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Full Field Measurements in a River Mouth by Means of Particle Tracking Velocimetry

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1. Introduction

The measurement of marine streams is a difficult task even for well tested velocimetry methods based on advanced image analysis. The wide size of the measurement domain (from hundreds to thousands meters), the extended range of flow velocities (from mm/s to several m/s), the long time-scales (from minutes to weeks) and the related length and time scales of vortical structures involved in marine dynamics do not allow a straightforward application of Particle Image Velocimetry (PIV) and related methods. Due to the previous requirements, a natural choice is to consider Lagrangian "tracers" to be introduced in the fluid as candidates to sample the flow field in time. Therefore, the most useful measurement technique which enables to derive global velocity data from Lagrangian "tracers" is Particle Tracking Velocimetry, PTV (Tropea & Foss, 2007). As will be outlined in section 3, a large variety of Lagrangian buoys have been designed in the past to probe large-scale marine motion (larger than 50 km), whereas a lot of work is still necessary regarding the measurements at smaller scales. This aspect must be also considered within the debate on the effective role of mesoscales (around 10 km) and small-scales (100 m) in generating the "local" geophysical turbulence field (submesoscales) in the sea and how this dynamics is also dependent on the large-scales (Kanarska *et al*. 2007, Özgökmen 2011). Therefore, on-site measurements of flow at submesoscale level by using effective Lagrangian buoys are needed (Griffa *et al*. 2007, Haza *et al*. 2010, Wang 2010).

Moreover, there are also many specific questions to be solved at small-scale levels regarding for example the diffusion of pollutants into the sea. The general question to be solved is usually related to the spreading of a polluted river water into the marine water and how such spreading can be improved, from the point of view of water quality along the shoreline. The problem is complex, due to the interactions of the river flow with the sea stream and with marine structures. The major phenomena are the interactions between the flow from the river and the harbor structures. Thus, a classical river mouth configuration can be considered as the combination of two flow fields frequently encountered in fluid mechanics, known as the "jet in a cross-flow" and the "impact jet on a wall".

The relevance of the present work is that real field measurements are performed by using almost completely submerged floating buoys which have been designed for the following specific purpose: to measure the velocity of the water stream close to the free-surface by minimizing the sensitivity to wind contributions. Here, the interest is focused on barotropic features, *i.e.* stratification effects are not considered, even if the design of the floating buoys was conceived to consider submerged streams also. The buoys are designed, built and set-up to test the Pescara river mouth spreading into the Adriatic Sea. The river outlet and harbor have been recently modified and faced by a large breakwater which gave rise to several significant environmental effects, as for example concentrating fresh water along the near shore and changing the sea water quality along the shoreline. The aim of the present analysis is to test, by field experiments, the effective velocity field at the channel-harbor outlet to investigate some possible lay-out improvements of the situation.

2. Experimental studies on coastal dynamics

The study of the coastal dynamics is very complex and has been faced during the last decade to understand a number of phenomena of different nature (Shibayama, 2009). The focus, regarding the action of the sea on the coastline, is directed not only to the study of waves and sea currents, but also to aspects related to chemical and biological parameters, especially in recent years in which the human activity has led to effects both in the open sea and near the coastline. Some examples of these effects are coastal erosion, dispersion of pollutants, effects on marine biodiversity (Mc Nealy *et al*. 1995) and influence of marine works on the sedimentation (Wang *et al*. 2011).

In this framework, it is really important to understand the fluid dynamics of the coastal flows, firstly to evaluate in advance what would be the effects of human activity on this area, but also to derive solutions to existing problems. An example is that of harbors where it is necessary to modify and adapt the marine structures to solve problems of sedimentation and pollution of the surrounding area (Shibayama, 2011).

This type of study is performed in recent years by two complementary approaches: numerical models, *i.e.* by simulating with computer dedicated algorithms the coastal area (Apsley & Hu 2003, Hillman *et al*. 2007), or field experiments with sensors detecting kinematic, chemical and physical parameters directly in the sea to correlate the results with scale models of the area (Lacorata *et al*. 2001, Lalli *et al*. 2010).

Numerical simulations bring significant advantages in terms of costs and allow to reproduce different environmental conditions, such as the analysis of critical conditions. However, there is still a lot of work to be done to connect among them the different scales in the ocean dynamics and to correctly modeling the fully three-dimensional phenomena involved (Özgökmen 2011, Balas & Ozhan 2000, Lalli *et al.* 2001). The combination of numerical simulations with laboratory experiments is a very interesting and promising opportunity (Lalli *et al.* 2001, Miozzi *et al*. 2010). Nevertheless, the experimental approach on the field has the strong advantage to directly measure the values of interest. Considering the costs of the tests and the fact that the devices are sometimes very complex in terms of setup and data handling, in most cases the use of a work team made up of many people is required (as in the present activity).

Regarding such experiments, different techniques have been used by many years to measure the speed of marine streams and to detect physical and biological parameters. All

of these are based on the two fluid dynamics frameworks, *i.e.* Eulerian or Lagrangian (Munson, 1994). In the Lagrangian methods, the variables are described in time following the trajectories of fluid elements, thus the observer is moving with the fluid particle motion. In the Eulerian approach, a control volume in a fixed reference system is defined within the fluid and its properties are measured as functions of space and time.

In the present study the Lagrangian framework was preferred because it is straightforward to assess for local fluid elements behavior. Otherwise, it would be necessary to install a large number of devices fixed in space, to be checked continuously in time.

