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DOWNSCALING THE OCEAN CIRCULATION ON WESTERN SOUTH ATLANTIC: HINDCASTING, MONITORING AND FORECASTING PURPOSES

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1. INTRODUCTION

The Western South Atlantic is characterized by oceanographic and meteorological features of great interest. The Brazil-Malvinas Confluence occurs within a well-known active cyclogenetic region east of Andes Mountains, with impacts on weather and climate conditions of southeastern South America.

Within the coastline of this study area, there are distinct combinations of regional effects and large-scale features regarding the maritime circulation. Brazil Current and Brazil-Malvinas Confluence are superposed to different tidal regimes as well as meteorological influence (wind and heat fluxes), becoming evident the need of a complete representation in space to include the large-scale influences over coastal portions.

In this context, the use of numerical modeling become a powerful tool to represent correctly the interaction between scales, since the increase of horizontal resolution through nesting procedures solve adequately the superposition of effects. This study shows the implementation of a customized version of Princeton Ocean Model (POM) as an oceanic module for numerical representation of the combined effect of tidal influence, fresh water discharge of Plata River and meteorological influences over the Brazil-Malvinas Confluence region.

The features of major interest are: storm surge events; coastal plume of fresh water of Plata River and its influence over the inner shelf of Uruguay and South Brazil; vertical mixing forced by tides; eddy activity at the confluence region and the intense SST gradient regions; and Brazil Current meandering. All these aspects can be investigated for hindcasting, monitoring and forecasting purposes.

2. METHODOLOGY

POM was created by Allan Blumberg and George Mellor in 1977 and since that it has been improved by many researchers. The complete description of the model can be found in Blumberg & Mellor (1983, 1987); other useful information is shown by Galperin & Mellor (1990).

It is a three-dimensional non-linear finite differences model for coastal and oceanic circulation, which includes a turbulence closure scheme (Mellor & Yamada, 1982) yielding to a realistic parameterization of vertical mixing processes. Besides, it uses sigma vertical coordinate, that follows the relief.

In this work, an optimized version developed by Ricardo de Camargo (IAG/USP) and Joseph Harari (IO/USP) was employed, which includes: river discharge, weighted spatial filtering, weighted relaxation to termo-haline climatic fields, tidal potential generator and a set of possible boundary conditions to many applications. This version is being applied to different spatial and time scales, since small scale domains (estuaries, bays, channels - Camargo & Harari, 2003; Harari & Camargo, 2003; Conceição & Camargo, 2004) up to large scale regions (ocean basin and global - Harari, Camargo & França, in prep.), which confirms its potentiality.

The system considers a large scale domain (85S-30N; 070W-25E) with 1/2 degree resolution and a one-way nested area with 1/12 degree parallel to the coastline, from northern Argentina (44S) to southeast Brazilian shelf (21S), both with 16 sigma levels for representing sea level and 3D fields of temperature, salinity and currents.

The coarse domain calculations include tidal potential generator besides winds and heat fluxes at the surface from global climatologic fields (Silva *et al.*, 1994), as well as the imposition of harmonic oscillations and mean sea level at the open boundaries. These fields are then interpolated spatially to feed the fine grid over the continental shelf and coastal region.

It is important to explain the procedure to get a dynamic equilibrium in the coarse domain. The 1x1 degree resolution global monthly T/S Levitus climatology presented by Levitus & Boyer (1994) was used to impose the annual cycle of the termo-haline fields. On the other hand, the

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variability of volume transport across the open boundaries - to represent the annual variability of Antarctic Circumpolar Current at southern boundaries and the influence of the North Atlantic sub-tropical gyre at northern boundaries - was obtained by the structure of sea level fields given by OCCAM (Webb *et al.*, 1998) which, through geostrophy into the proper model code, imposes the cycle.

