CAN WE RECONSTRUCT CLOUD-COVERED FLOODING AREAS IN HARMONIZED LANDSAT AND SENTINEL-2 IMAGE TIME SERIES?

Zhiwei Li[1,2], Shaofen Xu[1], Qihao Weng[1,2,]*

[1]JC STEM Lab of Earth Observations, Department of Land Surveying and Geo-Informatics, The Hong Kong Polytechnic University

[2]Research Centre for Artificial Intelligence in Geomatics, The Hong Kong Polytechnic University

ABSTRACT

Floods pose severe global risks. While Earth observation satellites offer extensive flood monitoring, cloud cover limits the effectiveness of optical satellite imagery. This paper develops a novel reconstruction method for spatially seamless time series flood extent mapping. Utilizing a fine-tuned large foundation model, the proposed method identifies water bodies and then reconstructs cloud-covered flooding areas based on water occurrence data in the Global Surface Water dataset. The reconstructed water maps are finally refined by spatiotemporal Markov random field modeling to delineate flood areas. Evaluated with Harmonized Landsat and Sentinel-2 datasets, the developed method achieves seamless flood extent mapping at 2–3-day intervals and 30-m resolution. This paper offers an effective approach for flood monitoring under cloudy and rainy conditions, supporting emergency response and disaster management.

Index Terms— Flood extent mapping, water extraction, cloud removal, harmonized Landsat and Sentinel-2

1. INTRODUCTION

Satellite remote sensing offers a cost-effective means for extensive flood monitoring. However, optical satellite imagery is inevitably affected by cloud cover, leading to missing ground surface information in images and reducing the frequency of valid observations [1]. Considering the revisit cycles of satellites and the duration of floods at their respective intervals, the frequency of satellite observation is crucial for flood monitoring [2]. Therefore, exploring the potential of using optical satellite imagery that might be cloud-covered in flood mapping to improve flood monitoring frequency is worth further investigation [3], [4]. Developing a cloud reconstruction method for multisensor optical satellite imagery in cloudy scenarios is essential for seamless flood extent mapping at high density. Recent studies [5], [6] have developed gap-filling methods for seamless water mapping, but these are not tailored for and validated in flood scenarios, thus leaving room for advancement. To overcome these limitations in flood extent mapping using optical images under varying cloud cover conditions, this paper introduces a novel method for seamless time series flood extent mapping. By leveraging a combined time series of Landsat and Sentinel-2 images, this study aims to enhance the completeness, frequency, and precision of flood extent mapping in cloudy and rainy conditions, thereby improving emergency response and contributing to effective flood management.

2. METHODOLOGY

The flowchart of the proposed method is illustrated in Fig. 1, encompassing three main steps. The proposed method first identifies water bodies from Harmonized Landsat and Sentinel-2 image time series using a fine-tuned large foundation model, i.e., Prithvi-100M-Sen1Floods11 [7], which is pre-trained on the Sen1Floods11 dataset [8]. Then, the cloud-covered areas in the water maps are reconstructed based on the spatiotemporal neighboring similarity and prior water occurrence data in the Global Surface Water dataset [9]. Finally, the reconstructed time series water maps are refined using spatiotemporal Markov random field (MRF) modeling to delineate flood inundation areas, which can be identified by excluding permanent water, i.e., non-flood water, from the refined time series water maps.

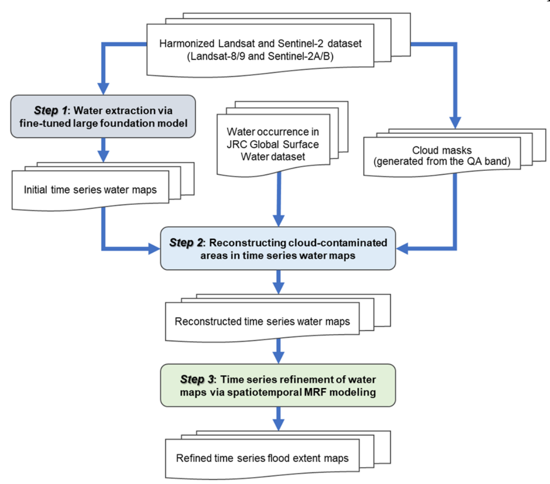

Fig. 1. The flowchart of the proposed seamless time series flood extent mapping method.

