Generating an Exclusion Map for SAR-Based Flood Extent Maps Using Sentinel-1 Time Series Analysis

Jie Zhao[1,2], Marco Chini[1], Ramona Pelich[1], Patrick Matgen[1], Renaud Hostache[1], Senmao Cao[2], Wolfgang Wagner[2]

[1]Luxembourg Institute of Science and Technology, Department of Environmental Research and Innovation, 4362 Esch-sur-Alzette, Luxembourg

[2]Vienna University of Technology, Department of Geodesy and Geoinformation, Gusshausstr. 27-29, 1040 Vienna, Austria

Introduction

Most of the studies in this field proposed change detection based methods that are based on the assumption that the appearance of floodwater results in a significant decrease of backscatter. However, limitations still exist in areas where the SAR backscatter is not sufficiently impacted by surface changes due to floodwater. For example, in shadow areas, the backscatter is stable over time because the SAR signal does not reach the ground due to prominent topography or obstacles on the ground (e.g., buildings). Densely vegetated forest is another insensitive region due to the low capability of SAR C-band wavelengths to penetrate its canopy. Moreover, in some areas such as arid regions, streets and buildings, the backscatter changes over time could not be detected because in such areas the scattering variation caused by the presence of water might be negligible with respect to the normal "unflooded" state.

In this study, we introduce a new method that allows identifying the abovementioned areas where SAR does not allow detecting surface water based on change detection methods. The resulting 'exclusion map' (EX-map) is crucial for providing reliable SAR-based flood maps.

Results

- Sentinel-1 Interferometric Wide Swath (IW) data with VV polarization acquired from 2016 to 2019 have been used in this study. All data has been pre-processed and provided by the TU Wien Data Cube. The spatial resolution is 20m.
- Six study sites with different land cover classes are selected (Figure 1).

