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CORRECTION ON COOPER AND HAINES METHOD WITH THE RELATIONSHIP BETWEEN SEA-LEVEL AND BOTTOM PRESSURE VARIABILITY

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Abstract. *The aim of this work is to analyze the importance of the relationship between sea-level and bottom pressure variability on the satellite altimetry assimilation with Cooper and Haines (CH) method [1] in a primitive equations regional ocean model. The CH method assumes that potential vorticity must be conserved when satellite altimetry is assimilated, so bottom pressure is unchanged with sea-level variability. However, several papers point out the relationship between sea-level and bottom pressure variability [2] due to the distinct nature of barotropic and baroclinic sea-level changes.*
As a first step we apply the CH method in a regional model of the Mediterranean Sea. With this exercise we recover an important part of the Eddie variability.
In a second step we make two simulations of a regional model focused on the Azores region with a 6 km horizontal resolution and 50 layers during 1 year simulation for each case. The "wrong" model radiates to an annual climatology and the "true" model uses the daily solution from MERCATOR global ocean model. Two twin experiments were performed to access the accuracy of CH Method corrected with the admittance values. In the first one the wrong model assimilates sea-level values from the "true" model using the traditional CH Method. And in the second one the assimilation is done using the CH method modified with the admittance values from Bingham and Hughes [2].

1 INTRODUCTION

Downscaling methodology on Regional Ocean Models with global operational models gives a solution without significant mesoscale processes. To suppress this lake of information its useful assimilate data in to the models.

In our regional model with have assimilate Sea Level Anomaly (SLA) from satellite data using the Cooper and Haines (CH) method [1]. This method was traditionally used on large scale models [1, 3, 4, 5, 6]. CH methodology assumes that the potential vorticity must be conserved when satellite altimetry is assimilated, so the bottom pressure is unchanged with the sea-level variability. To ensure this assumption the water column is lowered or lifted, changing the isopycnal surfaces.

The assumption that bottom pressure is unchanged when sea level varies can not be applied in all situations [7, 8, 2]. The relation between bottom pressure and sea level variability can be evaluated by an admittance (or transfer) function [8]. This relation has implications for the assimilation of satellite altimetry on numerical models [8].

In the present work we propose a correction in the CH method with the admittance function computed with bottom pressure and sea level variability.

Having in mind the application of the CH method in regional models, we make simulations for the Mediterranean Sea with and without assimilation. Assimilation was made without the proposed correction. Moreover simulations in the Azores region were made as a first step for a Twin Experiment.

2 DOMAIN DESCRIPTION

2.1 Mediterranean Sea

The Mediterranean Sea (MS) is composed of two nearly equal size basins, connected by the Strait of Sicily: the Adriatic Sea that extends northward between Italy and the Balkans, communicating with the eastern Mediterranean basin through the Strait of Otranto; and the Aegean Sea that lies between Greece and Turkey, connected to the eastern basin through the several straits of the Grecian Island arc. The Mediterranean circulation is forced by water exchange through the various straits, by wind stress, and by buoyancy flux at the surface due to freshwater and heat fluxes.

The new picture of the general circulation in the Mediterranean Sea which is emerging is complex and composed of three predominant and interacting spatial scales: the basin scale (including the thermohaline (vertical) circulation), the sub-basin scale and the mesoscale. From the multiple driving forces, strong topographic and coastal influences and internal dynamical processes it results free and boundary currents and jets which bifurcate, meander and grow and shed ring vortices; permanent and recurrent subbasin scale cyclonic and anticyclonic gyres; and small but energetic mesoscale eddies. As the scales are interacting, the details associated with each one of them must be taken in account when discussing any individual scale.

A complete description of the circulation in the Mediterranean Sea is made in a revision paper [9].

2.2 Azores Region

The circulation in the Azores region is strongly dominated by the Azores current (AC). This current have is origin in the Gulf Stream, flows eastward at latitude of 34º North, reaching the Gulf of Cadiz. The AC meanders all along its trajectory and has a meridional extension of around 5º in latitude [10]. With a vertical structure that can ataind 1000 m deep and its maximal velocity is found at surface.

3 MODEL IMPLEMENTATION

To implement the numerical models we use the MOHID system. MOHID is a three-dimensional water modelling system, developed by MARETEC (Marine and Environmental Technology Research Center) at Instituto Superior Técnico (IST) which belongs to Technical University of Lisbon.

