USING "MIKE 21" AND "POM" FOR NUMERICAL SIMULATIONS OF THE HYDRODYNAMICS IN BAIXADA SANTISTA REGION (SÃO PAULO, BRAZIL)

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1. Introduction

The effluent dispersion in sea water is extremely complex and, to understand its behavior, several factors should be considered, such as the kind of effluent, discharge points, hydrodynamics, tidal effects, meteorological influences, the bathymetry and the land boundary. Moreover, it is well known that between the atmosphere and the ocean there is a complex interaction. The combination of meteorological and oceanic effects produces strong variations in coastal areas, mainly in the sea water level, as well as in coastal currents.

To assess the impacts that effluents cause on coastal regions, studies that evaluate the hydrodynamic behavior and the effluent dispersion in sea water are necessary.

The circulation determination is essential in order to achieve full knowledge about the effluent disposal through a submarine outfall. This knowledge is also important for navigation, harbor projects and for contingency plans development as well. On the other hand, extensive programs of currents measurements are often difficult and expensive.

The numerical models represent natural phenomena through the solution of basic differential equations. A suitable choice of a model and its hypothesis is essential for correct results. In the ocean, variations may occur in horizontal directions and along the vertical axis, so the simulations may require three-dimensional (3D) models (Kowalik and Murty, 1993). Thus, numerical simulations, through suitable computational models are appropriate tools to determine hydrodynamic marine characteristics. However, a model always depends on field measurements for calibration and validation.

Therefore, the main purpose of this research consists in integrating the results obtained from numerical models and from field data, in order to evaluate the hydrodynamical behavior in a coastal region. Also, a future goal of this research is to approach the marine pollution issue, mainly concerning domestic wastewater and oil leakage.

2. Description of Study Area

São Paulo State is located at the southeastern region of the Brazilian Atlantic coast, and is the most populated and developed State in Brazil. There are 15 coastal municipal districts with a population of 2 million inhabitants that usually doubles during the summer season (http://www.seade.gov.br/produtos/spdemog/). Therefore, sewage generation, its treatment and disposal, are a major concern in these urban areas and fecal pollution of water bodies is a widespread problem in the coastal zone. Due to the lack of sewer systems and large rivers, ocean disposal has been an important alternative for the region, considering that its economy is mostly based on tourism.

The study area is located in the central coast of São Paulo State, named Baixada Santista, which is 160 kilometers long and 2,886 square kilometers, being composed by nine municipal districts - Bertioga, Santos, São Vicente, Guarujá, Cubatão, Praia Grande, Mongaguá, Itanhaém and Peruíbe (http://www.agem.sp.gov.br/). Figure 1 shows the geographic location of the Baixada Santista region.

This region has harbor activities (Santos Port) and the Cubatão Industrial Pole; besides, it has extensive tourism and leisure activities. The coastal municipal districts have low rates of sewage collection and treatment, so seawater is frequently unsuitable for bathing, mainly due to sewage disposals thrown directly into coastal streams.

Within the study area, the Santos Estuarine System is highlighted (Figure 2). This area is influenced by oceanic and continental waters: the continental waters come from the estuarine system through Santos Harbor Channel and São Vicente Channel so the main driving forces for the circulation in the Santos Bay are: the co-oscillation of the tides, fresh water discharge, density gradients, wind and the adjacent coastal circulation. The tides have amplitudes varying typically from 0.3 to 1.7 m, in neap and spring tides, respectively (Harari and Camargo, 1995).

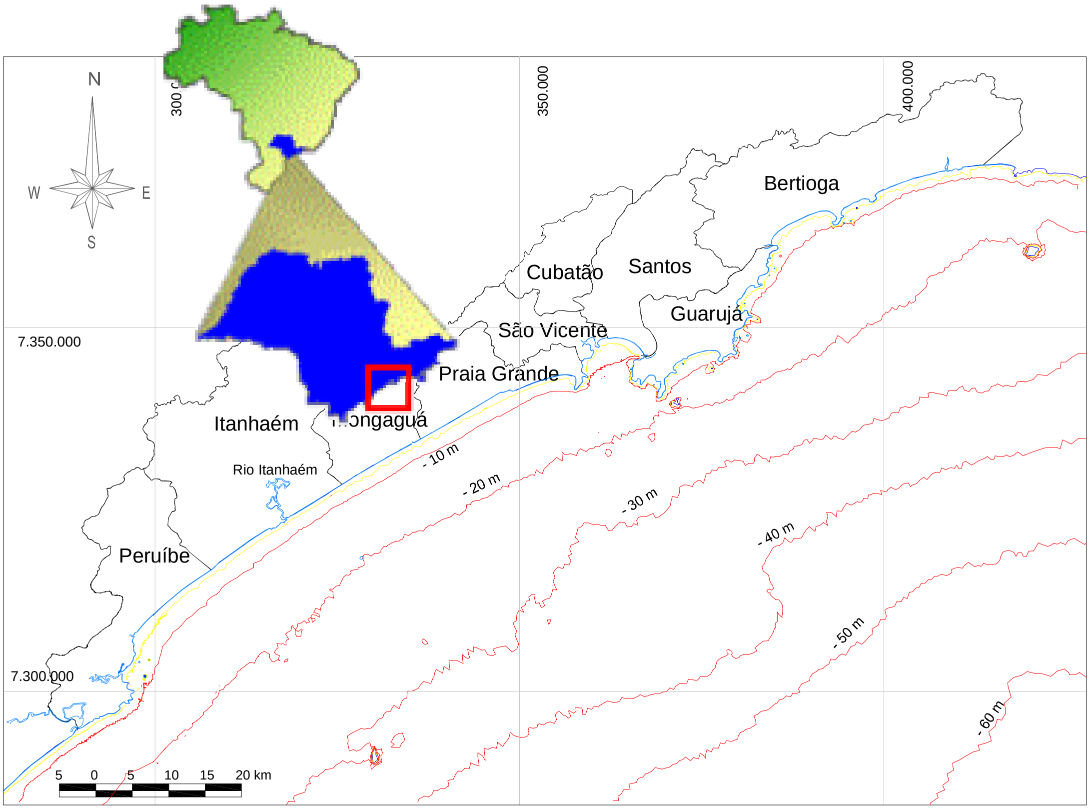

Figure 1 – Study area – Baixada Santista.

