National Report

a. Brazil – REMO

Background

- A specific Brazilian effort on operational oceanography with focus on short-range ocean forecasting and reanalysis started in 2008 under the Oceanographic Modeling and Observation Network (REMO) (Lima et al. Rev. Bras. Geofis., 2013). Today, REMO's members are: Brazilian Navy Hydrographic Center (CHM), Federal University of Bahia (UFBA), Federal University of Rio de Janeiro (UFRJ), Research and Development Center Leopoldo Américo Miguez de Mello (CENPES) of the Brazilian State oil company Petrobras.
- A nested operational forecasting system based on the HYbrid Coordinate Ocean Model (HYCOM) runs in CHM for the Atlantic Ocean (78ºS-50ºN, 100ºW-20ºE excluding the Pacific Ocean), for the tropical and South Atlantic (56ºS-10ºN, 67ºW-18ºW) that encompasses the so-called Atlantic Metarea V (35.5ºS-7ºN, west of 20ºW until Brazil), and for the S-SW Atlantic off the Brazilian S-SE coast (35ºS-12ºS, 54ºW-32ºW). The initial conditions are produced by the REMO Ocean Data Assimilation System (RODAS) based on a multivariate ensemble optimal interpolation (EnOI). A simplified version of RODAS was implemented in February 2013, substituting an optimal interpolation scheme, and an upgrade was implemented in January 2020.
- A new nested system with 1/12º resolution over 100ºW-40ºE, 78ºS-50ºN, and a 1/24º resolution over 65ºW-20ºW, 45ºS-10ºN with tidal forcing, both with 32 vertical layers, was implemented in January 2020. During 2020, CHM run operationally the two nested systems to produce 3-5 days forecasts, but the older system should be discontinued in 2021.
- The funding for REMO development come from Petrobras and the Brazilian Agency for Petroleum, Natural Gas and Biofuels (ANP). CHM staff maintains the operational system, but developments in the model and assimilation come from UFBA and UFRJ, which depend on soft money.

1. Input data

REMO's HYCOM+RODAS operational system took sea level anomalies (SLA) from Atobá-CLS - a special data produced by CLS for REMO - from December 2, 2014 until December 11, 2015. Since then, the system uses the publically available AVISO products from the Copernicus System. Sea surface temperature (SST) analysis from the UK Met Office OSTIA, along-track SLA data from DUACS/AVISO obtained at the Copernicus Marine Environmental Monitoring Service (CMEMS) site with 7 km resolution, and Argo profiles of temperature (T) and salinity (S) data are employed to constrain the initial condition in the 3 and the 2-nested-grid systems on operation.

2. Data serving

CHM has not yet made available forecast files and data. Only figures are made available in the CHM web page https://www.marinha.mil.br/chm/dados-do-smm-modelagem-numerica-tela-de-chamada/modelagem-numerica. UFBA was made available an area under the web page www.rederemo.org with THREDDS to make model outputs available, but only few runs were placed there.

3. Models

The HYCOM version 2.2.18 is used in REMO. The COSMO atmospheric model implemented in CHM is used to produce the atmospheric forcing for the operational HYCOM+RODAS 1/24º grids and for the 1/12º grid of the older 3-nested-grid system.

4. Assimilation method

RODAS is based on a multivariate EnOI. However, the RODAS version employed operationally in CHM assimilates along-track SLA data to create an SSH analysis without increments on the model state in the subsurface. The subsurface correction is done employing the Cooper and Haines scheme. This strategy was not employed in the construction of reanalyses by UFBA mentioned below.

5. Assimilation products and dissemination

Only figures of the model initial condition and forecasts are available in CHM´s web page https://www.marinha.mil.br/chm/dados-do-smm-modelagem-numerica-tela-de-chamada/modelagem-numerica for specific fields, such as SST, SSH, surface currents and vertical sections of temperature, zonal current and meridional current at specific latitudes and longitudes. This dissemination is part of the Brazilian Navy Marine Meteorological Service.

6. Systems

The operational system running in CHM today is based on HYCOM and in the REMO Ocean Data Assimilation System (HYCOM+RODAS). Three different domains are employed to daily produce 5 to 6-day forecasts using a nesting strategy: (i) a large-scale configuration with 1/4º of horizontal resolution and 21 vertical layers that covers almost the whole Atlantic Ocean, from Antarctica to 50ºN and from 100ºW to 20ºE, except the Pacific - constant barotropic mass fluxes and relaxation of temperature and salinity for climatology are imposed as lateral boundary conditions; (ii) an eddy resolving configuration with 1/12º of horizontal resolution and 21 vertical layers over the region 56ºS-10ºN, 67ºW-18ºW that contains the Metarea V; and (iii) a meso-scale configuration with 1/24º of horizontal resolution and 21 vertical layers for the S-SW Atlantic region off the Brazilian south-southeast coast, from the continent to 32ºW, and from 35ºS to 12ºS. This high-resolution grid contains tidal forcing with 8 components of the TPXO 7.2 model.

