TERRASAR-X RAPID MAPPING FOR FLOOD EVENTS

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ABSTRACT:
The use of Earth Observation techniques in the context of hazard management issues has received growing importance in recent years. Due to global climate change the scientific community foresees an increase in the intensity and frequency of extreme weather events, such as hurricanes, floods and windstorms. Specifically, floods already results in estimates of up to 25,000 annual deaths worldwide, extensive homelessness, disaster-induced disease, crop and livestock damage and other serious harm. The nearly all-weather capacity constitutes the main advantage of SAR data above optical systems for mapping of flood events. The high resolution, the multi-polarization and multi-incidence angle capability of TerraSAR-X, its quick site access and receiving times open very interesting perspectives for flood mapping, assessment of damages after a hazard. TerraSAR-X data, coupled with the use of optical data and auxiliary data allows getting one step further in the development of information services to better support risk management. The work presented in this paper focuses on the development of an object-based classification approach for operational flood extent mapping in near-real time conditions for TerraSAR-X data. The object-based methodology is implemented in a rule-based environment. Three modules sequentially activated are distinguished in the developed rules system: Segmentation, Water mask extraction and Flood extraction and refinements. The initial (Segmentation) and final (Flood extraction and refinements) modules are automated, while the Water masks extraction process is semi-automated. Two flood events of great intensities that occurred in May 2008 and January 2009, respectively in different environment conditions are used for illustrations. The robustness of the mapping chain is thus tested; the results obtained are compared with ones of a visual interpretation allowing a preliminary validation. The overall study demonstrates the potential of TerraSAR-X data and object oriented methods for the rapid delineation of flood extension maps in an operational environment.

1. INTRODUCTION

1.1 Flood as natural disaster

Flood is one of the most wide spread natural disasters; it regularly causes large numbers of casualties with increasing economic loss. Annually floods events results in estimates of up to 25,000 deaths worldwide, extensive homelessness, disaster-induced disease, crop and livestock damage and other serious harm (UNU, 2004). According with the Centre for Research of the Epidemiology of Disasters (CRED), floods are the environmental disaster which affects higher number of people in average (CRED, 2009). Even the most advanced nations are affected: the 2002 floods in Europe killed roughly 100 people, affected 450,000 people and left $20 billion in damages; the US, which suffered 50 deaths and $50 billion in damage in the Mississippi River flood of 1993 (USGS, 2008), have averaged.25 flood deaths annually since the 1980s (UNU, 2004). Consequently, disaster management is of particular social, economic, and political interest. It involves assessments of vulnerability and risk, the monitoring of hazard prone zones, the planning and management of rescue operations and post disaster damage assessment.

The study presented here will focus on two flood events of high intensities that occurred recently in highly populated areas of the USA and in an area of high flooding regime in Australia.
The first area of interest is located close to the St Louis County (see coordinates in Table 1). The flood event that occurred last year from May to August 2008 has been caused by heavy rains. It has affected the States of the Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, and Wisconsin.
The second area is the Gulf Country region in north Queensland (Australia) that is the mayor savannah area in north Australia (see coordinates in Table 2). It has a monsoonal climate with a winter dry season and summer wet season and a well known dynamic of flood events. Populations in the area are used to have 3 to 4 weeks of isolation during the wet season. Nevertheless at the beginning of the year 2009, the unexpected volume of water kept the two towns of the area longer isolated.

1.2 The Flood mapping workflow development

The production of maps often depends on manual processes. For a quick response in the case of a natural disaster it is necessary to count on an automated workflow providing reliable on-time information about the extent of a flood event. Such automated methodology needs to be time effective, robust, flexible (i.e. easily adaptable to different data and events) and simple to use in case of emergency situation.

Based on these observations, the work presented in this paper focuses on the development of an automated procedure for flood extent assessment in near-real time (NRT) conditions. Important matters related to the development of the tool are reliability, time and cost effectiveness, robustness (ability to be transferred to a multitude the image sources) and the flexibility (adaptation to the different flood scenarios).
Object-based classification methods are based on the extraction of homogeneous segments of the scene, which are classified in subsequent steps. Inserting object-based methodologies in a rule base environment offers numerous advantages for the development of automated thematic mapping tool. On one hand, unlike pixel-based techniques which only use the layer pixel

values, the object-based techniques profit from texture, shape and context information of a scene. On the other hand, the rule-set approach allows the construction of a hierarchy of process in which individual modules can be defined and adapted to different needs. It is thus possible to give a step-wise structure to the classification approach and to separate modules with different grades of automation in the overall process.