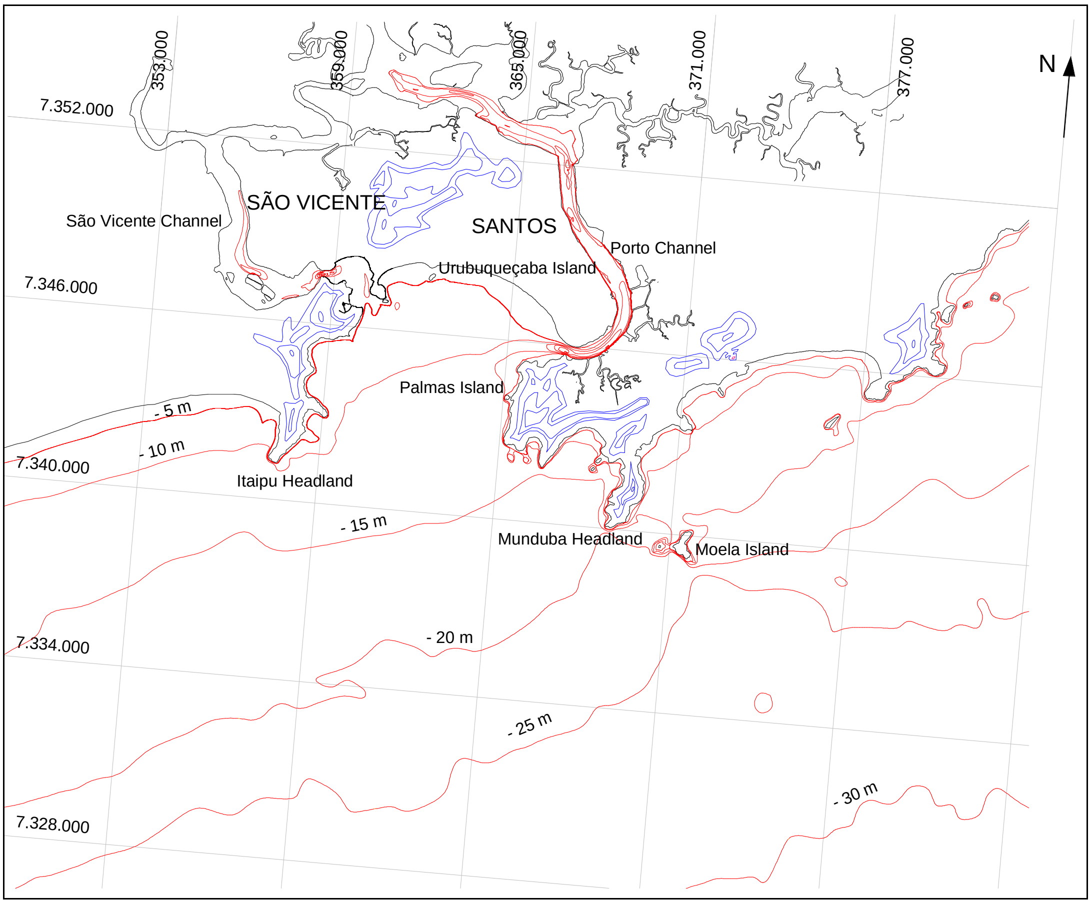

Figure 2 – Highlighted area – Santos Estuarine System

3. Methodology

The methodology of the research consists on the use of numerical models in order to assess the behavior of currents in the study area. In addition, field data have been used aiming to calibrate the models. Next, a brief description of the field measurements and models applied in the research are presented.

Table 1 and Figure 3 present the positions and times of the field measurements.

Data Description	Project / Localization	Coordinates				Period
		Geodesics		UTM		
		Latitude	Longitude	Latitude	Longitude	
Anemograph – Wind	CODESP (2002) – Cabras Island	24^o 0,5' S	46^o 13,1' W	7.344.279N	376.078E	07/02 - 03/04/2002 and 19/07-27/09/2002
Anemograph – Wind	SABESP (2006) – Praia Grande	24^o 1,46' S	46^o 27,6' W	7.342.274N	351.568E	22/07 - 17/11/2005
Surface Elevation – Tide	CODESP (2002) – Palmas Island	24^o 0,6' S	46^o 19,6'W	7.343.995N	365.060E	09/02 - 27/03/200 and 18/07-13/09/2002
ADCP - Currents	CODESP (2002) – Santos	24^o 5,2' S	46^o 17,8'W	7.334.187N	362.441E	09/02 - 27/03/2002 and 18/07-13/09/2002
ADCP - Currents	SABESP (2006) – Praia Grande	24^o 2,95' S	46^o 26,5'W	7.339.555M	353.476E	11/07 - 15/08/2005

Table 1 – Information on field measurements.

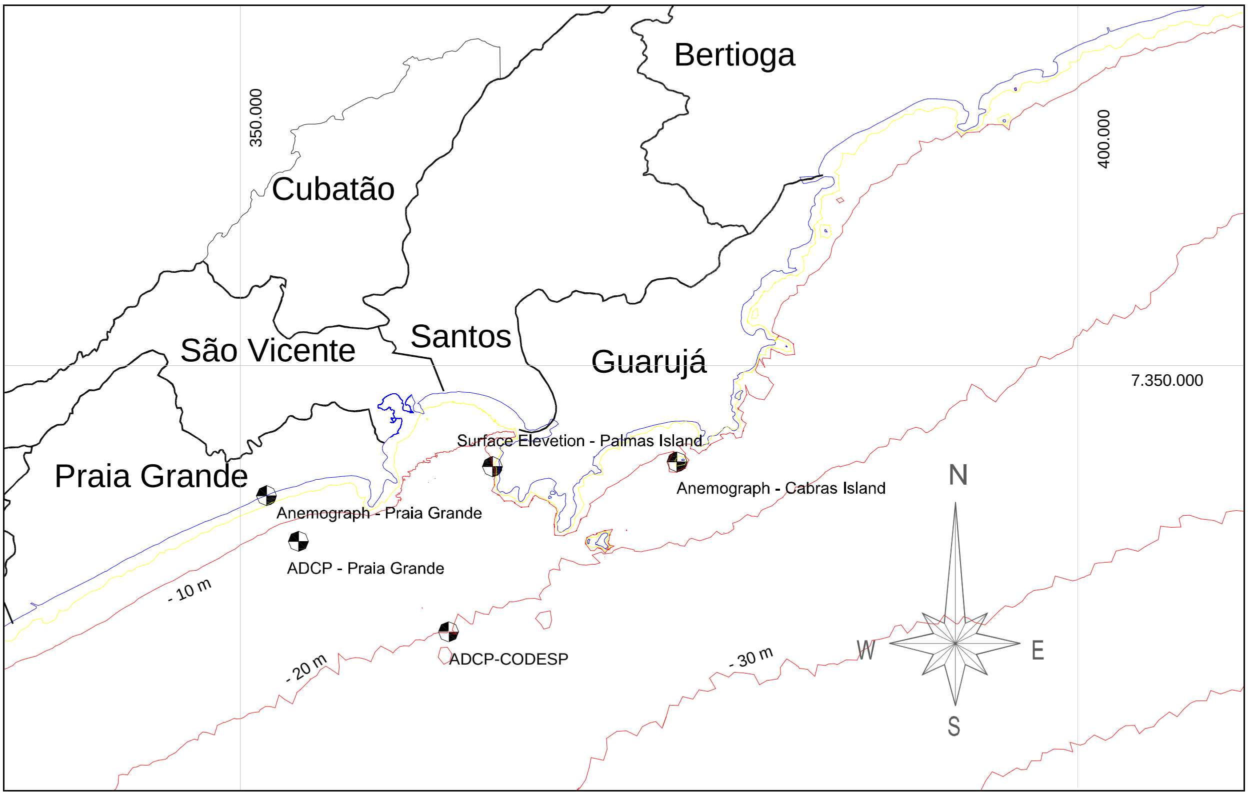

Figure 3 – Positions of field measurements.

Wind data are used to force the hydrodynamic models while sea level observations and Acoustic Doppler Current Profilers (ADCPs) data allow their validation and calibrations; the measurements were provided by Companhia de Saneamento Básico do Estado de São Paulo – SABESP (2006) and Compahia Docas do Estado de São Paulo – CODESP (2002).

Several basic studies were performed in the coastal area of Baixada Santista, such as the ones of Reis (1978) and Wellinford (1990). Some models have already been implemented in the coastal area of Baixada Santista and neighbor regions, with several purposes, for simulations of the tidal circulation in the platform (Harari and Camargo, 1998, 2003), meteorological effects in the shelf (Camargo & Harari, 1994), circulation and dispersion in the Port and Bay of Santos (Gordon, 2000), the circulation induced by tides and winds and correspondent dispersion in Praia Grande outfall (Baptistelli, 2003) and the general circulation in the shelf (Picarelli, 2006). Nowadays studies have been done in order to predict the effects of global warming in the coastal area (FCTH, 2005).

4. Numerical models

4.1 MIKE 21HD

MIKE 21 is a model frequently used for coastal simulations, developed by DHI – Danish Hydraulic Institute Environment (www.dhigroup.com/). The hydrodynamic module in MIKE 21 Flow Model (MIKE 21 HD) is a general numerical modeling system for the simulation of water levels and flows in estuaries, bays and coastal areas (www.dhigroup.com/Sofware.aspx); it simulates unsteady two-dimensional flows in one layer (vertically homogeneous).

Mike 21 HD solves the partial differential equations which represent the horizontal flux, requiring the correspondent boundary conditions; for these conditions, one may choose only the sea water level or the sea level together with the coastal flux (DHI, 2004). The wind may be specified as a constant value for the entire area modeled, or varying temporally and spatially. The wind friction, Manning number and viscosity coefficient may be used as calibration parameters in the modeling

The model has pre and post - processing modules, allowing the input of data to be made in an interactive and easy way. Likewise, the result outputs can be easily evaluated. The model also has tidal prediction and analysis tools within the Mike 21 PP module.

Tides may be characterized as periodic variations of the sea level under the influence of astronomical forces, so it is possible to analyze and forecast their behavior considering the sums of harmonic constituents; the amplitudes and phases of the tidal constituents (and angular speeds) are determined through tidal analysis and are called tidal constants.

Three grids have been used for Mike 21 simulations, which are: meso-scale grid (spacing of 2,000 meters), Baixada Santista grid (spacing of 300 meters) and Santos grid (spacing of 90 meters). For the bathymetry, a digitizing program was used and three files were generated, with (x,y) coordinates and corresponding depths. Figures 4, 5 and 6 present the bathymetries generated by MIKE 21 software, with grids geographical positioning shown on Figure 7.

