Interspill 2004
Presentation no. 478

Computational Tools for Contingency Planning in Brazil

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Abstract

Increasing demands for petroleum products along the Brazilian coast and Amazon area have enormous economic, social, and environmental importance. A wide variety of environments, from subtropical Patos lagoon in the southernmost part to equatorial Amazon riverine systems in the north, has prompted PETROBRAS, the Brazilian oil company to build up a robust oil spill contingency planning for diverse oil facilities along the Brazilian coast and the Amazon River tributaries. It is a pioneering and challenging project that clearly shows the importance delivered by PETROBRAS to achieve excellence in environmental and operational safety issues.

The present paper describes the steps involved in the development and implementation of computational tools for contingency planning in Brazil, including retrieval of available meteorological and oceanographic data in different agencies and institutions, the restrictions to plan and execute accurate measurement programs over a limited period of time, the stepwise procedure to design and improve model grids, introduce initial and boundary conditions, application of different modeling approaches (e.g., stochastic versus deterministic), comparing the results and calibration standards, and the interaction with contingency plan specialists that can have biased views about the results of oil spill models.

Overall, the project has achieved very good quality standards and can be considered a significant advance to build up an efficient oil spill response capability for a diverse and geographically spread range of oil facilities in Brazil.

Introduction

In 2000 PETROBRAS (a Brazilian company among the 15 largest oil companies in the world) launched a program for excellence in environmental and operational safety management, with investments in the order of US$1 billion. One of the key objectives of this program is to improve the prevention and control of accidents in all its facilities through automated contingency plans.

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The challenge to develop these plans resides on the continental dimensions of the Brazilian territory with more than 9.000 km of coastline, and environmental systems ranging from the subtropical Patos Lagoon in the southernmost state to the equatorial Amazon riverine system, including estuaries, coastal zones, and offshores sites (Figure 1). The oceanic basins of Campos, Espirito Santo, and Santos are responsible for more the 80% of the total oil production in Brazil.

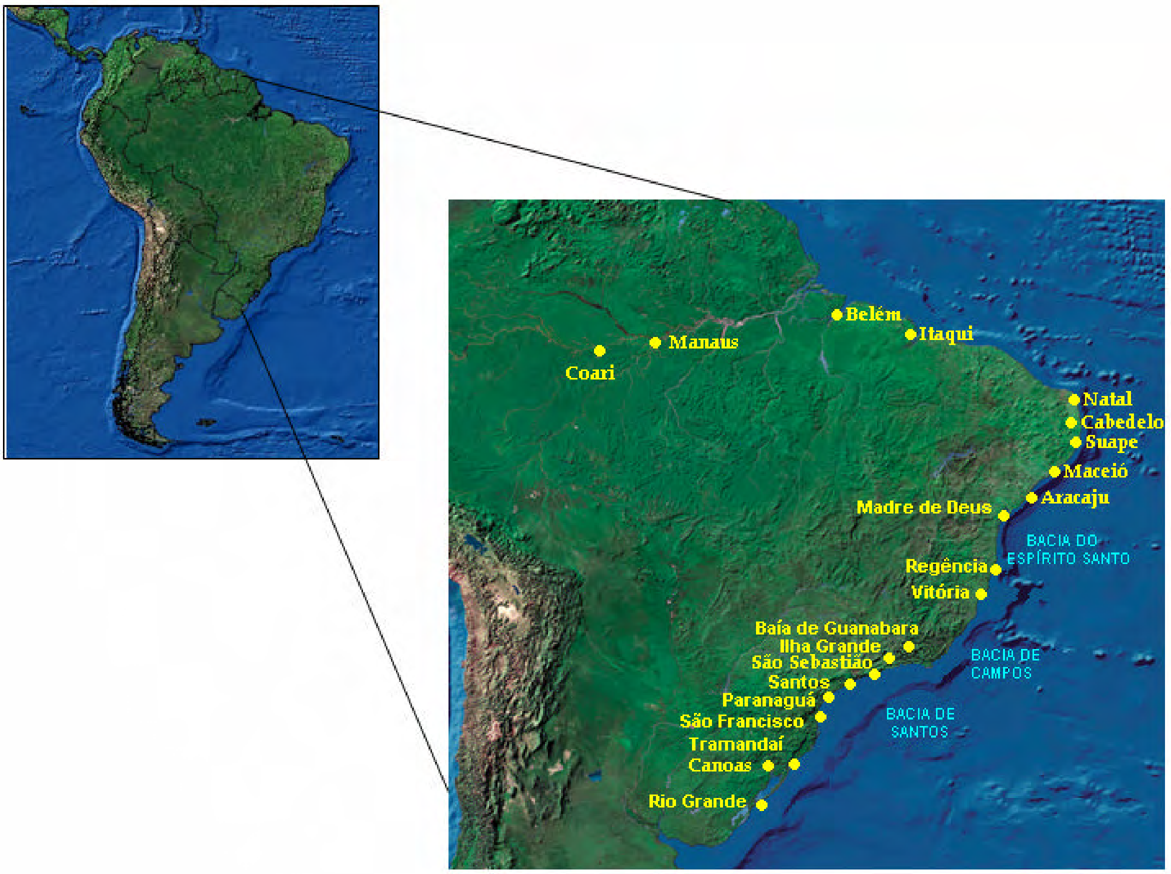

Figure 1 – Location of PETROBRAS facilities along the Brazilian Coast and the major oceanic basins for oil production.

Lima et al. (2003) described the steps involved in the development and implementation of this complex project, including:

- Historical meteorological and oceanographic (hereafter abbreviated to metocean) data analysis
- Data collection programs
- Hydrodynamic modeling
- Development of oil spill scenarios based on risk assessment
- Development of a management tool for comparing results and interacting with contingency plans

The present paper focuses on the development of a system with computational tools and operational procedures, which will allow the implementation of automated contingency plans in Brazil.
Figure **2** presents the system structure, showing the planning phase, including the development of oil spill scenarios for each facility based on the risk assessment, and a framework for future implementation of computational tools for real time emergency response.