3. A survey of Lagrangian buoys

In recent years, different types of Lagrangian buoys have been designed and manufactured with the aim of studying marine flows both in the open ocean and near to the coastline (Selsor, 1993). These devices were differentiated over the years depending on the purpose for which they were designed: some buoys were able to follow deep currents, whereas other types have been designed to follow the surface current. One of the most important parameter is the scale of the observed phenomenon, ocean large-scale, mesoscale, submesoscale and small-scale where sea bed effects must be also taken into account (Lalli *et al*. 2001). The design of a buoy must also take into account the residence time in water which can reach in some cases even more than a year for studies at oceanic scale (in general less in the Mediterranean sea and near the coastline). The Lagrangian buoys also differ depending on the type of on board sensor defining the range of use. Some are used to measure only the temperature, some only for the velocity field, while the most complex have onboard chemical and biological parameter sensors such as salinity, dissolved oxygen, pH *etc*. Series of Lagrangian buoys have been developed in different national and international research programs such as SVP (Surface Velocity Program) in the United States, for the investigation of ocean streams, or those within the European community concerning the observation of the Mediterranean sea. Hereafter, examples of developed Lagrangian buoy are reported.

SVP and "mini" SVP (Lumpkin & Pazos, 2006)

At present, there are two basic sizes of SVP drifters: the original, relatively heavy SVP drifter and the new "mini" version (Figure 1). The less expensive, easier-to-deploy mini design was proposed in 2002 and is currently produced alongside original SVP drifters by several manufacturers. The surface float ranges from 30.5 cm to 40 cm in diameter. It contains: batteries in 4-5 packs, each with 7-9 alkaline D-cell batteries; a transmitter; a thermistor to measure sea surface temperature; and possibly other instruments measuring barometric pressure, wind speed and direction, salinity, and/or ocean color. They also have a submergence sensor or a tether strain sensor to verify the presence of the drogue. The drogue is centered at 15 meters beneath the surface to measure mixed layer currents in the upper ocean. The outer surface of the drogue is made of nylon cloth. In the original design, it has seven sections, each 92 cm long and 92 cm in diameter, for a total length of 6.44 m. Mini drogues are not yet standardized among the manufacturers: they are 4 (Pacific Gyre) or 5 (Marlin-Yug) sections of original dimensions, or 4 (Clearwater) or 5 (Technocean) redesigned sections of diameter 61 cm, length 1.22 m per section. Throughout the drogue, rigid rings with spokes support the drogue's cylindrical shape. The drogue is a "holey-sock" and each drogue section contains two opposing holes, which are rotated 90 degrees from

one section to the next. These holes act like the dimples of a golf ball by disrupting the formation of organized lee vortices. While the size of the surface float and drogue vary, the manufacturers all aim for a specific non-dimensional goal: a drag area ratio of 40. This ratio is the drag area (drag coefficient times cross-sectional area) of the drogue, divided by the drag area of all other components. At a drag area ratio of 40, the resulting downwind slip (defined later) is 0.7 cm/s in 10 m/s winds (Niiler and Paduan, 1995). Once deployed, a modern SVP drifter lives an average of around 400 days before ceasing transmission. Occasionally, drifters are picked up by fishermen or lose their drogue and run aground.

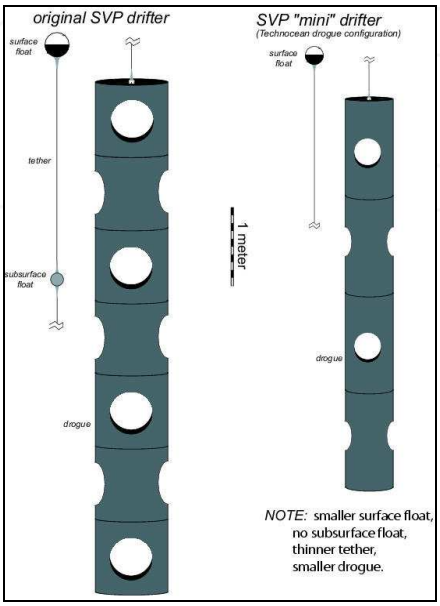

Fig. 1. SVP and Mini SVP Drifter Buoy.

Fig. 2. CMOD Buoy.

CMOD (Gerin et al. 2007)

The Compact Meteorological and Oceanographic Drifter (CMOD) (Figure 2) consists of a 60-cm-long aluminum cylindrical hull with a floatation collar (35-cm overall diameter). This is equipped with the sonobuoy case (62-cm-long and 12-cm-diameter) on a 100-m-long (4-m for a few of them) 0.5-in-diameter tether, resulting in a wet to dry area ratio of about 5 to 1. Air temperature is measured with a thermistor located in a radiation shield which houses the inlet for the barometer port and the Argos transmitting antenna and ground plane. This housing is on top of the mast about 50.8 cm above the surface. The sea surface temperature is measured at a subsurface depth of 44.5 cm.

MELBA (Dell'Erba, 2002)

The Lagrangian drifter used in the MELBA project is dedicated to the study in the Mediterranean Sea, in particular near the coastline (Figure 3). The body of the drifter consists of an aluminum tube, capable of withstanding up to 2000 meters deep, and containing the engine of the ascent and descent (single movement allowed to the buoy), the satellite communications system (active surface) and the mission control system. The accessory instrumentation sensors varies depending on the type of mission to perform: it may include measures of conductivity, salinity, temperature, chlorophyll, etc. The communication system, used to send the measurement data and to receive new subsequent missions is supported by two-way satellite constellation Orbcom. A GPS (Global Position System) is integrated for the geo-referencing of the measured data, once the drifter has emerged.

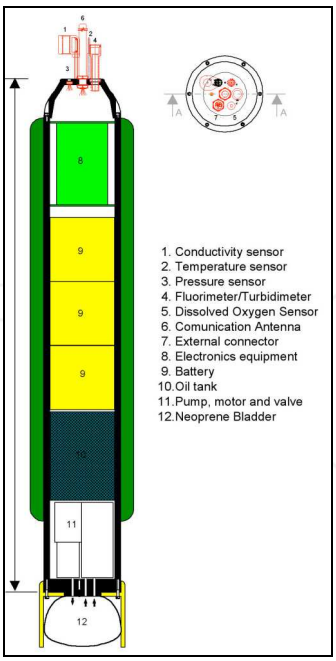

Fig. 3. MELBA Buoy.