The temporal and spatial variations of sea levels were computed through the tidal prediction module Mike 21 PP, by using the values of phase and amplitude of 9 tidal constituents, and were been employed for the model open boundaries specifying (in the meso-scale grid). According to Harari and Camargo (1994), nine constituents represent more than 90% of the tidal energy in the southeastern Brazilian Shelf area - M2, S2, N2, K2, K1, O1, P1, Q1 and M3.

Wind data (magnitude and direction) at the sea surface were used, by composing the coastal observations with outputs of the NCEP/NCAR Reanalysis Project, for the Meso-scale grid.

The Transfer Boundaries tool was used to specify the variations of sea level in Baixada Santista and Santos grids.

The numerical model run in three periods, namely: from February 9 to March 10, 2002; from July 18 to August 10, 2002; and from July 11 to August 3, 2005.

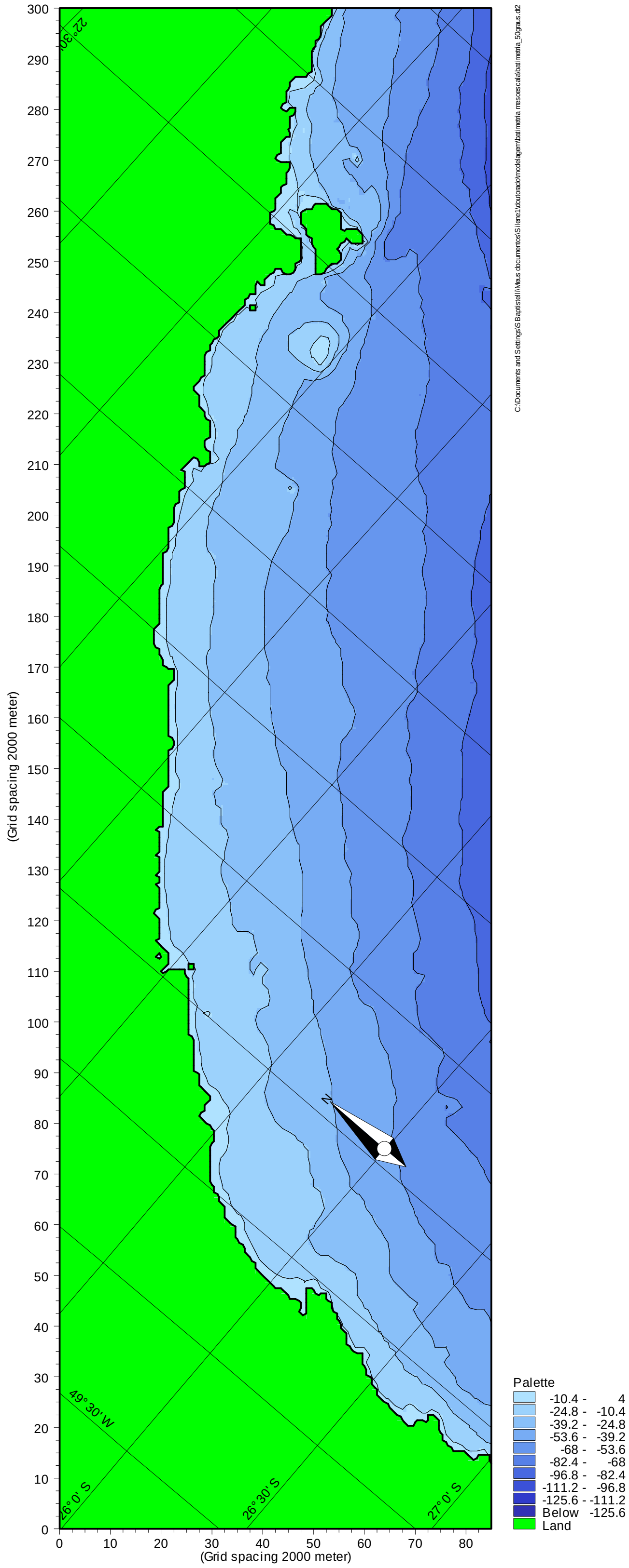

Figure 4 – Meso-scale Bathymetry – Spacing 2,000 m (grid of 86 x 301 points).

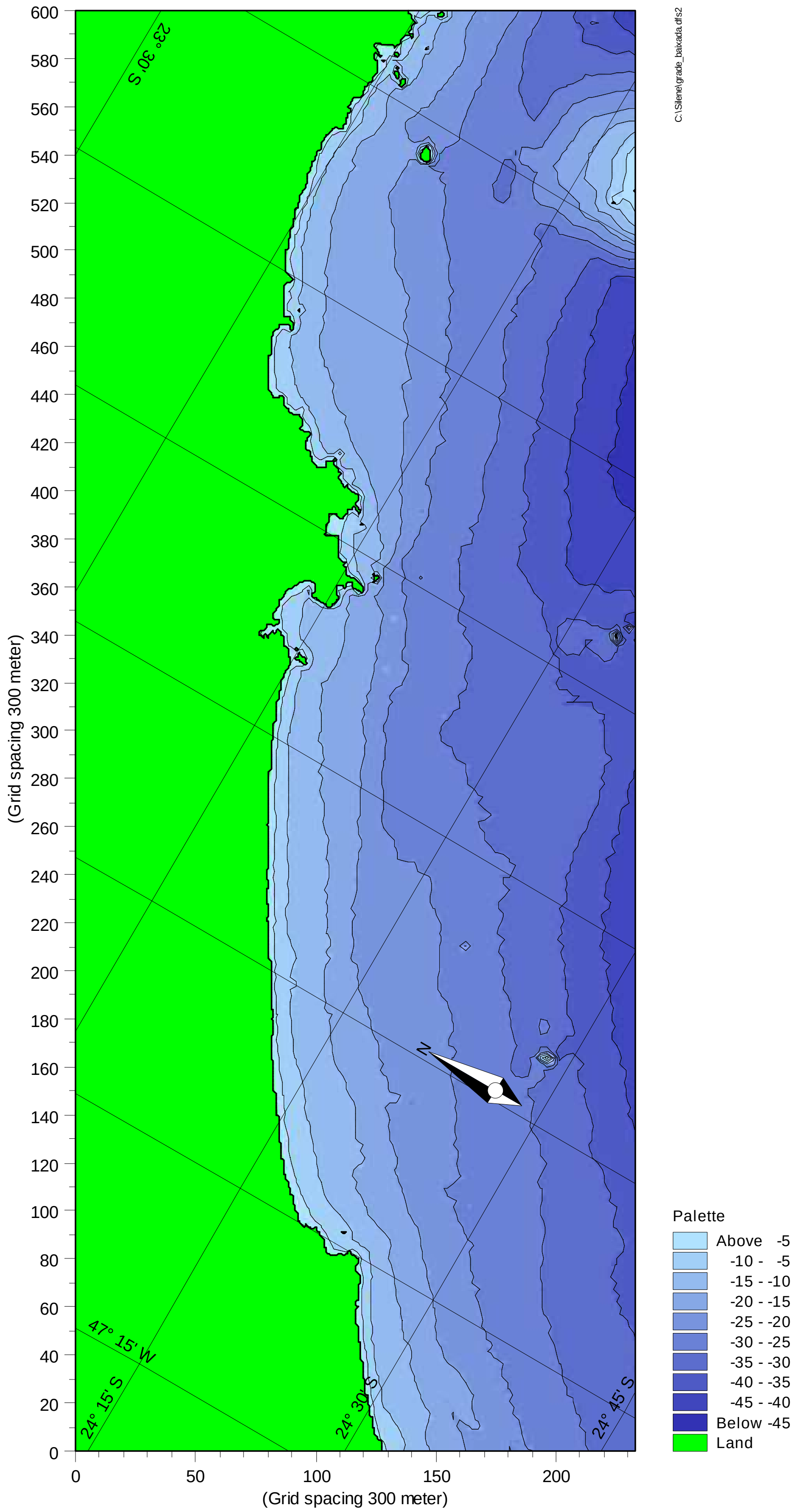

Figure 5 – Baixada Santista Bathymetry – Spacing 300 m (grid of 234 x 601 points).

