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Hydrology and Earth System Sciences Discussions

Interactive comment on "Improved estimation of flood parameters by combining space based SAR data with very high resolution digital elevation data" *by* H. Zwenzner and S. Voigt

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First of all, the authors wish to thank the anonymous referee for the constructive comments, criticism and suggestions which will definitely improve the final version of this paper. In the following pages we try to answer the issues raised by the referee in sequence. The referee comment is printed in italic and the answer is printed in bold.

It is stated that "'the flood profile is shifted horizontally along the cross section by using a moving window over a defined range of sampling points"' : is this a shift of the whole image (i.e. some kind of improved georeferencing), or is this only a part of the image, and if so, how is this done?

Initially, the cross sections are established according to the centerline of the main river course. Each cross section consists of a range of linearly arranged sampling points covering the entire flood plain. The distance between cross sections was set to 100 m for the Elbe case study (Radarsat-1) and 50 m for the Severn case study (TerraSAR-X), whereas the spacing of the sampling points within each cross section was set to 10 m for Radarsat-1 and 5 m for TerraSAR-X. Afterwards, the cross sections were intersected with the DEM and flood mask and the elevation and the flooding status (yes/no) were assigned to each sampling point. The subsequent correction or shifting process is then carried out for each profile individually. This automated process seeks to compensate classification errors and small geometric displacements of the initial flood mask locally, on the basis of each individual cross section profile. All flooded sampling points of one single cross section constitute the "‘flood profile"’ which has to be revised. Flooded profile segments which are not connected to the main water body are removed whenever they exceed a threshold (in this case 3 m) above the mean elevation of the main water body. This occurs for example on hill slopes which are misclassified due to low backscattering. The remaining flood profile is then shifted to find its lowest position in the valley-shaped terrain of the cross section using a moving window. We will explain the profile method in more detail to better cover these issues in the revised text version.

How do you use this moving window? And what is this defined range of sampling points?

The moving window is used to calculate the mean elevation of the flood profile for various positions on the cross section. The flood profile is then fixed at the position of the lowest mean elevation, thereby not exceeding a maximum shift of 10 sampling points either to the left or right from its original position on the cross section. That means a maximum shift of 100 m is allowed for Radarsat-1 (50 m for TerraSAR-X) in either direction perpendicularly to the centreline of the

river. Ideally, the displacement is very small. If there is a systematic shift in all profiles, the georeferencing of the initial SAR image should be checked and the whole procedure should be repeated. This information will also be included in the revised text version.

The text states further, that for calculating the water level from the left and right border, "‘this is done for each individual cross section along the river flow line in order to establish a longitudinal profile of the flood level. A moving average is applied to the longitudinal water level to obtain a smooth water surface which serves as reference water level for the flood depth delineation. The horizontal extent of the cross section flood profiles is adjusted according to the reference water level and the flood plain topography."’ So you somehow adjust the left and right border of the flood plane? How is this done exactly?

After the elevation of the water level (i.e. from the left and right point of the flood profile) is extracted for each of the shifted profiles, they are assembled in the longitudinal profile of the whole image. As shown in Figure 7, there is a rather high variation in the water levels of the longitudinal sequence of the flood profiles. This variation is mainly due to classification errors at the land-water-boundary where horizontal displacement leads to significant errors in elevation. By using a moving average over the whole sequence of the longitudinal water levels a smooth (i.e. more natural) water level is generated. This "‘smoothed"’ water level for each cross sectional flood profile is then given back to the flood profile correction process as "‘reference water level"’. In this process each flood profile is adjusted in its horizontal extent according to its reference water level, i.e. it grows or shrinks until it fits into the terrain. This will be made clearer in the final text version.

Shouldn’t you go through some kind of iteration in this step (because you started off with the levels at the right and left bank)? Where does the reference water level come from?

Unless there is no additional data available as reference water level, as it is the case in our example, an iteration process is not necessary. The reference water level comes from the initially revised flood profiles which are then smoothed in order to get a quasi-natural planar water surface level.

The preprocessing of the data for both examples (Elbe and the River Severn) is different: For the Elbe, you use: - a 7x7 window for speckle filtering; - a criterium based on a threshold for delineating the flood plane. It is found that the flood plane derived from the RADARSAT scene is too small: is this a result of an incorrect threshold?

