FLOODPLAIN INUNDATION MAPPING USING SAR SCATTERING COEFFICIENT THRESHOLDING AND OBSERVED DISCHARGE DATA

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ABSTRACT

Inundation area time series are important for wetlands monitoring and hydrological model validation. This study is conducted in Biebrza floodplain, which is a natural wetland with complex inundation generation processes. In order to map 2014-2018 series of inundation in the floodplain we test our automatic thresholding method on Sentinel 1 data. The threshold value is optimized using correlation of the inundation area with observed discharge at the floodplain outlet. The inundation maps match well the MODIS 500m reflectance data used as a reference, whereas, the total inundated area per Sentinel 1 image match well the observed discharge pattern. Unfortunately, this approach was unable to identify inundation in remote parts of the floodplain, what may have few reasons and needs further investigation.

Index Terms— SAR, floodplain, wetlands, thresholding, Sentinel 1, Biebrza

1. INTRODUCTION

Biebrza River floodplain is a natural wetland regularly inundated during spring floods. The inundation is composed of: (1) river water, contributing close to the river channel and (2) floodplain water, such as groundwater discharge, snowmelt or rain, contributing further away from the channel. Similar situation is observed in other natural, wetland floodplains such as Amazon, Ob and Irtish and other [1]. Spatial extent and the temporal variability of inundation zones originating from different water sources affects, among others, denitrification of flood water, sediment distribution in the floodplain and the flood magnitude [2, 3].

Therefore, continuous monitoring of the inundation extent, preferably with discriminating the contributing water sources is important for floodplain ecology and flood protection. Synthetic Aperture Radar (SAR) data is often used for flood extent mapping due to its high spatial and temporal resolutions unaffected by cloud coverage. Among other, a simple method often used for this purpose is grey-level thresholding

[4]. The thresholding method, however, is unable to discriminate between water from different sources. To overcome this issue hydrological models are used together with hydrograph separation features, such as Hydraulica Mixing-Cell [5].

An interesting union of SAR data with hydrological models is in using SAR-derived inundation maps for validation of the modelling results. Multiple studies have used this approach either for validation or for monitoring in one or few time slices, usually during the flood peak e.g.: [6, 7]. However, if a model has to be validated for entire (multiple) season(s) more validation data, also during low floods, should be acquired. This is may be an issue, especially if geodetic reference points representing inundation coverage are missing.

In this study we test a SAR thresholding approach allowing to find optimal threshold for inundation discrimination in a long time series of SAR data over a big area without need of in-situ geodetic measurement. We hypothesize that the discharge time series registered near the inundate floodplain outlet can be used to identify the optimal threshold value.

2. METHODS

The study is conducted in the lower Biebrza River floodplain (NE Poland), which covers about 220 km^2. This wetland area is a protected NATURA2000 and Ramsar site, has a National Park status in Poland and is a reference area for wetland research. The area is covered by various types of vegetation including open space meadows, shrubs and deciduous and coniferous forests.

We use Sentinel-1 data for inundation thresholding. Since phase information is not important in this approach we use Level-1 ground range detected (GRD) VV polarization data, which are further calibrated to Sigma0, cropped to the study area and terrain corrected using the ESA SNAP software. In total we use 120 SAR images acquired between 2014-12-03 and 2018-11-18, what corresponds to the intersection of the Sentinel 1 being operational and discharge data availability periods. Sentinel 1 data was obtained using the ESA Copernicus API and Alaska Satellite Facility API. For this analysis we used only imagery that entirely covered the study area.

Hourly time series of discharge data were obtained from Institute of Meteorology and Water Management - National

Research Institute. The gauging station is located near the confluence of the Biebrza and Narew Rivers, which is the outlet of the floodplain.

The inundation area is not directly a function of discharge at the outlet, however, these variables are related. Therefor our optimization function was to maximize the correlation coefficient (r) between the observed discharge (q) [m³/s] and the inundated area time series (a) [m²] expressed as an area of the SAR raster cells i with Sigma0 (s_0) [dB] lower or equal to the specified threshold (t) [dB]:

$$r = \mathrm{cor}\,(q, a\,(t))$$

where the inundated area for a single image d is:

$$a_d\,(t) = \sum_{i=1}^{N} \begin{cases} c, & s_0^i \leq t \\ 0, & s_0^i > t \end{cases}$$

where c is a raster cell area [m²] and N is the total number of raster cells.

