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CAMCAT: an oil spill forecasting system for the Catalan-Balearic Sea based on the MFS products

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Abstract

The Prestige oil spill crisis (2002–2003), one of the worst oil spills that affected the Atlantic Spanish coastal line, pointed out that some management tools are needed in the form of laws, regulations and technical procedures. In particular, the issues are contingency planning and prevention against marine pollution and prediction for a proper response. In that background, the Catalan local government approved the CAMCAT (2004), a Regional contingency plan against marine pollution, to be framed within the (Spanish) National Contingency Plan. The CAMCAT contemplated the implementation of a Regional Forecasting System for the North-Western Mediterranean area, intended to help Catalan Authorities during any pollution emergency. The Laboratory of Maritime Engineering (LIM/UPC) has been responsible for the implementation of this Regional CAMCAT Forecasting System that is based (nested) on existing larger Forecasting Systems/Products, and it integrates several coastal observational data. The present paper is aiming to make an overview of the several scientific and technical activities related to the implementation and validation of the CAMCAT System.

1 Introduction and main objectives

Maritime and coastal activities have been associated with an implicit risk or threat to the environment and to the human beings. Agencies responsible to control these activities (maritime or environmental agencies, coast guards) usually have to face events like marine pollution (oil and chemical spills), un-controlled drift of floating objects (containers, boats in distress), rescue of lost sail boats, etc.

It is in this context where meteorological and oceanographic data products (*meto-cean* observations and predictions) can be really helpful to responders. Despite of the existence of a good quality data, (scientific accuracy), the data should be ready to use, in terms of accessibility and data format and this presents a challenge to the operational meterological and oceanographic community.

Motivated by the aftermath of the *Prestige* oil spill crisis in Spain (2002–2003), the Catalan government approved the CAMCAT (2004), a regional contingency plan against marine pollution, to be within the framework of the (Spanish) National Contingency Plan. The CAMCAT contemplated the creation of a Regional Forecasting System for the North-Western Mediterranean area (Fig. 1), to be designed and implemented by the Maritime Engineering Laboratory (LIM/UPC). The so-called CAMCAT Forecasting System is intended to help Catalan Authorities in case of marine pollution emergencies, and it integrates several metocean data sets, e.g. forecast products from existing larger Forecasting Systems/Projects, and other coastal observational data.

The present paper is aiming to make an overview of the several scientific and technical activities related to the implementation of the CAMCAT Regional Forecasting System against marine pollution for the Catalan coastal waters.

The definition and implementation of such project has been addressed, taking into account the following questions:

- Which Centres/Projects/Systems currently provide oceanographic and meteorological data forecasts (or any other metocean data products) on a regular basis in the area of the Western Mediterranean Sea?

- What are the characteristics and limitations of the products that they are providing? (e.g. availability, temporal and spatial resolution, accuracy of the results)

- Using the metocean results as forcing inputs for the CAMCAT pollutant transport model, 1) How errors/uncertainties in the forcing fields are transmitted into the pollutant drift forecasts, and 2) How can we improve the accuracy of those predictions? (e.g. by means of forcing optimization)

- The implementation of the CAMCAT system, in terms of, for example, infrastructure, software/user-interface, and operational constraints (data availability, distribution, etc.)?

In the recent years, the LIM group has been involved in several operational oceanographic and meteorological activities, acquiring, integrating and providing different metocean data products. In particular, the CAMCAT system has been developed within the framework of the on-going operational oceanographic projects MFSTEP (Mediterranean Forecasting System Toward Environmental Predictions, Pinardi et al., 2004) and ESEOO (Development of a Spanish System of Operational Oceanography, Alvarez, 2004).

The development of the CAMCAT system led to a comparison of the different available metocean products, not only in terms of data quality (accuracy, forecasts vs. reanalysis, etc.) but also in terms of data distribution (availability, accessibility, etc.). Some research has been undertaken to evaluate such metocean products, in order to assess their benefits and limitations and to improve the CAMCAT forecasting system. In the framework of two maritime exercises in the Mediterranean Sea where several drifting buoys were released, observations were compared against forecasts.

While the graphic-user interface of the CAMCAT system was designed as transparent and lighter as possible, the modelling component, called “Arlequin”, is designed to integrate all the met-ocean data and to evaluate the best relationship of forcing inputs through a previous optimization analysis, and a state-of-the-art oil spill model that can take into account weathering processes such as emulsification or natural spreading.

The paper is organised as follows: first, the CAMCAT forecasting system is described (modules and technical characteristics). Then, some insight into the pollutant transport module is provided. And finally, details about some calibration and validation experiments are given followed by the conclusions.

2 Description of the CAMCAT pollutant forecasting system

2.1 Framework and scope of the operational system

Located in the northeast of Spain, Catalonia is a relevant hub for maritime transport, loading and unloading of oil and other petrochemical products. Tarragona, situated south of Catalonia, is an important refinery centre in the Western Mediterranean Sea. Therefore, due to the vicinity of these maritime corridors, the regional government, the "Generalitat de Catalunya", approved the regulation for a Regional/Catalan Contingency Plan for Marine Pollution (CAMCAT, 2003). This Plan aims to: 1) define the best way to respond in case of an hypothetical marine pollution crisis, in terms of organizational management, responsibilities or allocation of resources, and 2) setup an oceanographic monitoring and forecasting system that will help the authorities in charge of the crisis (called hereafter the "End-User" of the system).

In collaboration with the Catalan Met Office ("MeteoCat"), the Public Works and the Civil Protection departments of the Generalitat de Catalunya, the LIM/UPC group has been given the responsibility charge of developing the aforementioned CAMCAT system, covering the North-western Mediterranean Sea (Fig. 1). Its main features have been outlined as follows:

1. *Observational Component*: LIM/UPC is responsible for the existing Catalan Oceanographic and Meteorological Measurement Network (XIOM), operationally working since 1999 (S. Arcilla et al., 2002). The CAMCAT project required an update of the coastal XIOM network that now includes several surface current-meters, 6 meteorological stations, tide and wave buoys. Indeed, the XIOM network is already distributing near real time data results through the Internet (http://www.boiescat.org). Additionally, in case of an emergency, several drifting buoys can be released to help track any spilled pollutant or object.