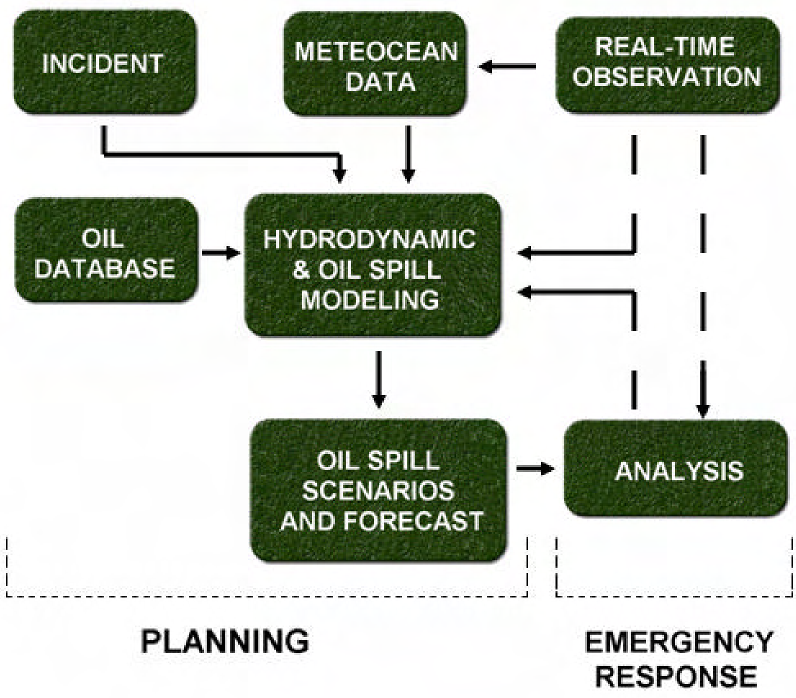

Figure 2 – Framework for computational tools developed for an automated contingency plan.

Procedures

The implementation of a project this size was conducted in 3 major blocks: (a) the environmental characterization, where available information and data were retrieved, analyzed, and the main biogeochemical processes relevant to the project were identified; (b) the hydrodynamic modeling, where the circulation and transport patterns were determined, and a robust modeling framework were setup for nowcast and forecast simulations; and (c) the pollutant transport modeling, where oil spill scenarios are simulated, and a management tool for contingency planning developed.

Environmental Characterization

Brazil is one of the richest country on Earth in biological diversity (Barbosa, 1998). The environmental characterization of such diverse systems and the development of automated computational tools for data analysis imposed a major challenge for this project. In the southern part of Brazil, extreme environmental conditions are typically generated by frontal systems; therefore, circulation and transport patterns are mainly characterized by remote forcing coupled to the Brazil Current along the continental shelf. Whereas in the northern part, around the Itaqui Terminal (Sao Marcos Bay, state of Maranhao) the systems are completely tidally dominated with tidal range reaching up to 7 meters. In the first phase of the project, base maps and bathymetric data for each study area were develop, compiled, and integrated into a uniform database. Figure 3 and Figure **4** show examples of the bathymetric and metocean database.

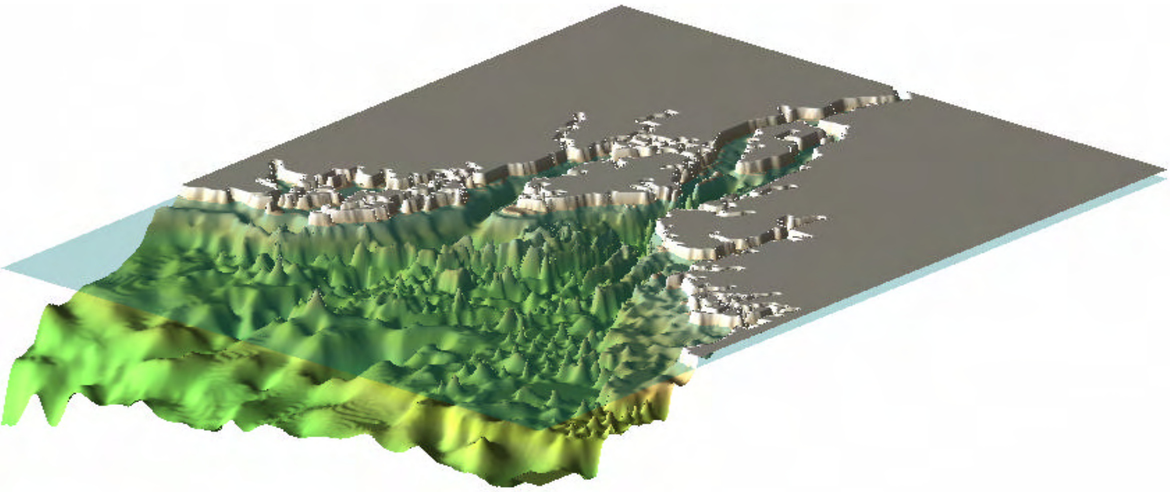

Figure 3 – Example of the environmental database with the bathymetric data for the Itaqui Terminal (Sao Marcos Bay, state of Maranhao) in the northern coast.