"Code" Davis Drifter (Davis, 1985)

The "Code" Davis Drifter (conceived by Dr. Russ Davis of Scripps Institute of Oceanography) or "ARGODRIFTER" is a surface current monitoring Lagrangian drifter (Figure 4). It reports its position by several means, from a calculated position through the ARGOS/CLS system, or by transmitting a GPS location through either ARGOS/CLS or the IRIDIUM satellite system. The surrounding water temperature can also be monitored. Data transmissions can be varied through a wide spectrum of options at the selection of the user. The ARGODRIFTER consists of two orthogonal 1 meter cloth planes oriented vertically around a central instrument containing core. Four 10cm. diameter polyethylene foam floats provide positive buoyancy and are tethered at the end of the arms on Dacron lines 25cms long. These floats insure that the antennas, sometimes two are used when GPS is required, are sufficiently clear of seawater to insure adequate electronic transmissions. The antennas are mounted on 316 stainless steel springs to protect them in case of contact with foreign bodies, or they can "flex" in very high seas.

Fig. 4. "CODE" Davis Drifter.

In the present study, a Lagrangian buoy has been designed and tested by taking inspiration from the drifter "Code" Davis, since it was evaluated as a solution which meets the criteria of reliability and flexibility, especially in a measurement campaign carried out in a short period and close to the coastline. Starting from this configuration, some structural changes have been applied to allow a successful measurements of the sea surface stream (as detailed in section 5a).

4. Use and applications of experimental data

The experimental tests presented in this study represent a first approach to an important problem, *i.e.* the study of the coastal flows to highlight possible solutions to problems

related to coastal hydrodynamics (Griffa *et al.*, 2007). Basically, the possible uses and implications related to the above issues can be classified into two approaches, diagnostic and prognostic which are also complementary.

The diagnostic approach is related to problems regarding monitoring of ocean streams, river plumes and discharges into the sea and analysis of biological and chemical parameters. The mark plume discharge into rivers and open waters is a typical phenomenon which can be investigated by a Lagrangian technique as Particle Tracking Velocimetry, PTV (Tropea & Foss, 2007). Simultaneously, with a prognostic approach the experimental tests are carried out also to validate the numerical models and codes used to simulate the phenomena. An example is given in this study in which the river freshwater flows into the sea having a different temperature and the determination of Lagrangian trajectories, provided by PTV, are also used to validate the numerical models.

Thus, the experimental investigation and the resulting data can be used in different ways and may be part of a process of analysis in which many aspects are involved, as numerical models validation, coastal erosion, sediments transport and deposition, marine works pre-planning, analysis for marine generators (renewable energy solutions).

5. Setup description

a. Drifter Buoy Description

The proximal sensing device used to derive the flow trajectories into the open field is a half-submerged buoy. The geometric and physical characterization have been defined to satisfy the main requirement, *i.e.* to follow the flow and to determine the trajectories close to the sea surface. The Lagrangian point of view allows to consider the buoys as macro-particles representing the flow behavior and transported by it while continuously acquiring the position with the on board electronics (GPS Data Logger). In order to verify the Lagrangian behavior, a system based on central fins has been designed with the objective of increasing as much as possible the wetted surface of the buoy, and consequently the drag produced by the flow.

A specific problem for the open sea measurements is to reduce the effects of the free surface where wind breeze effects are dominant. To minimize this disturb, the buoy have been weighted to reduce the area exposed to the wind, and the fins have been located about 20cm in depth, as displayed in Figure 5. The main dimensions of the buoy are reported in Table 1.

Height	41 cm
Width	50 cm
Cabinet Diameter	8 cm
Fins	25x25 cm
Optical Target	20x20 cm
Total Weight	1550 g
Cabinet Weight	1375 g
Appendages	175 g

Table 1. The designed buoy dimensions and weight.

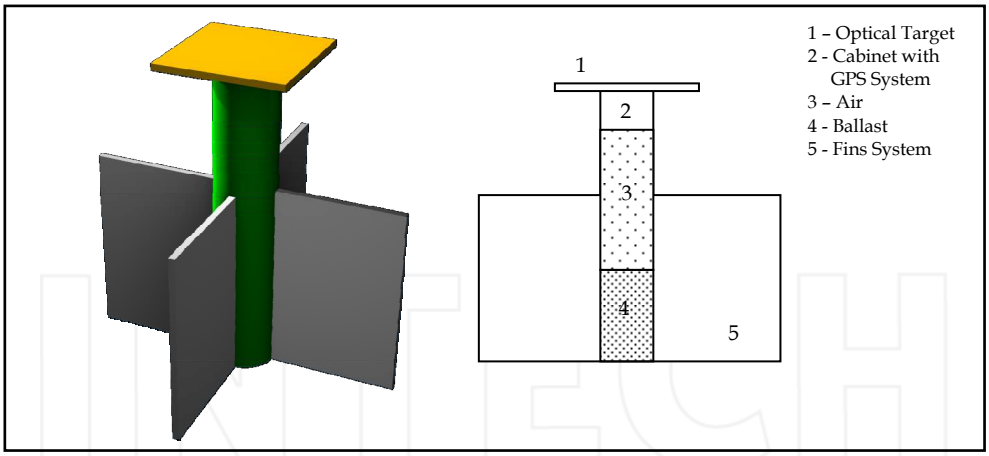

Fig. 5. Sketch of the Lagrangian buoy used in the present measurements.

