FLOOD ANALISIS USING SATELLITE BASED VERY HIGH RESOLUTION SAR DATA FOR FLOOD MANAGEMENT AND MODELING: THE ASPIO TEST BED

Emanuele Frontoni, Giuseppina Monacelli

ISPRA Dipartimento Acque Interne e Marine, Rome - Italy

frontoni@dii.univpm.it, giuseppina.monacelli@isprambiente.it

ABSTRACT: Demand for crisis information on natural disasters like severe flood events has increased substantially during recent years worldwide and especially in Italy. Simultaneously, a rising awareness of the availability of satellite information has lead to an increase in requesting the corresponding mapping services. Because of their specific illumination and their all weather capabilities Synthetic Aperture Radar (SAR) sensors are optimally suited for providing reliable information on extensive floods, which usually occur under rainy or at least cloudy conditions. Flood information is needed as quickly as possible to provide an overview of the situation and to improve the crisis management and response activities. Analysing regularly acquired images floods can be monitored, which represents a valuable input for subsequent flood modelling techniques. In this paper an overview of the use of SAR for flood mapping is given and first experiences using the very high resolution satellite system of SAR Cosmo SkyMed as well as key processing elements and some of the important analysis techniques used for the extraction of flood information are presented. Furthermore, a web based software platform for flood analysis and integration between ground stations and satellite-based information is presented. The test case of Aspio basin in Marche, Italy is presented and described. Finally, a conclusion and outlook to the future prospects of high-resolution SAR missions for flood mapping and monitoring is given.

Key Words: Satellite, SAR, Radar, Flood Extent, Mapping, high resolution, geographical information systems, Aspio lab.

INTRODUCTION

Over the past years airborne and space borne synthetic aperture radar (SAR) systems have increasingly been used for mapping and monitoring of hydrological parameters. The most popular of these parameters is the flood extent. Especially with the operationally and routinely available space borne systems like ERS-1/2, Envisat, Radarsat, etc. very powerful systems were (and partially still are) available to map flood situations in the C-Band (~ 5 cm) domain. With the Shuttle Radar Missions SIR A/B, X-SAR SIR-C and the Shuttle Radar Topography Mission (SRTM) also L-Band (23 cm) and X-Band (3 cm) observations, including different polarization modes became possible from space during the operation of the missions and within range of the respective Space Shuttle orbits.

From the data of those missions the backscatter characteristics and mapping capabilities with respect to the different features of water surfaces could be studied (e.g. Miranda et al., 1997). The ALOS PALSAR sensor provides the possibility to study and map water features in the L-Band and including the different polarization modes (HH, VV, VH and HV) from a polar orbiting platform. With the successful launch and commissioning of Cosmo SkyMed SAR a new class of space based SAR systems suitable for flood monitoring became available for the scientific community in the X-Band domain and in the one meter pixel spacing class. Further systems like COSMO-SkyMed (meter- class, X-Band) and Radarsat-2 (three meter class, C-Band) are to follow soon.

As SAR systems in general have good cloud penetration capabilities they are often the preferred tool to observe flood situations from space, as these often occur during long lasting precipitation and cloud cover periods which, in many cases, hinder an observation by optical imaging instruments.

The new class of high-resolution meter class SAR sensors offers great potential in the field of flood mapping; however, also new challenges for processing and analysis arise from these images. While availability of three systems in orbit increases the repetition rate and observation frequency strongly, the high spatial resolution of the systems results in large variety of image objects and poses new problems for image analysis. This is especially the case for areas where single strong scatterers dominate the radar reflection and make the imagery difficult to be analysed, as it is the case for example in urban areas (Solbø et al., 2004).

Especially in complex imaging scenarios such as highly structured built-up areas, the spatial resolution of classical space based SAR systems is too low for deriving flood perimeters with sufficient accuracy. Furthermore, also the SAR signal in the X-Band at 3 cm wavelength shows sensitivity to certain wave patterns induced by wind or heavy rain on the water surface. Water surfaces, under standard (calm) conditions, appearing black in a radar image suddenly turn out to be of strong scattering character. Also flood areas covered, even if only partially, by vegetation have different scattering properties in X-Band to those observed in C- Band (Townsend et al., 2002; Wang et al., 1995). New approaches have to be found to reliably identify water bodies in these high-resolution SAR images. Object based, as well as pixel based methods have been developed (e.g. Horritt et al., 1999; Ahtonen et al., 2004; Heremans et al., 2003) and need to be further refined for these purposes. Apart from these challenges of image classification, the high geometric accuracy and the repeated observation possibilities provide good options for the derivation of precise flood parameters like flood duration or flood dynamics. If further combined with geo information layers like high resolution digital elevation data of the river basis, the flood depth can quite well be estimated from these imagery.

