Centro Interdisciplinar de Investigação Marinha e Ambiental da Madeira

PSY2V4R4 Real Time Service

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Feedback and Activity Report 2014

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http://ciimarmadeira.org

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1 Introduction

Implementing an open-ocean circulation forecasting system on a small island poses several logistical and technical difficulties. Madeira Island is located ~400 km offshore of the African Coast and ~900km from the European Continent (Portugal). Four open-boundaries (OB) are often unstable conditions to be sustained by numerical models and climatic nudging at four OB are inaccurate reference states to produce daily forecasts. However, large numerical domains at medium to high resolutions (temporal and/or spatial) have high computational costs, thus the usage of an available global model solution to force a regional models enables forecasts to be calculated locally. In addition, small islands often have a limited computational resources and a limited internet connection to the nearest continent and thus limited (fast) access to large datasets. For the last five years we have been using the Mercator solution together with the Global Forecasting System (GFS) to force our Regional Ocean Modeling System (ROMS). Madeira Regional models have also been useful to help the planning of in situ campaigns and/or pursue dynamic case studies.

2 Madeira Oceanic Forecasting System: Global to Regional

The Madeira ocean circulation modeling system first started with climatology at the oceanic boundaries and reanalyzed atmospheric boundary conditions from NCEP. The spin-up period of the Regional model lasted 3 years until April 2010, and the forecasting mode started in May of 2010. In the forecasting model the ocean climatology was replaced by the global model solution and the atmosphere by its forecasting counterpart i.e. GFS. Every week, the real time MERCATOR global model solution (PSY2V4R4) is used to force the Regional Oceanic Modeling System (ROMS). Two nested grid inside ROMS allow the increase in spatial resolution from 3km down to ~900m (see figure 1).

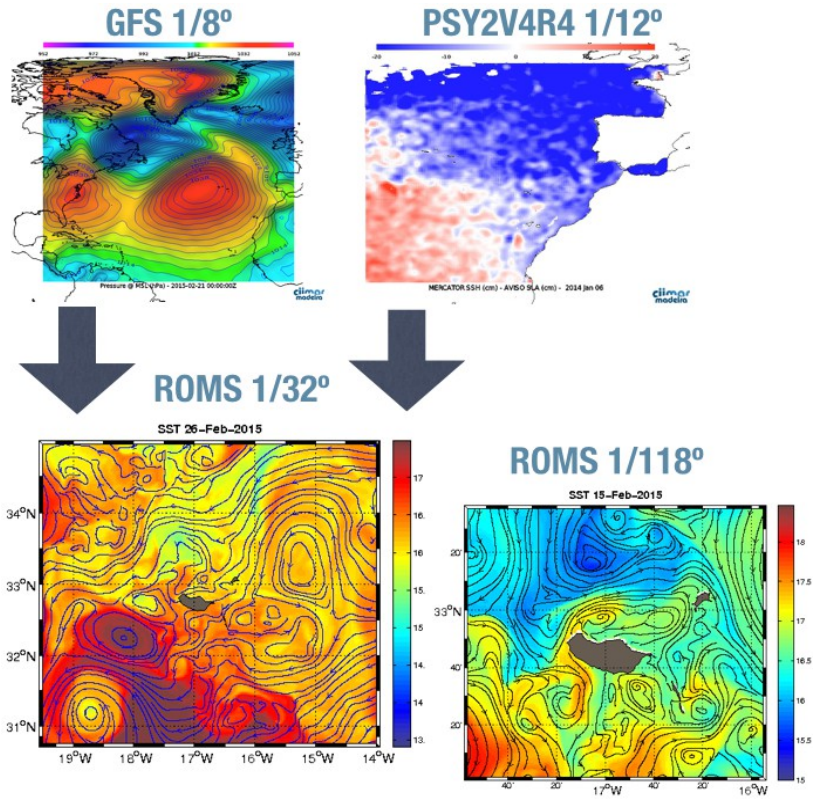

Figure 1 – Graphical representation of the Madeira Global to Regional forecasting system forced by GFS and MERCATOR models.

The Global Forecasting System (GFS) at 1/8º, provides the atmospheric wind and radiation fields for the Regional Ocean Model. The atmospheric fields are renewed every day, whereas the oceanic global model boundary fields are renewed once a week. Every Wednesday (T0) the whole system renews 7 days of hindcast (including nowcasts) and produces 7 new days of forecasts (figure 2). Thus the system advances 7 days every week.

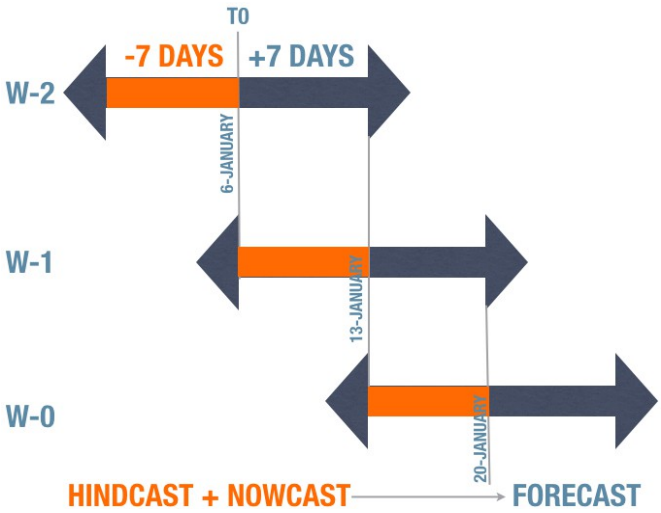

Figure 2 – Weekly timeline of the Madeira oceanic forecasting system.

