RESEARCH LINE 3.5.
Quantity and quality of exchanges between lagoon and sea

CURRENT STRUCTURE IN FRONT OF THE LAGOON OF VENICE AS DERIVED FROM THE COASTAL HF RADAR DATA

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1. *Introduction.*

The dynamics of the Venetian Lagoon system is characterized by locally determined factors, such as a geometry and a topography, which to a certain extent interact with the principal forcing mechanisms (tides, fresh water runoff, and those meteorologically driven). The Lagoon communicates with the open sea through three relatively narrow inlets, in which the currents are almost totally driven by the tides. The possible interaction with the adjacent open sea area, relatively deep (20 m) with respect to the lagoon itself, is one of the aims imposed by a complex multidisciplinary research project conducted by CORILA. Thus it has become one of the research topics within the framework of the sub-task 3.5 "Quantity and Quality of the exchange between the Lagoon and the open-sea". Its realization is provided by installing a high-frequency (HF) Coastal Radar in conjunction with the current measurements within the inlets (Fig. 1).

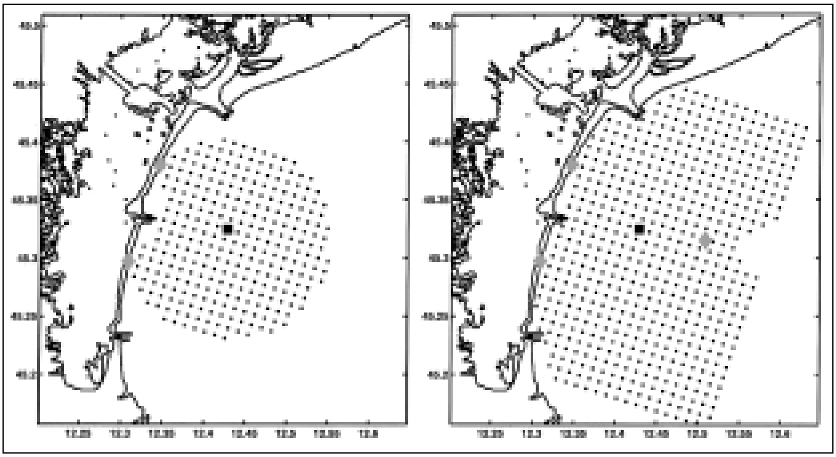

Fig. 1 - The regular spatial grid covered by two (left) and three antennas (right) operating simultaneously. The antennas are denoted by gray solid diamonds. The location for which the power spectrum has been calculated is denoted by a black square. Positions of the ADCP current meters inside the inlets are denoted by black solid circles.

2. *Data and methods.*

The Coastal Ocean Dynamics Applications Radar (CODAR) SeaSonde (by COS, LTD) is a system of antennas which emit electromagnetic radiation at about 25 MHz, and receive the backward signal, dispersed from the surface sea waves of exactly the half of the wave-length of the emitted radiation (Crombie, 1955). Algorithms were developed (Lipa and Barrick, 1983), which, on the basis of a Doppler shift, determine the radial currents obtained by a single receiving antenna, and subsequently combine the radials from at least two antennas in order to calculate the total currents. Individual current measurements have typical speed and direction uncertainties of about 4 cm/s and 12°, respectively. In our case, the two antennas, about 10 km distant from each other, situated on the islands of Lido and Pellestrina, have been continuously operating since November 2001. The third antenna, mounted on the Oceanographic platform “Acqua Alta”, was operating intermittently. However, after resolving the power supply problems, its mode of operation is going to be changed, and it will operate continuously within a short period of time. The advantage of a three-antenna system lies in the fact that a much wider area of the sea surface (of about 280 km^2) will be covered in front of the Lagoon, almost double with respect to the one covered by two antennas only (Fig. 1). The average currents within 1 m from the sea surface are available every hour at a regular spatial grid with a resolution of about 750 m. Maximum range reached is about 15 km off the coastline.

We have analysed the current data collected between November 2001 and March 2002. In particular, a spectral analysis has been applied to the November 2001 time series at one location about 5 km distant from the Malamocco inlet (Fig. 1), which was one of the three locations without gaps. The harmonic analysis has been performed on a 90-days long time series (November 2001 – January 2002) on a grid covered by the two antennas. Thus, a spatial distribution of the harmonic parameters, amplitudes and phases, is determined for the most significant constituents, M2 and K1. Averaging the hourly data at the same grid over a monthly period, mean monthly current structure and a corresponding eddy kinetic energy (a measure of the total variance) is obtained for the months November 2001, December 2001, January 2002, February 2002, and March 2002. The evolution of the current field during an episode of the strong north-easterly bora wind is followed using a sequence of hourly current maps between December 6 and December 9, 2001. Also in this case the area covered is determined from two antennas.