In this paper an overview of the use of SAR for flood mapping is given and first experiences using the very high resolution satellite system of SAR Cosmo SkyMed as well as key processing elements and some of the important analysis techniques used for the extraction of flood information are presented. Furthermore, a web based software platform for flood analysis and integration between ground stations and satellite-based information is presented. The test case of Aspio basin in Marche, Italy is presented and described. Finally, a conclusion and outlook to the future prospects of high-resolution SAR missions for flood mapping and monitoring is given.

A NEW SENSOR CLASS – COSMO SKYMED CHARACTERISTICS

Although current space borne C-band SAR platforms have already demonstrated their usefulness for large-scale flood mapping in a number of cases, they can only provide spatial and temporal resolutions that make a detailed and near-real-time assessment of floods hardly feasible. Hence, medium resolution C-band SAR data have only seen a limited use for the operational assessment of large area flood situations. In most cases, the low repetition rate typically only allows a single SAR data acquisition per flood event, at best, with an even lower probability to depict the maximum water level.

The Italian Cosmo SkyMed satellite was launched into a 514 km high, sun-synchronous and near-polar dusk-dawn orbit. While the nominal repetition rate of the satellite is 11 days, each point of the Earth can be targeted within two to four days depending on its latitude using a large variety of different look angles. The possibility to rotate the satellite system for an experimental left-looking mode can further accelerate acquisition times, which is particularly important in the context of disaster mapping and monitoring. The active antenna of Cosmo SkyMed SAR allows the following imaging methods to be used: a) In the SpotLight (SL) and High Resolution SpotLight (HS) modes, a pixel spacing between 1 and 2 meters can be achieved. Depending on the mode selection (SL or HS), the size of the ground track is either 5x10 or 10x10 km. Although both modes are very similar, the HS mode increases the geometric resolution in azimuth at the expense of azimuth scene extension.

For each imaging mode, a plethora of different acquisition parameters can be defined (incidence angle, polarization, look direction, processing parameters), which makes the SAR very versatile and adaptable to different application requirements. The Cosmo-SkyMed satellite system can provide X-band SAR data with previous described characteristics. Cosmo-SkyMed is a system comprising a configuration of four medium-sized satellites. As the first two satellites have already been successfully launched in June and December 2007, the possibility of observing an area of interest with a high temporal and spatial resolution has increased considerably. Together with the launch of the other two Cosmo-SkyMed satellites in 2008 and 2009, as well the new Radarsat-2 satellite, operating at C-band, a considerable number of space borne SAR systems will become available that will allow for rapid response times in order to map flood events at near-real-time.

In conclusion, the advent of these high resolution X-band SAR satellites dramatically increases the potential to detect water in complex, local monitoring scenarios and potentially fosters the application of satellite SAR imagery in the context of a rapid flood mapping and detailed post-disaster damage assessment.

THE TEST BED: ASPIO BASIN IN MARCHE, ITALY

The test bed of the evaluation process is the Aspio River (Fig. 1) in the Marche Region. A short history of the basin is reported here following.

The coastline remains almost in the same position from Roman to Medioeval times, where a progradation which received a considerable acceleration after the 1 400 is documented. During this period the Musone River is artificially diverted towards the Aspio River and delimitated by artificial level while the coastal plain is reclaimed and cultivated.

The alluvial plain keeps an aggradational phase until the end of 1 800 as well as the coastline which advances for more than 100 in comparison with the medioeval one. A strong downcutting started, following quarrying and the progressive building of artificial levees, after the '40-50. Several bridges were destabilized and fell down or refoundated. The building of trasversal dams locally stabilizes the erosion, but on a larger scale, creates more intense erosion and generates a step-like longitudinal profile. The downcutting reached values higher than 10 m in 50 years and interested at first the alluvial sediments then the bedrock. As a consequence of the reduced sediment lead, the coast underwent erosion; in order to prevent this phenomena a lot of artificial longitudinal barriers were erected. Nowadays along the coastline, relatively stable parts alternate with tracts in a state of erosion.