3. RESULTS AND ANALYSIS

The fine-tuned Prithvi-100M-Sen1Floods11 model was used for water extraction in HLS images. Among the 446 labeled 512×512 chips in the Sen1Floods11 dataset, 267 chips were used for model fine-tuning, 89 chips for model validation, and the remaining 90 chips for model testing. The results showed the testing performance of the fine-tuned model with an Overall Accuracy (OA) of 97.35% and a mean Intersection over Union (mIoU) of 0.809 for flood extent mapping.

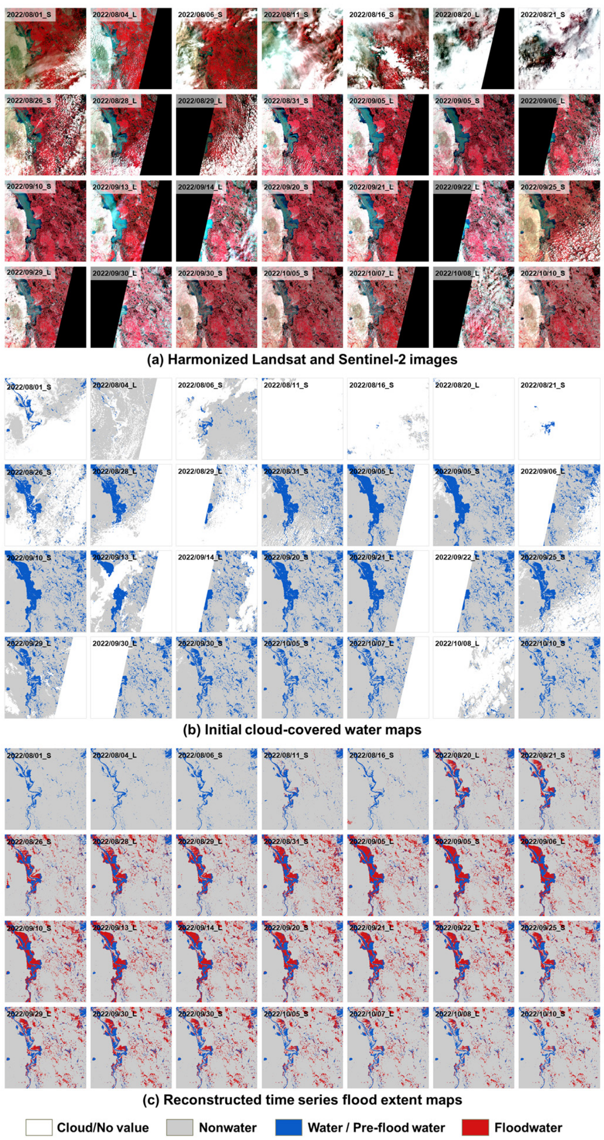

Fig. 2. Example reconstruction results of the proposed method for seamless time series flood extent mapping over Sindh, Pakistan in the 2022 flood event.

We selected a study site located in Sindh, Pakistan, which experienced a flood event in August and September 2022. This event was notable for its widespread impact, significant consequences, high satellite revisit frequency, and minimal cloud cover during the flooding, making it a focus for flood mapping study [10]. Fig. 2 shows seamless time series flood maps generated using the proposed method over Sindh, Pakistan in the 2022 flood event. Pseudo-color Harmonized Landsat and Sentinel-2 images, initial cloud-covered water maps, and reconstructed time series flood extent maps are provided for local areas. To increase mapping frequency, satellite images with orbital overlap within the study area are considered. For the unobserved portions in the overlapping images, the same reconstruction steps as for the cloud-covered areas are applied. The example reconstruction results demonstrate the effectiveness of the proposed method in seamless flood extent mapping, highlighting its capability in capturing both overall flood inundation trends and detailed extents. Therefore, the proposed method can provide seamless flood extent maps in areas affected by cloud cover and data gaps.

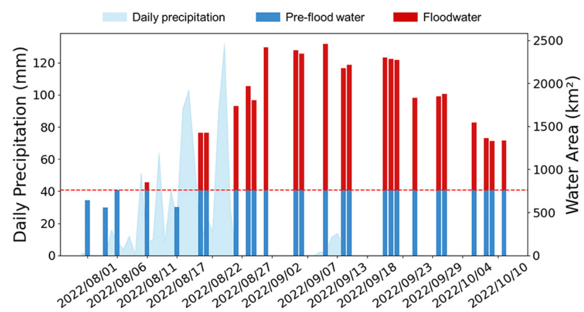

Fig. 3. Comparison of areas of identified floodwater (red bar) with daily precipitation (blue background) over Sindh, Pakistan in the 2022 flood event.