We verify the SAR derived inundation extent using optical satellite imagery acquired during cloud-free periods.

3. RESULTS AND DISCUSSION

Optimal threshold for inundation mapping in the Biebrza floodplain was $t = -20.97$ dB and the corresponding correlation coefficient was $r = 0.59$ (Figure 1). For the correlation range 0.50 to 0.59 the threshold range was -23.98 to -19.39 dB and the resulting inundation maps were not much different. For the optimal threshold value the temporal pattern of the total inundation area resemble well the discharge hydrograph (when noticing that the SAR imagery resolution was considerably lower than the discharge data resolution, Figure 2). The good temporal match is observed both in high and low discharge period. The inundation pattern frequency in the entire study period shows, as expected, higher frequencies close to the river channel (Figure 3). However, inundation maps for single day exhibit a considerable amount of noise and patches in the inundation extent. These features are the result of complex micro-topography, such as tussocks and pits and trees and shrubs cover. Most of these features can be removed by applying a majority filter. Nonetheless the vegetation impact on the inundation pattern is very clear and this is considered as a main drawback of our approach. The vegetation impact could be minimized if instead of Sentinel 1 C band a longer band, such as L band (e.g. ALOS PALSAR sensor) would be used.

The inundation extent match well the observations of MODIS Aqua 500m reflectance data acquired 2018-01-16 (Figure 4). Unfortunately we were not able to perform a broader comparison with the MODIS data, because only very few cloud free images were available during flood peaks in the study area.
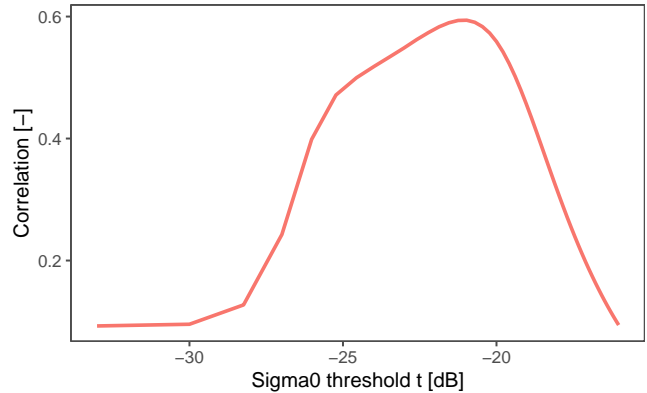

Fig. 1. Correlation coefficients between the observed discharge at the floodplain outlet and the inundated area derived from SAR imagery given the different threshold t values.
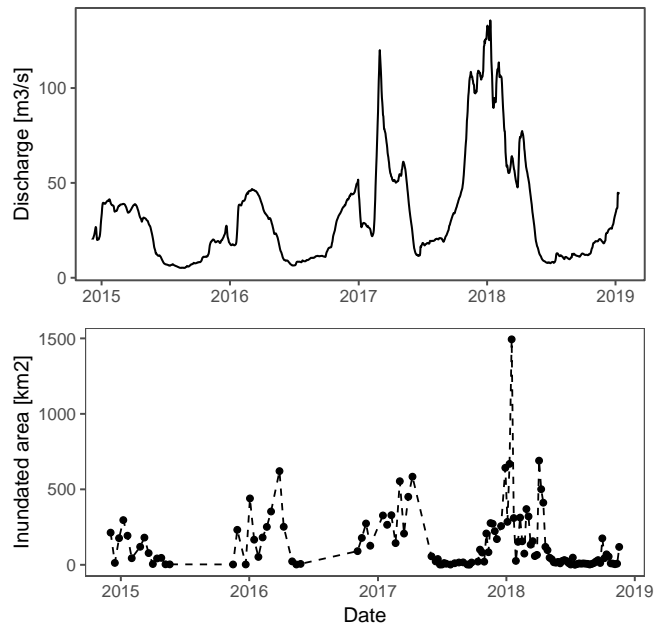

