WP4

Forecast numerical modeling for coastal extreme weather and flooding risk management

Activity 4.4

Set up of high resolution coastal dispersion model close to river outlet

D4.4.1 Evolution maps and quantitative indicators of large-scale transport and dispersion of tracer concentrations in open sea originating from environmental sensitive areas using FLOWAdria

PROJECT AND ACTIVITY DETAILS

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Activity	4.4
Activity Title	Set up of high resolution coastal dispersion model close to river outlet
Work Package	WP4: Forecast numerical modeling for coastal extreme weather and flooding risk management
Executive Summary	D4.4.1 consists of an introduction to Lagrangian modelling and fluid particle trajectory simulation and a

	description of some basic indicators of tracer transport and diffusion in open sea at basin scale.
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0. Introduction

Numerical simulation of passive tracer dynamics in the ocean is of great interest for a large number of important applications. For instance, one can exploit Lagrangian studies for implementing, or improving, evolution models of physical observables such as temperature and salinity, or chemical properties, pollutants, floating debris, particulate and sediments as well as biological tracers such as phytoplankton, zoo-plankton, eggs, and larvae of fishes (Lacorata et al., 2014).

In Lagrangian simulations of tracer dispersion in ocean or atmosphere, one usually deals with a given velocity field, at a given space-temporal resolution, from which passive tracer trajectories (i.e. non-inertial fluid particles) can be computed by suitable numerical integration codes.

If we define $\mathbf{U}(\mathbf{x},t)$, function of space and time coordinates, as the velocity field, then the motion of a fluid particle, with initial position $\mathbf{x}(0)$, is given by $d\mathbf{x}/dt = \mathbf{U}(\mathbf{x},t)$.

Information on ocean currents $\mathbf{U}(\mathbf{x},t)$ are usually provided by numerical model outputs, for which one must assume, of course, that the reconstructed velocity fields are not perfectly realistic, but contain errors.

Even in case of ‘‘ideal model”, small errors on the initial conditions typically tend to grow exponentially fast in time, because of nonlinearity always present in all physical systems. Therefore, one should expect no more than a good statistical agreement between simulation and observation, since the evolution of a single trajectory depends, significantly, both on initial conditions and model errors. This implies that indicators of “good” Lagrangian model skills consist, for example, of average quantities, or statistical moments, like the net displacement of a tracer concentration, or the variance of the particle distribution, etc.

A given velocity field $\mathbf{U}(\mathbf{x},t)$ provided, for example, by general circulation models, is necessarily computed on a 2D / 3D grid and is therefore affected from finite resolution issues (e.g., typical resolution scales for an Adriatic Sea model are 1-10 km in space and one day in time). Unresolved motions on sub-grid scales are smoothed out and do not contribute to the Lagrangian dynamics, although in many cases these terms play a valuable role and should not be neglected. There exist various techniques to replace the missing modes of the velocity spectrum, from classic stochastic models of diffusion (e.g. Langevin equations) to modern kinematic modelling that exploit Lagrangian chaos as primary mechanism of trajectory separation. The latter approach, based on an original and well-established Kinematic Lagrangian Model (KLM) (Lacorata et al., 2014; Lacorata and Vulpiani, 2017), was adopted here for all case studies under examination.

1. Lagrangian Dispersion in Adriatic Sea

For Lagrangian numerical simulations of surface tracer trajectories in Adriatic Sea we considered velocity field datasets provided by Mediterranean Forecasting System (MFS) model (Simoncelli, 2014).

The Mediterranean Forecasting System (physical reanalysis component) consists of a hydrodynamic model, supplied by the Nucleus for European Modelling of the Ocean (NEMO), with a variational data assimilation scheme (OceanVAR) for temperature and salinity vertical profiles and satellite Sea Level Anomaly along track data. The horizontal grid resolution is 1/16˚ (roughly 6-7 km at Mediterranean latitudes) and the number of unevenly spaced vertical levels is 72.

For the case study here discussed, a number of 25600 numerical particle pairs were released, with starting positions distributed near the Pescara river outlet (Figure 1.1).

Figure 1.1. Initial positions of numerical particles in the Adriatic Sea, near the Pescara River outlet.

Since we are interested in surface tracer dispersion, numerical particles depth was set at -3 m, between the first two vertical levels of the MFS model. At this depth, on one hand, marine currents are representative of the sea surface dynamics and, on the other hand, Lagrangian tracers are not responsive to the wind. For all simulations, the initial separation between particles was set to 100 m.

