REMOTE SENSING AS A TOOL TO MONITOR AND ANALYSE ABRUZZO COASTAL CHANGES: PRELIMINARY RESULTS FROM THE ASI COSMO-COAST PROJECT

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ABSTRACT
A clear view of actual and past processes affecting coastal areas at local and regional scale is the essential starting point to identify trends, issue forecasts and plan any protective measure. In low coastal areas, the simplest parameter which can be monitored as proxy of the very complex dynamic equilibrium between mean sea level height, tide/wave energy and amount of incoming sediment is the shoreline, defined as the instantaneous divide between water and land. The COSMOCoast project is applying standard image processing, object-oriented approaches and neural nets for boundary detection along the Abruzzo coast from high to very high resolution actual satellite data. Validation data are provided by a kinematic GPS as well as by a ground lidar campaign carried out simultaneously to satellite overpass. Boundary-extraction tests run on COSMO-SkyMed spotlight acquisitions taken at different polarisations and incidence angles have been carried out: the NN outperformed the traditional techniques (based on Sobel’s and Robert’s operators) both in terms of accuracy detection and of computational burden. Segmentation of optical data acquired by different satellites also provided very good results.

INTRODUCTION
In the last 50 years the inhabitants of the 19 municipalities along the Abruzzo coast have doubled and a strong increase of the tourism industry in the area has been experienced. Such an area that would have naturally been exposed to the effects of sea-level rise underwent a dramatic increase in erosion. Extensive works were in fact carried out on the watersheds to mitigate extreme rainfall and consequent flooding: this reduced solid transport from rivers to the sea and the capacity to reduce the erosion trend (i). To counter balance such effects, “low cost” interventions (breakwaters and groynes) have been created. Such structures are reported to have locally succeeded in their primary goal, which was to protect exposed infrastructures and facilitate the recreation of severely eroded beaches, however in overall they have transferred (and possibly worsened) the problem to other areas. This has called for further interventions, resulting today in protection works which extend over 61% of Abruzzo coastal zone. In the deliberation of June 13 2006 the Consiglio Regionale d’Abruzzo estimated the cost to contain the ongoing erosion in 200.000.000 €.

Statements on the evolution of the coasts of Abruzzo based on available cartographic production do not seem entirely reliable as they are:
• in scales which highly hamper 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...) each produced using different information extraction methodologies (often not described) and with different inherent positional errors.

An additional issue is that generally no information is provided concerning with the represented coastline: does it match the geodetic meaning of coastline (that can be defined as the intersection between Geoid and ground morphology)? Does it match the geomorphologic meaning (whose definition is the line comprised between the average high and low tide line)? In the case of coastlines extracted from observations taken from remote (airborne or spaceborne) devices, it is more likely that this is simply the instantaneous water divide, dependent on sea-state and tidal level as no other pre/post acquisition information is used. This further questions comparability of the observations. The problem is particularly relevant in those areas characterised by low coast, where cm changes in water levels may result in several meters of cartographic displacement, see Figure 1.

![Figure 1: Theoretic effect of a 10 cm, 20 cm, 50 cm or 100 cm tidal variation on planimetric location (in cm) of the coastline as a function of the slope. Focus is on mild slopes (up to 40%-roughly 21°) which represent the majority of “low” coastal areas.](image-url)

There is a need to identify data and elaborate tools capable to provide a synoptic and correct 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 plan interventions or assess efficiency of past interventions. The COSMOCoast project, carried within the framework of an ASI
contract (I/067/09/0), exploits satellite data to overcome observation limitations (eg areal extension of the data and dependency on meteorological conditions) of standard techniques based on aerial photography/videography/LIDAR, topo/bathymetric surveys and ground-based video-systems.

