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Editorial

Improving Flood Detection and Monitoring through Remote Sensing

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1. Introduction

Floods are among the most threatening and impacting environmental hazards. Their costs in terms of human lives, infrastructure damage or loss, and agricultural impact can be enormous and continue to increase due to climate change.

Investigating effects and extents of flood events in short times after occurrence is of utmost importance in order to quantify damage, organize rescue measures, determine insurance refunds, and calibrate prediction models for risk assessment and management. In the last years, remote sensing is proving to be a strong aid in this direction by providing large amounts of data of the Earth's surface at low to null costs. The increasing number of spacecraft and sensors available calls for the use of sophisticated procedures and algorithms to extract useful information from such large datasets. In [1], several examples of precise tools for investigating the effects of inundations were presented. Since then, improvements in technology, data availability, and processing power have occurred.

This Special Issue is a collection of six articles and one technical note, which provide a wide overview of recent advances in these fields. The papers deal with various aspects of flood monitoring by using diverse sensors such as backpack-mounted 3-D optical cameras, airborne LiDAR, GNSS reflectometry, and spaceborne synthetic aperture radar (SAR) data analysis from multiple sensors and wavelengths. Test sites are located in various parts of the world, including China, Japan, Philippines, Mozambique, Iran, UK, Greece, and Turkey. The volume represents, therefore, a useful survey of methods to improve the performance of techniques concerning remote sensing of floods in the mapping phase, including the assessment of post-disaster flood damage, integration of observed and predicted flood impacts, and evaluation of flood prevention measures such as levees.

2. Summary

The authors of [2] describe an experiment in retrieving field information about the effects of a flash flood that occurred in Japan in 2017 by using backpack-mounted equipment consisting of a series of optical cameras, a laser scanner, a GNSS receiver, and an IMU unit. They also realized a DEM of a strip of terrain around the water course after the event and compared it to one that was previously available. The resulting updated DEM was integrated with that coming from a flood propagation model run with parameters pertaining to the event, showing consistent improvements with respect to previous runs in terms of adherence to ground truth measurements. The authors also offer some interesting insight about issues and advantages encountered during the survey on the ground, showing how, even with ground-based equipment, remote and automated sensing by using sophisticated sensors brings a significant step forward in data collection campaigns. The

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results demonstrate, among other things, how sediment deposition plays an important part in flood propagation. This is in line with other studies in this direction [3].

In [4], high-resolution LiDAR data (16 points/m^2 on average) acquired from an airborne sensor are analyzed in depth to derive information about the condition and weathering state of levees along a section of river coastlines in Southeastern China. Levee geometric parameters, such as crown height, waterside, and landside slopes, and elevation transects are evaluated with respect to model flood heights for several return periods, resulting in scores assigned to each levee parcel to quantify its robustness against water overtopping. Such detailed scores improve upon previous classifications, mainly based on ground campaigns, which involved single parameters and sparse sampling. The great detail placed in the evaluation testifies the potential of remotely sensed data to extract fine-resolution information over relatively large areas with a fraction of the time-personnel effort necessary to perform field surveys.

Technical note [5] illustrates an example of application of three of the most diffused and well-known techniques for separating water and non-water areas in SAR images, namely the manual histogram "valley emphasis" thresholding method, Otsu's threshold determination, and K-means clustering. The latter algorithm is run here with two clusters. The three methods are tested on a series of Sentinel-1 images taken during a series of strong rain episodes that occurred between the end of 2018 and the beginning of 2019 over a region in the Philippines. Results are compared visually, as well as in terms of total detected flooded area. Although no ground truth was available to assess the methods' performances more quantitatively, the scatter of the results (relative differences in detected flooded areas reaching as much as 60% between manual and K-means) provides a fair idea of the care that should be placed in choosing algorithms and procedures to detect floodwaters in SAR imagery and the important role of reference data to assess algorithms quantitatively.

