Integrated Oil spill detection and forecasting using MOON real time data

M. De Dominicis[*1], N. Pinardi[2], G. Coppini[1], M. Tonani[1], A. Guarnieri[1], G. Zodiatis[3], R. Lardner[3], L. Santoleri[4]

[1] *Istituto Nazionale di Geofisica e Vulcanologia, Bologna, Italy*

[2] *Corso di Scienze Ambientali, University of Bologna, Ravenna, Italy*

[3] *Oceanographic Centre, University of Cyprus, Cyprus*

[4] *ISAC-CNR, Rome, Italy*

* Corresponding author, email: dedominicis@bo.ingv.it

1. Introduction

The Mediterranean research community started to develop the backbone of the Mediterranean ocean Forecasting System (MFS) in early 1998 and it has been progressing ever since.

More than 100 scientists, from 15 countries around the Mediterranean Sea, have been working, since 1998, to plan, implement and sustain the operations of operational marine forecasting services. In the past ten years European projects (FPIV, FPV and FPVI) contributed to develop the international scientific base for the deployment of an efficient and accurate forecasting system at basin scale, which is nowadays used by 32 Institutes/agencies from all the countries bordering the Mediterranean. A new consortia has been established, the Mediterranean Operational Oceanography Network (MOON, http://www.moon-oceanforecasting.eu/) coordinating the upgrades of the MFS, the subregional nested systems, the observation system and their applications.

MOON provides the generic, oceanographic data sets for the development of downstream services, one of them related to oil spill detection and forecasting. Several oil spill models have been developed and adapted to interface with the MOON real time oceanographic data. Here we will describe the most commonly used one, so-called Medslik (Lardner et al., 2006) and its recent improvements. On the other hand, satellite monitoring of oil spills is organised by EMSA (European Maritime Safety Agency) through the CleanSeaNet service providing SAR data and MOON provides complementary ocean colour data which will be used in this paper for detection.

The paper is composed as follows: section 2 provides a brief review of the oceanographic service, section 3 a brief overview of the Oil spill detection and forecasting system used in this paper to show applications in the Lebanon and Algerian Sea areas.

2. MOON Ocean Forecasting System

A basin scale, 10 days Mediterranean Sea forecast is produced on a daily basis by a complex system of data management and software tools composed of an oceanographic data pre-processing and quality control scheme, an assimilation scheme that corrects the model initial guess with all the "in situ" and satellite available observations and an ocean general circulation model (OGCM) that provides forecasts. The overall structure is called Mediterranean Forecasting System (MFS).

The MFS OGCM is at 6.5 km horizontal resolution and 72 vertical levels (Tonani et al., 2008) and uses a data assimilation scheme (Dobricic et al., 2007) capable of assimilating all the available satellite (SLA and SST) and in situ profile real time data (XBT, ARGO). MFS is forced by atmospheric forcing produced by ECMWF (European Centre for Medium term Weather Forecast) fields. The model output such as currents and temperature are delivered as a daily mean centred at 00:00 GMT or hourly mean centred at 30' of each hour. The hourly products are operationally available since November 2008. MFS produces also daily analyses which are best estimates of the oceanographic conditions for usage in applications such as oil spill modelling, especially hazard mapping.

The Mediterranean Sea is a unique area of the world ocean where not only the forecasting activities have started earlier for the open ocean areas, but also the downscaling to high horizontal resolution toward the coasts has been implemented routinely. Several MOON Members receive every day the MFS basin scale output, providing initial and lateral boundary conditions for high-resolution models, better resolving the coastal dynamics. Thus regional and shelf models are nested into the MFS products, producing themselves forecasts of up to 1 km resolution in the coastal areas.
The MOON forecasting models are:

1. MFS (basin scale): INGV-Italy, 5-6 km.
2. OGS-OPATM (basin scale): OGS-Italy, 10-12 km.
3. PAM (basin scale): Mercator-France, 6-7 km.
4. POSEIDON (basin scale): HCMR-Greece, 8-10 km.
5. Western Mediterranean Sea: IMEDEA-CSIC-Spain, 5 km
6. NW Mediterranean: IFREMER-France, 3 km
7. Sicily Strait: CNR-IAMC-Italy, 3 km
8. ADRICOSM (Adriatic Sea): INGV-Italy, 2 km
9. POSEIDON (Aegean Sea): HCMR-Greece, 2 km
10. ALERMO (Aegean-Levantine): UAT-Greece, 3 km
11. Malta Shelf area: IOI-MOC-Malta, 1.5 km
12. Cyprus Coastal: Oceanigraphic Center of Cyprus, 1.5 km
13. Cilician Basin and Northern Levantine basin: IMS-Turkey 1.5 km
14. SE Levantine Shelf: IOLR-Israel, 1.5 km