The experiments started from rest and after 5 years of annual cycle imposition (without tidal oscillations), the dynamical equilibrium was reached. This spin-up time was obtained through qualitative and quantitative evaluation of (i) cycles of potential and kinetic energy over the whole domain; (ii) sea level elevations patterns at South Atlantic and the correspondent sub-tropical gyre and (iii) the position of Brazil-Malvinas Confluence. This scheme allowed the determination of mean monthly conditions related to the termo-haline and wind-driven circulation for January and July (Fig. 1).

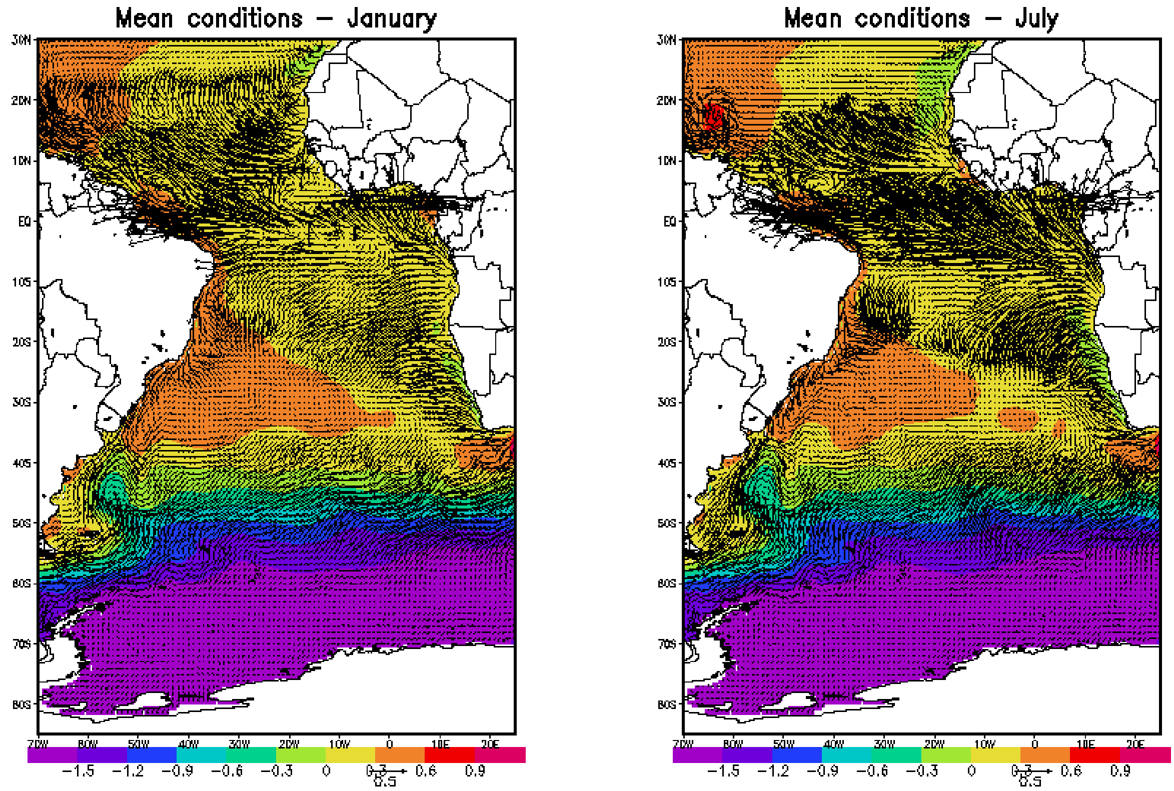

Figure 1 – Monthly mean conditions for January (left panel) and July (right panel). The shaded field represents the sea level (meters, colorbar) and the vectors are surface currents (m/s, vector scale).

The tidal patterns, also of great interest of the present study, reproduce very well the co-amplitude and co-phase lines of the M2, the major lunar constituent (Fig. 2). The amplification areas at the northern Brazilian coast, Argentinean coast and Weddell Sea, as well as the reduction of tidal range at South Brazil are very clear on the model results. The importance of tidal oscillations for the inner shelf and coastal areas justify the huge effort to get the right conformation of the amphidromes, which positions depend directly on the resonance related to the Weddell Sea configuration.