2. *Forecasting Component*: ideally, the system should be able to provide atmospheric and oceanographic forecast in an operational basis. However, some mod-

ules are still under development, pending budget approval for full development and implementation. On the other hand, in order to always ensure an answer to the responder (End User), the Forecasting Component has to consider additional emergency sources of metocean data forecast. In that sense, existing forecasting products like the one provided by MFSTEP in the Catalan coastal area have been crucial in the definition of this component.

3. *Data distribution and Operational Implementation*: Bearing in mind that the end-user is not familiar with oceanography, the final result of such a system should be as simpler and ready-to-use as possible. Hence, all the procedures (data acquisition, integration, modelling, and result provision) should be transparent to the end-user. Additionally, it was determined that the LIM/UPC will be hosting the System. That required a distributed Client/Server architecture design.

The final user of the system will be the technical personnel of the Emergency Centre of the Generalitat de Catalunya (CECAT). Indeed, CECAT is the regional authority responsible for handling oil or other marine pollutant spills that could threaten any Catalan shoreline. In case of a major pollutant spill, CECAT should coordinate the response with other National/Spanish agencies.

The budget of the CAMCAT system being limited, the project was aiming to maximise the use of available resources, for example using other existing forecasting system in the area and reducing the development of new technologies that could lead to an increase of time and cost. In that sense, public/open source software was used (like the GMT plotting libraries) and the graphic user interface was simplified as much as possible.

The CAMCAT system has been recently transferred to its pre-operational status. Modules and parts of each Observational and Forecasting components are being tested independently (measurement devices, numerical models, data transfer, etc.). In particular, as it will be described in following sections, some research has been done to evaluate the CAMCAT system, to calibrate and validate the forecasts with actual observed data.

2.2 Modules and implementation

The CAMCAT system is made of two main components: the *Interface Module*, which is responsible for the initial data acquisition, preparation, and distribution, and plotting of the predicted results by ARLEQUIN, the numerical model that constitutes the *Modelling Module*. This second component will be described further in Sect. 3.

A key feature of the two modules (*Interface* and *Modelling*) of the CAMCAT system is that it was conceived as a Client/Server application. A scheme of data flow between the modules is presented in Fig. 2. The System is hosted in the LIM/UPC facilities (the *Server Side*). The personnel of the CECAT, as a remote user of the forecasting system can connect to the CAMCAT system at any time through a restricted web site (the *Client Side*): information about the pollution event – or *scenario* – is introduced by means of a simple web page as shown in Fig. 3. Hence, date, location, type and volume of spill are requested as initial values of the transport pollutant model, Arlequin that can be run from that graphical interface.

The Client Side of the CAMCAT system is presented to the final user by means of a simple web browser application. This application that requires little computational resources in the user side is also known as Thin Client Application (Spaulding et al., 2005). Through additional pop-up web pages, the user can check and select available winds and currents to be used in the simulation, including the historical and forecasted metocean data. Other features such as location map and geographical calculator assists the user in introducing the initial data. Finally, scenario information is submitted and sent to the LIM/UPC CAMCAT machine (Server Side), which hosts the model component.

The CAMCAT Server is designed to regularly download and store winds and currents forecasts from different data servers. Previous (historical) data is stored, should the user wants to re-analyse a simulation. In the present configuration, winds are obtained twice a day from the MeteoCat Server, corresponding to the two configurations/resolutions of the MASS atmospheric model; those winds are being used operationally since 1999 as input to the wave forecasting system (Bolaños et al., 2004). Daily averaged currents are downloaded daily from the MFSTEP ftp site, corresponding to the basin model MFSTEP_1671 configuration (1/16° horizontal resolution and 71 vertical levels). Other additional meteorological and oceanographic data products that cover the North-western part of the Mediterranean Sea have been considered, and are summarised in Table 1.

At any time, with the all the available data stored locally in the CAMCAT Server, the user can run the Arlequin model through the web-interface. Results from the pollutant transport model are the predicted drifts and fate of the pollutants, driven by winds and currents specified by the user. The server application post-processes the results and sends them back to the CAMCAT web-interface where they are plotted (snapshot example in Fig. 4). Typically, the entire process takes some minutes, from the information submission to the images showing up in the web site.

The user can see the results as evolution of the spill within the +24 h and +48 h after the spill release. Predictions cannot last longer than the shortest horizon of the forcing field forecasts; (typically 48 h in the actual configuration). Additionally, the user can download plots and raw data of results (in ASCII format files) for a potential import into any other GIS based plotting software. Finally, the mass balance that includes weathering of oil is also plotted.

2.3 Available metocean data products and the MFSTEP framework

In the recent past years, the LIM/UPC group has been involved in operational monitoring/forecasting activities, taking part in several on-going Operational Oceanographic projects: the EU funded Mediterranean Forecasting System (MFSPP and MFSTEP phases, 2001–2006, http://www.bo.ingv.it/mfstep) and the National Spanish one, ESEOO (http://www.eseoo.org). Those projects have provided expertise and understanding of the main scientific and technical issues related with metocean data adquisition, integration, and provision.

In terms of operational response, redundancy of data is proven to be crucial to ensure proper information of the actual and future state of the weather, the ocean and any hypothetical pollutant spill. On the other hand, in terms of scientific accuracy, redundancy of data has been proven to be useful to ensure precision and error assessment of the provided data. Several techniques can be applied, as validation/calibration of observed vs. modelled data, inter-model comparison, etc.

Fortunately, increasing number of operational metocean data products are readily available worldwide. Nowadays, some regions are covered by several monitoring and forecasting systems, allowing the comparison and calibration between different data products. However, not all of those products are always ready-to-use for an end user like Maritime Safety or Environmental agencies. Some extra-effort has to be done to acquire, pre-process, and integrate datasets accordingly to the end-user requirements.

By the time the CAMCAT system was being set up, several operational forecasting systems were already running in the North-Western Mediterranean Sea (hereby NWMS). Even tough atmospheric/meteorological data products are typically further developed and operationally implemented than the oceanographic ones, up to 4 different hydrodynamic models were running in that area, corresponding to the basin, regional and local resolutions of the MFSTEP-TOP period.