MOON operational partners have set up a governance system built on the Data Exchange Agreement (DEA) which harmonises the data delivery and ensures the operational flow of data within the network ensuring the regular and systematic delivery of products at the level of the Mediterranean Sea and its sub-regional areas.

3. Integrated Oil Spill Detection and Forecasting System

Any Oil Spill Detection and Forecasting System can be sub-divided into four main module (see fig. 1): the satellite monitoring system, the atmospheric forcing, the oceanographic models and the oil spill models.
The oil spill models integrate atmospheric and ocean forecasts with oil spill detection in order to provide a prediction of the oil transport fate and dispersal.

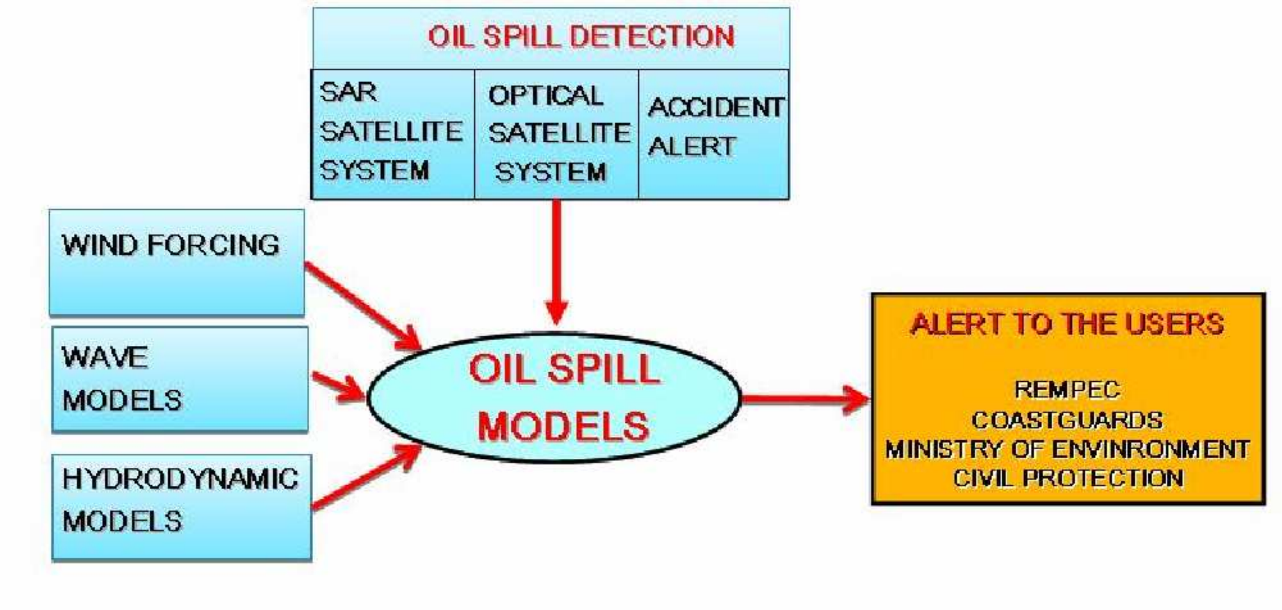


Figure 1. Architecture of a generic oil spill detection and forecasting system.

3.1 Detection system

The forecast skill of the oil spill dispersal and fate is intimately connected to the accurate knowledge of the marine currents and the wind field. The oil spill forecast accuracy is also connected to the knowledge of the oil density and the volume of the slick. The oil spill data required to define a numerical oil spill initial condition are: the location, time and area of the spill, as well as the age of the oil spill from initial arrival n the sea. The time, position and area data are provided by several satellite monitoring systems. While SAR is provided operationally by EMSA CleanSeaNet system, not dicussed here, MOON provides a complementary spectroradiometer satellite system composed of sensors like MODIS (on board of AQUA, since 2002 and TERRA, since 2000). Optical sensors do not guarantee all time, all weather coverage, on the other hand, they allow monitoring of wider areas (at lower resolution). They are not yet used in operational mode and in this paper they will be shown mainly as a validation/calibration tool for oil spill modelling.

