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Efficient tools for marine operational forecast and oil spill tracking

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A B S T R A C T

Ocean forecasting and oil spill modelling and tracking are complex activities requiring specialised institutions. In this work we present a lighter solution based on the Operational Ocean Forecast Python Engine (OOF_ε) and the oil spill model General NOAA Operational Modelling Environment (GNOME). These two are robust relocatable and simple to implement and maintain. Implementations of the operational engine in three different regions with distinct oceanic systems, using the ocean model Regional Ocean Modelling System (ROMS), are described, namely the Galician region, the southeastern Brazilian waters and the Texas–Louisiana shelf. GNOME was able to simulate the fate of the Prestige oil spill (Galicia) and compared well with observations of the Krimsk accident (Texas). Scenarios of hypothetical spills in Campos Basin (Brazil) are illustrated, evidencing the sensitiveness to the dynamical system.

OOF_ε and GNOME are proved to be valuable, efficient and low cost tools and can be seen as an intermediate stage towards more complex operational implementations of ocean forecasting and oil spill modelling strategies.

1. Introduction

Coastal areas house large populations and important economic activities (industry, tourism, fishing and ports). They constitute vulnerable regions with environmental sensitive areas which may be affected by pollution accidents occurring inside harbours or near the coast. The accident may also take place away from coast, but the pollution transported onshore by the ocean currents and surface winds. The outcome may result in catastrophic impacts on populations and devastating effects on marine life. The effects caused by an accident are dependent on many factors, such as the type and quantity of the pollutant, the geometry of the region, the prevailing wind system (direction and magnitude), the ocean currents, the small and mesoscale dynamics, as well as sea temperature, salinity and atmospheric variables (e.g. surface temperature).

A sustainable management of coastal regions, thus, benefits from the implementation of ocean forecast systems and pollution transport models. The ability to predict the evolution of an oil spill and to have data to analyse extreme events and scenarios, constitutes an indispensable tool for risk assessment, safety and contingency planning as part of the decision support framework. The monitoring and forecasting of marine pollution and impacts of offshore activities are two of the main uses of operational ocean numerical modelling (Hackett et al., 2006).

In order to deal with oil spill accidents, the marine security and safety agencies must have real time accurate ocean observations and forecast of oil trajectories for the next few days. Observations and monitoring of the spill are needed for model trajectories initialization, update and uncertainty assessment. Surface spills can be detected by airborne and satellite instruments (Brekke and Solberg, 2008; Ferraro et al., 2009; Cheng et al., 2011).

A key feature of operational forecasts is the data availability. End users should have easy web access to main model input/output figures as well as access to the full data sets in standard formats and service specifications. The freely distributed results are a useful tool for scientific applications and for the general community.

Ocean and atmospheric climatological data draw a picture of the seasonal variability of winds and currents scenarios, but it is inappropriate for oil spill forecast. Much of the mesoscale structures, meanders, eddies, are transitory so that averages fade out the amplitudes (e.g. the Loop Current in the Gulf of Mexico, Barth et al. (2008b), Marta-Almeida et al. (accepted for publication)) and may point for places too away from reality, putting the predicted impacts in question. It is nowadays known that pollution forecasts are much more reliable when based on realistic numerical forecast than based on climatological information. Moreover, the data

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frequency is also very important and depending on the location, frequency higher than one day may be required. The outputs of the current global and large scale models (such as HYCOM, http://www.hycom.org and MERCATOR, http://www.mercator-ocean.fr) are in general issued as daily snapshots or averages. In spite of including model assimilation and being capable of reproducing part of the mesoscale structures, short term events, tidal currents and coastal dynamics are not well resolved. The solution is the implementation of regional coastal models which may be nested in those larger scale assimilated models. Hence, high resolution model configurations and adequate observational facilities which provide data for model forcing (e.g. winds), calibration, validation and assimilation, are required to properly simulate the ocean circulation in coastal regions. A continuous effort must be done to improve model results and reduce forecast errors by accompanying developments of model physics and parametrisations, and by adopting suitable and advantageous assimilation techniques. The accuracy of atmospheric forcing and ocean currents forecast is considered the main factor to predict reliable pollution trajectories and final destination ([e.g.]González et al., 2008; Hackett et al., 2009; Broström et al., 2011). Pollution prediction quality is more related with the difficulty of the model to reproduce small scale eddies and meanders than with errors associated with the surface winds or even, sometimes, errors related to lack of complexity of the oil transport model. For this reason, the increase of accuracy of short term ocean projections constitutes a great advantage and may allow a faster response in case of accident. For instance, by reducing the search region or the area to be under surveillance.