A rule set is form by one or more processes (or rules). Each process contains the instructions for a specific image analysis algorithm. This algorithm could be applied to a pixel, a class, an object or to a region of the image set by a condition Such a condition is governed by a feature and a value (or range of values) which have to be fulfilled. These individual rules or processes are ordered in a process tree and are connected to follow a logical flow. The coherency of this flow and the optimal order of the processes is essential for the whole structure to work and furthermore to get the desired results. The sequentially, step by step processing of this approach allows an in depth manipulation of image objects using a large variety of operations (Kok, 2006).

The tools offered by Definiens AG were found to be the most adaptable to the development of a methodology in an operational environment. Definiens Enterprise Imaging Intelligence Suite is a software package for image analysis focused on object-oriented classification with focus on automation. The package is formed by different modules which work independently or connected .They allow to develop ruleware; build and tune complete image analysis from ruleware and create user friendly interfaces as well as they facilitate the completely automated execution of multiple projects as a batch process. For more information please see Definiens reference books and users guides.

The version 7.0.8 of Definiens Developer was used for the development of the flood mapping procedure. Three modules which are sequentially activated are distinguished in the developed rules system (Figure 2):

- Segmentation with automated selection of Area of Interest (AOI),
- Water mask extraction
- Flood extraction and refinements

The initial (Segmentation) and final (Flood extraction and refinements) modules are automated, while the middle one (Water masks extraction) is a semi-automated process.

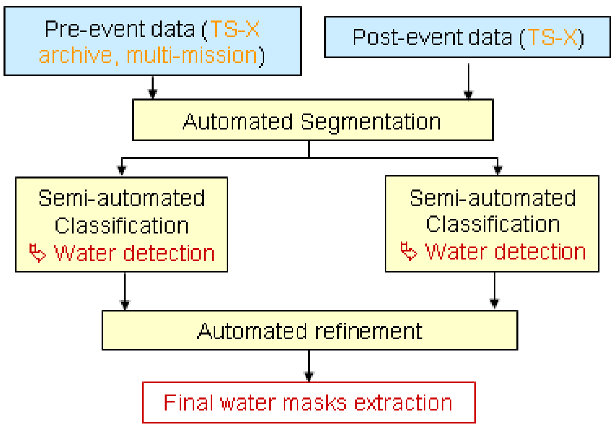

Figure 2: Flood mapping general workflow

The following sections are dedicated o the description of each processing step.

2. DATASETS SELECTION AND PREPARATION

Remote sensing data has the potential to map the inundated areas for more accurate estimation of the disaster extent (especially for hardly accessible areas) and in a more cost-effective way than ground observation (Okamoto et al., 1998) (Waisurasingha et al, 2008). Nevertheless as flooding events are often associated to extreme weather, optical data encounter limitations due to the cloud coverage. Contrarily, SAR data presents the advantage of their near all weather operating capability allowing accessing damaged area also during night time.
For the purpose of the study it was decided to use TerraSAR-X data, which coupled with the use of optical data and other data sources and allows getting one step further in the development of information services to better support risk management

2.1 High resolution TerraSAR-X data

TerraSAR-X is the new generation, high resolution German radar satellite operating in the X-Band. It was launched in June 2007 and will operate for a period of at least 5 years.
In the standard operating mode (so-called single receive antenna) image data can be acquired in three different imaging modes, ScanSAR, StripMap and SpotLight that differ in their spatial coverage and spatial resolution (Figure 3 to 5). The ScanSAR mode provides the larger possible coverage with a single scene of 100km (range) x 150km (azimuth, extension to up to 1650km possible) and a corresponding ground resolution of 18m. StripMap scenes cover a 30km-wide swath with a typical length of 50km (also extendable to 1.650km), the ground resolution improves to 3m. Finally the SpotLight mode allows the observation of relatively small areas (10x10km²) at up to 1m resolution.

