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# An application of COSMO-SkyMed to coastal erosion studies

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## Abstract
Started in 2009, the COSMOCoast project aims to the investigation of the potential of Remote Sensing in support to the management of coastal areas. Particular attention is paid to the contribution of data acquired from the COSMO-SkyMed constellation, in view of their frequency of acquisitions and ground resolution; in particular this paper aims at assessing the potential of COSMO-SkyMed data for coastline delineation. The results are conceived to be of particular interest for public administration bodies in charge of coastal defense.
**Keywords:** Remote Sensing, Coastal Zones Management, COSMO-SkyMed.

## Background
According to figures produced in 2006, 42% of the Italian coast is eroding and Abruzzo (Adriatic Sea, Central Italy) was one of the most endangered Italian regions [Ferretti et al., 2006]. Coastal erosion in the area seems to be associated to morphological causes and to the increase of sea-level height on one side and on the other side to the reduced solid transport from rivers to the sea, as a consequence of extensive works carried out on the watersheds to mitigate extreme rainfall and consequent flooding [Venturini et al., 2007].
Since the 90's, Regione Abruzzo (the regional Authority of Abruzzo) was involved in studies aiming to define procedures for mitigation of coastal erosion, in compliance with the regional law 108 (23-09-1997) that promoted research activities in support to regional planning of coastal defense. The findings of such research activities, carried within the

context of the RICAMA project and of its follow up project, SICORA, are currently exploited by Regione Abruzzo in support to coastal management. Municipalities, often with funds provided by Regione Abruzzo, are also involved in such management, when local interventions to restore the beach are needed (often before the start of the summer season). In addition, in case of violent storms which have the capability to modify the coastline, the declaration of "emergency state" from the Italian Council of Ministries, with provision of funds to restore the affected beaches of Abruzzo, has also been reported (e.g. after the December 12 and 13, 2008 storms). All such protection activities come with a cost and in the deliberation of June 13, 2006 the Regional Council of Abruzzo estimated the cost to contain the ongoing erosion in 200.000.000 €; furthermore every year urgent interventions to maintain some parts of the coast are reported.