BatteryLi-Ion, Charging time	3 h
Battery, Operation Time	32 h
Operating Conditions: temperature	-10°C to +60°C
Operating Conditions: humidity	5% to 90%
Accuracy on position	3.0 m
Accuracy on velocity	0.1 m/s
Velocity range	0 m/s to 515 m/s
Maximum acceleration	4 g
Protocols	NMEA-0183 (V3.01) - GGA, GSA, GSV, RMC (default)
Data bit	8
Size	46.5W x 72.2L x 20H mm
Weight	64 g
Data Log	up to 125,000 way points

Table 2. GPS Data Logger technical specifications

b. Electronic Transmission

The buoys are equipped with a GPS (Kaplan & Hegarty 2002) antenna Transystem i-Blue 747 which is an economic and functional satellite navigation system with storage of positions in time of the buoys on the on board data logger (maximum number of points equal to $1{,}25\times10^5$, one every second). This device is shown in Figure 6, while in table 2 the technical specifications are summarized. It uses a GPS Chip MTK with Frequency L1, 1575.42 MHz C/A Code 1.023MHz chip rate Channels 51 CH for tracking and Antenna Built-in patch antenna with LNA Datum WGS-84. The recording is performed switching the instrument to mode Nav-Log and storing the position data calculated by the GPS with an internal memory. The data are exported in ASCII format NMEA-0183 by connecting the device to the USB port of the PC.

Fig. 6. GPS Data logger.

c. Preliminary Tests

The preliminary tests have been performed on two buoy models aiming primarily to verify the feasibility of the measurement campaign and to highlight possible critical points regarding the devices used and logistical activities related to the release and recovery of the Lagrangian buoys. The buoys have been released in marine water to verify their stability, floating level, flow traceability, data acquisition, visibility and handling. A picture of the floating buoys during the tests is given in Figure 7, while the measured trajectories are overlapped to those derived during the final tests and reported in Figure 10. As a result of the tests, the following specific aspects have been pointed out:

- the buoys are very stable in marine water (even in presence of waves) and seem to follow very well the local flow direction;
- the floating level is so that almost 90% of the buoy is submerged; the part coming out of water surface is required to recover the buoy after the end of the measurements;

Fig. 7. Two drifting buoys during the preliminary tests.

- the position where buoys are released is crucial and the best place is as close as possible to the center of the river, because close to the boundaries they move into the boundary layer, thus decreasing their speed and increasing the risk to stop somewhere under the docks;
- the time scale for the whole phenomenon to be completed, from the river mouth to the main breakwater, is at least 30 minutes and no more than 3 hours;
- to avoid unnecessary and difficult interpretation of data, it is useful to acquire the GPS signal only for the time required by the test, therefore to turn-on the GPS just before putting the buoy into the water and turn-off immediately after recovering;
- the management program bundled with the GPS (GPS Photo Tagger) cannot handle many tracks simultaneously, so an appropriate script is needed.

6. Measurement campaign

The measurement campaign was performed at the Pescara river mouth located in the shallow coastal environment of the Adriatic Sea. In Figure 8, a satellite image of the region considered in this campaign is presented. The main characteristics of this area are the presence of the harbor on the right side of the river mouth, the shoreline on the left and the big breakwater recently built, which influences the flow outcome and gives rise to significant environmental effects. Specifically, the dispersion of polluted water from the river, the possible increase of sediments and the loss of biodiversity should be addressed.

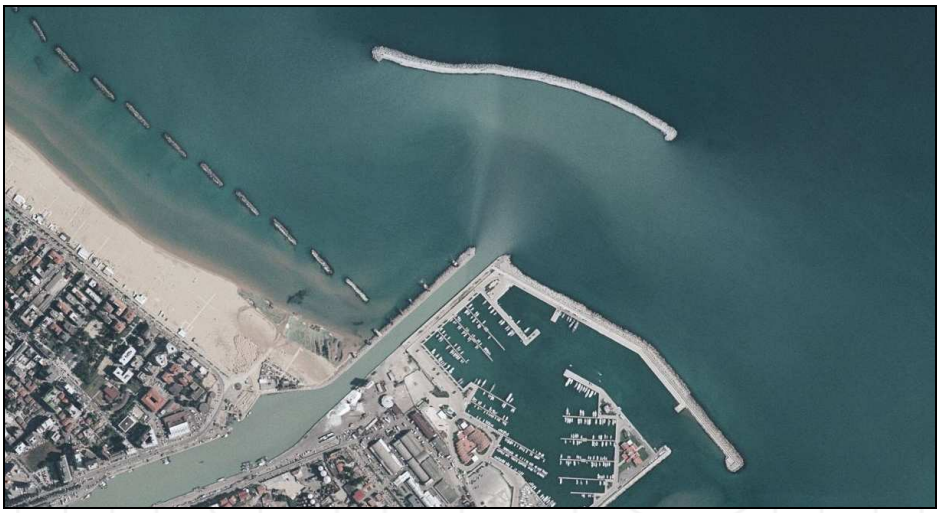

Fig. 8. Measurement region with the river mouth, the breakwater and the harbor.

The present activity aims to setup a method to measure the effective velocity field in order to investigate some possible change or modifications of the harbor and related structures. From the geometrical and dynamical point of views, such a problem is complex, due to the interactions of the river flow with the sea stream and with marine structure, as it is well visible by the satellite image. However, this activity has also a much general validity which can be adapted to similar conditions.

The final test was split into three different phases:

Test preparation. The first part of the test was dedicated to the preparation and mounting of the buoys and to the set up of the logistics with port authorities to stop vessels during the test period. At the end about 100 Lagrangian buoys were set-up, 30 of them mounting the GPS (plus fins and targets), while the other 70 are used for visual inspection of the phenomenon. All these buoys were led onto the supporting boats.

Buoy Release and data acquisition. After the preparation phase, the buoys were released at about 200 meters from the mouth of the river from the stern of the support boat as displayed in Figure 9 and data acquisition of their positions started. To measure the displacements of the buoys the devices have acquired samples at a data rate equal to 1Hz.

