# SATELLITE APPLICATIONS TO SEA STATE EVALUATION IN ENCLOSED SEAS

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## ABSTRACT

The evaluation of sea wave climate for a given location, both offshore and along the coast, is a never ending task; not only the requirements for the construction of coastal and offshore works become more and more stringent as the concerns for safety and environmental impact increase, but also the availability of data sources calls for new and more sophisticated procedures of data analysis.
In this paper the authors present an analysis methodology to evaluate the sea state in enclosed seas (Mediterranean Sea, Arabic Gulf) that use the wave data measured from satellite, buoy and wave data evaluated with numerical simulation.

## INTRODUCTION

The evaluation of sea wave climate for a given location, both offshore and along the coast, is a never ending task; not only the requirements for he construction of coastal and offshore works become more and more stringent as the concerns for safety and environmental impact increase, but also the availability of data sources calls for new and more sophisticated procedures of data analysis.
On a limited number of sites worldwide, where wavemeters have been operating for a long time, the historical records of direct wave measurements are now long enough to allow for a reasonable statistical extrapolation of data , while on most of the world locations there is no adequate instrumentation available; on the other hand the wider diffusion of numerical weather forecast model has led to a now practically standard procedure based on the chain: Global Weather Model archive data – Local Area Model – Wave Generation and Propagation Model.
A later arrival – even though no longer a novelty – is the use of satellite active sensor data, i.e. Synthetic Aperture Radar (SAR) and altimeter. These instruments have been used for many years now in order to supply large scale information of the wave fields – mainly over the oceans, but increasingly so, also over enclosed or semi-enclosed seas.

## SATELLITE DATA AND WAVE BUOY

The direct applicability of the satellite data to the actual evaluation of climate in a specific site is still questionable mainly because of their low passage frequency, since the time coverage of a small basin does not normally guarantee the availability of data at the peak of each storm; a number of practical applications are however already available.
Significant wave height has been regularly measured for many years by radar altimeter on both ESA satellites (ERS-1, ERS-2 and ENVISAT) and NASA/CNRS (Poseidon, Jason).

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 Figure 8, about 15 orbits of ESA satellites cover the southern Tyrrhenian Sea, thus providing an average of one useful measurement every second day.

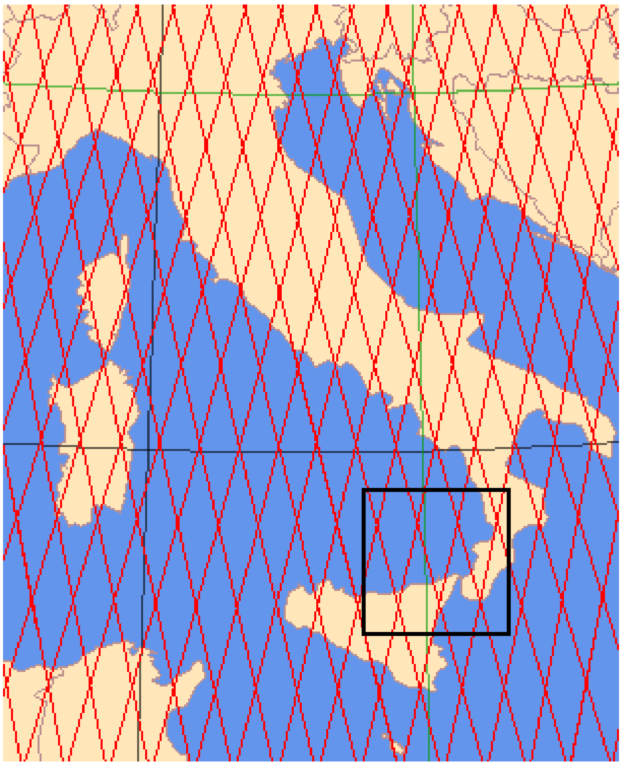


**Figure X: ERS and ENVISAT coverage of the Tyrrhenian sea**

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

The most obvious use of altimeter data is to verify or to calibrate the results of model-based procedures, and this has been indeed already been performed on a large scale in the past; the punctual comparison of active sensor data for extreme events with state of the art local area meteorological and wave models is still not a common practise. Some examples will be given for some historical Mediterranean storms.