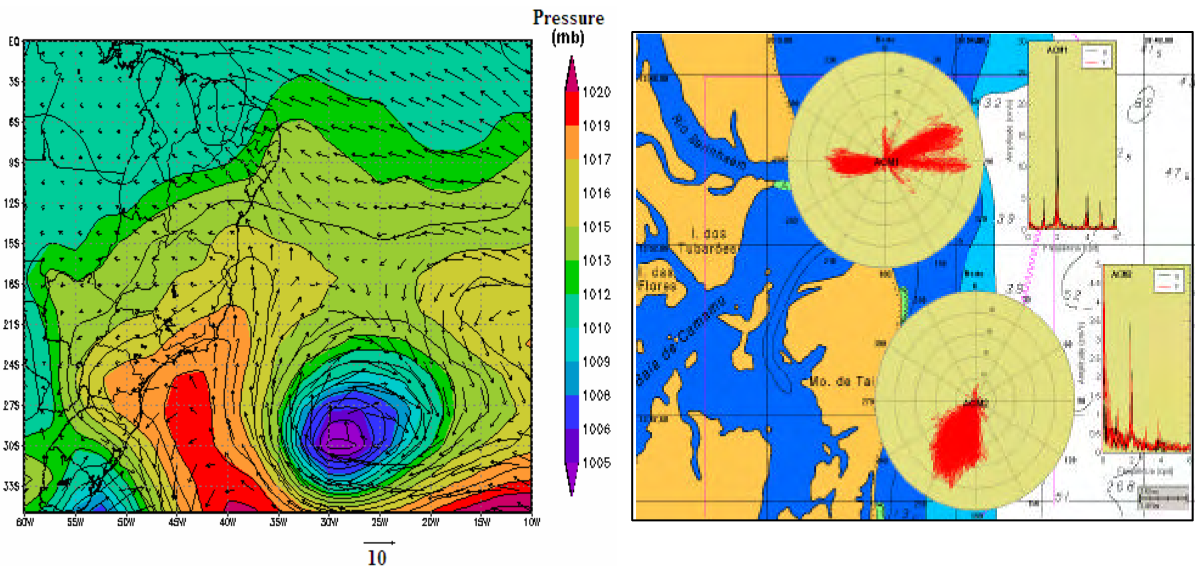

Figure 4 – Example of the environmental database with metocean data.

For the PETROBRAS facilities, available metocean data include wind, tides, currents, salinity, and temperature. The time series were initially analyzed for quality control. The QC tests were developed to identify errors and correct them whenever possible. The criteria to accept the data were based on the specifications presented in a PETROBRAS standard for metocean measurements (PETROBRAS, 1998). Only data collected with properly identified methods and reliable sources were registered in the database.

Aiming at the development of datasets for model evaluation, and to provide inputs for model simulations in nowcast and forecast, COASTMAP (Spaulding, 2003), a GIS system has been used to manage the environmental database, providing rapid access and data analysis to all parameters stored.

Hydrodynamic Modeling

For contingency planning, circulation and transport could be determined for climatological and seasonal patterns. Nevertheless, accurate predictions for currents in terms of nowcast and forecast are the key concern when responding to an emergency incident.

The criteria used to select the hydrodynamic model was a balance between: its scientific background considering relevant physical processes (e.g., tide, wind and baroclinic forces); operational aspects to run it under many different conditions; an open source code with easily modified model routines; and a user-friendly interface to achieve the needs of the project. The operational modeling system developed for this project was designed in a flexible structure based on a predefined netCDF (network Common Data Form, UNIDATA) format. Improvements to the modeling system incorporated all the information collected or generated for a specific study area in this pre-processed netCDF file. The model reads from this file all the forcing and variables required to start a simulation. The run keys and model parameters were intentionally kept separate, to assist in future developments of the model structure.

Basically all inputs, control files, new data for assimilation and outpus are centered in a common structure, as sketch in Figure 5. For non-global models there is a need to prescribe the boundaries conditions with tides, winds (localized and remote setup), baroclinic related gradients, sources and sinks of the model variables. All those data are somehow partially stored in world wide databases as (NODC – National Oceanographic Data Center NOAA, ERA40 – ECMWF European Centre Medium-Range Weather Forecast, WOCE, World Circulation Experiment-FSU) as well as in local universities, private database (SIMO, PETROBRAS), etc.

The upper part of the flowchart presents the initial procedures to compile that input file, including the curvilinear grid generation, meteorological and oceanographic boundary conditions, river inflows and mean sea level variations. The hydrodynamic model provides feedback to that file providing grid corrections and the coastline final tuning. Model results are then automatically transferred to the oil fates and trajectory modeling system OILMAP.