The scope of these tests is to highlight the major characteristics of tracer dispersion at the sea surface, in so-called normal climatological conditions. The response of the system to extreme weather/hydrological forcings will be matter of future studies.

2. Results

Dispersion maps of particles initially released near the Pescara River outlet are shown and discussed. Numerical simulations refer to July 1st 2014 and April 1st 2015, respectively, as starting day. Large scale current fields from MFS are mainly responsible of particle advection, i.e. the net displacement from the initial position after a given time interval, while the sub-grid Lagrangian model KLM simulates the relative dispersion between particles at small and meso-scales, compatibly with what is observed from real drifter motion. Indeed, KLM parameter set-up is determined from the analysis of a large dataset of drifting buoys in the Mediterranean Sea (Lacorata et al., 2014). Probability Distribution Functions (PDF) here reported must be considered as primary quantitative indicators of particle dispersion vs time. A more detailed analysis of the dispersion process is outside the scope of the present document and is left to future activities.

Figure 2.1a

2.1 Spatial distribution of Lagrangian tracers

The Adriatic basin was partitioned in 0.1 x 0.1 degree wide cells in order to define a discrete particle number distribution function. Hence, the probability of finding a particle in the ith cell at time t is $p_i(t) = N_i(t)/N$, where $N_i(t)$ is the number of particles in the i^{th} cell at time t and N is the total number of released particles.

Figure 2.1 (a,b) shows probability maps computed after, respectively, 10, 25, 40 and 60 days since the release, for two different years: 2014 and 2015. Despite some differences in the shape of the distributions, due to natural dynamic fluctuations from year to year, the fraction of basin filled by the tracer, after a given time interval, is similar for the two cases. In absence of anomalous weather or hydrological forcing, this is to be considered as the average phenomenological behaviour of the dispersion of tracer initially released near the Pescara River outlet area, in so-called normal climatological conditions.

Figure 2.2 displays maps of coastal points affected by the arrival of tracer particles after a given time interval from the release. Since the release site for the initial particle concentration was set near the Pescara River outlet, these simulations give valuable indications, for example, about the impact of accidental release of potentially dangerous substances in the vicinity of environmental sensitive areas like, e.g., a river outlet. Even in this case, except for natural inter-annual variability, the fraction of coastlines reached by the spreading tracer after a given time interval is substantially the same from year to year, in normal weather/hydrological conditions.

Figure 2.3 refers to histograms of the arrival time at a given distance from the initial position, computed on all the particles of the numerical simulation. It is interesting to observe the existence of a relation, at least in terms of order of magnitude, between the peaks of the probability distributions and the corresponding arrival times. The presence of primary and secondary peaks in the histograms indicate that the arrival time distribution at a given distance (25, 50 or 100 km) from the initial positions, or in other terms, the whole particle dispersion process is characterized by a “direct path” due to advection of the large-scale marine currents, and an “indirect path” due to small-scale turbulent diffusion.

