Application of Satellite SAR images to Sea and Wind Monitoring in Coastal Seas

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ABSTRACT: Wind velocity and wave height data from satellite – borne sensors such as radio altimeters and radiometers are now widely employed to assess ocean wave climate; their effectiveness is however limited over enclosed seas and along coastal areas since the complex morphology may cause sharp variations of the sea surface conditions. In these situations an important role may be accomplished by making use of SAR ("Synthetic Aperture Radar") imagery, which provides a global view of large areas and helps to highlight a number of important coastal phenomena. It is thus easily understandable why the interest in radar satellite data is rapidly increasing – especially so since the new ESA Envisat satellite has made a wealth of new SAR products available to end users. On the other hand, interpreting such data is far form being easy, since a radar image of the sea surface – and particularly a SAR image – is the result of a complex reconstruction procedure. In order to highlight different physical effects on the radar cross section and therefore on the images, some results are given from a test site along the coast of the Campania Region in Italy, together with simulation results in the Malacca Straits.

SAR data have been routinely employed for many years to evaluate wave spectra over the oceans, and now also non – spectral procedures to assess extreme waves are being tested.

The effectiveness of such methods over enclosed seas and along coastal areas, however, is severely limited. On the one hand the present resolution of satellite SAR is too low to be of any use with the relatively short wavelengths which are often encountered under short fetch conditions; on the other hand, the complex morphology of coastal bathymetry and topography often causes sharp variations of the sea surface conditions which can be very difficult to interpret.

In order to understand why this happens, it is useful to remember that the backscattering of EM waves relevant to SAR imaging depends on both the roughness (capillary waves and whitecaps) of the sea surface, which can be thought of as the short wave (SW) part of the spectrum and on the angle between the local sea surface and the radar look direction, which is determined by longer wavelengths (LW).

It is worth noting that the definition of SW as used in the remote sensing literature (wavelengths of up to a few tenth of centimetres) does not coincide with the definition normally used in engineering, where waves shorter than a few meters are seldom considered, and the term "long waves" often applies to swell.

The features of interest to oceanography and maritime engineering can thus only be revealed by considering their separate effects on SW and LW; in principle, of course, both SW and LW are caused by the wind, but while the former depends on the local and instantaneous wind velocity, the latter derives from long term action of wind over long distance.

Averaging over a large surface, the tilting effect deriving from LW becomes less important, so that wind speed can be estimated through reliable models – originally derived for the scatterometer, which have been available for quite a long time (see for instance Bentamy et al. 1995, Monaldo and Kerbaol, 2003).

On the contrary, evaluating effects of the LW part of the spectrum on the local radar backscattering cross section is much more delicate, as it implies an understanding of the so called modulation of SW by LW, which is far from being fully clear as it is not taken into account by any well tested model; the situation is further complicated by the image reconstruction mechanism of SAR, which introduces a positioning error due to the wave orbital velocity. The problem is fully described and defined in Romeiser & Alpers (1997), but research is still active on this subject; a recent numerical pseudo random approach is reported in Pugliese Carratelli et al. (2006).

Spectral shapes, for wavelengths higher than the resolution (twenty metres or more for satellite SAR) are routinely computed through an algorithm originated by Hasselmann & Hasselmann (1991), and alternative semi-empirical approaches have been tested over the years (Wang & Jensen 1993, Schulz-Stellenfleth & Lehner 2006), but – as stated above – this is seldom possible in enclosed seas. A recent paper by De Carolis et al. (2004) reports some results applied to a Mediterranean storm, but this seems to be more the exception than the rule.

Given all these constraints, it follows that remote sensing can only be of use in practical coastal engineering if all the underlying physical processes are fully understood and taken into account; besides, since the information gathered from images does not normally provide quantitative data on either the sea state or the wind field, SAR remote sensing only makes sense if it is considered within an integrated monitoring system.