Buoy Recovery. After a period of about 3 hours, the buoys have been led back on board and all the devices were switched off. All the GPS were ready to be transported into the laboratory to start the processing phase.

Fig. 9. Buoys release along the river mouth at about 200 m from the outlet.

7. Data analysis and results

At this stage, data download and processing is performed in order to derive the buoys trajectories. In particular, the sequential steps of analysis consist of downloading GPS data, creating a comprehensive data set, data pre-processing, correcting GPS by reference position, data processing and filtering, deriving velocity fields and comparisons. To this end, GPS are connected to PC and the tracks downloaded in the format defined in the initial configuration. In our case, the format used was NMEA-0183 (National Marine Electronics Association). This format allows to obtain the position data including the altitude and speed. As mentioned above, scripts are used for data analysis as the software supplied with the GPS data logger was unable to handle a big amount of data. Once exported in ASCII format data are analyzed as follows:

Raw data acquisition. Once connected to the PC at USB port, the GPS devices allow to view the raw tracks stored in the data-logger and to store the data in the desired format. With the included software the downloaded raw tracks can be viewed as presented in Figure 10. The GPS data given in ASCII format (NMEA type), are easily exported into spreadsheet form, extracting only the fields of interest (sample number, latitude, longitude, altitude and

speed). For each GPS a file containing the tracks of the stored trajectory is exported. *Differential correction of GPS data with reference position.* The GPS signal is affected both by random and bias errors. The main causes of failure are usually the variations of the orbits of satellites, the timing error of the satellites (different stages) and the atmospheric effects on the signal (weather, ionosphere disturbances). To reduce such bias errors, thus improving the precision, a differential GPS is used which provides a correction by referring to another reference GPS placed at a known position. In this way, it is possible to correct data to attain an accuracy up to 10 cm. The possible drawback is that this reference correction can be used only in conditions in which the position of the reference location is known very well.

Fig. 10. Raw trajectories of the Lagrangian buoys as measured by the GPS. The white and yellow line represent the two buoys trajectories during the preliminary tests.

In the present experiments, a fixed GPS, of the same type as those on board, has been placed at a point with known coordinates, and the position was acquired for the whole duration of the experiment. The chosen location has been identified on the outer edge of the dock of the river Pescara on the right side as displayed in Figure 11. It has the following WGS84 coordinates:

Reference position: coord_rif
Latitude: 42.469628 °
Longitude: 14.229803 °

Simultaneously to the GPS released with the buoys, also the acquisition of about 3500 samples of the fixed-point GPS position was performed and the results were analyzed in post-processing to make bias corrections. The measured positions by reference GPS were also corrected by knowing the exact point where the reference GPS is placed (differences around 1-10 m as displayed in Figure 11). Lastly, all the GPS position were computed as the difference between the true location and the median value of samples of fixed point reference. As a result, with this correction the effective accuracy of GPS data is under 1 m. It should be emphasized as the only possible correction on the data position is relative to the average of samples collected, thus reducing only the bias error. On the other hand, the use of the instantaneous data to correct even random errors (e.g. timing satellites) is not possible because it would require information on the phases of the satellites, currently not available with this low-cost technology.

Fig. 11. Reference fixed positions along the harbor dock and coordinates.

Indeed, when analyzing the sample distribution of the position of the fixed point GPS in UTM coordinates, it is not possible to recover a well defined probability density distribution. Rather, data are largely scattered and the mean value does not represent the most probable or a meaningful value. In Figure 12, at the top, the coordinates on the (*latitude, longitude*) plane are presented showing that none of the acquired data coincides with the mean value, thus indicating the fact that different ensemble of data are grouped together. Considering that the GPS is linked to a given satellite configuration for time intervals not longer than a few minutes, it can be argued that the observed scattering id due to the change of such a configuration in time. This is confirmed by the probability density distributions of the latitude and longitude given in Figure 12 at the bottom, where the overlapping of two distinct almost Gaussian distributions is noticed for both. So far, the mean value is simply the one among the two distributions. It is possible to correct this additional bias error by selecting which of the distribution is related to each period of time, even if the correction is smaller than 0.3 m.

Processing and data filtering (smoothing spline). The data acquired by GPS once corrected by the geographical reference are still subject to random errors due to the factors previously mentioned. These errors give rise to some noise in the derived buoy trajectories. Graphically, this is represented in Figure 13 where all raw measured trajectories are shown. Although the general features of the flow field can be derived, these errors could give strong oscillations especially when differentiating the data to derive the buoy velocity. Therefore, a smoothing spline filter among the acquired n data has been applied by minimizing the quantity

$$\sum_{i=1}^{n}(Y_i - \hat{\mu}(x_i))^2 + \lambda\int_{x_1}^{x_n}\hat{\mu}''(x)^2\,dx.$$

where Y_i are the measured data (at time x_i), μ is the smoothing spline estimator (to be determined), μ'' is its second-order derivative and λ is a positive coefficient taken equal to 2×10^3. The result of this spline is presented in Figure 14. The trajectories are now much smoother than before and the fluid-mechanics information can now be derived easily.