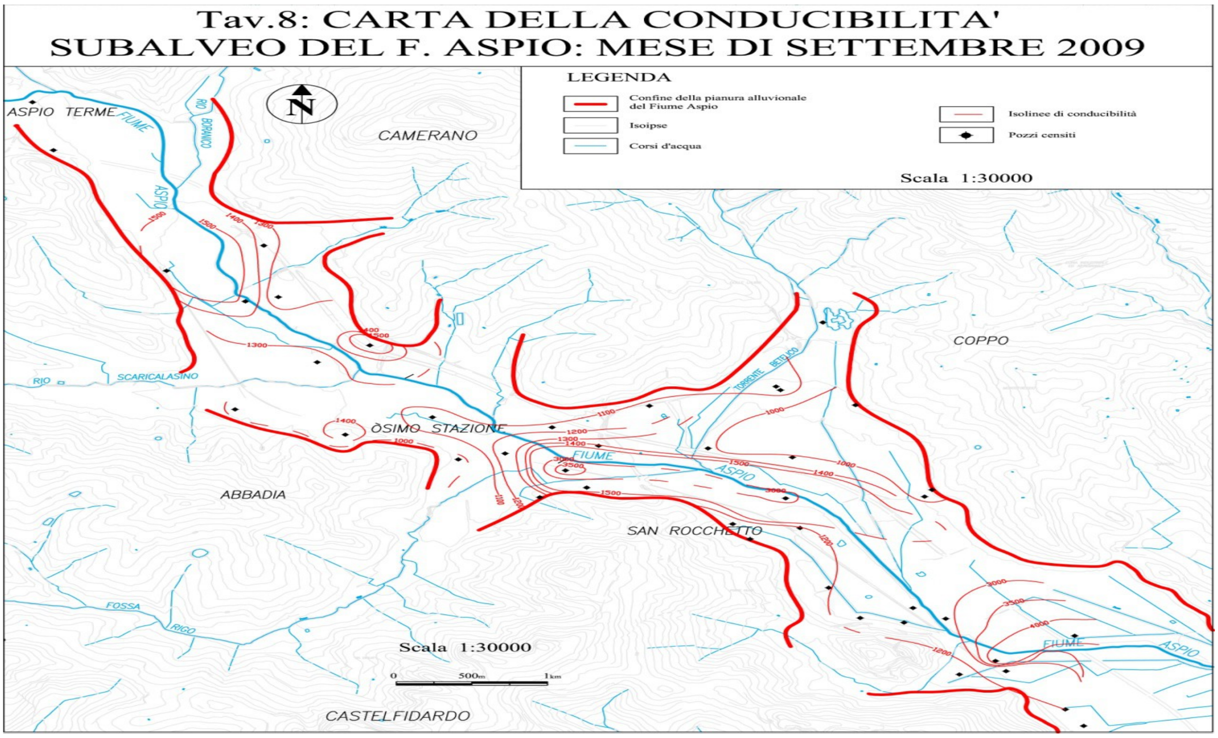

Fig. 1 The Aspio basin idrographic map

The river is an open laboratory with several measurement stations installed in various points in the years.

Fig.2 and 3 reports some examples of measurements acquired in time series and useful as basic data to verify the proposed approach.

Fig. 4 is an important prove of the relevance of the Aspio River as a test bed for this project. In particular the cartography represents flood risk areas and civil or industrial buildings in red, showing the high risk of the area.

