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EROSION AND STORM HAZARD MAPPING AND REAL TIME MONITORING THE ROLE OF REMOTE SENSING AND REAL TIME SYSTEMS

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Abstract:

The development as well as the protection of existing infrastructure in coastal areas requires a careful assessment of the risks deriving from wave action and from coastal erosion as well as the provision of real time warning and damage assessment systems. Besides, disasters connected to sea water pollution, even though very different from those related to wave action, share with them a number of problems and solution, and it is reasonable to assume that they should also share some of the prevention and abatement methods. A recent concern is also the protection, or the reduction of damage from tsunamis, i.e. earthquake generated long waves.

The paper gives a general outline of the technical and scientific problems related to the methods and the procedures for coastal hazard management

Coastal hazards are of course mostly felt along the coasts of the oceans, where the wave action is extremely strong; but enclosed or semi enclosed seas like the Mediterranean, the Black Sea, or the Arabian Gulf have their own specific problems, since the economic interests connected with seaside tourism have placed very densely populated coastal areas and valuable infrastructure within easy reach of wave action.

The design of coastal structures is of course a very old problem and a well established research sector; what is relatively new, however, is the concept of planning the protection of a whole coastal area on a large scale; carrying out such a task requires the integration of various complex tools such as meteorological, wave and circulation models, monitoring equipment, and remote sensing systems (Giarrusso et al, 1999, Ewing et al 2005, Mai et al 2005).

Background:

Disaster management of the costal zone activities can take two forms: the production of hazard scenarios (“static” measures) and the setting up of a forecasting and alert system (“dynamic”).

The first activity, which requires the evaluation of the probability of damage is a necessary requirement for the general planning of public works and activities: such information must be used by the Authorities as a planning tool in order to identify the needs and the priorities of structural actions such as shore protection works.

Forecast and alert (“dynamic”) systems should provide the Authorities with adequate warning of potentially dangerous storms and of their likely effects, the objective being thus of reducing the damage by alerting emergency services and – if possible – by taking pre-emptive measures such as interrupting marine, rail and road circulation and evacuating buildings and beaches.

It is also clear that a proper design of an alert system should be based on the best possible previous knowledge of the hazard scenarios; which in turn must be updated and calibrated during the operation of the alert system- the two aspects are therefore closely interconnected.

The planners have to provide a flexible and modular procedure in order to allow for periodic refinements and revisions. The operating experience will suggest changes and improvements which may vary from the calibration of parameters to the updating of hazard map

It is useful to introduce a distinction between erosion and flooding hazards, the former being those deriving from damage to houses and infrastructure caused by the removal or the collapse of the foundation ground due to beach erosion, while flooding or run up hazards are those directly caused by wave action. The two things are of course related since on the one hand it is the wave action which causes erosion, while in turn erosion processes cause changes of the shoreline that put the inhabited areas within reach of extreme wave run up.

A further classification should be introduced, based on the time scales involved. Short term risk is related to the damage which might be caused by a storm, given the present configuration of the coastline; long term (n years) risk is related to the damage that a storm will cause if it occurs when the coastline is changed due to erosion within n years. Of course both risks are characterized by their probability or return period.

A coastal hazard assessment should thus provide one or more maps with different scenarios, for the short term risk and for different risk time scales n (for instance, following a common practise, n=3 and n=10 years). Each of these scenarios should report the coastline estimated position and the flooded areas for various return times and various damage level.

The physical processes leading to coastal damage on the coast can be divided somewhat arbitrarily, but conveniently for our purposes – into two large blocks (Giarrusso et al, 1999)

1) wave transformation, run up and shore damage.

2) wind and wave field formation.

A costal hazard management system must be based upon a set of procedures, models and data sources aimed at simulating these processes: an early warning system ("dynamic") will make use of real time data and modeling software, while the drafting of hazard maps ("static") will need statistical elaborations of the results
In both cases, however, the two blocks must be divided into sub-blocks while the complexity, accuracy and detail of the models and of the data sources to be employed will vary according to the time, budget and quality of available data.