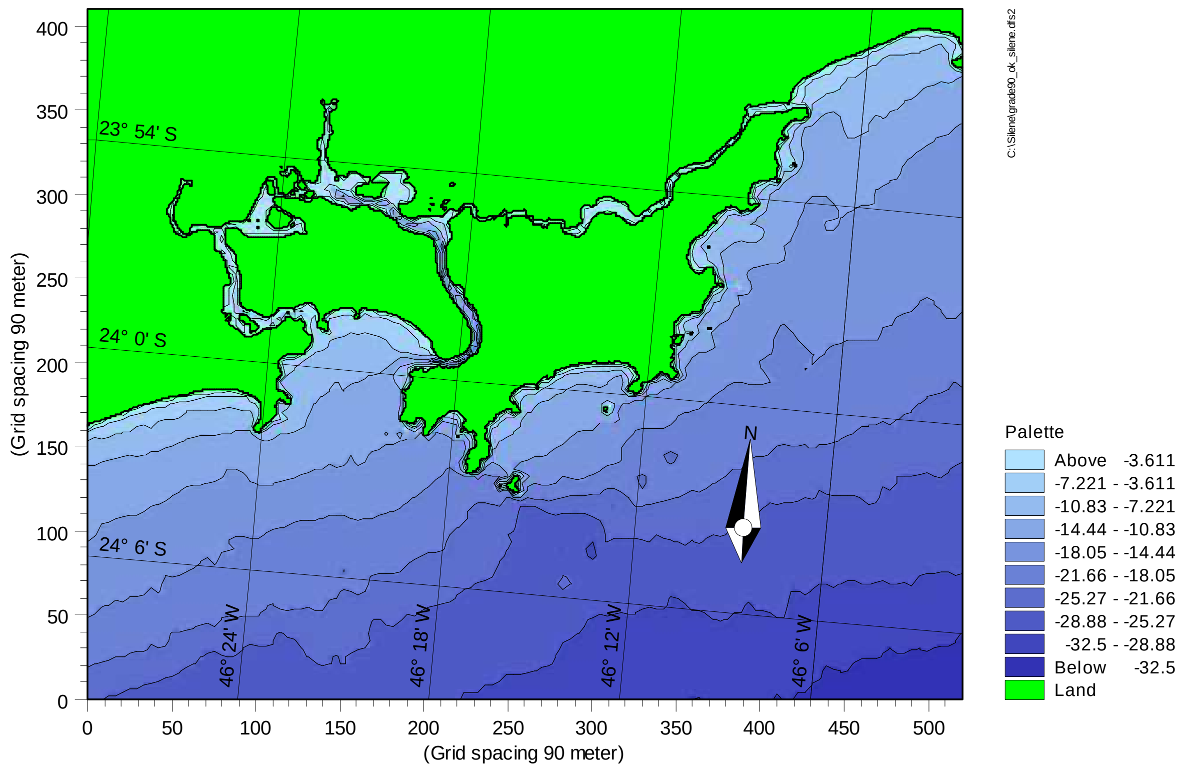

Figure 6 – Santos Estuarine System Bathymetry – Spacing 90 m (grid of 521 x 411 points).

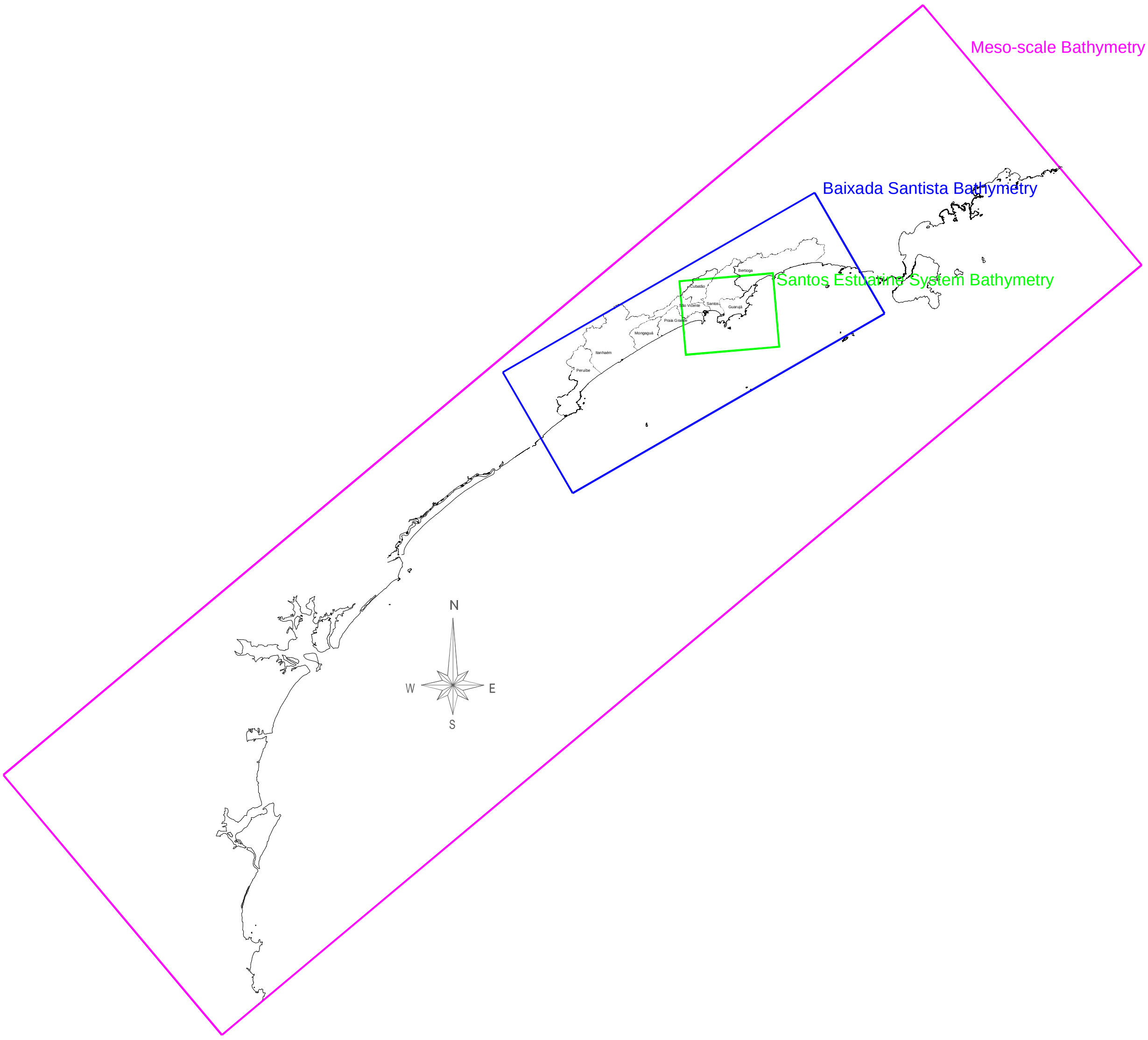

Figure 7 - Grids positioning scheme.

4.2 - Princeton Ocean Model – POM

Natural processes simulations sometimes require a three-dimensional (3D) standard, which was used for the Santos Estuarine System through the Princeton Ocean Model – POM (www.aos.princeton.edu/WWWPUBLIC/htdocs.pom/). This model was developed and applied to oceanographic problems in the Atmospheric and Oceanic Sciences Program of Princeton University (Mellor, 2003). The principal attributes of the model are: it contains an imbedded second moment turbulence closure sub-model to provide vertical mixing coefficients and it employs sigma coordinates in that the vertical coordinate is scaled on the water column depth.

The POM has been used through a version implemented by the Oceanographic Institute of the University of São Paulo by Prof. Joseph Harari, in a limited area domain (São

Paulo State coastal area) with a high-resolution grid, with realistic coastline and bottom topography (Figure 8). The forcings include space and time varying wind stress, termohaline fields, fluvial discharges, tides and mean sea level variations.