3.2 Oil spill modelling

The oil spill model used in this application is Medslik which is a lagrangian model designed to predict the transport and weathering of an oil spill, developed by the Cyprus Oceanographic Centre (Lardner et al.,2006).

Medslik simulates the transport of the surface slick governed by both water currents and by direct wind forced currents. In addition, oil parcels are dispersed by turbulent fluctuation components that are parameterized with a random walk scheme. Medslik, like most oil spill models, uses a drift factor approach, which is considered to be a most practical approach for adjusting the advection of oil slicks coming from rather low resolution circulation models which do not properly resolve Ekman currents. With this method the drift velocity of the surface oil is considered to be a weighted sum of the wind velocity and the eulerian velocity field, supposed to represent the deeper (geostrophic) velocity field. Let (X_i, Y_i, Z_i) be the position of the i-th parcel at a certain time. Then at the end of the time step of length τ the parcel is displaced to the point (X'_i, Y'_i, Z'_i)

$$
\begin{aligned}
X_i' &= X_i + \{u(X_i, Y_i, Z_R) + \alpha(W_x \cos\beta + W_y \sin\beta)\}\tau + \Delta X_i^{(d)} \\
Y_i' &= Y_i + \{v(X_i, Y_i, Z_R) + \alpha(-W_x \sin\beta + W_y \cos\beta)\}\tau + \Delta Y_i^{(d)} \\
Z_i' &= Z_i + \Delta Z_i^{(d)}
\end{aligned} \tag{1}
$$

where $u(X_i, Y_i, Z_R)$ and $v(X_i, Y_i, Z_R)$ are the water velocity components in the x and y directions at a subsurface reference water level, Z_R, W_x and W_y the components of wind velocity, a and b are the drift factor and the drift angle respectively and the diffusive displacements are given by

$$
\begin{aligned}
\Delta X_i^{(d)} &= [2rand(0,1) - 1]\sqrt{6K_h\tau} \\
\Delta Y_i^{(d)} &= [2rand(0,1) - 1]\sqrt{6K_h\tau} \\
\Delta Z_i^{(d)} &= [2rand(0,1) - 1]\sqrt{6K_v\tau}
\end{aligned} \tag{2}
$$

where K_h and K_v are horizontal and vertical diffusivities respectively, chosen as fixed values and rand(0,1) is a uniform random number between 0 and 1.It can be shown that a cloud of such particles can be re-written in term of concentration that satisfies the convection-diffusion equation with K_h and K_v the horizontal and vertical diffusion coefficients, chosen as fixed values ($K_h = 2$

m^2/s and $K_v = 0.01\ m^2/s$). The successive positions of the parcel of oil described by (1) and (2) is called the trajectory model of Medslik.
In addition to convective and diffusive displacements, the oil spill parcels change due to various physical and chemical processes that transform the oil. The lighter fractions of the oil disappear through evaporation and the remaining fractions begin to be absorbed in water, or emulsify. Each particle of oil, while moving with the flow as described before, changes its oil properties, such as its density and viscosity. Finally, some of the oil is driven below the surface by wave action that is parameterized in a simple way in MEDSLIK. This dispersion of the oil is treated as a random process that may drive any parcel into the water column. It may also happen that the horizontal displacement takes a particular parcel of oil into the coast. The beaching is not permanent and it is assumed that at subsequent time instant there is a probability that the parcel may wash back into the water. It is supposed that this probability of washing back on each time step τ is given by

$$\text{Prob.of release} = 1 - 0.5^{\frac{\tau}{T_w}}$$

where T_w is the half-life for oil to remain on the beach before washing off again. For each parcel a random number generator is called and the parcel is released back into the water if

$$\text{rand}(0,1) < \text{Prob. of release}$$

A value of T_w is assigned to each coastal segment depending on the coastal type, for example sand beach, rocky coastline and so on.