Several oil tracking model are nowadays in use by various oceanographic centres (Hackett et al., 2006; Hackett et al., 2009; Davidson et al., 2009). Their complexity has a wide range. Some are more dependent on parametrisations based on real wind, others rely on climatological ocean currents and they may consider oil as a lagrangian particle or use advection/diffusion algorithms. The oil weathering may also be or not taken into account. The influence of oceanic and atmospheric physical variables and processes like spreading, evaporation, dispersion, dissolution, emulsification, photo-oxidation, sedimentation and biodegradation, may change significantly the oil spill track and extension. Examples of operational implementations of oil spill modelling include the Norwegian Meteorological Institute Oil Spill Forecast System, based on the Oil Drift 3 Dimensional model (OD3D, Wettre et al., 2011; Broström et al., 2011); the Météo France Oil Spill Forecast System using the Météo France Oil Spill Model (MOTHY, Daniel et al., 2004; Daniel et al., 2005); The Japan Meteorological Agency Oil Spill Prediction (JMA, 2007); the Emergency Response Division of the United States Office of Response and Restoration, operating the General NOAA Operational Modeling Environment (GNOME, Beegle-Krause, 2001; Beegle-Krause and O'Connor, 2005).

In the present work we describe the development of a fully automated operational ocean forecast system, and the utilisation of the results to analyse and predict pollution dispersion with the NOAA oil spill model GNOME. This is a straightforward model to use and can be applied to any region in the world with few inputs, in opposition to most of the available oil spill models, which are more dependent on the study region and local parametrisations. GNOME uses wind and currents from the ocean model, so that it is possible to set-up hydrodynamical model configurations with realistic forcing in forecast mode and predict oil spill in different situations making the system robust and fully rellocatable. Wind and currents data from the implemented operational ocean modelling system can be easily converted to GNOME inputs. The operational system was developed and implemented at the Instituto Español de Oceanografía (IEO) at the Centro Oceanográfico A Coruña. The Galician operational effort was a consequence of the Prestige oil spill accident in Galician waters (NW Spain). The development and some results for the Galician region will be presented. Similar implementations are currently operating around the globe. Here we describe two of them with special interest concerning oil spill forecasts: the Brazilian region and the Northern Gulf of Mexico.

The Brazilian oil industry has seen a very fast growth in recent years caused by the discovery of new offshore oil sites and because of technological advances which allow oil drilling and extraction at deeper and deeper waters, in deposits inaccessible until very recently. This new oil race is synonym of high revenues and industrial opportunities, but it also represents an important environmental threat. Associated with oil industry and economic growth is the creation of oil pipelines, increase of maritime transit and ports size and activity. All of this means higher economic dependence on the sea, higher environmental impact and higher probability of accidents, like oil spills from ships or oil extraction facilities, accidents with containers and human lives. In spite of the importance of the capacity to perform oil spill forecasts in the Brazilian region, very few studies have been made so far, namely Lemos et al. (2009), Amorim (2005) and oil industry supported private initiatives by Applied Science Associates (Hackett et al., 2009). These studies have been forced with climatological data and/or model data to study events but without a systematic modelling approach.

The Northern Gulf of Mexico has been a major source of hydrocarbons in the United States for decades. But it is also a region of continuous concern due to oil spills originated by accidents, abandoned infrastructure, and natural leaks from the ocean floor. Very sensitive regions, like the Mississippi delta, are often threatened by the oil industry, like the Deepwater Horizon oil spill in April 2010, considered the largest accidental marine oil spill in the history of the petroleum industry.

The ability to understand the ocean circulation in these regions, and the capacity to predict the ocean state in a temporal window of a few days, is a decisive factor for the success of all kind of marine activities, enabling the creation of rapid response plans in case of an oil industry related accident. Ocean analysis and forecast can also help the study of hypothetical scenarios, water quality assessment, evaluate the impact of extreme events, etc., being useful for offshore industry much beyond the study of its impacts on the environment.

The aim of this article is to present efficient tools to run and distribute automatic ocean modelling implementations and to facilitate oil spill tracking in marine forecast systems. The article is organised in order to have the operational engine described in Section 2. The ocean and oil spill models are described in Sections 3 and 4, respectively. The implementation of the operational system for the Galician region (NW Atlantic Iberian coast) and some of its applications are outlined in Section 5. Section 6 covers the operational modelling set-up at the Brazilian region and simulations of hypothetical oil spill accidents under different oceanic and atmospheric conditions. Section 7 describes the Northern Gulf of Mexico (Texas–Louisiana shelf) operational forecast system and compares the track of a real oil spill with observations. Finally, Section 8 summarizes the achievements of the operational implementations described and concludes the work.

2. The operational engine

The operational system is fully supported by a comprehensive set of tools written in the Python programming language. These tools create and operate the model input/output and control all the required tasks for the operationality of the ocean model. Python is an object oriented scripting language and includes a very