3. *Preliminary results.*

Inspection of the power spectrum at a grid point indicated in Fig. 1, reveals the most significant characteristics of the current variability in front of the Lagoon (Fig. 2). The tidal motion is evident, but not so energetic as a low frequency signal, at time scales of the order of several days. On the contrary, in the lagoon inlets semi-diurnal and diurnal tidal con-

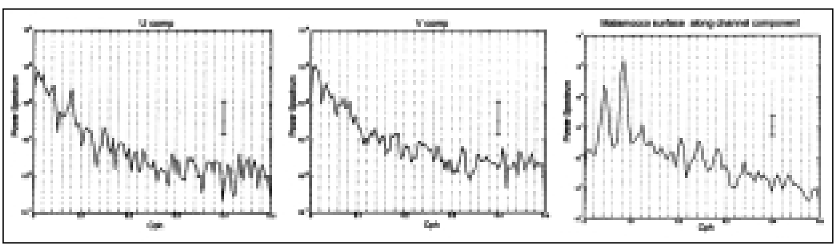

Fig. 2 - Power spectrum and the confidence limits for the east-west (left) and north-south current components (center) at the location indicated in Fig. 1, compared to that of the along-channel component in the Malamocco inlet right.

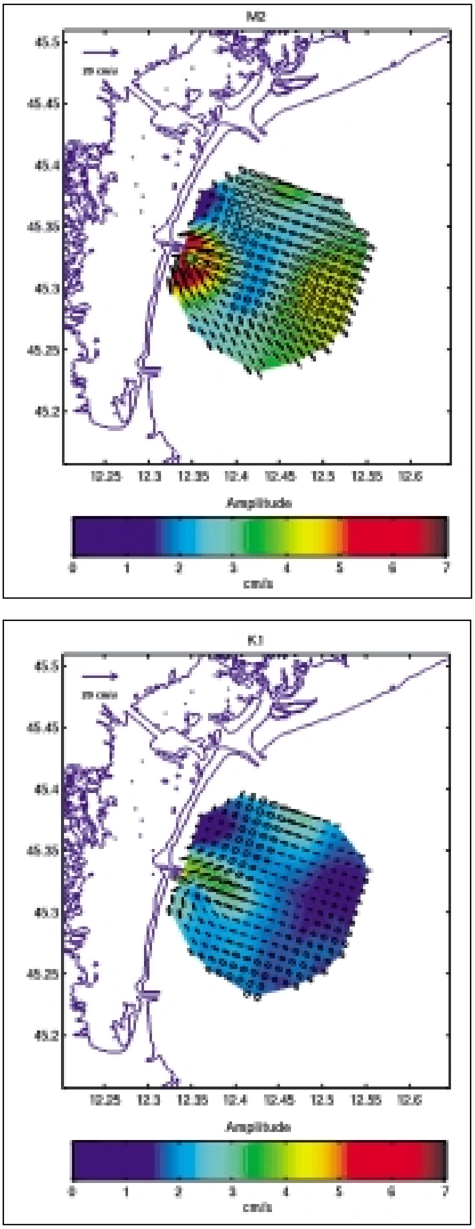

Fig. 3 - Spatial distribution of the tidal ellipses and amplitudes for the major semi-diurnal (M2) and diurnal (K1) constituents.