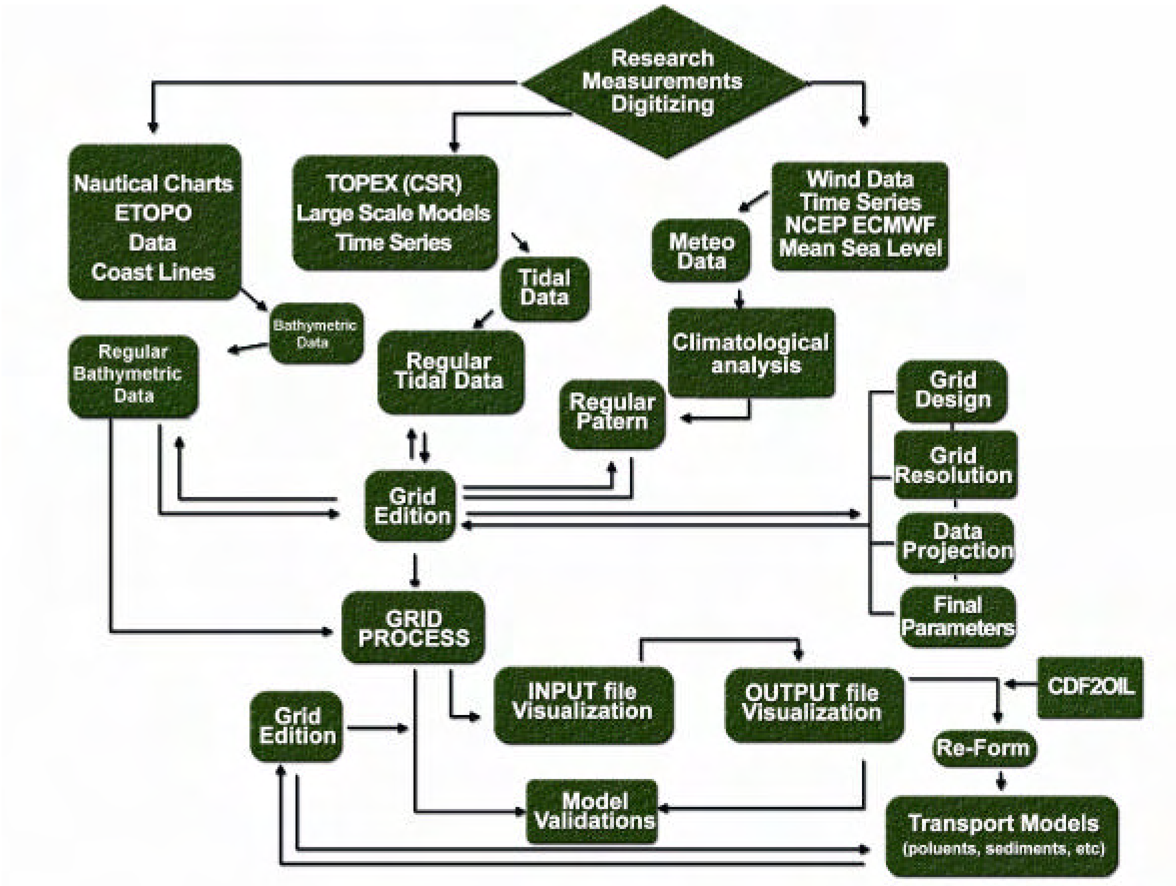

Figure 5 – Hydrodynamic model input-output structure.

For the emergency response phase, the modeling approach is to expand the relevant metocean processes to a regional and ocean basin so that large- and meso-scale processes are actually simulated, instead of prescribed at open boundaries. This is an ambitious project, from both the scientific side of developing numerical models for operational oceanography, and also for computer resources as it requires running hydrodynamic models for the entire South Atlantic (HYCOM)[4], regional basins (HYCOM,POM)[5], and coastal areas (POM, HYDROMAP)[6]. Depending on the scale and domain to be simulated, different modeling structures could be included. The decision on which scale and domain to use is crucial, especially if the model will be required at his maximum forecasting performance.

The implementation of these modeling systems is under development with a cooperative agreement between the Ocean Modeling Lab (LabMon) at the University of S.Paulo and Applied Science Associates (ASA). As an example of the large scale domain, Figure 6 shows climatological sea surface temperature (SST) pattern reproduced by HYCOM in a nested domain centered at South Atlantic. It's a preliminary result aiming to have large and meso-

[4] HYCOM – Hybrid Circulation Ocean Model
[5] POM – Princeton Ocean Model
[6] HYDROMAP – Hydrodynamic Orthogonal Model

scale domains setups in the area. These results will supply boundary and initial conditions to hindcast and forecast localized domains over shelf and continental break along South America and African coast. If the incident requires information on the continental shelf dynamics, the system migrates to a regional scale, where the outer model provides the boundary conditions for the regional model. For this same example, **Figure 7** shows the results for a regional circulation pattern simulated with POM for the Santos Basin. The same procedure applies when a local model is required, as shown in **Figure 8** for an incident inside the Santos Estuary.

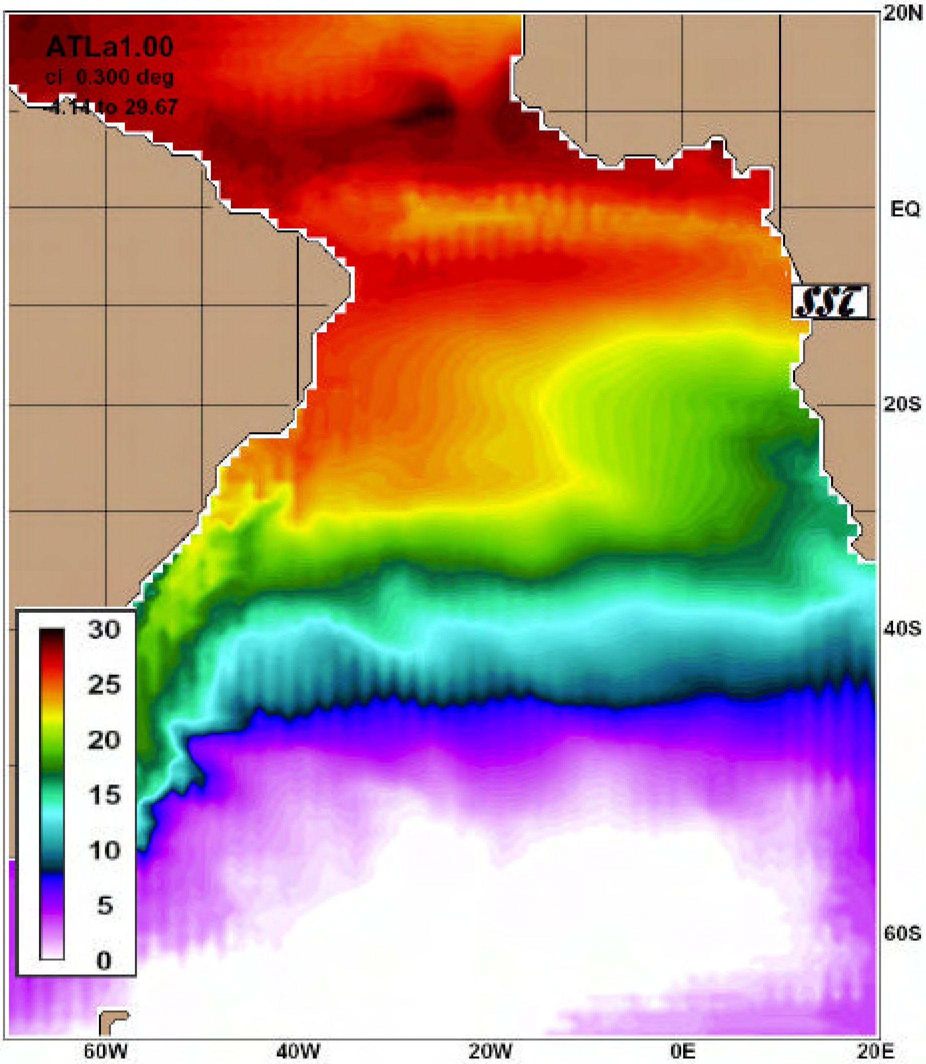

Figure 6 – Climatological sea surface temperature (SST) pattern reproduced by HYCOM in a nested domain centered at the South Atlantic.

