Breeze influence on waves and vertical current profile in the coastal area based on EOF analysis (Vilanova i la Geltrú, Barcelona)

J. Antonijuan[a*], G. Simarro[b], J. Guillén[b], M. Nogueras[c], A. Mànuel[c], A. Palanques[b], P. Puig[b]

[a] Matemàtica Aplicada IV Dept., EPSEVG-UPC (Universitat Politècnica de Catalunya),
Víctor Balaguer s/n, 08800 Vilanova i la Geltrú, Spain
Fax: +34938967700; E-mail: fina@ma4.upc.edu
[b] Institut de Ciències del Mar, CSIC,
Passeig Marítim de la Barceloneta 37-49, 08003 Barcelona, Spain
[c] SARTI Research Group, Electronics Dept. UPC (Universitat Politècnica de Catalunya),
Rambla Exposició 24, 08800 Vilanova i la Geltrú, Spain.

Abstract *- This article presents some preliminary results on the breeze influence on waves and vertical current profiles during eleven months of data recorded by an Acoustic Wave and Current Profiler installed in the OBSEA platform in the coast of Vilanova i la Geltrú (NW Mediterranean). The collected data has been analyzed using Empirical Orthogonal Functions and spectral analysis.*

Keywords *- Breezes, current profiles, EOF analysis*

I. INTRODUCTION

Although regional scale winds were generally considered to dominate upwelling processes, the influence of local sea breezes has recently shown to be relevant in these phenomena [1]. The upwelling episodes, which bring the deep waters to the surface, and drive the surface waters offshore, are of major importance in biological processes [2], algae blooms [3] and morphodynamics [4]. In this work we evidence the dominant role of the sea breezes in the across shore velocity profiles near the shore off Vilanova i la Geltrú (NW Mediterranean) through Empirical Orthogonal Functions technique and spectral analysis.

II. THE MONITORING SYSTEM

The monitoring of wind speed and direction was carried out at 1 minute interval using a Davis Vantage Pro weather station placed on the Land Station (see Fig. 1). Waves and currents were recorded using the expandable Seafloor Observatory (OBSEA) from SARTI (Technological Development Centre for Remote Acquisition and Data processing System) operated by the UPC [5]. The OBSEA infrastructure consists of the Shore and the Subsea Stations (Figure 1). The Subsea Station provides the oceanographic instruments and related electronics for its power supply, communications and control and it is directly connected to a Shore Station by a telecommunication cable. This Subsea Station was installed at a depth of 20 m in the marine reserve *Colls Miralpeix*, 4 km offshore of Vilanova i la Geltrú (Catalan Coast, Western Mediterranean: 41°10'54.87"N and 1°45'8.43"E).

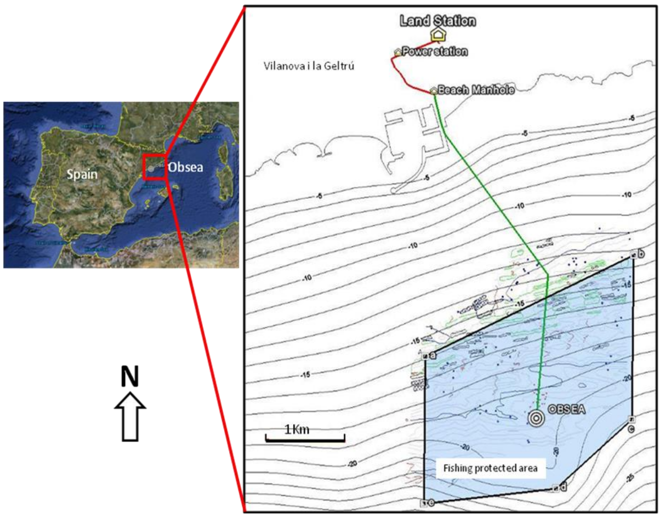

Fig. 1 Map of the western Mediterranean and detailed map of the coastal area in front of Vilanova i la Geltrú showing the location of the OBSEA observatory and the Land Station.