An upgrade of the forecasting system with higher resolution and 2 nested grids was implemented operationally in January 2020: a 1/12º resolution over 100ºW-40ºE, 78ºS-50ºN and, and a 1/24º resolution over 65ºW-20ºW, 45ºS-10ºN and 32 vertical layers with tidal forcing, both with 32 vertical layers.

The 24-h forecast produced by each grid in the nested system is used as the first guess for the analysis in their respective domains, but data assimilation is realized only on Tuesdays and Fridays.

The forecasts employ 3-hourly forcing from the National Centers for Environmental Prediction (NCEP) Global Forecast System (GFS) with 1/4º of horizontal resolution, but the higher resolution 1/24º grids employ forecasts from the Consortium for Small-scale Modeling (COSMO) that runs operationally in CHM. The horizontal resolution employed in COSMO is 10 km.

7. Observations

REMO contributes to the in situ observing system along the Brazilian continental shelf-shelf break as part of the Brazilian National Buoy Program (PNBOIA), partially covering the maintenance expenses of six other moored buoys. The moorings have sensors to collect atmospheric and oceanic data, such as SST, air temperature, air relative humidity, sea level pressure, wind direction and speed, solar radiation, surface wave direction, period and height, surface current and subsurface temperature and salinity. In 2020, a new mooring should be deployed in the slope in the Campos basin off Rio de Janeiro, but the exact date is not defined yet.

REMO is a member of the Brazilian regional observational system, a projection of GOOS in Brazil, called in Brazil as GOOS-BR. GOOS-BR considers observational systems that are Brazilian and others in which Brazil participates under international collaboration, such as PIRATA and the NOAA XBT line AX97. REMO will contribute to supporting the development of observational arrays and demonstrating its importance via observing system experiments (OSEs).

8. Internal metrics and intercomparison plans

The internal metrics used to investigate the skills of simulations and forecasts are root mean square errors, Taylor diagrams, correlations and mass transport at specific sections along the Brazilian shore wit focus on the Brazil Current. Not always the observational space is respected to calculate errors and correlations. Data from XBT, Argo, PIRATA, GLOSS and AVISO are employed for this assessment.

REMO would like to participate in the IV-TT by regularly offering initial condition, forecasts, persistence and climatology interpolated to the locations of Argo profiler observational space, along-track SLA data from satellites and SST analyses. Despite the attempts, different factors contributed to REMO's absence in the IV-TT, including the definition of a policy to provide near real time forecasts produced by the Brazilian Navy.

9. Targeted Users and envisioned external metrics

The main users of REMO products are the Brazilian oil company Petrobras and the Brazilian Navy. However, REMO would like to reach a large spectrum of users of the oceanographic community. Differently from the general user, Petrobras and the Brazilian Navy have direct access to the analyses and all forecasts produced in CHM. The users from Petrobras perform evaluation of the forecasting system with their own current and temperature data collected at the offshore oil platforms and also other reanalyses. REMO should work harder to reach external users in Brazil by providing reanalyses outputs and, if possible, forecast files in near real time.

10. Reanalysis activities

The group at UFBA produced 2 11-yr reanalyses with HYCOM+RODAS with 1/12^o horizontal resolution and 32 layers over the domain 56^{o}S-10^{o}N, 67^{o}W-18^{o}W from 1 January 2008 to 31 December 2018. The reanalyses were forced with NCEP/NOAA Climate Forecasting System Reanalysis (CFSR) and were performed each 3 days. One assimilated OSTIA SST, gridded SLA data from AVISO and Argo T/S profiles. The other assimilated OSTIA SST, gridded absolute dynamic topography and T/S profiles from Argo, XBTs, CTDs and PIRATA. The reanalyses were produced using different strategies to assimilate T/S profiles. One projected the data into the model isopycnic layers to calculate the innovation. The other calculated innovation in the observational space. Another 10-yr reanalysis was performed for the Southwest Atlantic (35^{o}S-7^{o}S, west of 31^{o}W) with 1/24^o of horizontal resolution and 32 vertical layers. It assimilated OSTIA SST, gridded SLA and T/S profiles from Argo, XBTs, CTDs and PIRATA. It is expected that the reanalyses will be soon made available in the REMO site.

The group at UFRJ produced 10-yr reanalyses employing HYCOM and the Tendral Statistical Assimilation System (T-SIS) over the regions 100^{o}W-40^{o}E, 78^{o}S-50^{o}N, and 65^{o}W-20^{o}W, 45^{o}S-10^{o}N with tidal forcing. The first had 1/12^o of horizontal resolution and the other 1/24^o, both with 32 vertical layers. T-SIS also employs EnOI.

11. Computing resources

The CHM operational system runs today in two machines: (i) a SGI Altix ICE 8200 machine with 640 Xeon 3 GHz processors organized in 48 computational nodes, each node with 24 GB of memory; and (ii) a SGI Altix ICE X with 648 Xeon 3 GHz processors organized in 27 computational nodes, each node with 24 GB of memory. The data storage system has a capacity of 110 TB.