The oil spill model output module provides the oil properties evolution and the position, every hour and for the next days, of the surface, dispersed oil and of the oil arrived on the coasts.

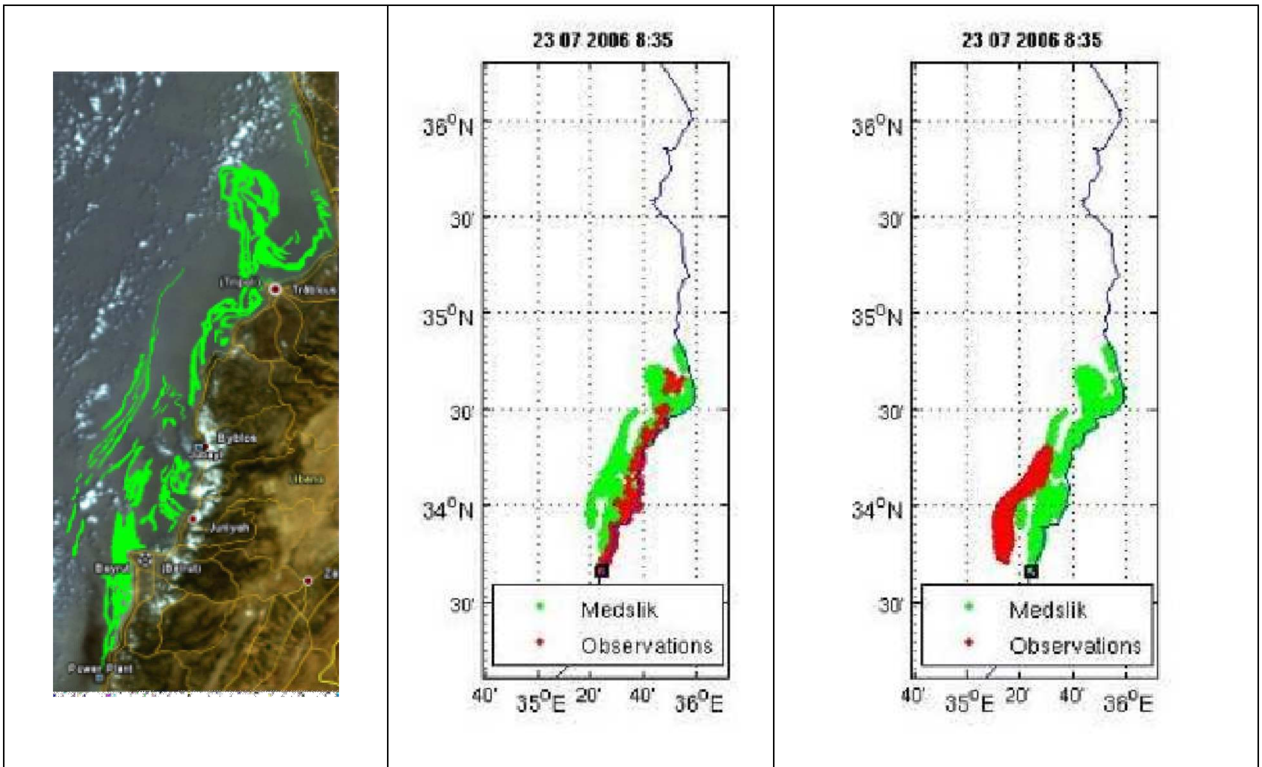
MEDSLIK has been coupled operationally with the MFS oceanographic model outputs at 1/16° lat,lon resolution, the Oceanography Center of Cyprus - University of Cyprus (OC-UCY) model output and the high resolution Adriatic forecasting System (AFS, Oddo et al., 2006). The two latter models are nested within MFS and downscale the current field down to 2 km resolution.

4. Operational Support in emergency cases and the oil spill model validation

The Integrated Oil Spill Detection and Forecasting system (IOSDF) described above has been used to provide timely information on the oil spill evolution during several emergency cases, such as the Lebanon crisis (2006), the Gibraltar (2007) and Und Adryiatik (2008) accidents. During these oil pollution crisis IOSDF successfully assisted the decision makers in Europe and the Eastern Mediterranean, such as REMPEC (Regional Marine Pollution Emergency Response Centre for the Mediterranean Sea), Lebanese Ministry of Environment and the Italian civil protection, to manage the emergencies.