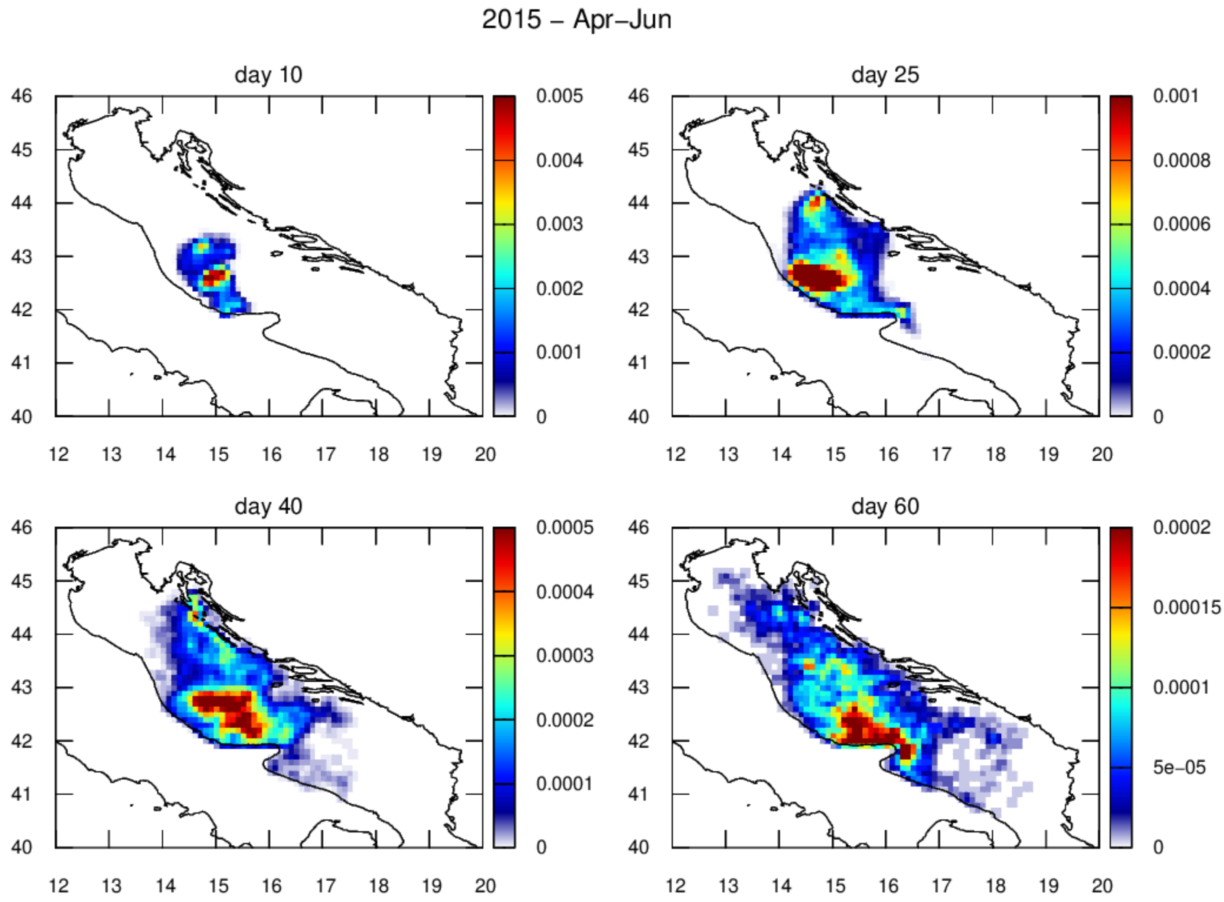

Figure 2.1b

Figure 2.1 Dispersion maps for years 2014 (a) and 2015 (b). Color bar represents the probability to find a tracer particle inside a 0.1° x 0.1° cell at a given time after the release. Notice that, except for normal inter-annual fluctuations, the fraction of the sea surface filled by the tracer distribution is similar, for same time intervals. Possible removal of particles due to "beaching-effect" along the coast is also considered.