The data servers of the Shore Station store the information and provide the interface with Internet, allowing controlled access to the scientific community. ICM (Institute of Marine Sciences, CSIC) provided OBSEA with a Nortek acoustic Doppler current profiler (ADCP) AWAC 1MHz equipped with pressure and temperature sensors. The ADCP was deployed on a bottom tripod in an upward configuration, and collecting information in water cells spaced 1 m. Waves (significant wave Hs and peak period Tp) were measured hourly in bursts of 8.5 minutes at 2 Hz, and currents were measured every 10 minutes averaging 1 minute bursts at 1 Hz.

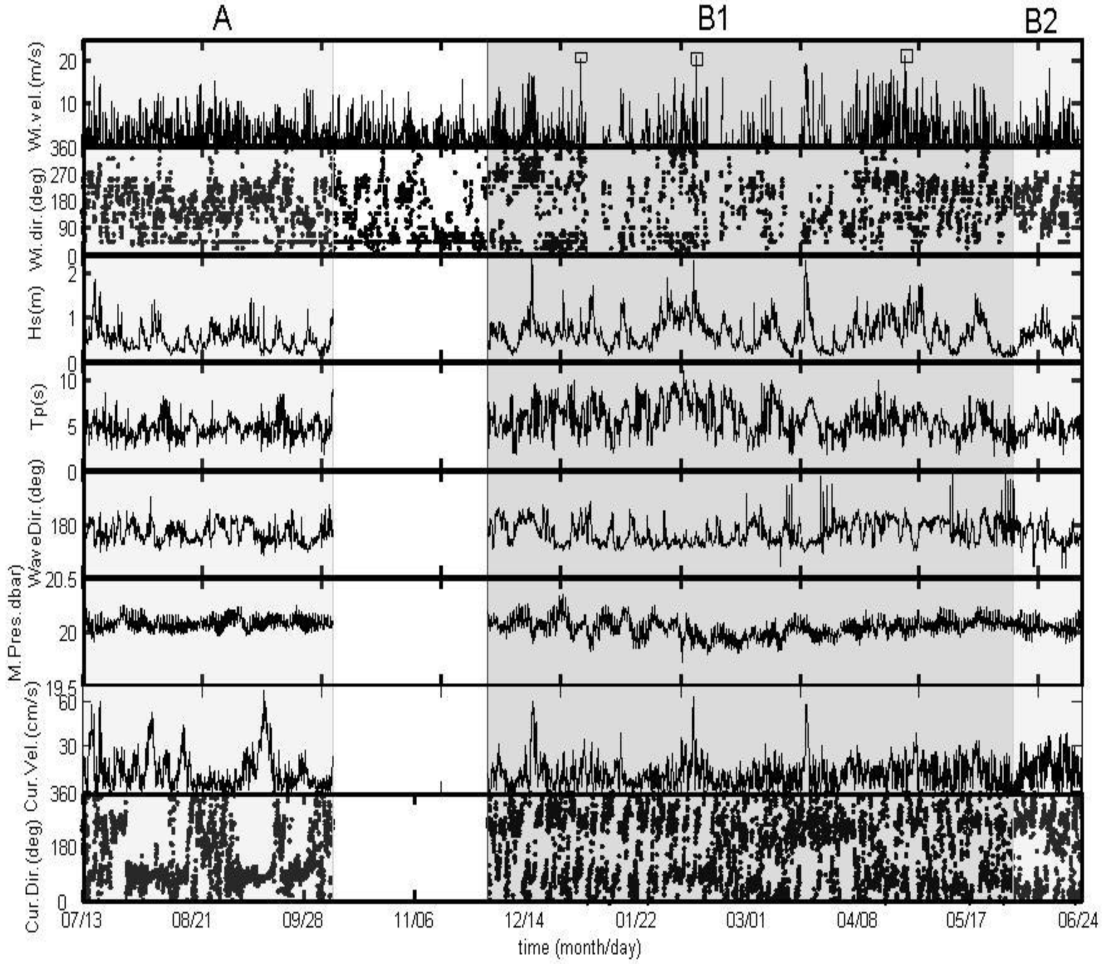

Fig. 2 Forcing conditions during the study period. From top to bottom: wind intensity; wind direction; significant wave height; wave peak period; wave direction; mean pressure; current intensity and direction at 17.4 m distance from transducer head (near the free surface).