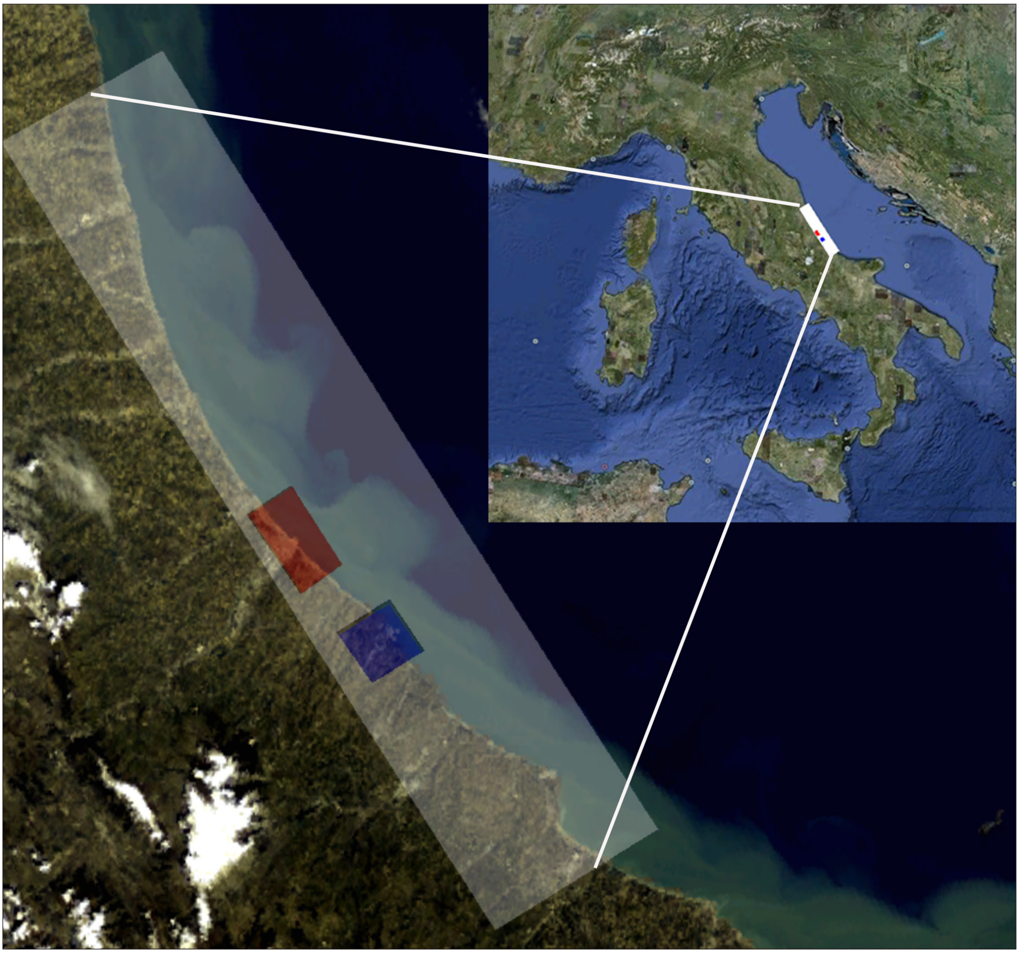

**Figure 1 - Top right: broad location of the study-areas © Google Earth optical image, bottom left detailed location over-imposed to an ENVISAT MERIS image (white: coast of Abruzzo test-site, red: Pescara test site, blue: Ortona test site).**

***Previous studies on the area***

There is an important requirement to identify tools capable to provide a synoptic view of the coastal area, offering the possibility to assess the evolution over time of the coast at regional scale and to extract at local scale dynamic information in order to allow the public administration to plan interventions or assess efficiency of past interventions.

Previous works to analyse coastal processes involving the coastline of Abruzzo account, at international level, for the EUROSION project (European Commission) which released a coastal erosion Data Base (DB) based on an update of CORINE Coastal Erosion (using data from 1985 to 1990) and mapped at 1:100.000. At national level previous works account for a National Atlas of Italian Coastal Dynamics completed in 1999 by CNR-MURST (the former Ministry of Scientific and Technological Research, National Research Council), with cartographic outputs in scale 1:100.000, for the cartographic production in scale 1:100.000 released by ENEA (the National Agency for new Technologies, Energy and Sustainable Economic Development) in 2003 and for the Geographic Information System (GIS) released by APAT (the former Agency for Environmental Protection and Technical Services) since 2005 which was based on aerial photos and LANDSAT TM data information remapped on toposheets in scale 1:25.000. At regional level coastal processes have been studied by the LIFE/RICAMA project in the late '90s and its follow-on project SICORA, which resulted in the creation and consolidation of a GIS incorporating existing data (Regional Technical Cartography maps scale 1:5000, aerial photos, local observations, DB of coastal interventions, etc.).

From the previous description it can be concluded that all existing cartographic production aiming to analyse and compare the state of coastal erosion over Abruzzo is:

- in a scale which highly hampers the quantification of erosion trends (in scale 1:100.000 the 0.2 mm line delimiting the boundary between sea and land corresponds to 20 meters, making comparisons between different age cartographic production highly unreliable).
- derived from different sources (as there exist products at more suitable scales -IGM tables 1:25000, regional cartography in a 1:5000 scale, aerial photos, etc.) each with different information extraction methodologies (often not described) and with different inherent positional errors, making comparisons between the various datasets unreliable.

In addition, based on the various environmental conditions at the time of (aerial, satellite or ground) data acquisition as well as on background and experience of the operator (data-processing, geomorphologist, engineer) who extracted the information, different definitions of coastal zones/beach/coastline can be applied: this further increases the level of uncertainty in the comparison of the information. Typically, according to a geomorphologic approach the shoreline marks the boundary between land and sea [Selby, 1985] and is a dynamic line ranging between high and low tide, but how can low tide and high tide be identified in a single date image? Furthermore, if the coastline is simply selected as the division between land and sea at the time at which the image has been taken, how the effect of tides or winds have been taken into account? Depending on the inter-tidal slope, also a low tidal excursion (less than 1 m) may in fact correspond to a range of several meters distance.