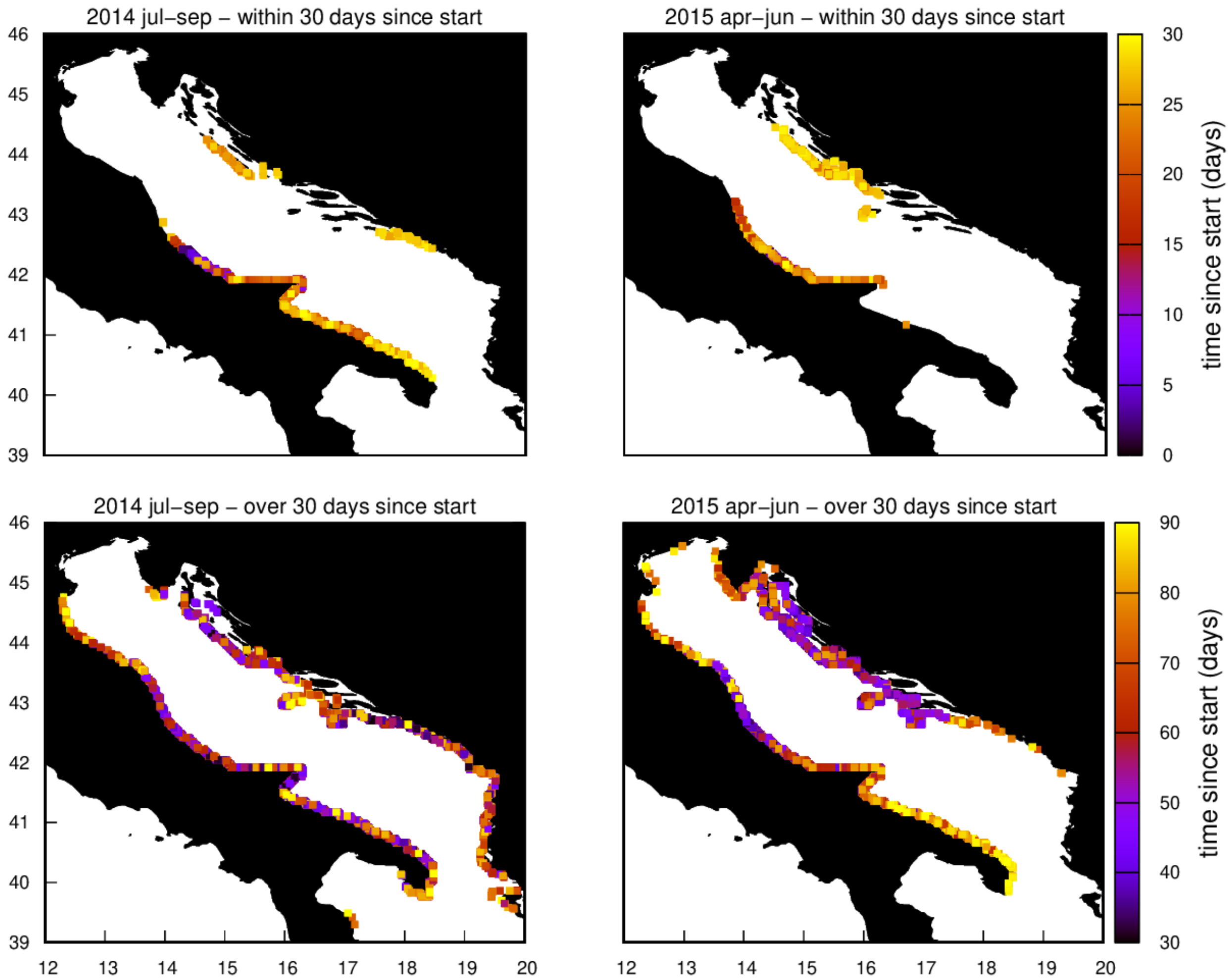

Figure 2.2. Spatial patterns of "beaching" particles along the coasts for 2014 and 2015 simulations. Despite some differences due to normal inter-annual variability the fraction of coastlines reached by the tracer is similar from year to year at a given time interval. It is worth noting the relation color-position in order to figure out the impact of the tracer diffusion along the coasts at different times. For all simulations, tracer particles were initially released near the Pescara River outlet.

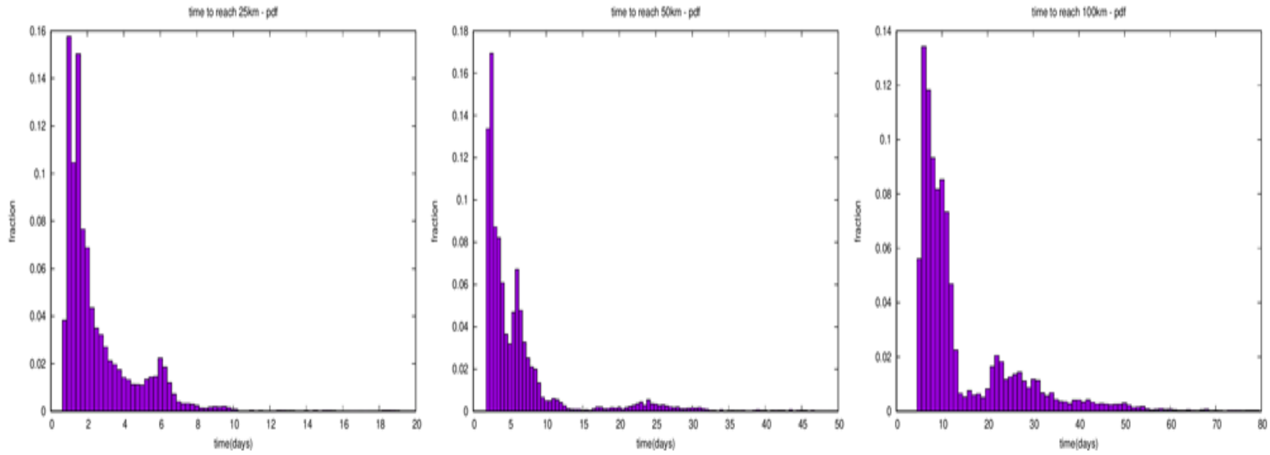

Figure 2.3 Dispersion time probability distribution: histograms of particle fraction displaced at a given distance from the initial position, respectively, at 25 km (left panel), 50 km (central panel) and 100 km (right panel), averaged on the two considered years (2014 and 2015). It is worth noting the relation between the peaks (primary and secondary) of the distributions and the corresponding arrival times to have an idea of the speed of the dispersion process.

3. REFERENCES

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