The Madeira forecasting system is fully automatic including the download of daily and weekly datasets. The results are published online at: http://home.ciimarmadeira.org/index.php?page=oceano. Maps of temperature, salinity, ocean currents, and vorticity are available for different depths (0-1000m). Sea Surface Height plots are also available for both sub-domains. Apart from plotting results in a 2D map, some variables are also plotted in relationship with the bathymetry, providing a 3D-like representation of the fluid moving in and around the Archipelago (see figure 3).

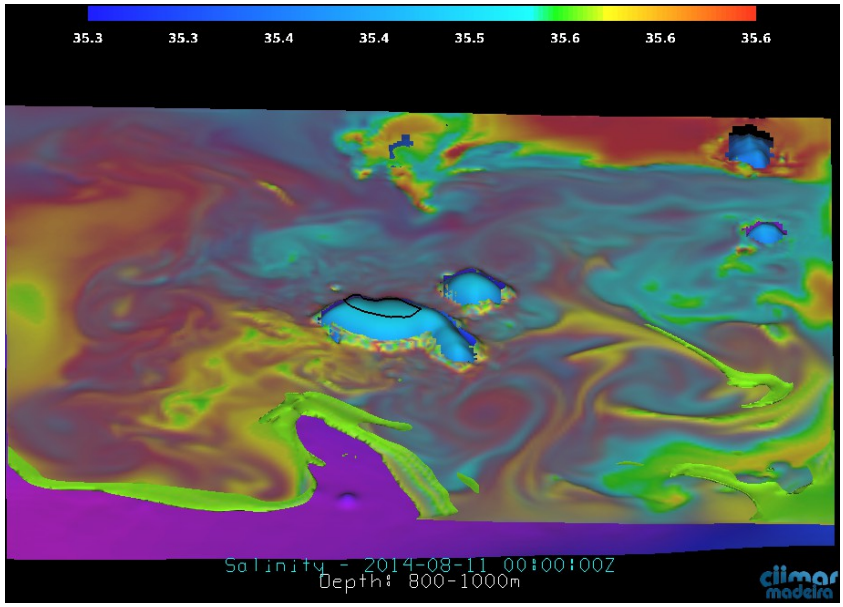

Figure 3 – Map of salinity (PSU), representative of the upper Mediterranean Intermediate Water (MIW) layer (800-1000m).

3 Model validation

Non spite the fact that the model is operational in forecasting mode since May 2010, there was a need to discard historical results in order to clear space for more recent ones. Nevertheless, the 2014 results were preserved in order to do an evaluation of the model relative to observations. Several comparisons were made considering both the Global and Regional solutions, namely:

(i) Sea surface current (model) vectors were compared with observed currents (http://www.oscar.noaa.gov/);

(ii) SSH-Sea Surface Height Anomalies compared model results with AVISO-SLA (http://www.aviso.altimetry.fr/en/data/products/sea-surface-height-products/global/sla.html#c10389);

(iii) SST-Sea Surface Temperature Anomalies, compared model SST with GHRSST (http://podaac.jpl.nasa.gov/GHRSST).

In general, MERCATOR represents well the NE Atlantic (known) sea surface circulation patterns, both in terms of intensity and direction. The turbulent Azores Current is well depicted by MERCATOR, as well as some of the mesoscale eddy features, as it is shown in figure 4 below. In some instances, MERCATOR under- or over-estimates current speed but in general most of the dynamics are well represented. The good comparison is maintained throughout the whole of 2014. The full dataset is available online: http://home.ciimarmadeira.org/index.php?page=valid