III. MEASUREMENTS

Time series of wind (intensity and direction) acquired at the offshore meteorological station are shown in Figure 2. There can be distinguished three wind velocities peaks with values of up to 20 m/s (January 2nd, February 11th and April 24th, 2012 boxed in Fig.2). Regarding wind direction, no mean dominant direction is observed. During the first and third highest wind events (April 24th and January 2nd, 2012) the winds blew from the W whereas during the second one (February 11th 2012) the wind blew from the SE.

ADCP measurements took place from July 13th 2011 to June 24th 2012. Although some electronic failures occurred and some data were lost (fall of 2011), the recorded time series allowed us to extract significant information about wave and current conditions in the aforementioned time period.

The pressure measured at the Subsea Station allows estimating the sea level changes corresponding to astronomical and meteorological tides. Wave conditions during the study period showed the occurrence of storms of a moderate intensity (Fig. 2). Only three peaks with wave height over 2 m were observed (Hs=2.28 m on December 16th 2011, Hs=2.26 m on February 10th 2012, and Hs=2.26 m on March 20th 2012). Maximum wave heights occurred mainly in periods with high wind intensity (i.e., local generated waves). The peak wave period differed between storm events fluctuated from 6.9 to 9.8 s. Current speed and direction at 17.4 m from transducer head are also shown in Figure 2 (bottom panels).

The time series has been split in three periods: A (from July 13th to October 8th, 2011), B1 (from December 1st 2011 to May 31st 2012), and B2 (from June 1st to June 24th, 2012) (see Fig. 2). A is mainly a summer period, B1 is almost entirely a winter season and B2 is in a spring season.

