IMPROVING FLOOD MAPPING IN ARID AREAS USING SENTINEL-1 TIME SERIES DATA

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ABSTRACT

This article presents a methodology to improve the flood classification results of an automatic Sentinel-1 Flood Service (S-1FS) in arid areas, where reliable SAR-based water detection is usually not possible. Statistical information of Sentinel-1 (S-1) backscatter time series data were used to remove water look-alikes related to sand surfaces which generally lead to significant overestimations of the flood extent as these are characterized by similar backscatter values as open water areas. The approach was demonstrated and evaluated on a flood event in May 2016 at Webi Shabelle River, Somalia, where a time series of 15 Sentinel-1 archive data were available. The algorithm proved capable to significantly improving the classification accuracy of the S-1 flood processing chain and increases the Overall Accuracy by approx. 5% and the User's Accuracy of the class flood by approx. 26% within the study area.

Index Terms— Flood, Sentinel-1, time-series desert, arid areas,

1. INTRODUCTION

Flooding is the most frequent and widespread natural hazard in the world. Due to the near all-weather/day-night acquisition capabilities of Synthetic Aperture Radar (SAR) this technology is very efficient for near-real time (NRT) flood mapping and for supporting disaster management and mitigation activities.

Within the last decade there has been a significant progress in SAR-based flood mapping. In particular, the increased availability of synoptic, high-resolution, multi-temporal data over large areas in NRT and the development of automatic flood detection algorithms [e.g. 3, 5, 6, 8] has been invaluable to flood mapping efforts. However, a certain amount of manual user interaction is commonly required for satellite data pre-processing, the compilation and adaptation of auxiliary data, map production, and the dissemination of flood the information to users.

Recently, an on-demand TerraSAR-X-based Flood Service has been presented by [4], which consists of a fully automatic processing chain geared towards NRT pixel-based flood detection using TerraSAR-X data. This processing chain has been adapted to Sentinel-1 (S-1) C-band data by [9], operated by the European Space Agency (ESA) in the frame of the European Union's Copernicus Programme. This mission consist of two systematically acquiring satellite sensors (S-1A/1B) with a repeat cycle of 6 days operating in a pre-programmed conflict-free mode which ensures a consistent long-term data coverage and archive for systematic flood mapping purposes.

Flood mapping approaches have in common that these are based on automatic thresholding algorithms for the initialization of the classification process in SAR amplitude data, e.g. using Otsu's method [7] on global gray level histograms [7, 8], non-linar fitting under the gamma distribution assumption [5], image tiling and KI thresholding [2] on selected image tiles [3], and hierarchical image tiling and bimodality testing [1].

Even if these methods are able to extract the flood extent if there is a significant contrast between water and non-water areas, the flood detection may related to significant overestimations if non-water areas have a similar low backscatter as open water. This is mainly the case in arid regions where sand surfaces are characterized as water look-alike areas. This makes a reliable SAR-based detection of flooding in these regions nearly impossible. This problem is hardy tackled in the literature and these arid areas are mostly excluded from classification. E.g. [10] use the land cover class "Unvegetated/Barren or Sparsely Vegetated Area" of the MODIS/Terra Land Cover Types dataset (2001-2004) which is available as a global 1 km raster dataset (MOD12Q1) to exclude desert areas from the computation of a global water indication mask using TanDEM-X data.

The objective of this study is to investigate the potential of using S-1 time series data to improve the reliability of flood classifications in arid regions where desert areas generally lead to significant overestimations of the water extent. This is accomplished by the use of statistical information of S-1 backscatter time series information which helps to identify non-water areas which have a permanent low backscatter over time and to exclude these areas from flood detection. Conversely, areas are identified where a flood mapping is possible due to time series statistics. The developed methodology is tested on a region near Beledweyne in Somalia.

2. METHODOLOGY

The following workflow is developed for the rapid mapping of flood surfaces in arid areas (see Fig. 1).

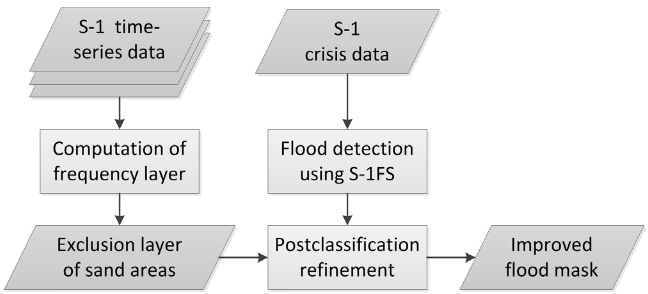

Figure 1: Workflow for improved flood mapping in arid areas using S-1 time series data.