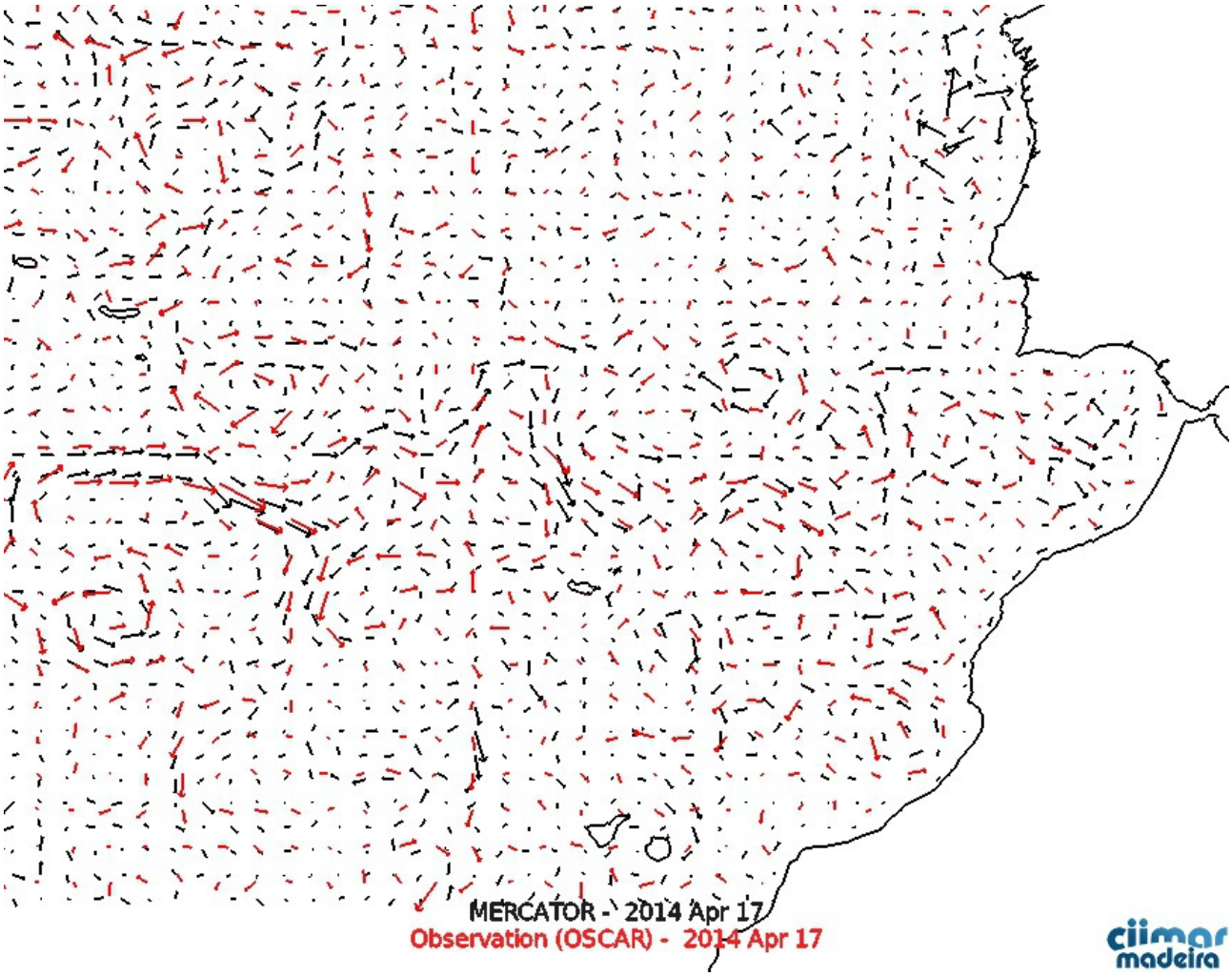

Figure 4 – Sea surface currents comparing Global model solutions (MERCATOR) with currents derived from satellite and in situ observations (OSCAR).

The comparisons between MERCATOR and SLA from AVISO and between Satellite SST and model-SST however shows some differences. MERCATOR often underestimates (10-20 cm) SSH in temperate and cold regions and overestimates SSH (10-20 cm) in tropical and sub-tropical regions. Differences in sea surface temperature are also notable reaching +/- 1ºC, in the NE Atlantic.

(a) (b)

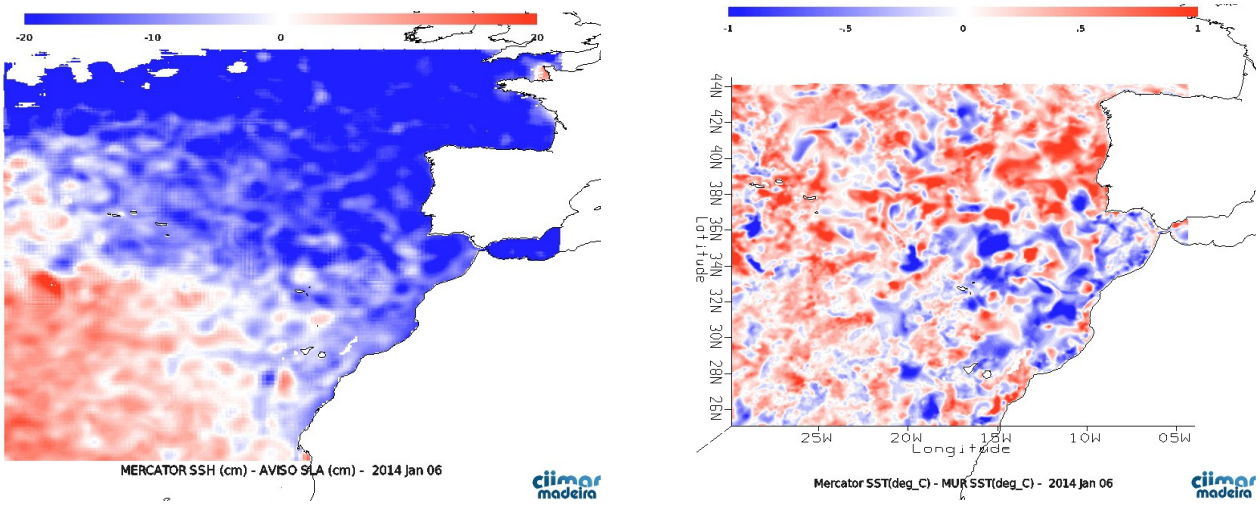

Figure 5 – Sea surface maps of the NE Atlantic comparing (a) AVISO SLA-Sea Level Anomaly with MERCATOR-SSH; (b) MERCATOR-SST with GHRSST derived from satellite measurements.