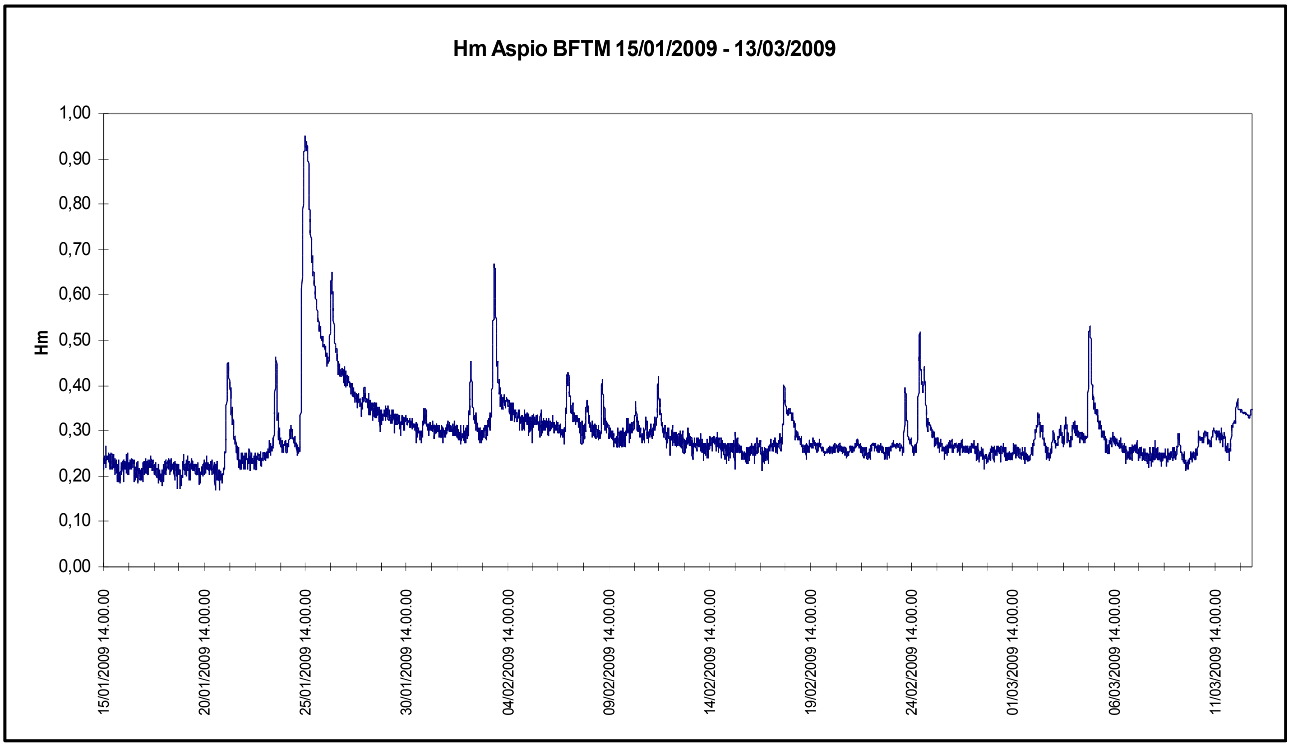

Fig. 2 Example of hydrometric highness in one of the ground station in Monte S. Pellegrino