The high resolution, the multi-polarization and multi-incidence angle capability of TerraSAR-X open very interesting perspectives for flood mapping, assessment of damages after a hazard. Further, the following system capabilities make TerraSAR-X very interesting for disaster management and monitoring:

- TerraSAR-X features a quick site access time of 2.5 days to any point on Earth at 95% probability.
- Time-critical data can be downloaded within seconds after acquisition to TerraSAR- X ground stations on-scene, thus enabling near-real time data processing.
- Satellite Tasking twice a day and priority settings for the ordered data takes allow for quick turnaround times in data delivery and late order changes.

Depending on the desired application, one of four different product types (processing levels) can be selected. In addition, TerraSAR-X data are available in single or dual polarization and even full polarimetric (Eineder et al., 2006).

- Single Look Slant Range Complex (SSC)
- Multi Look Ground Range Detected (MGD)
- Geocoded Ellipsoid Corrected (GEC)
- Enhanced Ellipsoid Corrected (EEC)

Spatially Enhanced (SE) products are designed for the highest possible square ground resolution. On the contrary Radiometrically Enhanced (RE) products are optimized with respect to radiometry. The range and azimuth resolution are intentionally decreased to significantly reduce speckle by averaging approximately 6 (5 to 7) looks (Fritz et al., 2008).

2.2 Pre- and post-event dataset selection criteria and pre-processing steps

First and foremost, the programming of TerraSAR-X acquisitions on the affected regions needs to be initiated; requiring a number of decisions regarding acquisition parameters:

- The selection of the best suitable acquisition mode is based on the assumed size of the area affected. StripMap was chosen to cover the area selected for the Mississippi event while a ScanSAR scene was acquired for the Gulf Country.
- The HH-polarized backscattered coefficient generally presents higher contrast between water and land surfaces (compared to VV-polarization). The use of dual-polarization acquisition mode results in a reduced coverage and resolution, which needs to be traded off against the increased information content. In the present work, HH polarisation was used for both areas of study.
- Finally shallow incidence angles are preferred for flood mapping, as steep incidence angles result in stronger backscatter for open water and reduce the contrast to land surfaces. In an emergency, however, acquiring the first possible scene of the area affected clearly takes priority over considerations on the choice of incidence angle.

Geocoded datasets are required for flooding extent assessment. Enhanced Ellipsoid Corrected (EEC) products were ordered. Preference is on Radiometrically Enhanced (RE) products as they already present a speckle reduction, and are then more suited to segmentation processing. In other cases speckle filtering of the TerraSAR-X data could be applied in order to minimize the heterogeneity of the overall backscattering information.

In parallel to acquisition planning, a search for existing pre-event and auxiliary is required. TerraSAR-X data are preferred for pre-event data, as scenes acquired by the same sensor can be directly compared. If no TerraSAR-X pre-event acquisitions are available, data from other sources (including optical and/or airborne) as well as raster data, if available, are used. In the case of the Mississippi, no TerraSAR-X data of the region was available; an extra Landsat 7 image was used as pre-event information quell. Additionally, approximately four months after the flood a new TerraSAR-X StripMap scene of the area was ordered and used as pre-event data, to simulate a real scenario where TerraSAR archive data is accessible. However, by the time that the Floods in Queensland in 2009 occurred, TerraSAR-X Background Mission was able to supply pre-event data from archive, and therefore a complete ScanSAR data set (pre and post event) was used for that area. Detailed information on the images parameters is proposed in Table 1 and 2. The post-event images are proposed in Figures 6 and 7.

Auxiliary datasets are also of great importance; all supplementary information about the test site support and accelerate the event interpretation, it also reduces the effort for the refinement step that is later described. In addition to the image datasets, a visual interpretation on standard requirements was generated in the case of the flood event in Australia. The interpretation map, chiefly based on manual work, was used as reference. It was delivered as a vector file with a minimum area for the polygons of 1 ha. The interpretation work exceeded 12 man hours for a flood mask of this magnitude.

