An experience in monitoring and integrating wind and wave data in the Campania Region

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ABSTRACT Some results of a wind and wave monitoring activity carried out for more than twenty years in the costal waters of the Regione Campania, by two scientific institutions are given and a discussion is provided. A clear understanding of coastal processes can only be gained if all available data are systematically integrated with up-to-date wave modelling techniques; in order to do so the Navier Stokes numerical integration LAM and spectral wave models have been employed over the years. The experience and the know-how, thus acquired, have been instrumental in defining a new regional wave measuring and monitoring system for the Civil Protection of the Regione Campania. While pursuing these tasks, a number of intermediate results on specific aspects, such as wind patterns over the sea in bays, the analysis of extreme events, the calibration of altimeter wave data and the influence of various factors on Synthetic Aperture Radar (SAR) images over enclosed seas were reached. A first hand experience of long-term wave and wind modelling is essential to improve the understanding of coastal processes as well as to develop techniques and methods for the design of monitoring networks and the integration of remote sensing data.

1. Introduction

A pioneering wind and wave monitoring activity has been carried out for more than twenty years in the costal waters of the Regione Campania, mostly due to the research efforts of two Universities, University of Naples "Parthenope" (formerly Istituto Universitario Navale) and the University of Salerno.

A Waverider buoy was installed in the bay of Naples by the Department of Science for the Environment at the Parthenope University, as early as 1986 (Pugliese Carratelli and Sansone, 1987), long before the Italian National Wave Measuring Network (RON) was initiated, thus building up a considerable expertise as well as a long standing record of wave data in the bay of Naples.

In the following years, University Consortium for Research on Great Hazards (CUGRI) developed a long range research programme aimed at experimenting and evaluating the integration of wind and wave data from various sources with up-to-date modelling techniques, in close connection with the parallel work performed by the Parthenope University.

This work has developed over the years by involving a large number of experimental and numerical activities, such as the positioning of a directional wave buoy (the only one so far ever located in the Campania Region) and a number of anemometers along the coast, as well as the acquisition of data from satellite SAR, altimeter and scatterometer. Wave data from a wave staff owned and run by the Civil Protection Service of the Regione Campania in the Bay of Salerno have also been usefully employed.

A clear understanding of the coastal processes, however can only be gained if all available data are systematically integrated with up to date wave modelling techniques; in order to do so, Local Area Models (LAMs) have been employed to compute wind fields, numerical solution of primitive Navier Stokes equation to evaluate local wind phenomena around the coast (Bovolin *et al.*, 1996), SWAN modelling to reconstruct wave agitation, and Montecarlo techniques to simulate SAR images.

The experience and the know-how acquired by installing and operating a variety of devices and models have been instrumental in the definition of a new regional wave measuring and monitoring system for the Civil Protection of the Regione Campania. Besides thit, in pursuing these tasks, a number of intermediate results were reached on specific aspects, such as the wind patterns over the sea in bays, the analysis of extreme events, the calibration of altimeter wave data, the influence of various factors on SAR images over enclosed seas. In the following, some of the problems which were encountered and the results which were gained will be briefly reviewed.

2. Local breezes

As it is well known, sea-land breezes are a kind of thermally induced local circulation found in coastal regions. They are driven by the differential heating rates over the sea and the land, and occur most visibly when the prevailing background wind is weak. They are usually weaker than mesoscale winds, but they have a great influence on the marine environment.

The coasts of the Gulf of Naples (GoN) are often sheltered by the direct impact of swell and wave storm activity, so that locally generated wind waves, particularly those associated with strong sea-land breeze activity, play a dominant role in controlling nearshore and foreshore processes.

The availability of both wind and wave data around the GoN provides an occasion to improve the understanding of the nature and the structure the coastal breezes, and in particular to clarify and quantify their role in the formation of sea waves. The meteorological database collected by the Meteorological Network (Fig. 1) of the Department of Environmental Sciences of the Parthenope University of Naples has provided an important contribution for the characterization, in a statistical sense, of the sea-land breeze regime.

For this purpose, an objective method for selecting sea breeze days was developed: wind data relative to the night hours of the summer months were examined (Pugliese Carratelli *et al.*, 2004) and a number of parameters were identified in order to characterise the intensity of each breeze event thus allowing a correlation to be made between wind and coastal data wave data – even along complex coastlines. The total wind energy flowing on a square meter cross-section was found to be a consistent indicator:

$$E = \int_{Tin}^{Tfin} \frac{1}{2} V^3 dt,$$

Fig. 1 – The meteo-oceanographic network in Gulf of Naples.

where *V* is the wind velocity.