Wave transformation, run up and shore damage

It is obvious that the tools needed analyse coastal hazard very much coincide with the methods of coastal engineering: research on wave transformation, run up and actions on coastal structures is of course very active and plenty of results are available for the design of harbours and coastal protection structures such as groynes and breakwaters.

The difference is largely a matter of scale, as these results must be extended, adapted and verified to the special needs of risk assessment of large coastal areas; the physical dimension of the problem are often huge, as they may involve tens of kilometers of coastline, and the results have to be frequently updated to account for natural or man made changes of the areas: hence the need for efficient hazard assessment procedures, including with this term not only formulas and software, but also data collection and analysis techniques. This obviously requires a close integration of the numerical models of the physical processes with continuously updated Digital Terrain Models.

Besides, the shape of inhabited coasts is usually rather complex, and many of the structures and buildings located near the shoreline are in a way "soft" targets, much more liable to wave damage than purpose built coastal works.

The available tools include all sort of formulas some of which simply yield the run up length as a function of the significant wave height; some other expressions provide more complex parameters such as the number of overtopping waves or the flow rate. All the formulas, however, necessarily refer to a simple geometry, e.g. to sea walls or to beaches without obstructions. (Cocco et al, 2001)

In real life applications inhabited coasts present a complex cross section also because of artificial structures – such as walls, railways, buildings – vertical or nearly vertical obstacles so that run up formulas may fail. Submerged breakwater, bars and troughs may further complicate the configuration. Numerical modelling offers a greater flexibility, but they require a higher computational time – a constraint that is becoming less and less important - and a greater detail of topographical and bathymetric data. The reader is referred to Giarrusso et al (2000) for an outline of the effects of complex cross section and steep obstacles on the results

In any case, the input data for any model must include a full description of the of the coastal area, including the bathimetry and a reliable estimation of the wave – or waves – likely to cause damage. The former aspect confirms again the necessity of a close integration, and possibly extension to the submarine area, of the existing DTMs.

The latter problem can be re-conducted to the estimation of storm parameters such as the significant wave height Hs and peak period Tp, a classical problem of maritime engineering; however relating the time description of the run up and of the overtopping to the expected damage is a problem in itself. A typical approach is described in Giarrusso et al (2002).

Once the relationship between Hs – and possibly Tp – is known, it is then an easy task to calculate the run up length, and therefore the hazard area for a given damage level. The variation of water level due to tides adds little to the conceptual difficulty

Wind and wave field formation

Wave climate assessment is obviously all-important in the evaluation of coastal hazards. For locations where there is not enough wavemeter data to provide a reasonably long history of wave heights, the now standard procedure is to provide a synthetized estimate of the storm statistics by making use of a model chain: Global Weather Model Analysis-Local Area Model – Wave Generation Model

10-m wind Analysis and Re-analysis data are now widely available from Global Meteorological services, such as for instance ECMWF, over various mesh sizes; also wave fields computed from state of the art models are often provided, so it is quite possible to build a whole time history – ranging for up to 40-odd years of wave data. A similar procedure has been for instance applied by Rakha et al. (2007), who provided an extended wave atlas to the ROPME sea.

Fig 1 gives an example of the ECMWF Wave model grid over the Southern Tyrrhenian Sea; a greater spatial detail can be obtained by nesting a finer wave model (SWAN, in this case) within the larger grid.