Sensor	Centre (lon/lat)	Mode	processing level	Acquisition time
TerraSAR-X	-90.75° / 38.96°	SM	EEC/RE	2008.06.23T 23:59
	-90.61° / 39.15°	SM	EEC/RE	2008.10.17T 23:51:25
Landsat7	39.3°/ 90.7°	x	x	2008.02.10

Table 1: Scene acquisition parameters for Mississippi area

Sensor	Centre (lon/lat)	Mode	processing level	Acquisition time
TerraSAR-X	-17.15°/ 141.00°	SC	EEC/RE	2008.06.03T 05:58:45
	-17.25/ 141.23°	SC	EEC/RE	2009.02.11T 08:57:05

Table 2: Scene acquisition parameters for Gulf Country area

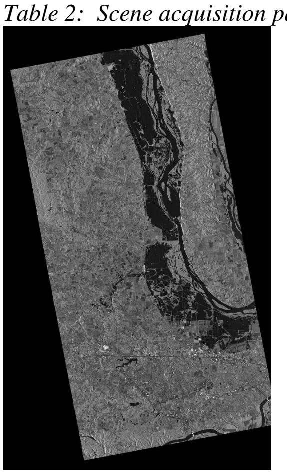

Figure 6: TerraSAR-X SM scene over the Mississippi River area

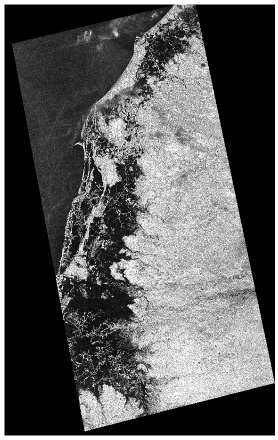

Figure 7: TerraSAR-X SC scene over the Gulf Country area

3. THE SEGMENTATION PROCESS

The first prerequisite to the object-based classification is to ensure proper segmentation of the datasets. Segmentation corresponds to the subdivision of an image into more or less homogeneous regions, called segments or objects. There is a high variety of segmentation algorithms (Meinel et al., 2004) (Neubert et al., 2008). The Multiresolution Segmentation algorithm which uses the Fractal Net Evolution Approach (FNEA), commercially introduced by Baatz and Schäpe (Baatz and Schäpe, 1999) is one of the most commonly used. It is a bottom-up region-growing technique starting with one-pixel objects. In many subsequent steps smaller image objects are merged into larger ones. The growing decision is based on local homogeneity criteria describing the similarity of adjacent image objects in terms of size, distance, texture, spectral similarity and form. The scale at which this segmentation is done can, and has to be chosen in relation to the characteristics of the dataset and the objective of the work. The aim of the segmentation is to delineate the meaningful regions which represent the objects that will be classified. For this reason it is mandatory for the quality of the further classification step that the borders of the water bodies (permanent or not) are clearly highlighted.

The Segmentation process is the most time consuming of the overall flood mapping processing chain. In order to reduce it regions potentially containing water are automatically selected. These regions, which will be concerned by the further Classification step, are then segmented. The amount of segments (objects) is thus drastically reduced and therefore the processing time. The result is an automated and target-centered segmentation in which the information of both dates, pre and post event is taken into account.

The obtained segmented level are overlaid on the post-event images is shown in Figure 9. These segmentation results can be compared with those obtained when the Landsat image is used as pre-event layer (Figure 8). The object shapes differ between the two images principally due to the different resolution of the two pre-event layers (3m for the TerraSAR-X image, and 30m resampled to 3m for the Landsat 7 image). Additionally the noisy effect that the natural pixel variation due to speckle of SAR images has also an influence on the left image object shapes and sizes.

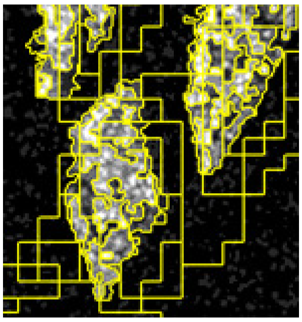

Figure 8. Multiresolution segmentation for combined Landsat7 TerraSAR displayed over TerraSAR post-event scene

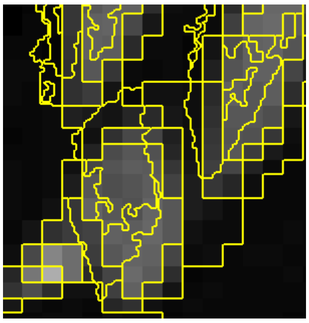

Figure 9. Multiresolution segmentation for combined Landsat TerraSAR displayed over Landsat 7pre-event scene

4. CLASSIFICATION-THE SEMI-AUTOMATED WATER MASK EXTRACTION

The classification process of the water extent is based on the extraction of the bio-physical parameters that characterize the backscattering from water bodies in the more adequate way. Unlike pixel-based techniques which only use the layer pixel values, the object-based techniques can also use texture, shape and context information of a scene. The optimal features (i.e. measurable properties of the segments) for water detection are identified, and constitute the basis of the "water"/"non water" classification of the pre-event and post-event scenes.