Thus, for instance, E1018 represents the energy value, E computed between *Tin* = 10 e *Tfin* = 18. Energy values can thus be taken as an index of the prevailing weather conditions (temperature, solar radiation) in the day and not just as a direct measure of the wind over the sea. Fig. 2 shows the empirical connection between E1018 wave height at midnight in various sites.

Similar results could be obtained by making use of the correlation between E0018 and the wave at 6 and 9 p.m. The effect of the sea breeze in the formation of daily sea states in the evening – and therefore possibly of daily periodical currents – is evident.

A second, and more detailed study was carried out more recently. Wind data was analysed in order to define the periods when the sea-land breeze regimes prevails over the winds produced by the synoptic-scale pressure gradient; in order to do so, the criteria from Steyn and Faulkner (1986) and Sills (1998) were followed, by taking into account the change in direction of the winds and in the thermal gradient between the land and sea. In particular, such criteria were improved to define the "sea-land breeze days", by considering that:

-the wind must blow from land before the sunrise and just before and after sunset;

-the wind must blow from the sea for at least two hours continuously during the day (between the two hours after the sunrise and two hours before the sunset).

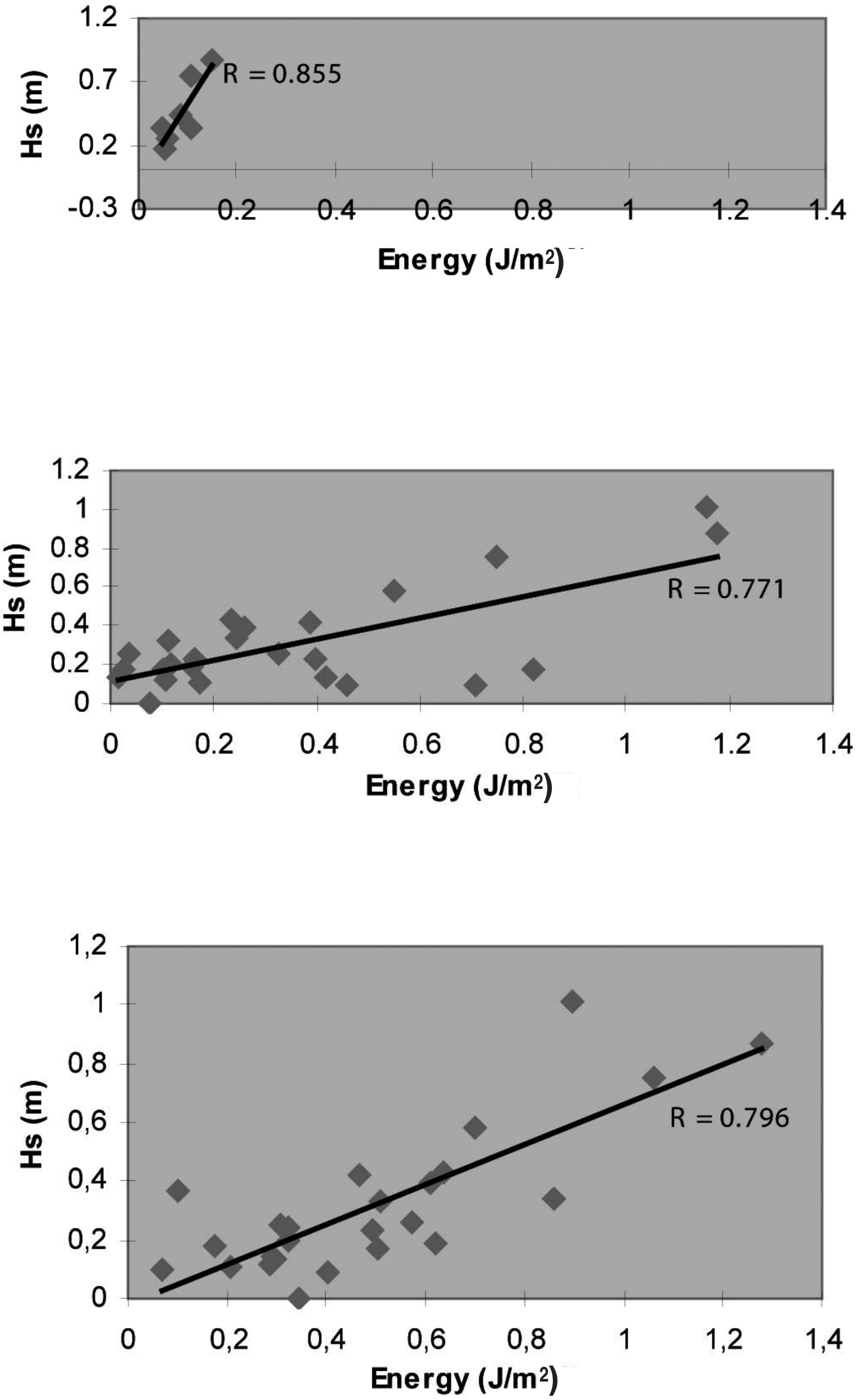


Fig. 2 - Correlation between wave height at 24.00 and E1018 in various locations.

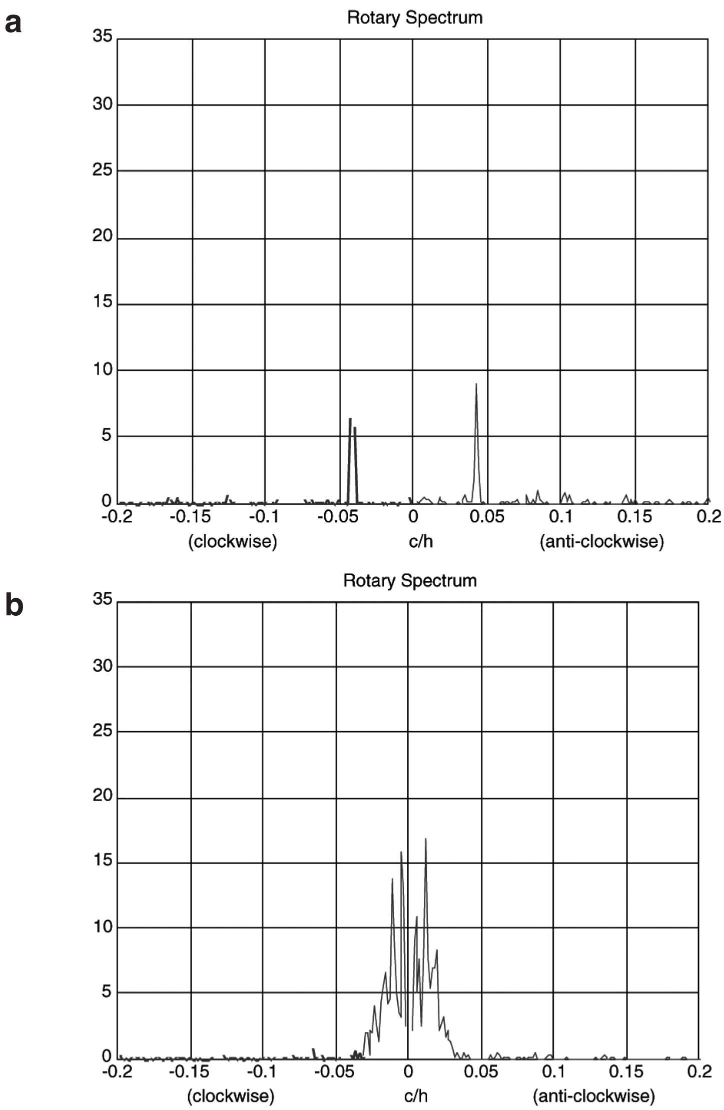


Fig. 3 - Example of rotary spectral analysis of the *u* and *v* components of the wind during a sea-breeze regimes (a) and in their absence (b).

The data which showed night winds blowing from the sea towards the coast were thus excluded from the analysis in order to avoid the condition produced by a large scale pressure gradient. To such an end, any flow moving with a direction of ± 45° perpendicular to the coastline was considered a wind "blowing from the sea" and, similarly, any flow coming with a direction of ± 75° was considered as a wind "blowing from the land".