As for the Madeira Archipelago Region, MERCATOR mostly underestimates SSH (10-20cm), and it slightly overestimates SST (0.5-1 ºC), particularly leeward of the Madeira Island, during summer months.

(a) (b)

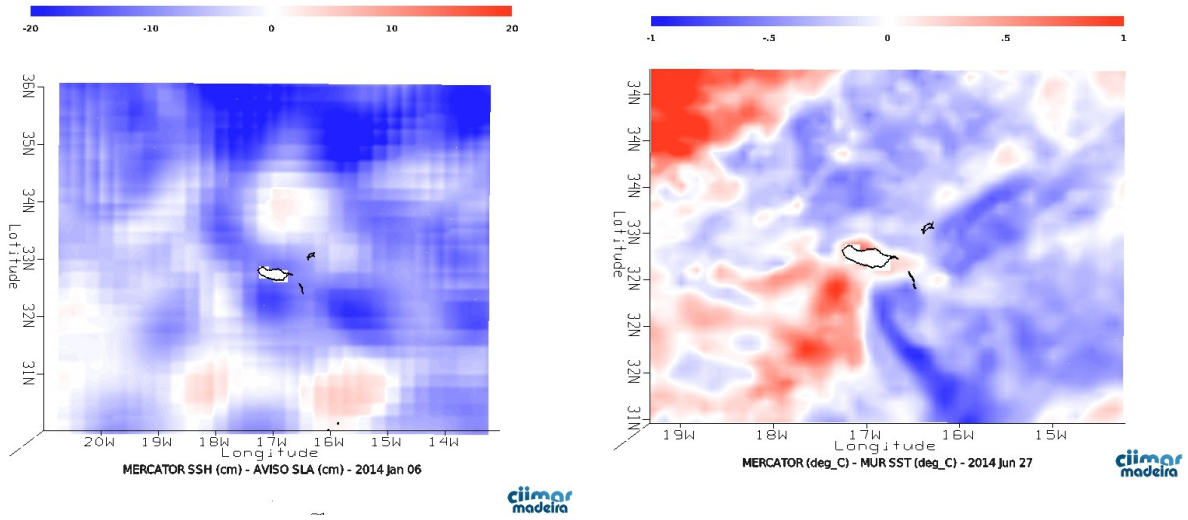

Figure 6 - Sea surface maps of the Madeira Archipelago Region comparing (a) AVISO SLA-Sea Level Anomaly with MERCATOR-SSH; (b) MERCATOR-SST with GHRSST derived from satellite measurements.

The Regional model (ROMS) is improving the representation of surface currents but is cooling the sea surface, relative to the observations. As figure 7 shows island-induced currents such as an anticyclonic eddy captured on the 12th of July 2014 by OSCAR data is well represented in ROMS but is missing in the Global model results. Therefore Global model represents well the Basin scale currents but Regional models are essential to resolved the local and Regional dynamics. In terms of SSH, ROMS slightly over- and under-estimates the SLA (~ +/- 5cm). Regarding SST, and contrary to MERCATOR, ROMS cools down the SST, relative to the satellite derived observations. However, there are better comparisons with far-field induced phenomena, than there are with near the islands.