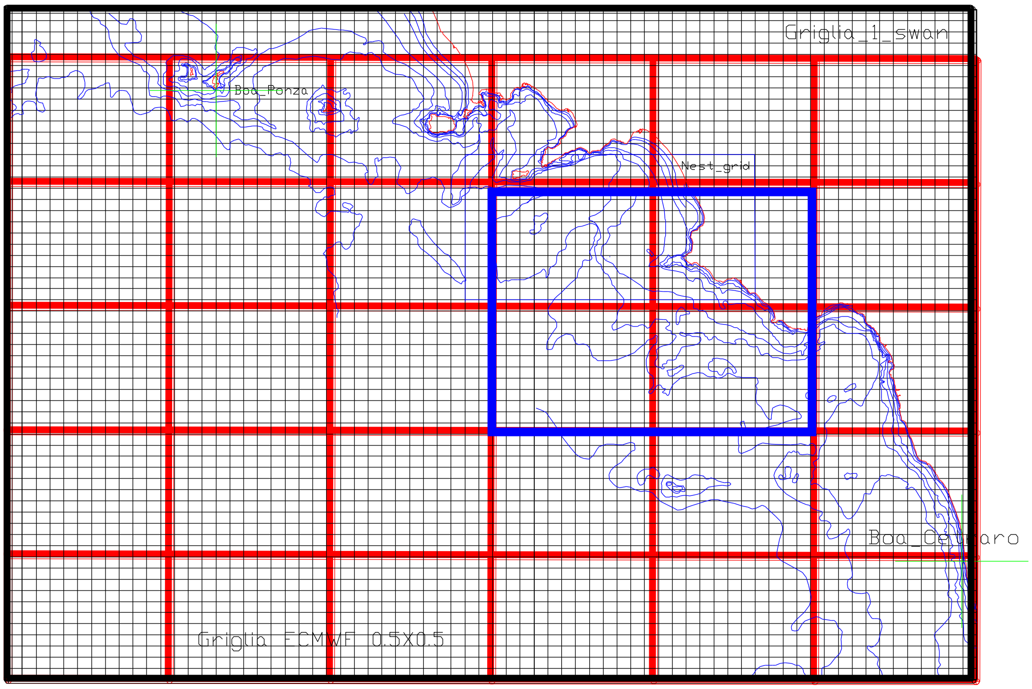


Fig 1: Global Weather and Wave Model (red) and nested SWAN grid (blue)

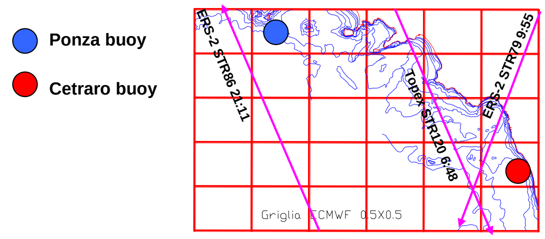
Appealing as this procedure may look, it implies a serious risk of under-evaluating extreme events, mostly because of the difficulty of taking into account subgrid phenomena, i.e. storms peaks which take place on a scale smaller than the computational spatial grids or time steps; the resolution can be improved by fitting a Local Area Model in the global grid on the areas of interest, but there is definitively a limit to the accuracy of weather models.

The first and most obvious use of satellite data (Della Rocca et al 2002), is to provide the possibility of verifying or calibrating the results of model-based procedures for coastal hazard evaluation.

The reliability of significant wave height radar altimeter measurements dates back to the eighties and is now well tested, but the time coverage of a small basin does not guarantee the availability of data at the peak of each storm. A number of practical applications are however already available: a comparison of model and altimeter data was for instance carried out by Cavaleri and Sclavo (2006), who showed the presence of both bias and scatter in the model data.

Also an important application of satellite altimeter, first considered by Abdalla and Cavaleri (2002), is to provide an indication of spatial storm variability on a smaller scale than that of the meteo grids.