In order to validate the reliability of the results, a classical rotary spectral analysis (Gonella, 1972) was applied to the *u* and *v* components in order to verify the rotational characteristics of the wind vector. Actually, as it is well known (e.g. Haurwitz, 1947; O'Brien and Pillsbury, 1974), the wind regime during the sea-breeze periods is characterized by a clockwise rotation. Fig. 3, yields the results obtained during two distinct wind time series: the rotary spectrum of the *u* and *v* components during periods dominated by a sea-breeze regime is characterized by a presence of

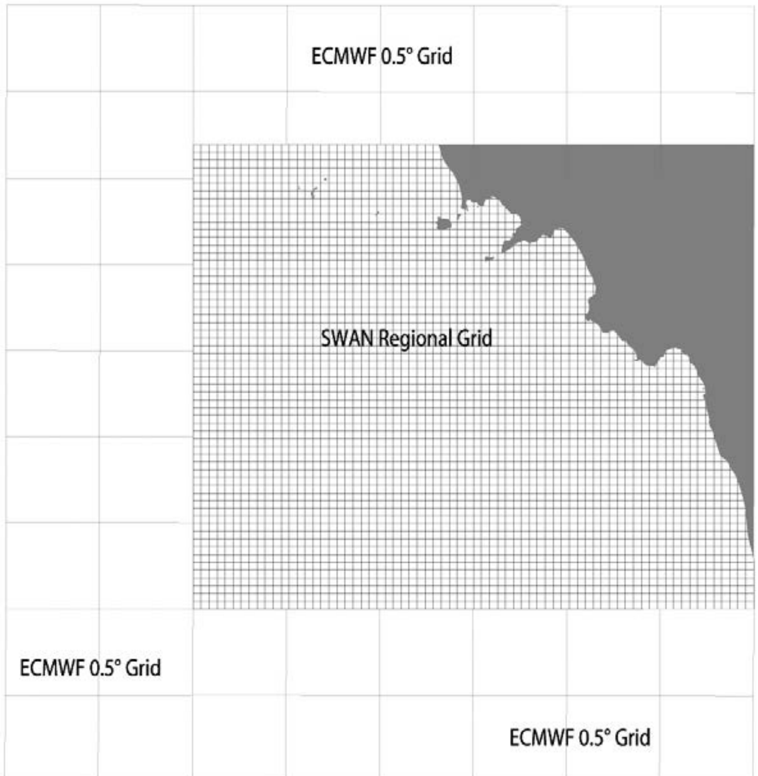


Fig. 4 - Matching between ECMW wave model and local SWAN grid.

larger peaks of energy in the clockwise sector (negative values, Fig. 3a) which are not detected during "normal" wind regimes (Fig. 3b).

The data over 4 years show that sea-land breezes are a significant feature of the local meteorology. However since the data and the statistical analysis refer to only four measuring stations which are non homogenously distributed over the coastline of the GoN, the spatial structure of the wind system is not entirely clear. A numerical diagnostic model with very fine resolution, will have to be employed to gain a full understanding of the sea-land breeze system along the GoN coast.

Some interesting conclusions, however, are already clear from the available data: sea-land breezes play a non-secondary role in the atmospheric regime over the GoN and they occur mostly in the northern sector as recorded by the weather stations of Naples and Licola. The monthly statistics, averaged over 4 years, reveal a seasonal variation. During the warm season, the breeze regime is regularly detected at Licola, while during the cold season sea-land breezes occur most frequently at the Naples weather station which is characterized, due to the well-known urban island heat effects, by higher air temperatures.

Sea-land breezes occur most frequently in May-August, and are less frequent during the winter period, since in May-June the thermal contrast between the air masses over the sea and the air masses over the land becomes higher.

By systematically analysing the character of the sea-land breeze days in the data set, typical values of $1.0 < v < 1.6$ m/s were found for sea breezes, with the maximum of intensity around 14:00 UTC.

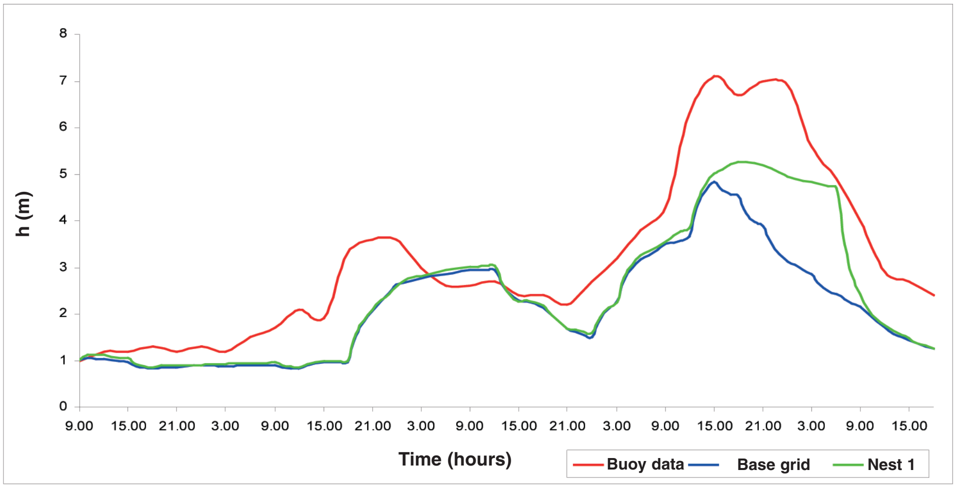


Fig. 5 - Recorded and computed significant wave height at the Ponza wave buoy from 09:00 on 25/12/1999 to 18:00 on 29/12/1999.