3.1 Hydrodynamic model

The MOHID hydrodynamic module solves the Navier-Stokes equations of a rotating fluid. The geophysical fluid is constrained to the hydrostatic and the Boussinesq approximations, as a practical result of a dimensional analysis (Bryan, 1969)[11]. The spatial discretization is done using a finite-volumes approach (Martins et al., 2001)[12] similar to the one described by Chu and Fan (2004))[13]. MOHID solves also a seawater density non-linear state equation depending on pressure, salinity and potential temperature (Millero and Poisson, 1981))[14]. To calculate the turbulent vertical mixing, MOHID embeds GOTM (Umlauf and Burchard, 2005 and Burchard, 2002))[15, 16]. By default the system uses the parametrization proposed by Canuto et al. (2001))[17]. The model uses a structured Arakawa C grid type (Arakawa, 1966))[18] in the horizontal. The vertical coordinate is a generic one, allowing to choose between several types of vertical discretizations (e.g. z-level, sigma and double-sigma coordinates).

The MOHID system allows the user to construct a tree of one-way nested models with no limitations on the number of nesting levels from the software point of view. By default, for each nesting level the external data for the open boundary conditions (OBC) is the upper level in the MOHID nesting system (we don't use the default solution).

In this study the numerical models were implemented using 2 nesting levels. The first domain (Level 1) is a 2D barotropic tidal-driven model, which uses the FES2004 global solution (Lyard et al., 2006))[19] as forcing. The subsequent nesting level (Level 2) is a 3D baroclinic model.

The OBC of Level 2 is defined adding to the solution of Level 1 (high frequency) the low frequency Mercator Ocean model (MO) solution (Bahurel et al., 2001))[20], which for this area has a resolution of 0.0833º. The surface boundary condition for momentum and heat is imposed using: the GFS solution (for the Mediterranean simulation); a MM5 solution from Azores University (for the Azores simulation). This methodology is described in detail in Leitão et al. (2005))[21]. Level 1 and Level 2 have both the same horizontal resolution 0.06º and level 2 (Level 1 is slightly larger than Level 2). For the Mediterranean simulation we use 37 vertical z-level layers and 7 sigma layers at surface. For the Azores Simulation we use 43 vertical z-level layers and 7 sigma layers at surface.

3.2 Assimilation scheme

As said before, we assimilate altimetry data from satellite using a scheme based on the CH method [1]. The assimilation scheme follows some corrections proposed by [6] and make a modification based on [8].

The original CH method imposes a vertical adjustment of the water column (lowering or lifting the isopicnal surfaces) to ensure potential vorticity conservation. The amount of ispicnal vertical displacement is set by specifying that bottom pressure should not change.

Following [6], the hydrostatic adjustment may be written as:

$$\Delta p_b = \rho_0 g \Delta\eta + g.\int_{-H}^{0} \Delta\rho(z)dz \qquad (1)$$

Where Δp_b is the bottom pressure change, $\Delta\eta$ is the sea level change and $\Delta\rho(z)$ is the density change profile.

According [8], bottom pressure variability is not independent of sea level variability and there are an admittance between them. Using the definition proposed for this admittance, the relation may be written as:

$$\Delta p_b = A.\rho_0 g \Delta\eta \qquad (2)$$

Where A is the admittance between bottom pressure variability and sea level variability. Using equation (2), equation (1) gets

$$\int_{-H}^{0} \Delta\rho(z)dz = (A-1)\rho_0 \Delta\eta \qquad (3)$$

If we know $\Delta\eta$, this equation is closed and according [1] isopycnal displacements are computed iteratively until the equation is satisfied.

When the admittance equals zero assimilation is made according traditional CH method and sea level gradient is totally compensated with density gradients. On the other hand if admittance equals one, there is no compensation for the sea level gradient.

4 RESULTS AND DISCUSSION

Using the same configuration we applied the model into two different dynamical regions: the Mediterranean Sea and the Azores region (see Figure 1 and Figure 4 respectively for the domain limits). The first one allowed the simulation of the Cadiz Gulf besides the western Mediterranean basin. And the second one includes the Azores current region.

4.1 Mediterranean model

Qualitatively simulations get circulation patterns in agree with literature. However in the region of the Alboran Sea the simulation doesn't reproduce correctly an anticyclonic eddy referred on literature [9] and is also visible on the bottom image of the Figure 2 centered at 356º E. One reason for this may be due to the fact that the global model doesn't reproduce this feature and the strong instabilities induces by the proximity of Gibraltar strait may prevent the formation of the eddy.