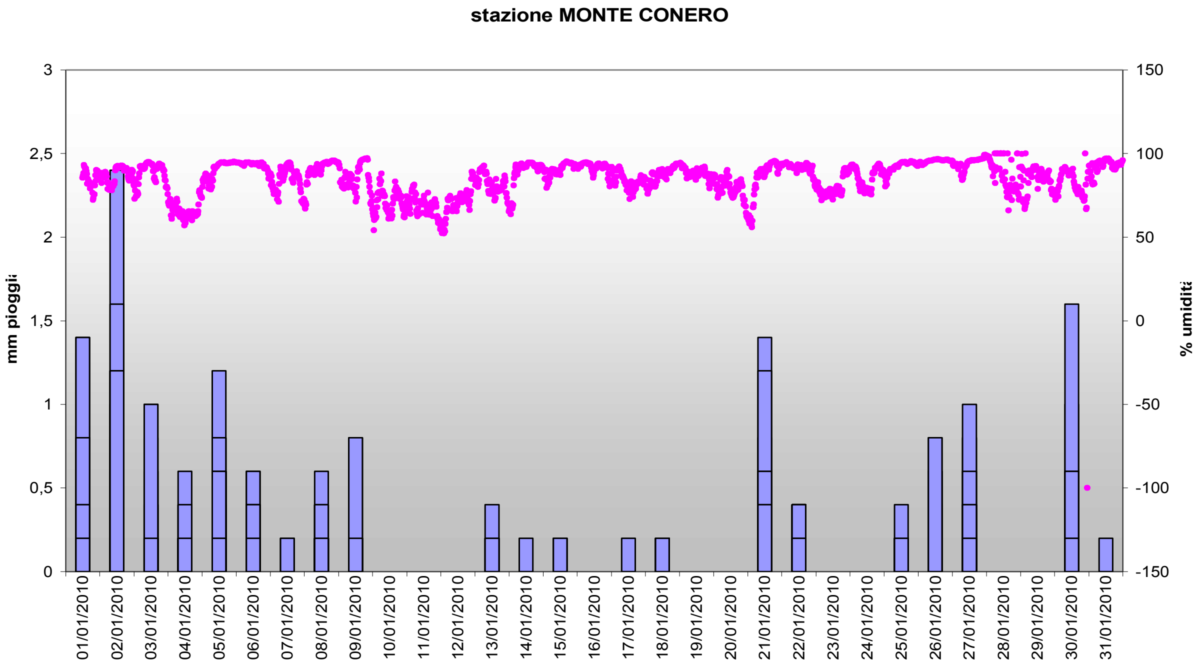

Fig. 3 Rain and humidity measures in one of the ground station in Monte Conero

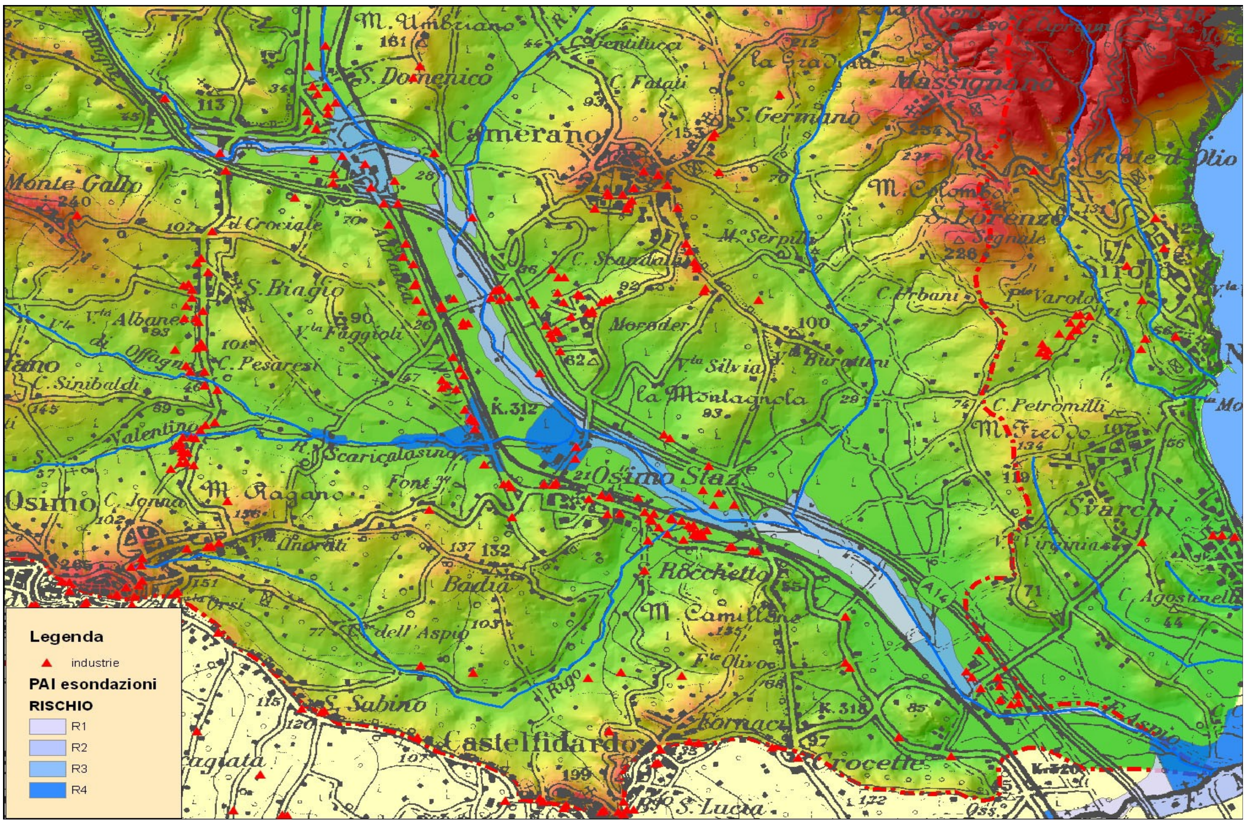

Fig. 4 DTM cartography with flood risk areas and civil or industrial buildings in red.

DERIVATION OF FLOOD MASKS FROM HIGH RESOLUTION SAR-SENSORS

Different backscatter characteristics of water in high resolution SAR data

The availability of high resolution Cosmo SkyMed SAR satellite imagery allows the image interpreter to distinguish more feature details on the earth's surface. Even waves with a wavelength in the range of the sensor resolution, of up to 1 m, may be visible as bright linear features on the surface of lakes or the sea. Texture analysis may be useful to use these regular features to classify them as water bodies. Vegetation standing within a water body may also increase the backscatter values, which in turn leads to regions that appear brighter than regular surfaces of water bodies.