On the other hand, in the night time, the land breeze is weaker with typical values 0.1 < v < 0.7 m/s.

3. Wave storm analysis

Synergy between sea level data, satellite observation and computer simulation can provide vital information about the effect of weather effects on semi enclosed seas; local wave calculations, carried out by the SWAN wave model with boundary conditions provided by the ECMWF WAM model (Fig. 4), help to reconstruct the time hystory and the effect of extreme storms, even when not enough buoy

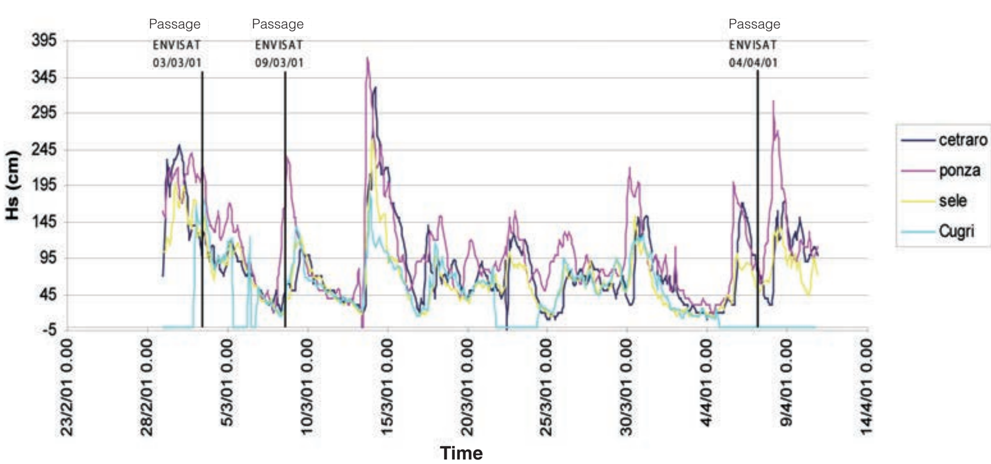
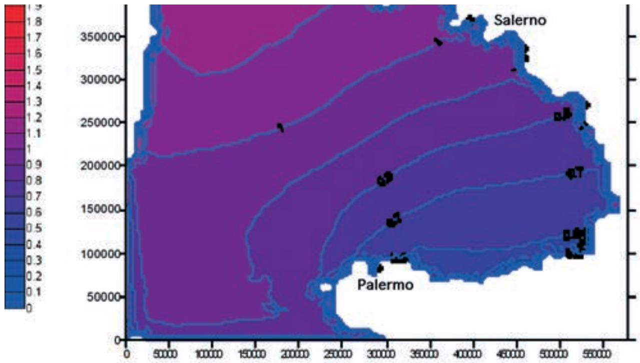


Fig. 6 - Recorded wave data and times of satellite passage (from March 1, 2001 to April 10, 2001).



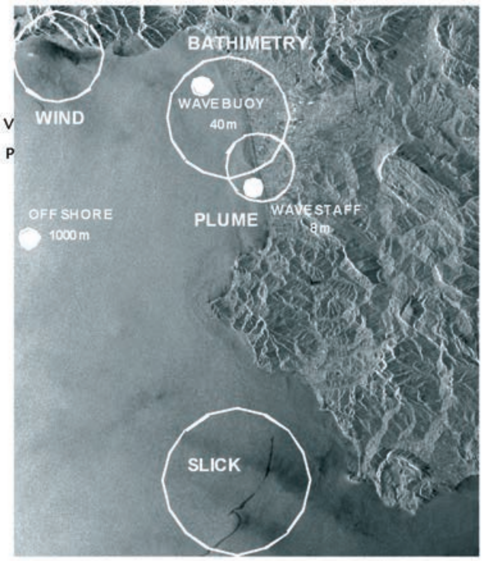


Fig. 7 - Simulated wave field and various SAR images features.

data are available.