To validate our model we compare the Level2 results of surface temperature with daily SST images[1] along January 2009. In Figure 1 is presented the statistical analysis results of the comparison of the model SST with the daily measured data (2009-01-01). It is compute the difference between the two fields and the follow statistic parameters: correlation, bias and root mean square error (RMSE). Globally, the results are satisfactory except in the Aborean Sea where the difference between model and data reach high values.

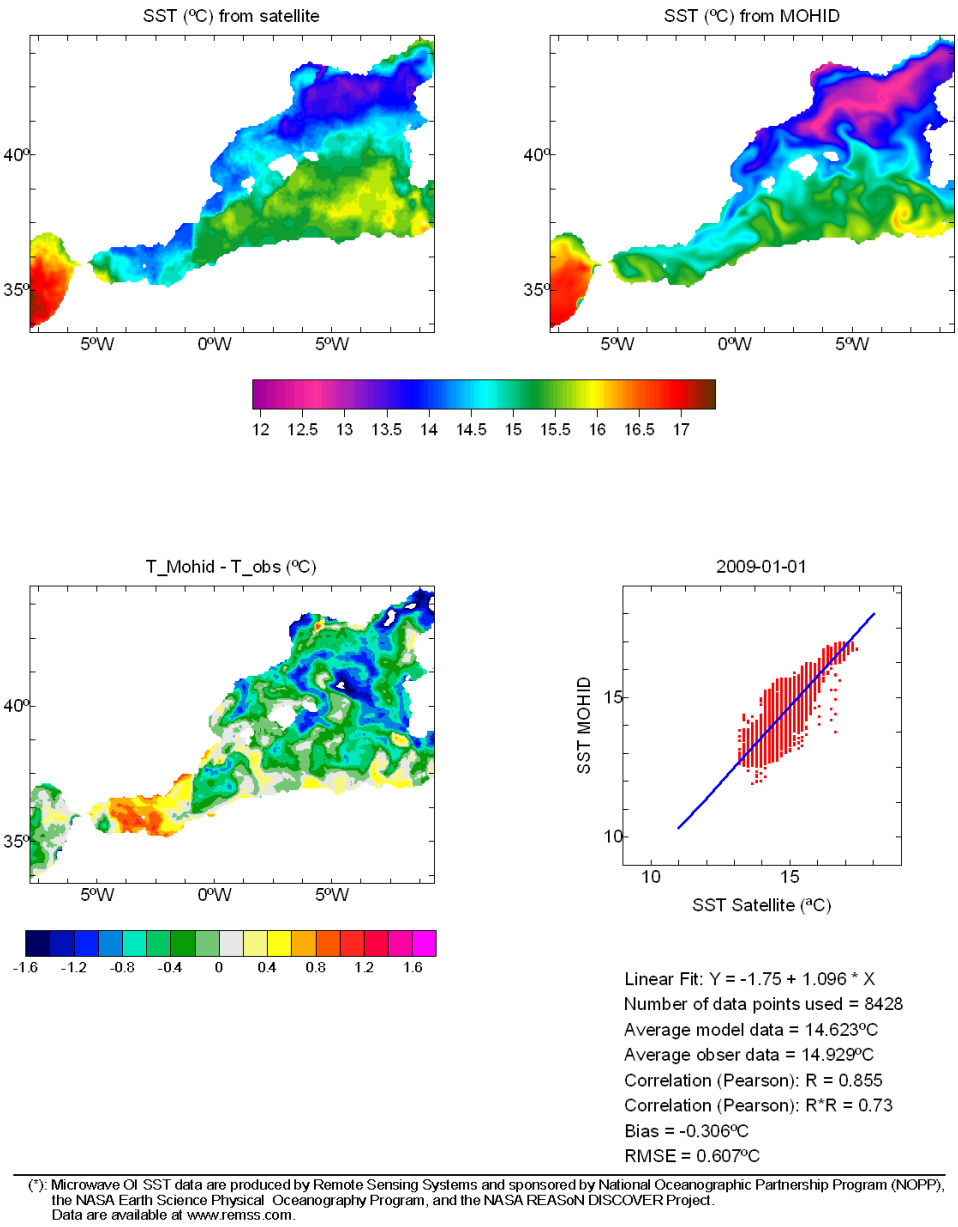

Figure 1 : MOHID SST compared to satellite SST (Microwave + Infrared). In upper left corner a SST image made based in the data disseminate by the DISCOVER initiative. In upper right corner the SST solution of Level 2. In lower left corner the difference between the two solutions. In the right lower corner the statistical analysis of the comparison of the two solutions.

