Improving Flood Monitoring Capabilities Using Synthetic Aperture Radar Data Cubes

Mark Edwin Tupas

Abstract

Flooding poses a significant challenge across much of the world. It ranks as a leading natural disaster in terms of damage and the number of people affected. Effective management of floods requires rapid or Near Real-Time (NRT) mapping, primarily using satellite-based earth observation data. Synthetic Aperture Radar (SAR) data is considered the most suitable for flood mapping operations due to its ability to operate in all weather conditions, both day and night, and its skill at distinguishing between open water and land.

The Sentinel-1 SAR system has unrivaled temporal and spatial coverage and thus has been tapped for various flood mapping operations. To better harness the vast Sentinel-1 data holdings, most researchers use data cube solutions. Notable in this regard is the TU Wien flood mapping algorithm. This algorithm is based on Bayes Inference that leverages a Sentinel-1 data cube to define the no-flood probability distribution of pixels via harmonic modeling and flood probability from historical water samples reckoned per incidence angle. It contributes to the Copernicus Emergency Management System's (CEMS) Global Flood Mapping (GFM) ensemble workflow being operated in NRT.

While working well in most cases, it has issues such as underestimation in flood transition areas and overestimation in agricultural areas. Further, limitations due to SAR-based flood retrievals necessitate the application of exclusion masks. However, over reliance on exclusion masks also presents an issue. As the TU Wien algorithm's novel Bayesian Inference formulation presents opportunities for improvement, this thesis aims further to improve it in the context of global NRT operations. To do this, we systematically analyzed the algorithm performance and Bayesian Inference components for improvement.

First, we compared the performance of change detection algorithms in the northern Philippines as a study area. We tested four well-known change detection algorithms that rely on time-series SAR inputs against reference data from Sentinel Asia and optical imagery. We tested parameterizations such as no-flood estimates or references and threshold determination methods. The TU Wien algorithm was also varied by checking the effect of its no-sensitivity masking. Our results suggest that the Bayesian Inference used for the TU Wien algorithm is superior to the other tested algorithms due to its stable performance regardless of parameterization.

We then proposed an alternative to non-informative priors using Height Above Nearest Drainage to derive spatially varying priors. The HAND data is used as an input to a two-parameter sigmoid function to generate the priors. We optimized and tested this new formulation of priors

on five test events, comparing the HAND-based prior versus the original non-informed priors using CEMS rapid mapping results. Overall, the proposed HAND prior improved the flood mapping results by reducing false negatives, with the added benefit of removing dependence on an external HAND exclusion mask.

Further, we explored the use of the exponential filter to estimate a no-flood reference probability and replace the harmonic model. This filter is a promising alternative because it accounts for the most recent backscatter observations, coupled with its recursive formulation, which makes it viable for NRT computation. We compared this filter and its parameterizations for flood mapping performance on four flood events in Europe covered by CEMS rapid activation and three sites in Asia covered by Sentinel Asia flood mapping activations. We then proposed a novel time series assessment of false positive rates to avert the pitfall of overfitting for flooded scenarios.

From the time-series assessments, we were able to analyze the causes of overestimation at no-flood scenarios by referencing ERA-5 data. We found that well-known causes of low backscatter, such as frost, dry soil conditions, and lesser-studied agriculture effects, trigger higher FPR at scale. In all cases, the exponential filter showed reduced FP. However, improvement to the exponential filter method is needed as prolonged floods in an area result in poorly estimated no-food references and, thus, poor flood mapping performance. We concluded that the exponential filter is an excellent alternative to the harmonic model.

In conclusion, we have established the TU Wien algorithm using the Sentinel-1 data cube as a robust method compared with other change detection algorithms. Further, we have shown improvements in the TU Wien algorithm from incremental changes to its Bayesian Inference framework. These improvements are being (and will be applied) to the TU Wien workflow under the CEMS GFM, thus impacting a true fully automated near-real-time global flood mapping operations.