In the following a test case is described along the coast of the Campania Region in Italy, where SAR images from ERS – 2 satellite were available at the same time as adequate data on sea state and wind field from both field instrumentation and computer modelling (Giarrusso et al. 2005, Pugliese Carratelli et al. 2005).

At the time of ERS – 2 SAR passage at 21:14 on the 9th March 2001 (Fig. 1) 2 wave meters located at different depth were operating in the bay of Salerno (Campania, Italy). One wave buoy and one wave measuring pole were located at a depth of 40 and 90 metres respectively.

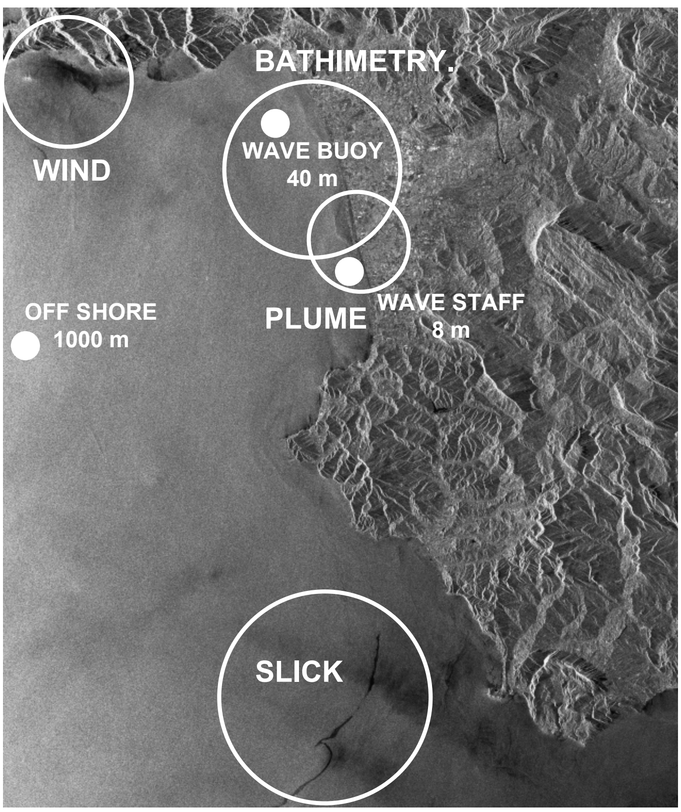

Figure 1. Test areas.

The image will be examined in order to highlight different physical effects on the radar cross section.

Combination of wave meters data and SWAN wave model simulation show a wave field offshore (Fig. 2) of about 1.00 metre significant height.

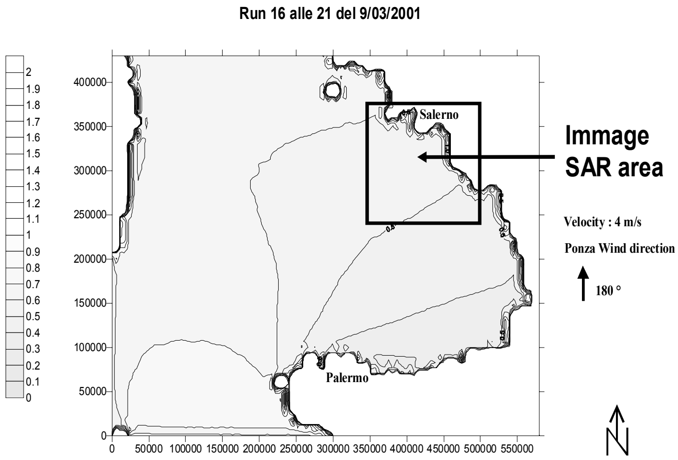

Figure 2. Wave field simulation.

Significant wave height measured at offshore was about 0.90 m, increasing to 1.2 m at the staff, mostly because of the shoaling effect.

Wave periods and therefore wave lengths were far too short to allow for any spectral analysis. Band values, averaged over a number of adjacent pixels provide information on both wave height and wind velocity. The following table yields the he values for 30 pixel areas around the wave meters and at an offshore water location.