In the framework of the ESEOO Oceanographic Operational project, the two maritime drill exercises performed by the Spanish Maritime Safety and Rescue Agency (Sasemar) in the NWMS area allowed to compare modelled and observed data. The study was aiming to optimize the forcing inputs of the transport pollutant modules of the CAMCAT forecasting system to be developed, using the drifts of several lagrangian/tracking buoys (Salazar, 2006). As it will be detailed further in Sect. 4, the following Table 1 summarises observed and modelled metocean data products available during those drill exercises (2004–2005); the list of acronyms is detailed at the end of the document. It should be noted that these metocean datasets have different time and spatial scale resolutions. Typically, data forecasts covering small/local areas are provided daily, with a 1 or 3 h resolution, meanwhile other metocean data covering larger areas (i.e. the entire Mediterranean Basin) were provided weekly, with a time resolution of a day as daily averages.

The authors want to acknowledge the importance of the availability of such kind of data, not only for scientific or research purposes, but in particular for the public/social benefit. Indeed, regional forecasting systems such as the CAMCAT are based (and rely) on the data supply from larger systems like the MFS.

Further developments of the actual configuration of the CAMCAT are pending. Some of the products listed in Table 1 have been tested, and compared against them. In the future, and depending on extended funding, a specific hydrodynamic modelling can be considered, and/or nesting to a larger forecasting systems like the ESEOO regional models.

3 Description of the Arlequin pollutant transport model

3.1 Background and previous work

The state of the art in pollutant transport and oil spill modelling has evolved dramatically in the last decades (ASCE, 1999). Nowadays, oil spill models can be incorporated into more sophisticated modelling systems. The latest oil spills accidents have proven the requirements of such kind of “richer” forecasting systems: three-dimensional hydrodynamics could provide more accurate information to the oil/pollutant transport models. However, while the main forcing of spill drift is well known (wind, waves, currents), more work has to be done to co-relate the interaction between these terms. In any oil spill forecasting system we can distinguish the forcing/hydrodynamic part (which involves wind forcing, wave generation and propagation and currents) and the pollutant transport and weathering modules (Fig. 2). Wind drift and currents represent the main forcing for the transport of the floating pollutant, while the interaction between wind, waves and currents is responsible for the vertical mixing.

Following this strategy, the CAMCAT oil spill forecasting system includes several modules which can be run independently: wind, waves, currents and oil spill evolution. Those modules are linked to provide the oil spill drift forecasts using all the available information (modules interconnections are plotted in Fig. 2).

As a final/product, a pollutant-oil spill model that was developed as a part of the PhD undertook in the LIM/UPC and Meteo-France (Comerma, 2004), and integrated later into the CAMCAT system was used as a reference in the ESEOO project. The model, called "Arlequin", is the back-bone of the modelling component, integrating all the pre-processing of the forcing inputs (temporal and spatial interpolation, data aggregation, etc.). This pollutant transport model is a 2-D lagrangian model that takes into account the advection and diffusion terms in the ocean-atmosphere boundary-layer, as well as some main oil weathering processes (namely evaporation, emulsification and subsequent changes in density and viscosity).

3.2 The pollutant transport and oil weathering modules in Arlequin

For several reasons, the lagrangian approach has been chose as the pollutant transport modelling technique in CAMCAT. Largely discussed in the oil spill modelling literature (ASCE, 1996; Grisolia, 1998; Mestres, 2002), lagrangian approach seems to be more efficient and flexible than Eulerian approach. In accordance to the level of resolution of the forcing input data of the CAMCAT forecasting system, a faster (Lagrangian) qualitative method is preferred to a more sophisticated (Eulerian) quantitative one. Indeed, at the expected spatial and temporal scale (O$\sim$10 km, 1 h), transport/advective processes can be more important than turbulent/dispersion ones (Comerma, 2004).

The following physics and chemical aspects are considered in Arlequin:

a) Horizontal transport

The pollutant is represented by a cloud of lagrangian particles that drift, each time step, independently one from each other. The transport module of the Arlequin model includes the advective and the diffusive terms, simulating the horizontal transport processes of the pollutant. Model results can be expressed in terms of concentration of the pollutant in the water surface (i.e. its thickness).

Advection is obtained directly from the input forcing: winds and currents fields are interpolated at each lagrangian particle position (bi-linear spatial interpolation) and for the corresponding time of the simulation (linear temporal interpolation). Hence, at each time step, the transport of each particle is evaluated as the weightened sum of wind drift and current as follows:

$$Dx\,(t*)_i = [Cw_x \cdot W_x\,(t*, i) + Ch_x \cdot U_x\,(t*, i)] \cdot \Delta t$$
$$Dy\,(t*)_i = \left[Cw_y \cdot W_y\,(t*, i) + Ch_y \cdot U_y\,(t*, i)\right] \cdot \Delta t \tag{1}$$

where:

- [Dx, Dy] $_i$: lagrangian (i) particle advective displacement vector at the time t*, during the time step Δt, in [m]
- t*: time, in [s]
- Δt: model time step, in [s]
- [Cw$_x$, Cw$_y$]: x-y components of the wind drift coefficient
- [Ch$_x$, Ch$_y$]: x-y components of the current coefficient
- [Wx, Wy]: wind vector, interpolated at (i) position, and at the time t*, in [m/s]
- [Ux, Vy]: current vector, interpolated at (i) position, at the time t*, in [m/s]

As it will be discussed later, this decomposition allows an adjustment of the wind and current factors in case of a re-analysis and comparison of predicted pollutant drift against observations. Preliminary results have showed that those parameters are ranged within [0, 0.10] for Cw and [0.5, 1.0] for Ch.

Accordingly to the *random walk* method, horizontal diffusion term is evaluated as a random movement of each particle, function of a fixed and uniform turbulent diffusion coefficient and the time step as follow:

$$u_d = [\mathrm{Rnd}]_{-1}^{+1} \cdot \left(\sqrt{6 \cdot K \cdot \Delta t}\right) \tag{2}$$

where :

- u_d: lagrangian particle diffusive displacement, during a time step Δt, in [m]
- K: constant/uniform horizontal coefficient diffusion [m^2/s]
- Rnd: random number between (–1,1), following a normal distribution

Unfortunately, operational hydrodynamic models do not typically provide turbulence as an additional/ ancillary model output. In some situations (storms, eddies, etc.), user-introduced turbulent diffusion can differ largely from the physics predicted by the hydrodynamic model.