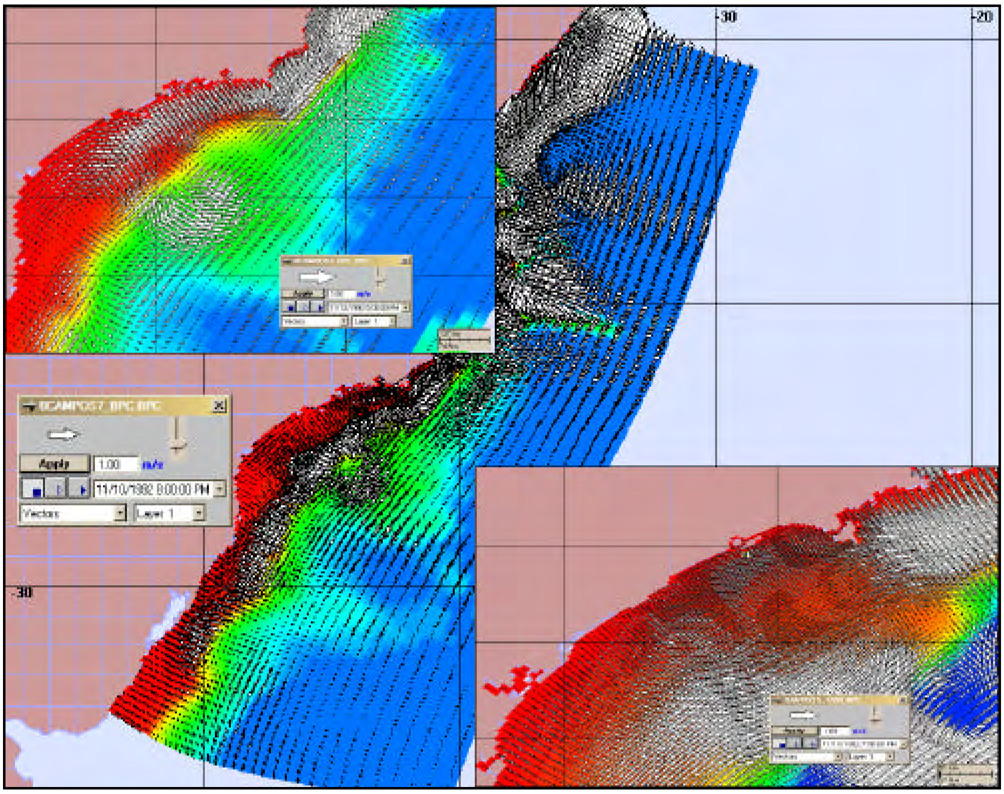

Figure 7 – Regional circulation patterns simulated with POM.

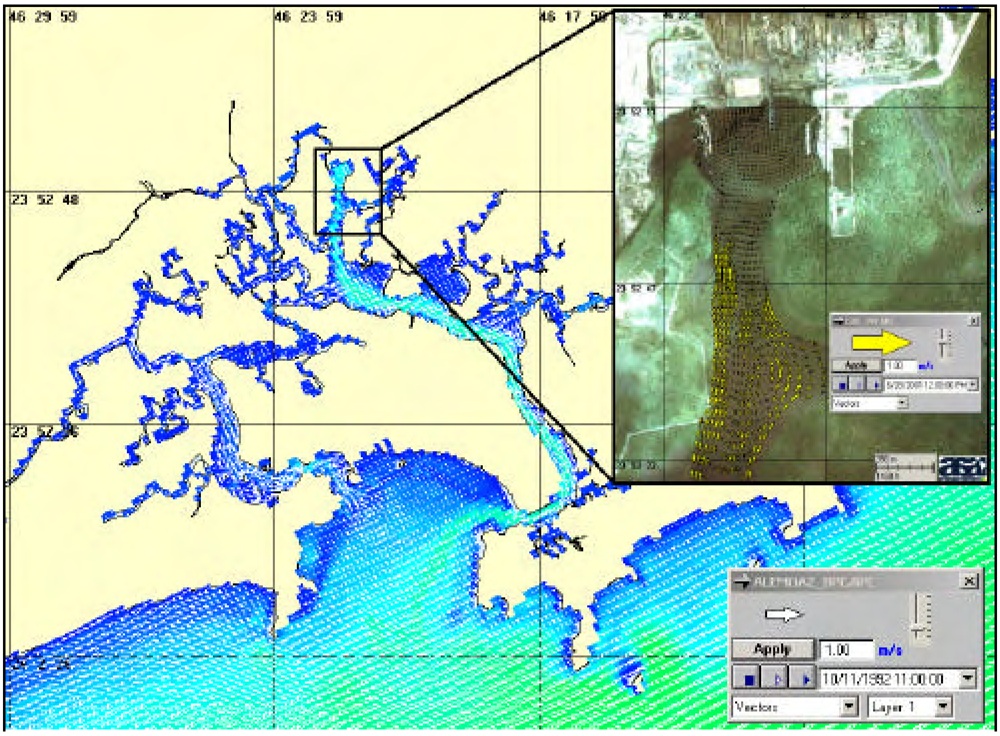

Figure 8 – Local circulation patterns simulated with HYDROMAP.

