Oil Spill Detection and Prediction in the Northwest Mediterranean Sea

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Abstract

In recent years the marine pollution has been highlighted thanks to the advances in detection techniques. There is also more public awareness to both the large nautical catastrophes (e.g. oil tankers Amoco Cadiz, Exxon Valdez and recently Erika and Prestige) and the habitual smaller oil spills from the ships. The range of marine pollution events should even consider, due to their overall importance, the very much smaller oil spills of a few square meters caused by small boats. The middle size oil spills often originate due to coastal sources and from small accidents or habitual cleaning of ballast water in ships. The larger oil spills are caused by crude/oil tankers catastrophic accidents of varied consequences. From the analysis of SAR observations and new satellite based sensors new methods of oil spill detection in the Ocean, coupled with self–similar statistical techniques allows to determine with precision the size statisticas of the pollution events and their topological structure.

The oil pollution of Gulf of Lion in the NW Mediterranean has been studied further than from the two–year period from December 1996 until November 1998 within the framework of the EC–funded project “Clean Seas”. New images during the period 1999 −2005 have been analysed, together with a more comprehensive identification of other patterns and eddies detected in the ocean surface. More than 1000 synthetic aperture radar (SAR), some ASAR and many other types of images have been compared over the test sites used by the Clean Seas project. We have analyzed these SAR images with respect to radar signatures of (natural and man–made) oil pollution and other surface features. Other phenomena causing similar signatures are considered and evaluated, such as wind, river plumes, eddies and convergence areas. The results of our statistical analysis are presented. The additional SAR images reveal that the NW Mediterranean is most polluted along the main ship traffic routes, but comparatively less that near other routes in the Indic and the Pacific. The oils spil index, defined as the number of detected spills per 10^4 Km^2 is higher than one. The sizes of the detected oil spills vary over a large range, and if the statistics of the largests accidents are also considered on a longer timescale, we show that the Zipf's Law, relating the frequency and the size of the spill in a hyperbolic fashion is applicable. Moreover, the higher amount of oil spills on SAR images acquired during summer (April – September) than on SAR images acquired during winter (October – March). When evaluated statistically together with the local wind velocity data show a chi distribution for the probability of detecting oil spils in high winds.

Advanced image analysis techniques, such as the calculation of the multi–fractal dimensions of the observed SAR signatures, have been applied to distinguish between natural slicks and anthropogenic spills. Fractal dimensions can also be used to predict the time of release of the spill with an appropriate non dimensionalization of the time based on the turbulent dissipation. The multiscale appearence, the topological structure and the fractality of the slicks and spills may also be used as a measure of the diffusiveness of the observed signatures, they yield additional information on the signatures' origin, on eddy and jet type of structures which in turn may improve automated detection algorithms and be used in numerical models.

Fractal analysis was used to identify different dynamic processes that influence the radar backscattering from the ocean surface. We used a box–counting algorithm that is able to detect the self–similar characteristics for different SAR–image intensity levels. It is very interesting to relate D to the frequency spectrum or to the
spatial spectra obtained from the Fourier transform of the time or spatial correlation functions, usual in studies of turbulence. The reason is that from such frequency spectrum the corresponding fractal dimension may be derived, if the tracer scalar is passively advected by a turbulent flow. Then the fractal dimension is related to the energy of the turbulence with a certain spatial or temporal dependence, then the frequency spectrum exponent, provided an inertial subrange exists, is a function of the box–counting fractal dimension as demonstrated by Derbyshire and Redondo (1990) and Redondo (1990).

The interactions between the self–similar ocean turbulent flow, where the Rossby deformation Radius plays an important role and the oil spills is used to model numerically the dispersion. (Gade and Redondo 1999 and Redondo and Platonov 2001)

Traditionally in environmental studies of diffusion, oil patches have been numerically predicted and computed with homogeneous environmental forcing and random free paths, which gives Brownian behavior. These stochastic methods have the objection that they do not take into account the topology of the flow.

On the other hand, there are many ways to simulate a fluid flow, but when this is turbulent, these simulations become complicated, expensive and inaccurate. Together with examples we present the theoretical and experimental bases needed to simulate accurately the behaviour of oil spills (or tracer particles) in a turbulent flow, in a simple and efficient way that may be updated in an emergency with the latest output from dedicated environmental Atmosphere (wind) and ocean currents and wave nested models. This is accomplished with a Kinematic Simulation (KS) model and in this work we compare some predictive results with detected oil spills and field measurements. There is a strong dependence of horizontal eddy diffusivities with the Wave Reynolds number as well as with the wind stress measured as the friction velocity from wind profiles measured at the coastline. Some of these results have been published in Bezerra et al. (1998). Both effects are important and give several decades of variation of eddy diffusivities measured near the coastline (between 0.0001 and 2 m2s−1).

A good estimate of the eddy diffusivity comes from a scaling that includes the thickness of the surf zone as well as the depth and the wave period. Measurements in the Mediterranean are almost two orders of magnitude smaller than in the Pacific coast. On a larger scale, and further away from the coast the relevant eddy diffusivities are much larger, because large eddies, that often scale on the Rossby deformation radius disperse further the spills. Examples of SAR image signatures of different oceanic and atmospheric origin are compared, In the Figure a distribution of the detected vortical structures and the size distribution of oil Spils are presented with a set of eddy diffusivity values measured near the Ebro Delta.

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References


Figure: Oil Spill Analysis