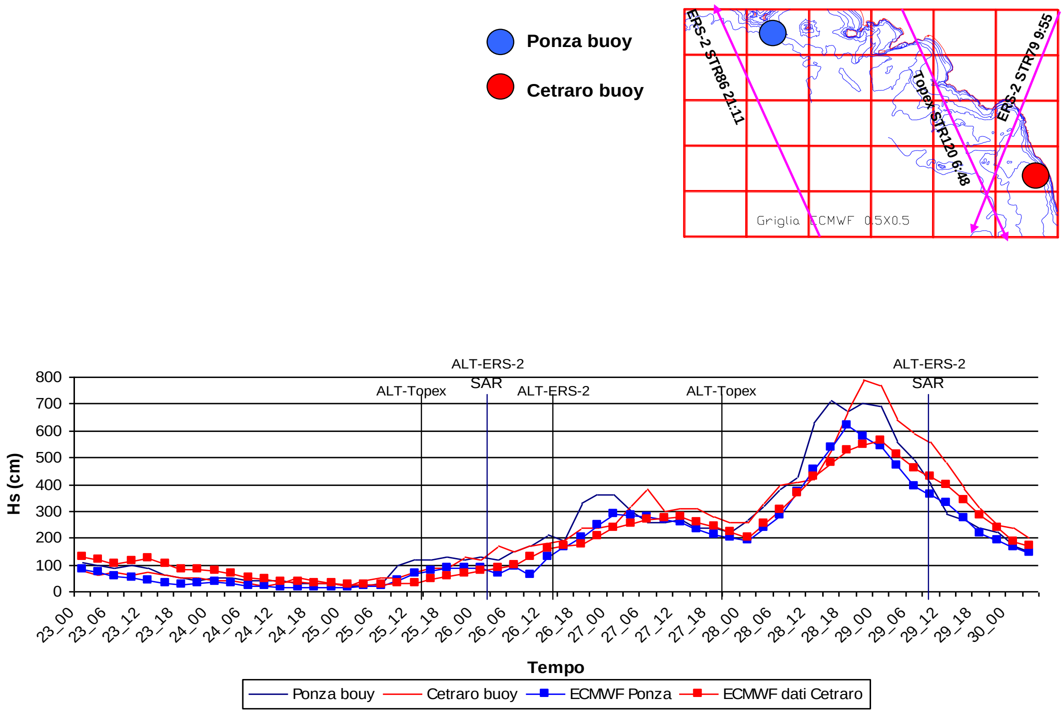



Figure X: December 1999 Storm in the Tyrrhenian sea

Wind data on the sea surface as supplied by satellite scatterometers can be employed to improve Local Area Model weather simulation, thus providing greater detail and insight on the sea conditions (De Martino et al, 2000). (Fig X)