In order to develop a robust flood mask workflow, which served to analyse not only TerraSAR-X data, but also historical data, parameters common to optical and SAR images are selected:

- In optical image water absorbs most of the incident radiation and therefore appears dark in colour-infrared images. The characteristic spectral reflectance curve shows a reduction of intensity with increasing wavelength. In the near infrared the reflectance of deep, clear water is virtually zero, for this reason the channel 4 from Landsat7 is used for the water class.
- In the case of the radar, under low to moderate wind conditions, backscattering from water surface is low. The water body backscattering appears dark compared to the backscattering from the environment.

Based on those parameters, a rule-based classification system with tuneable variables and a user-friendly interface is constructed for the effective extraction of water extent.

Figure 10 and Figure 11 show the permanent water extent extracted using the TerraSAR-X dataset acquired on the 2008-10-17 and the Landsat acquisition 4th channel respectively. Main discrepancies in the water masks are due to the diverse image resolutions. Differences are also due to the different nature of optical and SAR sensors; same representative features are selected in both cases but the dissimilar values are chosen for detecting water.

It can be also noticed that in the two cases areas affected by shadowing are classified as water as they present a low reflectivity. Those misclassifications, that appear more on the Landsat-based results, will be corrected later in the refinement step.

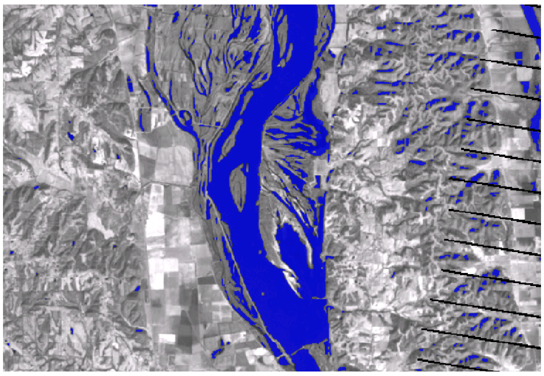

Figure 10: Pre-event water mask based on the 4th channel of the Landsat 7 ETM+ acquisition

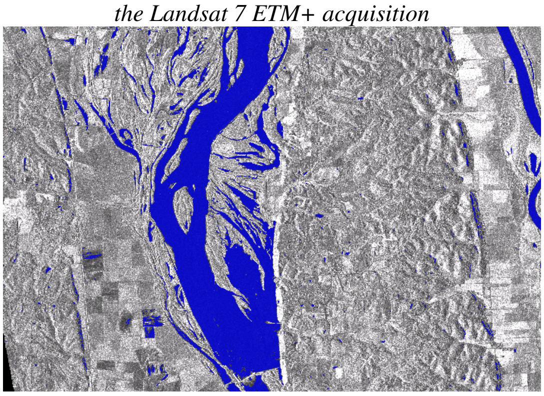

Figure 11: Pre-event water mask based on the TerraSAR-X acquisition of the 2008 10 17

The semi-automated extraction of the water extent after the rainfalls is made on the post-event datasets. The obtained results are shown in Figure 12 and Figure 13 for the Mississippi River case. The water masks look really similar despite the fact that two different layers were used as pre-event data for the original segmentation. It is worth mentioning that the selection of the pre-event layer had a direct influence in the shape of the objects and in the specific value needed for the selected features within the classification process.

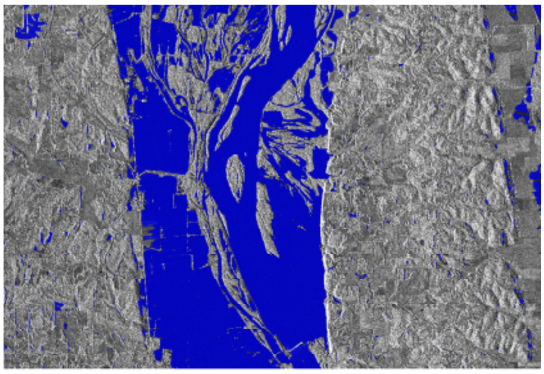

Figure 12: Post-event water mask based on the 4th channel of the Landsat 7 ETM+ acquisition

