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Floodwater detection in urban areas using Sentinel-1 and WorldDEM data

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1. Introduction

Remote sensing using SAR is an important tool for emergency flood incident management. At present operational services are mainly aimed at flood mapping in rural areas, as mapping in urban areas is hampered by the complicated backscattering mechanisms occurring there. However, people and assets are concentrated in the urban areas. We describe a method for detecting flooding in urban areas that may contain dense housing [1]. This largely uses data sets that are readily available on a global basis, including open-access Sentinel-1 data (20 m resolution), the WorldDEM DSM (12 m resolution) and open-access World Settlement Footprint data (10 m resolution) to identify urban areas.

2. Method

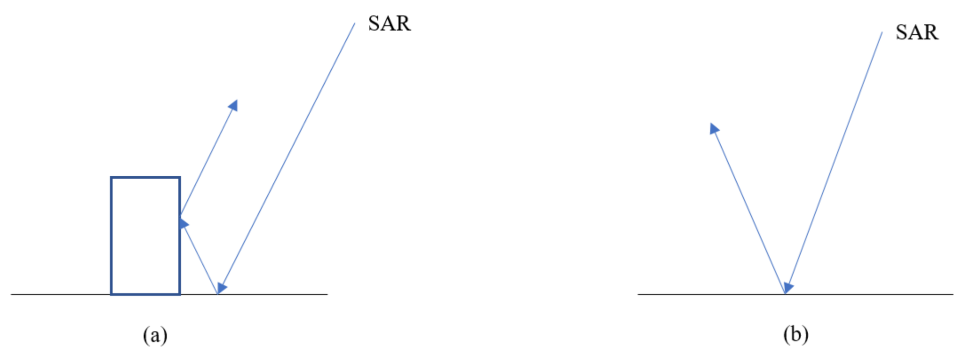

Fig. 1. (a) Urban double scattering (SAR flying into paper), (b) rural water reflection away from SAR.

The method is a change detection one that estimates flood levels using pre-flood and post-flood S-1 images. In urban areas, it searches for strong double scattering from wall-ground structures in the pre-flood image, where the wall is aligned within 30° to the satellite direction of travel (fig. 1a). If such double scatterers have high backscatter ratios in the post-flood compared to the pre-flood image, they are likely to be flooded (assuming flood depth small compared to wall height), as the dielectric constant (and hence reflectance) of water is much higher than that of asphalt. However, double scatterers having ratios close to 1 are likely to be unflooded. Flooded double scatterers are paired with nearby unflooded ones, and the associated ground heights from the DSM averaged to estimate local flood levels.

Rural flooding adjacent to the urban areas will often have a reduced SAR backscatter in the post-flood image due to water acting as a specular reflector away from the sensor (fig. 1b). Rural flood regions are identified using adaptive backscatter thresholding, with flooded regions having backscatter below the threshold. The flood levels found in the urban and rural areas are interpolated over the domain to form a flood level surface. Areas of urban flooding are detected by comparing this surface to the DSM.

3. Results

The method is illustrated using the flood that occurred in the village of Fishlake on the river Don in the north of England in November 2019 (fig. 2). The flooding was caused by an extreme weather event due to a stalled area of low pressure. More than 1000 homes from the village and surrounding area had to be evacuated.

Fig. 2. Flooding in Fishlake on 14 November 2019, from NE (©PA)

Rural flooded areas were first mapped using the HASARD adaptive thresholding algorithm [2] on the ESA G-POD platform. The S-1 images were pre-processed prior to application of the algorithm.