First, the fully automatic S-1 Flood Service (S-1FS) presented in [9] for the NRT extraction of the open flood extent from S-1 crisis data is applied. In a second step, the whole S-1 time series information available for the affected area is used for the generation of an exclusion layer which is used to eliminate areas which often have a low backscatter over time and therefore would result in an overestimation of the flood classification.

First a frequency map is computed which counts the number of acquisitions over the study area in the whole time series for each pixel i. In a second step a raster layer is generated which exhibits the frequency f of each pixel i that has a backscatter lower than a predefined threshold τ in the whole time series. The parameter τ is empirically defined as -15 dB. Finally all pixels are assigned to 10 classes ranging from 0-100% with a 10% interval.

The exclusion layer is built using the classes which offer a certain frequency that a pixel has a value below τ over time. This layer is used within a final post-processing step to improve the flood classification result of the S-1FS by subtracting the exclusion layer from the automatically derived flood mask. Finally, in order to filter out isolated flood objects resulting from this processing step, a minimum mapping unit of 30 pixels is applied.

The exclusion layer can be processed offline to improve the NRT applicability of the S-1FS during disaster management activities.

3. EXPERIMENTAL RESULTS

3.1. Study site and data set

The study area is located in the arid climate zone south of the city Beledweyne in Somalia at Webi Shabelle River which begins in the highlands of Ethiopia, and then flows in southeastern direction into Somalia towards Mogadishu. The study site covers an area of ~103 km² (1132 x 931 pixels). The approach is tested on an S-1 scene of 30/05/2016 which covers flooding along the Webi Shabelle River (see Fig. 2 and 3). Large parts of the area of interest are cover by sand which has nearly the same backscatter as open flood surfaces.

The exclusion layer is generated on the basis of 15 VV polarized S-1 time series data covering the period of one year between 20/10/2014 - 27/10/2015. Beside September 2015, each month is at least covered by one data set. Thus, also seasonal variations of the land surface are covered. The frequency classes 40-100% are visualized in Fig. 3.

Two Landsat-8 data sets acquired on 28/08/2016 and 04/06/2016 with a spatial resolution of 15 m and one Sentinel-2 data set of 25/05/2016 with a spatial resolution of 10 m are used for the generation of a reference water mask by visual interpretation and manual improvement of the original flood extent derived from the S-1FS.

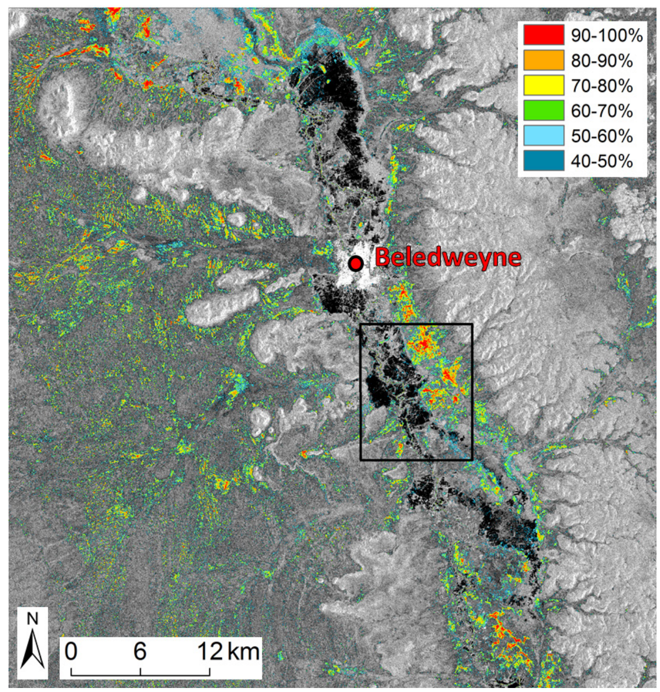

Figure 2: Subset of the S-1 scene of 30/05/2016 overlain by frequency classes 40-100%. The black polygon is related to the study area (see Fig. 3).

3.2. Results and discussion

In this section the effectiveness of the proposed extension of the S-FS is evaluated. The flood masks post-processed using the time series-based exclusion layers are compared to the optical data-based reference flood mask.

Different combinations of frequency classes are tested for the computation of the exclusion layer. Fig. 3 illustrates the Overall Accuracy (OA), Producer's (PA), and User's Accuracy (UA) of the original flood mask of the S-1FS (result 1) and the improved flood masks using different exclusion layers (result 2-7). The original flood mask (Fig. 2c) is related to strong overestimations as sand surfaces are wrongly classified as water. The UA has a value of only 73.4%, the OA a value of 94.0%. The larger the frequency range used to compute the exclusion layer the more increases the UA of the class flood. However, this is also related with a decrease of the PA of the class flood.