Use of VHR satellite optical data for coastal studies is not new: ii reported with simulated optical data 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 resolution and that overall accuracy of classification run on data downsampled at 4 m was better than the corresponding one at 1 m. iii demonstrated the feasibility to use high/medium resolution data (SPOT and LandSat) for monitoring mud bank migration rates. They also pointed out the need for tidal information for a date-to-date comparison. iv used LandSat and ASTER data to extract the waterline on tidal flats and noted that during bands ebb tides TIR is more effective than NIR and SWIR. However it appears evident that the lower the ground resolution, the lower the potential cartographic accuracy of the retrieved coastline. Preliminary studies intercomparing object oriented and pixel based techniques for coastline extraction from VHR data carried in v demonstrated the usefulness of segmentation-based approaches.

Spaceborne SAR data (generally at a ground resolution of roughly 25 m) have been widely used for mapping the coastline: specially in wet tropical coastal environments they presented large advantages compared to use of optical EO (vi, vii). Edge detection methods used on radar data suffer from the fact that the edge pixels are quite discontinuous and seldom characterize a coastline completely (viii, ix). In contrast, image segmentation methods have the advantage in creating a continuous boundary; according to x, SAR data of very high resolution might be very suitable for the use of segmentation-based methods. However, segmentation methods require more postsegmentation processing steps to delineate the boundary pixels, and face difficulties of determining a reliable threshold and formulating homogeneous criteria in region growing, and region splitting and merging algorithms. Additional techniques use filters to identify thresholds (xi) and combinations of operators, but thresholding fails when it is applied in presence of strong and local rough surface areas (strong wind). xii applies a neural network method on a texture measure of images to separate land and water regions. The use of texture influenced the accuracy, and the need for training neural nets also limited its application.

In the past, studies of coastal areas with EO data were limited 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 (e.g. COSMO-SkyMed or TERRASAR-X), 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 studying coastal areas with EO. Observations taken by different platforms can be used to derive time-series of coastline positions and 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. To allow intercomparability of such data, providing the instantaneous water divide, ancillary data such as topographic and bathymetric information as well as meteoro-marine information are essential.

MATERIALS AND METHODS

Different tests at different scales are foreseen by the project which identified the overall coast of Abruzzo as the general study-area and focussed on two zones within such area, representative of low and high coast: Pescara and Ortona respectively.

A number of satellite acquisitions, both already existing (and allowing to expand the study-interval back in time up to the early 90’s) and new have been gathered by the project. Figure 2 provides an overview of the new satellite acquisitions gathered during a 16-days interval in July 2010. Whereas with optical sensors (eg Formosat-2) the same area could be imaged within a 3-days interval, 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 twice per day, resulting in acquisitions almost coinciding with daily low and high tide.
Figure 2: The 16 days time interval during which data acquisition (from satellite and ground campaigns) were concentrated. Information about tidal levels derived from Ortona station, belonging to the Italian tidegauge network, is also provided.

The need to validate the information extracted by the satellite data with an independent dataset, resulted in a limited survey during which a ground-Lidar was deployed. The advantages of this technique compared to traditional surveys (e.g. kinematic GPS which was also carried out to gather a third independent dataset) are twofold:

- the acquisition can be simultaneous to the satellite acquisition, imaging exactly the same boundary observed from space at the same tidal condition and leaving no room for errors or uncertainties
- morphology of the shoreline can also be retrieved

Figure 3 provides an overview of the proposed processing chain and used data from acquisition to generation of the coastline referred to a 0 m level tide and extraction of indicators. An important step to allow intercomparison, validation and an anchorage between elevation data, ground laser data and tidal data might encompass the derivation of the absolute height over the geoid of the Ortona tidegauge station. This opportunity, aiming to solve the problem of the different height datum (Geoid materialized by the national tidegauge station or materialized by local stations) will be evaluated later on.

Traditional techniques have been applied for the extraction of the DSM from ALOS PRISM data and orthorectification of the optical data (using a photogrammetric rigorous model when orbital metadata and ground control point (GCP) with proper accuracy were available, as suggested in xiii, xiv and xv and of radar data, for which a Range-Doppler method was adopted. Availability of vector data collected during an aero photogrammetric campaign carried out in 2005 allowed the project team to generate a DSM of high quality, which in view of its higher resolution has been preferred to the DSM derived from PRISM.

