Metocean Operational Modeling To Support Outfall Construction Along The Coastal Water Of Brazil

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Abstract

Along the coastal zone of the State of Sao Paulo – Brazil, known as Santos Metropolitan Area, only about 43% of businesses and residences are connected to a sewer system. The sanitation program is aimed at raising the sewer system along the coastal zone of Sao Paulo (Baixada Santista) to 95% collection and to triple the availability of clean water. In order to achieve this goal, the sewage network have been expanded, the existing outfalls improved and a new oceanic outfall has been constructed in Praia Grande.

This paper presents the implementation of a meteorological-oceanographic (metocean) operational modeling system to support the construction and deployment of the new ocean outfall in Praia Grande and the expansion of the existing one in Santos. The seasonal variability of the metocean conditions was modeled through numerical simulations which determined the local circulation and transport patterns. The models were able to capture and reproduce these dynamics and then a daily metocean forecast bulletin, which will be presented in this work, was created to support operations.

The modeling system’s role in this important sanitation project is to provide metocean forecast bulletins for the construction consortium. The operational modeling system analyzes in-situ collected data and the results of ocean and meteorological models with different scales on a daily basis, issuing a bulletin with the forecast for the next 5 days. During the construction and deployment phase, the forecast bulletin became an important management tool, which assisted the construction consortium in defining the work load and project schedule.

Keywords

Meteorological-oceanographic modeling, outfall, forecast, Metropolitan Region of Santos, project management tool.

INTRODUCTION

With 2.2 millions people, the Metropolitan Region of Santos (known as Região Metropolitana da Baixada Santista – RMBS) is the greatest one in the coast of São Paulo state, the most populous state in the country (41 million), responding for 33.1 % of the Gross Domestic Product.

Every year, during the summer season, the region receives an increment of approximately 2 million tourists, looking for its beaches. Considering the importance of the tourism to the region, it may come as a surprise that only 43% of the region’s businesses and residences are connected to a sewer system. To change this situation, the state government implemented the Clean Wave Program (Programa Onda Limpa – POL). This program aims to raise the number of residences connected to the sewer system to 95%. In order to achieve this goal, the sewage network has been expanded, the existing outfall in Santos improved and a new oceanic outfall has been constructed in Praia Grande. Both, the expansion in Santos outfall and the new one in Praia Grande were made with a High-Density PolyEthylene (HDPE), a flexible material that allows the outfall to follow the bathymetry. In Santos one tube was used with around 450 m while in Praia Grande three tubes with 1.5 km each were used. The tubes were assembled in a river inside Santos estuary. One at time they were sunk slowly in position. It’s a very delicate operation and depends very much on good oceanic and meteorological conditions.

To help during the construction and deployment of a new ocean outfall in Praia Grande and the repair and expansion of the outfall already existent in Santos, a meteorological and oceanographic (metocean) operational modeling system was implemented to the region. This system consists of three sets of model:

- Hydrodynamic, consisting of two nested grid of POM;
- Wave, consisting of one meso-scale grid of WAVEWATCH III (WW3) nested with a small scale grid of SWAN;
- Atmospheric, consisting of three nested grids of Non-hydrostatic Mesoscale Model (NMM) core of the Weather Research and Forecasting (WRF) system.

With the results of the models, daily metocean forecast bulletins were provided to the construction consortium with the forecast to the next five days. In addition to these results, the forecast bulletin also considers satellite images and data collected in-situ.

Meteo-oceanographic characteristics

The RMBS has a tropical humid climate with high rainfall rates. The atmospheric circulation is dominated by the South Atlantic Anticyclone (SAA), which induces fair weather with NE mild to moderate winds. Periodically, this pattern is disturbed by the presence of frontal systems, causing moderate to strong winds ranging from SW to SE (in most of the cases). These frontal systems affect the region during an average period of 2 days, happening from 3 to 6 times a month (Stech & Lorenzetti, 1992) and can create and transport waves, which represents the greater threat to engineering works on the sea.

According to Farinnaccio (2009) the waves along Sao Paulo coast are within 0.5 m to 2.0 m during 90% of the time, while 50% of the time they are within 1.0 m to 1.5 m. Usually, the waves are greater during the passage of a frontal system and take a few days to decrease after the system moved. During the summer, the average number of frontal systems is approximately four, while in the winter this number rises to approximately 5.

In this particular case, the work could only happen during “windows of fair weather”, when the winds are mild to moderate and the wave height is above 0.8 m. Considering the time the waves take to decrease after a frontal system, a small difference in their number between the seasons can mean the existence or not of such windows. Therefore, to know when they will happen is essential to properly manage the work.