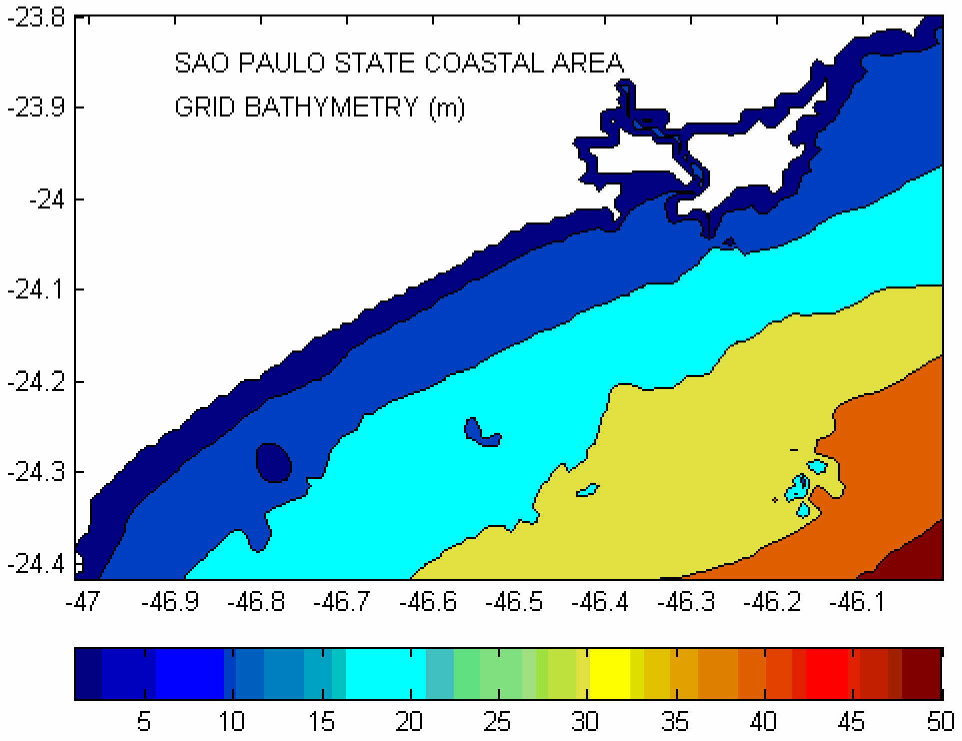

Figure 8 – São Paulo State bathymetry (120 x 80 points and 11 sigma levels).

5. Preliminary Results

<u>5.1 - MIKE 21HD</u>

Three Mike 21 HD simulations were made for each of three grids, using tides, pressure and wind fields as model forcings; the simulation periods correspond to field measurement times.

The comparison of measurements and the sea level variation modeled by Mike 21 HD is presented in Figures 9 and 10, with correlation coefficients of 0.83 for winter and summer 2002, and 0.88 for winter 2005.

Figure 9 – Comparison of the surface elevation values between MIKE 21HD simulation and field data (winter and summer 2002, and winter 2005)

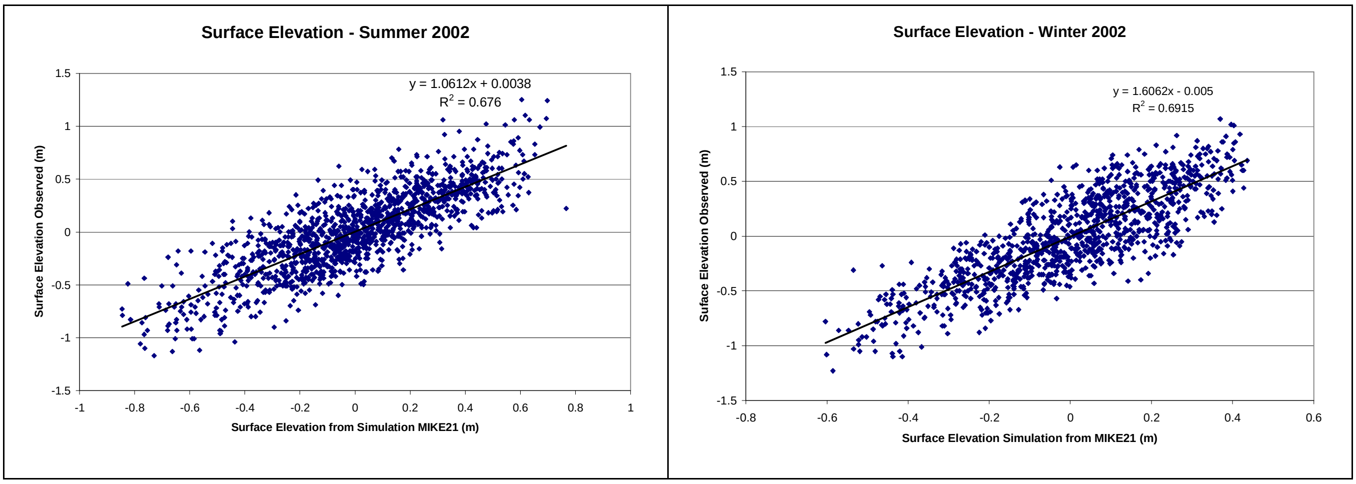

Figure 10 – Scatter plot of the surface elevation values computed in MIKE 21HD simulation and field data (winter and summer 2002)

Figure 11 presents a comparison between simulation results of MIKE 21HD and field currents data, considering vertically averaged values. Figures 12 and 13 present currents distribution maps, for the meso –scale and Santos Estuary grids.

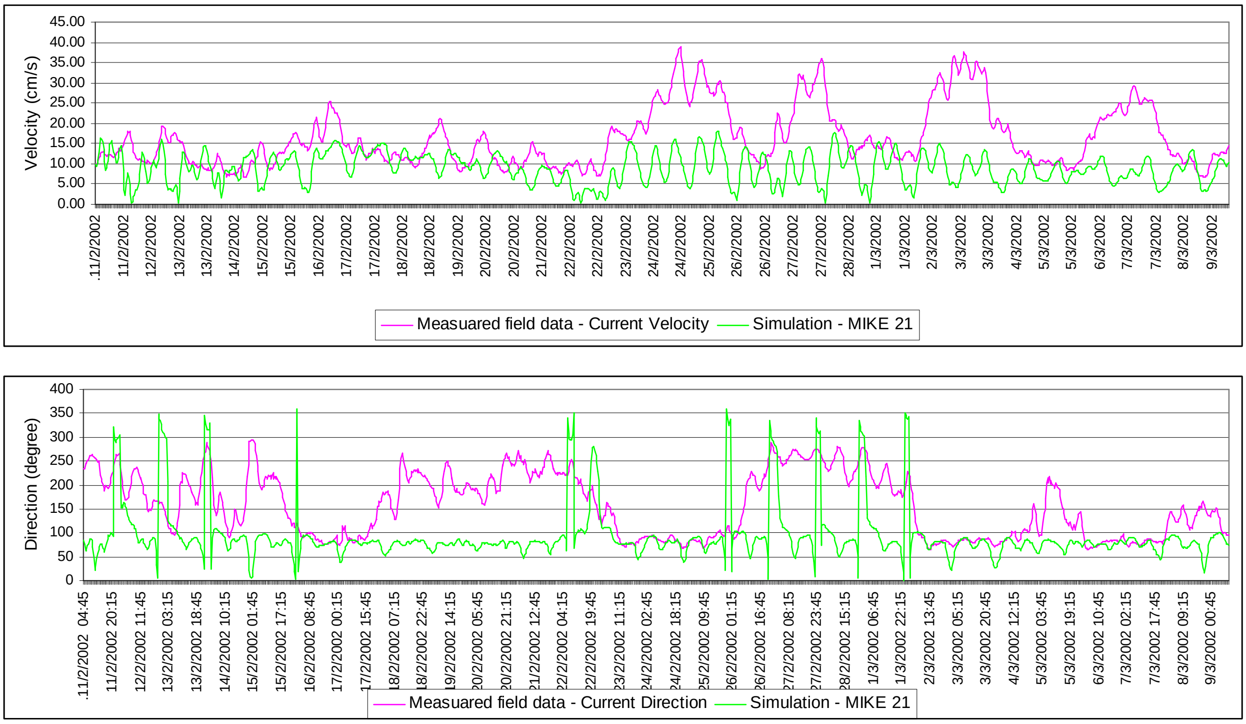

Figure 11 - Current data comparison between field data and Mike 21 HD numerical simulations – Summer 2002