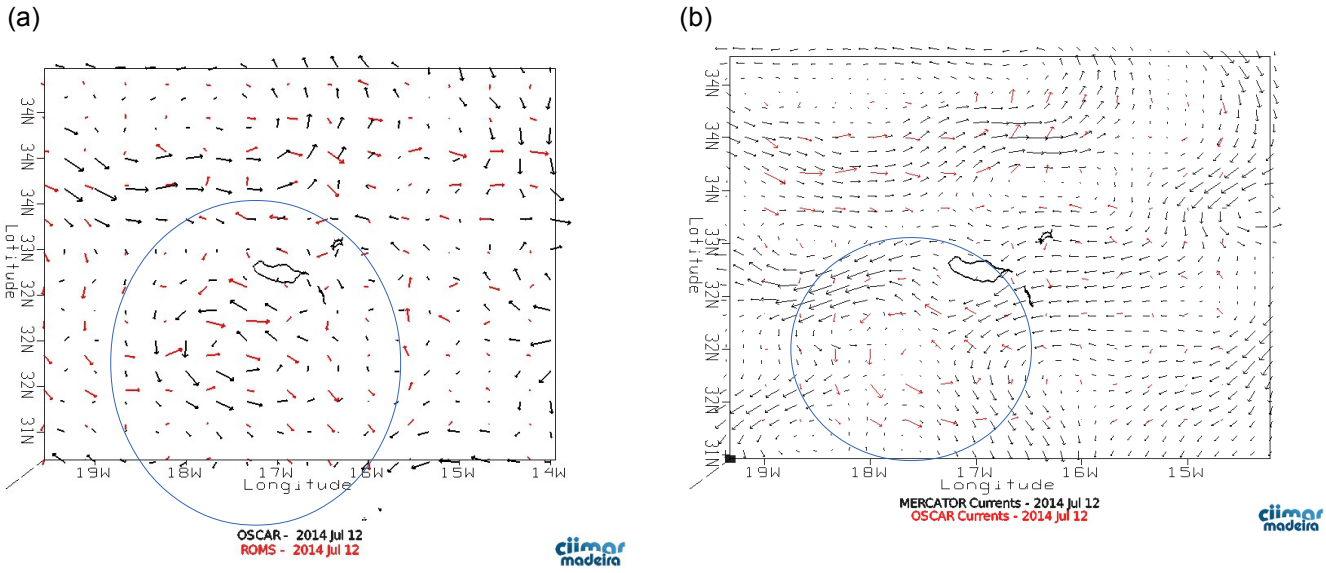

Figure 7 – Derived sea surface currents for the Madeira Archipelago Region comparing OSCAR with (a) ROMS and (b) MERCATOR.

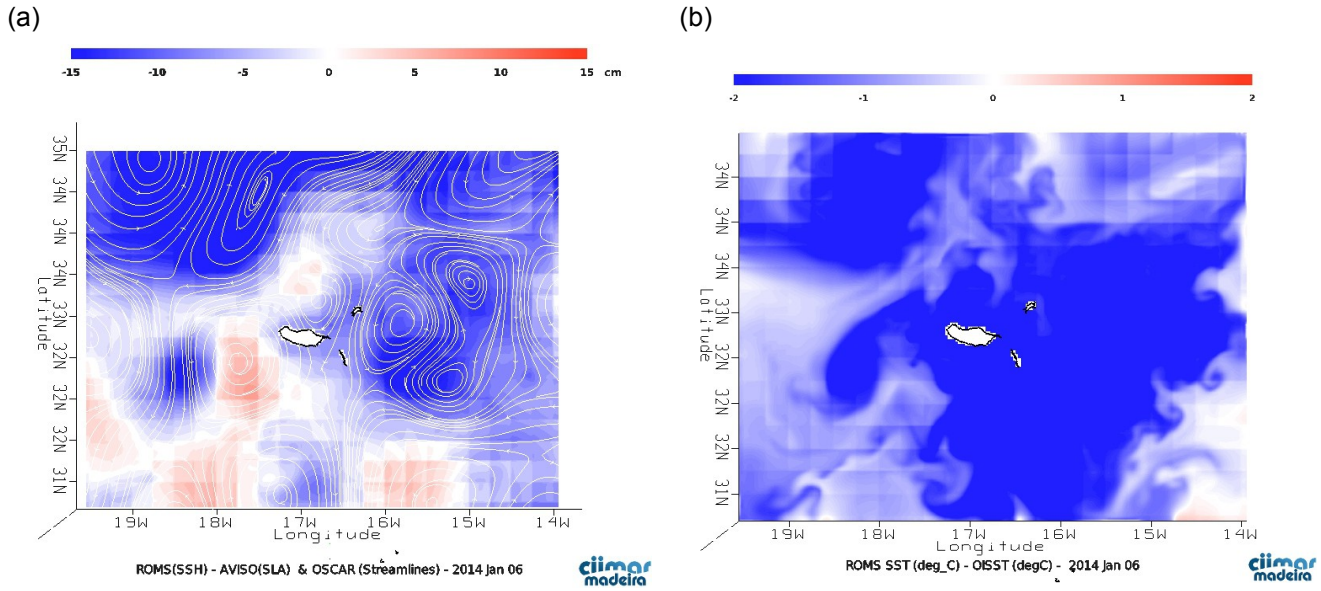

Figure 8 - Sea surface maps of the Madeira Archipelago Region comparing (a) AVISO SLA-Sea Level Anomaly with ROMS-SSH. Oscar streamlines are also represented as white lines; (b) ROMS-SST with GHRSST, derived from satellite measurements.

It is important to note that the MERCATOR V3 SST values are less biased than the V2 version thanks to the assimilation of AVHRR-AMSRE 1⁄4° Reynolds products. This also explains the patchy look of the SST anomaly maps shown is figures 5b and 6b,, since most variability patches seem to occur in regions smaller than 1/4º (~30km). The data are assimilated by means of a reduced-order Kalman filter with a 3D multivariate modal decomposition of the forecast error. It includes an adaptive-error estimate and a localization algorithm. A 3D-Var scheme provides a correction for the slowly-evolving large-scale biases in temperature and salinity (Dombrowsky, et al., 2011). MyOcean altimeter data, in situ temperature and salinity vertical profiles from ARGO drifters and satellite sea surface temperature are jointly assimilated to estimate the initial conditions for numerical ocean forecasting. In addition t3 the quality control performed by data producers, the system carries out an internal quality control on temperature and salinity vertical profiles in

order to minimize the risk of erroneous observed profiles being assimilated in the model. Note that in addition to Jason 2 and Cryosat 2 altimetry observations, Jason 1 altimetry observations are assimilated until June 2013 (until the end of the mission on June 21st) and SARAL/Altika observations start being assimilated in August 2013. As expected the assimilation only pursued in hindcast products to produce the analysis. The analysis is not performed at the end of the assimilation window but at the middle of the 7-day assimilation cycle. The objective is to take into account both past and future information and to provide the best estimate of the ocean centered in time. With such an approach, the analysis, to some extent, acts like a Smoother algorithm.