The Lebanese oil pollution crisis occurred in mid July-August 2006. On the 13 and 15 July 2006 the oil tanks at Jieh power station, located 30 km south of Beirut and directly on the coast, were hit by bombs. About 20,000 tons of oil was spilt into the sea. The oil spill released at sea, from the Jieh power station storage tanks is considered as the biggest so far in the Eastern Mediterranean. At the time of the Prestige oil spill accident in 2002 only limited operational oceanographic products were available to assist the response agencies and certainly none at the time of the Haven oil spill incident in 1991. On the contrary, during the entire period of the Lebanese oil pollution crisis in July-August 2006, the IOSDF system described above has been able to provide daily information for the forecasting of the displacement of the oil slicks (Coppini et al., 2009).
In this section the results of the coupling of MFS and CYCOFOS ocean forecast with MEDSLIK, are described. Moreover, the oil spill model output is inter-compared with satellite images from MODIS. In this simulation experiment the MEDSLIK model uses hourly time resolution

oceanographic fields from MFS and the 6 hourly wind forcing, with an horizontal spatial resolution of 0.5°, provided by the ECMWF.
The amount of oil spill was reported as being 18770 tons and the type of oil was believed to be a heavy fuel oil of about API 20. The position of the spill was 33° 41' N and 35° 10' E (actually the spill was on the coast, but we choose the MFS grid point nearest to the coast). The begin of the spill was supposed the 13 of July 2006 at 8:00 and the duration of spill was assumed equal to 144 hrs.



(a) Zoom of MODIS-ACQUA image, July 23: (08:35): oil (green) is already in Tripoli. Mushroom-like feature.	(b) The position of the oil slicks and oil concentration after 240 hours predicted by CYCOFOS-MEDSLIK (red), corresponding to July 23 8:00 GMT compared with the slick observed by MODIS (green). Parameters: wind correction factor: 0.008, wind angle: 10, currents depth: 30 m and horizontal diffusivity: 2 m2 s-1.	(c) The position of the oil slicks and oil concentration after 240 hours predicted by MFS-MEDSLIK, corresponding to July 23 8:00 GMT compared with the slick observed by MODIS (green). Parameters: wind correction factor: 0, wind angle: 0, currents depth: surface currents and horizontal diffusivity: 2 m2 s-1.

Figure 2. Panel (a) shows the MODIS AQUA images of July 23. Positions of the observed slicks (panel a and b) is compared with the predicted positions by CYCOFOS-MEDSLIK (panel b) and by MFS-MEDSLIK (panel c).

Figure 2 shows the comparison of oil slicks position and extension detected by satellite images (MODIS) and simulated by the CYCOFOS-MEDSLIK and MFS-MEDSLIK models. On July 23 the satellite image (Figure 2a) shows the oil spill in the Gulf of Tripoli and verifies the CYCOFOS-MEDSLIK prediction (Figure 2b), which did not simulated any offshore oil slick. The off-shore part of the slick is partially reproduced by MFS-MEDSLIK predictions (Figure 2c). The oil near the coast is not simulated by the MFS-MEDSLIK model, this inaccuracy is avoided by coupling MEDSLIK with the CYCOFOS higher resolution currents.

MOON supported the regional and local authorities (i.e. REMPEC and Coast Guards) during the possible oil spill accidents in the Gibraltar Strait (August –September 2007) and in the Adriatic Sea