In case of marine emergency, attention is focussed mainly on the water surface (or in the upper layer of the water column), where almost all the pollutants and floating objects/debris are drifted and can be easily located by ships, aircraft or satellite. However, operational hydrodynamic models are not yet able to describe with enough accuracy the vertical profile of horizontal velocities, neither spatially nor temporally. Moreover, most floating objects can be drifted by a particular combination of surface/sub-surface currents, winds, and an interaction of both (as waves and wind driven currents).

In that sense, when using wind and current forcings from model outputs, the typical question is how to avoid counting twice the effect of wind stress in modelling the drift of an object in the water surface. That will be determined partially by the shape of the object, the surface of exposure to the wind and/or to the currents (i.e. sailing effect), but also in how the modelled hydrodynamics took into account wind forcing (Daniel et al., 2003). For that reason, in the upper water layer an additional/analytic term may be added to the hydrodynamics in order to attain the wind stress driving. In summary, as will be described in the following sections, available winds and currents forcing must be optimised in order to improve drift predictions (Salazar, 2006).

b) Vertical process

In the actual configuration of the CAMCAT system, the pollutant transport model Arlequin is 2-D, further work is envisaged to include the vertical dimension. The model can take into account different particle sizes aiming to reproduce the behaviour of the different components of the pollutant: evaporated (through the weathering module), floating in the water surface and vertically dispersed (Comerma, 2004).

c) Weathering

The weathering of crude or refined oil is a set of physical and chemical processes that modifies the properties of the initial released pollutant. We are particularly interested in simulating those processes that may imply variation of mass (evaporation, emulsification and vertical dispersion) and especially the way these processes modify the physical-chemical properties and the rheology – of the non-conservative pollutant. Then, the main question is how this rheology interacts with the drift and spreading processes.

In an operational forecasting system we should find an agreement between accuracy of the simulation and the available data needed as input to this system during a crisis event. In fact, some processes such as evaporation and emulsification evolve very quickly, within hours or days. Then, it could be more important to know the threshold values of these processes (related basically to oil composition) rather than to assess the kinetics of the rheological evolution (related to a changing environment). In that sense, Arlequin meets the balance between the state-of-the-art in oil spill modelling and operational requirements (Jorda et al., 2006; Comerma, 2004).

d) Implementation aspects

The Arlequin pollutant transport model has been tested with different forcing available in the NWMS area. From those listed in Table 1, some combinations of winds and currents were compared (more details). In particular the *pairs* SMC-MFSTEP1671, Aladin-Symphonie, and INM-Mercator were used and compared against real observations (Salazar, 2006). In the actual configuration, CAMCAT is currently using the first combination.

Hence, Arlequin performs the spatial and temporal interpolation accordingly to the metocean data available in the CAMCAT server. The system can typically be run in two modes: forecasting and re-analysis. In the forecasting mode, predictions are made using the most recent forcing forecasted data available, and their time horizon (forecast length) is always limited to 48 h. In the re-analysis mode, the simulation can last as long as the forcing data has been available. In that case, as each wind prediction file released twice daily contains 48 h of forecast data, the time series files have to be aggregated, and linearly interpolated. Only initial half-day predictions are used from each file of the simulation run time series.

4 Evaluation of the modelling component – forcing optimization

Beginning 2006, the CAMCAT forecasting system has been transferred to its pre-operational status; it is know available and ready to be used by the CECAT personnel. Partially motivated by real operational constraints (easy to use, transparency, readiness, etc.), some research work has been done to evaluate the accuracy of the predictions of the system. In particular, this section will summarise the work done to answer two main questions:

a) Within the modelling component, how the errors propagate? How an intrinsic error of one module (winds/currents) is transferred to another module (pollutant transport)? Which models are, error-wise, the more critical or sensitive?

b) If the forcing input is fixed (i.e. introduced in the system as external data), how can we improve the predictions of the pollutant transport model? If several forcings are available, how can we combine them to improve the results?

4.1 Error propagation analysis

As described previously, the modelling component of the CAMCAT forecasting system is made up of several linked models. Numerical errors, improper physics or wrong forcings, for instance, can induce errors in the models. Typically, errors can be magnified through the data flow between models. Hence, the concatenation of several modules adds complexity to the estimation of the errors in the final pollutant spill forecasts, may be caused by errors in each module.

In Jorda et al. (2004), by means of the twin-experiments approach, some work was done to evaluate the impact over the CAMCAT pollutant (oil spill) drift forecasts due to different sources of error present in the system: a reference run was compared against different runs with a perturbation in some of the forcing fields. The comparisons between the different oil-spill predictions helped to evaluate the impact of the different sources of error. The strategy was intended to define the relative importance of each forcing component over a potential oil spill in the Northwestern Mediterranean Sea area.

An important point in this strategy was the definition of the perturbations introduced into the forcing fields. In order to be consistent with a real event, these perturbations had to be carefully defined to represent, in a realistic way, the typical errors present in the forecasting system. Hence, an estimation of the errors was carried on, and different techniques were used to synthetically represent the errors in the forcing fields.

In the Northwestern Mediterranean Sea, the weak-tide circulation is characterized by a quasi-permanent slope current (the Northern Current; Millot, 1999) that can be modified by mesoscale events such as current meanders or eddies. Over the wide shelf, circulation is mainly controlled by the Ebro river plume dynamics and the wind. The numerical simulation experiments have been carried out during the January 2003 period when several storm and calm periods were found, aiming to compare the forecasts of the forcing fields with real observed data and to evaluate the quality of those modeled fields.

To define a comprehensive study, four potential scenarios of oil spills were defined, accordingly to two metocean conditions (i.e. two different periods) and two different spill locations. The different scenarios were intended to reproduce the most important and probable emergency contexts that can be found, that are mainly established by the different meteorological conditions and the different positions of the oil spill.