Another important point, related to all the purposes of the oceanic module based on POM, is the possibility of inclusion of satellite observations of SST in order to include specific information during periods or events of interest. The forecast simulations with this system, for example, employ the weekly optimal interpolation of SST available at NOAA/NCEP website, as well as the GFS/NCEP global atmospheric model.

Once the simulations at the coarse domain are available, post-processing tools for spatial and temporal interpolations are executed to generate forcing fields of elevation and 3D termo-haline at the fine grid boundaries. As the tidal signal has been incorporated at the coarse domain, there is no need of harmonic oscillations at these boundaries, which implies in a quasi-perfect match between the fields from the different resolution grids.

As an example, the operational run of March, 29, 2006 is shown in both grid resolutions, for SST and surface currents. For this specific period, the meteorological forecast indicated the passage of a frontal system over southern Brazil, with mean southerly winds over 10m/s over the Western South Atlantic from 29 to 31 March, 2006. These strong winds were able to revert the surface flow associated with the Brazil Current over the southeastern Brazilian platform, as can be seen either on the coarse domain or on the fine resolution grid (Fig. 3 and 4, respectively).

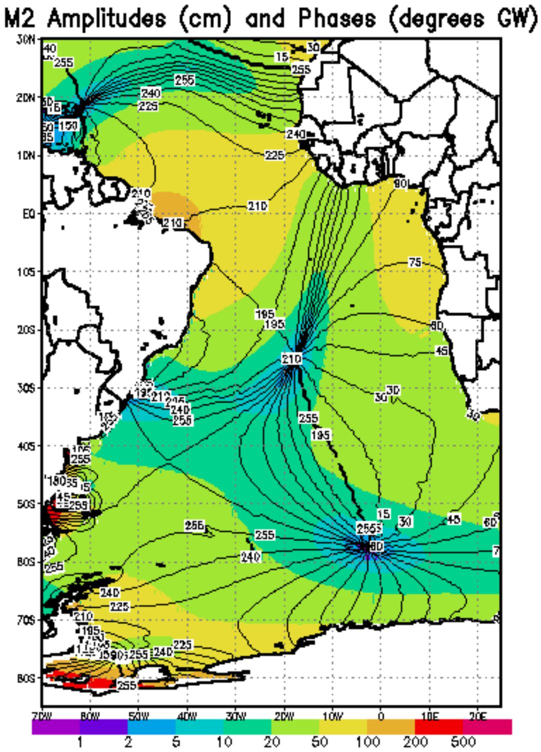

Figure 2 – Cotidal charts of the M2 constituent: amplitudes (centimeters, colorbar) and phases (degrees Greenwich, contours).

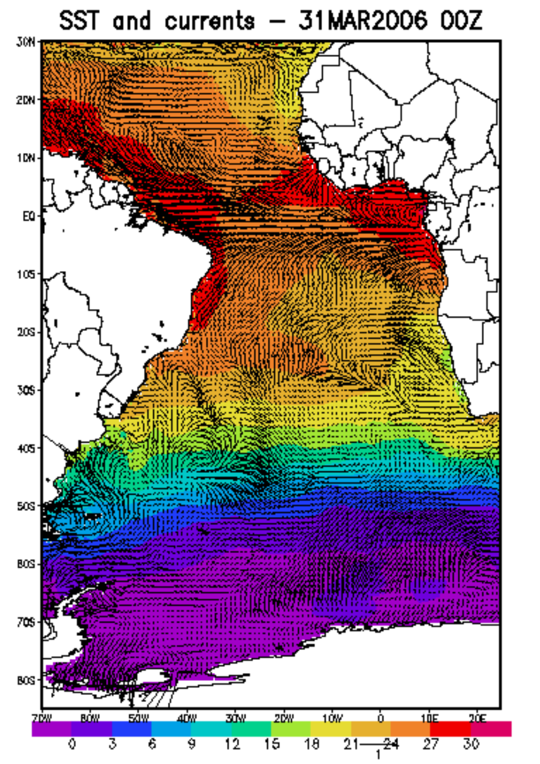

Figure 3 – Snapshot of forecasted SST (Celsius, colorbar) and surface currents (m/s, vector scale) for 00Z March, 31, 2006 for the coarse grid.

