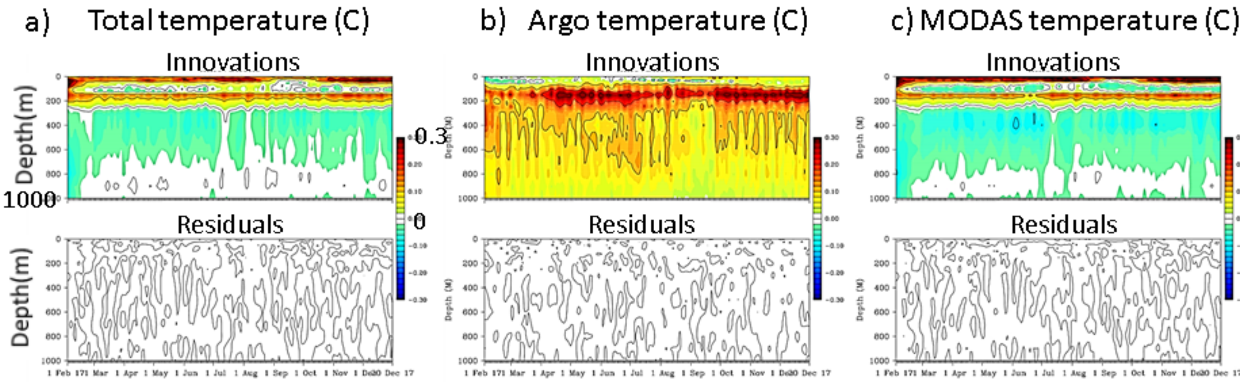

Figure 1. MODAS simulation, temperature bias verification for vertical sections, horizontal global averages at each depth vs. time, in the upper 1000 m, Feb-Dec 2017 (°C) : a) Total temperature innovations (observations – forecast, top), and residuals (observations – analysis, bottom); b) same as a) but for Argo Float temperature; c) same as a) but for MODAS temperature.

For the two simulations, the global SSH field for the ADT simulation shows less large scale drift from its verified initial condition. For these reasons, assimilation of the ADT observations using the direct corrections to the HYCOM layer structure is currently selected as the best approach.

The temperature bias verification in vertical sections for the ADT simulation (Oct-Dec 2017) are shown in Fig 2a, b. The innovation bias for total temperature closely follows the Argo temperature bias, with a maximum bias of about 0.5°C at a depth of about 170m. Tests are underway to reduce this bias. The global SSH towards the end of the simulation (Dec 8 2017, Fig. 2c) shows an active eddy field. No large scale drift is noted during the 3 months of the simulation.

A real-time setup based on the ADT simulation is planned for operational implementation at NCEP.

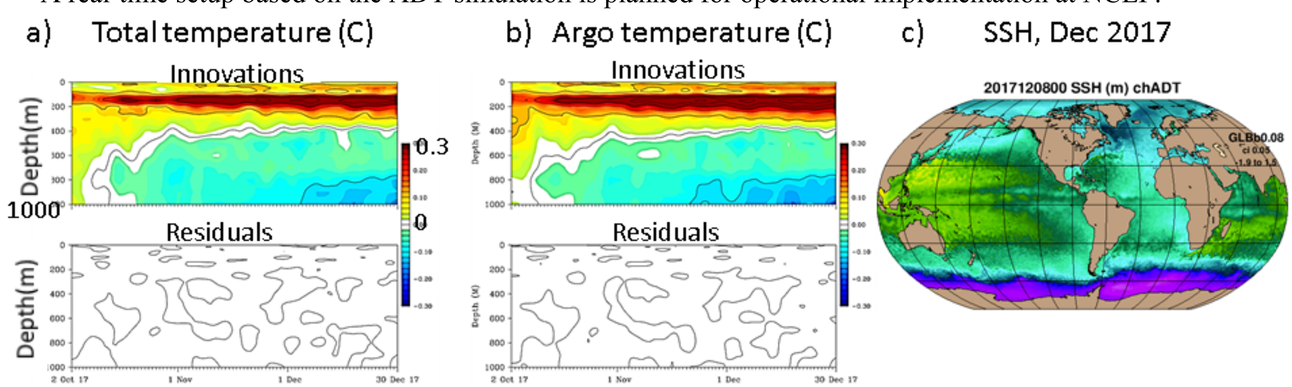

Figure 2. ADT simulation, October-December 2017: a) Temperature bias verification vertical sections: total temperature innovations (observations – forecast, top, °C), and residuals (observations – analysis, bottom); b) same as a) but for Argo Float temperature; c) SSH (m), 2.5 month from the beginning of the simulation.

References

Bleck, R. 2002. An oceanic general circulation model framed in hybrid isopycnic-Cartesian coordinates, *Ocean Model.*, 4, 55-88.
Cooper M, Haines KA, 1996. Altimetric assimilation with water property conservation. J. Geophys Res 24, 1059-1077
Cummings, J. A. and O. M. Smedstad. 2013. Variational Data Assimilation for the Global Ocean. Data Assimilation for Atmospheric, Oceanic and Hydrologic Applications (Vol II) S. Park and L. Xu (eds), Springer, Chapter 13, 303-343.
Fox, D.N, C.N. Barron, M.R. Carnes, M. Booda, G. Peggion, J.V.Gurley, 2002.The Modular Ocean Data Assimilation System. Oceanography 15 (1): 22-28
Mehra, A.; I. Rivin; Z. Garraffo; B. Rajan, 2015. Upgrade of the Operational Global Real Time Ocean Forecast System, 2015. In: Research Actiivties in Atmospheric and Oceanic modeling, Ed. Askathova, WMO/World Climate Research Program Report No.12/2015. http://bluebook.meteoinfo.ru/uploads/2015/chapters/BB_15_s8.pdf
Metzger, E.J; O.M. Smedstad; P.G. Thoppil; H.E. Hurlburt; J.A. Cummings; A.J. Wallcraft; L. Zamudio; D.S. Franklin; P.G. Posey; M.W. Phelps; P.J. Hogan; F.L. Bub; and C.J. DeHaan, 2014. US Navy Operational Global Ocean and Arctic Ice Prediction Systems. *Oceanography* 27(3):32–43 http://dx.doi.org/10.5670/oceanog.2014.66