Istituto Nazionale di Geofisica e Vulcanologia

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- Sez. di Bologna -

MEDSLIK-II

lagrangian marine surface oil spill model

User Manual

D. Bruciaferri, and the MEDSLIK-II system team

- Version 1.02 -

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- INGV: Istituto Nazionale di Geofisica e Vulcanologia
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Chapter 1

Introduction

An oil spill is the release of any oily substance into the environment due to human activity, and is a form of pollution. The term is usually applied to marine oil spills, where oil is usually petroleum released into the ocean or coastal waters.

Fig. 1.1: The oil slick in the Gulf of Mexico is seen from a helicopter. (by Rick Loomis, Los Angeles Times, May 6, 2010)

Oil spills may be due to releases of crude oil from tankers, offshore platforms, drilling rigs and wells, as well as spills of refined petroleum products (such as gasoline, diesel) and their by-products or heavier fuels used by large ships

such as bunker fuel.

They endanger public health, imperil drinking waters, devastate natural resources, and disrupt the economy and when they occur human health and environmental quality are put at risk and every effort must be made to prevent or to clean them up promptly once they occur [5].

The ability to represent the transport and fate of an oil slick at the sea surface is a formidable task: by an accurate numerical representation of oil evolution and movement in seawater, the possibility to asses and reduce the oil-spill pollution risk can be greatly improved.

Many factors affect the motion and transformation of the slick. The most relevant of these are the meteorological and marine conditions at the air-sea interface (wind, waves and water temperatures); the chemical characteristics of the oil; its initial volume and release rates; and, finally, the marine currents at different space scales and timescales [4]. Therefore oil spill management strategies need to be developed together with the improvement of meteorological, ocean and wave forecasting models.

MEDSLIK-II is an oil spill model designed to predict the transport and weathering of an oil spill or to simulate the movement of a floating object and its code is a freely available community model which can be downloaded from *http://medslikii.bo.ingv.it*.

This Technical Report describes the properties and the features of the oil spill model MEDSLIK-II version 1.02 and it is organized as follows:

- In Chapter 1, a summary of the new features and properties of the version 1.02 is given.
- In Chapter 2, the governing equations solved by the model and the physical processes involved are briefly described.
- In Chapter 3, the model solution methodology and the numerical schemes and technics used in the model are presented.
- In Chapter 4, the software installation procedure and the description of the code structure are given.
- In Chapter 5, the Meteo-Oceanographic input data needed to force the model are presented.

- In Chapter 6, the steps needed to run both an oil spill-slicks simulation and a particle tracking Lagrangian simulation are described in detail.
- In Chapter 7, the three test cases performed to validate the model are described and the results are given.

1.1 The version 1.02

The new characteristics of the oil spill model MEDSLIK-II v1.02 can be divided into two groups: the **new physical-geometrical properties** and the **new model code features**.

The new physical-geometrical properties comprehend:

- The capability to simulate multiple independent oil spill sources or slicks. This means that each source/slick has its own oil properties (as spill rate and spill time, geometry, ecc.) and its own gravity center where the physical properties needed for the oil wheathering processes are calculated.
- The capability to be forced by Stokes' Drift velocities computed using a wind-wave model.
- The wind drift velocities are calculated using the total local wind fields and not the wind interpolated at the lonely gravity center.
- The possibility to use a 4th order Runge-Kutta numerical scheme to solve the advective-diffusive part of the active tracer equation.
- The possibility to switch off the transformation/reaction part of the model code to use MEDSLIK-II as a particle tracking Lagrangian model.

The new model code features are:

- A modular $Fortran90$ $ExtractII.F90$ subroutine : this subroutine is responsible for the pre-processing of the meteo-oceanographic data used to force MEDSLIK-II. With the new structure, it can be easily adapted to read any kind of netcdf input file.
- A more general linear time interpolation subroutine in the main code: now only 3 time interpolation subroutines exist, one for each kind of forcing. Each subroutine works with a specific kind of forcing at any time resolution.

- An external modular Fortran 90 package to create a netcdf output has been added.
- A visualization package based on python and PyNIO and PyNGL libraries (products of the Computational and Information System Laboratory at the National Centre for Atmospheric Reasearch, NCAR, Boulder, Colorado, USA) has been added.

Chapter 2

Governing Equations

This chapter summarizes the main aspects of the theory on which MEDSLIK-II is based. For a fully detailed description see [4], [3] and [2].

MEDSLIK-II is a Lagrangian marine surface oil spill model designed to simulate oil slick transport and transformation processes for realistic oceanic cases.

Oil discharged in the marine environment moves driven by the advection due to the large-scale flow field and by the dispersion caused by local turbulent flow components. While the oil moves, its concentration changes due to weathering processes.

2.1 The active tracer equation and the model state variables

The general equation for a tracer concentration, $C(\boldsymbol{x}, t)$, with units of mass over volume, mixed in the marine environment, is

$$\frac{\partial C}{\partial t} + \boldsymbol{U} \cdot \boldsymbol{\nabla} C = \boldsymbol{\nabla} \cdot (\boldsymbol{K} \cdot \boldsymbol{\nabla} C) + \sum_{j=1}^{M} r_j(\boldsymbol{x}, C(\boldsymbol{x}, t), t) \tag{2.1}$$

where $\frac{\partial}{\partial t}$ is the local time-rate-of-change operator, $\boldsymbol{U}$ is the three dimensional ocean current mean field, $\boldsymbol{K}$ is the diffusivity tensor which parameterizes the

turbulent effects, and $r_j(\boldsymbol{x}, C(\boldsymbol{x},t),t)$ are the M transformation rates that modify the tracer concentration by means of physical and chemical transformation processes.

Assuming that the slick is composed of oil constituent particles which move like water parcels and considering that the physical and chemical processes act on the entire slick rather than on the single particles properties, the active tracer equation 2.1 can be effectively split into two component equations:

$$\frac{\partial C_1}{\partial t} = \sum_{j=1}^{M} r_j(\boldsymbol{x}, C_1(\boldsymbol{x},t),t) \tag{2.2}$$

$$\frac{\partial C}{\partial t} = -\boldsymbol{U}\cdot\boldsymbol{\nabla}C_1 + \boldsymbol{\nabla}\cdot(\boldsymbol{K}\cdot\boldsymbol{\nabla}C_1) \tag{2.3}$$

where C_1 is the oil concentration solution solely due to the weathering processes, while the final time rate of change of C is given by the advection-diffusion acting on C_1.

Equation 2.2 describes the evolution in time of the oil slick concentration due to the transformation processes acting on the total oil slick volume: therefore, **oil slick state variables** have to be defined.

On the other hand, in order to solve equation 2.3 by using a Lagrangian particle formalism, it is needed to discretize the oil slick in particles with associated **particle state variables**, some of them deduced from the oil slick state variables.

Finally, four **structural state variables** C_S, C_D, C_C and C_B are defined, which describes, respectively, the oil concentration at the surface, in the subsurface, adsorbed on the coasts and sedimented at the bottom (see Fig. 2.1).

Table 2.1 lists all the *Structural*, *Slick* and *Particle* state variables defined in MEDSLIK-II.

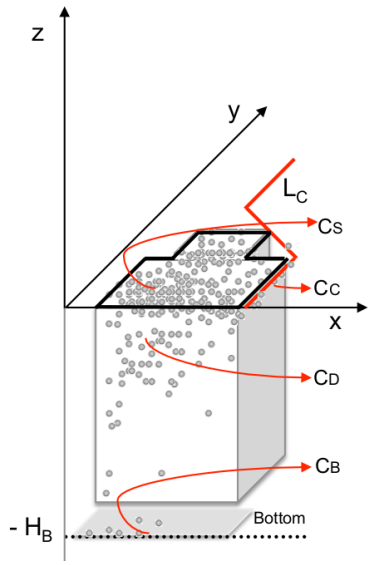


Fig. 2.1: Schematic view of the oil concentration classes (the grey spheres represent the oil particles and L_C the coast line) (modified from [4])

Table 2.1: Oil spill model state variables (modified from [4])

Variable name	Variable type	Variable Description	Dimensions
$C_S(\boldsymbol{x},t)$	Structural	Oil concentration at the surface	Kg m^{-2}
$C_D(\boldsymbol{x},t)$	Structural	Oil concentration dispersed	Kg m^{-2}
$C_C(\boldsymbol{x},t)$	Structural	Oil concentration on the coast	Kg m^{-2}
$C_B(\boldsymbol{x},t)$	Structural	Oil concentration on the bottom	Kg m^{-2}
$V_S(\boldsymbol{x},t)$	Slick	Oil slick surface volume	m^3
$V_D(\boldsymbol{x},t)$	Slick	Oil slick dispersed volume	m^3
$V^{TK}(\boldsymbol{x},t)$	Slick	Thick part of the surface oil slick volume	m^3
$V^{TN}(\boldsymbol{x},t)$	Slick	Thin part of the surface oil slick volume	m^3
$A^{TK}(\boldsymbol{x},t)$	Slick	Surface area of the thick part of the surface oil slick volume	m^2
$A^{TN}(\boldsymbol{x},t)$	Slick	Surface area of the thin part of the surface oil slick volume	m^2
$T^{TK}(\boldsymbol{x},t)$	Slick	Surface thickness of the thick part of the surface oil slick volume	m
$T^{TN}(\boldsymbol{x},t)$	Slick	Surface thickness of the thin part of the surface oil slick volume	m
$\boldsymbol{x}_k(t) = (x_k(t), y_k(t), z_k(t))$	Particle	Particle position	m
$v_{NE}(n_k,t)$	Particle	Non-evaporative surface oil volume particle attribute	m^3
$v_E(n_k,t)$	Particle	Evaporative surface oil volume particle attribute	m^3
$\sigma(n_k,t) = 0,1,2,<0$	Particle	Particle status index (on surface, dispersed, sedimented, on coast)	-

2.2 The Oil Weathering-Transformation Equation

In MEDSLIK-II, the concentration C_1 in the weathering equation 2.2 represents the oil concentration at the surface C_S and the oil concentration dispersed in the water column C_D.

Therefore, the oil weathering equation in MEDSLIK-II comprehends the following

$$\frac{dC_S}{dt} = \frac{\rho}{A}\frac{dV_S}{dt} \tag{2.4}$$

$$\frac{dC_D}{dt} = \frac{\rho}{A}\frac{dV_D}{dt} \tag{2.5}$$

where A is the unit area, V_S is the oil slick surface volume, V_D is the oil slick dispersed volume and ρ is the sea water density.

Regarding the surface oil which arrives close to the coasts and is adsorbed, the concentration of beached oil is given by

$$C_C(\boldsymbol{x}, t) = \frac{\rho}{L_C} V_C \tag{2.6}$$

where L_C is a coastline segment and V_C is the adsorbed oil volume calculated from the oil particle state variables.

In the present version of the model, the oil concentration on the bottom, C_B , is not computed, and it is simply represented by a number of oil particles that reach the bottom.

The weathering acting on the surface oil comprehends three main processes: **Evaporation**, which occurs for first and usually acts on the lighter fractions of the oil, **Dispersion** of the remaining oil fractions below the water surface and **Spreading**, which is responsible for the mechanical spreading of the spill over the water surface under the action of gravitational forces (see Fig. 2.2).

Equations 2.4 and 2.5 are solved by using the Mackay et al. (1980) transformation process algorithms, which are based on the assumption that the oil surface volume can be divided into a thin part, V^{TN} , and a thick part, V^{TK}.