***The contribution from space***

To achieve a good coastal management plan, where most critical areas are identified and specific type of interventions are defined, a clear picture of the current situation and of

its evolution is needed. In addition, to monitor the effect of interventions, following the evolution in time of the coast after the intervention is also essential.
Although aerial photography has been used for decades as a standard technique for coastline delineation, other techniques may be used for coastline positioning and mapping or coastal erosion studies over the emerged part of the beach, such as airborne or ground based videography, LIDAR, topo/bathymetric surveys, video systems, optical satellite EO (Earth Observation) and active radar satellite EO.
In most of the cases which rely on data acquired on the ground, acquisition campaigns are affected by "traditional" limitations such as cost, weather conditions and capability to acquire data only over small areas. Satellite EO presents advantages such as the availability of repeated acquisitions over a same test site, hence offering the opportunity to extend backwards in time the analysis of variations, and the capability to instantaneously image large areas (freezing sea-state conditions, which may instead vary sensibly during surveys carried on the ground).
Use of HR and VHR satellite data for coastal monitoring studies is reported in literature for what concerns the exploitation of optical data. [Gilvear et al., 2004] reports that all the most relevant features associated to geomorphology and human impact on tidal rivers and estuaries can be detected with a 4 m ground pixel size. [Gardel and Gratiot al., 2005] demonstrated the feasibility to use high/medium resolution optical data for monitoring mud bank migration rates. [Ryu et al., 2002] derived the shoreline on tidal flats, noting in specific cases the relevance of TIR compared to NIR and SWIR, [Baiocchi et al., 2008] showed the usefulness of segmentation-based approaches for retrieval of the shoreline from VHR data. The new generation of SAR sensors (e.g. COSMO-SkyMed and TERRASAR-X) launched in the new century offers to date an opportunity to test usefulness of VHR satellite SAR data for coastal studies. Mainly due to ground resolution, in fact, SAR for shoreline mapping was used so far in in wet tropical coastal environments [Rudant et al., 1996], where optical EO would have failed.
Studies of coastal areas with EO data were limited in the past by ground resolution, observation conditions (cloud cover for optical data), cost and revisiting times. The enlarging "portfolio" of available satellites, the increased ground resolution and revisiting capacities of recent satellites, as well as the data cost policies implemented by some satellite distributing agencies (e.g. ESA or USGS) suggest today the feasibility of an integrated approach for monitoring coastal areas with EO. Observations taken by different platforms can be used to derive time-series of coastline positions to be used for the analysis and quantification of coastal processes, hence - in the case of monitoring activities - minimizing the failure risk related to the deployment of a single sensor. The COSMO-Skymed constellation, with its potential to frequently acquire data over the same area and its high spatial resolution capabilities represents a break-through in mapping and monitoring applications. In particular, for coastal areas, where high to very high resolution optical data may fail due to cloud-cover and where high resolution radar data from existing C and historic L band missions can offer a low (e.g. monthly) frequency of acquisitions (and in the case of airborne L-band it is reported a lower potential for discrimination of the exact land/water boundary – [Kim et al., 2007]), data acquired by the COSMO-SkyMed constellation can make a difference.

## Data and methods

The project focuses on two different scales of detail: the regional scale, for which the goal is to study long term changes of the Abruzzo coastline, trying to extend the timeframe covered by the new COSMO-SkyMed acquisitions with historical acquisitions taken by other radar satellites (in particular ERS and ENVISAT), and the local scale, focussing on two different test sites, representative respectively of low coast and high coast, where processes are analysed over shorter timeframes, and where COSMO timeseries are integrated with new optical high resolution acquisitions (FORMOSAT-2, KOMPSAT-2, World View II) or where archived high resolution data (IKONOS, PRISM) are used to extend backward in time the monitoring process.

