Operational Rapid Flood Mapping: a Pilot Study in the Mekong Area

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Abstract - Reliable and timely information is essential for appropriate flood management. This article describes a probabilistic method to assess flood extent from SAR data. It also addresses the derivation of flood levels and flood depth based on probabilistic flood extents and SRTM. The methods are tested on multiple incidence angle Envisat ASAR images. Providing flood extent maps in terms of probabilities using multiple angle data offers advantages for operational purposes, like major improvement of revisit time from 35 to 1-2 days. It also includes the possibility for weighted merging of various data sources (in-situ, optical and SAR) and uncertainty propagation in models. This approach will be adequate when more and higher resolution measurements like Sentinel-1 become available. The future objectives are extension to global use and a systematic and automated open-standard and open-source near real time output.

1. INTRODUCTION

The consequences of flooding due to rain, high tide or dike failure can be devastating and need to be detected and mapped as quickly as possible. In-situ sensor networks of hydrological gauges are increasingly aided by satellite imagery, which will play an important role in the GMES Emergency Response Core Service. This service is written in the light of so-called 'Rapid Mapping': fast retrieval of information from satellite imagery in order to map consequences related to hazards and civil protection.

Flood Control 2015 is a Dutch research programme in which government and industry work together to develop new technologies for combating flood risks. It has started in 2009 and continues up to 2015. The project focuses on observing, measuring, inspecting and forecasting. As part of the overall project the subproject 'Operational Rapid Satellite-based Flood Mapping' has been defined and executed in 2009. The goal of the project was to make Synthetic Aperture Radar (SAR) satellite-based flood mapping more operational using near real time (NRT) satellite images and to apply these images for improved flood mapping and management. Fast retrieval and operational use are different terms: a number of commercial and non-commercial agencies can correspond to flood disaster within a short amount of time, but not always on a daily basis and not within a time comparable to the caption time of the satellite image. Although not being able to look through clouds, Brakenridge (2007) from Dartmouth Flood Observatory has shown operational use of MODIS data for global flood mapping; a website showing flood images on a six-daily basis. By using SAR images we are able to look day and night and through clouds. Flood inundation mapping by using SAR images corresponds to surface water information, using the low backscattering characteristic of water. Also, the future use of freely available high resolution data from Sentinel-1 opens up many opportunities of mapping data for large as well as small and urbanized areas within a short amount of time. However, semiautomatic classical water extraction techniques, such as thresholding or change detection technique applied on SAR images, may fail due to windy conditions, or partially submerged vegetation, resulting in higher backscattering values (Yesou, 2007, and Prathumchai and Samarakoon, 2005). According to Silander et al. (2006) misclassifications may also be caused by the dependency of backscattering on detection angle. In a pilot study we try to add processing techniques to improve water recognition on SAR images while still being able to combine other data.

2. METHOD

2.2. Probabilistic classification of flood extent

The proposed method to overcome misclassification as mentioned in the introduction and to able to combine with other sources in the future, is a probabilistic method. For this study, we have used ENVISAT-ASAR Global Monitoring data. This data was continuously downloaded from a NRT rolling archive at the European Space Agency. The DTM used is SRTM. For SAR images in general it can be stated that non-flooded land provides more backscatter than water, because water does not disperse radar signals. Dispersion in general decreases with increasing incidence angles. For this reason the practical use of a fixed threshold to distinguish between these two signals is limited, because they are a function of the local incidence angle and seasonal factors. Therefore we train the decisive function using the SAR data itself by selecting a number of 'training areas', e.g. non-flooding land and water. Using the amount of backscatter and the local incidence angle, for both the 'always wet' and the always dry' datasets, a 2D histogram cam be made, as shown in figure 1. Both the histograms are normalized so that every row contains the same amount of data.

The histograms show that when using multiple angle data, the high incidence angles (< 30 degrees) show a clear distinction between water and land. For incidence angles lower than 30 degrees the difference becomes less evident, making a distinction less certain. Using this histogram, for every pixel the amount of backscatter and the local incidence angle are known. The probability of water is then estimated by:

$$P_{flood} = \frac{P(\sigma \mid \alpha)_{water}}{P(\sigma \mid \alpha)_{water} + P(\sigma \mid \alpha)_{land}} \quad (1)$$

Where α is the local incidence angle, and σ is the backscatter. The resulting probability map of flood is shown on the right of figure 1.

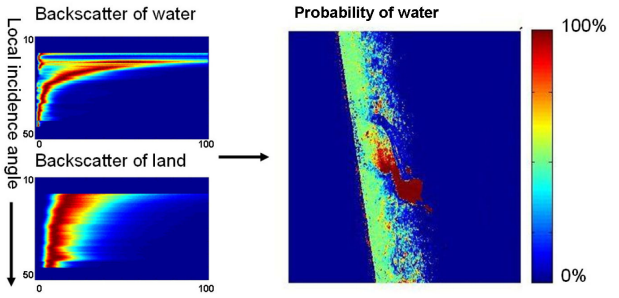


Figure 1. Histogram of the water (top-left) and land backscatter (bottom left) in the training area and the resulting probability of water (right).