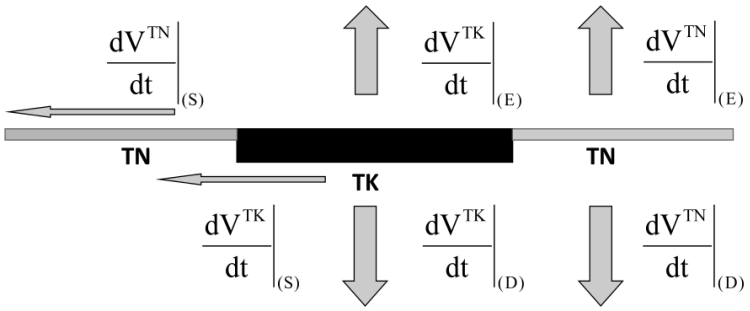


Fig. 2.2: Weathering processes using Mackay's approach. TK indicates the thick slick and TN the thin slick. V^{TK} and V^{TN} are the surface oil volumes of the thick and thin part of the slick and the suffixes indicate evaporation (E), dispersion (D) and spreading (S) (from[4])

Consequently, the weathering processes are considered separately for the thick slick and thin slick and the prognostic equations are

$$\frac{dV^{TK}}{dt} = \frac{dV^{TK}}{dt}\Big|_{(E)} + \frac{dV^{TK}}{dt}\Big|_{(D)} + \frac{dV^{TK}}{dt}\Big|_{(S)} \tag{2.7}$$

$$\frac{dV^{TN}}{dt} = \frac{dV^{TN}}{dt}\Big|_{(E)} + \frac{dV^{TN}}{dt}\Big|_{(D)} + \frac{dV^{TN}}{dt}\Big|_{(S)} \tag{2.8}$$

where the suffixes indicate evaporation (E), dispersion (D) and spreading (S).

All the oil slick state variables are defined only at the slick's central geographical position (Gravity Centre, hereinafter GC), which is updated after each advection-diffusion time step. In the case of multiple slicks, each slick is characterized by its own GC.

The oil spill centre position $\boldsymbol{x}_C^s = (x_C^s(t), y_C^s(t))$ is defined as

$$\begin{cases} x_C^s = \frac{\sum_{k=1}^{N_s} x_k^s(t)}{N_s} \\ \\ y_C^s = \frac{\sum_{k=1}^{N_s} y_k^s(t)}{N_s} \end{cases} \tag{2.9}$$

where s ($1 < s <$ number of slicks) is an integer which identifies the s^{th} slick, N_s is the number of oil constituent particles into which the s^{th} slick is broken and $(x_k^s(t), y_k^s(t))$ is the position at time t of the k^{th} particle of the s^{th} slick.

2.3 The Advection-diffusion Equation

Medslik-II before solves the weathering equation 2.2 and then uses the oil concentration solution C_1 to solve the advection-diffusion equation 2.3 .

In order to solve the latter with a Lagrangian particle formalism, the oil slick is before discretized in N_{TOT} particles with associated particle state variables and then the oil concentration is computed by assembling the particles together with their associated properties.

The horizontal current field used in the Lagrangian model is taken to be the sum of different components:

$$\begin{cases} \sigma = 0, \quad d\boldsymbol{x}_k(t) = [\boldsymbol{U}_C(x_k, y_k, 0, t) + \boldsymbol{U}_W(x_k, y_k, t) \\ \qquad\qquad\qquad + \boldsymbol{U}_S(x_k, y_k, t)]dt + \boldsymbol{U}_D(x_k, y_k, t)]dt + d\boldsymbol{x'}_k(t) \\ \\ \sigma = 1, \quad d\boldsymbol{x}_k(t) = \boldsymbol{U}_C(x_k, y_k, z_k, t)dt + d\boldsymbol{x'}_k(t) \end{cases} \tag{2.10}$$

where σ is the particle status index which identifies if a particle is on the sea surface ($\sigma = 1$) or dispersed into the water column ($\sigma = 0$), $\boldsymbol{U}_C$ is the wind, buoyancy, and pressure-driven large-scale current velocity field, $\boldsymbol{U}_W$ is the local wind velocity correction term (wind drift term), $\boldsymbol{U}_S$, called hereafter wave current term, is the velocity due to wave-induced currents or surface Stokes drift, $\boldsymbol{U}_D$ is the wind drag correction due to emergent part of the objects at the surface and $d\boldsymbol{x'}_k(t)$ is the displacement due to the turbulent diffusion.

In Medslik-II the turbulent diffusion is parameterized with a random walk scheme as follows:

$$d\boldsymbol{x}'_k(t) = \sqrt{2\boldsymbol{K}dt}\boldsymbol{Z} \tag{2.11}$$

where $\boldsymbol{K}$ is the turbulent diffusion diagonal tensor and $\boldsymbol{Z}$ is a vector of independent random numbers used to model the Brownian random walk processes. The three components of $\boldsymbol{K}$ are K_h, K_h, K_v. Usually, the isotropic K_h is set equal to 2 $m^2 s^{-1}$ while K_v is set to be 0.01 $m^2 s^{-1}$ in the mixed layer (assumed to be 30 m deep) and 0.0001 $m^2 s^{-1}$ below it.

Chapter 3

Numerical Approaches

This chapter describes the main numerical aspects which have to be considered in order to run Medslik-II. The main consequences of the *new physical-geometrical properties* on the numerical features of the model as well as the *4th order Runge-Kutta scheme* implemented in this new version of Medslik-II are presented and described.

For a fully detailed description of the numerical approaches used in Medslik-II see [4] and [3] .

This chapter is organized as follows:

- First, the model solution methodology is outlined (section 3.1) .
- Then, how MEDSLIK-II sets the initial conditions for particle and slick variables at the surface for single or multiple spills or slicks is discussed in section 3.2.
- Finally, in section 3.3 the Euler Forward scheme as well as the 4th order Runge-Kutta scheme used to solve the governing equations of the model are described.

3.1 Model solution methodology

In order to solve coherently the transformation and the advection-diffusion equations, an algorithm wich links the oil slick and the particle state variables is needed. The model *sequential solution method* is represented schematically in Fig. 3.1.

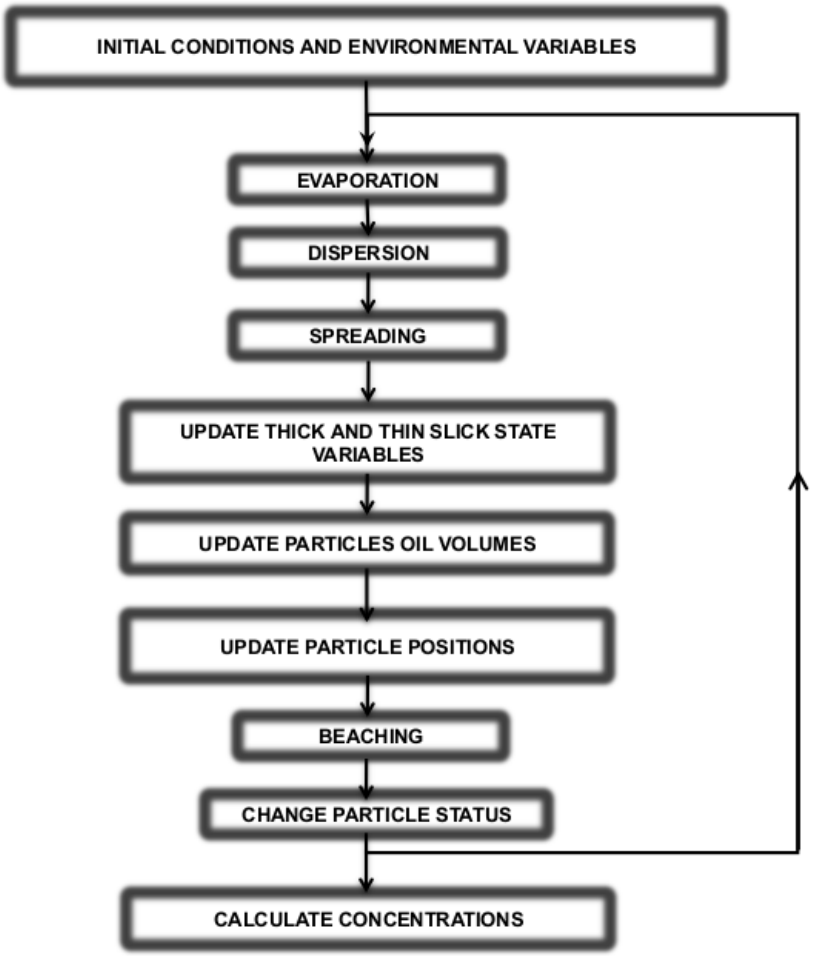


Fig. 3.1: MEDSLIK-II model solution procedure methodology (from [4])

3.2 Initial conditions

A surface oil release into the marine environment can be instantaneus or continuous: in the first case, all the oil is spilled instantly, while in the latter the leakage may last for several hours or even months. Furthermore, the simulated scenario could involve an oil slick detected by satellite or at sight. Finally, the simulated oil spills or detected slicks can be more than one.

Medslik-II version 1.02 is designed to simulate instantaneous or continuous single spills, instantaneous multiple spills and single or multiple detected slicks.

The approach used is the same adopted in the version 1.01 (see [4] for a detailed explanation), except for the fact that the structural, oil and particle state variables are defined for each spill/slick.

A **continuous oil spill release** is modeled dividing the total spilled oil into a number of sub-spills consisting of a given part of the oil released at the spill location during the prescribed computational time interval. As each sub-spill is moved away from the source, the total spill becomes a chain of sub-spills. In a continuous release, a given fraction of the total amount of particles used in the simulation is released with each sub-spill.

In the case of an **instantaneous release**, at the beginning of the simulation all the oil is released on the sea surface at the spill location and all the particles are released.

Satellite or at sight detected slicks are modeled as instantaneous spills except for the fact that the total amount of oil and particles of each slick are released inside the boundary line which identifies and describes the shape of the slicks. Therefore, in this case each oil spill source is not described by a single location, but by an ensamble of geographical points which identify a contour line.

The oil-spill data required to define a numerical oil-spill initial condition are:

- LOCATION : the geographical coordinates of the oil source location. In the case of a detected slick, the geographical coordinates of all the points which identify the oil slick polygonal contour line have to be provided.

- START TIME : it is the start time of the spill or the time of the slick detection.
- VOLUME : it is the total amount of oil released in a spill or the total oil of a slick.
- DURATION : the spill duration (for a detected slick it is zero).
- AGE : age of the oil spill from initial arrival in the sea. This information can be easily provided to MEDSLIK-II by satellite monitoring systems.

If the simulated scenario consists of multiple spills-slicks, all these informations have to specified for each spill-slick.

3.3 Numerical time integration schemes

Medslik-II solves its governing differential equations by using finite-difference numerical methods.

- The version 1.02 allows to choose an Euler forward scheme or a 4^{th} order Runge-Kutta scheme to solve the **Lagrangian horizontal particle motion** (equation 2.10).

  Euler Forward scheme

  The particle position at time step $t + \Delta t$ is calculated as follows:

  $$\boldsymbol{x}_k(t + \Delta t) = \boldsymbol{x}_k(t) + \boldsymbol{U}(\boldsymbol{x}_k, t)\Delta t + \Delta \boldsymbol{x'}_k(t) \tag{3.1}$$

  where $\boldsymbol{x}_k(t)$ represents the position of the k^{th} paricle at the current time step t, Δt is the discrete Lagrangian time step, $\boldsymbol{U}(\boldsymbol{x_k}, t)$ is the total Eulerian velocity field at the current time step at the particle position and $\Delta \boldsymbol{x'}_k(t)$ is the particle displacement due to turbulent motion.

  The total velocity field at the current time step at the particle position is computed performing a linear interpolation in time between successive input velocity fields, a bi-linear interpolation in horizontal space using the four external field grid points of the Eulerian model field (oceanographic or meteorological) nearest the particle position and a

linear vertical interpolation between the two field at the Eulerian model levels nearest the particle depth.

Normally, the Lagrangian time step Δt is taken to be 1800 s.