**Table1 - Two weeks of satellite acquisitions over the test area.**

| Date/Time | Satellite/Mode | Ground resolution |
|---|---|---|
| July 6, 04:01 | COSMO/Spotlight | 1 m |
| July 7, 04:01 | COSMO/Spotlight | 1 m |
| July 7, 16:54 | COSMO/Spotlight | 1 m |
| July 9 04:07 | COSMO/Spotlight | 1 m |
| July 10 05:13 | COSMO/Spotlight | 1 m |
| July 10 17:00 | COSMO/Spotlight | 1 m |
| July 15, 04:49 | COSMO/Himage | 3 m |
| July 15, 16:54 | COSMO/Spotlight | 1 m |
| July 17, 08:37 | KOMPSAT-2 | 1 m (PAN) 4m (MS) |
| July 19, 08:40 | FORMOSAT-2 | 2m (PAN) 8m (MS) |
| July 21, 08:40 | FORMOSAT-2 | 2m (PAN) 8m (MS) |

Table 1 shows how the COSMO-Skymed acquisitions of first half of July 2010 were completed with optical high resolution acquisitions in the second half of the month. Use of satellites belonging to the COSMO-SkyMed constellation allowed a systematic monitoring of the test-sites offering different ground resolution/territorial coverage and enabling acquisition of data as far as twice per day, enabling to plan the acquisitions closest in time to the forecasted phenomenon to be monitored (in the specific case daily peaks of low or high tide).

The COSMO-SkyMed (COnstellation of small Satellites for Mediterranean basin Observation) system consists of a constellation of four Low Earth Orbit mid-sized satellites, each equipped with a multi-mode Synthetic Aperture Radar (SAR) operating at X-band. Several different SAR modes are available for civilian customers: Spotlight mode (metric resolutions over small images), Himage and PingPong mode (metric resolutions over tenth of km images), WideRegion and HugeRegion mode (medium to coarse -100 m) resolution over large swaths. More information can be found in [Battazza et al., 2009].

In order to validate the accuracy of the shoreline extracted by the COSMO-SkyMed data, a ground LIDAR survey (see Fig. 2) was synchronised at the same time of one COSMO-SkyMed spotlight mode acquisition, so as to image exactly the same meteomarine instant. In addition a traditional survey (kinematic GPS) was also carried out, resulting in the delineation of a coastline, averaged by the time of the survey.

Satellite data have been orthorectified using a photogrammetric rigorous model when orbital metadata and ground control points (GCP) with proper accuracy were available, and in the case of radar data a Range-Doppler method described in [Small and Schubert, 2008] was adopted.

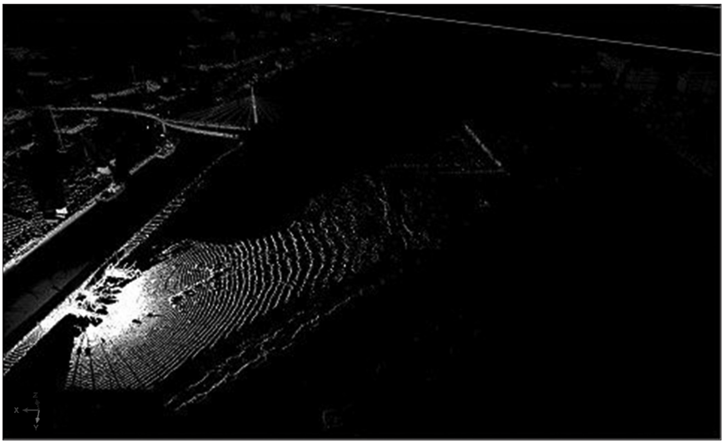

**Figure 2 - Ground LIDAR image (3D perspective). In white the areas imaged by the LIDAR. This acquisition allows to image exactly the same boundary observed from space at the same tidal condition and leaving no room for errors or uncertainties, in addition it might be used to retrieve the morphology of the shoreline.**

Object-oriented techniques for the automatic extraction of shorelines from optical data are applied, whereas for radar data a "standard" methodology widely applied for C-band data [Lee and Jurkevich, 1990] was compared with an innovative approach based on Pulse Coupled Neural Networks (PCNN). PCNN entered the field of image processing in the 1990s, following upon the publication of a new neuron model [Eckhorn et al., 1990]. Applications to the use of satellite data can be found in [Karvonen, 2004] and [Waldemark et al., 2000].
Each of the extracted coastlines is then associated to the closest tidal state observed by the Italian tide gauge network, in order to account for the positive or negative bias which may have been induced by such tidal state and increase comparability of observations taken at different times.