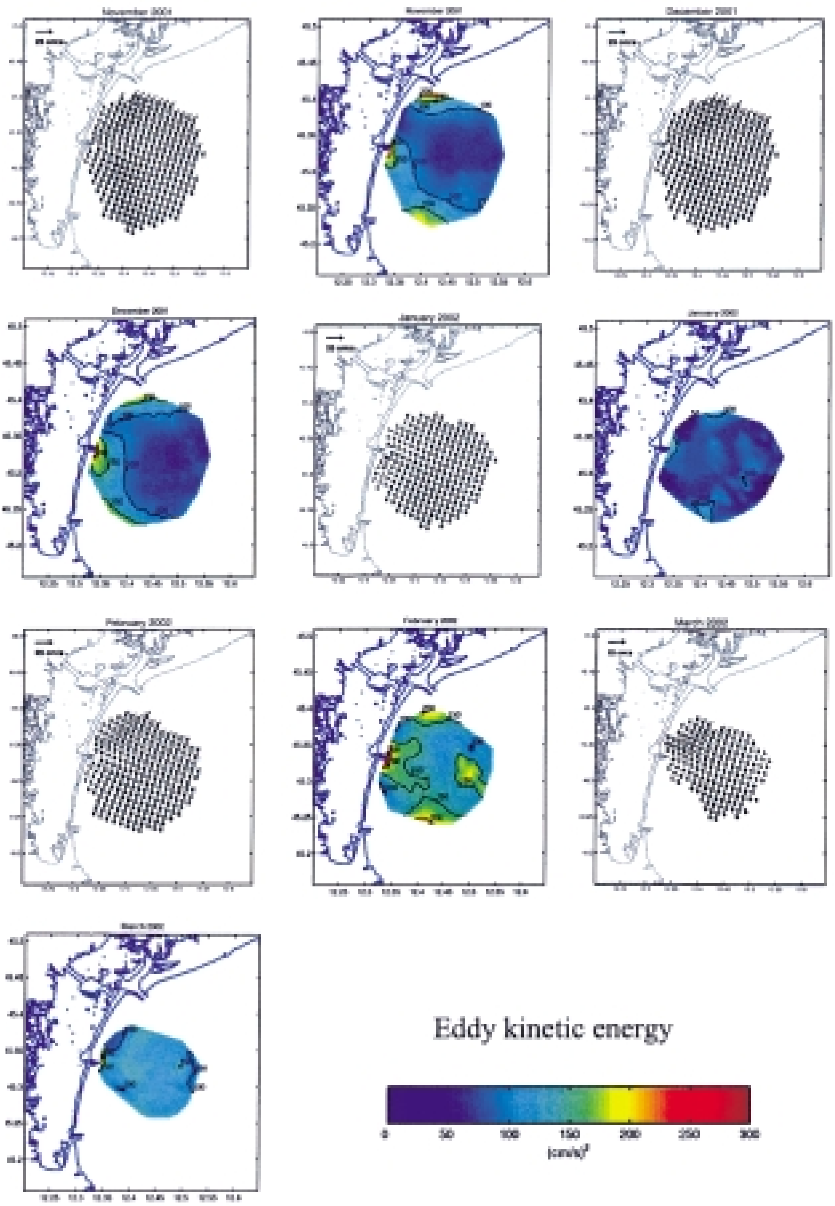

Fig. 4 - Maps of the mean monthly surface currents in the period November 2001 – March 2002, and a corresponding eddy kinetic energy per unit mass.

stituents play much more important role, and exceed significantly the residual, low-frequency currents, as reported for the Malamocco inlet in Fig. 2.

The maps of the amplitude distribution for M2 and K1 (Fig. 3) confirm that a tidal signal is much lower than in the inlets, where it reaches amplitudes of about 70 cm/s and 30 cm/s for M2 and K1, respectively. Tidal signal from the inlets dissipates quite quickly, within 3-4 km offshore. Thus M2 amplitudes away from the inlets are within 2-4 cm/s, while those of K1 drop below 2 cm/s. Current ellipses associated with the tidal flow are radially polarized in the vicinity of the inlets, whereas they become almost circular at a distance of 3-4 km from them.

The monthly mean current structure is represented in Fig. 4 for a 5-month period, from November 2001 to March 2002. Inspection of these maps reveals that a long term current flow is prevalently southward, parallel to the coast, with velocities of about 10-15 cm/s. This type of flow is coherent with the branch of the general cyclonic circulation cell which embraces the whole Adriatic Sea, and in particular, its northernmost basin, adjacent to the Venetian Lagoon (see Cushman-Roisin et al., 2001, for an overview). Eddy kinetic energy per unit mass is obtained as follows:

$$EKE = \sum_{i=1}^{T}[(u_i - u_a)^2 + (v_i - v_a)^2]/2$$

where u_i and v_i are eastward and northward hourly components, T is the total number of hours in a monthly time interval, subscript "i" counts the hourly data, while u_a and v_a are the corresponding monthly means.