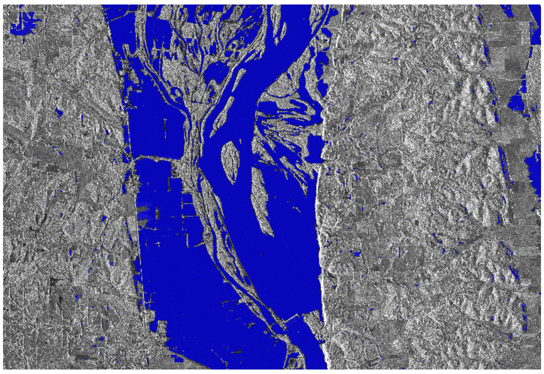

Figure 13: Post-event water mask based on the 4th channel of the Landsat 7 ETM+ acquisition

5. FLOOD EXTRACTION AND FINAL REFINEMENTS

The final step in the flood mask production is the generation of two water masks in order to separate flooded areas from existing water bodies like rivers, lakes and ponds. The need for refinement typically depends on environmental conditions and on the relief: Wind has a particular influence on SAR-based classification results, higher wind speeds resulting in larger errors. The refinement step consists in the improvement of the classifications made on the pre-event and post-event scenes. It includes the automated extraction of the Flood/ permanent water mask as well as final refinements, smoothing and minimum mapping filters. The aim is to re-classify segments which were misclassified due to segmentation vagueness (e.g. shadow areas), as well as incoherencies (e.g objects classified as "water" in the pre-event water mask, but as "non water" in the post-event water mask).
A final Minimum Mapping Unit is also defined depending on the quantity of detail desired in the final water mask and the precision of the final map.

Figure 14 and Figure 15 show details of the flood masks that were generated for the 2008 Mississippi flooding event. In the first case the Lansdat 7 scene is used as pre-event data, while in the second case it is the October acquisition of the TerraSAR-X the scene used as pre-event data. The masks look similar but Figure 14 shows that the Landsat 7 and the TerraSAR-X images were not exactly co-registered (overlay of the pre- (in light blue) and post-event (dark blue) water masks showing the mis-registration). This can be due to a problem of georeferencing and can be corrected adding a data registration step during the data preparation phase (Figure 2).

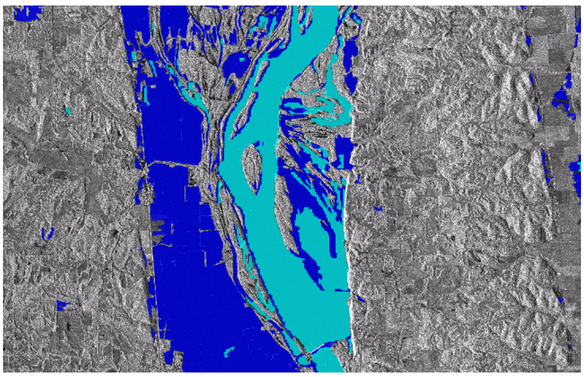

Figure 14: Pre-event and post-event water masks derived from Landsat 7 ETM+ and TerraSAR-X acquisitions

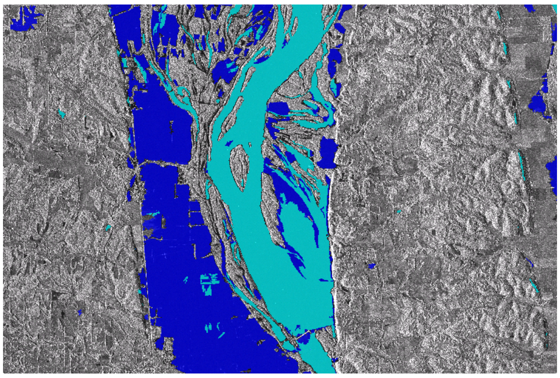

Figure 15: Pre-event and post-event water masks derived from TerraSAR-X acquisitions

The results obtained for the Australia case are also really satisfying. Figure 16 show a zoom of the area considered for the interpretation map generation (Figure 17). This latter is used as reference and allows a preliminary qualitative evaluation of the results of the developed flood mapping processing chain.