## Examples of results

Several optical images have been pansharpened, orthorectified and managed in an object-oriented environment to extract the shoreline. A subset of such orthorectified images is shown in Figure 3, information about the used dataset is shown in Table 2.

**Table 2 - Overview of the used optical data.**

| Satellite (sensor) | Nr images used | Bands | Wavelengths µm |
|---|---|---|---|
| IKONOS | 4 | 5 | PAN (0.45-0.90), MS(0.445-0.516; 0.506-0.595; 0.632-0.698; 0.757-0.853) |
| FORMOSAT-2 | 2 | 5 | PAN (0.45-0.90), MS(0.45-0.52; 0.52-0.60; 0.63-0.69; 0.76-0.90) |
| KOMPSAT-2 | 1 | 5 | PAN (0.50-0.90), MS(0.45-0.52; 0.52-0.60; 0.63-0.69; 0.76-0.90) |
| ALOS (PRISM) | 2 | 1 | PAN (0.52-0.77) |
| WORLDVIEW II | 1 | 9 | PAN (0.45-0.8), MS(0.400-0.450; 0.450-0.510; 0.510-0.580; 0.585-0.625; 0.630-0.690; 0.705-0.745; 0.770-0.895; 0.860-1.040) |

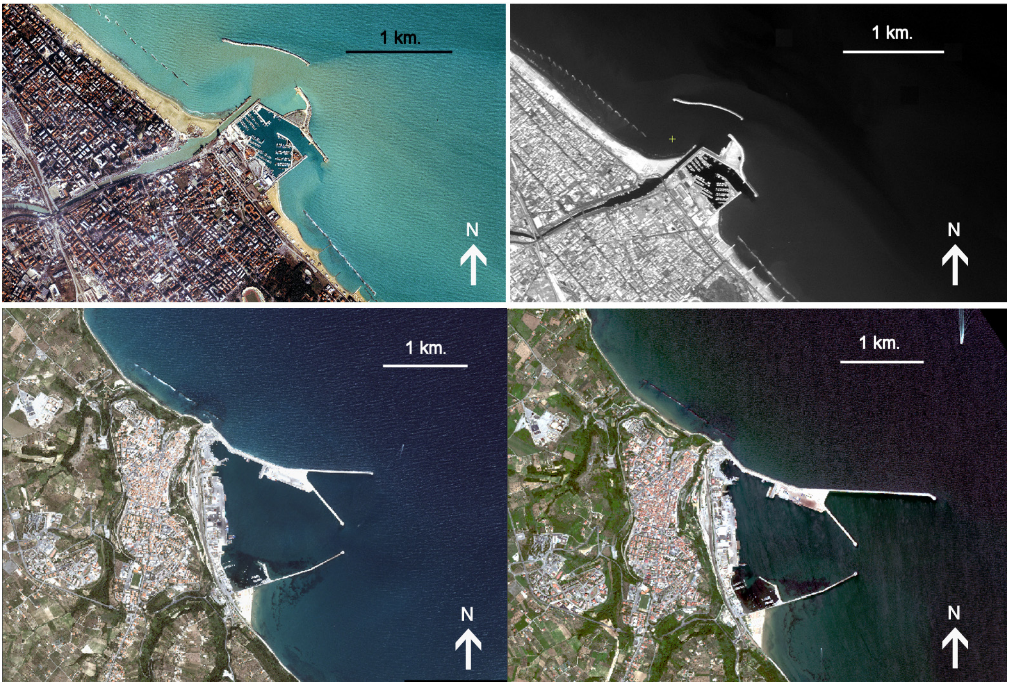


**Figure 3 - Some of the acquisitions on two test sites (Top: Pescara left: Ikonos – 29-01-2004; right: FORMOSAT-2 - 19-07- 2010; Bottom: Ortona left: Ikonos - 28-06-2007; right: WorldView-II -29-06-2010). For all the four images UTM north is up and for Pescara images are approximately 4.5 km wide while for Ortona the width is approximately 6 km.**