Development of Oil Spill Scenarios and Real-Time Forecast

In order to develop an effective response system, the trajectory of the spill has to be predicted by a fast and accurate modeling system. In Brazil, the modeling system OILMAP developed by Applied Science Associates (ASA) was implemented in 25 Terminals, 6 Refineries, 18 Distribution Centers, and more than 50 offshore platforms to meet this requirement. OILMAP is a state-of-the-art, personal computer based oil spill response system applicable to oil spill contingency planning and real time response (Jayko and Howlett, 1992; Spaulding et al., 1992a,b). OILMAP was designed in a modular structure so that different types of spill algorithms could be incorporated within the basic system, as well as a suite of sophisticated environmental data management tools, without increasing the complexity of the user interface. Figure 9 shows the structure of the OILMAP modeling approach.

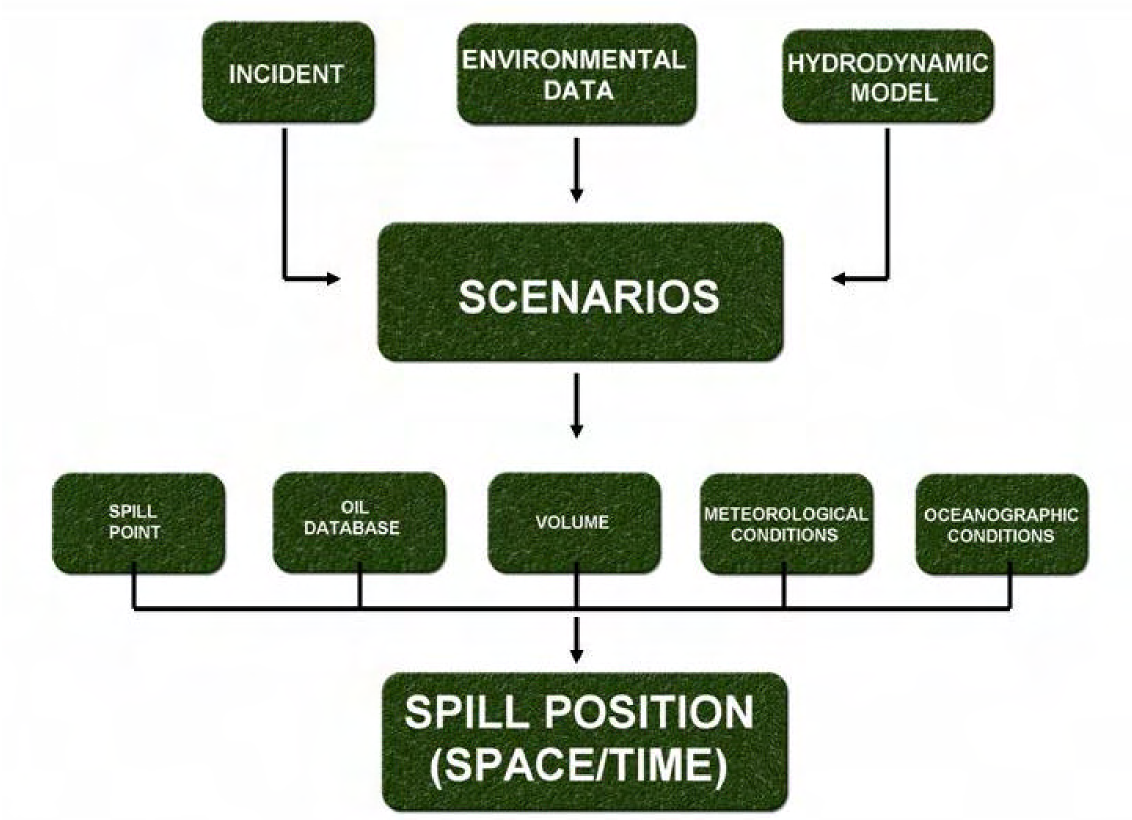

Figure 9 – Oil spill modeling structure.

During the planning phase, oil spill scenarios were simulated based on the risk assessment for each facility. Considering only the 25 Terminals, more than 4,000 scenarios and almost 100,000 oil spill maps were generated. To make it manageable and efficient, a visualization tool was develop, so that an operator responding to some basic on-line questions would have access to the most appropriate scenario map for immediate emergency response. Figure 10 presents the visualization tool for the Itaqui Terminal (Sao Marcos Bay, state of Maranhao). Depending on the demand, model output for visualization could also be presented as Vulnerability Maps and Stochastic Simulations (Figure 11).