Some examples are reported in Fig 3 to 6



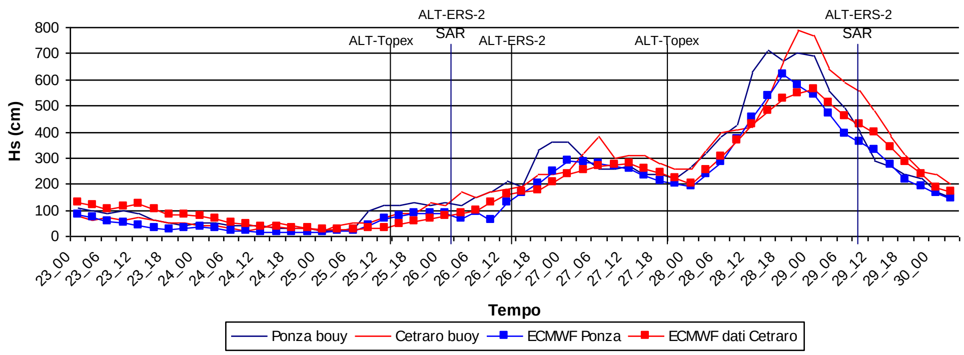


Fig 3 - Satellite, buoy, and model wave data

In December 1999 the strongest ever recorded sea storm struck the Southern Tyrrhenian sea; even though no satellite passages are available at the peak, a careful comparison of all available data, such as in fig 4, confirms on the one hand that altimeter data are fully consistent with buoy measurements; and on the other the limits of modelling techniques.

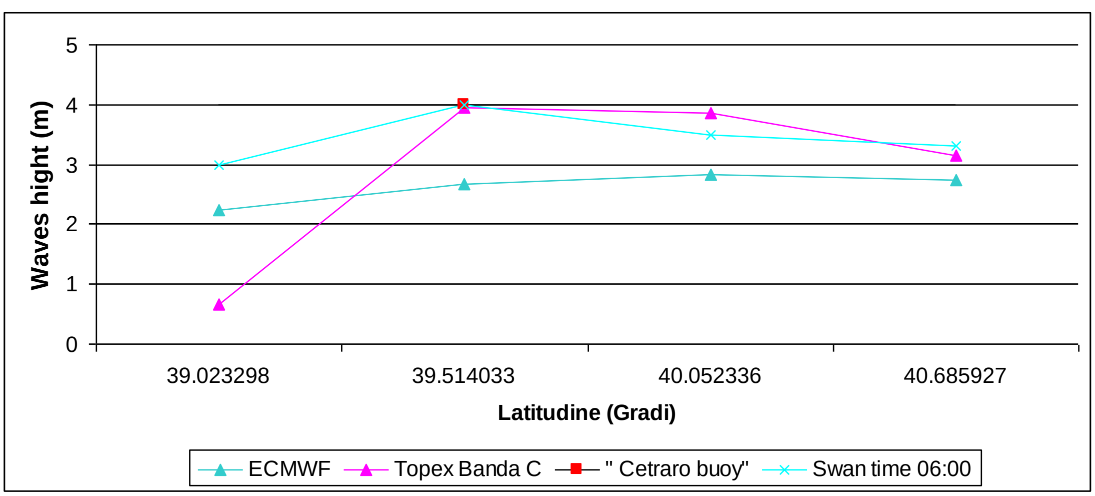
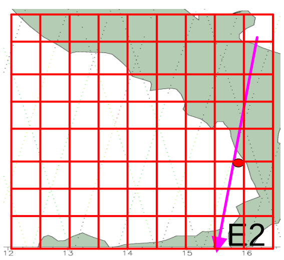


Fig 4 - 28/12/1999 TOPEX STR-120 (06:48) versus ECMWF (06:00), ECMW/SWAN model (06:00) and buoy (06:00)

An interesting feature is the frequent presence of random variation of both wind and wave data around a generally regular trend; even though such a “gustyness” has been noticed and studied before, there are two aspects that are worth considering: on the one hand, the time scale is smaller than what expected in previous studies; on the other hand, the irregularity of wave data seems to be of the same magnitude – or even larger - than the irregularity of wind data, against all intuitive expectation.