In October 2010, the Envisat altimeter was brought to a lower orbit, which has led to a slight degradation of data quality (Ollivier and Faugere, 2010). This degradation is due to the fact that SLA is computed with respect to a Mean Sea Surface of lower quality because it falls outside the historical repeat track. This is particularly true at high latitudes where no tracks from other missions are available. For this reason, the Envisat error was increased by 2 cm over the entire domain and by 5 cm above 66° N. In view of this 2-5cm error, the calculated anomaly for SSH-SLA is not has large has originally considered, particularly for the Madeira Archipelago Region.

In terms of representation of the water masses the Theta-S analysis shows good correlations for all seasons between MERCATOR and CORIOLIS-ARGO profiles, for 2014 (figure 9). This is somewhat expected since most of these profiles are assimilated onto the Global model.

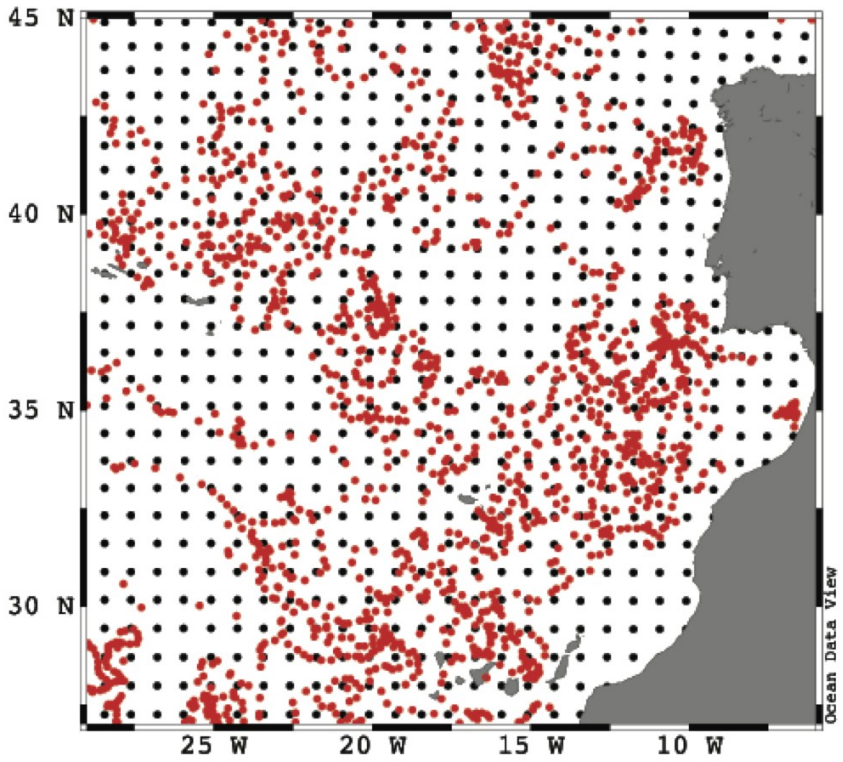

Figure 9 – Map showing the MERCATOR grid points (black dots) and the CORIOLIS_ARGO profiles (red dots).

Most interesting to observed however is the fact that in periods where the mixed layer is destroyed I.e. less T-S variability is also observed (Winter and Autumn), inferring that the Mixed Layer Depth is generally well represented in the Global Model.