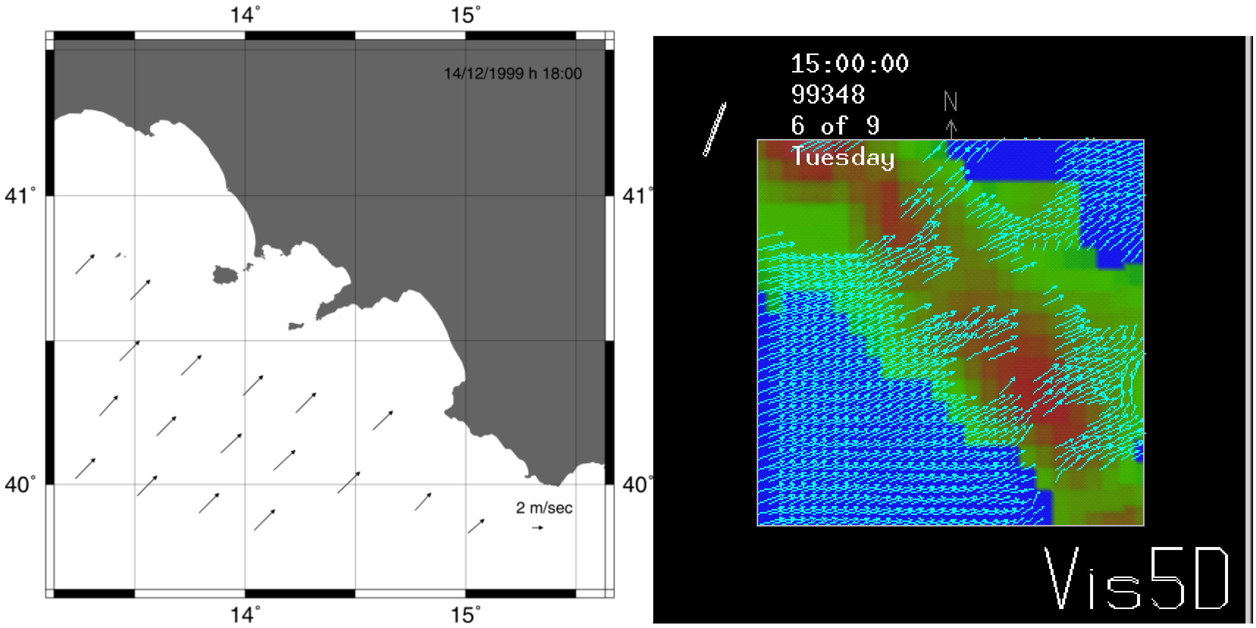



**Figure X: Wind velocity vectors as computed with a Local Area Model and measured by satellite scatterometer**

**WAVE STORM ANALYSIS**

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

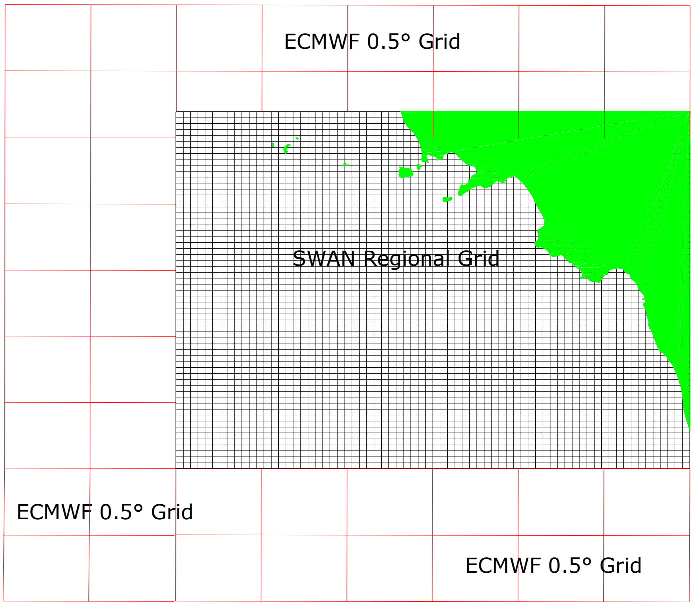



**Figure X: Matching between ECMW wave model and local SWAN grid.**

An 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 buoy owned and operated by a scientific institution (CUGRI) on 40 meter deep water, and a wave measuring staff operated by the Civil Protection Service of the Campania Region, over a 8 meter deep bottom at the Sele River mouth; wave data at different location north (Ponza) and south (Cetraro) of the area are also available from the National Wave Measuring Network (RON). During the same time interval the ESA Envisat Satellite provided three SAR images of the area (Figure X).