The phenomenon seems to be present in many different situation and geographical areas (fig 5 and fig6)



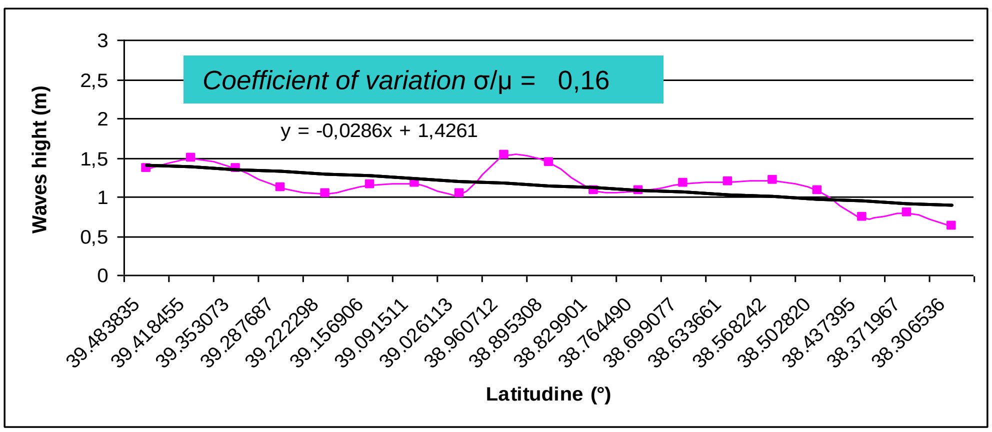
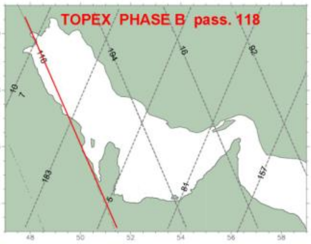


Fig 5 “gustiness” variation - ENVISAT (09:36) 23/03/2008 Southern Tyrrhenian Sea



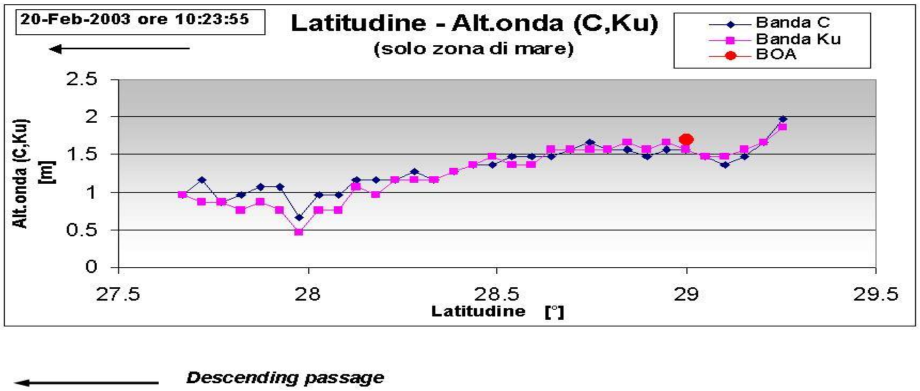


Fig 6 "gustyness" variation – Topex (09:36) 12/02/2004 - ROPME SEA (Wavemeter data from KISR Kuwait Institute for Scientific Research)

Forecasting and alert system

Real time warning and hindcasting system for wave storms are another example of application of satellite data. Even though the coverage frequency is not adequate to provide direct information for disaster monitoring, here again such data can be useful in calibrating and checking procedures which rely upon simulated data or on site measurements.

The following figures provide an example of a real time storm monitoring system meant to provide an estimate of wave effects on the coast.