2.3. Probabilistic classification of water depth

The flood probability map and a SRTM based DTM with a vertical resolution of 1 meter are used to estimate the water level. Based on Huizinga et al (2005) the probability of water body extent is compared to a range of pre-made scenarios of water levels using DTM-based virtual flood extents for various consecutive water levels in the range between 0 and 15 meter with respect to mean sea level.

The flood probability map can be delivered within 2 – 6 hours after caption time, depending on the processor calculation speed and data availability on ESA's NRT Rolling Archive of ASAR data.

3. RESULTS FROM PILOT

3.1. Pilot area – The Mekong River and Tonle Sap lake

As a pilot area, the Mekong River was selected with a focus on the Tonle Sap Lake in Cambodia. The lake is a combined lake and river system that is also the largest body of water in South East Asia. It remains relatively small for most of the year, covering around 2,700 square kilometers. However, during the monsoon season water flows in from the Mekong river, resulting in an expansion of the Tonle Sap lake up to 16,000 square kilometers measuring about 9 metres in depth. The lake always has its lowest water level in April and highest in October. The Tonle Sap Lake does not suffer from short-term flash flooding issues and in-situ monitored water levels can be used for comparison with the flood mapping results. The hydrological and forthcoming social environment at the lake are has been described a number of times by a.o. Mekong River Comission (2005, 2008). Also, hydrological research has been done by many (a.o. Hironori and Kzauhiko, 2008), making it a useful location for this study. The Mekong river and its environment are known for regular flooding from the river and man made agricultural purposes (i.e. rice). The data in the project was updated whenever new ASAR Global Mode (GM) images were downloaded from the ESA servers, which was in practice once every 1 – 2 days.

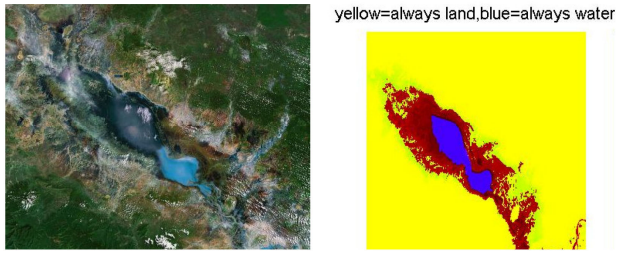


Figure 2. Tonle Sap lake, from Google earth (left) and from SRTM (right): yellow is always dry, blue, is always flooded, brown colors show the floodplains.

3.2. Probabilistic classification of flood extent

Two training areas have been selected in and around the Tonle Sap lake: one area that covers with certainty non flooding land ('always dry', for instance high land), and one area that is always flooded ('always wet'), like rivers and the central area of the Tonle Sap lake shown in figure 2. Figure 3 shows a screenshot for the month August 2009 in an open-standard environment (called Delft-FEWS), where flooding in the Mekong area is shown in blue. It should be noted that the classification in the Tonle Sap area is erroneous, which will be described in the discussion.

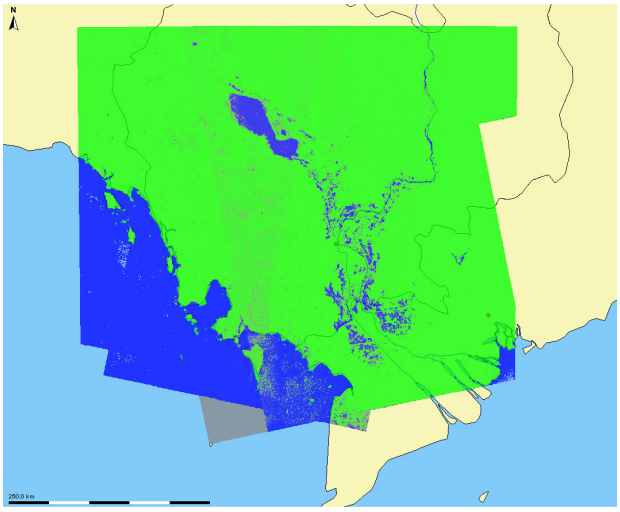


Figure 3. The probability of water as derived from ASAR Global Monitoring satellite data of multiple angles.

3.3. Probabilistic classification of water depth

The result is shown in figure 4. The maximum of the graph is the most likely water level of the lake. The shape of the curve shows the match with the virtual water level scenario maps and is a measure for the certainty of the result. The central part of Tonle Sap lake is deep with steep shores, surrounded by a large floodplain. When the water level is inside the core lake, the water level is nearly independent of the lake size, making it difficult to predict the water level. This is the reason that the left side of figure 4 remains high. When performing a first rough interpretation on each pixel, where the highest point in the water level probability information for each pixel is estimated as the most probable water level, we get a first estimation of the water level per pixel.