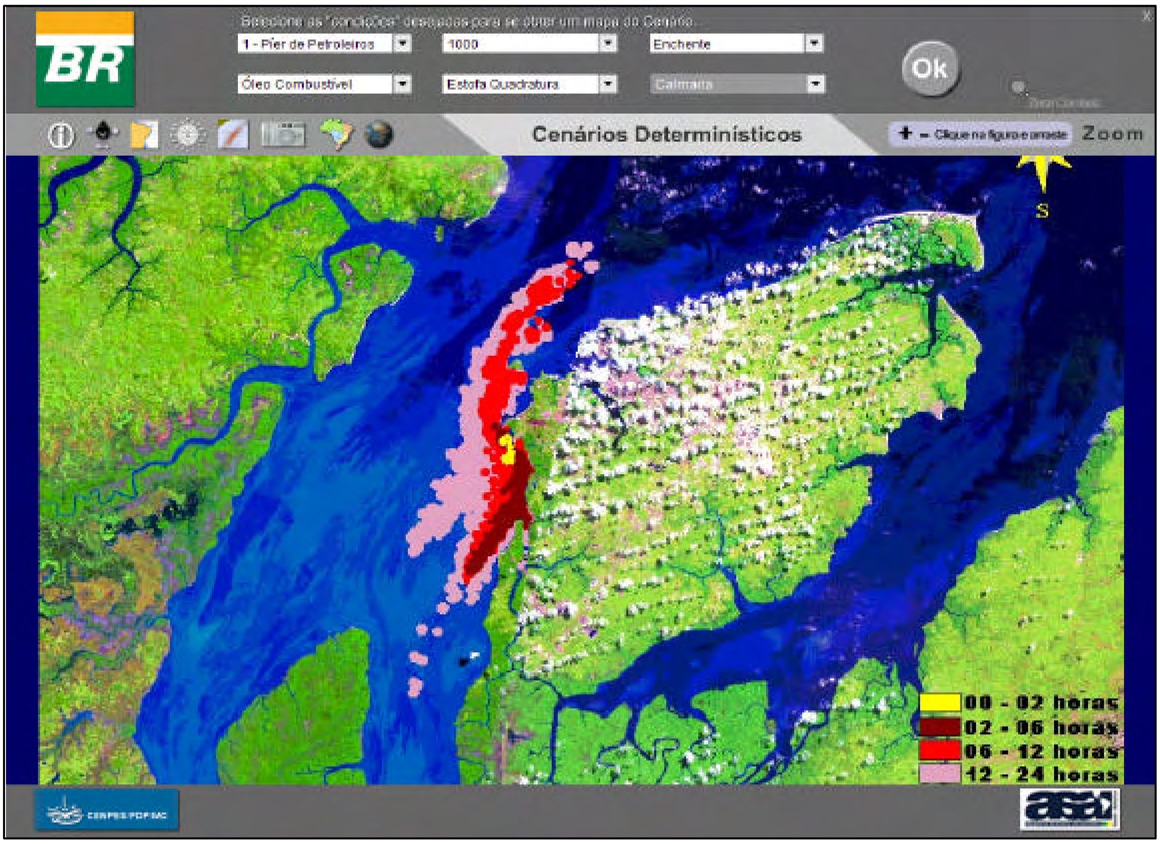

Figure 10 – Visualization tool showing the spill position in the first 24 hours of the incident for the Itaqui Terminal (Sao Marcos Bay, state of Maranhao).

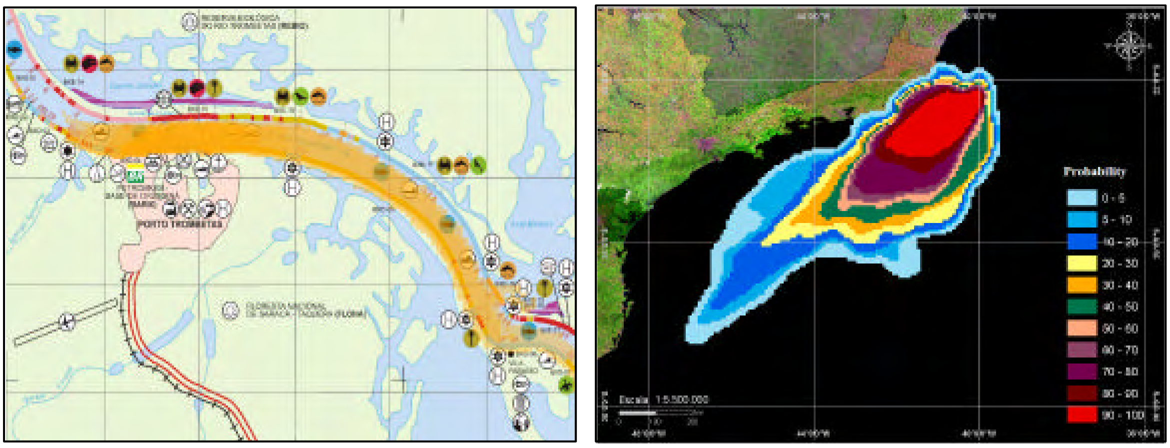

Figure 11 – Visualization options in terms of vulnerability map (Amazon River tributary) and stochastic simulation (water probability) for worst-case scenario in Campos Basin.

In case of an environmental incident, the response team will activate the contingency plan based on the most appropriated scenario and the guidelines of the PETROBRAS Emergency Response System (InfoPAE). Forcefully, emergency responders need clear and precise information about the environmental conditions and the oil spill, including its present position and future trajectory. From Figure 2, it is obvious that to be operational (i.e., to respond a fast demand in any specific area), the flow of information between real-time observations, incident reports, computational modeling, and data analysis has to be flawless.

In operational mode, the emergency response modeling system would be required to produce daily predictions of the current field. On an incident demand, the visualization tool provides the expected trajectory of the spill for the next 24 hours. At the same time, real-time metocean data is retrieved and analyzed by automated procedures for quality control and consistency with previous data stored. Subsequently, a preliminary prediction of the current field in the vicinity of the incident would be calculated using numerical techniques such as artificial neural network models (Conrads & Roehl, 1999). This preliminary trajectory would then be compared to the daily prediction, and a check point determines if the discrepancy between the two (emergency response model results and prediction using the in-situ data) is satisfactory. If acceptable, the system publishes the trajectories for the next 24 hours and communicates with the response team for feedback and updates (e.g., aerial photos, satellite images, and incident reports). If not acceptable, the modeling system would use data assimilation techniques to incorporate the new information into the hydrodynamic model, generates new predictions for the current field, which feedback to oilmap for new oil spill trajectory and fates.

As an effective computational tool, the emergency response modeling system would also allow crisis managers to evaluate different alternatives in responding to an incident. Modeling results could provide information such as how long an oil spill takes to reach a highly sensitive site, and in which conditions (Figure 12). Straight away, the crisis manger could evaluate the use of response options to protect specific environmental resources (Figure 13), with precious information such as the amount of time to respond, the amount of oil to recover, and the metocean conditions to come across.

Concluding Remarks

This paper presents the computational tools for contingency planning in Brazil developed by PETROBRAS, Applied Science Associates, and LabMon-USP. The system is based on a robust oil spill contingency planning for diverse oil facilities along the Brazilian coast and Amazonriver area. It is a pioneering and challenging project that clearly shows the importance placed by PETROBRAS to achieve excellence in their environmental and operational safety focus.