In order to do so the procedures have to be tested and calibrated on test cases when enough data are available, such as for instance the storm which took place in the Tyrrhenian Sea at the end of 1999 – the strongest storm ever recorded by the wave meters in the area (Fig. 5).

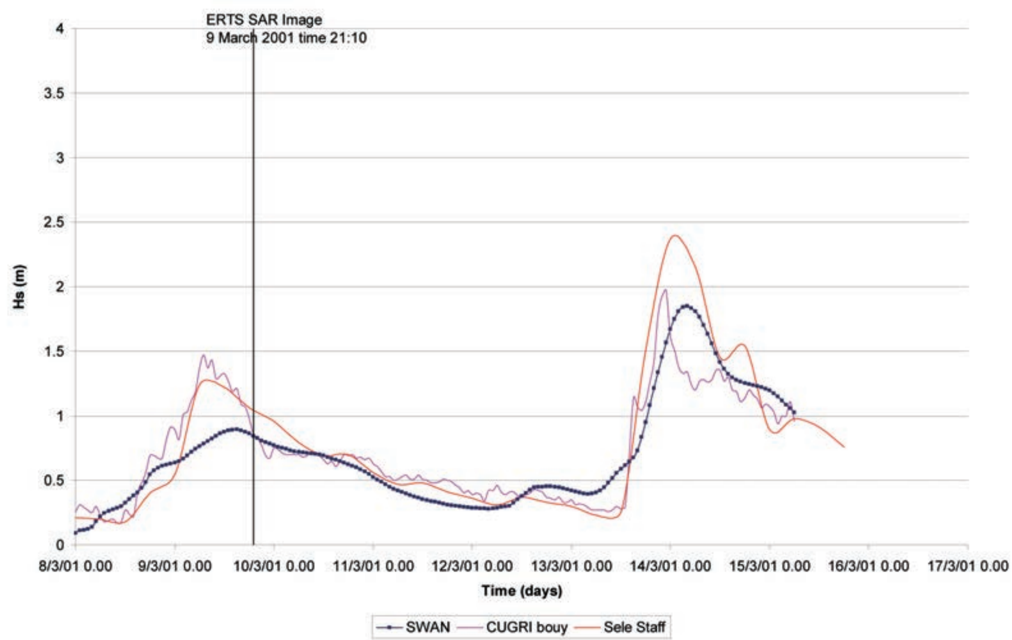


Fig. 8 - Comparison between simulated and measured wave heights.