[1] Microwave OI SST data are produced by Remote Sensing Systems and sponsored by National Oceanographic Partnership Program (NOPP), the NASA Earth Science Physical Oceanography Program, and the NASA REASoN DISCOVER Project. Data are available at www.remss.com.

Having in mind the failure of our solution in the Alborian Sea we have made an experience where a satellite image was assimilated in the model, for the month of June 2009. Some results are presented in Figure 2. Now, the missing eddy is found on model outputs for the sea level. This structure appears also in the temperature results (Figure 3), where we can identify its signature, indicating that this methodology permit the readjustment of the temperature field in the model assimilating only altimetric data.

However, this assimilation scheme generates wrong vertical velocities near the coast spoiling the true solution, suggesting that we should use the admittance correction on CH methodology in regions where the flow is predominantly barotropic.

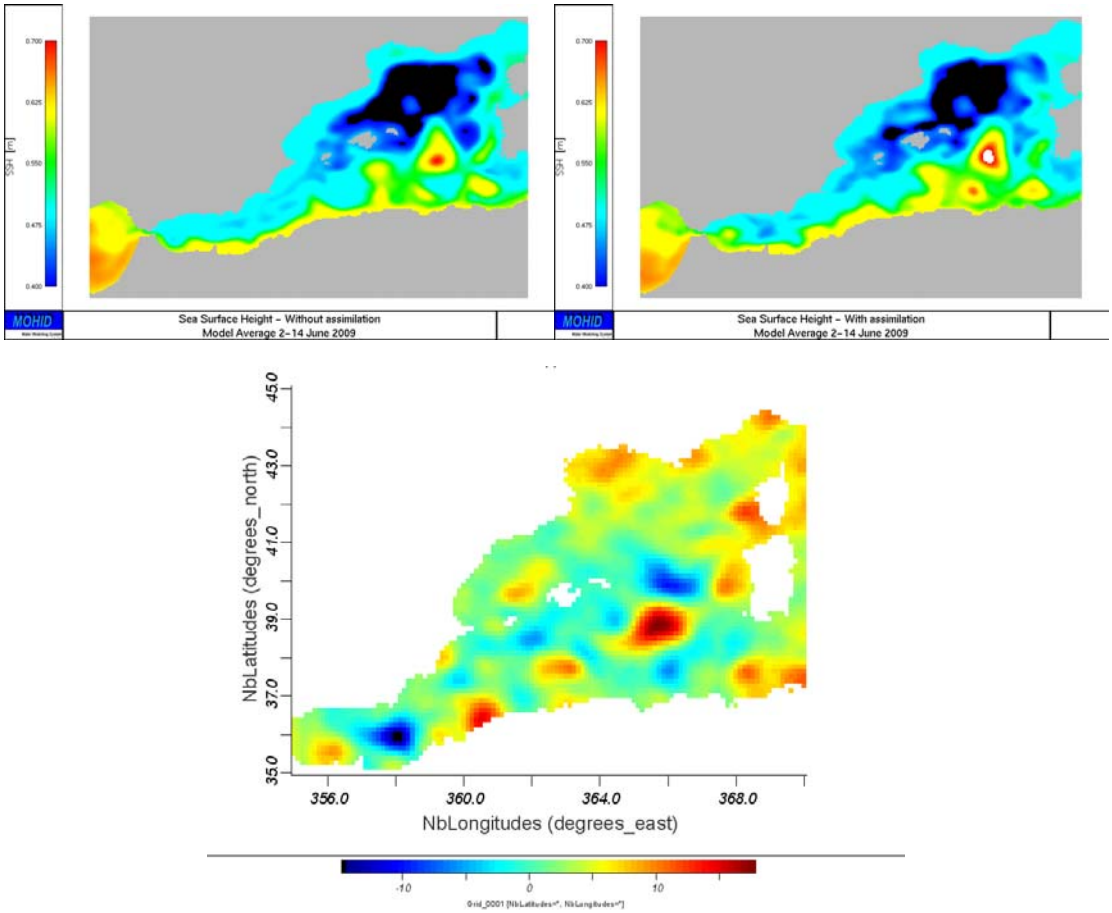

Figure 2 : MOHID SSH compared to satellite SSH (2009-6-14). The image in the upper left corner is a SSH solution of Level 2 without assimilation. The image in the upper right corner is a SSH solution of Level 2 with assimilation. The bottom image is a SLA image from AVISO.