4^{th} order Runge-Kutta scheme

The particle position at time step $t + \Delta t$ is

$$\boldsymbol{x}_k(t + \Delta t) = \boldsymbol{x}_k(t) + \frac{1}{6}\Big(\boldsymbol{K}_1 + 2\boldsymbol{K}_2 + 2\boldsymbol{K}_3 + \boldsymbol{K}_4\Big)\Delta t + \Delta \boldsymbol{x'}_k(t) \quad (3.2)$$

where

$$\begin{aligned}
\boldsymbol{K}_1 &= \boldsymbol{U}(\boldsymbol{x}_k, t) \\
\boldsymbol{K}_2 &= \boldsymbol{U}(\boldsymbol{x}_k + \frac{1}{2}\boldsymbol{K}_1\Delta t, t + \frac{\Delta t}{2}) \\
\boldsymbol{K}_3 &= \boldsymbol{U}(\boldsymbol{x}_k + \frac{1}{2}\boldsymbol{K}_2\Delta t, t + \frac{\Delta t}{2}) \\
\boldsymbol{K}_4 &= \boldsymbol{U}(\boldsymbol{x}_k + \boldsymbol{K}_3\Delta t, t + \Delta t)
\end{aligned}$$

The 4^{th} order Runge-Kutta scheme needs the total velocity field at time steps t, $t + \Delta t/2$ and $t + \Delta t$ at the position $\boldsymbol{x}_k$, $\boldsymbol{x}_k + \frac{1}{2}\boldsymbol{K}_1\Delta t$, $\boldsymbol{x}_k + \frac{1}{2}\boldsymbol{K}_2\Delta t$ and $\boldsymbol{x}_k + \boldsymbol{K}_3\Delta t$. If the Runge-Kutta method is chosen, before a linear interpolation in time between successive input velocity fields is performed to compute the total velocity field at the necessary time steps. Then, a bi-linear horizontal spatial interpolation and a vertical linear interpolation are carried out to find the field values at the needed positions.

- On the other hand, **the weathering equations** 2.8 are solved with the Euler forward scheme, but with a different time step, the so-called weathering time step. The surface oil volumes of the thick and thin part of the slick are computed as follows:

$$V^{TK}(t + \delta t) = V^{TK}(t) + \frac{dV^{TK}}{dt}\delta t \quad (3.3)$$

$$V^{TN}(t + \delta t) = V^{TN}(t) + \frac{dV^{TN}}{dt}\delta t \quad (3.4)$$

where $\frac{dV^{TK}}{dt}$ and $\frac{dV^{TN}}{dt}$ are calculated using the empirical relationships which parameterize the weathering processes and the weathering time step δt is equal to $\frac{\Delta t}{30}$.

Chapter 4

Installing MEDSLIK-II

This chapter describes the technical details needed to properly install Medslik-II version 1.02. Furthermore, in section 4.5 a description of the code structure is given.

Medslik-II version 1.02 is written in FORTRAN-77/90, with in no machine-dependent elements, so that it can be installed without modifications on most platforms.

The architecture currently supported is Linux (tested on Ubuntu 10.04 LTS, Lubuntu 14.04, Debian 7 and Centos 5).

4.1 Downloading the code

MEDSLIK-II is a freely available community model and its code can be downloaded from the web page `http://medslikii.bo.ingv.it`, at the `Download` section.

After registration and be logged in, two links, named `Version_1.01` and `Version_1.02` respectively, are accessible. Each link leads to the homepage of the corresponding version of the model: here there are the links to download the code, to download the user manual and to download all the data needed to run the test cases.

After downloading the version 1.02 code, it is needed to move and extract the gzip compressed tar archive in the chosen installation path:

```
mv /${DOWNLOAD_FOLDER}/MEDSLIK_II_1.02.tar.gz /${INSTALLATION_FOLDER}
cd /${INSTALLATION_FOLDER}
tar -xvzf MEDSLIK_II_1.02.tar.gz
```

The variables `${DOWNLOAD_FOLDER}` and `${INSTALLATION_FOLDER}` have to be replaced by the user specific path of the `DOWNLOAD` and user chosen `INSTALLATION` folders, respectively. Because the installation process requires write, read and execute permissions, it is needed that the user has the necessary permits for the chosen installation folder.

4.2 Structure of the model

Extracting the gzip-tarball file creates the `/${INSTALLATION_FOLDER}/MEDSLIK_II_1.02` directory which is organized with the following structure:

Fig. 4.1: Tree list of the directories into which the model code is organized.

The description of the meaning and the function of each folder is given below:

`./DATA/` : Contains the directories for the NetCDF meteo-oceanographic model output data files needed to run a simulation

`./DATA/MET/` : Contains the NetCDF atmospheric model output data files needed for the simulation

`./DATA/OCE/` : Contains the NetCDF oceanographic model output data files needed for the simulation

`./DATA/WAV/` : Contains the NetCDF wave model output data files needed for the simulation

`./EXE/` : Contains the executable files created after having compiled the Fortran code and all the Python code needed to pre-process the data

`./OUTPUT/` : Contains the simulation output directories

`./PLOT/` : Contains the Python code needed to plot the simulation results

`./RUN/` : Contains the `data` and `INP_DATA` directories and all the shell scripts needed to configure and run a simulation

`./RUN/data/` : Contains bathymetry files for several regions of the Mediterranean Sea and other associated data files

`./RUN/INP_DATA/` : Contains the directories for the ASCII formatted meteo-oceanographic model output data files. These files are written after pre-processing of the original NetCDF files stored in `./DATA/*/`

`./RUN/INP_DATA/MET/` : Contains the ASCII formatted atmospheric model output data files

`./RUN/INP_DATA/OCE/` : Contains the ASCII formatted oceanographic model output data files

`./RUN/INP_DATA/WAV/` : Contains the ASCII formatted wave model output data files

`./RUN/template/` : Contains template files for the input and the parameter files.

`./SRC/` : Contains the model FORTRAN-77/90 source code

4.3 External libraries needed for computing and plotting

Nowdays, meteo-oceanographic model output data are usually provided as NetCDF datasets and therefore Medslik-II is designed to work with NetCDF files. Furthermore, in version 1.02 an external modular FORTRAN-90 package to create a Medslik-II NetCDF output file has been added.

Concerning the plotting procedure, a visualization package based on Python and PyNIO and PyNGL libraries has been added in this last version of the model. PyNGL and PyNIO libraries are products of the Computational and Information System Laboratory at the National Centre for Atmospheric Reasearch, NCAR, Boulder, Colorado, USA. PyNGL, as well as the associated modules PyNIO and NumPy, are all freely available.

NetCDF

NetCDF is a set of software libraries and self-describing, machine-independent data formats that support the creation, access, and sharing of array-oriented scientific data. NetCDF was developed and is maintained at Unidata. Unidata provides data and software tools for use in geoscience education and research. Unidata is part of the University Corporation for Atmospheric Research (UCAR) Community Programs (UCP). Unidata is funded primarily by the National Science Foundation.

The NetCDF homepage may be found at `http://www.unidata.ucar.edu/netcdf`. The NetCDF source-code is hosted at GitHub, and may be found directly at `http://github.com/Unidata/netcdf-c`.

In order to run Medslik-II version 1.02 it is needed to install NetCDF 4.3 or later. Documentation on how to install properly NetCDF4 FORTRAN libraries can be found at `http://www.unidata.ucar.edu/netcdf`.

PyNGL

PyNGL (`https://www.pyngl.ucar.edu/newusers.shtml`) is a Python language module used to visualize scientific data, with an emphasis on high quality 2D visualizations. A working knowledge of Python is assumed. The

NumPy extension module is used for array processing.

PyNGL provide Python interfaces to most of the graphics and file input/output functionality existing in the NCAR Command Language (NCL). A knowledge of NCL is not necessary because they are meant to be independent from NCL and used as a stand-alone suite of Python functions. In a few circumstances where the NCL documentation applies directly to PyNGL and there is no ambiguity, links are made to the NCL documentation from the PyNGL documentation.

Documentation on how to install properly PyNGL can be found at `https://www.pyngl.ucar.edu/Download/`.

PyNIO

PyNIO (`https://www.pyngl.ucar.edu/Nio.shtml`) is a Python package that allows read and/or write access to a variety of data formats using an interface modeled on NetCDF. PyNIO is composed of a C library which contains the same data I/O code used in NCL, a scripting language developed for analysis and visualization of geo-scientific data. In a few circumstances where the NCL documentation applies directly to PyNIO and there is no ambiguity, links are made to the NCL documentation from the PyNIO documentation.

Currently supported formats include NetCDF3 and NetCDF4 classic format (read/write), GRIB1 and GRIB2 (read-only), HDF4 (read/write for Scientific DataSets only), HDF-EOS2 and HDF-EOS5 (read-only for Grid and Swath data only), CCM history files (read-only), OGR-Open Geospatial Consortium's Simple Feature formats (ESRI Shapefile, MapInfo, GMT, Tiger) (read-only).

PyNIO interfaces with the Python environment using the multi-dimensional array module, NumPy. Documentation on how to install properly PyNIO can be found at `https://www.pyngl.ucar.edu/Download/` .

4.4 Compiling and linking the code

In order to easily compile the code, a bash script named `compile.sh` exists inside the directory `MEDSLIK_II_1.02/SRC/`.

A **GNU Fortran compiler** is needed.

To compile properly the model FORTRAN code, first it is needed to open the `compile.sh` file with any editor and change the bash variable `NETCDF_DIR` adding the exact absolute path of the NetCDF libraries installation directory.

Once you are sure that the file has execute permission, just run the build process with the following command: `./compile.sh`.

4.5 Structure of the code

The Medslik-II code comprehends FORTRAN-77/90 source code and Bash and Python scripts.

Bash scripts are located into the `RUN` directory and they are:

- `medslik_II.sh` : it is the main script and it controls the pre and post processing, the model run and plot procedures.
- `RUN_drifter_TESTCASE.sh`, `euler_RUN_drifter_TESTCASE.sh` and `runge_RUN_drifter_TESTCASE.sh` : they run the drifters test case (see 7).

Python scripts control the oil initial conditions processing and the output plotting procedures.

The oil initial condition processing python scripts are located inside the `EXE` directory (because Python source code is automatically runtime compiled into Python byte code by the CPython interpreter):

- `read_oil_data.py` : it reads the oil related variables into the `medslik_inputfile.txt` (`$OIL` and `$OIL_TYPE`) (see ??) and processes these informations in order to find the specific characteristics of the simulated oil.

- `ReadSatData.py` : it is able to read data for satellite detected oil spills and processes these informations in Medslik-II model format.

The python scripts which plot MEDSLIK-II `version_1.02` output results are located inside the `PLOT` directory. They are

- `MEDSLIKII_plot_slick.py`: it is a general scripts able to plot MEDSLIKII oil simulations output results stored in NetCDF output files.
- `MEDSLIKII_plot_oilfate.py`: it is able to plot MEDSLIKII oil simulations output results written in the `medslik.fte` file, which contains the trend over time of: the oil volume spilled, the percentage of oil evaporated, the percentage of oil on the surface, the percentage of oil dispersed, the percentage of oil on the coast, the oil-water emulsion viscosity, the oil viscosity, the oil density, the fraction of water contained in the oil-water emulsion, etc.
- `MEDSLIKII_plot_traj.py`: it is a general script able to plot MEDSLIKII Particle Lagrangian simulations output results.
- `plot_slick_ALGERIA.py`: it is an AlGERIAN test-case scripts, meaning that it is a customized version of the `MEDSLIKII_plot_slick.py` file for the ALGERIAN test case: it uses an appropriate palette for the oil concentration and it plots satellite observations at the right time-step (see 7 for a detailed description of this test case).
- `plot_slick_LEBANON.py`: it is a LEBANON test-case scripts, meaning that it is a customized version of the `MEDSLIKII_plot_slick.py` file for the LEBANON test case: it uses an appropriate palette for the oil concentration and it plots satellite observations at the right time-step (see 7 for a detailed description of this test case).
- `plot_slick_SRG.py`: it is a SERIOUS GAME test-case scripts, meaning that it is a customized version of the `MEDSLIKII_plot_slick.py` file for the SERIOUS GAME test case: it uses an appropriate palette for the oil concentration and it plots oil samples and drifter release locations at the right time-step (see 7 for a detailed description of this test case).
- `plot_traj_BEACON.py`: it is a SERIOUS GAME test-case scripts, meaning that it is a customized version of the `MEDSLIKII_plot_traj.py` file for the SERIOUS GAME test case: it plots BEACON real trajectory and results for all the three simulations performed in this test case (see 7 for a detailed description of this test case).

- `plot_traj_CODE.py`: it is a SERIOUS GAME test-case scripts, meaning that it is a customized version of the `MEDSLIKII_plot_traj.py` file for the SERIOUS GAME test case: it plots CODE real trajectory and results for all the three simulations performed in this test case (see 7 for a detailed description of this test case).