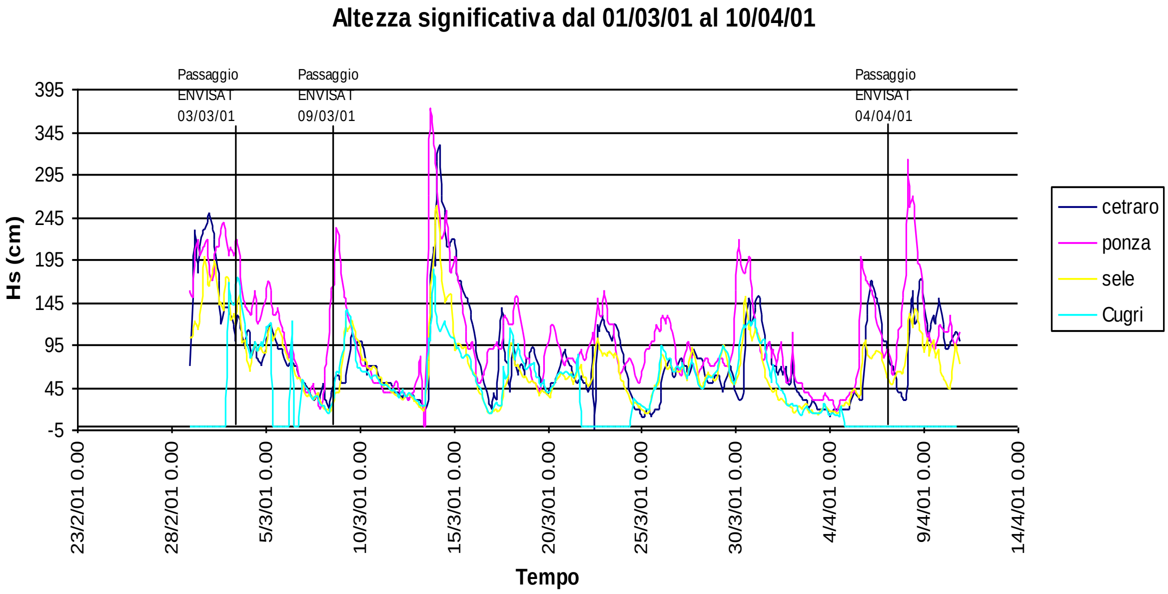



**Figure X: Simulated wave field and various SAR images features**

All this information provides an interesting benchmark for different experimental and analysis techniques (Giarrusso et al., 2004, Pugliese Carratelli et al., 2005 and 2006).
Besides that, a very important possibility, first considered by Abdalla and Cavaleri (2002), is to provide an indication of small scale spatial storm variability: the stream of altimeter (ESR, ENVISAT and TOPEX) wind and significant wave data, acquired at intervals a few kilometres can be used to provide an indication of such variability ("gustyness") on a scale that is far lower than the resolution of meteorological models – present, and probably also future. It is likely that gustyness is an important element in understanding extreme wave distribution, even though there are still open questions before satellite estimates become reliable enough to provide a quantitative estimate of the phenomenon.
Some examples will be given in the paper from both the Mediterranean and the Arabic Gulf.