MODELING

The operational procedure for the metocean monitoring of RMBS involves the integration of three distinct types of numerical models. A high resolution atmospheric model was implemented in the region, which supplies boundary conditions to the wave and current models. The hydrodynamic model results also supply boundary conditions to the wave model. The main characteristics of these three models will be summarized next.

Hydrodynamic modeling

The hydrodynamic model used is based on the Princeton Ocean Model (POM), developed by Blumberg & Mellor (1987), implemented by the ASA South America modeling group. The model uses as forcing fields, tides from the Center for Space Research global model of tides - CSR3, three-dimensional wind fields of NCEP (National Centers for Environmental Prediction) meteorological models reanalysis and termohaline field treated from OCCAM (Ocean Circulation and Climate

Advanced Modeling Project) results. At the open edges, dated conditions of the OCCAM for elevation, barotropic speed, temperature and salinity are also used.

The hydrodynamic model has a non linear three-dimensional structure, with the hydrodynamic equations written in the flow form, under Boussinesq and hydrostatic approximations. This model allows the use of curvilinear grids, σ vertical coordinate and the resolution of surface and deep turbulent layers by means of a turbulent closure submodel of second order, which allows the model to reproduce the Ekman surface and bottom layers in a more realistic way.

The implemented general grid results from a commitment to attend the description of the relevant hydrodynamic processes for the present region, the computational capacity, and the necessary processing time. A final meso-scale grid with horizontal dimension of 100x300 points was implemented over the region, with average resolution of approximately 3 km. In this grid 20 sigma layers have been used for the definition of the vertical structure of the region.

For the continental shelf region, the bathymetric data have come from DHN nautical charts. For the topographical representation of the continental slope and abyssal plain regions, the bathymetric database extracted from ETOPO 2 of NGDC (National Geophysical Data Center) from NOAA (National Oceanic and Atmospheric Administration) , resampled for a 10' resolution, was used. Aiming at having a fine adjustment of the bathymetry to the shoreline and to the layers of geographical information systems (GIS), used by the mathematical models implemented in the region, information proceeding from satellite images has also been used, complementing the ASA South America bathymetric database in the area.

Wave modeling

The state of the art for the numerical simulation of the processes of generation, waste and interaction between waves, is present in the third generation models. For simulation of the wave field at Sao Paulo Coast and Santos Bay, two third generation wave models are used: WW3 (WAVEWACTH III) and SWAN (Simulating WAves Nearshore).

WW3 is a large scale model which was nestled to a meso-scale grid. This nestling allows to get information on the wave spectrum and to characterize the sea state in the neighborhoods of the study region. In order to effectively monitor and foresee the maritime agitation on the surroundings of Santos Bay, the SWAN model was implemented in a small-scale grid.

SWAN is a wave model with appropriate formularizations to represent the processes of wave propagation in shallow waters. The system works using the WW3 output results and the meteorological field from WRF-NMM model (which will be explained in the next section) to supply boundary conditions to the local grid of SWAN.

The grid implemented for the wave model is focused on Santos Bay. A meso-scale grid with horizontal dimension of 140 x 230 points was implemented on the region with maximum average resolution of 1 km. The bathymetric data have come from DHN nautical charts put in digital format and, also, extracted from ETOPO 2 of NGDC. The curvilinear grid was developed in order to follow the shoreline and bathymetry lines of the region, favoring the propagation of the waves in the domain, with the minimum possible interference.

Atmospheric modeling

The model used for the atmospheric fields simulation was WRF-NMM (version 3), developed by NOAA/NCEP, and is designed to be a flexible, state-of-the-art, portable code efficient in a massively parallel computing environment (WRF, Janjic 2003). The WRF-NMM is suitable to use in a broad-range of applications across scales, ranging from meters to thousands of kilometers, including forecast research, parameterization research and coupled-model applications.

The data processed by the WRF typically come from a previously run from a global forecast model, Global Forecast System from National Center for Environmental Prediction (GFS/NCEP). The GFS is a global spectral data assimilation and forecast model system. GFS forecasts are produced every six hours at 00, 06, 12 and 18 UTC. The resolution of the global forecast is 0.5º, with 3 hourly outputs. The vertical resolution is 64 layers, with top at 0.2 hPa. The GFS contains a full suite of parameterized physics as well as accompanying sea-ice and land-surface models.

