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Operational Ocean Forecast Systems at NWS/NCEP (RTOFS)

1. Global Real Time Ocean Forecast System (RTOFS) v2 Upgrade

1.1 Introduction

NOAA's flagship ocean and sea ice operational forecast system — the Global Real-Time Ocean Forecast System (Global RTOFS) — was upgraded to version 2.0 in December, 2020 that introduced a global mesoscale ocean data assimilation capability at NWS/NCEP for the first time.

RTOFS v1(Mehra et al., 2015) was 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. With RTOFS v2, a multivariate, multi-scale 3DVar data assimilation was 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. Global RTOFS provides predictions for up to eight days of ocean currents, salinity, temperature and sea ice conditions around the world.

1.2 **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 6-hourly Incremental Analysis Update (IAU) procedure.

1.3 **Users**

Forecasters at NOAA's Ocean Prediction Center and the National Weather Service's National Hurricane Center are the primary users of the Global RTOFS model, as it provides numerical guidance for marine forecasts and warnings, including those from hurricanes and other extreme weather events over open waters, islands and coastal regions. Additionally, the U.S. Coast Guard uses this ocean forecasting system routinely, especially during search and rescue operations.

During testing, the upgraded Global RTOFS helped improve hurricane track and intensity forecasts. Additional improvements include more detailed and improved sea ice concentrations, regional sea surface temperature and near-surface ocean conditions in all global oceanic basins.

Global RTOFS is part of a larger national backbone capability of ocean modeling at the National Weather Service in partnership with the U.S. Navy. The advancements made to the Global RTOFS version 2.0 help pave the way forward for future ocean, sea ice and coupled data assimilation efforts at the National Weather Service — leading to improved forecast skill and products, and helping to build a more Weather-Ready Nation.

References:

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2 Regional Coupled Hurricane Forecast Systems

NWS/NCEP runs two operational Hurricane Forecast systems, namely, HWRF (Hurricane Weather Research and Forecast) system and HMON (Hurricanes in a Multiscale Ocean-coupled Nonhydrostatic) modeling system. Both these systems are coupled fully to regional ocean models -- either HYCOM or MPIPOM (MPI Princeton Ocean Model). Figure 1 (below) describes the differences between individual basins in terms of coupled ocean models used and their sources of initialization in these operational system:

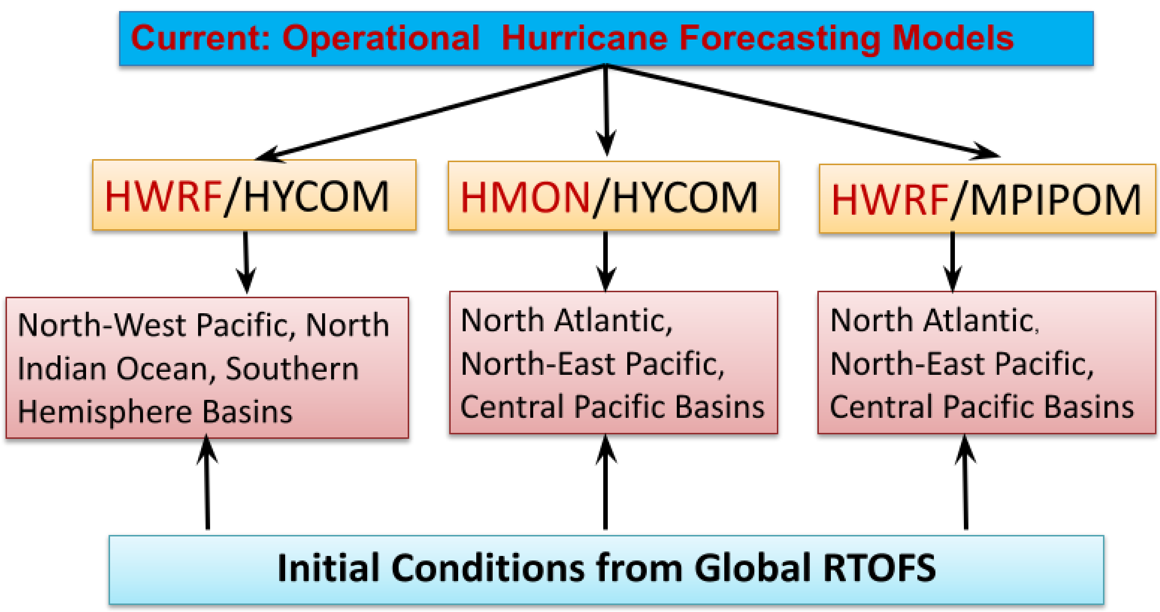

Figure 1: Operational regional coupled Hurricane models at NWS/NCEP are initialized using ocean states from RTOFS.

More details on these operational Hurricane Forecast Systems is available at:

https://www.emc.ncep.noaa.gov/gc_wmb/vxt/HWRF/about.php?branch=summary

and

https://www.emc.ncep.noaa.gov/gc_wmb/vxt/HMON/about.php?branch=impl