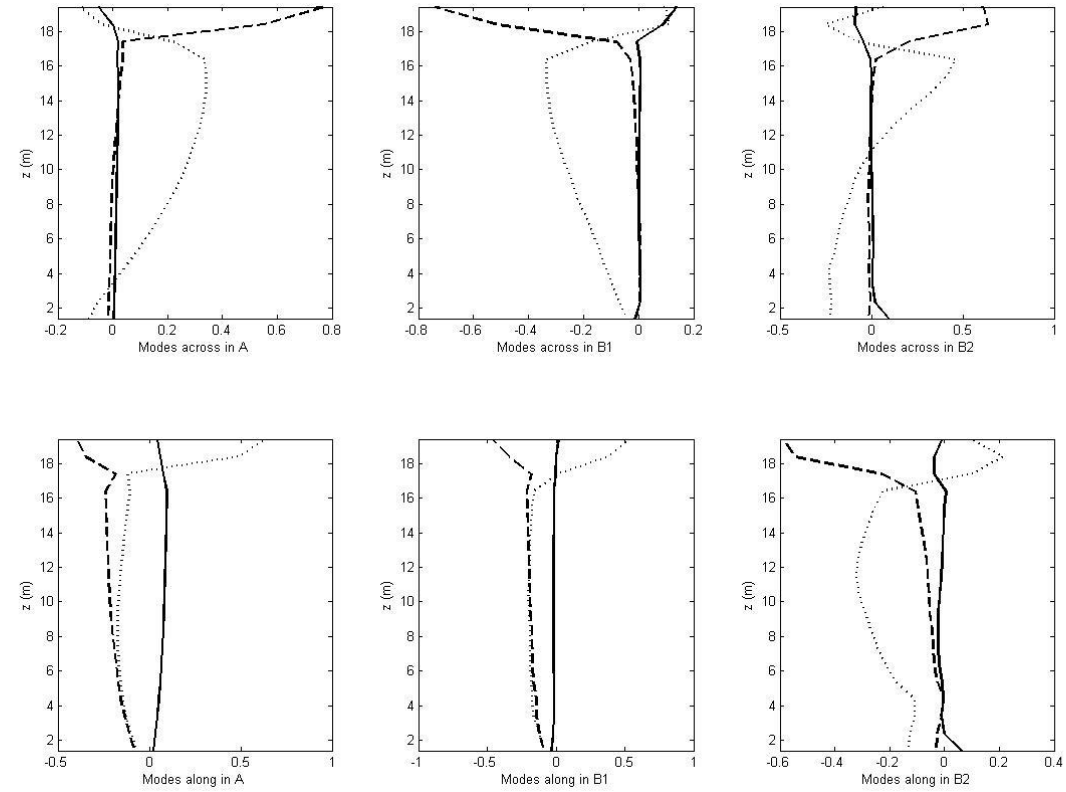

Fig. 3 In continuous line components F_0 (time averaged profile) in dashed line first components F_1 and in dotted line second components F_2 of the empirical orthogonal modes in the spatial domain for the across (top) and along (bottom) velocity in periods A (left), B1 (middle) and B2 (right). In the vertical axis z are meters above the sea bottom.

The ADCP data was analyzed using Empirical Orthogonal Functions (EOFs). This technique has been widely used in meteorological, environmental and oceanographic studies [6]. EOF links together the spatial and temporal domains of the current data. The variance of the data is partitioned into orthogonal spatial patterns called modes. These modes can be ordered in terms of the percentage of the total variance they describe. The modes are statistically uncorrelated with each other. The time evolution of each EOF mode is described by a time series called the principal component or amplitude. The observed current pattern $v(z,t)$ at a given time is given by the sum of the EOF modes (called $F_i(z)$), each being modulated by the value of the corresponding principal component (the amplitudes $a_i(t)$) at that time:

$$v(z,t) = F_0(z) + \sum_{i=1}^{N} a_i(t) F_i(z)$$

A common use of the EOFs is to reconstruct the data by truncating this sum, that is, by using only the first few terms which capture the dynamical behavior of the data. In this case, the first two modes allowed a good representation of the whole set of data.

IV. RESULTS

The wind velocity, wave height and EOF amplitudes were subjected to spectral analysis. Wind velocities spectra of the entire time series showed a pronounced peak at the diurnal frequency (period of one day) that represents sea breeze activity. A complementary peak occurs at first harmonic of the diurnal frequency (12 h). Wave height spectra shows a significant diurnal frequency in the A period but this peak is less clear in the B2 period (were the mean Hs was higher) and it just does not show up in B1. Therefore, diurnal frequency of waves appears in spring and, mainly, summer periods when sea breeze activity appears to be the main stirring mechanism for waves [7].

EOF analysis was carried out on the current intensity, and along and across velocity in aforementioned periods A, B1 and B2. The first and second principal components of the along and across velocity represented in all cases over 90% of the variance and their amplitudes were also analyzed using spectral analysis. A pronounced peak at the diurnal frequency was found in the principal component a_1 of the across velocity in all the periods. Therefore, it looks like the across velocity is strongly affected by the sea breeze activity. The principal component a_1 of the along velocity does not show significant peaks. Nevertheless, the a_2 component of the along velocity reveals a diurnal frequency peak in periods A when sea breezes are stronger.

Figure 3 illustrates the first spatial modes (average F_0, F_1 and F_2) of the EOF decomposition for the across and along velocity. The across mean flow F_0 is almost zero below 17 m. At 19.4 m above the seafloor, the across mean flow goes slightly onshore in A and B2 and offshore in B1. Still for the across velocities, F_1 modes show a current near the surface, induced by breezes according to the above referred spectral analysis of a_1 for the across velocities; F_2 modes of the across velocity follow, essentially, a logarithmic-like profile in the three cases.