Two grids have been configured encompassing the study region. The first one was nested in the one from GFS and has a resolution of 0.1º x 0.1º. The second is a local one was nested in the first, with 1 km resolution allowing to resolve satisfactorily the local characteristics of the wind generated by the jagged geography of the region.

WIND DATA COLLECTION

In order to validate the atmospheric model and to help the forecasting process, a weather station Davis Pro2 was installed above the operational center. This station acquires wind intensity and direction, atmospheric pressure, humidity, temperature and rainfall data, which were transferred to computer inside the operational center, where they were treated, analyzed and filed.

OPERATIONAL PROCEDURES

The operation system consists of the planning, structuring, automation, standardization and assembly of several procedures which allows to meet the demands of the project. The meteorological conditions and sea state (waves) for Santos bay and adjacent oceanic regions were simulated continuously.

Figure 1 summarizes the stages and resources used in the project. Basically the system consists of an automatic integration of a set of local mathematical prognostic models (WRF and SWAN) to the results of global models, nestled specifically for the region (GFS and WW3). For hydrodynamic modeling, the same model (POM) was used on both scales.

As previously mentioned, the results of the nestled model were not directly used by the ASA system, first receiving treatment and analysis until it was available as a final product. The access to these results were carried through the ASA server and, after analysis and approval by the team on duty, directly sent to the control center of operations by email. These results and their sub products were also available through remote access on a webpage.

The functioning of the metocean forecast system, presented in Figure 1, requires several routines of processing. That flowchart was configured aiming at providing the biggest automation of the system. These routines were acquiring information, executing models, generating pre-analyzes results and keeping all the hardware system under permanent surveillance. The drive of internal maintenance teams were also made by the routines, automatically. A summary of the main processing routines is described below:

- Daily runs to create the meteorological fields from WRF model and the wave fields from WAVEWACTH III model;

- Real time evaluation of the physical system promptitude situation, considering the operation state (Normal, Attention, Emergency);
- Data transference, treatment and formatting, by ASA team, to provide boundary conditions for the local wave model and to perform analysis of several atmospheric fields, formulating the weather forecast for the next 3 days;
- Treatment and formatting of the hydrodynamic model results, by ASA modeling team, to be incorporated as forcing in the local wave model;
- Joining of the different forcings and simulation of wave fields with the local wave model (SWAN);
- Processing of the results and incorporation in the metocean bulletin;
- Analysis of the bulletin by the briefing team, determination of the system state and sending the information to the control center of operations.

Metocean bulletin

The metocean bulletin was elaborated aiming to supply the operation teams with the main atmospheric and oceanic parameters and pointers to the Santos Bay region (São Paulo). This bulletin was elaborated to make it possible to integrate the information that comes from the different numerical models, supplying in regular time intervals a characterization of the weather and maritime agitation conditions in the region.

The complete metocean bulletin were available once a day, having a synoptic description of the region atmospheric and oceanographic forecast for the next 72 hours and a table with the mean values of the main oceanic and atmospheric parameters (e.g. significant height, periods, currents, elevation, winds, precipitation, etc.). After the approval of the bulletin by the responsible team, it was automatically sent by email. In parallel, an internet page (with restricted access) was created, where the metocean bulletin was available, making it possible to get a better visualization of color graphs and satellite images. Also on the Internet page, animations of wind fields and waves evolving in time and space were made available.

In order to mobilize the monitoring team and to have a perfect system functioning in possible anomalous conditions of weather and agitation of the sea, three states for the monitoring system have been defined: Normal, Attention and Emergency states. The abnormal conditions are defined based on critical values for some parameters, forecasts of abrupt weather or according to previous criterions.

Meteorological information

The atmospheric information made available in the bulletin consisted of average information for the main meteorological parameters, a present synoptic characterization of the region and a meteorological forecast for the next 72 hours, based on the results of the atmospheric simulations and satellite and radar images.

A synoptic description of the present conditions was supplied based on observed meteorological data (winds, relative humidity, etc.) available on the internet, satellite images and results generated from atmospheric models. Together with the synoptic description the representative image of the more recent observed conditions was sent.

Oceanographic information

The oceanographic information in the bulletin was aimed to supply the characterization and forecast of the sea agitation and complementary information about the oceanic circulation dynamics on the region for the next 72 hours.

The complex wave field representation generated by SWAN allows the representation of the wave field not only in function of wave height and period but also in function of a wave spectrum. This spectrum, named wave directional spectrum, describes energy distribution in all the directions and frequencies for a determined locality. This representation was also part of the oceanographic information in the bulletin.