World View II gave the best results for the resolution that allow to reach the best accuracy and precision and also for the availability of eight multispectral bands (with one called "coastal blue" 400 - 450 nm). Table 3 provides information about precision (RMS on GCP) obtainable from some of the images used.
Geometric accuracy of IKONOS, KOMPSAT-2 and FORMOSAT-2 seems however enough to extract the location of shorelines on low-laying beaches (with slopes less than 6°). It has to be underlined that this is only geometric accuracy from the photogrammetric point of view, automatic or manual vectorialisation of the feature shoreline may add additional inaccuracy related to feature extraction uncertainties.

**Table 3 - Precision (RMS on GCP) and accuracy (RMS on CP) for some of the images used.**

| | | | GCP | | CP | |
|---|---|---|---|---|---|---|
| **Satellite** | **Acquisition (DD/MM/ YYYY)** | **Nr GCP** | **RMS X** | **RMS Y** | **RMS X** | **RMS Y** |
| IKONOS II | 28/06/2007 | 30 | 1.11 | 1.09 | 2.87 | 1.68 |
| KOMPSAT-2 | 17/07/2010 | 24 | 0.97 | 1.25 | 1.98 | 1.96 |
| FORMOSAT-2 | 19/07/2010 | 22 | 1.0 | 1.3 | 1.6 | 2.4 |
| VorldView-II | 29/06/2010 | 23 | 0.41 | 0.51 | 1.22 | 1.03 |

For what concerns radar processing, the application of the PCNN technique allowed to reduce the number of steps associated to pre/postprocessing, resulting in an output image which preserves better the features of the original image and also in a much faster processing time (less than 7 minutes for a COSMO-SkyMed Spotlight image). One source image and its PCNN output are shown in Figure 4.

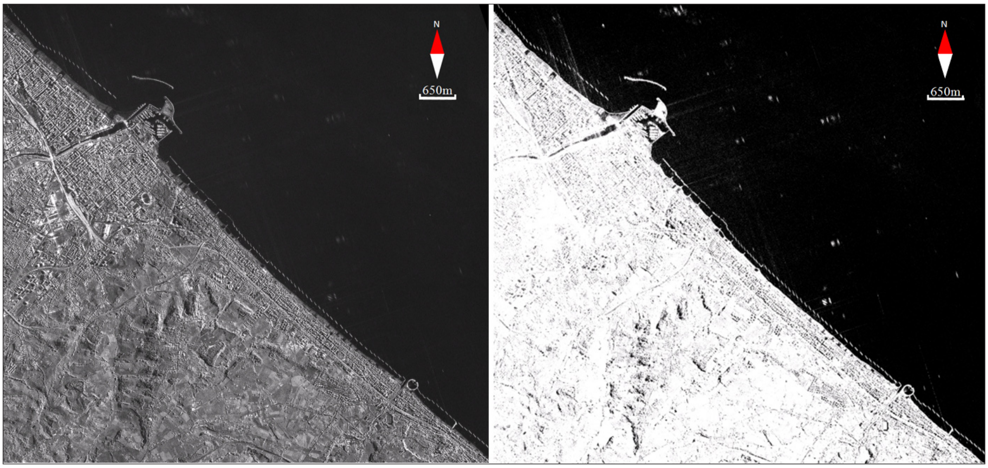


**Figure 4 - Left: original COSMO-SkyMed image (Spotlight) acquired on July 6 2010 –Product COSMO-SkyMed © ASI (2010) –All rights reserved, Right: outcome of PCNN processing.**

Edge detection and coastline extraction are then applied to such product, resulting in a coastline which perfectly overlaps the source data, as shown in Figure 5.