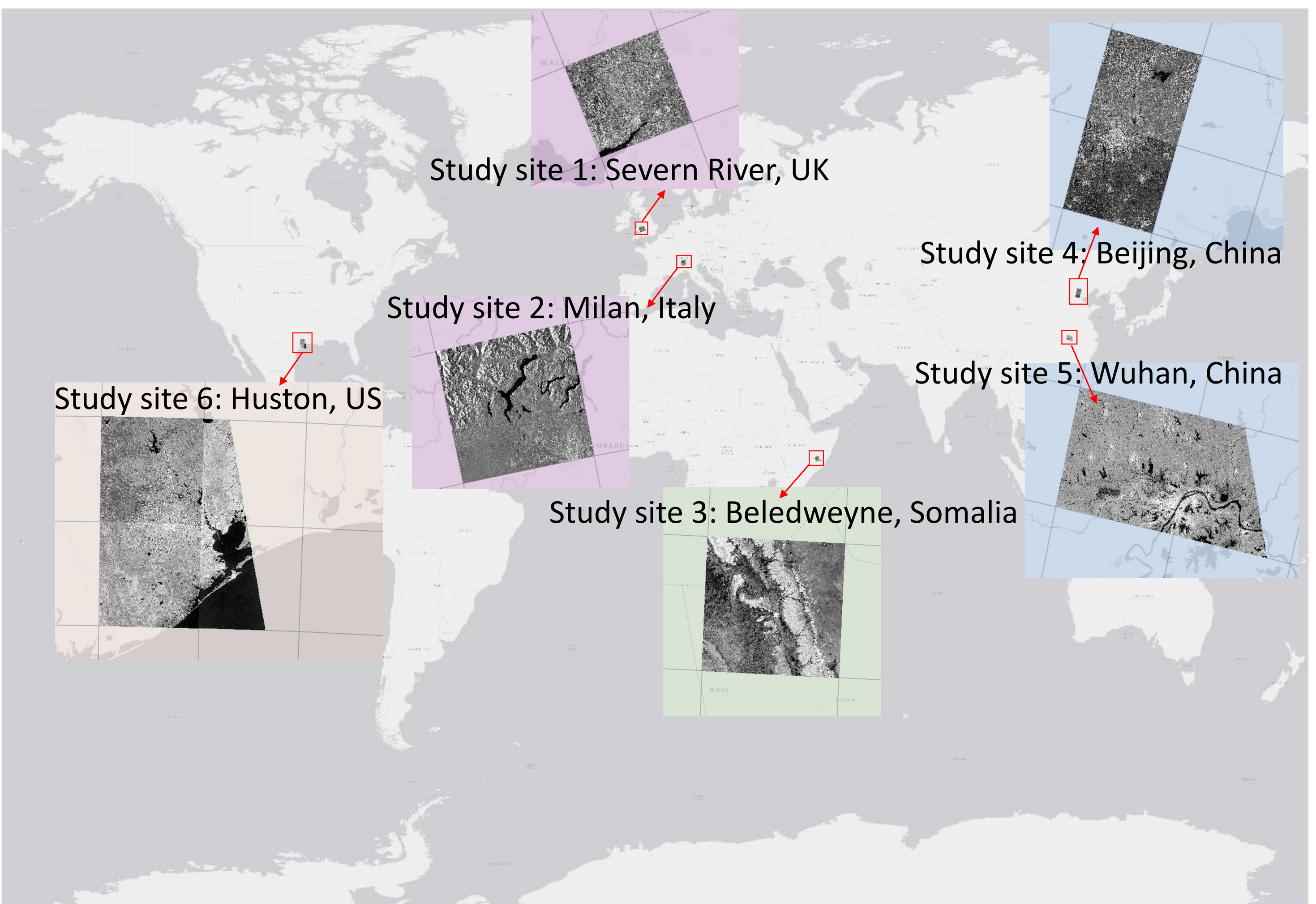

Figure 1. The six study sites.

- To evaluate the newly generated EX-map, we take advantage of three different products:
  i. 30m FROM-GLC map derived from optical data;
  ii. 30m resolution shadow/layover layer simulated by 30m STRM DEM using SARscape;
  iii. 12m resolution global urban footprint (GUF) data provided by DLR.