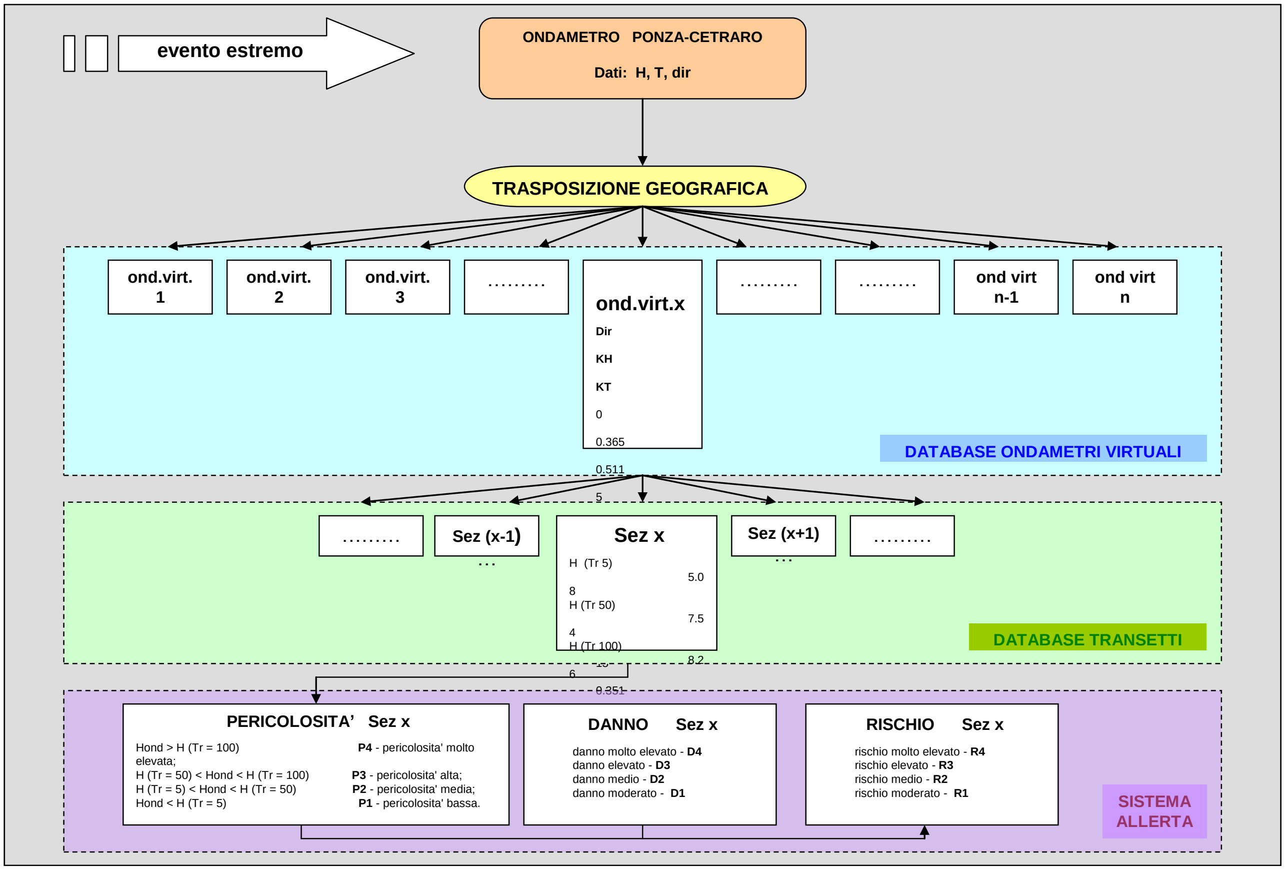


Fig 7 - Storm forecasting and real time monitoring system

In the example shown (Fig. 7), real time data are provided by a wave meter buoy located about 100 miles north of the area of interest (the Campania Region, on the Southern Tyrrhenian Sea)

A transposition procedure – which in the example implemented here is simply based on a comparison between fetches, but in principles could make use of the same modelling chain described in the previous sections – calculates the wave height on a number of “virtual wave metres” located along the coast (Fig 8)