- `plot_traj_ISPHERE.py`: it is a SERIOUS GAME test-case scripts, meaning that it is a customized version of the `MEDSLIKII_plot_traj.py` file for the SERIOUS GAME test case: it plots I-SPHERE real trajectory and results for all the three simulations performed in this test case (see 7 for a detailed description of this test case).

- `plot_traj_SLDMB.py`: it is a SERIOUS GAME test-case scripts, meaning that it is a customized version of the `MEDSLIKII_plot_traj.py` file for the SERIOUS GAME test case: it plots SLDMB real trajectory and results for all the three simulations performed in this test case (see 7 for a detailed description of this test case).

FORTRAN-77/90 source code is located inside the `SRC` directory. It comprehends the following files:

- `Extract_II.F90` : This program reads meteo-oceanographic data from NetCDF model output files and writes the required data into Medslik-II ASCII formatted input files. It contains a main program and two modules, namely `env` and `utils`.

  `env` contains the declaration statments for all the variables used by the main program.

  `utils` contains all the subroutines used by the main program.

  Figure 4.2 represents the call graph for the `Extract_II.F90` program.

- `jday.f` : This program gets a day in the format `YYYYMMDD` as first argument and returns a date in the same format adding or subtracting a number of days given as a second argument.

- `lat_lon.F90` : This program computes the geographical limits of the area affected by the spill and writes the limits in the `RUN/medslik.tmp` file.

- `create_netcdf.F90` : This program reads MEDSLIK-II Ascii formatted outputs and creates, by the bilinear interpolation and linear interpo-

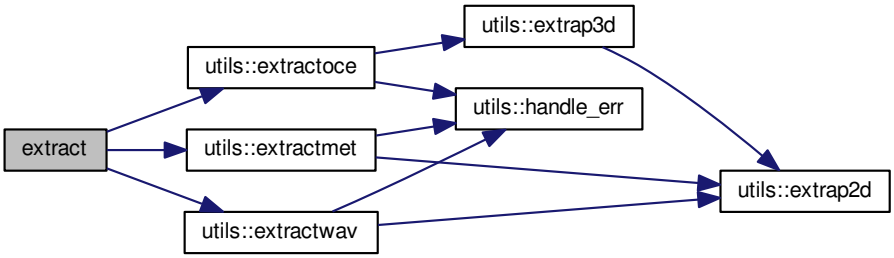


Fig. 4.2: Call graph for the Extract program.

lation methods, netcdf outputs of the Oil Concentration, the Ocean and the Wave-induced currents and the Wind velocities fields. Wind velocities are defined at the gravity centre point of each slick. On the other hand, ocean forcing fields are defined on their original grids and oil concentration is defined on the 150mx150m grid. This software uses the following external modules: `module_phymat.F90`, `module_interpolation.F90` and `module_netcdf.F90`.

Figure 4.3 represents the call graph for the `Extract_II.F90` program.

- `medslik_II.for` : This is the Medslik-II v1.02 program.

  The program `medslik_ii` consists of a `main` and several subroutines and functions. Figure 4.4 represents the call graph for the `medslik_II.for` program.

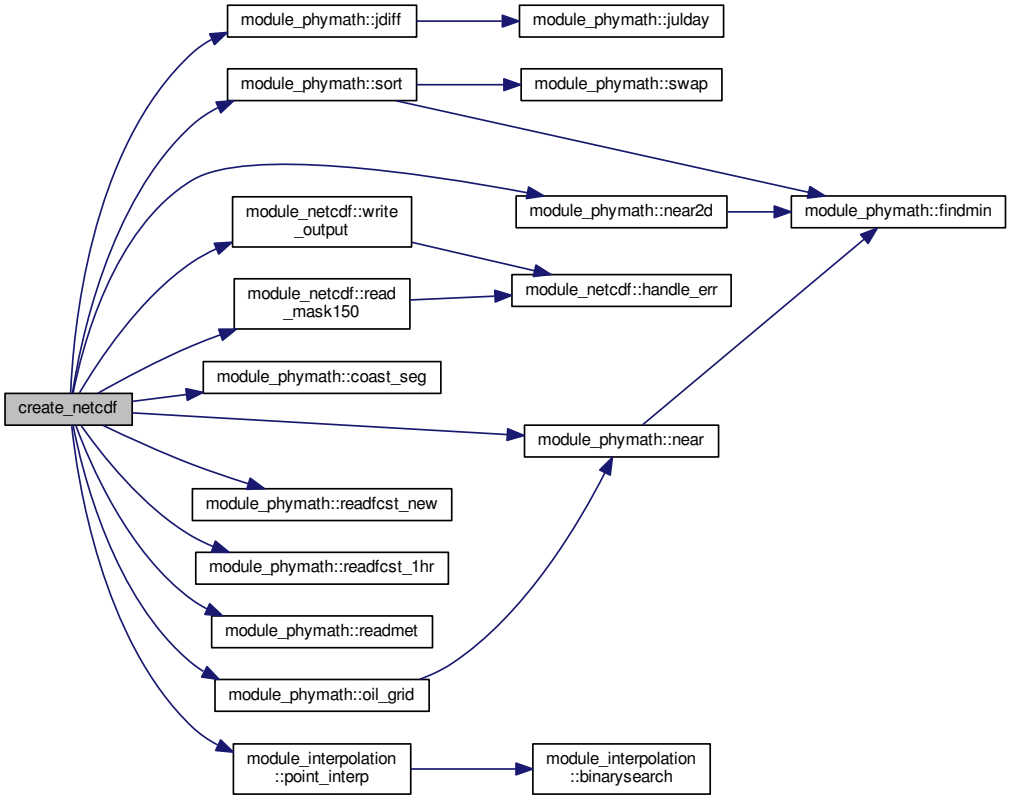


Fig. 4.3: Call graph for the create netcdf program.

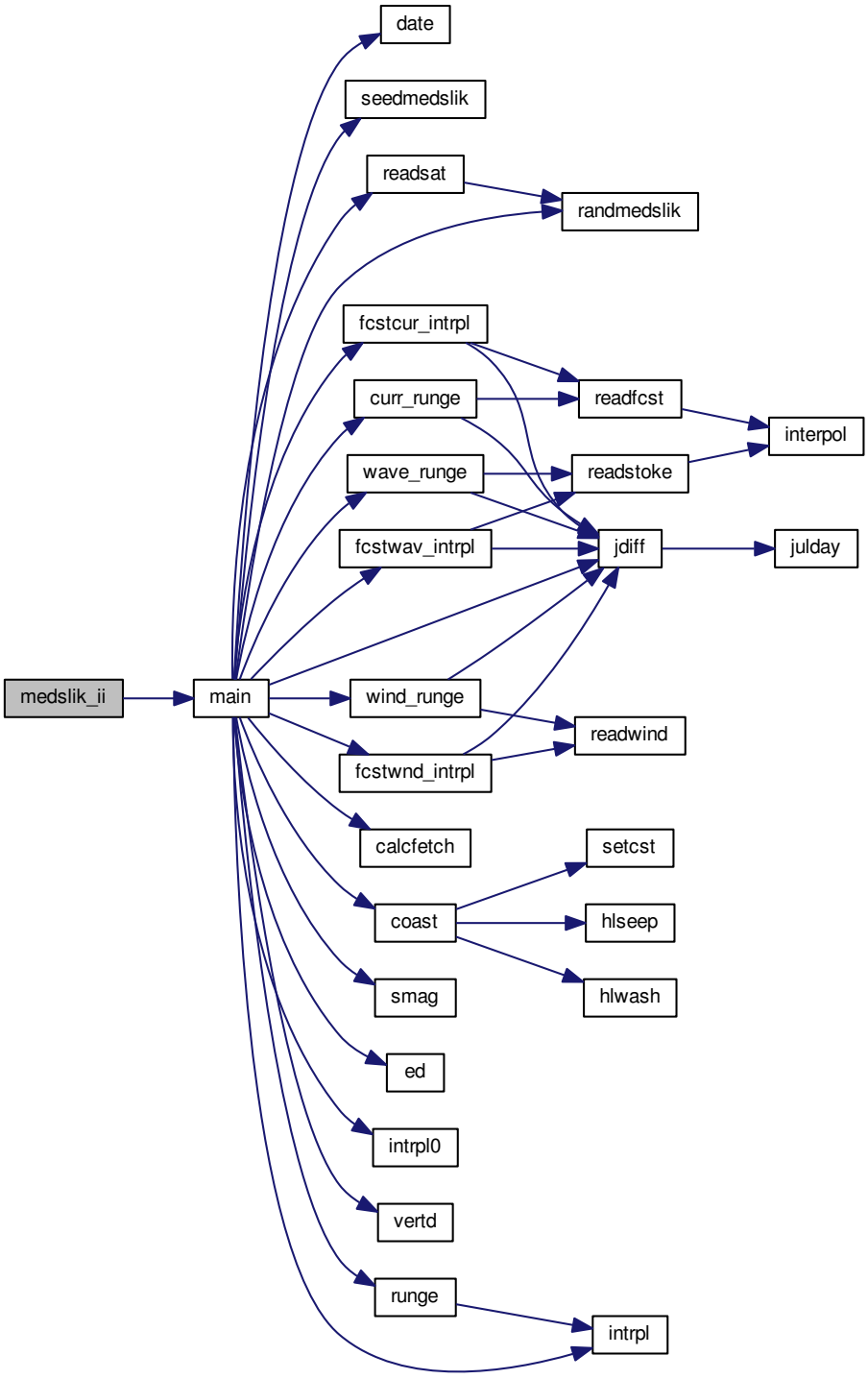


Fig. 4.4: Call graph for the medslikii program.

Chapter 5

Meteo-Oceanographic input forcings

Meteorological and oceanographic data are needed to force the model.

The meteo-oceanographic forecasts-analysis NetCDF data needed for a simulation have to be placed in one of the directories listed below:

- `MEDSLIK_II_1.02/DATA/MET` is for the atmospheric wind forcing data;
- `MEDSLIK_II_1.02/DATA/OCE` is for the oceanographic (i.e, current and sea surface temperature) forcing data;
- `MEDSLIK_II_1.02/DATA/WAV` is for the oceanographic wave-induced current forcing data;

Medslik-II 1.02 code is designed to use the following meteo-oceanographic model output fields.

5.1 Ocean Current and SST data

Copernicus Mediterranean Forecasting System products

These data can be daily or hourly average forecasts and analysis and are produced in NetCDF format for the whole Mediterranean Sea. Copernicus

Mediterranean Forecasting System data and the MFS system are fully described at `http://marine.copernicus.eu/` and `http://medforecast.bo.ingv.it/` respectively.

In order to run a simulation, two files named as follows are needed for each simulated *YYYYMMDD* date :

Daily mean data

- For forecast data

1) `YYYYMMDD_dm-INGV--RFVL-MFSs4e-MED-b${bulletin_date}_fc-fv05.00.nc`
2) `YYYYMMDD_dm-INGV--TEMP-MFSs4e-MED-b${bulletin_date}_fc-fv05.00.nc`

- For analysis data

1) `YYYYMMDD_dm-INGV--RFVL-MFSs4e-MED-b${bulletin_date}_an-fv05.00.nc`
2) `YYYYMMDD_dm-INGV--TEMP-MFSs4e-MED-b${bulletin_date}_an-fv05.00.nc`

Hourly mean data

- For forecast data

1) `YYYYMMDD_hm-INGV--RFVL-MFSs4e-MED-b${bulletin_date}_fc-fv05.00.nc`
2) `YYYYMMDD_hm-INGV--TEMP-MFSs4e-MED-b${bulletin_date}_fc-fv05.00.nc`

- For analysis data

1) `YYYYMMDD_hm-INGV--RFVL-MFSs4e-MED-b${bulletin_date}_an-fv05.00.nc`
2) `YYYYMMDD_hm-INGV--TEMP-MFSs4e-MED-b${bulletin_date}_an-fv05.00.nc`

where `${bulletin_date}` is the data production date (`YYYYMMDD`).

2008 Mediterranean Forecasting System hourly mean products

These data are hourly average forecasts produced in NetCDF format for the whole Mediterranean Sea. They have been created following the time convenction on which the MFS system was based in 2006-2008 and they have been added in the Medslik-II code in order to run the Algeria and Libano test cases with the same data used for the Medslik-II 1.01 test cases.