Generally, the concept of a threshold is a fairly simple classification approach and it should be taken into account that one single threshold for the whole image always implies some uncertainty. However, the threshold used to separate water and land pixels is increased iteratively until an optimal threshold is found. An image interpreter can get intuitively a comprehensive image of the flooded areas by looking at the original SAR image. However, it is difficult to extract a similar flood mask automatically. Thus, the optimal threshold is found by visual comparison of the original SAR image with the classification result. Such visual comparison is often adopted in Rapid Mapping Applications when no reference data is at hand. If the threshold is too low the flooded area is underestimated and if it is too high the flood mask gets dispersed and too many pixels outside the floodplain are classified as water. Certainly, the threshold alone does not explain the large underestimation of the flood extent in the RADARSAT data. We rather assume this underestimation is caused by classification errors due to flooded vegetation, wind and a turbulent water surface which all tend to result in higher backscattering in the SAR data. Furthermore, there may be too much distortion from the proximity of urban areas in the RADARSAT data. Also the pixel size of 12.5 m has a significant influence on the accuracy of the water mask when compared with a high resolution DEM of 1 m pixel spacing. The threshold only captures pure water pixels, whereas pixels at the land/water boundary are clas-

sified as land because of higher backscatter values. That means the boundary of the water mask tends to be biased towards the water which leads to an underestimation of the flood extent. Ultimately, we come to the conclusion that such traditional medium resolution SAR systems are not appropriate for such detailed studies and the derivation of more advanced and precise flood depth maps.

This threshold was chosen by trial and error: this was probably done by comparing the resulting flood plane for a given threshold with some reference image: which image (or map) was this? Definitely not the one obtained from the IKONOS image.

The resulting flood extents were later compared independently against official municipality flood maps derived from aerial survey and citizen interviews. These official flood maps showed good agreement with the IKONOS image and a substantial underestimation of the flood extent derived from RADARSAT-1 data. Details of the reference flood maps will be given in the final text version.

For the River Severn, you applied: - a 31x31 window for speckle filtering; - a multiresolution segmentation technique to delineate the flood plane.

I would suggest to use the same technique for both examples, such that the robustness of the technique can be demonstrated (now the results are not good for RADARSAT whereas the TerraSAR-X yields good results: this may partially be the result of different preprocessing steps.

Although we agree that this is a good suggestion, we have to state that the derivation of the flood mask was not the main focus of our paper. It will be emphasised in the final text version that we rather take the flood mask as an input and focus on the methods of correcting and improving them as well as to elaborate how precise maps of flood depth can be derived. Therefore, we used our standard preprocessing procedures and the flood mask delineation methods according to the literature. For high resolution SAR data the object-oriented segmentation of the image prior to classification has proven to yield

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best results (Blaschke et al., 2000; Baatz Schäpe, 2000), whereas for medium resolution imagery the pixel based approach has proven to be the most efficient method (Brivio et al., 2002; Bonn Dixon, 2005). Nevertheless, we also tried the segmentation approach on the RADARSAT data and received a nearly identical flood mask.

Some minor comments: - page 2954, line 14: combining (typo)

Corrected.

- page 2955, line 9: depend (instead of depends)

Corrected.

- page 2956, line 8: "'It is supposed ...'": why?

We tested the proposed method only in flood plains with pronounced terrain. In very flat areas a small deviation in the elevation of the water level has a much greater influence on the horizontal extent of the flood water than it is the case in more hilly terrain. It was demonstrated in this study that the derivation of the water level from a satellite image and an elevation model is very difficult and minor errors due to misclassifications and scaling issues may still occur. Thus, we assume that the proposed methodology is not appropriate for very large and flat flood plains.

- page 2958, line 4: are you sure it is radar shadow, or is it a low backscattering due to stretching of the backside of the mountain? Please check and correct if necessary at all places where radar shadow is mentioned.

We agree that this formulation may be misleading. We accordingly changed it to: "'low backscattering due to geometric effects such as radar shadow or stretching of the backside of the mountain."'

- page 2959, lines 1-3: this contradicts the title of the paper which states "'Improved

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estimation"': here you in fact say that the radar derived flood image is not good.

Improvements of the RADARSAT flood mask could be achieved to some extent by shifting the flood profiles to their lowest position within the terrain and thus make them hydraulically more plausible. However, the following analysis showed that no meaningful flood level estimates could be computed from the flood mask derived from this sensor because of the large underestimation of the flood extent. This is why the work flow stopped at this point and we stated that no further parameters such as flood depth could be derived. We will make this clearer in the final text version.

- page 2960, lines 17-19: explain better how this digitisation of the centerline was done.

For the Elbe case study the centreline was automatically derived from vector data showing the normal water level using GIS functions (dual-line to centreline). In the case of the River Severn, the centreline was manually digitised from the satellite imagery. We will include this information in the revised text version.

- page 2961, lines 11-16: here you mention the construction of a TIN: this was not explained in the methodology and was not applied to the RADARSAT image. The same technique should be used on both examples.

As previously mentioned, no meaningful elevation of the flood profiles from RADARSAT could be derived. This means that the work flow stopped prior to the TIN creation. A TIN of the water level is only necessary for the calculation of flood depth. Since this was obviously not clearly explained in the text, we will elaborate on that in more detail in the final text version.

- page 2963, line 23: typo: built-up areas

Corrected.

- figure 7: legend: change TSX to TerraSAR-X.

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Corrected.

References

Bonn, F., and Dixon, R.: Monitoring Flood Extent and Forecasting Excess Runoff Risk with RADARSAT-1 Data, Natural Hazards, 35, 377-393, 2005.

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