(February 2008) but since there was no real dispersal of contaminants the two cases will not be reported here.
Instead, IOSDF supported several requests from REMPEC to forecast the dispersion of slicks detected by SAR images in the Tunisian and Algerian waters. The IOSDF provided the wind, the currents forecasts and the oil slick evolution for 72 hours after time of the detection, using the MFS forecasting system coupled with the Medslik oil spill model.
The slick information, such as the position of the centre of the slick, the slick polygonal coordinates, the time of the observation and the area of the slick are calculated by the satellite system and used by Medslik. An age of the slick observed by the satellite must be hypothesized in order to calculate the initial properties of the spill at time of the observation.
Following the request from REMPEC, the IOSDF produced the simulation, using MFS system coupled with MEDSLIK oil spill model, related to the oil spill detected the 6 of August 2008 at 9:50 with high confidence in the Algerian waters. Ancillary data such as wind stress and surface marine currents were delivered together with the oil drift simulation (figure 3).
The SAR data (observation time and date, position of oil slick centre, area and oil slick polygonal contour) has been provided by REMPEC. The input data provided by the satellite system and the input data hypothesized are listed in table 2. The wind and currents parameters chosen are: wind correction factor= 0, wind angle= 0, surface currents and horizontal diffusivity= 2 m^2/s.
In order to consider the possible errors in the current fields and in the oil volume estimation, several simulations has been carried out, varying the initial position and thickness (volume) of the oil slick. The overlay of the simulated oil slick position (red) and the MODIS observation (green) of the 7th August 2008 is shown in figure 5. The oil slick areas with a oil density higher than 0,1 m^3/km^2 are highlighted in blue. The best agreement between the simulated and the observed slick has been obtained shifting the oil slick 2 point grid in the south-west direction from the original position and with a thickness of 0.0001 mm (volume equal to 7 tons).

Input data			
Observation Date	**06/08/2008**	***Density (hypothesized)***	**0.934 tons/m3**
Observation Time	**09:51**	***Thickness (hypothesized)***	**0.0001 mm**
Latitude	**38° 17.39'**	***Age of the Slick (hypothesized)***	**24 hrs**
Longitude	**5° 23.53'**	***Current velocities***	**MFS 1 hourly Analysis**
Area	**75712496 m2**	***Wind forcing***	**ECMWF 6 hourly Analysis**

Table 2. Input data needed for the oil spill simulation.

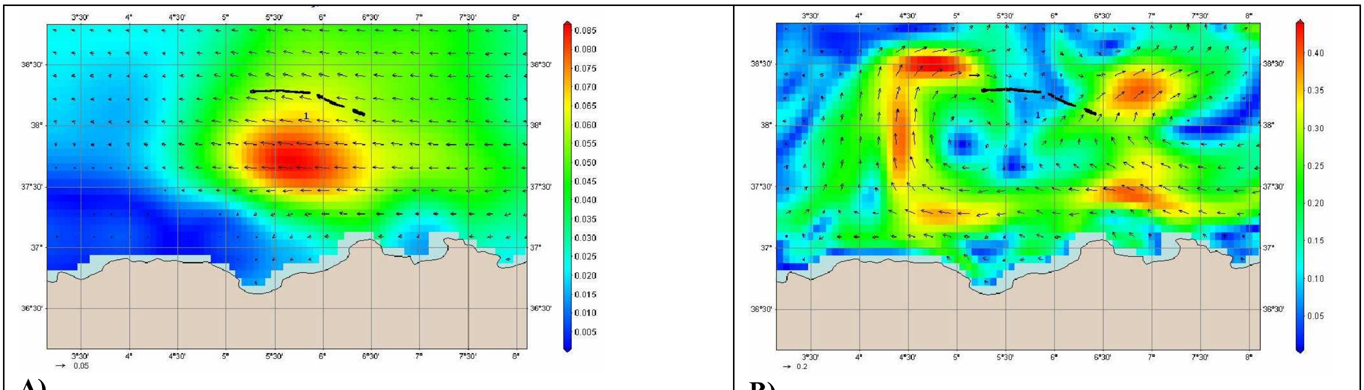

A) B)

Figure 3. Panel A) Wind Stress (N/m2) mean field from 12:00 20080805 to 12:00 20080806 on the August 6 9:50 GMT; Panel b) Current (knots) mean field at the surface from 12:00 20080805 to 12:00 20080806. In both panels there is the position of the slick observed by SAR (black).