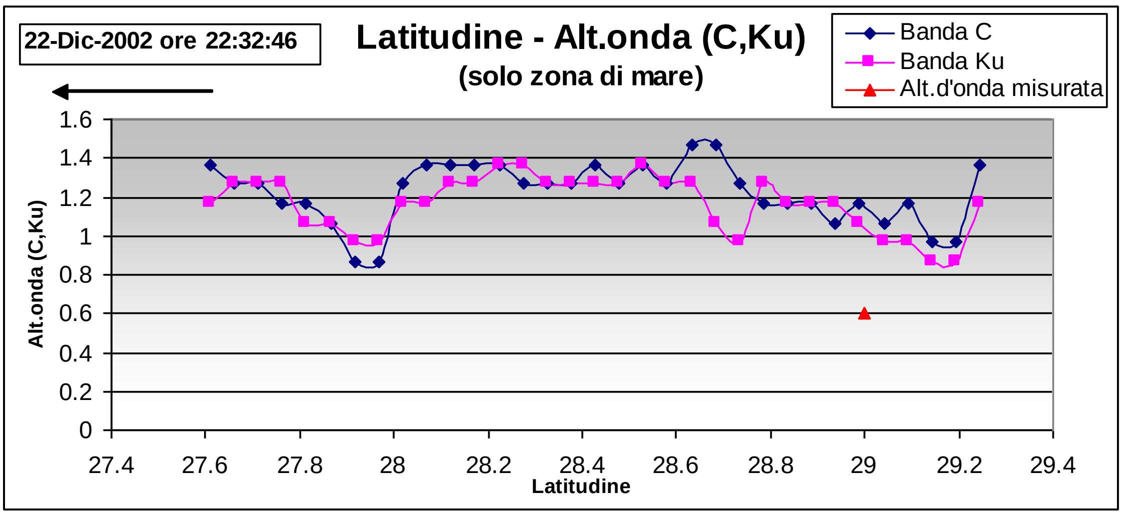
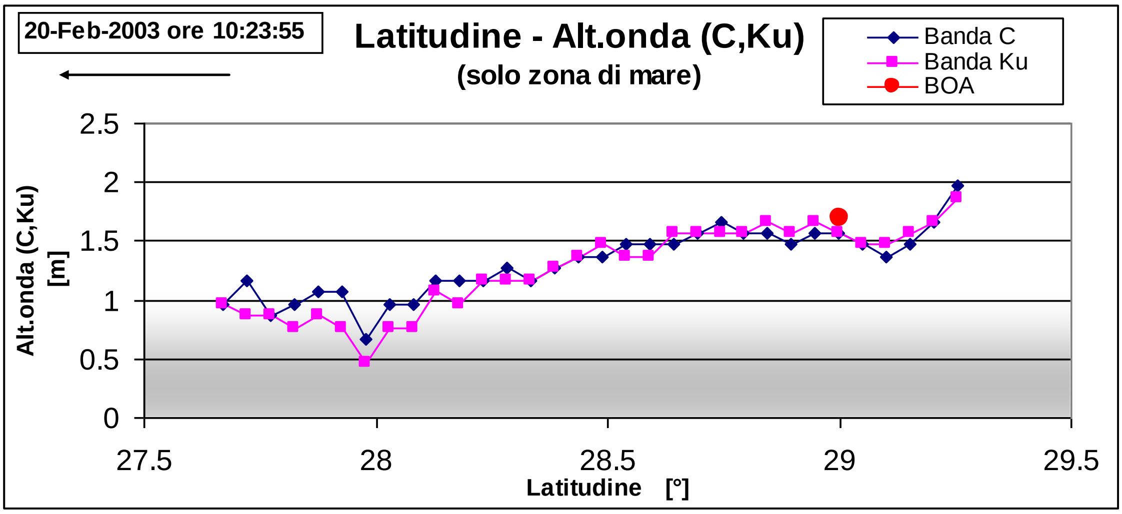
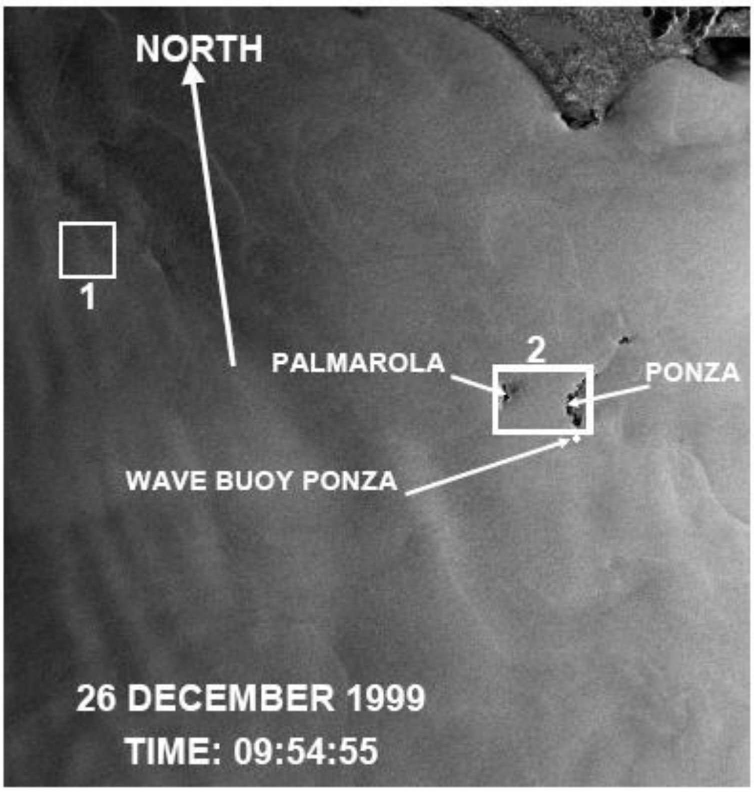