Object-oriented techniques for the automatic extraction of coastal lines from optical data have been applied to the orthorectified images. Designing an automatic image processing method dedicated to VHR images is rather complex, since the spectral heterogeneity of these images brings about the presence of many irrelevant objects (of no interest for the task under consideration, e.g. coastline extraction in this case). A well defined segmentation procedure, which is at the basis of the object-oriented classification, should guarantee the generation of meaningful objects, whose dimensions are adequate with respect to the scale of work. This consideration brings the discussion to the problem of the different image resolution. In panchromatic images, which generally present...
the advantage of a better ground resolution, absence of separate spectral information may result in lack of useful data for correctly extracting coastline. To avoid under or over segmentation, the parameters shall differ depending on the images spatial resolution. Once these parameters are defined, (scale, colour and shape parameters have to be carefully selected for each type of image) the coastline extraction procedure passes through the object-oriented image classification.

Figure 3: Flowchart depicting the involved processes from satellite data acquisition up to the generation of the corrected coastlines.

In the case of radar data, the difficulties in discriminating water from land in SAR images stem from the fact that the backscattering from the water can be influenced by different effects due to wind and wave modulation. This can determine a not easy discrimination between sea and land. Moreover, it is well known that SAR images are affected by the speckle effect which hence represents an additional issue to be to be taken into account by coastline detection procedures. Figure 4 shows the preliminary processing chain for coastline extraction from radar images being developed by the project.
While coastline extraction from SAR data can be attempted by means of photo-interpretation, the use of more automatic techniques may play a crucial role especially in real-time or near-real-time operational scenarios or in the cases where the processing of huge quantities of data is required. In traditional techniques specific knowledge concerning the boundary is used to form rules that guide the grouping of pixels into boundaries. Moreover, the local edge tracing in coastline detection must be guided by the global information about the coastline; that is, information extending over the whole image. Such peculiarities encouraged us to compare a standard approach for edge detection (described in viii) with an innovative approach based on Pulse Coupled Neural Networks (PCNN). This is a relatively new technique based on the implementation of the mechanisms underlying the visual cortex of small mammals (xvi). The visual cortex is the part of the brain that receives information from the eye. The waves generated by each iteration of the algorithm create specific signatures of the scene, which are successively compared for the detection of the coastline.

RESULTS

This paper describes the outcome of the application of feature extraction techniques described in the previous paragraph to radar and optical data, as well as the preliminary tests run to allow comparisons between coastlines extracted at different dates. The dataset used in this experiment consists of two Cosmo-SkyMed spotlight products taken over Ortona (high coast) and two optical products (IKONOS and Quickbird) taken over Pescara (low coast).

Table 1: List and characteristics of the used dataset.

<table>
<thead>
<tr>
<th>Satellite</th>
<th>Acquisition date</th>
<th>Additional information</th>
</tr>
</thead>
<tbody>
<tr>
<td>COSMO-SkyMed</td>
<td>6 July 2010 04:49</td>
<td>1m res, HH polarisation</td>
</tr>
<tr>
<td>COSMO-SkyMed</td>
<td>15 July 2010 16:54</td>
<td>1m res, VV polarisation</td>
</tr>
<tr>
<td>IKONOS</td>
<td>28 June 2007 10:02</td>
<td>1m res (PAN), 4m res (MS)</td>
</tr>
<tr>
<td>Quickbird</td>
<td>30 September 2006 10:16</td>
<td>0.6 m res (PAN), 2.4 m res (MS)</td>
</tr>
</tbody>
</table>

Radar processing

Figure 5 shows the original COSMO-SkyMed VV product acquired on 15 July 2010, the binary processing results obtained applying a PCNN algorithm and applying the standard technique.
The PCNN technique requires a few minutes to process an image of almost 1 Gb compared to much longer times needed by the standard technique to apply edge detection, filtering, histogram analysis, thresholding and further edge detection to achieve a result comparable to the PCNN result. The detailed investigation of the processing outputs enlightened a better efficiency of the PCNN technique for delimiting the boundaries between land and sea, as compared to the traditional approach tested. This is shown in Figure 6, where a close-up is shown for the processing results of the VV image.

