RTOFS-DA: Real Time Ocean-Sea Ice Coupled Three Dimensional Variational Global Data Assimilative Ocean Forecast System

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Introduction

The operational Real Time Ocean Forecast System (RTOFS v1, Mehra et al., 2015) is initialized each day with ocean analyses produced daily at the Naval Oceanographic Office (Metzger et al., 2014). The core of this system consists of the coupled HYCOM and CICE numerical models, at 1/12 degree horizontal resolution with 41 layers on a global tri-polar grid. The ocean models are forced by GDAS/GFS forcing fields. In the upcoming upgrade of RTOFS (RTOFS v2), a multivariate, multi-scale 3DVar data assimilation is being added to RTOFS, which is referred to as RTOFS-DA. This new initialization capability is a coupled ocean and sea ice end-to-end system with data quality control, variational analysis and diagnostics. The analysis is performed directly on the HYCOM tri-polar grid layers using a 24-hour update cycle.

RTOFS-DA system

The daily RTOFS-DA cycle consists of several steps. The first step is decoding observational data from NetCDF or BUFR formatted input sources. The observations currently processed by RTOFS-DA include: (1) satellite and in situ Sea Surface Temperature (SST) from METOP-A, METOP-B, JPSS-VIIRS, NPP-VIIRS, GOES-16, HIMAWARI-8, ships, and buoys; (2) Sea Surface Salinity (SSS) from SMAP, SMOS, and buoys; (3) profiles of Temperature and Salinity from XBT, CTD, Argo floats, buoys, gliders, Alamo floats, animal-borne sensors, and Saildrone; (4) Absolute Dynamic Topography (ADT) from Jason, Cryosat, Altika, and Sentinel altimeters; (5) sea ice concentration from SSMI/S, AMSR2, and VIIRS; (6) surface velocity from HF Radar, ADCP, and drifting buoys; and (7) chlorophyll from ocean color (VIIRS, Sentinel). The system is designed to incorporate new observing systems, such as METOP-C, GOES-17, and HIMAWARI-9, as the data become available.

The second step is quality control (QC) of the observations in real-time using a fully automated system. The QC is done in stages incorporating sensibility, error and consistency checks. The QC outcomes are the likelihood that an observation contains an error, plus condition flags. All QC tests are performed before a QC decision is made on accepting, rejecting or scheduling the observation for correction. The QC decision-making algorithm resolves multiple background field checks (climate, cross validation analysis, and model forecasts). The QC error outcomes and condition flags are used to select valid observations for the assimilation.

The third step is forming the innovations (observation minus forecast) of validated observations within the synoptic time window of the assimilation (24-hours). This step includes application of various data thinning and data selection criteria to remove redundancies in the observations with respect to the HYCOM horizontal and vertical grid resolution. The high-density SST, SSS, and sea ice data are assimilated using the First Guess Appropriate Time (FGAT) method using innovations created from hourly HYCOM surface forecast fields. FGAT is used to prevent aliasing of the diurnal cycle in the analysis. Absolute Dynamic Topography (ADT) data are assimilated by first removing a HYCOM mean Sea Surface Height (SSH) bias with respect to the altimeter data. The correction is nearly constant (~50cm) for each altimeter track and for each altimeter satellite. ADT data assimilation adjusts HYCOM layer interface pressures by using a direct method (Cooper and Haines, 1996) that preserve model Temperature-Salinity relationships, with surface constraints provided by forecast SST, SSS, and mixed layer depths.

The fourth step is execution of the variational analysis system. The analysis takes on input innovations from randomly located observations and outputs increments, or corrections, on the HYCOM tri-polar grid layers. The increment fields include corrections to model prognostic variables not directly observed using multivariate relationships built into the analysis covariances (Cummings and Smedstad, 2013). The RTOFS-DA analysis increments are then added to the 24-hr forecast fields in the HYCOM restart file using a 3-hourly Incremental Analysis Update (IAU) procedure.

Simulation Results

A simulation that started on 23 August 2019 continues to the present in near real time. The global horizontally averaged vertical sections (Figure 1) for temperature bias (Observations-Forecast, O-F) show a maximum of 0.5°C at the depth of the seasonal thermocline (~150m) and a negative bias (-0.2°C) at the depth of the permanent thermocline (~800m). The maximum salinity bias is approximately 0.02 PSU at 150m. The residuals (Observation-Analysis, O-A) are essentially zero, which indicates that RTOFS-DA is effective at extracting all of the information contained in the observations.

RTOFS-DA Florida Current transports (Figure 2) show good agreement with observations and operational RTOFS during the time period of Hurricane Dorian, with a sharp decrease in transport due to the hurricane-force winds (08/31/19 – 09/07/19).