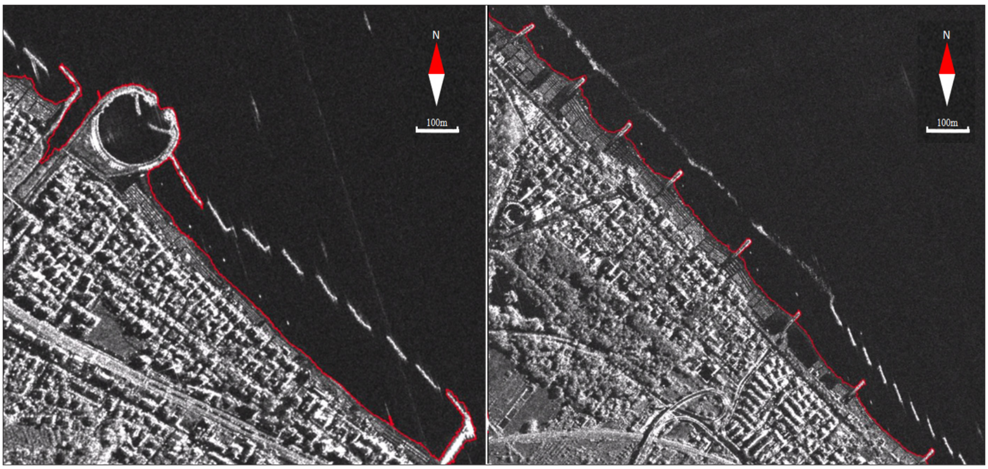


**Figure 5 - Extracted coastline (red) overimposed to the source product (close-up over two fragments of the image shown in Fig. 4) - Product COSMO-SkyMed © ASI (2010) –All rights reserved.**

## Conclusions and next steps

Satellite images have very interesting potential for coastline extraction and update. Latest generation optical data, such as those provided by the World View II mission, increases results precision thanks to the multispectral and VHR capabilities. In the case of the radar dataset, we observed that wind conditions at the time of acquisition highly influence the possibility of separation between land and sea, as they modify wave energy and height. This remark is particularly valid in the case of X-band data, which appear to be more sensitive to small-scale waves. As a consequence, and based on the analysis of a COSMO-SkyMed dataset encompassing more than 20 scenes, different angles of incidence and test-areas on mild and steep coast, HH polarisation appears preferable to VV, being less sensitive to the backscatter of the wavefronts. However, also in the case of VV polarization useful information can be extracted from the image. A visual analysis of the COSMO-SkyMed dataset available over the study-area aiming at examining the influence of incidence angle (grouped in the classes 20°-30°; 30°-40; 40°-50°) shows that a better contrast in the scene is obtained with the class of incidence 30°-40° followed by the class 40°-50°. The class 20°-30° seems to offer the worst performances. The satellite acquisition geometry that appears more suitable for the studied area is right descending (equivalent to left ascending) with an orbit as parallel as possible to the coast. Other acquisition geometries may yield shadow and layover effects over the areas of high coast. All the above observations are valid for the analysed dataset, given the wind conditions at the time of the acquisitions.

The project is close to its completion, an analysis of accuracy of the retrieved shorelines is ongoing, whereas the assessment of the health state of the analyzed coast at different scales/resolution (including the estimation of the tidal bias, based on a high resolution DEM of the coastal area) is being carried out in a GIS environment. Feasibility to run an operational service based on such data has to take into account as a minimum the geolocation accuracy of the resulting products, the availability of ground (ancillary) data, the frequency of updates needed by the authorities in charge and the timescale (or areal extent) of the phenomenon considered. The test run on the study-area provided positive indications, however it has to be noted that the latter point calls for an extension backward in time of the observation period, as the annual coastal variability detectable in the examined area seems to lay within the accuracy boundaries of the products. An observation interval of 3 to 4 years seems suitable to clearly locate the trends: today this is achievable only with an integration of COSMO-SkyMed observations with VHR optical observations.

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