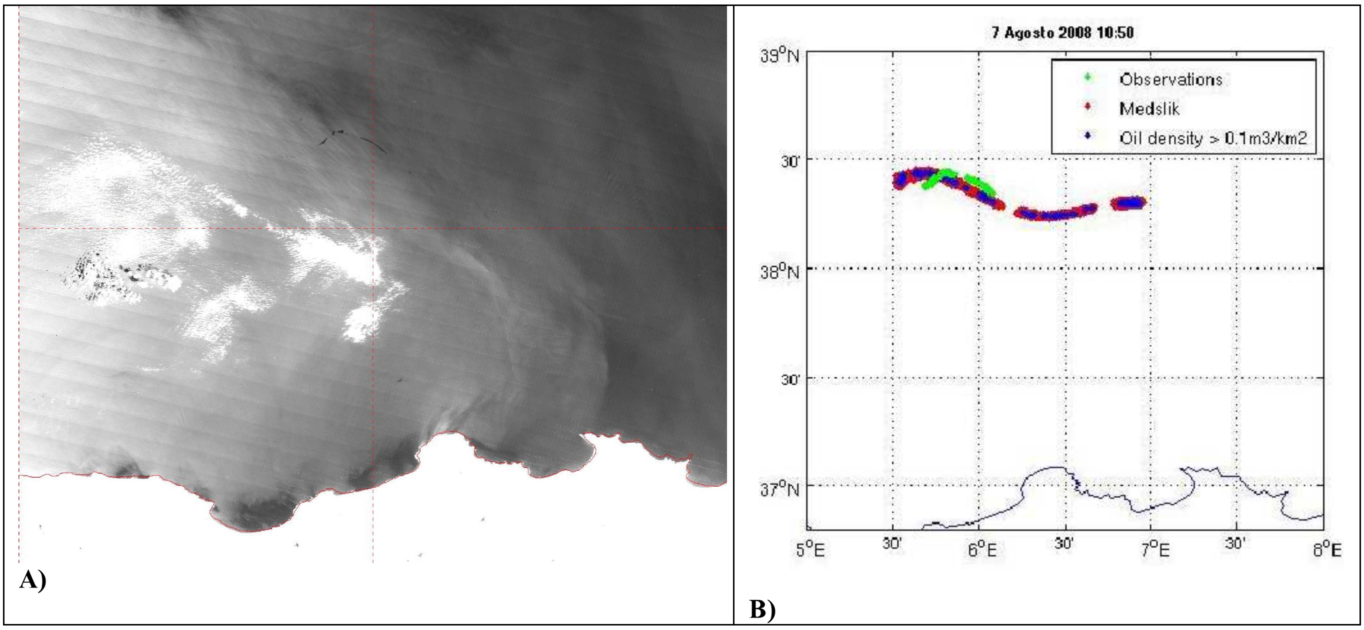


Figure 4. Panel A) MODIS-TERRA image, August 7 (10:50); Panel B) The position of the oil slick after 25 hours predicted by MFS- MEDSLIK (red), corresponding to August 7 10:50 GMT compared with the slick observed by MODIS (green). Parameters: wind correction factor: 0, wind angle: 0, currents depth: surface and horizontal diffusivity: 2 m2 s-1.

The results of the oil spill model MEDSLIK has been also compared against observed drifter tracks. For this validation exercise, MEDSLIK has been used to simulate only trajectories without computing the oil transformation processes or the spreading of the slick by turbulence. MEDSLIK uses the wind fields provided by the ECWMF (6 hourly winds) and the oceanographic fields (1 hourly currents) provided by the operational oceanographic model MFS.
The study case is the Marine Rapid Environmental Assessment (MREA07) experiment. During this experiment five drifters (74871, 74872, 74873,74874 and 74875) were deployed on May 14, 2007 in the Ligurian sea.