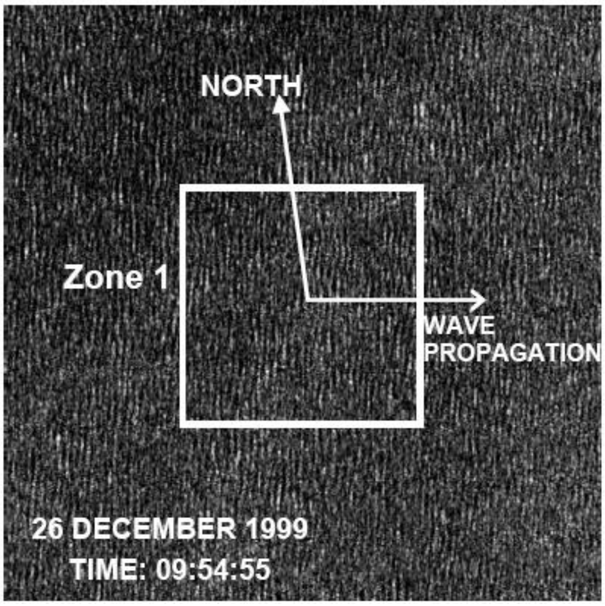

Figure 2: December 2002 Significant wave height form Topex altimeter-

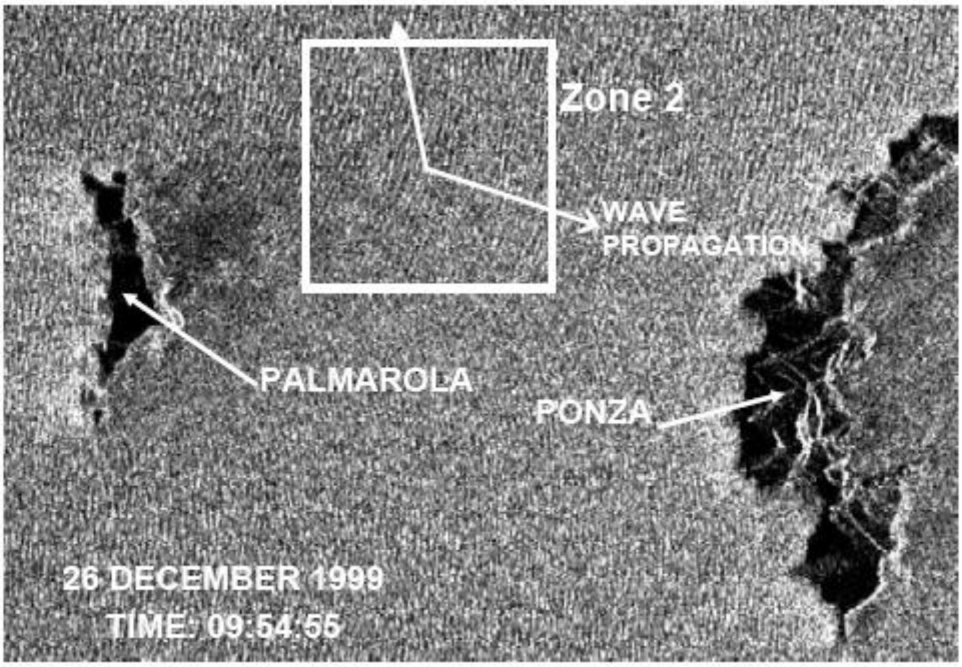



As for SAR (Synthetic Aperture Radar) images, a theory for the extraction of wave field information was constructed in the early nineties (Hasselmann et al. ), so that wave spectra have been routinely provided by ESA satellites (ERS–1, ERS–2 and ENVISAT) for many years. This is still however still impossible in confined seas, where the wavelength is often too small for the spatial resolution of present day satellite SARs, but it could become a distinct possibility as new satellites data from TerraSAR-X and COSMO-SkyMed will be available. SAR data are however already a precious help because of the detailed information they can provide on the spatial distribution of wind and wave fields.