In order to run a simulation, three files named as follows are needed for

each simulated *yyyymmdd* date :

1) `MEDffEyyyymmdd_01_grid_T.nc`

2) `MEDffEyyyymmdd_01_grid_U.nc`

3) `MEDffEyyyymmdd_01_grid_V.nc`

where T, U and V mean, respectively, Temperature, Zonal ocean current velocity and Meridional ocean current velocity.

5.2 Atmospheric Wind data

European Centre for Medium-Range Weather Forecasts products

The ECMWF wind forecasts and analyses are available for the whole Mediterranean Sea with a horizontal resolution of 0.125 degrees since March 23^{th}. They are snapshots every 6 hours (at hours 00, 06, 12, 18). Between the 11^{th} of January 2009 and the 23^{th} of March 2015 the ECWMF wind forecasts and analyses products were available for the whole Mediterranean Sea with a horizontal resolution equal to 1/4 of degree while before the 11^{th} of January 2009 the ECWMF analysis were produced at a resolution of 0.5 degrees. The temporal resolution of the forecasts and analysis did not change during the different versions developed.

In order to run a simulation, one file named as follows is needed for each simulated *YYYYMMDD* date:

0.5 degrees horizontal resolution (for forecast or analysis data)

- `YYYYMMDD_6hi-INGV-ECMWF-AM050-MED.nc`

0.25 degrees horizontal resolution (for forecast or analysis data)

- `YYYYMMDD_6hi-INGV-ECMWF-AM025-MED.nc`

0.125 degrees horizontal resolution (for forecast or analysis data)

- `YYYYMMDD_6hi-INGV-ECMWF-AM0125-MED.nc`

5.3 Ocean Wave-induced current data

Copernicus Mediterranean Forecasting System hourly instantaneous products

These data are hourly instantaneuos forecasts produced in NetCDF format for the whole Mediterranean Sea. Copernicus Mediterranean Forecasting System data and the MFS system are fully described at `http://marine.copernicus.eu/` and `http://medforecast.bo.ingv.it/` respectively.

In order to run a simulation, one file named as follows is needed for each simulated *YYYYMMDD* date:

- `YYYYMMDD_hi-INGV--WAVE-MFSs4e-MED-b${bulletin_date}_fc-fv03.00.nc`

Chapter 6

Running MEDSLIK-II

This chapter describes the steps needed in order to run both an oil spill-slicks simulation and a particle tracking Lagrangian simulation.

All the files needed to specify the initial conditions and the physical parameters which will be used in a simulation as well all the bash scripts which run the model are located inside the directory `RUN`.

- `medslik_inputfile.txt` is the file where initial conditions have to be specified.
- `medslik5.par` is the file where the parameters to be used in the simulation are set.
- `medslik_II.sh` is the bash script which controls the model run.

6.1 Parameter file

`medslik5.par` is the file where the simulation parameters are set.

It is organized in the following sections: *Physical Parameters*, *Evaporation Parameters*, *Emulsification Parameters*, *Dispersion Parameters*, *Spreading Parameters*, *Coastal Impact Parameters* and *Computational Parameters*.

In the **Physical Parameters** section it is possible to control the physics which governs the model activating or not some physical processes, choosing between some simulation options and setting some coefficients values.

Here, it is possible to activate or not the wave-induced current term, the wind-drift term and the wind-drag term of the advection-diffusion equation 2.10.

The **wave-induced current term**, $\boldsymbol{U}_S$, can be simulated by using the Medslik-II Jonswap parameterization or with wave-induced current velocities from wave model outputs. The choice is made writing `01` or `02`, respectively, in the line corresponding to the `Stokes' Drift`. If `00` is written in the same line the wave-induced current term is not activated. If the Medslik-II Jonswap parameterization is chosen (01), then the 4^{th} order Runge-Kutta scheme can not be chosen.

The **wind-drift term**, $\boldsymbol{U}_W$, is activated by setting the `Drift Factor` and the `Drift Angle at zero wind speed` with values different from `0.00` and `0.0` respectively. The `Drift Factor` and the `Drift Angle at zero wind speed` represent the α and β coefficients of the parameterization formula for the wind-drift term (see [4] and [2] for a detailed description).

The **wind-drag term**, $\boldsymbol{U}_D$, is activated by setting the `Drift Factor` with values different from `0.00` and setting the `Drift Angle at zero wind speed` equal to `0.0`. In this case the `Drift Factor` represents the γ coefficient of the parameterization formula for the wind-drag term (see [2] for a detailed description).

The `Variable Drift Angle` flag allows the model to use a drift angle that decreases as the wind speed increases; if this flag is activated (flag set equal to 01), then a wind speed at which the drift angle is reduced by 50 % must then be entered in the line below. The default is that such a reduction is not made.

The `Reduction of Forecast Wind Speed` flag: when using forecast water circulation in a simulation, the forecast water velocities already include the effect of the wind forces on the water surface. It may be thus be considered appropriate in some cases to reduce the wind speed used in the drift formula by a fraction of the wind used in the forecasts. This can be done writing 01 in `effective wind speed` and entering in the line below the reduction fraction (between 0 and 1). The default is that such a reduction is not made.

`Smagorinsky Scheme`: Choosing 01 allows the horizontal diffusivity to be computed from the water currents using the Smagorinsky scheme. The default value is 0.

The default value for the `Horizontal Diffusivity` is 2.0 $m^2 s^{-1}$. A larger value will cause the slick to spread faster.

The model allows the use of two values of `Vertical Diffusivity`: a larger value in the top well-mixed layer and a smaller value below the mixed layer. The defaults are 0.01 and 0.0001 $m^2 s^{-1}$ respectively.

The ocean current fields are extracted from NetCDF files and are given in the the ASCII formatted files in `RUN/INP_DATA/OCE` directory at fixed `depths`. Whatever depths are used in the text files (they can only be changed by modifying the `Extract_II.F90` code) the same depths must be entered in the parameters file. In MEDSLIK-II version 1.02 the ocean current fields are given at the surface, 10 m, 30 m and 120 m.

`Selection of currents for convection of slick`: it is possible to choose between 4 options: 00 for surface currents, 01 for 10 m deep currents, 02 for 30 m deep currents and 03 for 120 m deep currents.

The default strategy is to use surface velocities for advection of the slick and to ignore the wind drift altogether (by setting the `Drift factor` equal to 0.0).

6.2 Input file

`medslik_inputfile.txt` is the file where the simulation initial conditions have to be declared. It has been changed from the version `1.01` in order to account for multiple spills/slicks, the 4^{th} order Runge-Kutta scheme and the particle tracking Lagrangian mode. Now, it comprehends the following bash variables:

- `SIM_NAME` : the name of the simulation. It will be a part of the output directory name.
- `RESTART` : the hour of the simulation restart file.
- `TRACKMODE` : type of the simulation: 0 = Oil fate and transport, 1 = Lagrangian trajectory.

- `OCEAN` : A string which specifies the ocean current forcing type (see the file `forcing_medslik.txt` for a list of the forcing available in the version 1.02).
- `WIND` : A string which specifies the wind forcing type (see the file `forcing_medslik.txt` for a list of the forcing available in the version 1.02).
- `WAVE` : A string which specifies the wave forcing type (see the file `forcing_medslik.txt` for a list of the forcing available in the version 1.02).
- `SIM_LENGTH` : it is a 4 digits integer which indicates the lenght of the simulation.
- `NUM_SCHEME` : it indicates the numerical scheme chosen: Euler = 0, 4^{th} order Runge-Kutta = 1

- `GRID_SIZE` : it indicates the spatial resolution (in meters) of the oil tracer grid.
- `OUTPUT_NAME` : it a 4 letters string which will be a part of the output files name.
- `STEP_OUTPUT` : it represents the time interval for printing results to output files.
- `NSLICK`: it indicates the total number of spills/slicks which will be simulated.
- `SAT_DATA`: it indicates if the simulation will envolve satellite detected slicks or not. It can be equal to "YES" or "NO". For point source/s it has to be always "NO".
- `NAMEFILE_GML` : if the previous variable is set as "YES", this variable indicates the absolute path where the `Xml` file is located.
- `CONTOURSLICK` : it indicates if the simulation will envolve at sight detected slicks, meaning that the user will manually provide, for each simulated slicks, the coordinates of all the corners which approximate the boundary line which identifies and describes the shape of the slicks. It can be equal to "YES" or "NO". For point source/s it has to be always "NO".
- `OIL` : it is a string which indicates how the oil type will be declared, by "NAME" or "API".

- `OIL_TYPE` : depending on the previous variable, it can be a real number indicating the API of the simulated oil or a string which identifies the name of the oil.
- `AGE` : age of the oil spill from initial arrival in the sea.

The next section of variables consists of a list of the **N** oil slicks/spills ordered from the nearest to the farthest in time to the time start of the simulation. For each N^{th} oil slicks/spills it is needed to specify:

- date of the N^{th} (the bold **n** represents an integer which specify the identity of the slick) slick observation/oil released:
  - day: S**n**DD: it is a 2 digit integer
  - month: S**n**MM: it is a 2 digit integer
  - year: S**n**YY: it is a 2 digit integer
- time of the N^{th} (**n**) slick observation/oil released:
  - hour: S**n**HR: it is a 2 digit integer
  - minutes: S**n**MN: it is a 2 digit integer
- spill duration of the N^{th} (**n**) slick/spill, in hours:
  - spill duration: S**n**durath: it is an integer. If the spill is instantaneous or it is a detected slick type 0.
- spill rate in tons/hours of the N^{th} (**n**) slick/slick: if the spill is instantaneous or it is an observed slick write the total tons spilled
  - spill rate: S**n**spllrt: it is an integer. If the spill is instantaneous or it is a detected slick write the total tons spilled
- Longitude and latitude (in decimal degree) of the N^{th} (**n**) slick/spill: For point sources spill, write the coordinates of the N^{th} point (k=1). For polygon detected slicks, write the coordinates for each K^{th} (**k**) corner of the N^{th} slick.
  - Longitude: S**n**lon[**k**]
  - Latitude: S**n**lat[**k**]

Here, an example for 2 quadrilateral detected slicks is given:

```
S1DD=17
S1MM=05
S1YY=14
```

```
S1HR=05
S1MN=38
S1durath=0
S1spllrt=34
S1lon[1]=10.0069
S1lat[1]=42.9656
S1lon[2]=10.0120
S1lat[2]=42.9656
S1lon[3]=10.0120
S1lat[3]=42.9706
S1lon[4]=10.0069
S1lat[4]=42.9706
S2DD=17
S2MM=05
S2YY=14
S2HR=05
S2MN=38
S2durath=0
S2spllrt=1
S2lon[1]=9.9831
S2lat[1]=42.9567
S2lon[2]=9.9881
S2lat[2]=42.9567
S2lon[3]=9.9881
S2lat[3]=42.9617
S2lon[4]=9.9831
S2lat[4]=42.9617
```

Here, an example for a continuous single point spill source is given:

```
S1DD=01
S1MM=11
S1YY=15
S1HR=15
S1MN=08
S1durath=24
S1spllrt=50
S1lon[1]=12.0669
S1lat[1]=43.9371
```

Medslik-II version 1.02 is designed to simulate **instantaneous** or **continuous single spills**, **instantaneous multiple spills** and **single** or **multiple**

detected slicks.

This means that for **multiple spills** S**n**durath has to be set always equal to 0 and that for **single** or **multiple detected slicks** S**n**DD, S**n**MM, S**n**YY, S**n**HR and S**n**MN have to be the same for each N^{th} slicks.

If the **Particle tracking Lagrangian simulations** flag is activated (`TRACKMODE=1`), then the variables `OIL`, `OIL_TYPE`, `AGE`, S**n**durath and S**n**spllrt can be set with any value you want since they are not used in the computation.