The use of dual polarization data can help to distinguish between dry surfaces, vegetation under water and standard water bodies. In built up areas it is often difficult to distinguish between radar shadow areas and water bodies, which both appear dark. In the context of flood situations, the improved pixel spacing of high resolution Cosmo SkyMed SAR data potentially helps to map the inundated urban areas more reliably, although the limitations in very small-scaled scenarios also need to be assessed carefully. Rivers are not very susceptible to wind induced waves due to their small width and hence appear predominantly dark in SAR data. If the flow velocity and the river dynamic increases and therefore the river surfaces become rougher and more turbulent, this as well can lead to higher backscatter values.

Although X-Band radar waves are claimed to be independent of atmospheric disturbances there can be situations with heavy thunderstorms containing big raindrops, which may influence the radar image. Such an event can be seen in the Cosmo SkyMed SAR image as a dark veil. High mountainous terrain with steep slopes may cause radar shadow when the SAR data is acquired at shallow incidence angles. Auxiliary data like the SRTM digital elevation model can be utilized to distinguish between the dark radar shadow western slopes and the dark water surface of lakes. Another problem for the automatic classification of water bodies are man-made obstacles like fish farming basins, ships or bridges with ghost effect caused by multiple reflections at the bridge and the water surface, which can be seen in several SAR image examples.

Comparison of Pixel-Based and Object-Based Approaches

Pixel-based and segmentation-based classification techniques can be distinguished as the two main concepts for the identification of flooded areas in radar imagery (Heremans et al., 2003). Traditional classification approaches use pixels as smallest geometrical components of raster data.

The grey values of the pixels, which correspond to the spectral properties of a target, can be used to group the image information into different semantic classes. Routinely, these approaches are widely applied to low and medium resolution remote sensing data. However, parameters for the classification are limited. Additionally, pixel based classifiers do not make use of spatial information of the image and thus are not suited to deal with the inherent heterogeneity within land-cover units.

Furthermore, even if noise reduction by speckle filtering is applied, classification results usually suffer from a salt-and-pepper effect and a post-processing classification by filtering becomes necessary. These smoothing methods however work without considering the original information. By the use of image segmentation techniques, some problems of pixel-based image analysis can be solved.

The created homogeneous, non-overlapping segments have a strong correlation with real objects or areas of the earth's surface. Image segmentation methods become more and more important in the field of remote sensing image analysis – in particular due to the increasing spatial resolution of imagery. Especially for data of the new generation of very high resolution optical and SAR sensors with a geometrical resolution of less than 1 m the use of segmentation-based methods appears promising. A disadvantage of this technique is the high processing demand of the segmentation step, which mostly limits the size of the processed image.

Thresholding is one of the most frequently used techniques to separate flooded from non-flooded areas in a SAR image (e.g. Townsend et al., 1998; Brivio et al., 2002). Commonly, classification is performed by assigning all elements of the SAR intensity data with a lower scattering cross-section than a given threshold to the flood class. One of the main advantages of this classification method is that it is computationally relatively inexpensive and therefore suitable for rapid mapping purposes. Its results are reliable and commonly, most of the extent of an inundation area can be derived by this technique.

Thresholding works satisfactory for calm water surfaces, which can be regarded as specular reflectors with low backscatter values for the used radar wavelengths. In contrast, the surrounding terrain exhibits higher signal return due to strengthened surface roughness. The applied threshold will depend on the contrast between the water and land classes as well as on the deviation of the flood area from a smooth surface due to influences of wind induced waves, precipitation as well as of diffuse and corner reflecting vegetation. Given this drawback, active contour models (e.g. Williams and Shah, 1992; Horritt et al., 1999) have recently gained popularity as a means of finding smooth boundaries from incomplete and noisy images using local tone and texture measures. These "snake" algorithms had been used by e.g. Ahtonen et al. (2002), Horritt et al. (2001) and Matgen et al. (2007) for flood boundary delineation in medium resolution SAR imagery. Thus, flooded areas are identified as regions of homogeneous speckle statistics. Due to the fact that originally the snake has to be initialized manually for each water area, too much user input is required to extract flood masks from very high resolution SAR imagery on which large inundation areas mostly are divided into numerous flooded parcels.