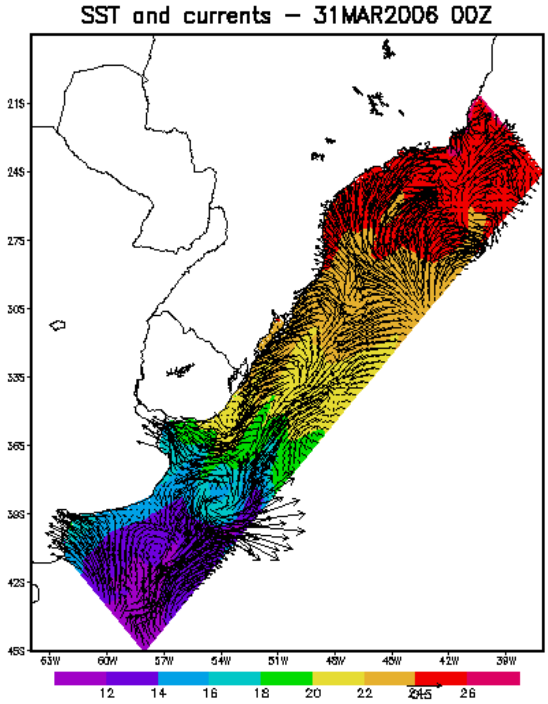

Figure 4 – Snapshot of forecasted SST (Celsius, colorbar) and surface currents (m/s, vector scale) for 00Z March, 31, 2006 for the fine grid.

The results of the coarse grid simulation in terms of sea level for 3 coastal stations are compared to their correspondent on the fine domain. These stations were selected to show the difference in tidal oscillations as well as the influence of atmospheric fields over the mean sea level and surface temperature: Mar del Plata, Rio Grande and Santos. It is possible to confirm the agreement between sea level and SST series from both grids.

For this specific case, it is important to stress that the time interval of these series are not the same, being 30 minutes for the coarse grid and 3 hours for the fine resolution. This fact needs to be token into account when comparing the series. Other relevant aspect is related to the fact that the difference in spatial resolution can imply in better representation of the meteorological influence over the continental shelf and coastal areas, meaning that the series are not expected to be exactly the same.

On the coarse grid, the tidal range at Mar del Plata appeared with about 1 meter, while Rio Grande presented 0.5 meter and Santos less than 1 meter (Fig. 5). On the other hand, these tidal ranges represented by fine grid appeared respectively with 1.4, 0.5 and 1.2 meters (Fig. 6).

The same kind of consideration can be applied to the time series of temperature. The characteristic of heating or cooling is correspondent in both grids, but the values are not exactly the same. This means that the solution for the SST field obtained by the high resolution grid can express more effectively the local interaction between ocean and atmosphere, which can reveal the relevance of the downscaling procedure.