6.3 Running the model

After having properly edited the `medslik_inputfile.txt`, modified the `medslik5.par` files and placed the needed forcing files into the right directories, just type the following command to run the model:

```
cd RUN
./medslik_II.sh
```

While the simulations is running, several files needed by the model code are created in the `RUN` directory and they can be checked to understand what is the model state. Here it is a brief description of each run time created files:

- `medslik_pnts.inp` : if point spill sources are simulated, this file contains a list of the geographical coordinates of the spill sources.
- `medslik_plgs.inp`: if polygonal slicks are simulated, this file contains a list of the geographical coordinates of all the corners which describe the slicks shape.
- `files-oce`: it contains informations about the time resolution of the ocean current model outputs forcing fields.
- `files-met`: it contains informations about the time resolution of the wind model outputs forcing fields.
- `files-wav`: it contains informations about the time resolution of the wave-indeuced current model outputs forcing fields.
- `medslik5.inp`: this is the file which is directly read by the model: it contains all the input informations written in the `medslik_inputfile.txt`.

- `medslik.tmp`: it contains the geographical limits of the area affected by the spill.
- `Extract.log`: it is the log-file for the program `Extract_II.F90`.
- `medslik.log`: it is the log-file for the program `medslik_II.for`.
- `coast.map`: if `TRACKMODE=0`, this file contains the coordinates of all the coastal segments which are in the simulated area.

6.4 Output files

Medslik-II output files are located in `OUTPUT/MEDSLIKII_YYYY_MM_DD_hhmm_${SIM_NAME}`, where YYYY is the year, MM the month, DD the day, hh the hour, mm the minutes and `${SIM_NAME}` the name of the simulation.

The folder always contains:

- the input files `medslik_inputfile.txt`, `medslik5.inp`, `medslik.tmp`, `medslik_pnts.inp` and `medslik_plgs.inp`.
- the parameter file `medslik5.par`.
- the `OCE`, `MET` and `WAV` (if waves are used) directories which contains the ASCII formatted data used to force the model.

If an "**Oil fate and transport**" simulation is performed (`TRACKMODE=0`), then the output folder contains also:

- the `medslik.fte` file, which contains the trend over time of: the oil volume spilled, the percentage of oil evaporated, the percentage of oil on the surface, the percentage of oil dispersed, the percentage of oil on the coast, the oil-water emulsion viscosity, the oil viscosity, the oil density, the fraction of water contained in the oil-water emulsion, etc.
- `${OUTPUT_NAME}hhhh.srf` files: they contain the values of the oil concentration on the surface; hhhh indicates the number of hours after the start of the spill.
- `${OUTPUT_NAME}hhhh.dsp` files: they contain the values of the dispersed oil concentration;
- `${OUTPUT_NAME}hhhh.cst` files: they contain the values of the oil concentration on the coast;

- `${OUTPUT_NAME}.nc` file: it contains data about the Oil Concentration, the Ocean and the Wave-induced currents and the Wind velocities fields. Wind velocities are defined at the gravity centre point of each slick. Ocean forcing fields are defined on their original grids. Oil concentration is defined on the 150m×150m grid.

If a "**Lagrangian trajectory**" simulation is performed (`TRACKMODE=1`), then the output folder contains:

- `${OUTPUT_NAME}.trj`: it contains the position in time (trajectory) of the gravity centre of the particles used in the advection-diffusion simulation.

Chapter 7

Test cases

In order to test the correct operation of the MEDSLIK-II version 1.02 system, the meteo-oceanographic data and input files needed to run 3 test cases are provided. In this chapter, the procedure for each test case to download the data and to set-up the model is described.

At MEDSLIK-II web page (`http://medslikii.bo.ingv.it`), after registration and be logged in it is possible to access the `Version_1.02` homepage (just clicking the corresponding link). Here 5 links exist: the first is to **Download the model**, the second is to **Download the User Manual** and the latter three are to download the test cases data.

7.1 Algeria test case

This test case simulates 3 satellite detected oil slicks off the Algerian coast (August 6-10, 2008) certified by REMPEC. A detailed description of this experiment can be found in [3].

The data needed to run this test case can be downloaded through the `Algeria_test_case` link at the MEDSLIK-II `Version_1.02` homepage.

After the download is finished, it is needed to go to the `${DOWNLOAD_DIRECTORY}` and type the following commands:

```
cd ${DOWNLOAD_DIRECTORY}
tar -xvzf Algeria_test_case.tar.gz
cd Algeria_test_case
cp OCE/* ${INSTALLATION_DIR}/MEDSLIK-II_v1.02/DATA/OCE/
cp MET/* ${INSTALLATION_DIR}/MEDSLIK-II_v1.02/DATA/MET/
gunzip ${INSTALLATION_DIR}/MEDSLIK-II_v1.02/DATA/*/*
```

This procedure will extract the `Algeria_test_case.tar.gz` archive and will copy the meteo-oceanographic data needed for the simulation into the right directories. The last command will extract the gzipped NetCDF data files.

After that, it is needed to copy the set-up files (`medslik_inputfile.txt` and `medslik5.par`) into the `RUN` directory:

```
cp SET-UP/medslik_inputfile.txt ${INSTALLATION_DIR}/MEDSLIK-II_v1.02/RUN/
cp SET-UP/medslik5.par ${INSTALLATION_DIR}/MEDSLIK-II_v1.02/RUN/
```

This will overwrite the `medslik_inputfile.txt` and `medslik5.par` files located in the `RUN` directory. A default template of these two files can be found in the `RUN/template` directory.

To run the model, just type

```
./medslik_II.sh
```

The output directory will be located at `${INSTALLATION_DIR}/MEDSLIK-II_v1.02/OUTPUT`.

Inside the `${DOWNLOAD_DIRECTORY}/Algeria_test_case/OUTPUT/` directory you can find the reference output and plot files which can be compared to the local system outputs to check the correct operation of the model.

The oil initial conditions, physical and numerical parameters and meteo-oceanographic forcings used in this test case simulation are listed in table 7.1.

Table 7.1: Oil initial conditions, physical-numerical parameters and meteo-oceanographic forcings used in Algeria test case

Start date	06-06-2008
Start hour	09:51
Simulation length	36 hours
Ocean Forcing	MFS hourly mean fields
Wind Forcing	ECMWF 1/2 degree resol.
Wave Forcing	NONE
Physical processes	MEDSLIK-II JONSWAP param.
Number of Slicks	3
API	22
TONS of 1^{st} slick	240 tons
TONS of 2^{nd} slick	225 tons
TONS of 3^{rd} slick	215 tons
NUM SCHEME	EULER

Figure 7.1 represent output maps after 25 hours of simulation performed with the Euler Forward scheme.

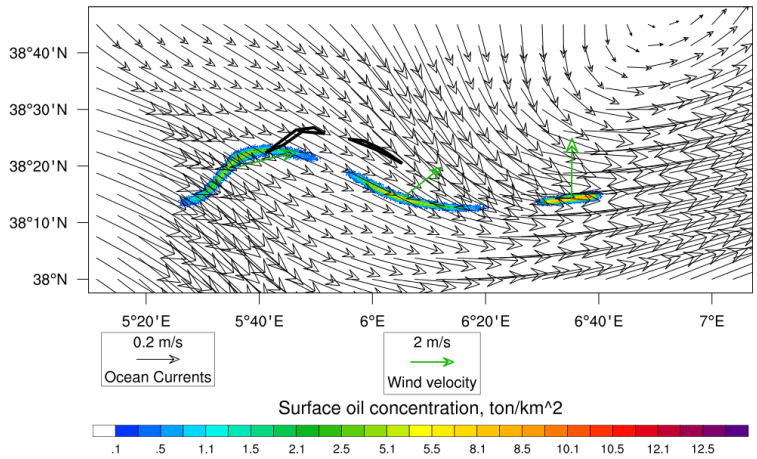


Fig. 7.1: Output maps after 25 hours of simulation performed with the Euler Forward scheme. It represents oil-slick concentration, current fields (black arrows), wind in the gravity centre of each slick (green arrows) and satellite observations (black slicks)

.

7.2 Lebanon test case

This test case simulates the Lebanon coastal spill caused by air raids on coastal power plants on July-August 2006. A detailed description of this experiment can be found in [1].

The data needed to run this test case can be downloaded through the `Lebanon_test_case` link at the MEDSLIK-II `Version_1.02` homepage.

The instructions to run this test case simulation are given in the following list:

```
cd ${DOWNLOAD_DIRECTORY}
tar -xvzf Lebanon_test_case.tar.gz
cd Lebanon_test_case
cp OCE/* ${INSTALLATION_DIR}/MEDSLIK-II_v1.02/DATA/OCE/
cp MET/* ${INSTALLATION_DIR}/MEDSLIK-II_v1.02/DATA/MET/
gunzip ${INSTALLATION_DIR}/MEDSLIK-II_v1.02/DATA/*/*
cp SET-UP/medslik_inputfile_euler.txt ${INSTALLATION_DIR}/MEDSLIK-II_v1.02/RUN/medslik_inputfile.txt
cp SET-UP/medslik5.par ${INSTALLATION_DIR}/MEDSLIK-II_v1.02/RUN/
cd ${INSTALLATION_DIR}/MEDSLIK-II_v1.02/RUN/
./medslik_II.sh
```

This set of command will run a simulation with the Euler Forward numerical scheme activated.

In order to run a simulation with the 4^{th} order Runge-Kutta numerical scheme activated it is needed just to type the following commands:

```
cp SET-UP/medslik_inputfile_runge.txt ${INSTALLATION_DIR}/MEDSLIK-II_v1.02/RUN/medslik_inputfile.txt
cp SET-UP/medslik5.par ${INSTALLATION_DIR}/MEDSLIK-II_v1.02/RUN/
cd ${INSTALLATION_DIR}/MEDSLIK-II_v1.02/RUN/
./medslik_II.sh
```

The output directories will be:

`${INSTALLATION_DIR}/MEDSLIK-II_v1.02/OUTPUT/EULER`
`${INSTALLATION_DIR}/MEDSLIK-II_v1.02/OUTPUT/RUNGE`

Inside the `${DOWNLOAD_DIRECTORY}/Lebanon_test_case/OUTPUT/` directory you can find the reference output and plot files which can be compared to the local system outputs to check the correct operation of the model.

N.B.: Because of the simulated period is very long (660 hours), the computational times of the simulation and the NetCDF creation can be very long: it is due to the fact that the re-gridding algorithm has to process a big amount of grid points, given that the grid on which the oil concentration is calculated is a 150m $\times$ 150m grid.

The oil initial conditions, physical and numerical parameters and meteo-oceanographic forcings used in this test case simulation are listed in table 7.2.

Figures 7.2 and 7.3 represents output maps after 147 and 216 hours of

Table 7.2: Oil initial conditions, physical-numerical parameters and meteo-oceanographic forcings used in Lebanon test case

Start date	13-07-2006
Start hour	08:00
Simulation length	660 hours
Ocean Forcing	MFS hourly mean fields
Wind Forcing	ECMWF 1/2 degree resol.
Wave Forcing	NONE
Physical processes	WIND DRAG = 1.2 %
Number of Spills	1
API	20
Duration of the release	144 hours
Spill rate	130.35 tons/hours
NUM SCHEME	EULER and RUNGE-KUTTA

simulation, respectively, both performed with the Euler Forward and the 4^{th} order Runge-Kutta schemes, respectively (a) and (b) in each figure.