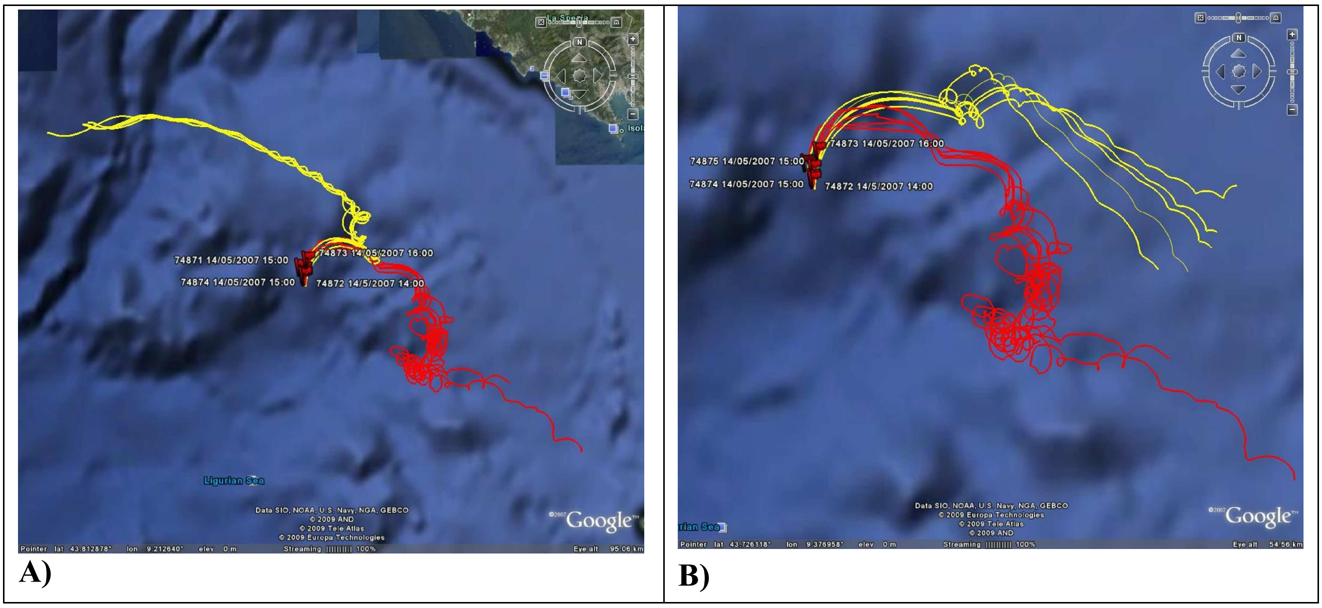


Figure 5. Overlay of the observed drifter trajectory (red lines) and the Medslik trajectories (yellow lines) from 14/05/2007 to 24/05/2007. Wind and currents parameters: Wind Correction: 0, Wind Angle: 0, Current depth: surface. The trajectories in the panel A) are obtained with the MFS 1 hourly currents (horizontal resolution 6.5 km), in the panel B) are obtained with the ALMA-RENO (horizontal resolution 3 km).

Figure 5 shows the observed drifters tracks (red lines) and the Medslik trajectories (yellow lines), obtained using the MFS 1 hourly currents and the ECMWF 6 hourly winds. In this simulations MEDSLIK uses the surface currents and the wind correction and the wind angle has been equal to zero. In the MREA07 case, the MFS coupled with MEDSLIK model is not capable to reproduce the correct drifters direction. When higher resolution modeling is used for the eulerian velocity field, the trajectory in the Ligurian Sea is reconstructed. In figure 3 the results of the simulation carried out with the MEDSLIK model coupled with the ALMA-RENO model, that provides higher horizontal resolution (3 km) current nested in MFS, are shown. When the eulerian velocity field is not accurate enough, as the MREA07 case, there is a need for higher resolution currents, such as the one given by ALMA-RENO.

Conclusion

The MOON satellite observing and forecasting products, used for oil slicks detection and for forcing and validate the MEDSLIK oil spill model, have all been shown to be robust and capable to provide valuable operational information during oil spill events. Nowadays an integrated system for operational monitoring and forecasting of oil slicks is possible, thanks to the use of different satellite platforms and the operational ocean forecasting systems. During the Lebanon crisis the MEDSLIK oil spill model coupled to CYCOFOS and MFS ocean forecasts has been capable to predict the pattern of the oil slick evolution, both in terms of space and time scales. The MFS-MEDSLIK is today available at basin scale allowing a possible support to such crisis in the entire Mediterranean basin.

Moreover, the operational support capability shown by MOON during the possible oil spill accidents has proven that the modelling and forecasting system is ready to be used operationally in any case of emergencies at sea. Furthermore it is a useful tool for contingency planning during emergencies.

The IOSDF support capability in the case oil slick detection from satellite system has been demonstrated. The MEDSLIK simulation can be automatically initialized from satellite images and therefore during an emergency satellite images can also be used to restart a simulation with MEDSLIK from the new detected slick position.

These experiences has highlighted the necessity of strong coordination among different institutions for a rapid and efficient exchange of information. It would be then mandatory in the future to consolidate the relationship and the agreements among all the institutional entitities in order to assure an integrated operational service for oil spill emergencies at sea.

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