Therefore, approaches approximating the numerous flood areas by thresholding and transferring these initial polygons to the active contour algorithm appear more promising (Heremans et al., 2003). However care must be taken initializing the algorithm both manually and automatically. In most cases, multi-temporal analysis has proven superior to single data approaches. However, in rarest cases reference data are available for the respective flood area. Different change detection approaches for the derivation of flood dynamics between registered SAR data have successfully been applied in the past. These include amplitude based (e.g. Townsend et al., 1998; Heremans et al., 2003) as well as coherence-based techniques derived from the use of C-Band SAR interferometry (e.g. Geudtner et al., 1996; Dellepiane et al., 2000; Nico et al., 2000). Using amplitude change detection in combination with C-Band multi-temporal SAR imagery, areas of flooded dense vegetation were mapped successfully e.g. by Townsend et al. (2002). This arises from the fact that microwaves at longer wavelengths can penetrate the forest canopy and are double bounced at the smooth water layer and the forest stems which causes a significant increase in backscatter.

DERIVATION OF FLOOD RELATED PARAMETERS

To develoap the proposed approach the NEST Toolbox was applied. The Next ESA SAR Toolbox (NEST) is an open source (GNU GPL) toolbox for reading, post-processing, analysing and visualising the large archive of data (from Level 1) from ESA SAR missions including ERS-1 & 2, ENVISAT and in the future Sentinel-1. In addition, NEST supports handling of products from third party missions including JERS-1, ALOS PALSAR, TerraSAR-X, Radarsat-2 and Cosmo-Skymed. NEST has been built using the BEAM Earth Observation Toolbox and Development Platform.

The following processing scheme is applied to extract features and to derive measurements, as described before.

For the purpose of flood risk and flood damage assessment, other flood related parameters than flooded area such as inundation depth and flood duration are required. Since these parameters can not be derived directly from satellite data, additional information has to be included.

The factor which is of most concern with respect to damages caused by flooding is water depth. A standard approach for the estimation of direct physical damages to housing and property are stage-damagefunctions for different building types or building uses (Thieken et al., 2005). Hence, damages measured in monetary loss can be described and modeled as a function of water depth. Other more complex damage modeling approaches also include the duration of floods and flow velocity.

The latter has to be seen as the major damage factor in case of flash flood situations especially on smaller rivers. Apart from flow velocity which can only be estimated by hydraulic models, remote sensing has the potential to derive flood depth and flood duration with a very high spatial resolution compared to hydraulic approaches. In addition, remote sensing based approaches can be valuable for the validation and verification of hydraulic model parameters.

Flood depth

The derivation of inundation depth requires the incorporation of a high resolution digital terrain model (DTM). DTMs from LIDAR with 1-2 meters pixel resolution and 0.1 meter height accuracy are nowadays available for many river flood plains and have been satisfactory used for hydrological applications and for the purpose of flood depth assessment. Promising methods of the latter are presented by Matgen et al. (2007) and Bates et al. (2006). A raster layer of flood depth can be derived by subtracting the terrain elevation from the elevation of the water surface. For the derivation of the flood water surface elevation the flood mask must be interlinked with the terrain data. Figure 2 (left) depicts the elevation of certain points on the flood boundary showing several variations and irregularities due to classification errors or location discrepancies between the DTM and the flood mask. Several correction steps have to be applied. As shown in figure 2 (right) this can be done by drawing cross-sectional profiles which connect the left and right river banks. According to these profiles the flood mask boundary can be adjusted (shifted) and rectified to the terrain model in order to generate a "smooth" water surface layer from which a TIN (triangular irregular network) can be derived. Figure 2: Left: Cosmo SkyMed SAR image of the flood situation of July 25, 2007, at the River Severn near Tewkesbury, UK. The elevation of the borderline of the flooded area was extracted from an elevation model and drawn as colored points. Right: Cross-sectional profiles with a distance of 100 meters at the centerline of the river. The profile color represents the mean elevation of the left and right river bank. Problems and irregularities can be identified in built-up urban areas close to the river junction.

Duration and Dynamics

Generally, the great advantage of SAR satellite systems for assessing floods is due to their reliable and genuine spatial representation of the flood extent. However, the temporal delineation of floods is limited because one satellite data take is only a snapshot in time. The assessment of flood dynamics and flood duration from satellite data requires a number of data takes recorded on different time steps during the flood period. A common technique for displaying changes in flood extent between two or three SAR satellite scenes is the generation of a color-composite as shown in figure 3. In this technique the grey values of one image are reassigned to one of the three color channels blue, green or red. A certain color can then be attributed to changes in flood extent. In the future, multi-observation conditions can be fulfilled with the various operational high resolution SAR satellite systems (see chapter 2). Through the combined use of different satellites, a repetition rate of less than 12 hours can be achieved.