Hence, the CAMCAT system was run during two episodes within January 2003: one corresponding to strong winds, as it will be the situation in the case of a ship accident, and a calm period, as will be the case of a spill due to illegal operational discharges. On the other hand, as the hydrodynamic conditions change depending on the spill position, two potential spill sites were considered: one considering the spill takes place where large scale circulation is important and another one where it is not. In the first case we considered the spill over the slope, where the slope current has an important role, and in the second case we consider it over the shelf, where the circulation is controlled by the wind.

Some of the conclusions of this work is that the inclusion of mesoscale currents as a forcing factor have shown to be essential, i.e. if the oil is spilled in an area with strong currents. Current and wind fields must be provided with the highest frequency available as their fast changes have a strong impact in the trajectories and dispersion of the pollutant. Additionally, the perturbed runs showed that errors in the winds and currents forecasts are the most influential ones over the forecast of the final position of the pollutant. A proper characterization of the spilled pollutant is also important in the forecast of the vertical position and final properties of the product. Finally, waves proved to have little impact over the forecasts, maybe due to the way they have been included in the forecasting system.

More details can be found in Jorda et al. (2004).

4.2 Adjustment of forcing inputs

Framed in the ESEOO project and aiming to improve the forecasting system, some work has been done to evaluate the optimization of forcing inputs in the pollutant transport model. Assuming that in a real crisis the provided winds and currents forecasts can not be improved, the practical approach is to find out which will be the best combination of those winds and currents that will give the *best* drift prediction.

During two maritime drill exercises, *Lionmed-2004* and *MED-05*, carried out by the Spanish Maritime Safety and Rescue Agency – Sasemar, several drifting buoys were deployed and tracked. Accordingly, several drift predictions were performed and compared to actual observed drifts, using as inputs metocean data forecasts provided by different institutions.

During the exercise LIONMED in December 2004, one PTR surface drifting-buoy was released in the half way between Barcelona and Palma of Mallorca, North-Western Mediterranean Sea. The buoy drifted several days (14–26 December 2004) before landing in Menorca Island (Fig. 5).

Several forecasting models were already operational at the time of the drill exercises (listed in Table 1). Hence, outputs from the following models has been used to force the drift module of ARLEQUIN: winds from ALADIN (0.1° resolution, Meteo-France), and MASS ($5'$, Catalan MetOffice – SMC) and HIRLAM (10 km, Spanish MetOffice – INM), hydrodynamics from SYMPHONIE (3 km res., POC/Noveltis) and MFS1671 (1/16° res., MFSTEP project).

It's worthwhile to mention that SYMPHONIE hydrodynamic model is forced with the atmospheric model ALADIN. Hence, one can expect more coherent results using that pair of wind and currents models than with any other combination. Additionally, observed met-ocean data corresponding to the period of the exercises were also available from the coastal net buoys of *Puertos del Estado* (Spanish Harbours Authority) and XIOM.

Winds and currents model outputs were compared, between them and against observed data, corresponding to LIONMED Exercise (Comerma et al., 2005). Some expected results have been:

- Forecasted wind fields from different models are quite similar, in time, space, speed and direction, leading to a similar wind-driven prediction. They widely agree with coastal buoys observations. Some slight differences appear mainly in open sea, where there are no measurements. Figure 6 plots predicted winds speeds from Meteo-France, SMC and INM atmospheric models, obtained all along the path followed by the drifting buoy.

- Forecasted and analysed current fields differ greatly from model to model, even giving sometimes predicted opposite directions. It should be noted that only daily averaged values could be compared. Consequently, drift forecasts forced only with currents (without an additional wind stress term) are highly sensitive to hydrodynamic output.

Forcing optimization: methodology

In the forcing optimization study, the following pairs of winds and currents model outputs have been defined: Aladin/Symphonie, INM/Mercator, and SMC/MFSTEP (Salazar, 2006).

All along the observed path of the LIONMED drifting-buoy, successive positions were interpolated in regular spans of 30 min (Fig. 7). At each 30 min-position, forcing fields were interpolated, comparing actual speed and direction of buoy velocities, and predicted currents and winds. During some episodes, buoy drift can be clearly correlated with the winds and/or currents; in some others, velocities of the buoy are still unexpectedly large compared to forcing. Figure 7 plots several drift predictions made with the forcing pair SMC/MFSTEP.

The aim of forcing optimization is to obtain an averaged (weighting) relationship between buoy movement and forcing inputs, that is, to be able to define the wind and currents factors in the calculation of the buoy drift (Eq. 1). At each 30 min-position of the buoy, two *deflection angles* are defined as the difference in directions between "buoy drift & wind", and "buoy drift & currents". Figure 8 plots the adjustment of the relationship between predicted SMC wind speeds (W) and the wind drift factor (Cw, Eq. 1) required to reproduce the corresponding observed buoy drift speed, only for that episodes/positions when deflection "buoy-wind" is smaller than 25° (i.e. closer to Ekman surface drift). Paying attention to winds greater than 5 m/s, we obtain a parabolic relationship that will be used in future runs of the drifting model.

The parabolic function Cw(W) in Fig. 8 gives an average drift factor of 5% that was used to simulated the buoy drift in Fig. 7; other functions Cw (W) were obtained including episodes/positions when deflection "buoy-wind" was greater than 45° and 90° (Salazar, 2006).

5 Conclusion and future lines of work

The CAMCAT regional forecasting system against marine pollution was presented. This system developed by the LIM/UPC group is aiming to help Regional Catalan authorities in case of an emergency in the North-Western Mediterranean Sea (NWMS). The system includes an Observational Component and a Forecasting Component which integrates daily several observed and forecasted metocean data sets in the NWMS. Indeed, the system has been developed within the framework of two operational oceanography projects, the EU-funded MFSTEP and the Spanish ESEOO.

The CAMCAT System was designed following a distributed Client/Server architecture: the remote CAMCAT user can request a drift forecast through a web site at any time. The CAMCAT Server, hosted in the LIM/UPC facilities is responsible of the daily metocean data acquisition and integration; in case of a user request, the server prepares the input data and runs the pollutant transport model Arlequin.