Table 1. Band value for pixel of test areas.

LOCATION	DEPTH m	BAND VALUE Max	BAND VALUE Min	BAND VALUE Av.	BAND VALUE St. Dev.
WAVE BUOY	40	1007	118	**461.24**	136.12
WAVE STAFF	8	760	83	**377.88**	123.86
OFFSHORE	>100	1796	120	**675.56**	241.07

Two opposite mechanisms seem to be acting: offshore wind causes a stronger backscattering offshore (675.56) than at the buoy (461.24), even though according to the SWAN simulation the wave height is approximately the same; whereas the shallow water effects near the coasts cause an increase of the wave height on shallow water zone and therefore a change in the LW part of the spectrum which affects the radar cross section.

When averaged band values on points on 20 metres depth are systematically compared with their counterparts closer to shore on 10 metres depth, the cross section is nearly always lower, as shown in Figure 3.

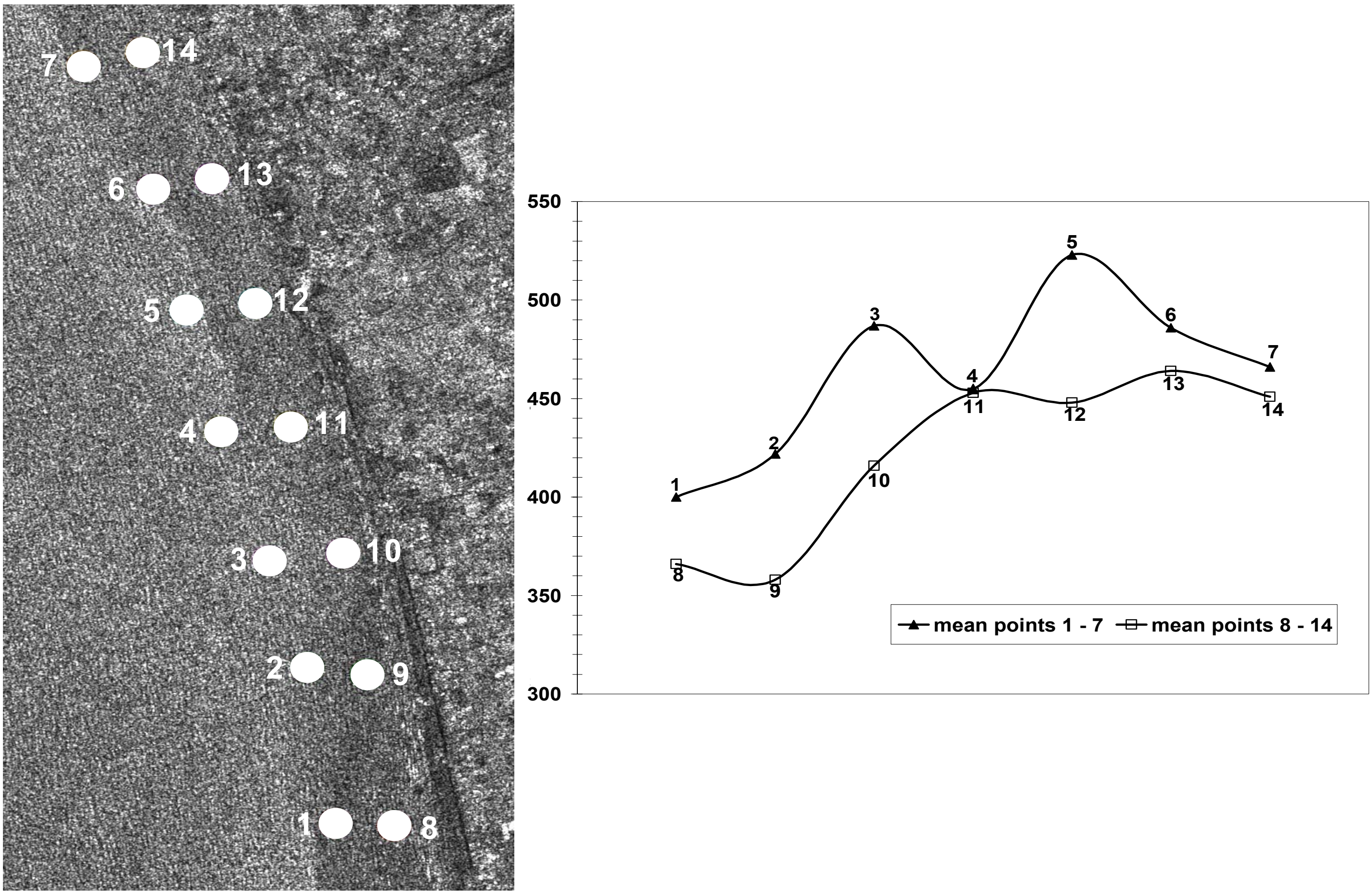

Figure 3.Bathimetry effects.

The reduction in the radar cross section is relatively small, as was to be expected since it is mostly due the changes on wave slope caused by the bottom effects and not on the short wave part of the spectrum.

The former kind of changes can be easily taken into account by making use of state-of-the-art models such as SWAN. A typical example (Fig. 4) shows some 1-d results carried for a literature test case (from Romeiser et al. 1997).

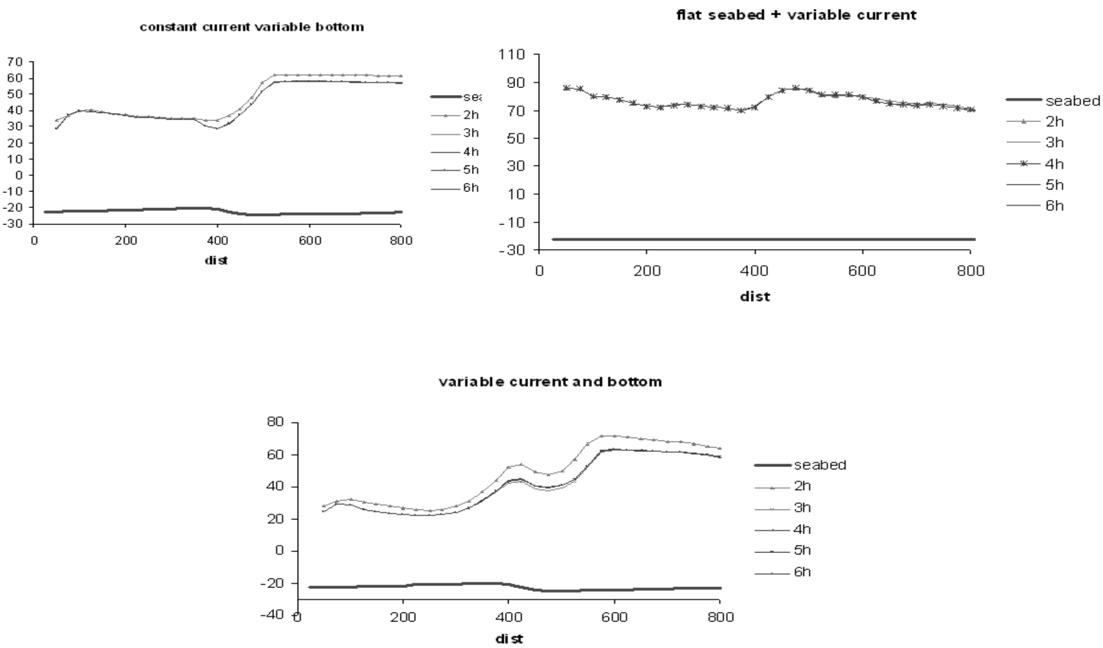

Figure 4. Influence of water depth on wave characteristics.