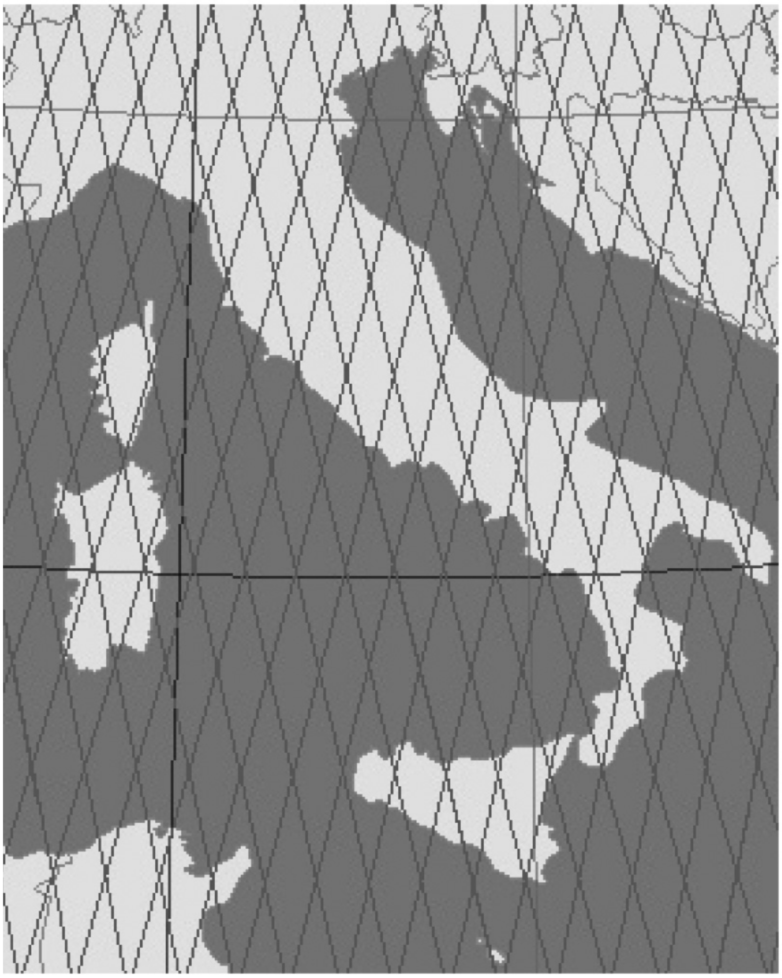


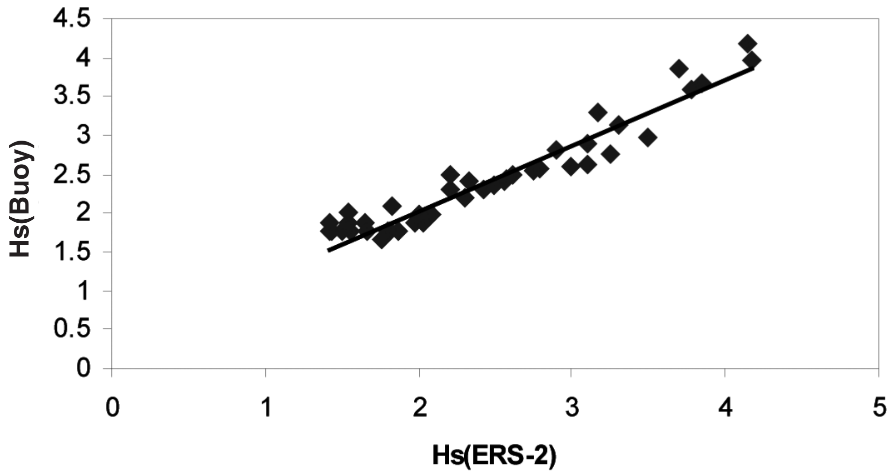
Fig. 9 - ERTS and ENVISAT coverage of the Tyrrhenian sea.

A much better insight can be gained when satellite data is available. Between February and April 2001, two reliable wave measuring systems were operating along the coast of the Bay of Salerno: a Datawell directional wave buoy owned ("WAVE BUOY" in the SAR image in Fig. 7, in the following referred to as "CUGRI") and operated by a scientific institution on 40 m deep water, and a wave measuring staff operated by the Civil Protection Service of the Campania Region, over a 8 m deep bottom at the Sele River mouth ("WAVE STAFF" in the SAR image in Fig. 7, in the following referred to as "Sele").

Wave data at two different locations not reported in the map, about 70 nautical miles north of the Gulf of Naples (Ponza) and 80 nautical miles south of the Gulf of Salerno (Cetraro) are also available from the RON. During the same time interval the ESA ENVISAT Satellite provided three SAR images of the area; Fig. 6 shows the available data as well as the satellite passage time.

All this information provides an interesting benchmark for different experimental and analysis techniques (Giarrusso *et al.*, 2004; Pugliese Carratelli *et al.*, 2005, 2006).

SWAN wave simulation, coupled with Envisat SAR imagery can help highlight various features a



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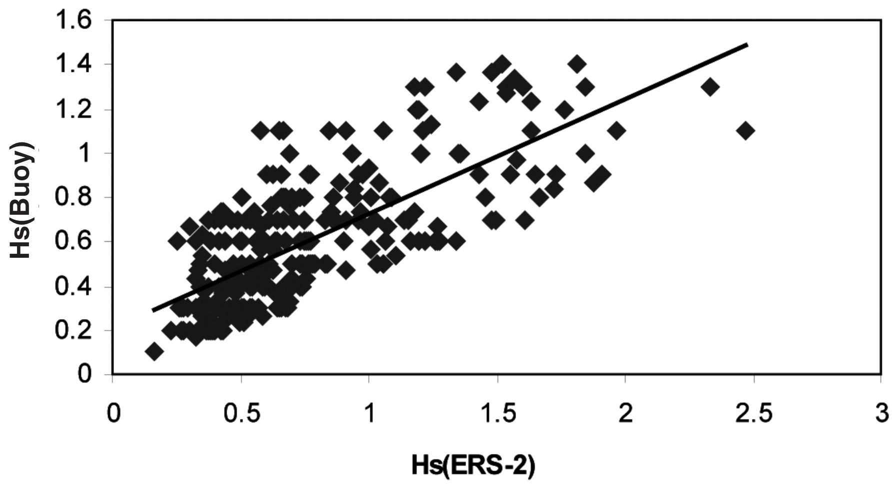

Fig. 10 - ERS-2 wave data calibration.

of wind and wave fields (Fig. 7).