The Arlequin lagrangian model includes several physical and chemical modules accordingly to the state-of-the-art in oil spill modelling (Comerma, 2004), running in an operational framework. The transport model is currently using SMC winds forecasts and MFSTEP hydrodynamics.

Several studies were carried out to evaluate the capabilities of the CAMCAT modelling components, aiming to understand its limitations and trying to improve the drift forecasts. In an operation framework where metocean data forcing is supplied by external providers, a practical approach has been suggested to improve pollutant drift forecast by means of forcing optimization. Hence, several winds and currents model outputs were combined to reproduce the observed drifts of several drifting buoys released during two maritime drill exercises.

Several further developments can be envisaged, accordingly to future funding. In particular, more sophisticated pollutant transport modelling can be considered: 3-D hydrodynamics are already available, and more information about turbulence (horizontal and vertical) can improve the simulation of the different compound of the pollutant (i.e. vertical dispersion).

Appendix A

Acronyms

CECAT:	Emergency Response Centre of the Generalitat de Catalunya.
Cedre:	Centre of Documentation, Research and Experimentation on Accidental Water Pollution (http://www.le-cedre.fr)
ESEOO:	Development of a Spanish System of Operational Oceanography (http://www.eseoo.org). This project is a joint effort of organisations like PdE, INM and LIM/UPC
INM:	National Spanish Met-Office (http://www.inm.es)
MeteoCat:	Regional Catalan Met Office (http://www.meteocat.org)
MFSTEP:	Mediterranean Forecasting System Toward Environmental Prediction (http://www.bo.ingv.it/mfstep)
POC:	Coastal Oceanography Observatory Midi-Pyrénées (http://poc.omp.obs-mip.fr/)
PdE:	Spanish Harbours Authority (http://www.puertos.es)
Sasemar:	Spanish Maritime Safety and Rescue Agency (http://www.salvamentomaritimo.es, http://www.centrojovellanos.com)
SMC:	Regional Catalan Met-Office (http://www.smc.gencat.es)
XIOM:	Regional Catalan Met-Ocean Measurement Net (http://www.boiescat.org)

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Table 1. Metocean Data products available in the NW Mediterranean Sea (2005).

	Model/data [Institution]	Forecasting cycle/data frequency	Spatial resolution (horizontal)	Hindcast (H)/ Forecast (F)
Model products				
Winds				
	ALADIN [Meteo-France]	Weekly/3 h	0.1°	H
	HIRLAM [INM/ESEOO]	Daily/3 h	0.2°	H/F
	MASS [SMC]	2 day/3 h	5′	F
Currents				
	SYMPHONIE [POC/Noveltis]	Weekly/daily averaged	3 km	H
	MFS1671 [MFSTEP]	Weekly/daily averaged	1/16°	H/F
	PSY2V1R1 [Mercator]	Weekly/daily averaged	∼1/16°	H
Waves				
	WAM/SWAM [LIM/UPC]	2 day/hourly		H/F
Observations				
Winds	Measurement Buoy Net [PdE & XIOM]	Hourly		NRT
Currents	Measurement Buoy Net [PdE]	Hourly		NRT
Drifters	PTR – Argos Buoys [Sasemar, Cedre, ESEOO]	0.5–2 h		NRT

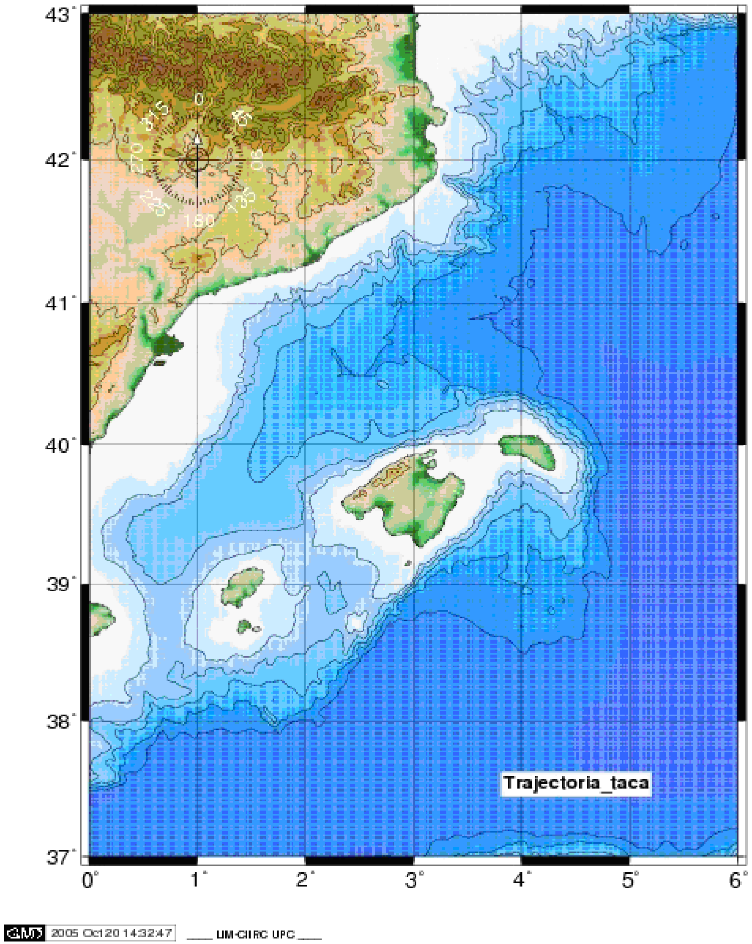


Fig. 1. Domain of CAMCAT Forecasting System (North-Western Mediterranean).