It is well worth noting that in some circumstances the interaction between currents and waves (Doppler) is more important than the simple shoaling: the bathymetry influences the current velocity, which in turn affects the waves.

This could be the case of an enclosed sea as the Persian Gulf, and this is certainly the case depicted in Figure 5, where a numerical experiment is shown to evaluate the influence of the current on wave field characteristics such as significant wave height and steepness in the Malacca straits.

coastline. Wind speed reduction or even stagnation on the wind side of a mountain is of course a well known phenomenon. It increases with the spanwise to extension of the coast as well as with its height (Bauer et al. 2000), and SAR imagery seems to provide a useful tool when analysing such an effect.

Finally, the effect of floating pollutants or surfactants is a widely studied subject, which needs not be discussed in this paper; the long dark line on the southern side of the image points out to a possible oil slick, and the grey level distribution

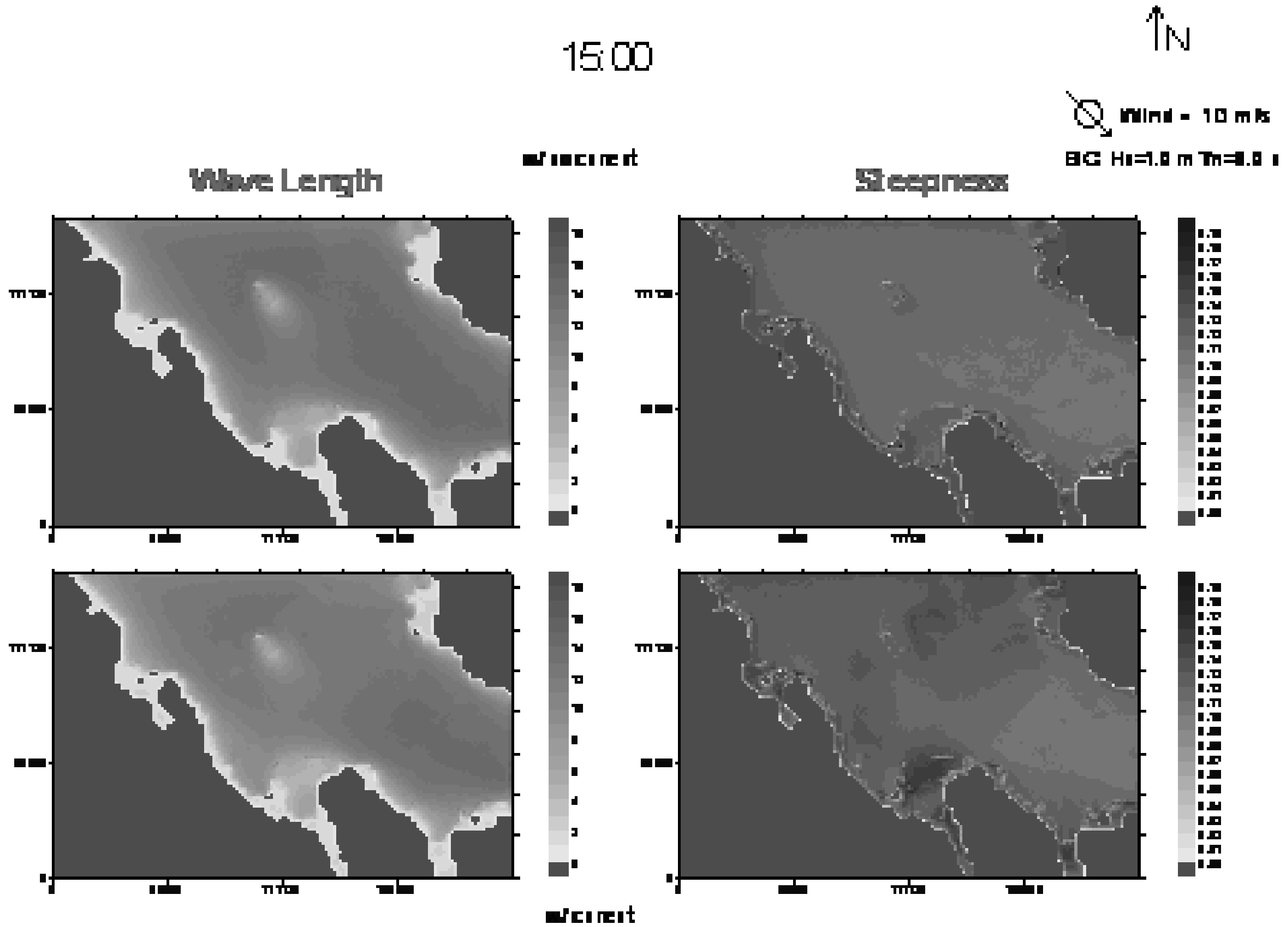

Figure 5. Influence of currents on LW field.

Current field was here simulated by making use of a POM model and the results were supplied to SWAN thus providing a simulated wave field which bears some relevant resemblance to the SAR image.

An entirely different situation is highlighted in the upper left part of the image (Fig. 1); wave height does not change, but the band values change sharply not only in their average values, but also in their frequency distribution as shown in Figure 6.

This seems to point out to a sharp reduction in the wind field on the windward side of the rather high

(Fig. 7) is a useful way of identifying and quantifying it.

It is worth mentioning here that the effects of fresh water on SW and therefore on the radar scattering are not as well understood as those deriving from floating oil; Figure 8 shows quite clearly the outflow from a river mouth outflow, but the reason for a darker grey lever surrounded by a thin whiter line are not completely clear.

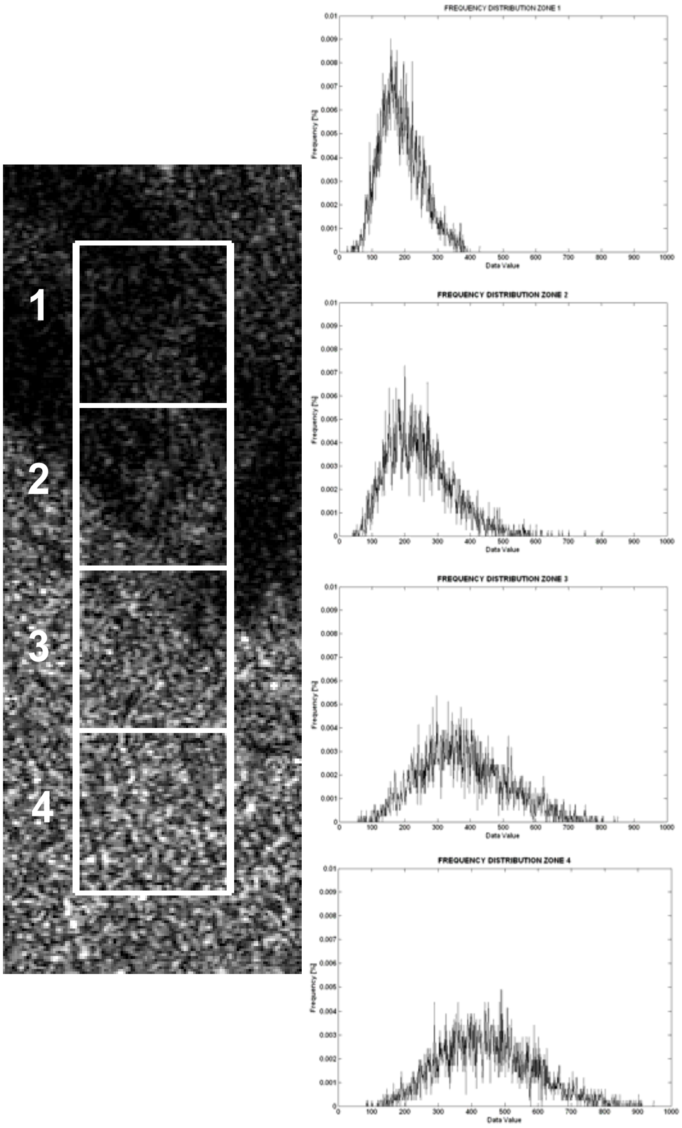

Figure 6. Wind effects.