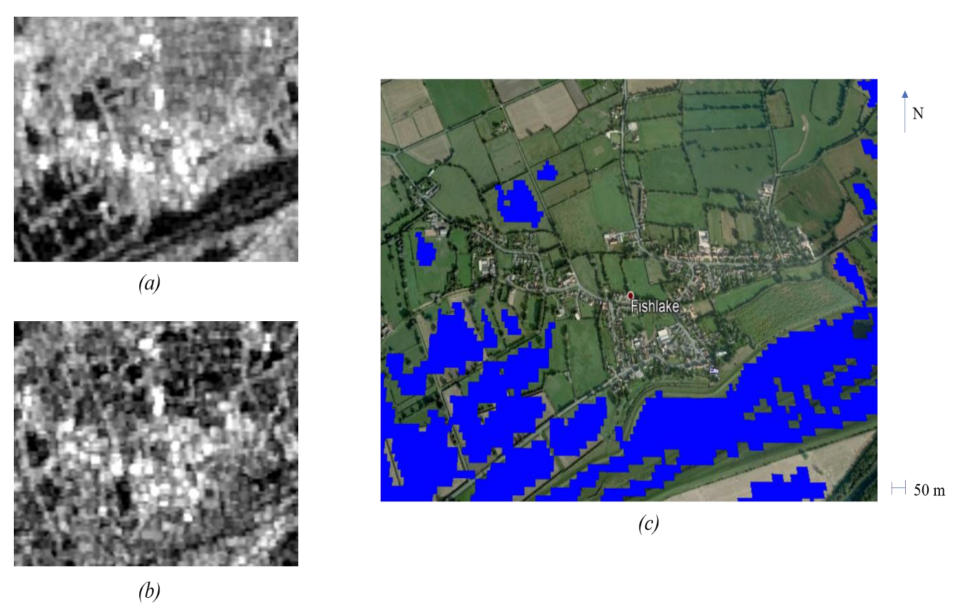

Fig. 3 (a) Postflood S-1 intensity image of Fishlake flood of 14 November 2019; (b) preflood S-1 image of Fishlake of 15 September 2019; and (c) rural flood map produced by HASARD (flood-water = blue)

Figure 3 shows the flood extent determined for Fishlake on 14 November 2019 using HASARD, together with post- and preflood S-1 images. There was flooding in the rural areas surrounding the village, but little flooding was identified in the urban area because backscatter here was higher than the threshold used in HASARD.

Urban flooding was identified using double scattering between flooded roads and adjacent building walls. Double scatterers are strong edges in the DSM oriented within 30° of the satellite track. A set of strong edge pixels was chosen that had high post- to pre-flood image intensity ratios and were likely to be mainly flooded, together with another set whose members had ratios close to 1 and were likely mainly unflooded. Each member of the first set had to be be spatially close to a member of the second set, and vice versa. This ensured that the flooded double scattering pixels were near the flood edge, so that their flood depths were likely to be shallow.

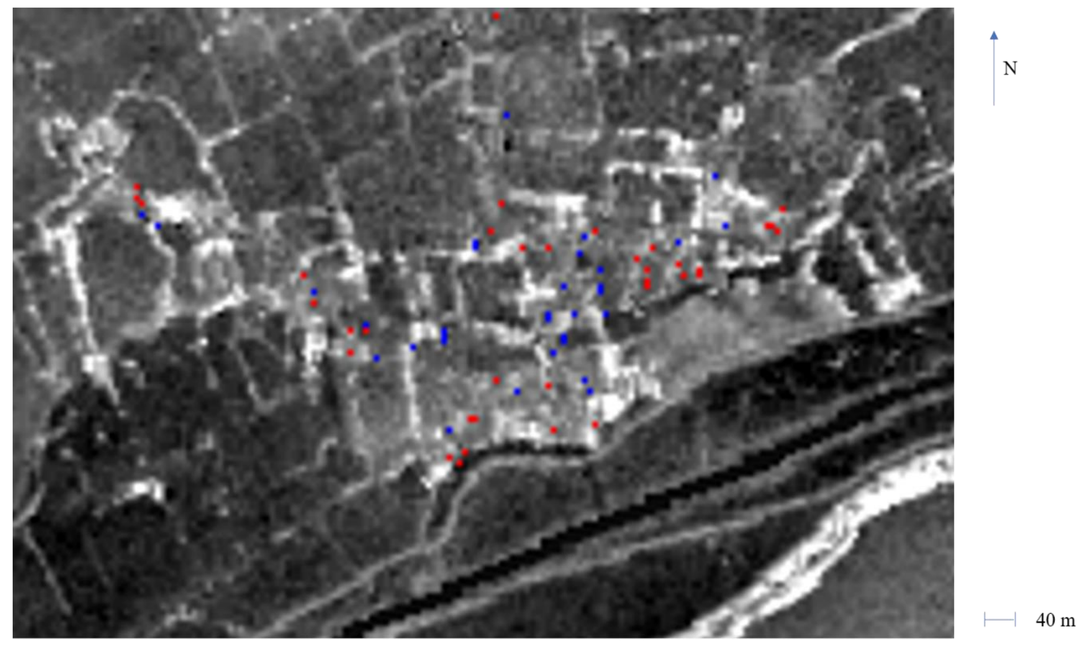

Fig. 4. WorldDEM DSM for Fishlake urban area, with double scattering points for descending-pass S-1 image of 14 November 2019 superimposed (height range = 0 to 19 m, lighter grey = higher, blue/red = flooded/unflooded double scatterers).