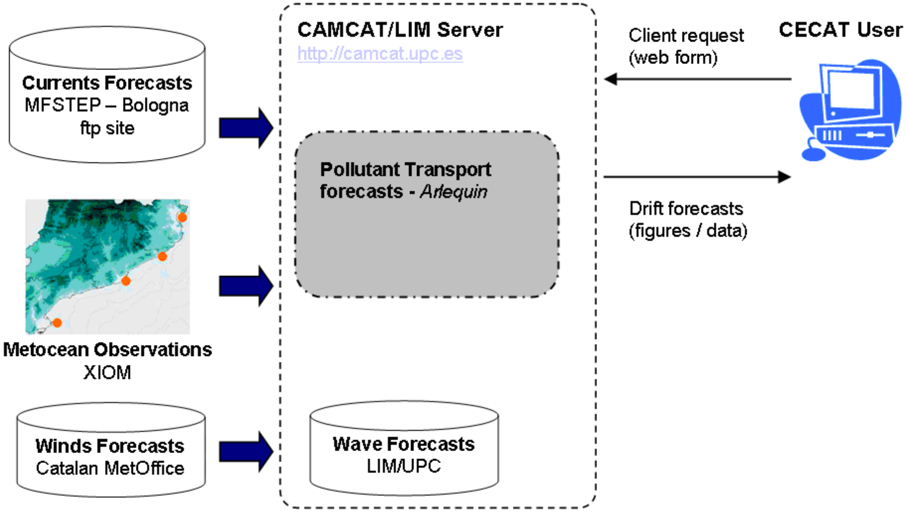
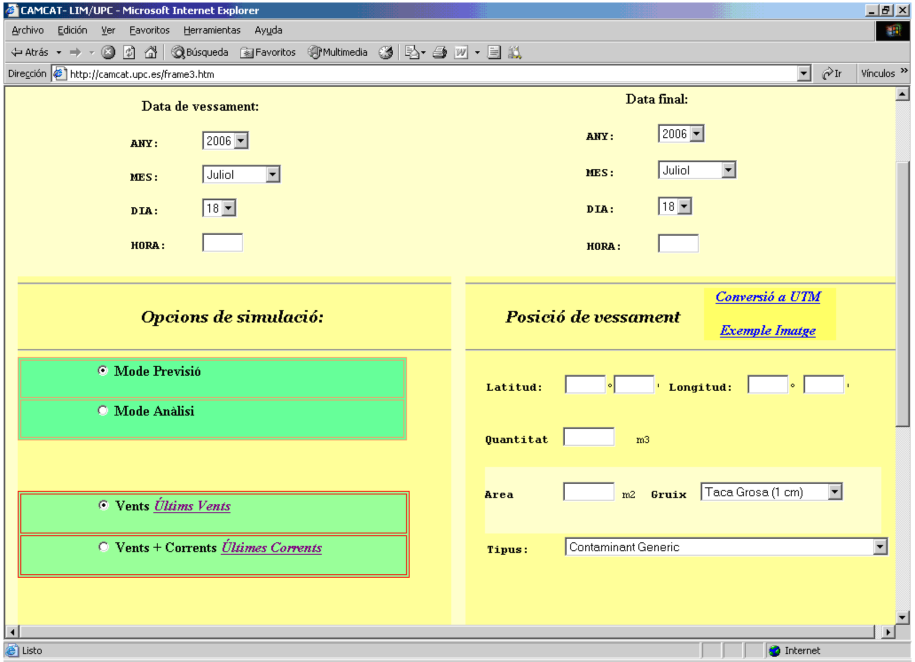


Fig. 2. Scheme of CAMCAT Forecasting System, modules and processes.



Data de vessament:

ANY: 2006

MES: Juliol

DIA: 18

HORA:

Data final:

ANY: 2006

MES: Juliol

DIA: 18

HORA:

Opcions de simulació:

● Mode Previsió

○ Mode Anàlisi

● Vents *Últims Vents*

○ Vents + Corrents *Últimes Corrents*

Posició de vessament

Conversió a UTM

Exemple Imatge

Latitud: ° ' Longitud: ° '

Quantitat m3

Area m2 Gruix Taca Grosa (1 cm)

Tipus: Contaminant Generic

Fig. 3. Example of the CAMCAT User web-interface (client side).

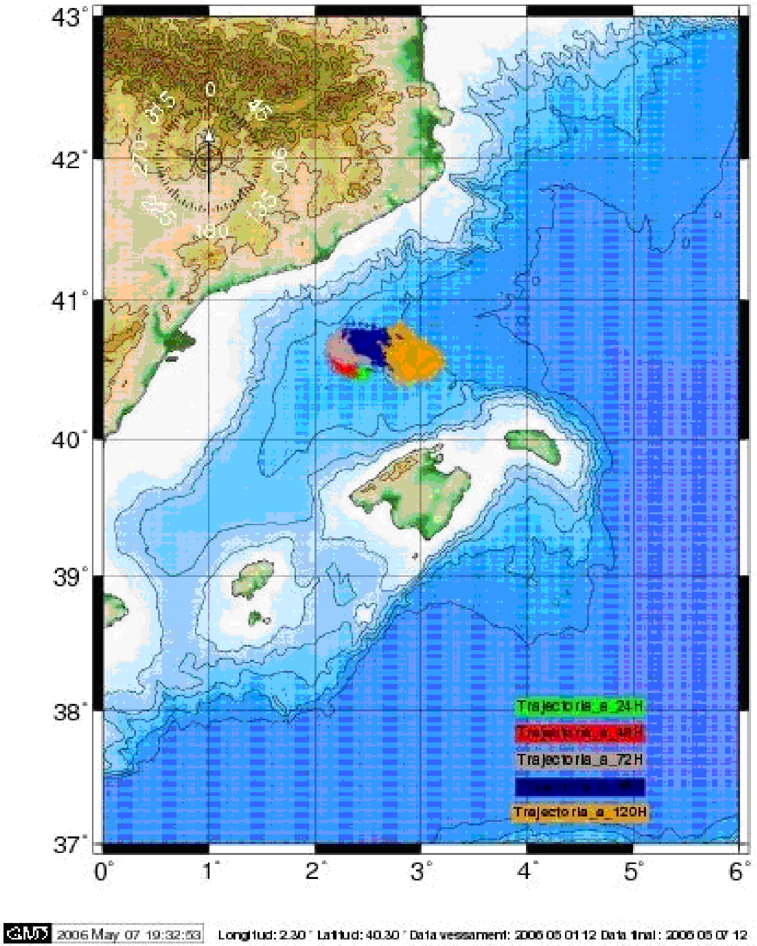


Fig. 4. Example of CAMCAT's Arlequin model output results.