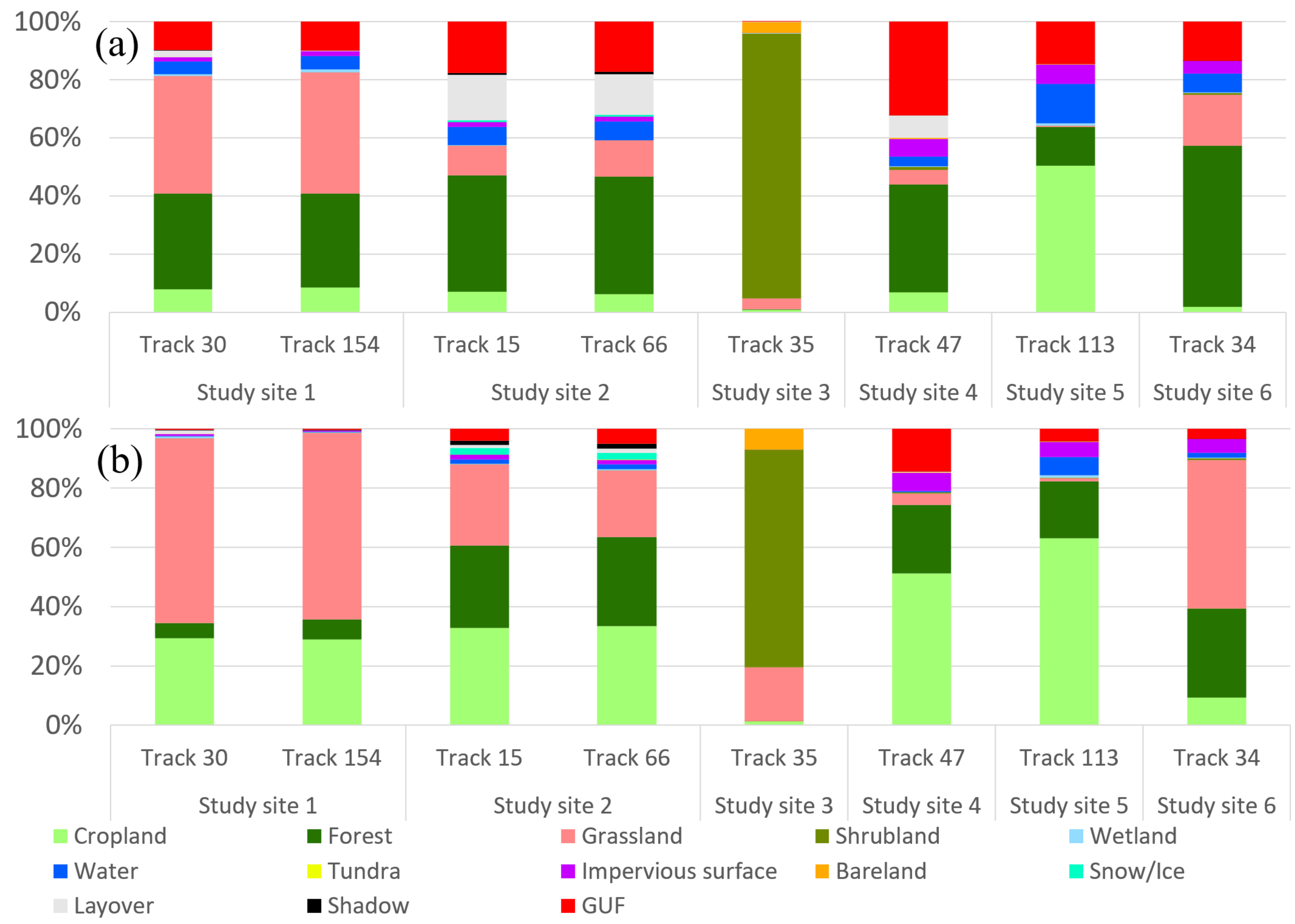

Figure 2. (a) the land cover classes of pixels included in the newly generated exclusion map.
(b) the land cover classes of pixels excluded from the newly generated exclusion map.

Conclusions

- With the notable exception of study site 3, 50% - 80% of pixels included in the exclusion maps correspond to areas that are known to be insensitive to flooding-related change detection using SAR data based on their definition (Figure 2(a)), while 55% - 95% pixels outside the exclusion map are located in areas where we expect floods to be detectable by SAR-based change detection based methods (In Figure 2(b)).
- Some disagreements are caused by pixels located on the boundary between different land cover classes due to the different projections and different resolutions of the 3 reference products and the Sentinel-1 data, respectively.
- The study site 3, which is located in Somalia and covered by very dry areas, has a reference dataset suspected to be not suitable.

Methodology

In this study, the targeted exclusion map is expected to include: (1) areas with permanently very low backscatter (e.g. shadow areas, arid regions and permanent water bodies), (2) areas with permanently very high backscatter (e.g. layover areas), (3) urban areas and (4) densely vegetated regions with moderately high backscatter. Here, time series of Sentinel-1 data are analyzed and three parameters are employed: local Getis-Ord Gi, multi-temporal standard deviation (MSD), the multi-temporal median (MM).

1) Identification of areas with permanently very low/high backscatter :
   - Since such areas are considered to be homogeneous with permanently very low/high backscatter, we propose to use a local indicator of spatial autocorrelation , i.e. local Getis-Ord Gi (Getis and Ord, 1992) which considers backscatters of neighboring pixels. The local Getis-Ord Gi is defined as:

$$G_i = \frac{\sum_{j=1}^{n} w_{i,j}x_j - \bar{X}\sum_{j=1}^{n} w_{i,j}}{S\sqrt{\frac{n\sum_{j=1}^{n} w_{i,j}^2 - \left(\sum_{j=1}^{n} w_{i,j}\right)^2}{n-1}}}, \qquad j \neq i$$

$$\bar{X} = \frac{\sum_{j=1}^{n} x_j}{n}, \quad S = \sqrt{\frac{\sum_{j=1}^{n} x_j^2}{n} - (\bar{X})^2}$$

w_{ij} = the spatial weight between i and j that represents their spatial relationship
x_j = the value of variable x at location j
n = the total number of image's pixels

   - The areas with permanently very low backscatter over time have low negative local Getis-Ord Gi while the areas with permanently very high backscatter over time have high positive local Getis-Ord Gi.

2) Identification of urban and densely vegetated regions with moderately high backscatter
   - For such areas, we consider two indices MSD and MM, enabling the characterization of their temporal pixel backscatter stabilities and their relatively high backscatter values with respect to pixels from other land cover classes.

References

Chini, M., Hostache, R., Giustarini, L., Matgen, P., 2017. A Hierarchical Split-Based Approach for Parametric Thresholding of SAR Images: Flood Inundation as a Test Case. IEEE Trans. Geosci. Remote Sens. 55, 6975–6988. https://doi.org/10.1109/TGRS.2017.2737664
Getis, A., & Ord, J. K. (1992). The analysis of spatial association by use of distance statistics. Geogr. Anal. 24, 189-206.
Getis, A., Ord, J.K., 1992. The Analysis of Spatial Association by Use of Distance Statistics. Geogr. Anal. 24, 189–206. https://doi.org/10.1111/j.1538-4632.1992.tb00261.x

Acknowledgement

This work was supported by the Luxembourg National Research Fund (FNR) (reference: FNR PRIDE HYDRO-CSI 10623093).