RTOFS-DA ocean heat content (OHC) for the same period was compared to the NESDIS product (not shown) with very similar distributions of OHC and 26°C isotherm topography. SST cooling in the wake of the hurricane, however, was not present in the NESDIS product. Surface drifter tracks (not shown) verify the positions of the Kuroshio, Gulf Stream, and Agulhas Current fronts and corresponding ocean circulation features in the HYCOM SSH forecast fields.

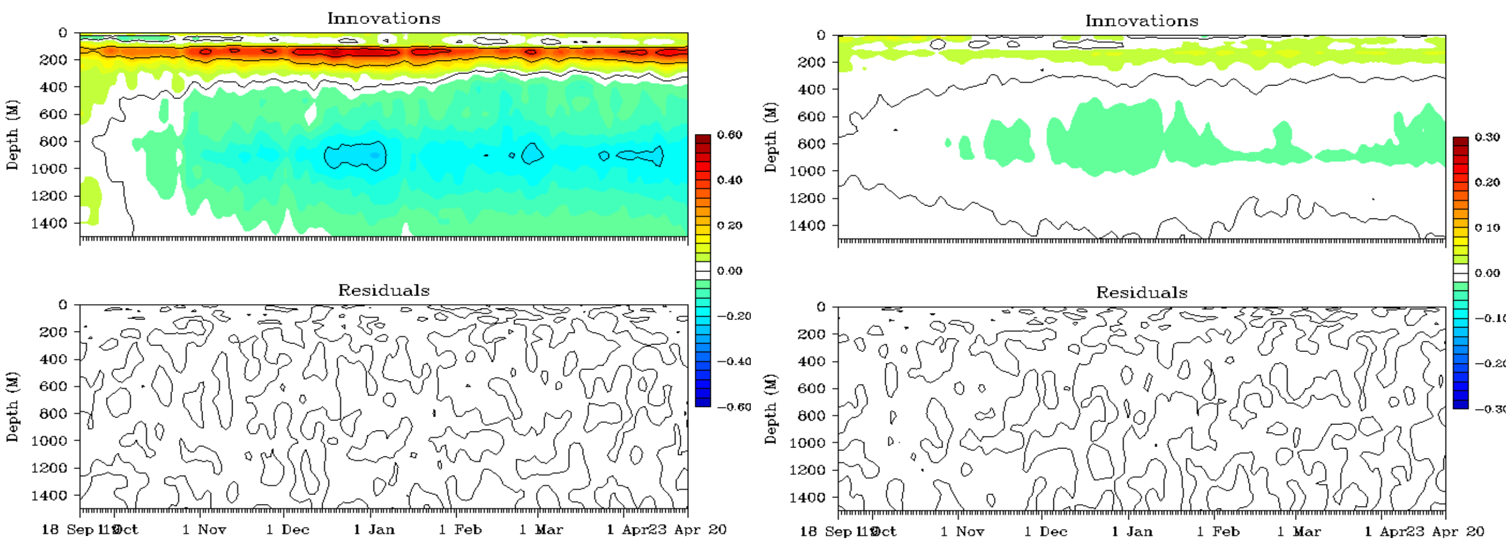

Figure 1: Horizontally averaged vertical sections of Temperature (left) and Salinity (right) innovations (O-F) and residuals (O-A) from 18 September 2019 through 23 April 2020.

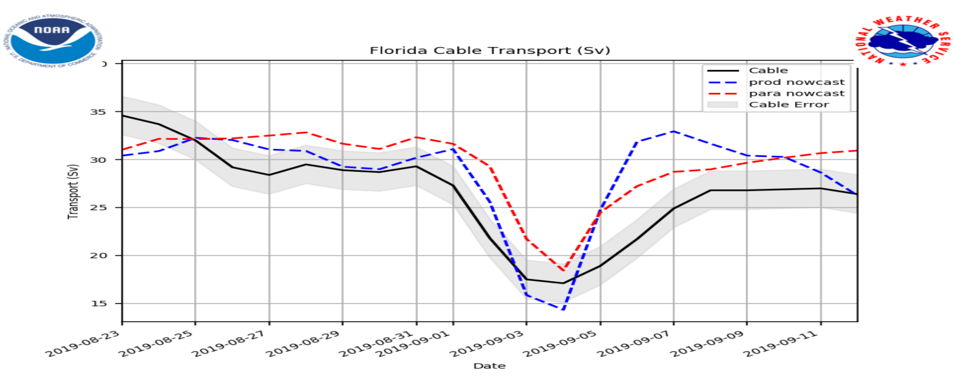

Figure 2:
Florida Current transports from RTOFS-DA (in red) compared with those from cable observations (in black) and operational RTOFS (in blue).

References

Cooper M. and 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.

Mehra, A.; I. Rivin; Z. Garraffo; B. Rajan, 2015. Upgrade of the Operational Global Real Time Ocean Forecast System, 2015. In: Research Activities 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