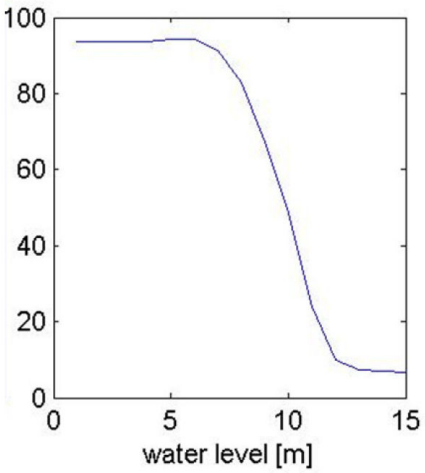


Figure 4. Probability of water level calculated for one pixel as derived from virtual water scenarios, the flood probability map and SRTM data in the Tonle Sap lake.

4. DISCUSSION

4.1. Probabilistic classification of flood extent

Using a probability map of flood has more than one advantage. First, by using multiple angle data, the revisit time of the area is shortened to an average of 1 – 2 days instead of 35 days. Also, slight enhancement of classification of the flooded area when compared to only an amplitude map is reached. The probability method is open for combination with other data (e.g. MODIS, optical data), improving the bandwidth of flood probability and the NRT character of the method. While other sources indicate that the Tonle Sap flood plain is filled with water, the probability map from the ASAR GM data shows that the area is probably not flooded. When using only these 1 x 1 km GM data, this calculation may lead to an erroneous interpretation. The reason for this is the double bouncing due to vegetation and canopy in the lake. When looking at figure 5, where an ASAR GM image is compared with one ASAR Wide Swath Mode (WSM, 150 x150 m spatial resolution) image of the same time, we see that the higher resolution data indicates the difference between flooded, flooded vegetation and dry area better. However, the time between WSM images in the area on ESA's NRT Rolling Archive is 35 days. The future use of Sentinel-1 data (20 x 20 m spatial resolution) will bring significant improvement in this area. The probabilistic method is very suited for the weighted addition of other in-situ and EO sources and the flood classification will be improved by the addition of these sources.

4.2. Probabilistic classification of water depth

The estimation of water level for each flooded pixel is a precursor for adding more data as extra 'virtual' hydrological water level gauges. At this stage however, when compared to other virtual water gauges (from e.g. ESA River and Lake Service), we see that the use of SRTM is too coarse and a DTM with higher vertical resolution is needed. Although quick and easy to use, the SRTM spatial resolution (30 - 90 m) may be insufficient when dealing with slight changes in topography, and the vertical resolution of data is highly variable. Farr et al (2007) conclude that the deviation in vertical measurements from SRTM can be several meters. The largest errors are associated with steep terrain and very smooth surfaces with low signal-to-noise ratio.

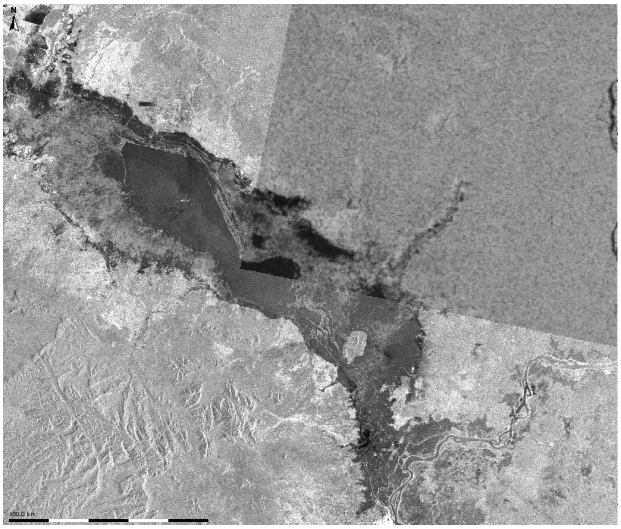


Figure 5. the difference between ASAR GM 1 x 1 km (top right) and ASAR WSM 150 m x 150 m can improve the probabilistic method for creating flood maps.

4.3. The way forward: global maps in open standard

The presented algorithm has been implemented in an operational monitoring platform and has worked for over a year in the Mekong pilot area in 2009. In January 2011, the Flood Control 2015 Programma has started a follow-up project which is called 'Systematic and Automated Global Flood Observatory'. The first goal in this project is to implement the above presented algorithm in an automated workflow in which global NRT ASAR data will be automatically matched with pre-trained histograms. The output will be an NRT global water extent map in a minimum resolution of 1x1 km (150x150m where there is WSM data). The water extent maps will be presented in an open-standard NetCDF and in open source so that they can be globally used by a diverse range of organizations (UN, Red Cross, local, national or international emergency response services, etc). The long term objectives of the observatory are

- to optimize the processing in order to cope with the huge amount of Sentinel-1 data coming up after 2012;
- to give more uncertainty information of the probability;
- to improve the probability algorithm by combining with other (e.g. in-situ or MODIS) data. These parameters can be merged (although weighted) with the existing interpretation criteria of in the histogram of backscatter and angle of incidence.

5. CONCLUSIONS

Flood extent maps with low (1 x 1 km) or medium (0.15 x 0.15 km) spatial resolution are available on a NRT basis within 2 – 6

hours after caption time by using a probabilistic classification and imaging them in an open standard hydrological platform. Working in this way, NRT flood extent maps can be used for damage assessment and mitigation actions in remote areas.

6. ACKNOWLEDGEMENTS

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- Envisat ASAR NRT data (ESA);
- SRTM (NASA).

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