From the image it is clear that the PCNN technique follows better than the traditional technique the boundary between land and sea (no omission of coastline in the considered case), but it appears also more sensitive to image artifacts. This issue shall be solved by the tracing algorithm which will lead to the extraction of the vector map of the coast. A comparative test to assess sensitivity of the technique applied both to VV and HH images compared to the traditional technique was conducted.
on 20% of the overall coast. Coastline extracted by means of photo-interpretation was compared to the coastline extracted from PCNN and the traditional technique. A success rate in mapping the coastline of about 96% was found in case of PCNN and about 80% with the standard technique.

**Optical processing**

Processing of optical data demonstrated that in order to provide good segmentation data, the accuracy which can be derived from MS data at 4 m ground resolution is not satisfactory. A pansharpen image is needed in this case, which would considerably augment the time of image processing, considering also the amount of images needed for extracting coastlines at regional level. Fused data increase the precision of identification of objects, as compared to multispectral data. The attempt to quantify the transformations by describing the reciprocal positions of coast lines in 2006 and 2007, shows no sensible variations along the reduced area under examination. The differences, contained in the order of 14 m, are likely due to the effects of the wave energy at the moment of the shots, and to the tide conditions in images depicting very different seasonal situations: winter and summer, respectively (Figure 7). These conditions cause the foreshore width in the two images to be very different. For this reason, the extracted central lines result sensibly shifted.

![Figure 7: Extracted coastlines in 2007 (blue) and 2006 (red), represented over the panchromatic image of 2007 (fragment).](image)

**Tidal correction**

A preliminary check on tidal information acquired by the Italian Tide Network at the time of the two optical satellite acquisitions described in the previous paragraph has been carried out. This was performed to assess the effect of tidal variations to the real case and hence to verify the overall applicability of a "0 tide correction". An intertidal DSM at 1 m pixel size was generated from the interpolation of available aero photogrammetric points of the emerged beach and the bathymetric lines -5 and -10. A quantitative analysis of slopes in a buffer of 100 m around the derived coastline resulted in an overall slope of less than 1% for the test site. The reported tidal difference of 22 cm between summer and winter acquisition for such slope corresponds to a planimetric variation in the order of 20 m (Figure 1), in general agreement with the 14 m measured on the optical images. The comparison of more data taken in similar seasons will allow to state whether the considered part of the coast is in erosion, prograding or stabilised (effective protection works). Availability of a better
quality elevation model of the intertidal zone would greatly benefit the calculation of planimetric variations based on the simple geometric model used. Attempts will be therefore done to refine the intertidal DSM exploiting the equipotential lines derived by the multitemporal VHR acquisitions acquired in similar seasons.

CONCLUSIONS

Preliminary results of the project are encouraging: the various components of the processing chain have been separately tested and demonstrated, furthermore experimental tests run in “non ideal” conditions (comparison of datasets derived from different sensors and acquired in different environmental conditions –eg summer and winter) provided results in line with the expectations. Next steps foreseen by the project will aim to implement the tracing algorithm for automatic extraction of coastline from radar data and to validate the extracted radar coastline with the ground truth acquired during the simultaneous fieldwork. This information will be used to estimate the geolocation accuracy of the retrieved coastline. Systematic comparison of acquisitions taken in similar season (to reduce the cumulative impact of meteomarine conditions on the dynamic equilibrium line representing the coastal profile, which may differ between summer and winter) will then be performed in order to analyse coastline evolution at local and regional scale and to derive coastal change indicators.

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