Fig. 2. Comparison of the discharge hydrograph near the floodplain outlet and the inundation area time series derived using 120 Sentinel 1 images.
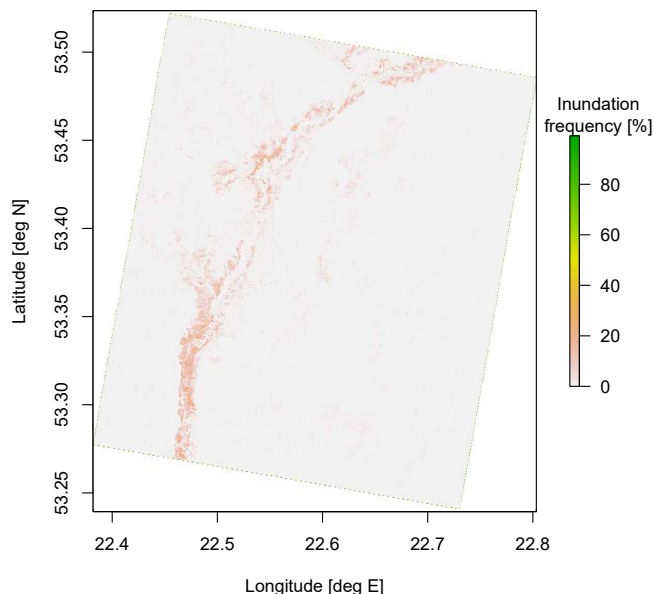
Fig. 3. Inundation frequency map derived from 120 SAR images in the period 2014-2018.
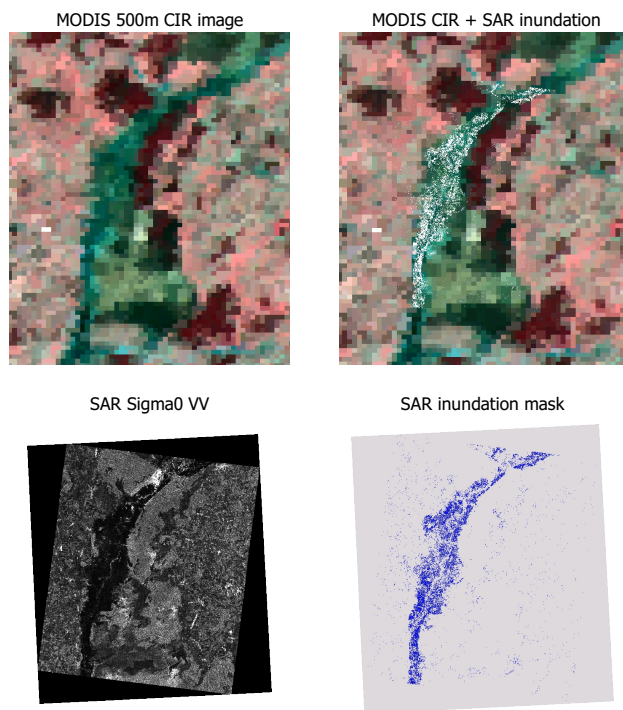

Fig. 4. Inundation area in the lower Biebrza floodplain on 16 January 2018. Top panels present MODIS CIR composite (left) with the inundation mask overlay (right). The bottom panels present the Sigma0 VV data and the corresponding inundation map. The scene is 25 km width and 30 km height.

Based on former groundwater monitoring in the study area the floodplain was usually inundated in the remote areas valley where groundwater, snowmelt and rain contribute more than the river water. However, the approach used in this study failed to show extensively inundated area outside the proximity of the river channel. The reason for this could be the generally dry conditions in 2014-2017 period, what is also reflected by lower than usual flood peaks. The other reason is that the inundation in the remote parts of the floodplain is usually very shallow (e.g. few centimeters) what with presence of vegetation made this approach unable to identify the inundation. Another reason could be that the inundation in the remote parts of the floodplain is not related to the river discharge and the threshold optimization based on the correlation with discharge data cannot be used for identifying inundation caused by water from sources other than river.

4. CONCLUSIONS AND OUTLOOK

This study showed that thresholding for inundation extent mapping using correlation with discharge data is feasible for long time series of SAR images over big areas. Due to the inundation extent correlation with discharge the method presented here could potentially be used to predict discharge from SAR imagery in similar study sites. The method presented here may be improved by collecting longer SAR time series and by introducing a vegetation pattern removal technique. We would like to test in the future how temporal and spatial filtering and polarimetric techniques can improve the mapping. The approach should also be subjected to independent validation using e.g. GPS data. Based on this preliminary study, it appears that the method may not be good for areas where inundation is generated by water from sources not directly related to river discharge, but this have to be investigated deeper during more moist hydrological conditions.

5. REFERENCES

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