Acknowledgments

The authors would like to thank the entire project team without whom this challenge could not be accomplished. Especially, Dr. Marco Antonio Correa, Dr. Andrea Gallo Xavier, Marcelo Martinelli, Eoin Howlett, Tatsu Isaji, Roderick Gama, Ágata Romero, Mauricio Lammardo, Ana Carolina da Rocha, André Marquez, João Marcos Azevedo, Maria Regina Guimarães, Ronaldo Palmeira, Rafael Bonanata, Carlos Eduardo Simão, Caroline Fisch, Christian and PETROBRAS/TRANSPETRO staff.

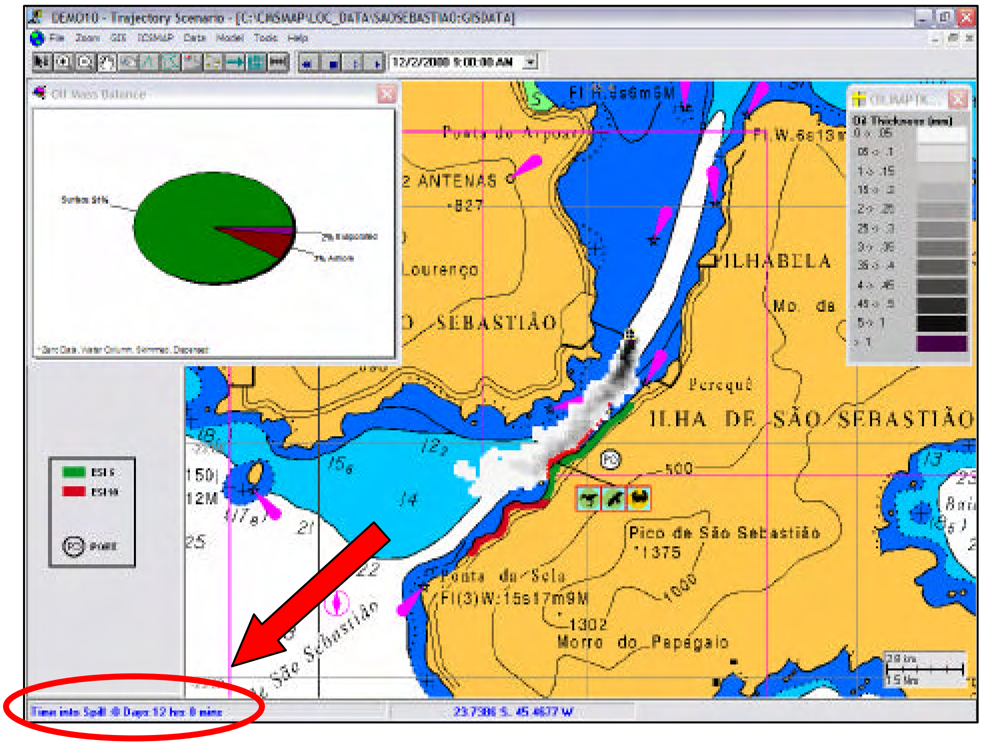

Figure 12 – Oil spill position, thickness, and mass balance after 12 hours of the incident, along with information on the sensitivity map.

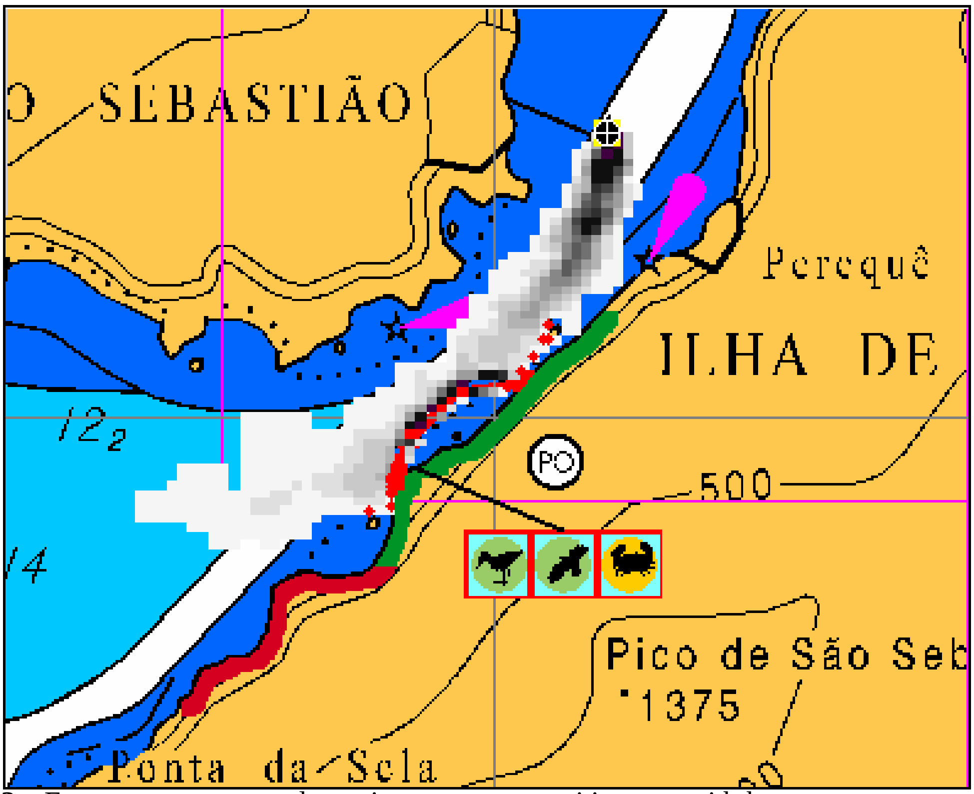

Figure 13 – Emergency response alternative to protect sensitive area with booms.

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