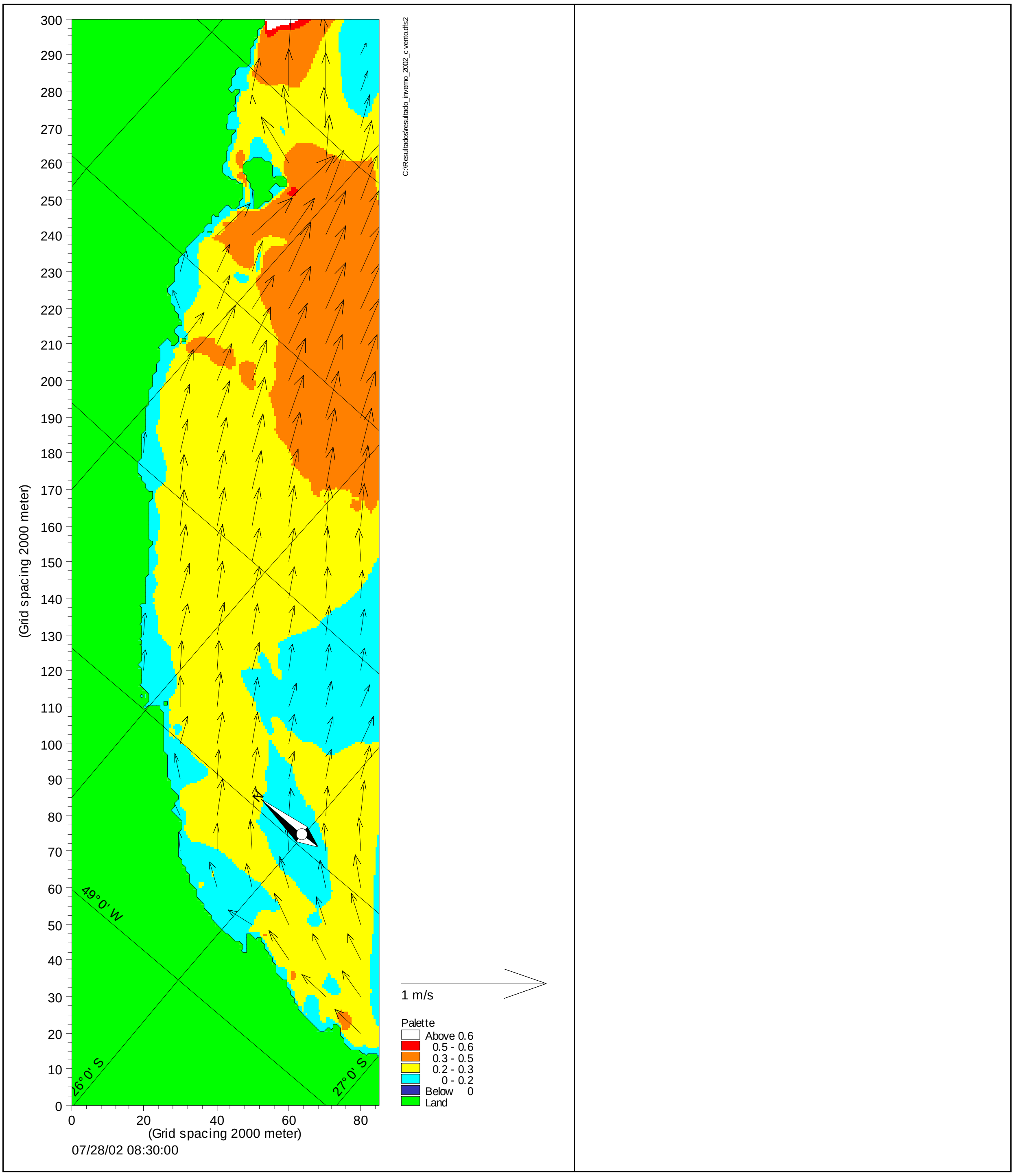

Figure 12 - Current Maps from Mike 21 HD simulations – Winter 2002 – Meso-scale Bathymetry.

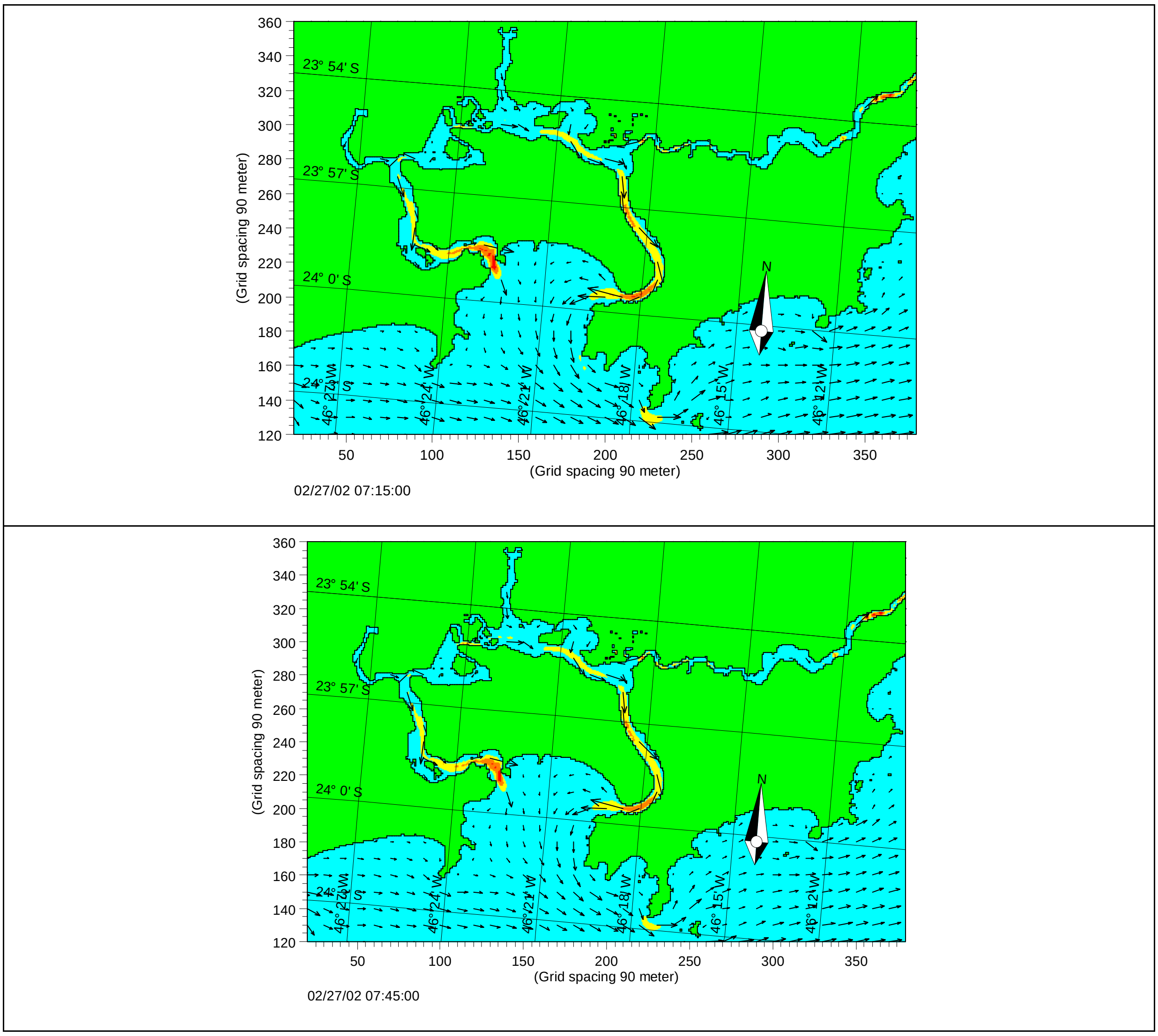

Figure 13a – Ebbing current maps from Mike 21 HD simulations – Summer 2002 – Santos Estuarine System Bathymetry.