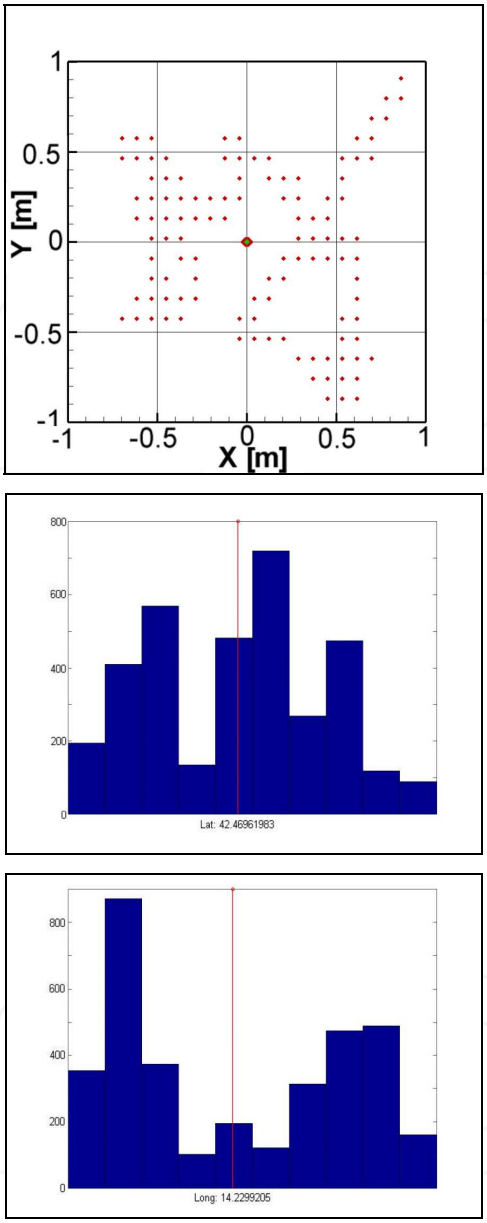

Fig. 12. Spatial distributions of the data acquired at the fixed reference GPS position (at the top) and statistical distributions of latitude and longitude of these data.

Coordinate transformation from WGS84 to UTM. After completing the previous differential correction, the coordinates of the GPS have been converted from WGS84 to UTM format (Universal Traverse Mercator).

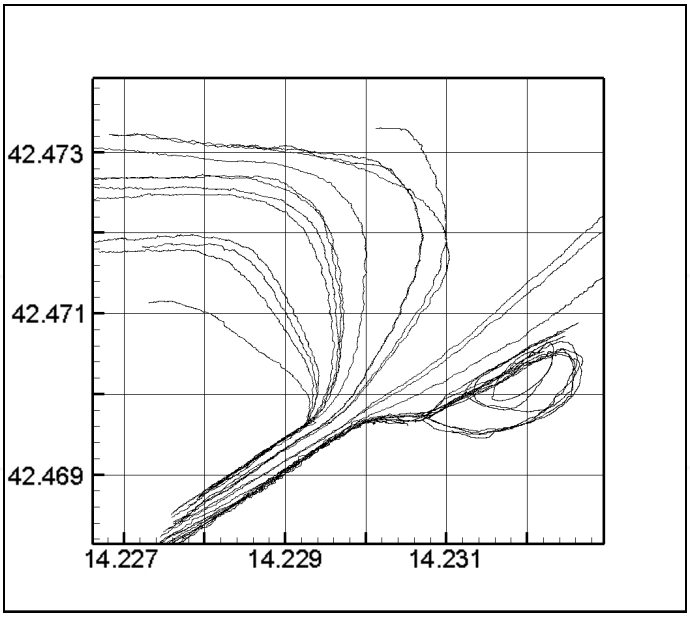

Fig. 13. Raw trajectories of the GPS buoys, before filtering.

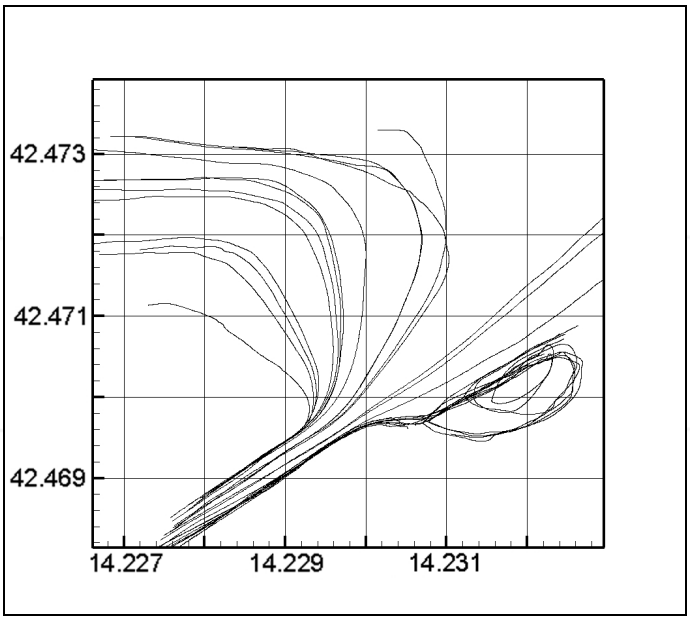

Fig. 14. Trajectories of the GPS buoys, after filtering.

Once obtained the final filtered coordinate data, these can be displayed in space (as in Figures 13 and 14) or in time as given in Figure 15 for one specific buoy. In this case the two coordinates are increasing in time with a similar behavior thus indicating that the buoy moved along a diagonal as the one colored in yellow in Figure 10. For increasing time, the horizontal coordinate has a maximum and then decreases, thus indicating that the buoy is turning on the left side of the field, whereas the vertical coordinate continues to increase departing from the river mouth. A displacement equal to several hundred meters is attained after about 1500s, thus indicating an average velocity equal to 0.3 m/s for both velocity components. Similar information can be derived for the other buoys. From plots like that given in Figure 15, it is possible to derive the velocity of the buoy. The two velocity components in the measurement plane can be computed by centered differences on the positions dividing by the time interval among data acquisition (1 s). An example is given in Figures 16 for the two velocity components separately and in Figure 17 for the absolute value of the velocity (the trajectory is the one displayed in Figure 15). At a first sight, the velocity behavior appears very noise regardless of the filtering applied to the data in position. However, it is still possible to derive meaningful behaviors if interpolation are performed as reported in the figure (consider that the large oscillations are on a time scale of 1 s, whereas the useful information are on time scales one or two order of magnitude larger, so that averaging over 10-100 samples is reasonable). As expected from the previous raw computation, the velocity components have values ranging in the interval (0 - 0.9) m/s and the maximum value is observed just after 500 s as in Figure 15. After about 2000 s the horizontal velocity is almost vanished, whereas the vertical one attains a constant value around 0.5 m/s. Similar information can be derived from the plot given in Figure 17.