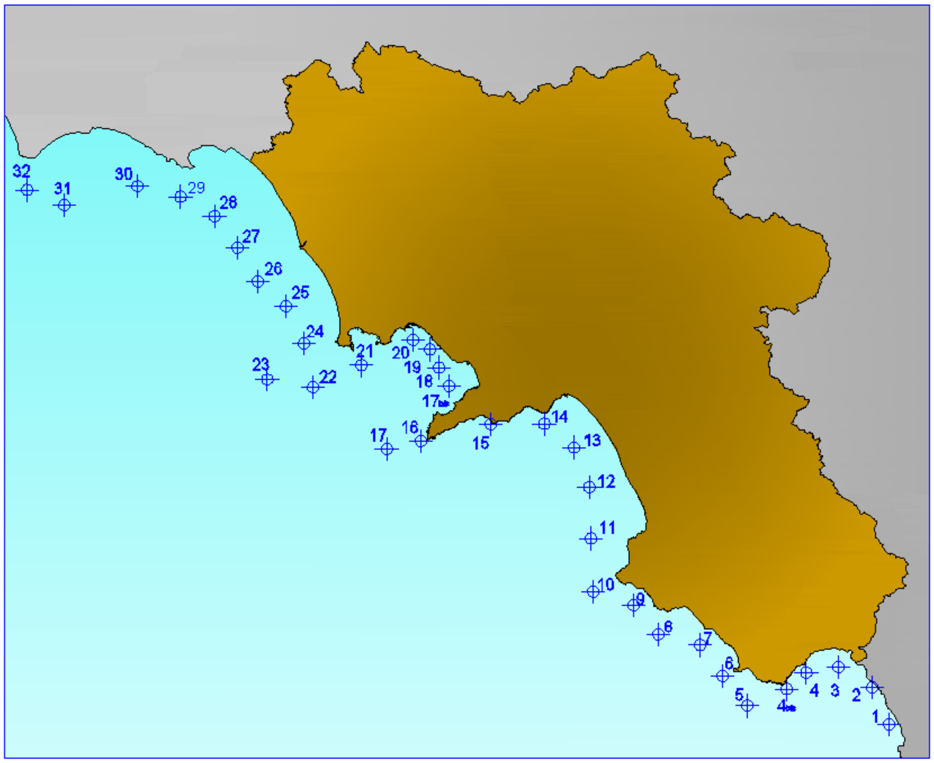


Fig 8 "virtual wave metres" along the coast

Wave transformation and shallow water models finally provide an estimate of the effects along the coast, with a simple colour code to visualize the risk level (Fig 9)

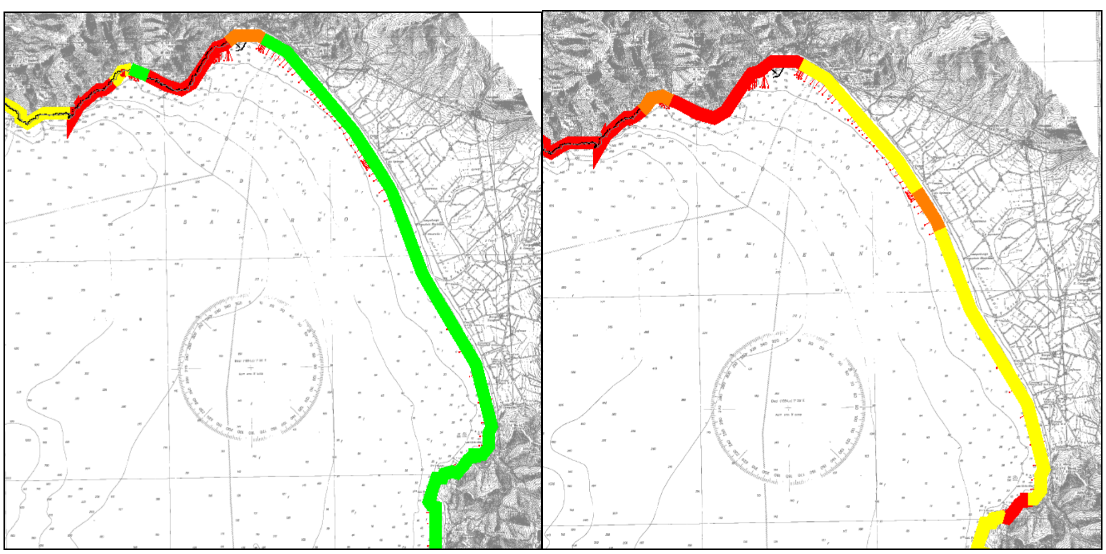


Fig 9 Real time estimated Risk level along the coast

The whole system has to be calibrated before it can work properly; altimeter satellite data are the cheapest and most efficient way to carry out such a calibration, by correlating the in site measured data at the master wave meter with those provided by the altimeter at the virtual buoy location – as for instance for location C1 and C2 (Fig 10)