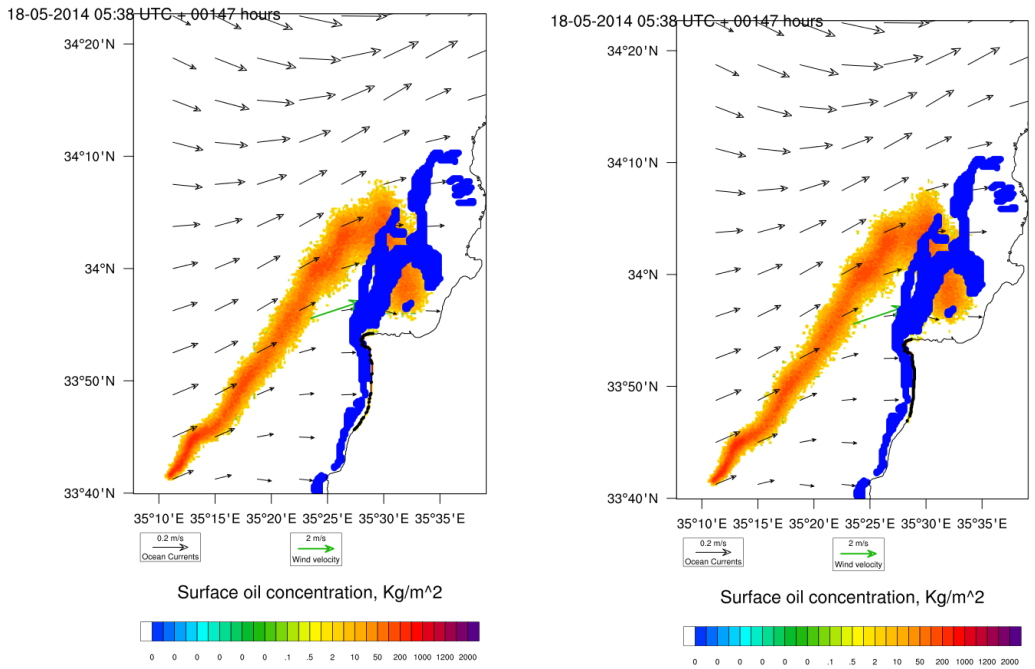


Fig. 7.2: Output maps after 147 hours of simulation performed with the Euler Forward and the 4^{th} order Runge-Kutta numerical schemes (respectively (a) and (b)). They represent sea surface oil-slick concentration, coastal oil impact (bold black coast line), current fields (black arrows), wind in the gravity centre of each slick (green arrows) and satellite detected observations on 19-07-2006 at 10:35 (blue slicks).

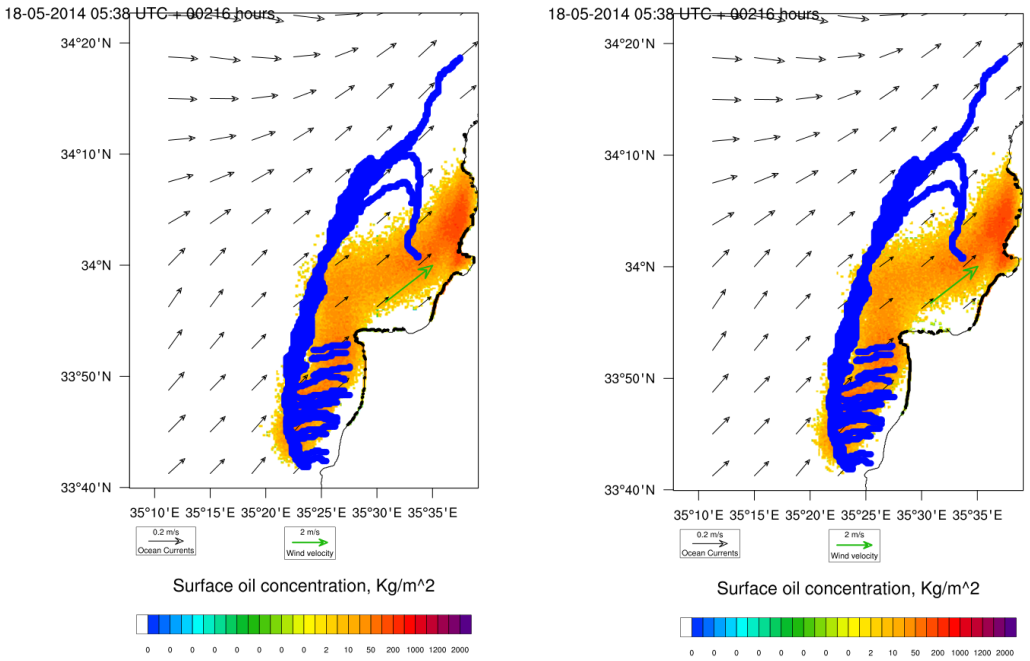


Fig. 7.3: Output maps after 216 hours of simulation performed with the Euler Forward and the 4^{th} order Runge-Kutta numerical schemes (respectively (a) and (b)). They represent sea surface oil-slick concentration, coastal oil impact (bold black coast line), current fields (black arrows), wind in the gravity centre of each slick (green arrows) and satellite detected observations on 22-07-2006 at 07:55 (blue slicks).

7.3 Elba island - Serious Game test case

This test case comprehends 2 experiments: the first simulates 7 satellite detected oil slicks on May 17^{th} 2014 certified by Italian Coast Guard while the second simulates 6 drifters released inside the oil slicks. The data to validate the result have been collected during the MEDEDESS4MS Elba Island Serious Game ((`http://www.medess4ms.eu/`).

The data needed to run this test case can be downloaded through the `Serious_Game_test_case` link at the MEDSLIK-II `Version_1.02` homepage.

Figure 7.4 shows the EMSA satellite detected slicks image provided by the Italian Coast Guard.

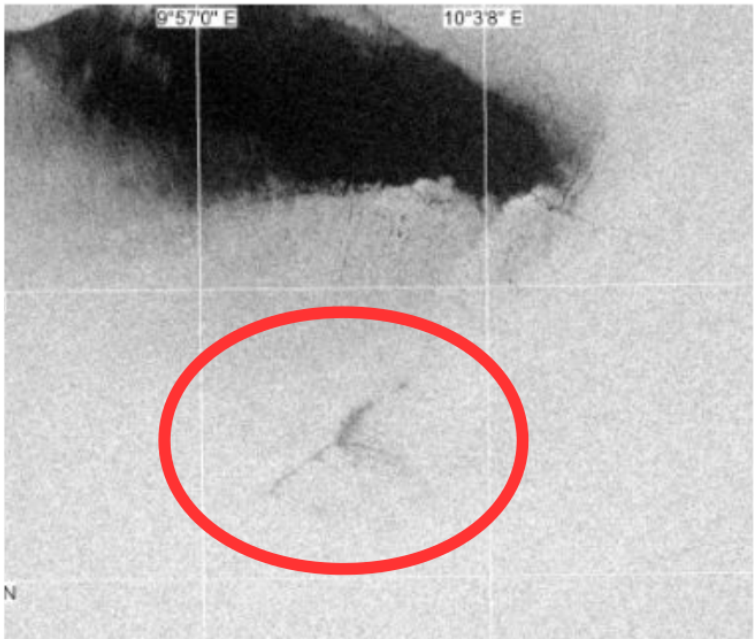


Fig. 7.4: Elba Island MEDESS4MS Serious Game EMSA satellite detected slicks image provided by the Italian Coast Guard

.

OIL SLICKS SIMULATION

The procedure to run this test case simulation is identical to the previous one, except for the name of the simulation and the wave data:

```
cd ${DOWNLOAD_DIRECTORY}
tar -xvzf Serious_Game_test_case.tar.gz
cd Serious_Game_test_case
cp OCE/* ${INSTALLATION_DIR}/MEDSLIK-II_v1.02/DATA/OCE/
cp MET/* ${INSTALLATION_DIR}/MEDSLIK-II_v1.02/DATA/MET/
cp WAV/* ${INSTALLATION_DIR}/MEDSLIK-II_v1.02/DATA/WAV/
gunzip ${INSTALLATION_DIR}/MEDSLIK-II_v1.02/DATA/*/*
cp SET-UP/medslik_inputfile_euler.txt ${INSTALLATION_DIR}/MEDSLIK-II_v1.02/RUN/medslik_inputfile.txt
```

or

```
cp SET-UP/medslik_inputfile_runge.txt ${INSTALLATION_DIR}/MEDSLIK-II_v1.02/RUN/medslik_inputfile.txt
```

and

```
cp SET-UP/medslik5.par ${INSTALLATION_DIR}/MEDSLIK-II_v1.02/RUN/
cd ${INSTALLATION_DIR}/MEDSLIK-II_v1.02/RUN/
./medslik_II.sh
```

The output directories will be:

`${INSTALLATION_DIR}/MEDSLIK-II_v1.02/OUTPUT/EULER`
`${INSTALLATION_DIR}/MEDSLIK-II_v1.02/OUTPUT/RUNGE`

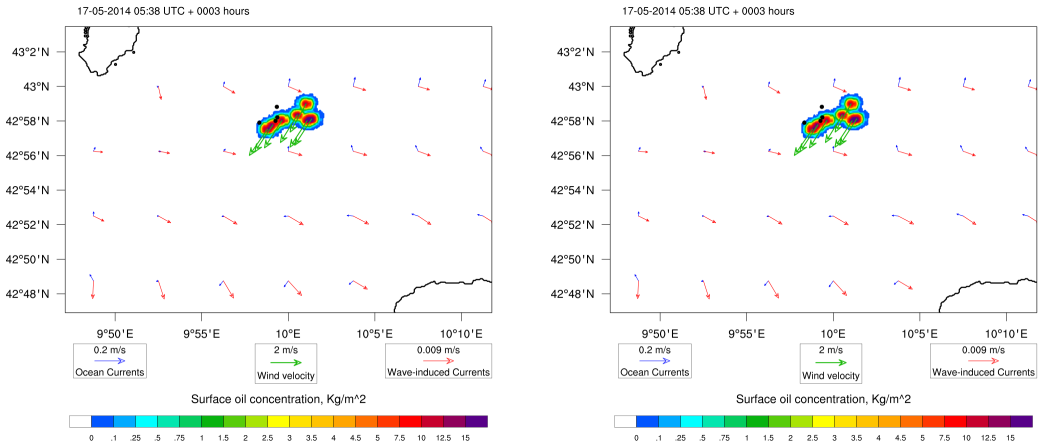
Inside the `${DOWNLOAD_DIRECTORY}/Serious_Game_test_case/OUTPUT/OIL_EXP` directory you can find the reference output and plot files which can be compared to the local system outputs to check the correct operation of the model.

The oil initial conditions, physical and numerical parameters and meteo-oceanographic forcings used in this test case simulation are listed in table 7.3.

Figures 7.5 and 7.6 represents output maps after 3 and 6 hours of simulation, respectively, both performed with the Euler Forward and the 4^{th} order Runge-Kutta schemes, respectively (a) and (b) in each figure.

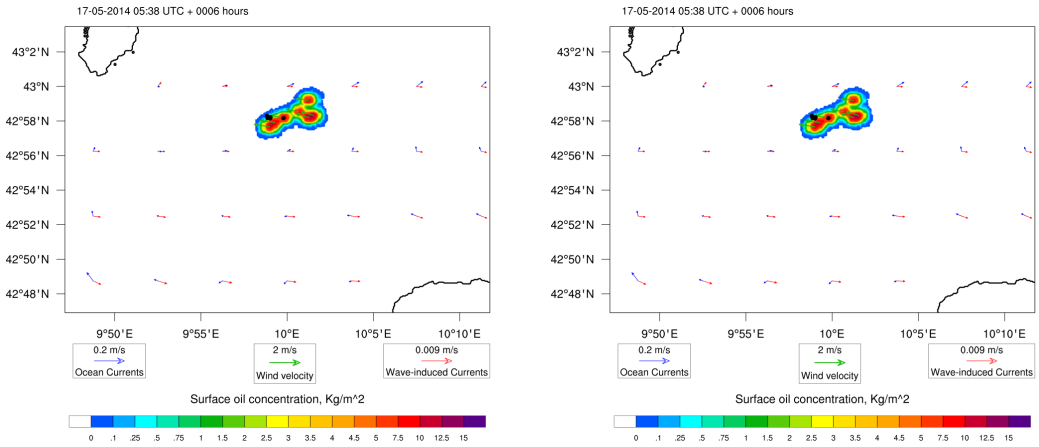
Table 7.3: Oil initial conditions, physical-numerical parameters and meteo-oceanographic forcings used in Serious Game test case

Start date	17-05-2014
Start hour	05:38
Simulation length	24 hours
Ocean Forcing	MFS hourly mean fields
Wind Forcing	ECMWF 1/4 degree resol.
Wave Forcing	MFS-WW3 hourly fields (snapshot)
Physical processes	NONE
Number of Spills	7
API	22
TONS of 1^{st} slick	34 tons
TONS of 2^{nd} slick	1 tons
TONS of 3^{rd} slick	6 tons
TONS of 4^{th} slick	8 tons
TONS of 5^{th} slick	3 tons
TONS of 6^{th} slick	6 tons
TONS of 7^{th} slick	5 tons
NUM SCHEME	EULER and RUNGE-KUTTA



(a) (b)

Fig. 7.5: Output maps after 3 hours of simulation performed with the Euler Forward and the 4^{th} order Runge-Kutta numerical schemes (respectively (a) and (b)). They represent sea surface oil-slick concentration, current fields (black arrows), wind in the gravity centre of each slick (green arrows), wave-induced current fields (red arrows) and the locations where oil slick samples were taken on 17-05-2014 at 08:00 (black dots).