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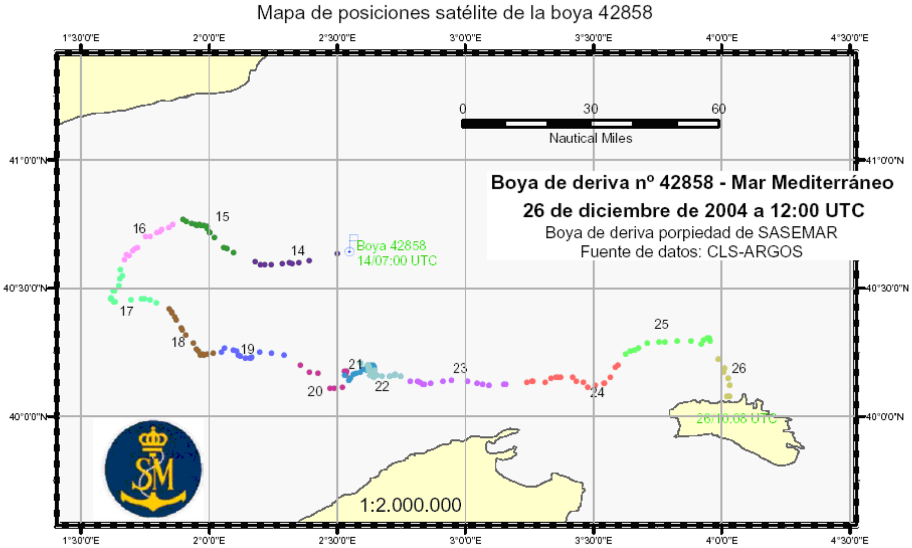

Fig. 5. Surface drift of buoy released during LIONMED Exercise, 14–26 December 2004 (source: Sasemar).

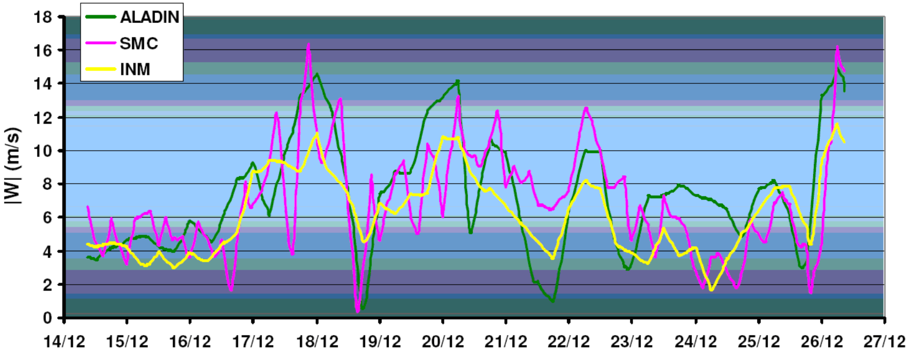

Fig. 6. Comparison of predicted wind speeds W (m/s) from Meteo-France (Aladin), SMC and INM models along the path of the LIONMED drifting buoy (Salazar, 2006).

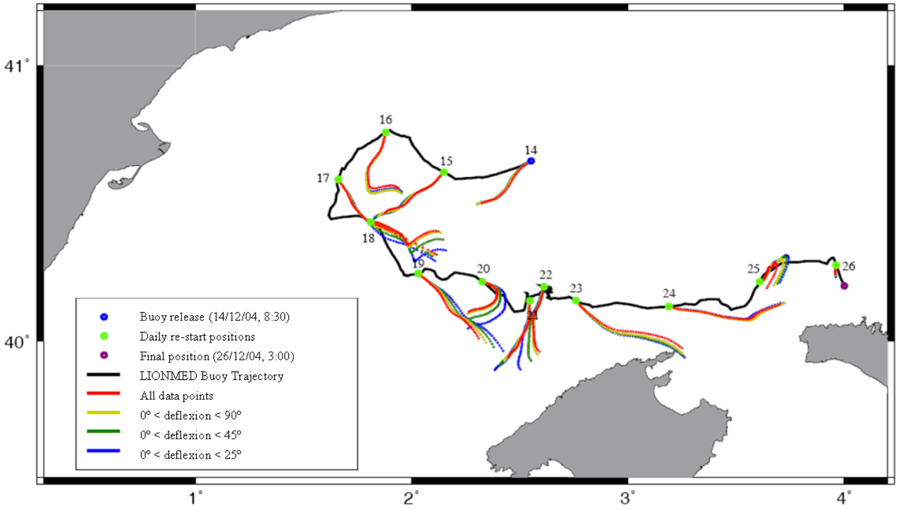

Fig. 7. Comparison of LIONMED buoy observed track and predicted positions using SMC winds and MFSTEP currents, using different wind drift factors (from Salazar, 2006).

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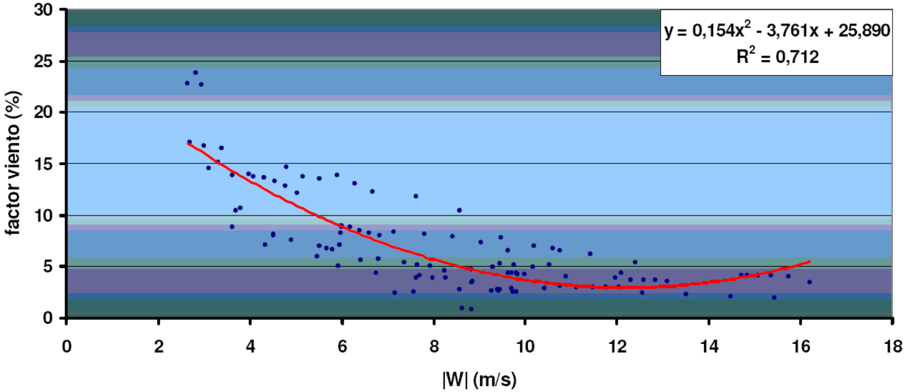

Fig. 8. Adjustment of variable wind drift factor Cw (%) against wind speed W (m/s), for wind deflection values <25° (Salazar, 2006).