The highest OA is achieved by improving the flood mask of the S-1FS by an exclusion layer (Fig. 2c) computed with a frequency interval of 70-100% (result 5). At this classification result the PA has a value of 98.0% and the UA a value of 99.3%. Most of the flood overestimations resulting from sand surfaces are eliminated (Fig. 2d). Simultaneously, only a low number of originally correctly classified pixels are removed from the flood mask by the exclusion layer. These are mainly permanently sand-covered areas which are flooded on 30/05/2016.

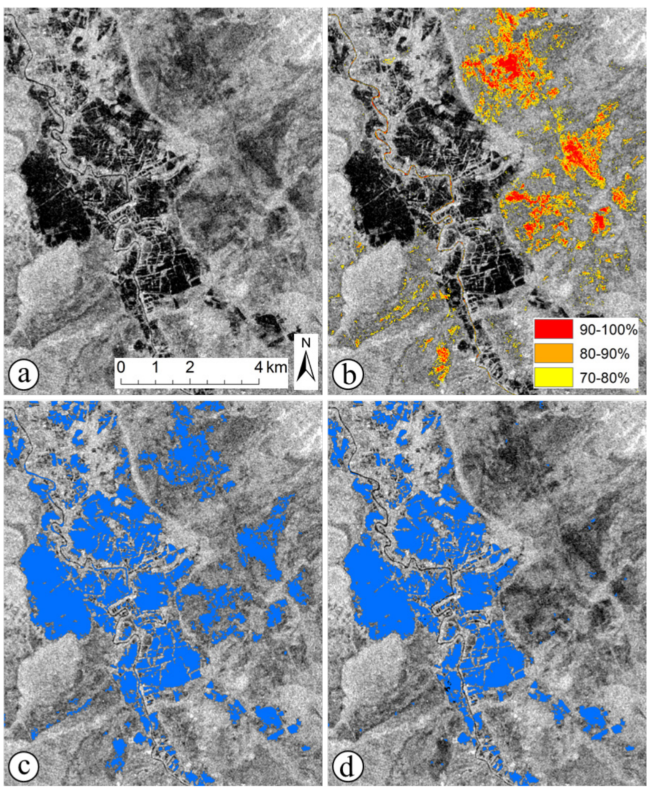

Fig. 2: a) S-1 data set of the test area near Beledweyne, Somalia, b) exclusion layer, c) original flood mask of the S-1FS, d) improved classification result using the exclusion layer (f = 70-100%). Coordinates of the study area: 4.695°N, 45.287°E (upper left); 4.593°N, 45.287°E (lower right).

5. CONCLUSION AND OUTLOOK

In this work, an approach to improve the classification results of an automatic S-1 Flood Service in arid areas is presented, where reliable SAR-based water detection is usually not possible. This is accomplished by an exclusion layer computed from 15 S-1 time-series data which is used to remove low backscattering sand surfaces from the flood mask.

The highest OA is achieved by improving the flood mask of the flood processor by an exclusion layer computed with a frequency interval of 70-100%. The algorithm proved capable to significantly improving the classification accuracy and increased the OA by ~5 % and the UA of the class flood by ~26 % within the study area.

Future work will focus on testing the transferability of the methodology to other flood scenarios in arid areas.

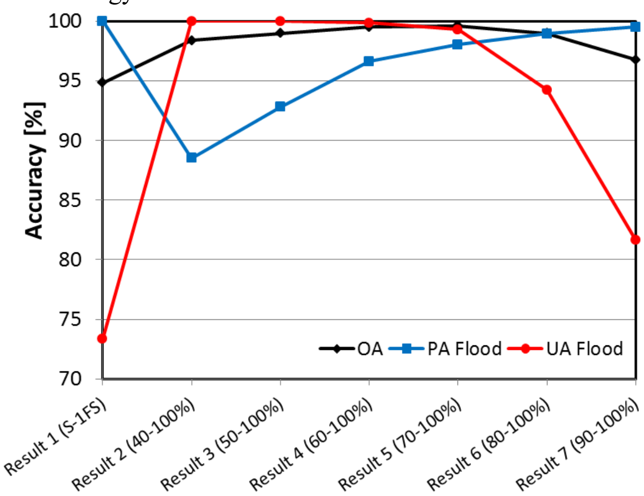

Fig. 3: Accuracies of the classification of the S-1FS and of the improvements using the sand exclusion layers computed with different frequency intervals.

11. REFERENCES

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