This quantity is proportional to the flow variance, which contains variations around the monthly mean at both tidal and sub-tidal frequency scales. Once again a variability close to the inlets is put into evidence, while further from the coast it diminishes. In November and December 2001 monthly mean maps reveal a mean current field intensity of about 12-13 cm/s, while in January 2002 it is lower than 10 cm/s. In addition, the current field in January is much less energetic. Both facts may indicate that during this month the current field was not affected much by forcing such as a meteorological one. Indeed, the time series of wind data available from the platform 'Acqua Alta' (not shown here) were an indicator of a low meteorological activity during January 2002. On the contrary, it was much more energetic during the rest of the studied period.

An episode, characterised by a strong north-easterly bora wind blowing for a couple of days in December 2001, has been taken as an example of response to extreme wind conditions. Evolution of the currents is depicted through a sequence of six hourly maps, unequally distributed in time (Fig. 5). The corresponding flow in the Malamocco inlet is going to be reported as well. The first snapshot on 6th of December at 13 GMT (1), has been taken as a representative of the current flow during the weak wind conditions. Mean hourly wind effectively is lower than 5 m/s. In the inlet, the tidal current is almost zero (slack water). In the open sea distant from the coast and islands, southward flow of about 10 cm/s is evident, while close to the islands the presence of small scale clock-wise eddies is hinted. The second snapshot (2), taken four hours later still corresponds to low wind conditions. Generally, the flow is weak, except near the inlets, where it is about 10 cm/s. Inside the inlet maximum ebb current of about 50 cm/s is observed. The day later at 23 GMT (3) the wind conditions indicate ENE bora wind of about 13 m/s mean hourly speed. The CODAR map shows onshore surface flow of about 10-15 cm/s, coinciding with the almost maximum flood current in the inlet of about 50 cm/s. On 8th December at 16 GMT (4) the ENE bora reaches speeds of about 17 m/s. The south-westward velocity in the north-eastern portion of the area is about 20 cm/s, while it diminishes in the southern part. Along the lagoon islands, the flow is parallel to the coast, and there are no longer small scale eddies evident near the shore. Relatively strong currents near the Lido and Chioggia inlets are just at the margins of the covered area, and there is no possible justification for it. The flow inside the inlet is characterized by a maximum ebb tide of about 30 cm/s. The next two snapshots (5 and 6), taken on the 9th December at 10 GMT and 20 GMT, respectively, correspond to the ENE and NE bora with the mean hourly speed of about 18 m/s. The next surface map (5) shows the flow parallel to the shore of about 20 cm/s, while in the central zone the flow is weak, and slightly divergent. In the inlet there is an ebb current of about 30 cm/s. The surface map (6), on the contrary, represents southward and south-westward flow, more intense near the shore (about 30 cm/s), decreasing offshore (20 cm/s). Simultaneously, in the inlet the flow intensity of about 70 cm/s denotes the maximum ebb tide.

This example of the evolution of the current field in front of the lagoon during an episode of bora wind illustrates that the effect of the wind acts most probably through the on-shore piling up the water, caused by the Ekman transport in the surface layer. Consequently, the pressure gradient is established, which in turn leads to the geostrophic balance and causes a southward flow parallel to the coast. Weak small-scale eddies, near the islands, observed during calm weather conditions, disappear and the current field becomes more homogeneous.