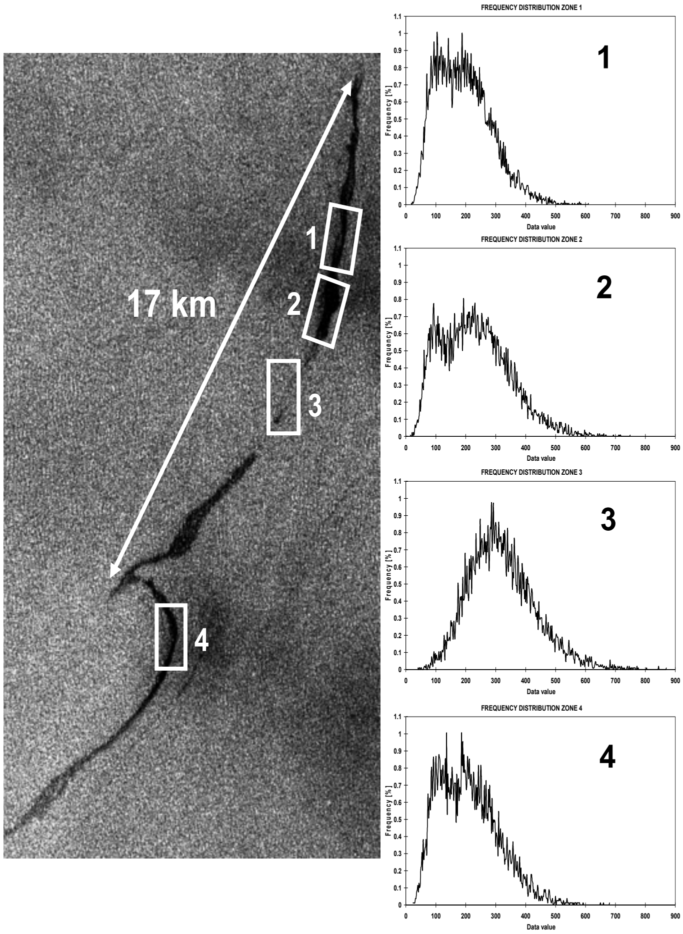

Figure 7. Floating pollutant.

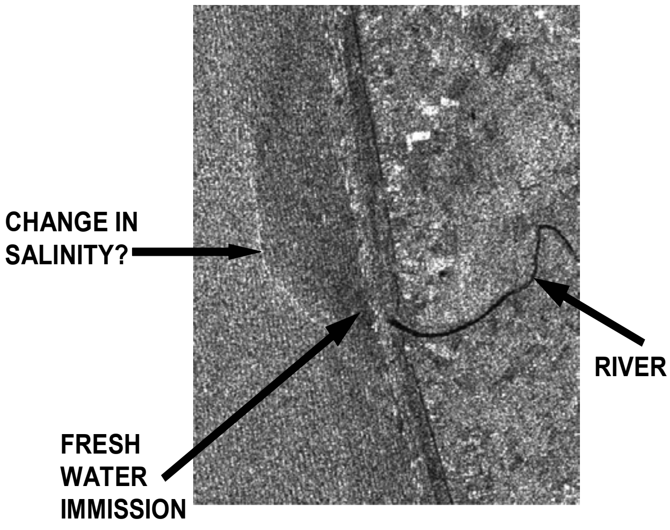

Figure 8. River outflow effects.

CONCLUSION

SAR satellite imagery can provide useful information on wave and wind processes in enclosed seas and help understanding circulation, wave and wind dynamics and locating pollution sources. This can only be done if all available data are integrated with up to date wave modelling techniques in order to achieve a sound physical comprehension of the relevant phenomena.

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