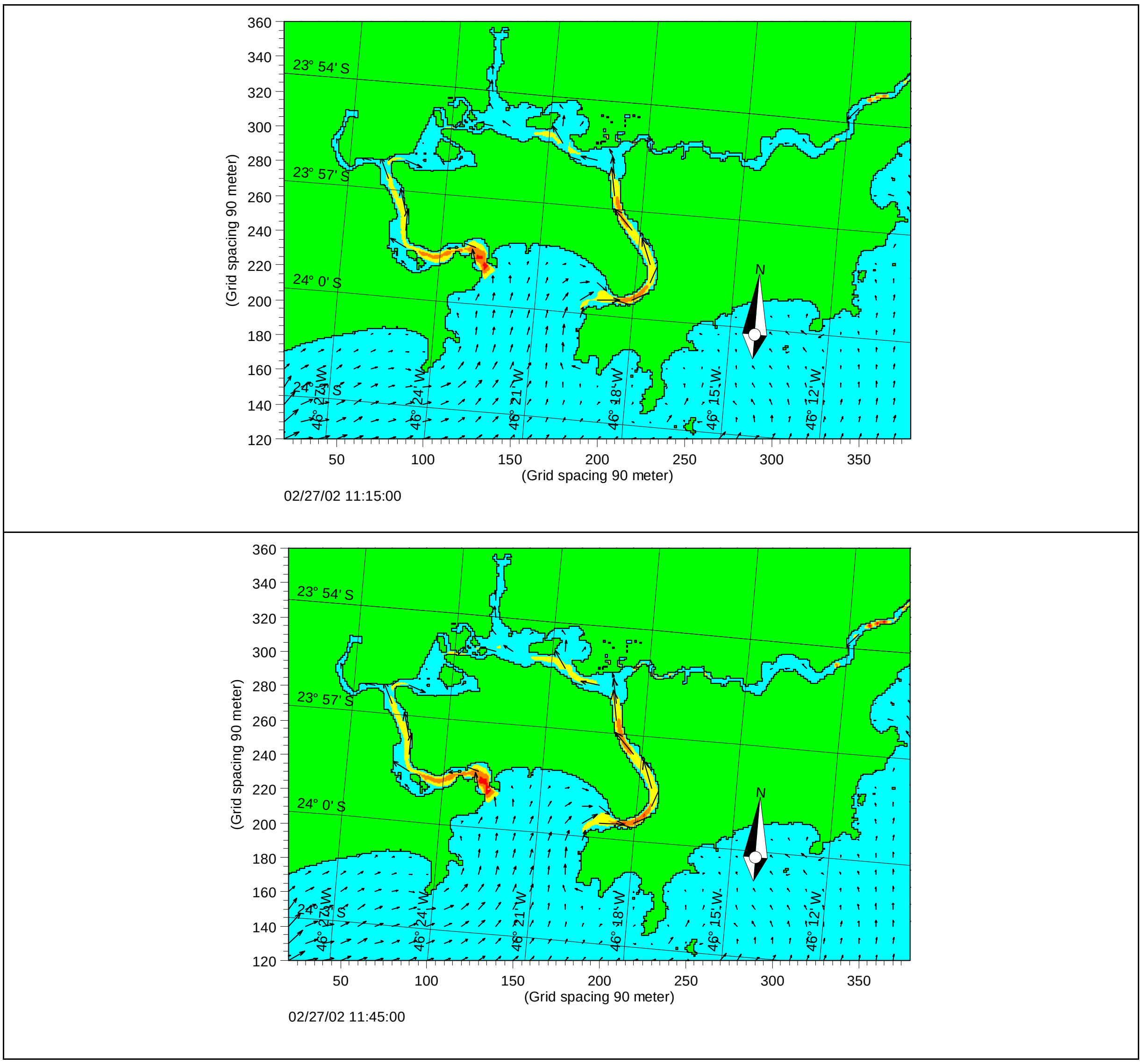

Figure 13b – Flooding current maps from Mike 21 HD simulations – Summer 2002 – Santos Estuarine System Bathymetry.

In addition, Mike 21 simulations introducing large scale POM data at the boundary grids were made; this large scale data consider remote winds and density currents. The surface elevation from POM was therefore used as forcing in open boundaries of MIKE grid. The simulation results improved, as presented in Figure 14.

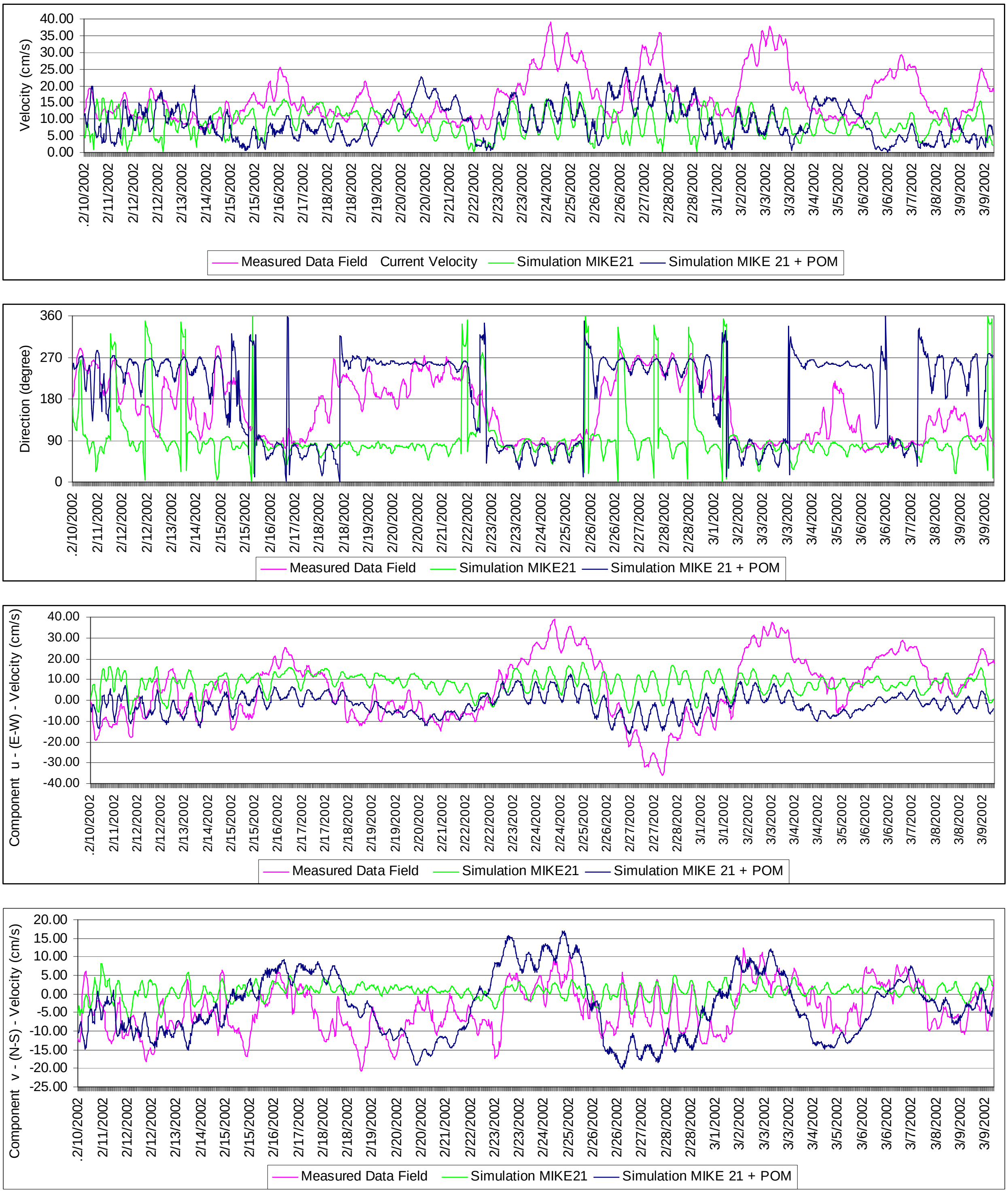

Figure 13 - Current data comparison between field data and Mike 21HD simulations considering at the grid boundary surface elevation data generated by large scale POM run – Summer 2002.

<u>5,2 - POM</u>

Figure 14 presents a comparison between simulation results from POM and field data, for currents data – Winter 2002.