Fig. 4 shows flooded and unflooded double scatterers for the Fishlake urban area for the S-1 image of 14 November 2019. This was a descending pass image and S-1 is right-looking, so that most of the double scattering pixels should lie immediately to the east of buildings, which does appear to be generally the case.

Fig. 5 shows the correspondence between the SAR flood extent of 14 November 2019 and the aerial photo flood extent in the urban area visible in the aerial photo. The flood detection rate was 100%, with a false alarm rate of 8%.

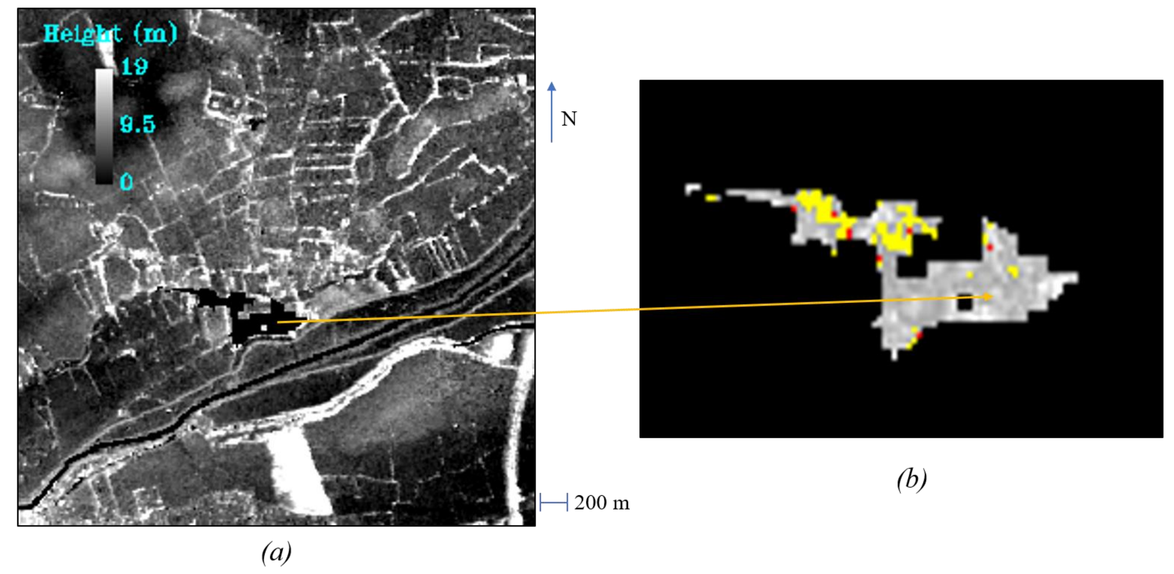

Fig. 5 (a) WorldDEM DSM of Fishlake area (area visible in aerial photos masked out (black)), and (b) correspondence between SAR image of 14 November 2019 and aerial photo flood extent in urban area that is visible in aerial photos, superimposed on the DSM (yellow, wet in SAR and aerial photos; red, wet in SAR only; and cyan, wet in aerial photos only)

The method was also tested on the Pontypridd flood of 16 February 2020. Pontypridd is a former coal-mining town on the river Taff in Wales, with narrow streets and higher housing density than Fishlake. More than 1000 homes and businesses were damaged after rivers flooded when Storm Dennis hit communities in south- and mid-Wales. Here the flood detection rate was lower, at 72%, with a false alarm rate of 37%. The double scattering method estimated the local flood height correctly in the urban area, but the DSM was not always able to provide sensible ground heights because street widths became comparable to the DSM resolution. However, the flood extent estimated would still be useful for incident management.

4. Conclusion

The method has potential for operational use for detecting urban flooding in near real-time on a global basis.

References

1. Mason D.C., Dance S.L., Cloke H.L. (2021). Floodwater detection in urban areas using Sentinel-1 and WorldDEM data, *Journal of Applied Remote Sensing,*, 15(3), 032003.
2. Chini M. et al. (2017). A hierarchical split-based approach for parametric thresholding of SAR images: flood inundation as a test case. *IEEE TGARS*. 55, 6975–6988.

Acknowledgements

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