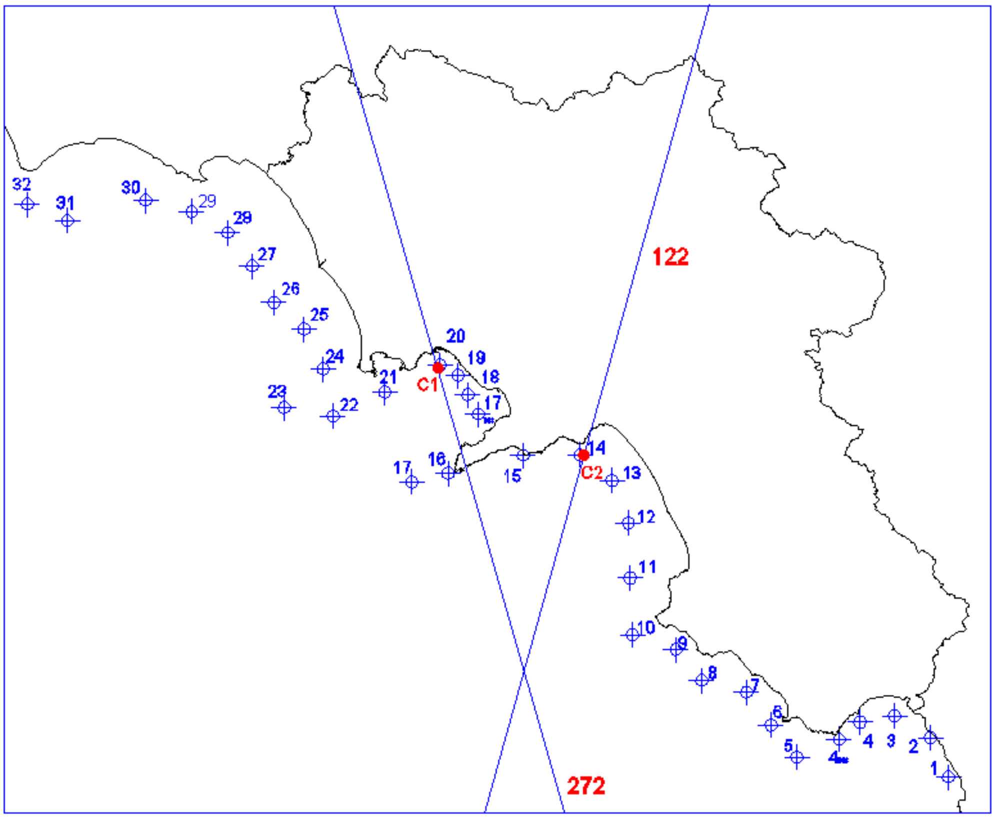


Fig 10 - Storm fore and now-casting system calibration with altimeter data

Conclusions

Satellite active sensors are an important tool, both for the preparation of contingency plans and for the calibration of real time working systems.

Even the most sophisticated models need a careful evaluation, and this can be done – even at a regional level – by making use of easily available satellite data.

A question which remains to be clarified is the origin and the effects of wave and wind data fluctuations ("gustyness") as shown by altimeter data on the scale of a few miles.

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Altimeter were acquired through Radar Altimeter Database System (RADS) http://rads.tudelft.nl/rads/rads.shtml and through ESA/EO Project 1172 “Remote Sensing of Wave Transformation”

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