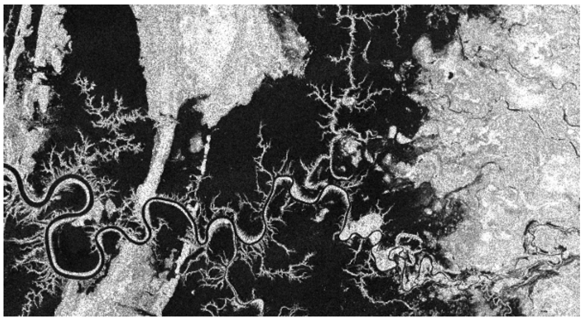

Figure 16: Zoom of the scene over the the Gulf Country affected area

Figure 18 shows the final mask of the permanent water (light blue) and flood water (dark blue) extents. The masks are in agreement with the ones displayed in Figure 17. Main differences are due to zones affected by shadowing that are classified as "flooded area". Work for improvement of the refinement is still on-going.
It is finally worth mentioning that the manual delineation required more than 10 working hours for the study of a third of the total scene while the semi-automated process needed less than 4 hours for the whole scene processing. This thus means that even if no further process was implemented for the correction of the shadows in flood plain areas, it could be assumed that deselecting shadows by manual editing tools might be still more time-effective than visual interpretation.

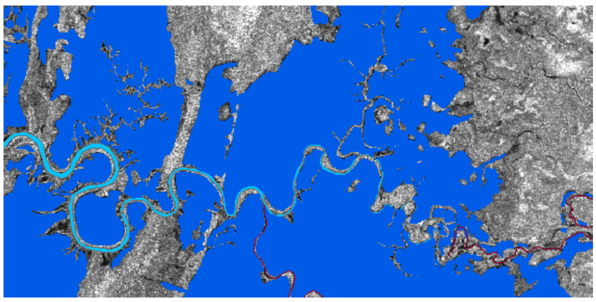

Figure 17: Interpretation map generated by a manual delineation of the water extent (Gulf Country affected area)

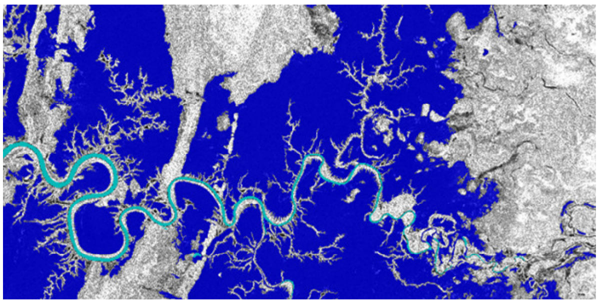

Figure 18: Detailed flood mask derived from TerraSAR-X data (Gulf Country affected area)

6. CONCLUSION AND DISCUSSIONS

The present document gave an overview of the work realized on the flood extent assessment. This tool was developed in the framework of the DeSecure project (DeSecure homepage). A semi-automated workflow was developed based on the use of TerraSAR-X data and on data acquired by other sensors.

The developed workflow was tested in two flood scenarios; the following points need to be highlighted:

- Large images were successfully processed: 30x50 km^2 and 100x150 km^2. for StripMap and ScanSAR scenes, respectively
- The adaptability and flexibility of the workflow was demonstrated working with scenes presenting a different relief and environment.
- The mapping chain robustness has been tested using different data source in the case of the Mississippi River flooding (TerraSAR-X data - 3m res and with Landsat 7 ETM+ - 30m res).

Finally a preliminary validation of the results has been made confronting them with map generated manually, by visual interpretation. It has been noticed that:

- First of all, the processing of the whole scene with the developed procedure required five times less work time that the manual delineation of the flood extent.
- The flood delineation was similar with the two methods. Further refinement could be required for the semi-automated processing in order to exclude from the classes "flooded areas" the shadow regions.
- This comparison has also demonstrate the effectiveness of the workflow; the mask generated with the semi-automated process show a level of detail that an interpreter digitalizing is not able to effectively reach.

In conclusion, developing this semi-automated system as a multi-mission concept has several advantages in the case of Near Real Time damage assessment:

- Flood extent delineation with high accuracy can be produced even when no TerraSAR-X pre-event data are available;
- The revisit time over the affected region is increased by the use of multi sources remote sensing data, this is an important factor when processes such as rising or declining water levels should be monitored.

The validation of the mapping chain is on-going, testing it for different flood scenarios and further improving the refinement step.

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