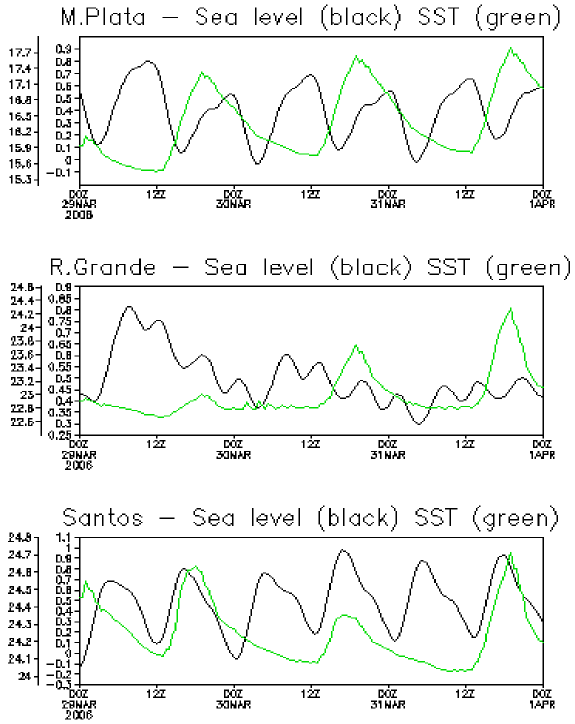

Figure 5 – Time series of sea level (meters, in black) and SST (Celsius, in green) for 3 coastal stations over Western South Atlantic represented by the coarse grid: Mar del Plata, Rio Grande and Santos (top to bottom, respectively).

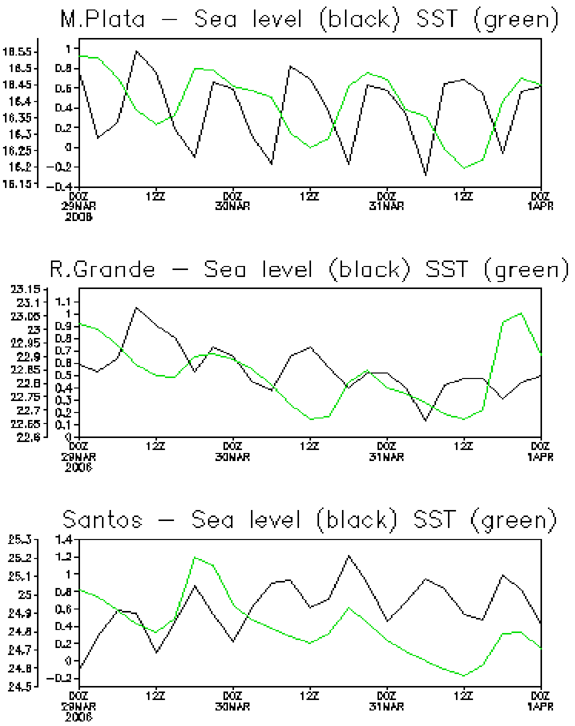

Figure 6 – Same as Fig. 5, but for the fine grid.

Another interesting feature to mention concerning the sea level series for these coastal stations is the storm surge represented by both grids. It is clearly observed the over-elevation of sea level in Rio Grande during March, 29 as well as the same feature in Santos, but during March, 30. One can note that the fine grid could represent more effectively the storm surge in these stations, which is very important for coastal floods, beach erosion, current reversions and so on.

3. RESULTS AND DISCUSSION

During the implementation stages, the Brazil-Malvinas Confluence region – and its typical seasonal variability – was the most sensitive indication of correct specification of volume transport across the southern open boundaries, between South America and Antarctica and between Africa and Antarctica, which is the key for a realistic representation of known circulation features.

Other major highlight is the importance of Weddell Sea on tidal propagation and amphidromes formation over the South Atlantic, being decisive for correct representation of tidal amplitudes and phases at the south-southeastern Brazilian coast.

There are many plans to evaluate the whole set of numerical simulations. For example, altimetric data of Topex/Poseidon satellite mission was initially used for the evaluation of cotidal charts and SSH variability given by the model on the low-resolution domain. In the fine resolution grid, a set of observations at coastal stations (sea level, sea surface temperature and currents) are being collected for the evaluation of the model results.

4. CONCLUDING REMARKS

The importance of a correct numerical representation of the oceanic phenomena for an adequate use of coastal region and continental shelf is the main point of this effort. To this, it is proposed a downscaling procedure based on a well-known numerical code.

This work aims to introduce the downscaling procedure applied over Western South Atlantic using a customized version of Princeton Ocean Model and to show the initial considerations regarding this effort.

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