In [6], a detailed analysis is proposed for an approach to flood vulnerability mapping that makes use of high-resolution, SAR-derived, and model-derived flood hazard maps. Results are assessed by using aerial photos available for three test sites during two flood events in UK. Various combinations of remotely sensed and model information are compared. It was concluded that SAR flood maps improve detection performance especially when surface flooded areas are not necessarily due to river water inundation, while modeled flood maps obtained from gauge data are most useful for areas where the SAR sensor cannot "see" due to its side-looking geometry, such as streets in high-density urban centers. Synergetic use of both data types results in detection accuracies of up to 94%, with false positive rates as low as 9%, improving by several percent points performances obtained with the use of SAR data only. As discussed in the paper, although high-resolution SAR data are still mostly not free and open access (with the significant exception of the European Sentinel-1 constellation, and with several other SAR sensors collections foreseen to become available as open access in the next future), their use is crucial for complex sites such as urban areas, especially those characterized by relatively high building densities as in many European countries, where high-resolution digital surface models (DSM) are necessary in order to properly model hydrological dynamics. In such cases, current sensors such as Sentinel-1, despite their unparalleled temporal acquisition frequency that is showing promising results in several applications [7,8], may still have insufficient spatial resolution, while higher-resolution sensors such as the Italian COSMO-SkyMed and the German TerraSAR-X lack temporal frequency.

A potentially innovative data source for flood monitoring is investigated in [9]. GNSS reflectometry is a technique that uses microwave signals emitted by global positioning system constellations and collected by suitable receivers to gain information about (bistatic) reflectivity of the Earth's surface. NASA's CYGNSS mission is a constellation of microsatellites carrying receivers to exploit GNSS signals, which has proven to be useful in many land and ocean studies [10]. In this case, CYGNSS-collected reflectivity signals were used to map inundated areas during an exceptional precipitation event that occurred in January 2020 over a large basin in Southeastern Iran. Despite its relatively low resolution

(25×25 km^2), the high temporal acquisition frequency (average of about 7 h, reaching about 2 h as a maximum) makes it a very promising tool to improve the timeliness of flood survey maps over large areas.

In [11], an in-depth discussion is presented about the application of a methodology [12] to detect flood water both on open areas and under vegetation (indicated, respectively, as "temporary open water" and "temporary flooded vegetation" in the article) from time series of SAR images. Sentinel-1 data are analyzed over three test sites in Greece and Turkey that were affected by floods in March and April 2015 and June 2017, respectively. Identifying flooded vegetation, typically through the detection of the "double bounce" scattering behavior that causes significant backscatter increase with respect to non-flooded conditions, is considered one of the most difficult tasks in flood monitoring by SAR data. In the article, various combinations of the two available Sentinel-1 polarization channels, namely VV and VH, are considered as possible features to detect different terrain classes. The relative importance of single polarization channels and the difference, sum, and ratio of the two were evaluated by using statistical means, using information extracted from optical images as reference data, to identify the most relevant one(s) for the detection of each class. Results point to single VV polarization as the most efficient for open water flood identification, while the sum of VV + VH polarizations is recommended for detecting flooded vegetation, although small variations in performance for the different features appear from one test site to another, which seems to suggest that choosing one feature over the others may actually be a site-dependent task.

The task of discriminating terrain cover during floods is also considered in [13], where both C-band (Sentinel-1) and L-band (ALOS 2) data are exploited in order to extract information about a prolonged, large inundation, which affected a part of the Zambesi river basin in Mozambique, Africa, from December 2014 to April 2015. No useful optical data are available for this event, as is normally the case over equatorial sites that are mostly clouded for long periods of time. Nevertheless, the analysis of multi-temporal series, aided by the use of the CORINE land cover database, available at a resolution of 100 m over Africa and the synergy between the different wave penetration and backscattering characteristics of the two sensors allowed the derivation of an informative set of multitemporal maps of flood evolution, as well as an integrated, multi-sensor map discriminating various types of ground features and situations, such as flooded crops, grassland, and forest in addition to open water areas.

3. Conclusions

The papers in this Special Issue cover a broad spectrum of techniques and data analyses aimed at improving the performance of flood monitoring activities from remotely sensed data. Improvements come essentially from (i) availability of innovative data sources, such as backpack-mounted 3-D cameras or spaceborne GNSS reflectometry; (ii) precise assessment and validation of algorithm performance through comparison with independent data; (iii) integration of multiple data sources such as multi-frequency, multi-sensor, and multi-temporal satellite SAR data. Results of tests over sites located throughout the world demonstrate the great potential of such methods to bring significant innovation and increase algorithm precision in the field of inundation monitoring.

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