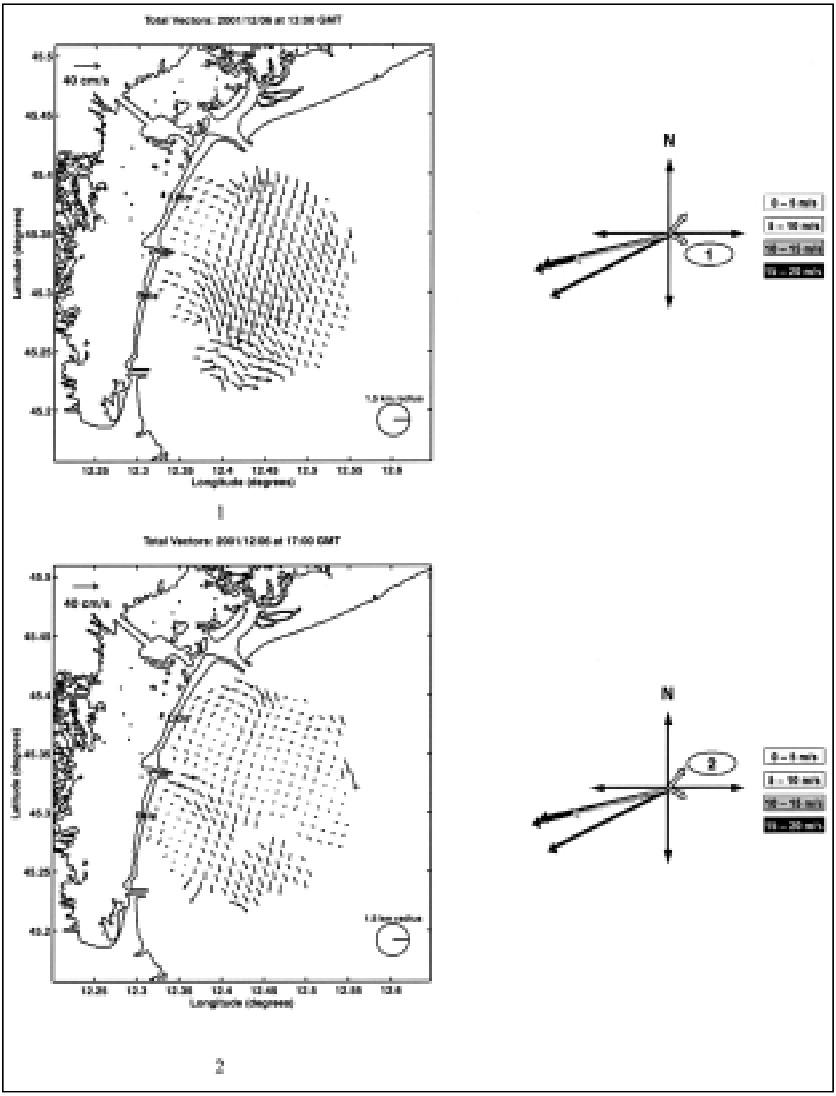

Fig. 5 - A sequence of six hourly maps, and corresponding mean hourly winds in the period 6-9 December 2001.

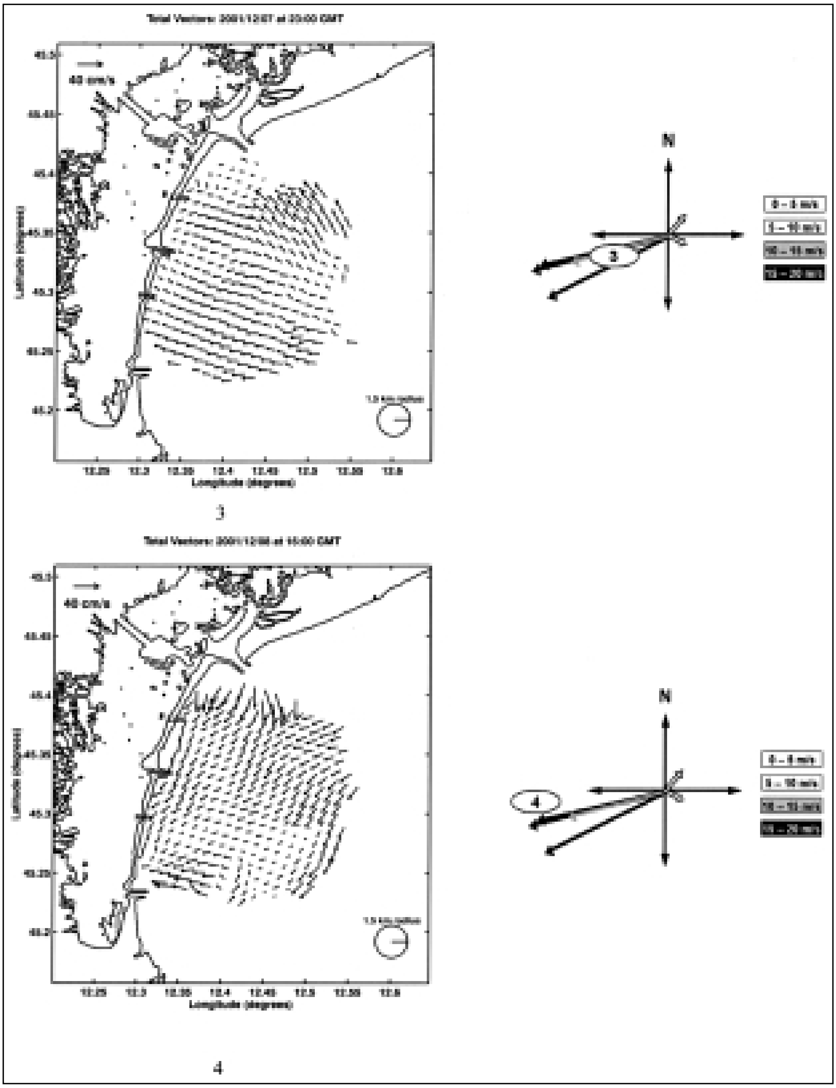

Fig. 5 - Continued.