Smaller machines are also available for each REMO member, such as the SGI Altix XE 1300 with 40 Xeon 2.6 GHz processors each node with 16 GB of memory and the SGI Rackable cluster with 13 computational nodes, each containing 2 eight-core Xeon 2.4 GHz with 64 GB of memory. Data storage with 156 TB serves UFBA systems. An SGI ICE X machine at UFBA with 936 processors distributed in 39 blades was used to produce the HYCOM+RODAS reanalysis. New computer should be purchased in 2021 by CHM, but the configuration is still not closed.

12. Consolidation phase and transition to operational system (activities)

The 3-grid nested system mentioned above will be discontinued in 2021. The new higher resolution system composed by 2 nested grids has been running operationally for more than 1 yr with success. It will replace the older one.

An approach to construct synthetic salinity with a 5th order polynomial depending on temperature was successfully implemented into HYCOM+RODAS. This allowed the system to assimilate vertical profiles of temperature without its pair salinity. In the surface, up to about 100-200 m, the polynomial attains larger errors than climatology, when compared to independent CTD data, but below the polynomial performs much better. The proposed approach is hybrid, since it combines the use of climatological data and polynomial data (Dorfschafer et al. JGR Oceans, 2020)

13. GODAE OceanView related achievements and measures of success

Several graduate and undergraduate students were and are involved with REMO under GODAE OceanView and OceanPredict research lines from 2007 to 2020, specifically: (i) 21 bachelor monographs, 28 M.Sc. dissertations and 12 D.Sc. thesis were produced to date; and (ii) 1 undergraduate student, 2 M.Sc. students and 4 Ph.D. students are today working under REMO. Also, 8 post-docs and senior researchers have worked in the group. This shows that REMO is committed to capacity building and education in physical oceanography and operational oceanography.

REMO was among the three finalists to the 2019 Award in Technological Innovation by the Brazilian Agency for Petroleum, Natural Gas and Biofuels (ANP) under the theme “Safety, Environment and Health”.

REMO was also invited to participate in the 3nd BRICS Meeting of the BRICS Working Group on Ocean and Polar Science and Technology, organized by India on September 23, 2020. REMO could contribute to offer guidelines for calls of proposals for joint research in oceanography, particularly in operational oceanography, among Brazil, Russia, India and South Africa.

REMO published 67 papers in international journals from 2007 to 2020, including a special issue in the Brazilian Journal of Geophysics in 2013.

System information overview

System name	REMO- HYCOM 1/4 Regional
Ocean Models	
OGCM	HYCOM
Domain	78ºS-55ºN 100ºW-20ºE excluding the Pacific
Horizontal resolution	1/4 degree
Vertical sampling	21 hybrid layers
Atmospheric Forcing	NCEP GFS 0.25º 3-hourly
Assimilation characteristics	
Assimilation Scheme	EnOI and Cooper and Haines
SST	OSTIA
SSH	Along-track SLA NRT CMEMS/AVISO L3
Other	Argo T/S vertical profiles
System Set-ups	
Forecast range	144 h (6 days)
Update frequency	Daily, analysis at each 5 days
Hindcast length	None
System website links	
General information	not available
Technical description	not available
Viewing service	not available

System name	REMO- HYCOM 1/12 Regional
Ocean Models	
OGCM	HYCOM
Domain	56ºS-10ºN 67ºW-18ºW
Horizontal resolution	1/12 degree
Vertical sampling	21 hybrid layers
Atmospheric Forcing	CHM COSMO with 0.1º resolution
Assimilation characteristics	
Assimilation Scheme	EnOI and Cooper and Haines
SST	OSTIA
SSH	Along-track SLA NRT CMEMS/AVISO L3
Other	Argo T/S vertical profiles
System Set-ups	
Forecast range	120 h (5 days)
Update frequency	Daily, analysis at each 5 days
Hindcast length	None
System website links	
General information	https://www.rederemo.org
Technical description	https://www.marinha.mil.br/chm/dados-do-smm-paginas-modelagem-numerica/modelo-hycom
Viewing service	https://www.marinha.mil.br/chm/dados-do-smm-modelagem-numerica-tela-de-chamada/modelagem-numerica link to METAREA V

System name	REMO- HYCOM 1/24 Regional
Ocean Models	
OGCM	HYCOM
Domain	35ºS-12ºS 54ºW-32ºW
Horizontal resolution	1/24 degree
Vertical sampling	21 hybrid layers
Atmospheric Forcing	CHM COSMO with 0.1º resolution

Assimilation characteristics	
Assimilation Scheme	EnOI and Cooper and Haines
SST	OSTIA
SSH	Along-track SLA NRT CMEMS/AVISO L3
Other	Argo T/S vertical profiles
System Set-ups	
Forecast range	96 h (4 days)
Update frequency	Daily, analysis at each 5 days
Hindcast length	None
System website links	
General information	www.rederemo.org
Technical description	https://www.marinha.mil.br/chm/dados-do-smm-paginas-modelagem-numerica/modelo-hycom
Viewing service	https://www.marinha.mil.br/chm/dados-do-smm-modelagem-numerica-tela-de-chamada/modelagem-numerica link to 4KM