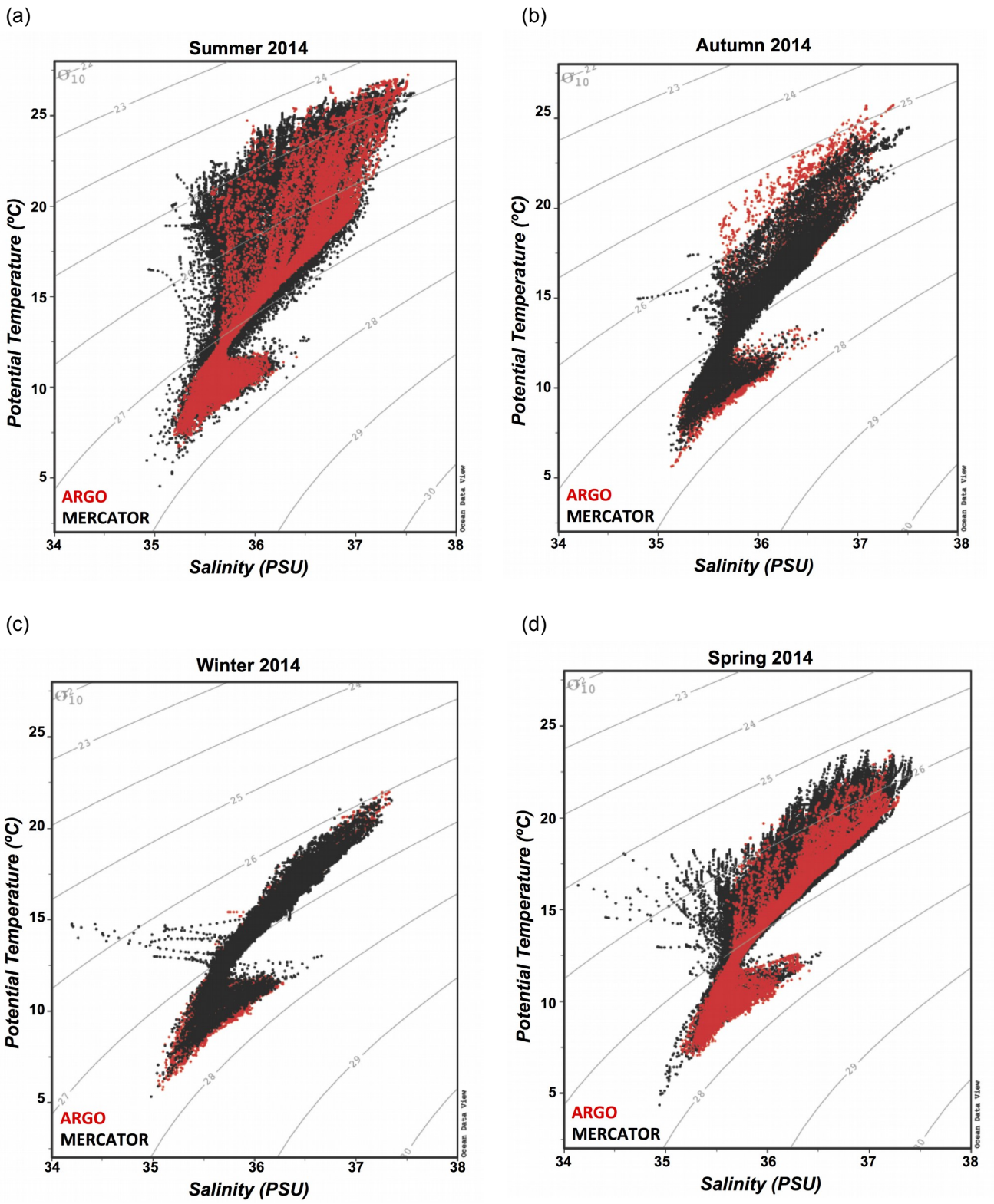

Figure 9 (cont.) - Theta-S diagrams comparing MERCATOR T-S variability with the observed Coriolis_ARGO dataset for 2014.

Non-spite having no data assimilation, the Regional model maintains the good representation of the waters masses around the Madeira Archipelago, inherited by the Global model at the four OB. Figure 10 shows a

comparison between ARGO and ROMS T-S profiles for the whole year (2014). ROMS shows slightly more variability at the surface but it keeps a good representation of the North Atlantic Central Surface Water (T:4-20ºC; S:35-36.8PSU); of the MIW – Mediterranean Intermediate Water (T:6-11.9ºC; S:35.3-36.5PSU) as well as of the NADW – North Atlantic Deep Water (T:3-4ºC; S:34.9-35.0PSU).