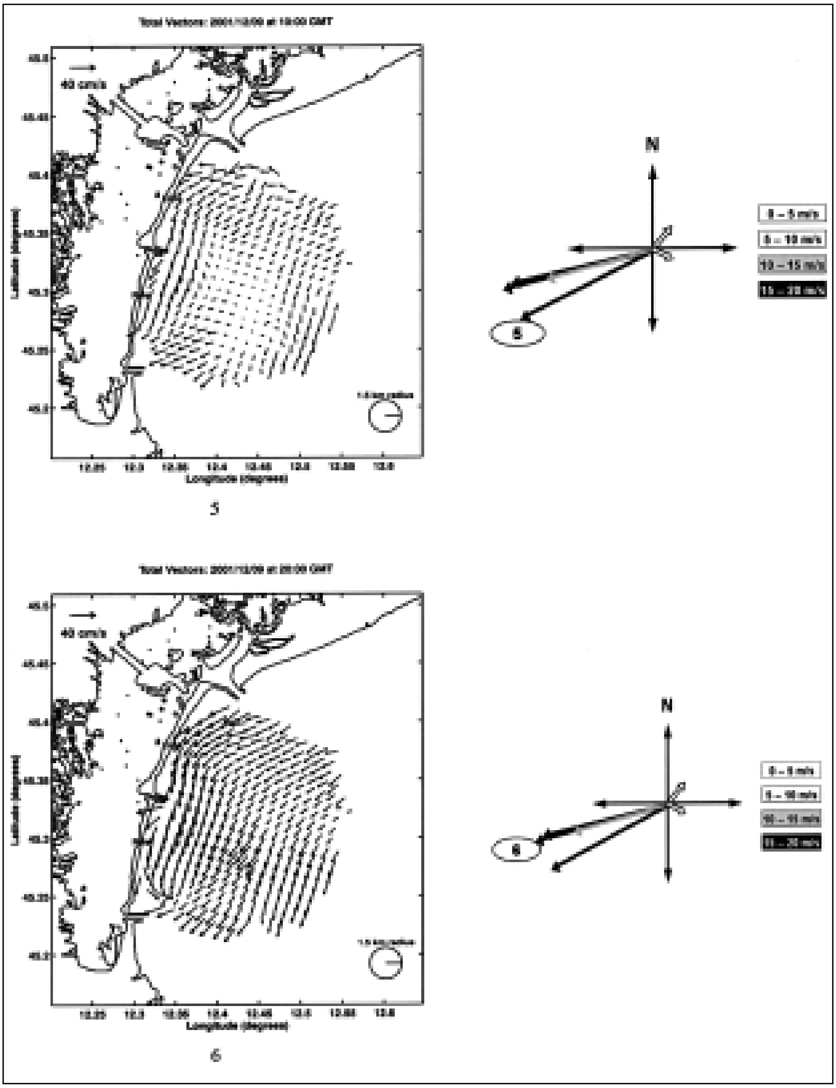

Fig. 5 - Continued.

4. *Concluding remarks.*

It is noteworthy to mention that these are preliminary results, which require a more detailed analysis, especially in the sub-tidal frequency range. Thus, the future efforts will be focused more in detail on the dynamical aspects of the connection between the residual flow (obtained by subtracting a tidal signal from the raw hourly data) and the strong wind conditions, connected to the both NE bora and SE sirocco winds (onshore piling up of water which results in the geostrophic flow parallel to the coast). Once the third antenna at the Oceanographic platform will be operating in the continuous mode, the investigated area will be extended, and this will enable studying the flow structure in the vicinity of all three inlets. Moreover, surface current data on such an area will make possible comparing the circulation results derived from ecological-hydrodynamical numerical modelling and those measured by HF radar. Ongoing measurements will contribute to long-term time series construction (of about a year), which is crucial for determining with a sufficient resolution all important tidal constituents in the current field.

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