CONCLUSIONS

After analyzing the available data and the existing literature about the region, it was possible to successfully implement the operational forecasting system, with meteorological, hydrodynamic and waves' models, which were able to represent the dynamics of the region. The results of the models were used to produce a daily forecast bulletin, which was sent to the people involved in the project through email and made available in a webpage during the whole extension of the operations in the sea.

This management tool has proved its reliability assisting the consortium in defining the work load and the project schedule, especially during the most sensitive phases.

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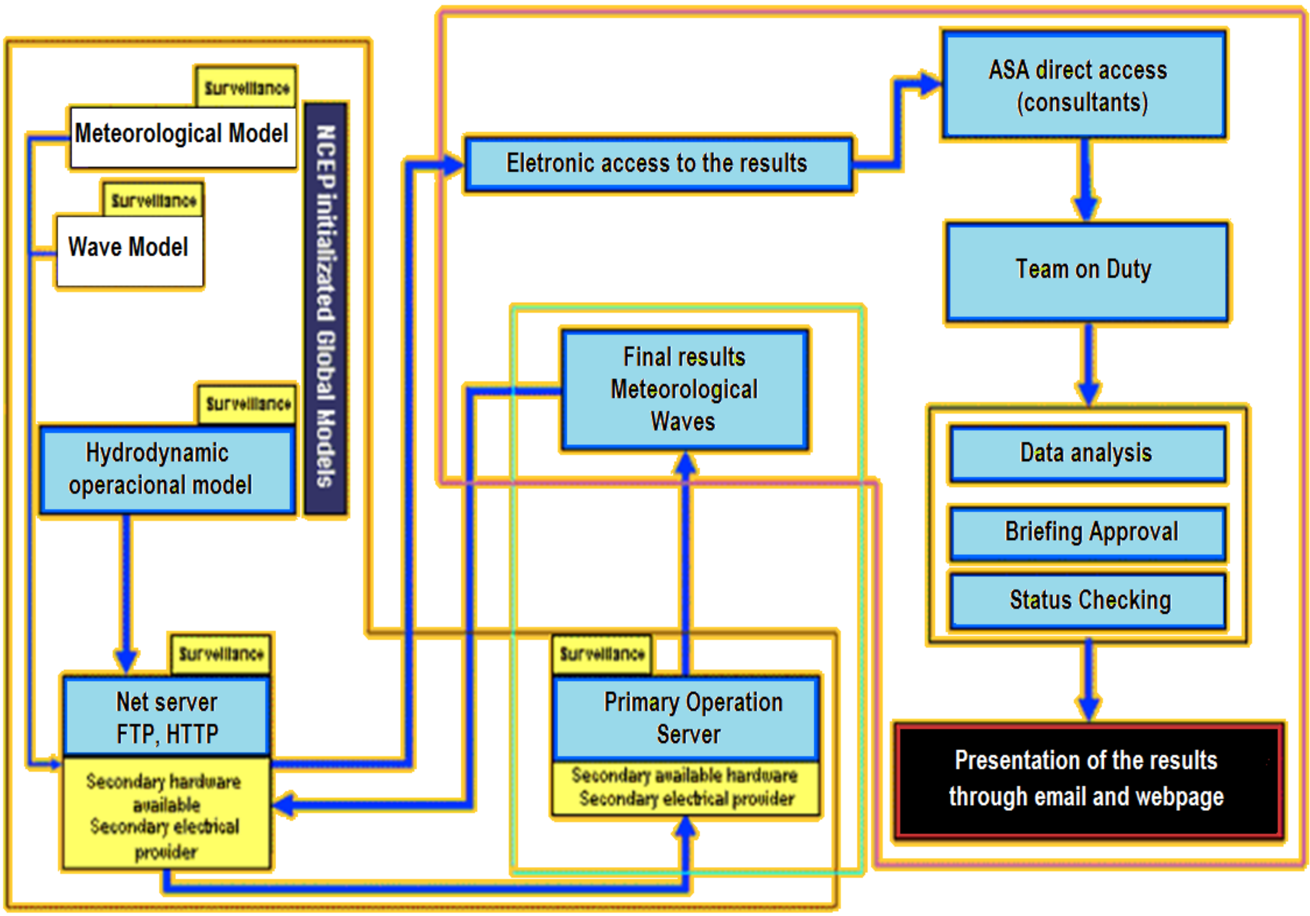

Figure 1.Illustrative diagram of the automatic procedures used on the project.