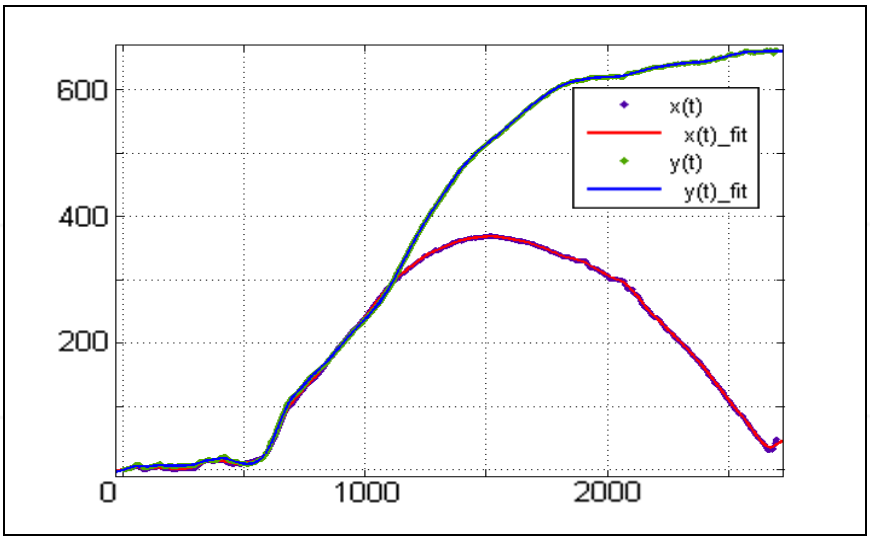

Fig. 15. Values of x and y position in time (in meters) of GPS buoys *vs* time (in seconds) with interpolating fits.

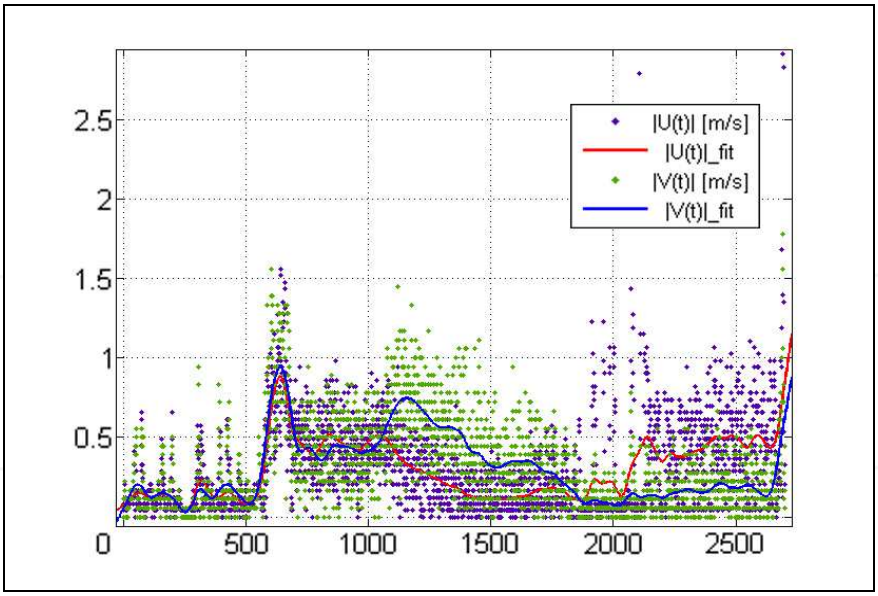

Fig. 16. Modules of the buoy velocity for x and y components (in m/s) *vs* time (in seconds), GPS raw data and interpolating lines.

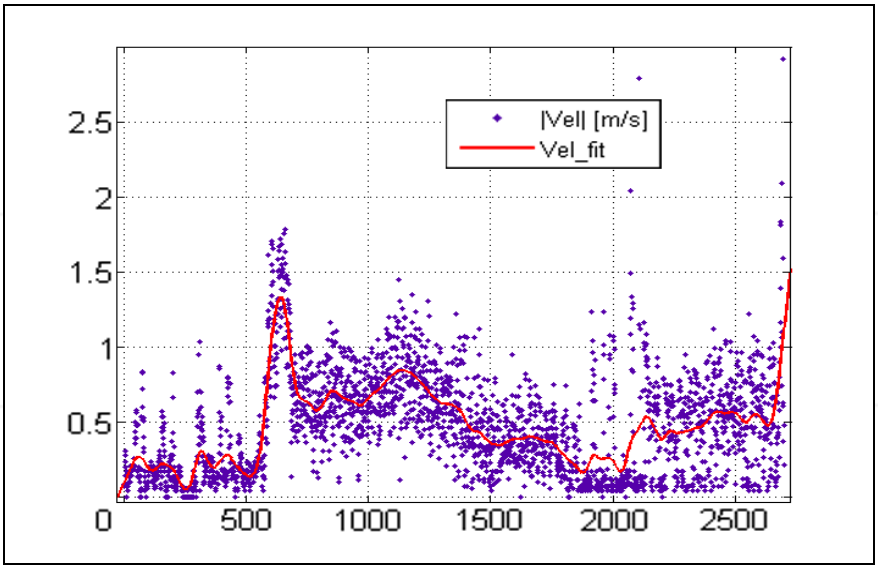

Fig. 17. Absolute value of the buoy velocity (in m/s) over time (in seconds), GPS raw data and interpolating line.