THE ASPIO GEOHOGRAPHICAL INFORMATION SYSTEM

A main result of the project is the Aspio Information System (AIS). AIS is a web based platform (Fig. 5) that is written in PHP and based on a MySQL database. All open source platforms that together with Google APIs V3 bring on a usable web interface data collected by measurement stations on the field and data measured using the proposed approach on SAR data.

Experiments are on going and the final results will be the collection of all important data on the web application, giving to all the community a fundamental instruments for evaluations and planning on that territory.

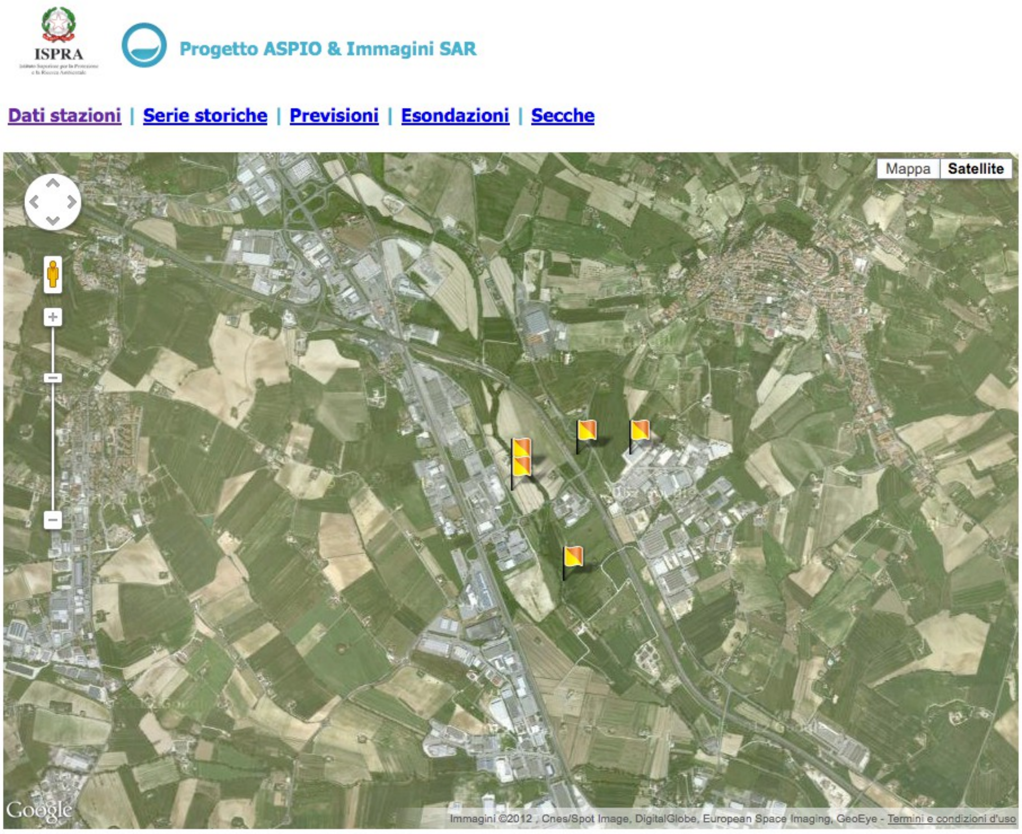

Fig. 5 An example of the web based interface of AIS (based on Google Maps)

CONCLUSION AND OUTLOOK

In this paper the advantages and challenges of the use of very high resolution SAR imagery for the analysis of flood situations could be shown. It can be concluded that the future of operational SAR mapping of floods is very positive, especially when looking at the currently launched space systems. Since many different parameters influence radar backscatter, the extraction of flood masks from X-band SAR data is not a trivial task. Robust methods need to be further developed to extract the water masks of inundated areas with high accuracy, but also as rapidly as possible. Such good and reliable availability of flood observations is of high relevance, especially during a flood disaster, when decision makers and relief organisations need a quick overview of the situation and detailed insights into the affected area in order to allocate their resources with maximum efficiency. With new possibilities in polarimetry, wavelength, spatial resolution and other characteristics given by the new available SAR sensors new approaches to extract the flood mask are currently being developed and need to be further automated and operationalized in order to improve the routine availability of space based flood monitoring to the extent possible.

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