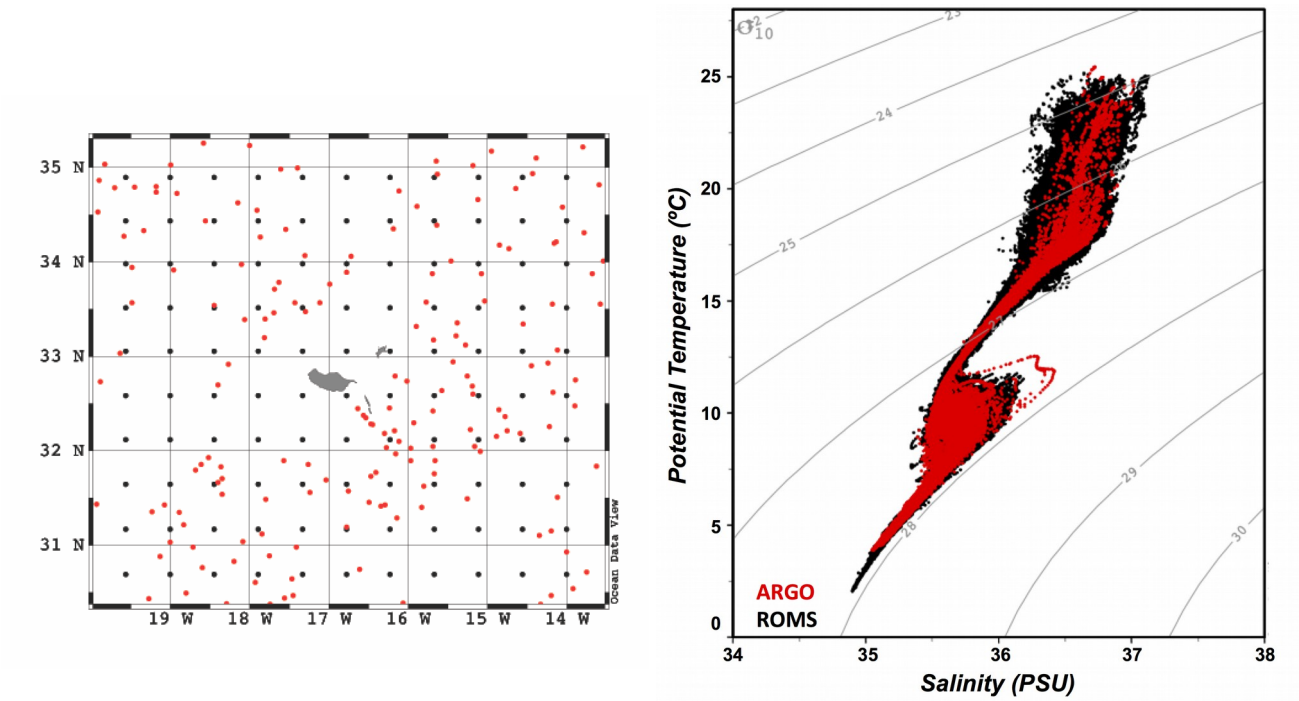

Figure 10 – Comparison between CORIOLIS-ARGO profiles (red dots) and ROMS profiles (black dots), in the Madeira Archipelago Region during 2014.

4 Published Articles

We have used different configurations of ROMS for different studies that were published recently, namely:

- X. Couvelard, R.M.A. Caldeira, I.B. Araújo, R. Tomé, (2012). Wind mediated vorticity-generation and eddy-confinement, leeward of the Madeira Island: 2008 numerical case study. *Dynamics of Atmospheres and Oceans*, 58: 128-149.
- Sala, I., R.M.A. Caldeira, S. Estrada-Allis, E. Froufe, X. Couvelard (2013). Lagrangian transport pathways in the northeast Atlantic and their environmental impact. *Limnology and Oceanography: Fluids and Environments*, 3: 40–60.
- Caldeira, R. M. A., A. Stegner, X. Couvelard, I. B. Araujo, P. Testor, and A. Lorenzo (2014), Evolution of an oceanic anticyclone in the lee of Madeira Island: In situ and remote sensing survey. *Journal of Geophysical Research: Oceans*, 119 (2): 1195–1216.

5 Conclusions and Future Work

In this report, we have demonstrated that MERCATOR was very useful to force our Regional ocean Modeling System (ROMS). Non-spite the cold bias in higher latitudes and warm bias in tropical and sub-topical regions, the surface currents are well represented. A change in ENVISAT altitude has degraded the altimetry data and thus the data error is considered acceptable between 2-5 cm, which encompasses a great extent of the anomalies calculated for the Madeira Archipelago Region with MERCATOR and with ROMS. Thus until new satellites with higher resolution are launched it will be hard to validate and consequently improve the model SSH. Weak spatial resolution (1/4º) of the assimilated Reynolds SST also poses some limitations in model corrections, specially if they induced patchy overestimations (MERCATOR) in smaller regions and

patchy underestimation (ROMS) in others. For Madeira, an accurate representation of the sea surface temperature is important since the leeward side of the island is often 2-6ºC warmer than the surrounding oceanic region, with subsequent impacts on the local atmospheric dynamics (see Caldeira and Tomé, 2013). This temperature gradient is important for biological activities such as mariculture, which is wiling to rely on our forecasting system to further develop their production in the Region. In the future, the Regional Madeira Archipelago configuration should have a coupled atmosphere-ocean system in order to better represent the SST fields. Recent (unpublished) studies have demonstrated that the best way to replicate the warm wake which often occurs in the leeward side of the island is to have correct radiation fluxes, which can only be achieved with coupled atmosphere-ocean modeling systems. With one-way and/or uncoupled (offline) systems, atmospheric models often have different SST fields relative to the 3D ocean circulation model, thus providing erroneous and incompatible fluxes. In the scope of the recently formed Oceanic Observatory of Madeira (OOM: http://oom.arditi.pt), the collection of new and systematic datasets are expected to help improve the Regional forecasting systems.

6 References

R.M.A. Caldeira and R. Tomé (2013). Wake response to an ocean-feedback mechanism: Madeira Island case study. Boundary-Layer Meteorology, 148:419–436. DOI: 10.1007/s10546-013-9817-y

Dombrowsky, et al.,(2013). QUALITY INFORMATION DOCUMENT (MYO2-GLO-QUID-001-002-V1.2) http://catalogue.myocean.eu.org/static/resources/myocean/quid/MYO2-GLO-QUID-001-002-V1.2.pdf

Ollivier, A. and Faugere, Y.: Envisat RA-2/MWR ocean data validation and cross-calibration Activities, Yearly report, Technical Note CLS.DOS/NT/10.018, Contract N SALP-RP-MA EA-21920-CLS, 2010.