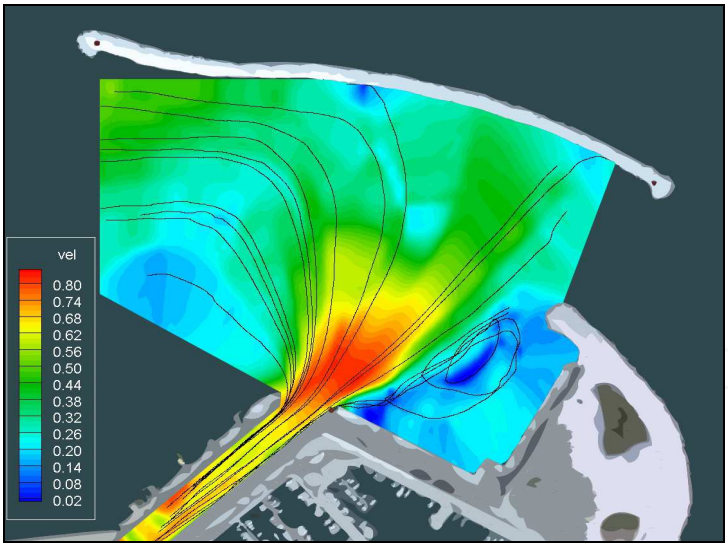

Fig. 18. Trajectories of buoys and geographical distribution of the absolute value of the velocity (in m/s) calculated on filtered data.

Therefore, it is possible to establish that after about 500 s, this specific buoy felt an increase of the velocity which is then decreasing slowly to a constant value after about 2000 s.

To connect this behavior in time to the spatial position and to a general view of the flow field, the buoy trajectories have been reported on the geographical reference of the river mouth. This has been performed in Figure 18, where the entire set of buoy trajectories is displaced. The color code represents the velocity absolute value. It is possible to notice several aspects:

- first of all, the spatial distribution of the buoys is rather homogeneous thanks to the care adopted for the initial release into the river, nonetheless the small number of employed buoys;
- secondarily, the buoys are dispersed all over the measurement field, either in the recirculation region on the right side of the river mouth, or towards the breakwater and the left part of the field;
- as already noticed, the velocity, which is almost constant within the river, is increased just at the river mouth (and this is a possible effect of the specific bathymetry and sedimentation), then decreasing especially when moving orthogonally to the river axis as in jet flows;
- the largest part of the buoys are forced on the left side of the field (and a possible effect of the sea stream and waves on this phenomenon cannot be ruled completely out) or trapped into the recirculation region close to the harbor dock.

The quality of these results is high and the data contains a large quantity of information, so that the measurement of Lagrangian trajectories by means of floating boys equipped with GPS fulfills all the initial requirements. Therefore, from such an analysis it is clear how large are the potential applications of the tested technique in similar or different conditions.

8. Conclusions and future developments

The hydrodynamic field of the mouth of the river Pescara has been investigated, covering an area of 2 km x 1 km and performing measurement on floating buoys in order to get information on flow diffusion from the river onto the sea.

The Particle Tracking Velocimetry (PTV) technique has been successfully applied to this phenomenology, by using a set of drifting buoy equipped with GPS system measuring consecutive positions in time. The determination of the best buoy to be used for this specific purpose, the consequent set-up and tests have been performed step by step.

Once tested, the buoys have been released into the sea for a measurement campaign, obtaining a characterization of the hydrodynamic field in terms of trajectories and velocity components in the plane.

After data pre and post-processing, the reconstructed field allows to derive information on the behavior close or far from the river mouth and so on the possible consequences on the environment.

Specifically, the velocity is clearly larger at the river mouth, decreasing when the river water spreads into the sea. Other two important features to be pointed out, are that the tracer are mostly directed towards the left part of the field and this could depend on the sea stream and waves during the experiments, as well on the curved breakwater placed in front of the river. Secondly, probably independently on the sea conditions, there is a considerable number of tracers which are trapped on the right part of the field and start recirculating with also negative velocities as an effect of the recently added harbor docks and structures.

The experimental setup together with the methodology have demonstrated the possibility to derive the fluid dynamics features of the mouth of the river using very simple and low cost devices (drifting buoys) that have been studied and designed for the specific survey. In this context important conclusions have been achieved especially observing the interactions between the flow and the marine structures, thus representing a high value result to improve the harbor impact on the coastal zone.

The increase of the number of buoys (thus increasing the spatial resolution of the measurement), the possible additional simultaneous measurement of temperature and other atmospheric and sea parameters, the possibility of using a variable height of the fins to measure also the flow stream at different depths are some of the possible improvements that the authors are going to test in the near future.

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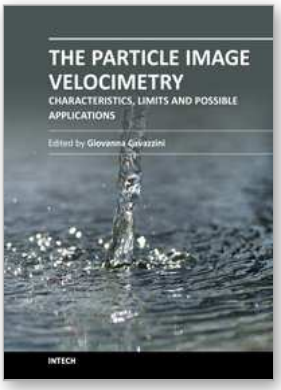

The Particle Image Velocimetry - Characteristics, Limits and Possible Applications

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The Particle Image Velocimetry is undoubtedly one of the most important technique in Fluid-dynamics since it allows to obtain a direct and instantaneous visualization of the flow field in a non-intrusive way. This innovative technique spreads in a wide number of research fields, from aerodynamics to medicine, from biology to turbulence researches, from aerodynamics to combustion processes. The book is aimed at presenting the PIV technique and its wide range of possible applications so as to provide a reference for researchers who intended to exploit this innovative technique in their research fields. Several aspects and possible problems in the analysis of large- and micro-scale turbulent phenomena, two-phase flows and polymer melts, combustion processes and turbo-machinery flow fields, internal waves and river/ocean flows were considered.

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