Same examples are reported in following figures.
Figure Nr shows a SAR image around the northen Ponza buoy. The image gives an outline of the general situation in the area.



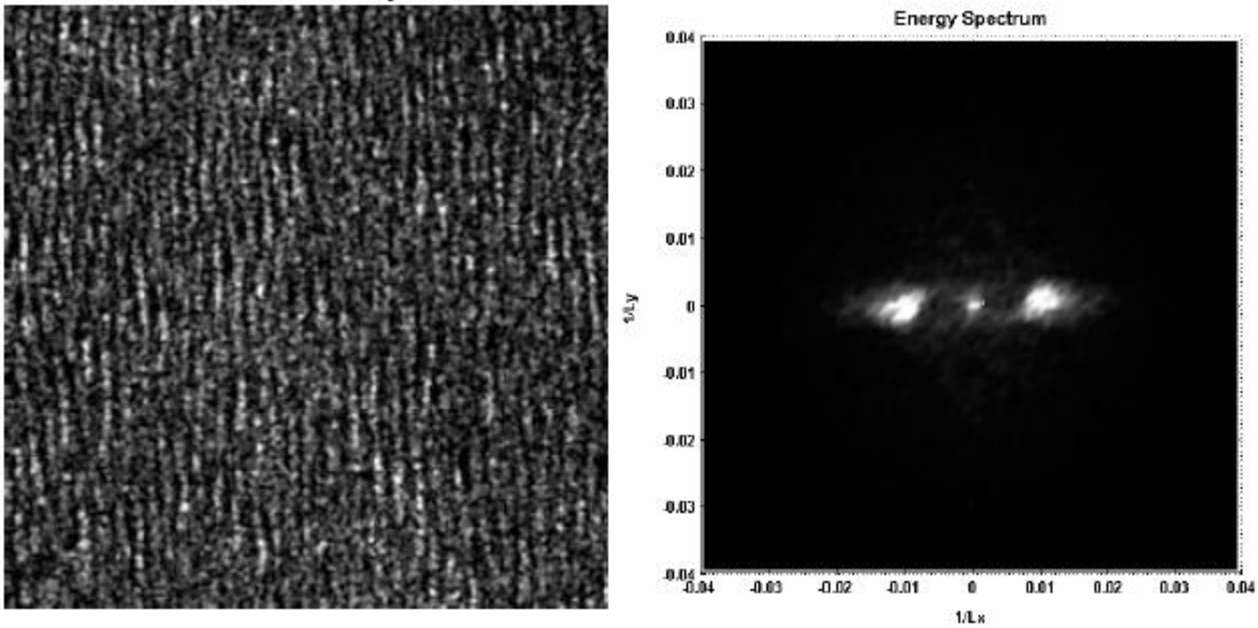
Wave parameters measured at 09:00 the Ponza buoy (about 1 km south of the islands) are: Hs = 1.70 m, Tm = 5.3 s, Tp = 6.7 s, propagation direction = 66°.Wind direction, as measured from the local anemometer in the Ponza island itself is 250° and its 10 meter velocity $V_{10}$ is 6.5 $ms^{-1}$ while the same value at the nearest ECMWF grid point is about 4 $ms^{-1}$. Figures 3 and 4 give an enlarged view of areas 1 and 2 respectively.