To generally evaluate the accuracy of the reconstructed flood maps, we compared the areas of flood-inundated regions with rainfall amounts. We collected daily precipitation data from CPC Global Unified Gauge-Based Analysis of Daily Precipitation from the NOAA Physical Sciences Laboratory website (https://psl.noaa.gov/) at the study site covering the flood period. In Fig. 3, areas of identified pre-flood water and floodwater are compared with daily precipitation at the study site. The comparison results showed a general consistency between the changes in floodwater areas and rainfall with consideration of the time lag effects, which demonstrated the effectiveness of the proposed method from a different perspective.

4. CONCLUSION

This paper investigated spatially seamless flood extent mapping using Harmonized Landsat and Sentinel-2 image time series. We developed a novel method to reconstruct cloud-covered areas in generated time series water maps and evaluated its feasibility for spatially continuous flood extent mapping under cloudy and rainy conditions. The method was proven effective in enhancing time series flood monitoring. Reconstructing cloud-covered water maps benefits the composition of maximum-extent flood inundation maps and flood duration maps. Note that flood inundation can be hindered by persistent and dense cloud cover and may not be effectively recovered. Overall, the proposed method offers an effective approach for flood monitoring in cloudy and rainy scenarios, thus supporting emergency response and disaster management. Future studies could explore the transferability of the proposed method in other areas worldwide, as well as the harmonization of water maps derived from multi-modal and multi-sensor data sources.

5. ACKNOWLEDGMENTS

This research was supported by the National Natural Science Foundation of China (No. 42101357), the Global STEM Professorship by the Hong Kong SAR Government, and The Hong Kong Polytechnic University Start-up Fund.

6. REFERENCES

[1] Z. Li, H. Shen, Q. Weng, Y. Zhang, P. Dou, and L. Zhang, "Cloud and cloud shadow detection for optical satellite imagery: Features, algorithms, validation, and prospects," *ISPRS J. Photogramm. Remote Sens.*, vol. 188, pp. 89–108, 2022.

[2] M. G. Tulbure *et al.*, "Can we detect more ephemeral floods with higher density harmonized Landsat Sentinel 2 data compared to Landsat 8 alone?," *ISPRS J. Photogramm. Remote Sens.*, vol. 185, pp. 232–246, 2022.

[3] B. DeVries, C. Huang, J. Armston, W. Huang, J. W. Jones, and M. W. Lang, "Rapid and robust monitoring of flood events using Sentinel-1 and Landsat data on the Google Earth Engine," *Remote Sens. Environ.*, vol. 240, p. 111664, 2020.

[4] S. Li *et al.*, "A downscaling model for derivation of 3-D flood products from VIIRS imagery and SRTM/DEM," *ISPRS J. Photogramm. Remote Sens.*, vol. 192, pp. 279–298, 2022.

[5] G. Zhao and H. Gao, "Automatic Correction of Contaminated Images for Assessment of Reservoir Surface Area Dynamics," *Geophys. Res. Lett.*, vol. 45, no. 12, pp. 6092–6099, 2018.

[6] C. Mullen, G. Penny, and M. F. Müller, "A simple cloud-filling approach for remote sensing water cover assessments," *Hydrol. Earth Syst. Sci.*, vol. 25, no. 5, pp. 2373–2386, 2021.

[7] J. Jakubik *et al.*, "Prithvi-100M.https://github.com/NASA-IMPACT/hls-foundation-os." 2023. doi: 10.57967/hf/0952.

[8] D. Bonafilia, B. Tellman, T. Anderson, and E. Issenberg, "Sen1Floods11: A georeferenced dataset to train and test deep learning flood algorithms for sentinel-1," in *IEEE Computer Society Conference on Computer Vision and Pattern Recognition Workshops*, IEEE, Jun. 2020, pp. 835–845.

[9] J.-F. Pekel, A. Cottam, N. Gorelick, and A. S. Belward, "High-resolution mapping of global surface water and its long-term changes," *Nature*, vol. 540, no. 7633, pp. 418–422, 2016.

[10] M. G. Tulbure *et al.*, "Can we detect more ephemeral floods with higher density harmonized Landsat Sentinel 2 data compared to Landsat 8 alone?," *ISPRS J. Photogramm. Remote Sens.*, vol. 185, no. February, pp. 232–246, 2022.