Regarding the along velocity, the mean flow F_0 is almost zero throughout the water column. Now F_1 and F_2 modes have a logarithmic-like profile in A and B1 (except in the 2 meters above).

V. CONCLUDING REMARKS

Spectral analysis of wind data, collected during eleven months, indicated a pronounced presence of sea breeze activity. Wave conditions are significantly affected by sea breeze in summer period, i.e., when sea breeze activity is greater than those generated by storms.

The EOF method provides an efficient way to analyze the current behavior and it has been applied to the along and across-shore components of the current velocity. The EOF spatial modes show the current profile and, from the spectral analysis of the principal components, it is derived their time evolution characteristics. From this study, we could conclude that across velocity is strongly affected by sea breeze activity. The across velocity profile is dominated by the surface flows, which appears to be induced by breezes.

ACKNOWLEDGMENT

OBSEA has been installed within the framework of ESONET (European Seas Observatory NETwork; FP6-2005-Global-4, ESONET 036851-2), EMSO (European Multidisciplinary Seafloor Observation; Framework Program-FP7 Infraestructures-2007-1, Proposal 211816) and the project Sistemas Inalámbricos para la Extension de Observatories Submarinos (CTM2010-15459). ADCP and associate sensors used in this paper belong to the Coastal Ocean Observatory (http://coo.icm.csic.es/). Researchers from the CSIC and UPC are members of the Associated Unit UPC-CSIC Tecnoterra (ref. 126307). Gonzalo Simarro is supported by the Spanish government through the "Ramón y Cajal" program.

REFERENCES

[1] C.B. Woodson, D.I. Eerkes-Medrano, A. Flores-Morales, M.M. Foleyd, S.K. Henkel, M. Hessing-Lewis, D. Jacinto, L. Needles, M.T. Nishizaki, J. O'Leary, C.E. Ostrander, M. Pespeni, K.B. Schwager, J.A. Tyburczy, K.A. Weersing, A.R. Kirincich, J.A. Barth, M.A. McManus, L. Washburn, "Local diurnal upwelling driven by sea breezes in northern Monterey Bay," Continental Shelf Research, vol. 27, pp. 2289-2302, 2007.

[2] G.H.Rau, S. Ralston, J.R. Southon, F.P. Chavez, "Upwelling and the condition and diet of juvenile rockfish: a study using ^{14}C, ^{13}C, and ^{15}N natural abundances," Limnology and Oceanograph, vol. 46, pp. 1565–1570, 2001.

[3] G. Basterretxea, E. Garcés, A. Jordi, M. Masó, J. Tintoré, "Breeze conditions as a favoring mechanism of Alexandrium taylori blooms at a Mediterranean beach", Estuarine, Coastal and Shelf Science, vol. 62 ,pp.1–12, 2005.

[4] G. Masselink, C.B. Pattiaratchi, "Sea breeze climatology and nearshore processes along the Perth Metropolitan coastline, Western Australia," Coastal Engineering, vol. 26, pp. 3165-3177, 1998.

[5] A. Mànuel, M.Nogueras, J.del Río, "Features and capabilities of the OBSEA. Test bed for scientists and technicians: flexibility, connectivity and real time data delivery, "Instrumentation Viewpoint, vol. 10, pp. 13-14, 2010.

[6] W. J. Emery, R.E. Thomson, "Data Analysis Methods in Physical Oceanography," Elsevier H.V., Netherlands. 2004.

[7] C. Azorin-Molina, D.Chen S. Tijm, M.Baldi. "A multi-year study of sea breezes in a Mediterranean coastal site: Alicante (Spain), "International Journal of Climatology, vol. 31, pp. 468-486, 2011.