(a) (b)

Fig. 7.6: Output maps after 6 hours of simulation performed with the Euler Forward and the 4^{th} order Runge-Kutta numerical schemes (respectively (a) and (b)). They represent sea surface oil-slick concentration, current fields (black arrows), wind in the gravity centre of each slick (green arrows), wave-induced current fields (red arrows) and the locations where 6 drifters were released inside the oil slick on 17/05/2014 at 11:15 (black dots).

DRIFTER SIMULATIONS

In order to run this test case it is needed to follow the instructions listed below:

```
cd ${DOWNLOAD_DIRECTORY}
tar -xvzf Serious_Game_test_case.tar.gz
cd Serious_Game_test_case
cp OCE/* ${INSTALLATION_DIR}/MEDSLIK-II_v1.02/DATA/OCE/
cp MET/* ${INSTALLATION_DIR}/MEDSLIK-II_v1.02/DATA/MET/
cp WAV/* ${INSTALLATION_DIR}/MEDSLIK-II_v1.02/DATA/WAV/
gunzip ${INSTALLATION_DIR}/MEDSLIK-II_v1.02/DATA/*/*
cp SET-UP/medslik5_0.par ${INSTALLATION_DIR}/MEDSLIK-II_v1.02/RUN/
cp SET-UP/medslik5_1.par ${INSTALLATION_DIR}/MEDSLIK-II_v1.02/RUN/
cp SET-UP/medslik5_2.par ${INSTALLATION_DIR}/MEDSLIK-II_v1.02/RUN/
cp -r drifters_observations ${INSTALLATION_DIR}/MEDSLIK-II_v1.02/RUN/
cd ${INSTALLATION_DIR}/MEDSLIK-II_v1.02/RUN/
```

The `medslik5_0.par` is the parameter file to run a simulation without activating the wave-induced currents physical process.

The `medslik5_1.par` is the parameter file to run a simulation with the MEDSLIK-II JONSWAP parameterization for the wave-induced currents physical process activated.

The `medslik5_2.par` is the parameter file to run a simulation with the wave-induced current fields provided by wave model output files.

The `SG_drifter_test_case` can be started just executing the following command:

```
./RUN_drifter_TESTCASE.sh
```

This script will excute 6 drifter simulations using both the Euler Forward and the 4^{th} order Runge-Kutta numerical schemes: simulations with the Euler Forward scheme activated are controlled by the script `euler_RUN_drifter_TESTCASE.sh` while simulations with the 4^{th} order Runge-Kutta scheme are launched by the `runge_RUN_drifter_TESTCASE.sh`

The output directories will be:

```
${INSTALLATION_DIR}/MEDSLIK-II_v1.02/OUTPUT/EULER_SG_drifter_test_case
${INSTALLATION_DIR}/MEDSLIK-II_v1.02/OUTPUT/RUNGE_SG_drifter_test_case
```

Inside the `${DOWNLOAD_DIRECTORY}/Serious_Game_test_case/OUTPUT/DRIFTER_EXP` directory you can find the reference output and plot files which can be compared to the local system outputs to check the correct operation of the model.

Figure 7.7 shows the results for simulations with the Euler Forward scheme activated. In figure (a) the 48 hours simulated trajectories are compared to the BEACON real one. Sub-figure (b) shows the results for a 48 hours simulation compared to the Italian Coast Guard SLDMB (Self-Located Datum Marker Buoy) real trajectory. In figure (c) and (d) the 24 hours simulated trajectories are compared to 2 CODE and 2 I-SPHERE real trajectories, respectively.

Figures 7.8 shows the results for the same kind of experiments except for the fact that simulations are performed with the 4^{th} order Runge-Kutta scheme activated instead of the Euler one.

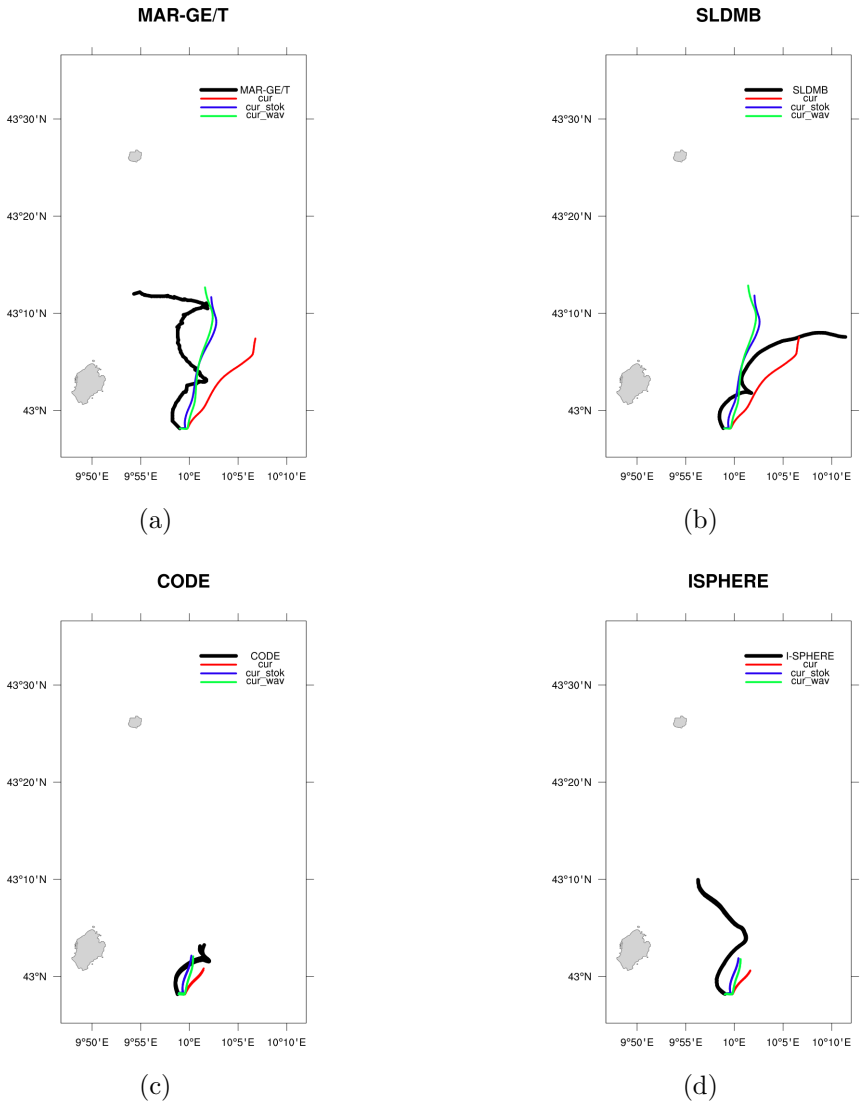


Fig. 7.7: Results for simulations with the Euler Forward scheme activated. In (a) the 48 hours simulated trajectories are compared to the BEACON real one. In (b) the results for 48 hours simulations are compared to the Italian Coast Guard SLDMB (Self-Located Datum Marker Buoy) real trajectory. In figure (c) and (d) the 24 hours simulated trajectories are compared to 2 CODE and 2 I-SPHERE real trajectories, respectively.

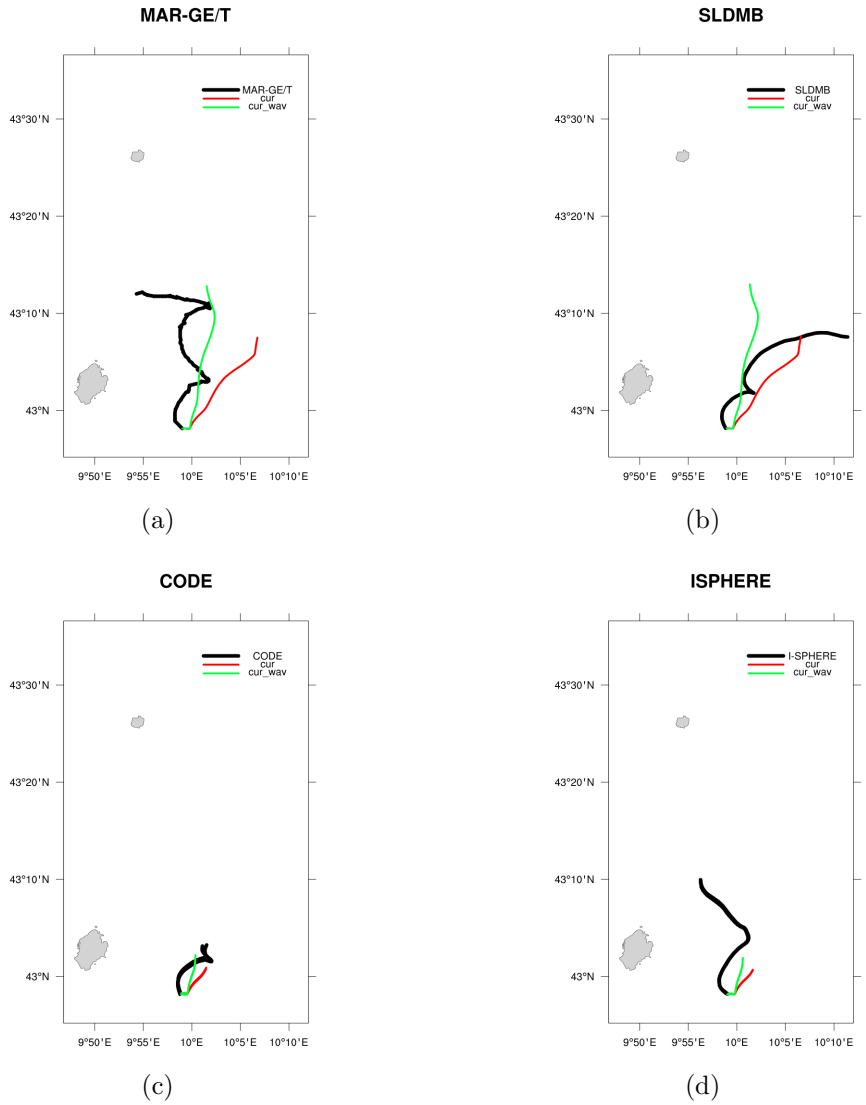


Fig. 7.8: Results for simulations with the 4^{th} order Runge-Kutta scheme activated. In (a) the 48 hours simulated trajectories are compared to the BEACON real one. In (b) the results for 48 hours simulations are compared to the Italian Coast Guard SLDMB (Self-Located Datum Marker Buoy) real trajectory. In figure (c) and (d) the 24 hours simulated trajectories are compared to 2 CODE and 2 I-SPHERE real trajectories, respectively.

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[2] M. De Dominicis, S. Falchetti, F. Trotta, N. Pinardi, L. Giacomelli, E. Napolitano, L. Fazioli, R. Sorgente, P. Haley, P. Lermusiaux, F. Martins, and M. Cocco. A relocatable ocean model in support of environmental emergencies - the costa concordia emergency case. *Geosciences Model Development*, in press.

[3] M. De Dominicis, N. Pinardi, G. Zodiatis, and R. Archetti. Medslik-ii, a lagrangian marine surface oil spill model for short-term forecasting - part 2: Numerical simulations and validations. *Geosciences Model Development*, 6:1871–1888, 2013.

[4] M. De Dominicis, N. Pinardi, G. Zodiatis, and R. Lardner. Medslik-ii, a lagrangian marine surface oil spill model for short-term forecasting - part 1: Theory. *Geosciences Model Development*, 6:1851–1869, 2013.

[5] United States Environmental Protection Agency (EPA) Office of Emergency and Remedial Response (OSWE). *Understanding Oil Spills And Oil Spill Response*. United States Environmental Protection Agency (EPA), December 1999.

Appendix A

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