Fig. 8 shows that, as it was to be expected, an-up-to date simulation model can reproduce the behaviour of a sea storm fairly well; a greater accuracy over such a fine resolution, however could only be achieved if the wind were known with adequate precision. Over enclosed or semi-enclosed seas, the wind is field highly irregular both in time and space.

4. Satellite data integration and calibration

Significant wave height has been regularly measured for many years by radar altimeters on both ESA satellites (ERTS1, ERTS2 and ENVISAT) and NASA/CNRS (Poseidon, Jason). The time interval between passages is too long to provide real time monitoring of restricted areas like the coasts of the Campania Region, but the spatial extension of the altimeter data can provide a useful integration of wave buoy time series. As shown in Fig. 9, about 15 orbits cover the southern

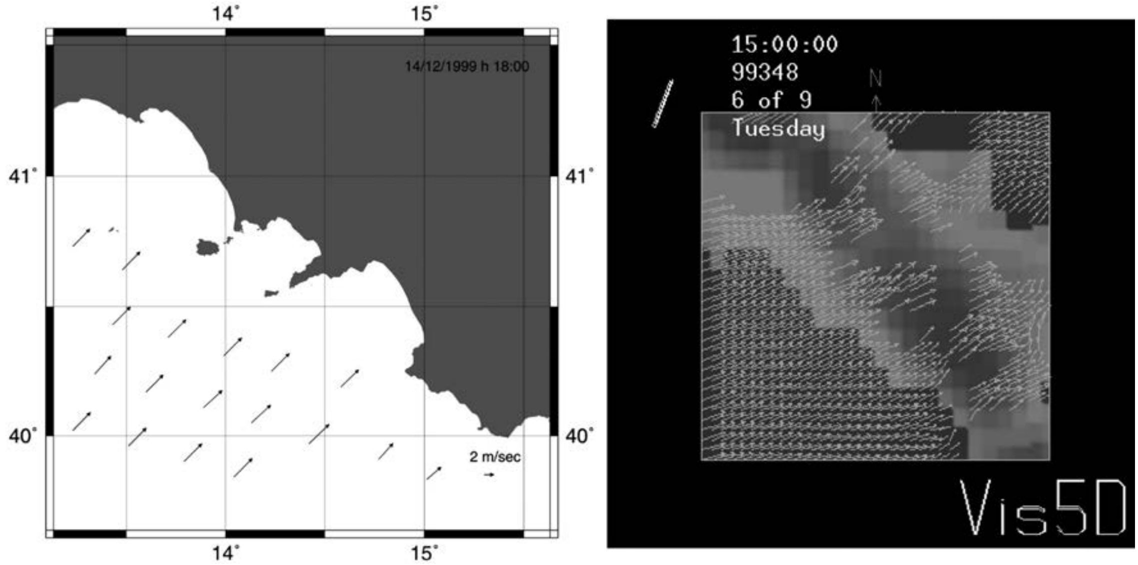

Fig. 11 - Wind velocity vectors as computed with a Local Area Model and measured by satellite scatterometer.

Tyrrhenian Sea, thus providing an average of one useful measurement every second day.

The reliability of such measurements has to be routinely verified and calibrated in various regions of the globe, and this is best done by making use of buoy data (Cotton *et al.,* 1997; Young, 1999). This was carried out for the area around the Ponza wave meter and other Italian National Wave Network buoys (Della Rocca and Pugliese Carratelli, 2000), and results show a satisfactory agreement for strong sea states (Fig. 10a), less so for lower wave heights (Fig. 10b).

Wind data on the sea surface as supplied by satellite scatterometers can be employed to improve LAM weather simulation, thus providing greater insight on the sea conditions (De Martino *et al.,* 2000).

Such information, however (Fig. 11), has a much coarser resolution than what would be needed for an accurate simulation of near coast sea conditions; scatterometer data can therefore only be considered as a qualitative addition to data supplied by other sources.

5. Conclusion

Systematic collection of environmental data with operational objectives is not among the goals of universities or scientific institutions; however a consistent activity of long term recording and analysing wind and wave parameters can do much to improve the understanding of coastal processes and thus help to develop techniques and methods for the design of monitoring networks and the integration of remote sensing data.

Given the complexity of coastal processes, remote sensing and field data can only be useful if all the information is fully integrated and analysed by making use of the most advanced meteorological and wave modelling techniques.

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