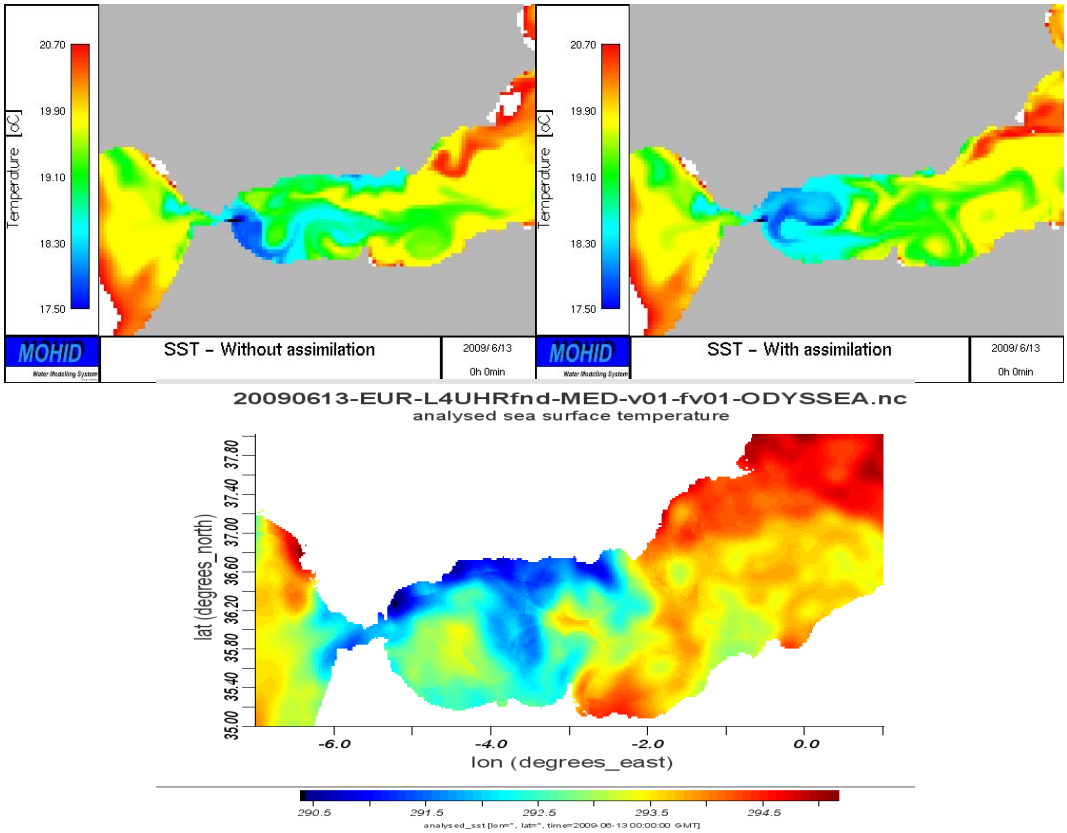

Figure 3: MOHID SST compared to satellite SST (Microwave + Infrared). The image in the upper left corner is a SST solution of Level 2 without assimilation. The image in the upper right corner is a SST solution of Level 2 with assimilation. The bottom image is a SST image made based in the data give by the ODYSSEA initiative.

4.2 Azores model

The circulation results reproduce correctly the main features described in literature. Particularly, the Azores current is well located (near 34ºN) with a mean velocity of 30 cm/s. The vertical structure extended until 1000 m deep and the vertical termohaline distribution present the same behavior described in literature; the Mediterranean water fills its lower limit and the North Atlantic central water fills its central body.

We made a comparison between model results with daily SST images[1] along June 2009. In Figure 4 is presented the same statistical analysis described for the Mediterranean Sea simulation. Results are also globally satisfactory. The deviation between model and data in this simulation reach higher values than the Mediterranean Sea simulation. This can be related to the higher currents strength of the Azores region and with local topography effect over the flow.

The assimilation simulations experiences into the Azores region are ongoing.