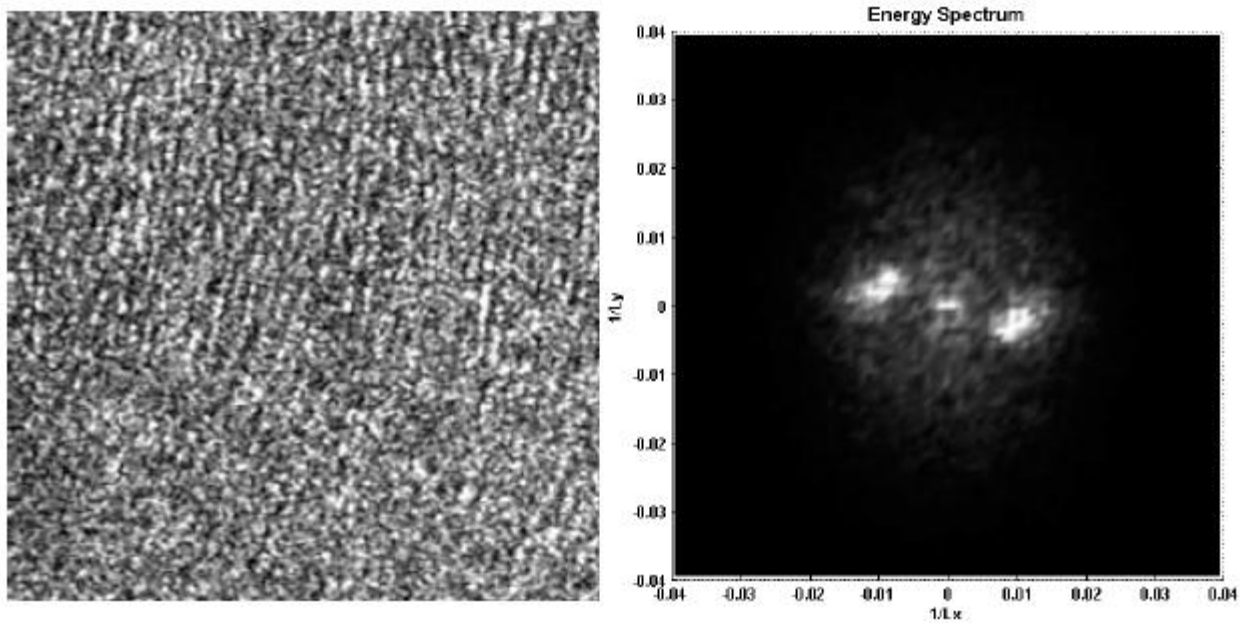




The image texture is clear enough to detect the wave fronts, and to evaluate the wave direction, both for location 1 and 2. Power spectra of the pixel intensity values were also calculated (figures 3a and 4a).

**Zone 1: 256 x 256 pixel**




**Zone 2: 256 x 256 pixel**




The only information that can be gathered form such an elaboration is an estimate of the wave direction – or at least of the direction of those components whose length is grater than about 60 meters. The correspondence between reflectance spectrum and actual wave is a classical research subject, and some new elements are produced in Pugliese Carratelli et al. (2007). It is interesting to consider, however, that according to the results by De Carolis et al. (2004) in similar circumstances, there seems to be no substantial advantage in making use of Hasselmann's method. In both cases, it is well evident that the average direction as obtained from the spectrum roughly coincides with the direction estimated from the image: nearly exactly along x axis for area 1, i.e. about from about 281.5° since satellite descending orbit direction is about 8.5° to the west.; and about 300° or area 2. As for the average wavelength, the spectrum centre seems to be located at about 1/L = 0,010 which yields an average wavelength of 100 meters; there seems to be

no visible component beyond 1/L = 0,015 i.e. L = 65, as it was to be expect according to the resolution limit mentioned above.
Further possible uses of SAR data – still at the pre-application phase – concern the evaluation of the probability of extreme waves within a storm and the monitoring of shallow water sand banks.

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