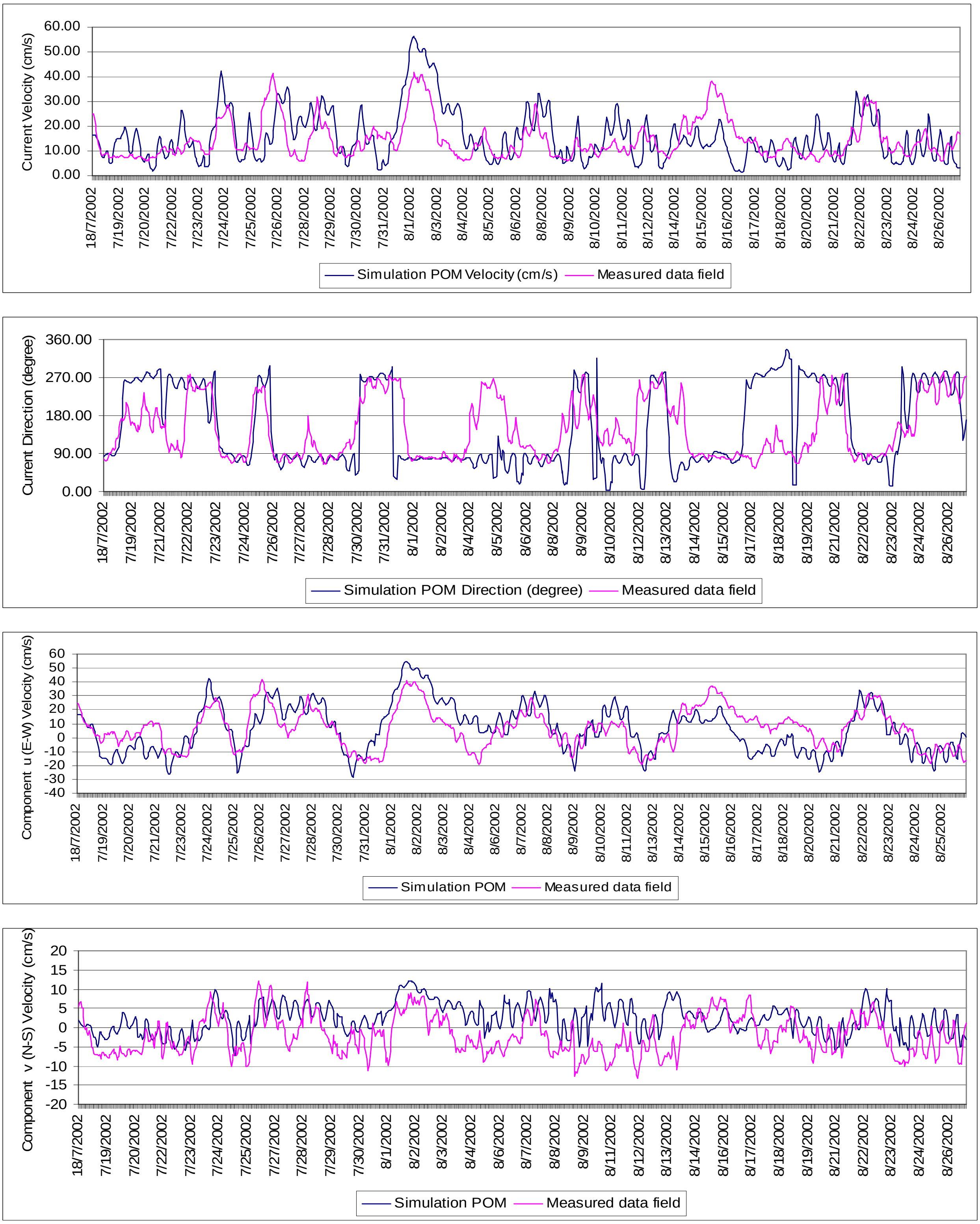

Figure 14 - Currents comparison between field data and POM simulation – winter 2002.

The comparison of measurements and POM simulation has a correlation of 0.52 for velocity, 0.44 for direction, 0.67 for component u (E-W) and 0.35 for component v (N-S), for winter 2002.

6. Preliminary Conclusions

An integrated approach of field data and model simulations can considerably help to understand the behavior of coastal currents.

The research reveals that the results from the numerical models reasonably agree with measurements, demonstrating that this approach has general applicability for environmental assessment in coastal area. Nevertheless, further research is necessary in order to improve the simulations.

The main findings of the studies, so far, are:

- For wind data, the assessment of amplitude spectrum shows that the principal energy concentrations occur in frequencies of 1cpd and 0.2 cpd, corresponding to 1 and 5 days, respectively. This variability confirms the predominance of the breeze and cold fronts in the study area.
- The currents data show that meteorological forcing is responsible for most energetic variability observed in the currents behavior.
- With MIKE 21HD, the barotropic circulation, forced by winds and tides, can not fully represent the maximum currents in the study area. The introduction of large scale data, such as mean sea level variations at the boundaries (due to remote winds and density currents) is necessary. These data can be introduced through large scale or global simulations.
- The POM simulations present good results mainly due to the model characteristics (baroclinic), adequate calibration and the introduction of remote winds and density currents effects through large scale simulations.

Next goals to be achieved in the research are:

- Improvements of MIKE 21HD results.
- Using Delft3d Model and compare its results with those of MIKE21 HD and POM.
- Approach the marine pollution issue concerning domestic wastewater and oil leakage. For this assessment, simulations will be done with CORMIX Program.

7. References

BAPTISTELLI, S. C. Modelação Numérica da Circulação de Correntes de Maré e Induzidas pelo Vento Aplicada a Estudos de Disposição Oceânica de Efluentes na Praia Grande – São Paulo. Dissertação de Mestrado apresentada à Escola Politécnica da Universidade de São Paulo, 168p. 2003

CAMARGO, R.; HARARI, J. Modelagem numérica de ressacas na plataforma sudeste do Brasil a partir de cartas sinóticas de pressão atmosférica na superfície. Bolm. Inst. Oceanográfico, São Paulo, 42(1):19-34, 1994.

CODESP – Companhia DOCAS do Estado de São Paulo. Pesquisa de determinação de áreas de descarte de material de dragagem na zona oceânica exterior à Baía de Santos. Trabalho realizado pela Universidade Santa Cecília – UNISANTA para a CODESP. Relatório Final. 2002.

DHI SOFTWARE 2004. Coastal and inland waters in 2D. www. Dhisoftware.com/MIKE21/.

FCTH. Diagnóstico sobre efeitos da elevação do nível do mar decorrente do aquecimento global da atmosfera nos ecossistemas costeiros Brasileiros – Sub região do litoral das regiões Sudeste e Sul. Trabalho realizado pela Fundação Centro Tecnológico de Hidráulica (FCTH), relativo ao Projeto PROBIO. São Paulo. 2005

GORDON, M. Modelagem da dispersão de substâncias no Porto e Baía de Santos. Dissertação de Mestrado apresentada ao Instituto Oceanográfico da Universidade de São Paulo. 128p. 2000.

HARARI, J.; CAMARGO, R. Simulação da propagação das nove principais componentes de maré na plataforma sudeste brasileira através de modelo numérico hidrodinâmico. Boletim do Instituto Oceanográfico, São Paulo, 42(1): 35-54, 1994.

HARARI, J.; CAMARGO, R. Tides and mean sea level variabilities in Santos (SP), 1944 to 1989. Relatório Interno do Instituto Oceanográfico da USP, n°36, 15 p, 1995.

HARARI, J.; CAMARGO, R. Modelagem numérica da região costeira de Santos (SP): Circulação de maré. Revista Brasileira Oceanogr. 46(2):135-156, 1998.

HARARI, J.; CAMARGO, R. Numerical simulation of the tidal propagation in the coastal region of Santos (Brazil, 24° S 46°W). Continental Shelf Research, vol. 23 (2003), p. 1597 – 1613, 2003.

WELLINGFORD, H. R. Santos Bay Projecty – Preliminary Hydraulic Study. Hydraulics Research Report. Report EX2241. 1990.

KOWALIK, Z.; MURTY, T. S. Numerical modeling of ocean dynamics. World Scientific - Advanced Series on Ocean Engineering, vol. 5, 481 p, 1993.

MELLOR, G. L. Users guide for a three-dimensional, primitive equation, numerical ocean model (June 2003 version). Prog. in Atmos. and Ocean. Sci, Princeton University, 53 pp, 2003.

PICARELLI, S. S. Análise da hidrodinâmica da região costeira Centro-Sul do estado de São Paulo através de modelagem numérica – Efeito de maré, de ventos e do campo de densidade. Tese de Doutorado apresentada ao Instituto Oceanográfico da Universidade de São Paulo. 115p. 2006.

REIS, L.F.B. Estudo em modelo reduzido de fundo móvel do Porto de Santos. Apresentado no 1º Ciclo de Palestras de Engenharia Costeira. Rio de Janeiro, 1978.

SABESP. Programa de Monitoramento Ambiental da Área sob Influencia dos Emissários Submarinos de Esgotos de Santos/São Vicente e Praia Grande Subsistemas 1, 2 e 3. Relatórios Parciais. São Paulo. 2006