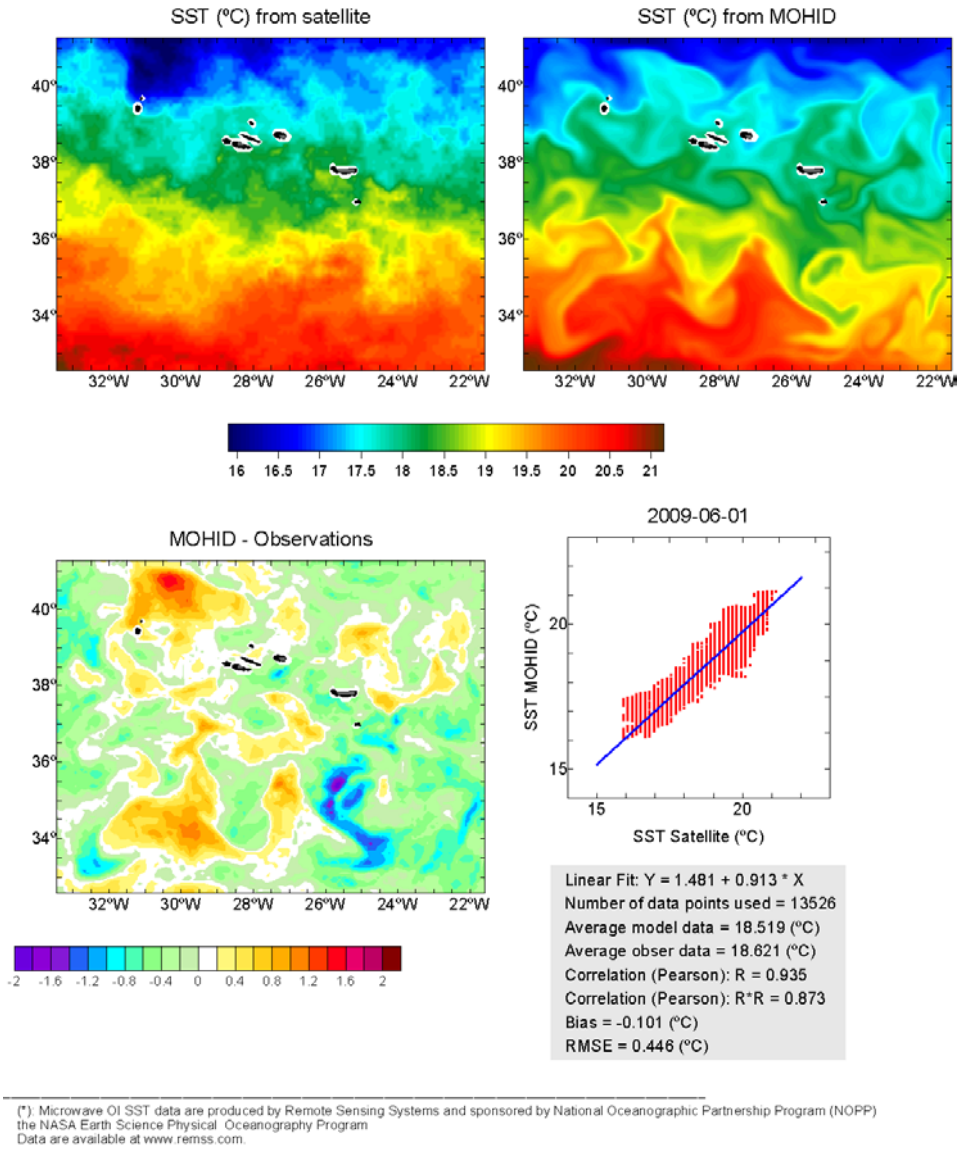

Figure 4 :MOHID SST compared to satellite SST (Microwave + Infrared). In upper left corner a SST image made based in the data disseminate by the DISCOVER initiative. In upper right corner the SST solution of Level 2. In lower left corner the difference between the two solutions. In the right lower corner the statistical analysis of the comparison of the two solutions.

5 CONCLUDING REMARKS

In global terms, the results of the simulations without assimilation are satisfactory and in both cases (Mediterranean Sea an Azores region) gives dynamic solutions compatible with the literature. Despite this, the local results for the Alborean Sea highlighted the strong dependency of the regional models on the global solutions and the necessity of improve the model with assimilation schemes.

The results of the model with assimilation near costal zones suggest the use of a correction with admittance on CH methodology.

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