USING A SENSORWEB FOR HIGH-RESOLUTION FLOOD MONITORING ON A GLOBAL SCALE

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ABSTRACT

Flooding has serious environmental and humanitarian effects. To track these effects, previous work has used remote sensing to achieve global monitoring at low to moderate resolutions or regional monitoring at high resolutions. We proposed that implementing a new sensorweb that had previously been prototyped only regionally in Thailand could combine moderate-resolution flood detection with targeted high-resolution observations to enable worldwide high-resolution flood monitoring. Furthermore, we aimed to integrate both commercial and government satellites into this sensorweb to improve upon previous efforts, which only used government satellites. To this end, we first gather data from several moderate-resolution sensors to identify large, flooded regions. We then task high-resolution sensors to observe these floods and analyze the resulting data, thus enabling global high-resolution flood monitoring. Overall, our approach improves worldwide analysis of floods, which can be further improved by our ongoing efforts to incorporate more flood detection sensors and generate more products.

1. INTRODUCTION

Flooding is a constant problem around the world. Due to its destructive nature, flooding poses an expensive and deadly threat to humans. In 2019 alone, floods were responsible for nearly $45.9 billion in economic losses and 4,500 deaths worldwide [1], and these numbers will only continue to grow as urbanization increases and the climate changes. Therefore, improving our understanding of the size, impact, and causes of flooding is critically important to help limit its effects.

One important tool in studying floods is remote sensing. High-resolution images captured from a birds-eye view can provide valuable data regarding the size and impact of a given flood. However, high-resolution observations can only capture a small area and floods are very sparse on the surface of the earth. Therefore, the most efficient way to observe as many floods as possible is to task high-resolution satellite imagery instruments to point their sensors at individual flood events. However, these pointable instruments are in great demand and low supply, so optimizing their scheduling and allocation is crucial. Thus, the key challenge is to find a way to monitor floods at the ideal high resolution without using high-resolution assets to search for them. To solve this problem, we use Artificial Intelligence to interpret data from additional moderate-resolution sensors for flood identification and then schedule high-resolution observations accordingly. This system is an example of a "sensorweb", or a network comprising several instruments that use information from other sensors in the network to determine their own configuration for the study of an environmental event [2]. The use of this fully automatic sensorweb can improve assessment of flood effects globally while minimizing the use of the scarce satellite instruments capable of capturing high-resolution images.

In our sensorweb, we use moderate-resolution data from the Moderate Resolution Imaging Spectroradiometer (MODIS) aboard the Aqua and Terra satellites of NASA, the Visual Infrared Imaging Radiometer Suite (VIIRS) aboard the Suomi NPP and NOAA-20 satellites, and the Synthetic Aperture Radar (SAR) aboard the Sentinel-1 satellites to identify current flood events. Then, we task the Planet SkySat constellation to collect high-resolution images of these floods and use this data to generate products and improve alerts (Fig. 1).

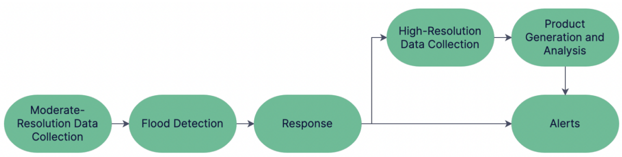

Fig. 1. Workflow diagram for this sensorweb.

2. PRIOR WORK

Several sensorwebs have previously been implemented for monitoring flooding and other environmental phenomena. A MODIS-based sensorweb for flood monitoring was used dur-

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ing the 2010 and 2011 flooding seasons in Thailand [2]. This sensorweb searched a set of predetermined regions in Thailand and tasked the Earth Observing-1 (EO-1) spacecraft for high resolution (30 m/pixel) imagery [2]. More recently, sensorwebs strategies that aim to use flood forecasting models to predict flooding and avoid observation latency have been demonstrated in simulation [3, 4]. EO-1 was also used for automated wildfire tracking in Thailand based on FIRMS/MODIS alerts [5]. Additional sensorwebs have been utilized for volcano monitoring as well [6, 7].

Furthermore, other efforts have been made to use remote sensing, including MODIS imagery, to track flooding either on a regional scale at higher resolutions, or on a global scale at lower resolutions. Chien et. al. have previously written a comprehensive overview of such projects [2].

3. A SENSORWEB FOR GLOBAL SPACE-BASED FLOOD MONITORING

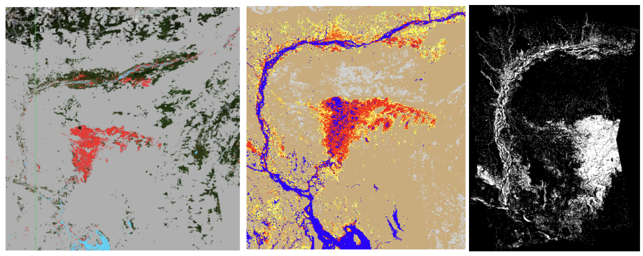
We have implemented a fully automated, space-based sensorweb intended to monitor flooding on a global scale using Artificial Intelligence. Although other efforts have been made to monitor flooding using satellite imagery (e.g., [2], [8]), no other project has been able to detect flooding worldwide and deliver high-resolution surface water products while utilizing only moderate-resolution imagery for flood detection.

3.1. Automatic flood detection with moderate-resolution data

Our sensorweb first interprets moderate-resolution data from the MODIS instrument aboard the Aqua and Terra satellites of NASA to detect flooded regions. Specifically, we use a global flood product with 250 m/pixel spatial resolution and a 2-day composite period provided by NASA LANCE [9]. However, the MODIS sensor measures light from the visible spectrum, so any flooding located underneath cloud cover that persists through the two-day composite period will not be identified. Furthermore, clouds and cloud shadows are often mistaken for flooding, but clouds that are misidentified as floods often show up as sparse clusters of flooded pixels, while real floods are typically denser clusters. Thus, we mitigate this problem by searching the MODIS flood product specifically for dense clusters of flooded pixels.

To improve flood detection and help mitigate the cloud cover present in the MODIS flood product, our sensorweb also automatically retrieves and interprets VIIRS data from Suomi NPP and NOAA 20. We use a global flood product provided by the SSEC with 375 m/pixel spatial resolution and a five-day composite period [10]. The five-day composite period of this product ensures that it has far less problems with clouds than the MODIS product. Floods are also more rigorously identified, so there are fewer false positives in the VIIRS flood product. Thus, we simply search it for large clusters of flooded pixels. However, this longer composite period also means that the VIIRS flood product is more likely to fail to identify the latest flooding and may also detect flooding in regions that were recently flooded but have since cleared.

Finally, to further mitigate cloud cover, we first identify regions in the VIIRS flood product that are blocked by persistent cloud cover. We then download and analyze any available Sentinel-1 SAR data (10 m/pixel resolution) [11] from these regions in the last two days. Unlike the visible spectrum data that the MODIS and VIIRS instruments collect, SAR data is not affected by cloud cover, which makes it ideal for flood detection. However, it is not suitable for a global product due to the low revisit rate of Sentinel-1. To analyze the SAR data, we first preprocess it and convert it to a flood product using techniques similar to those described in a tutorial provided by the European Space Agency [12]. Then, we search for any significant flooding present in the region. Figure 2 illustrates how a flood event appears in the MODIS flood product, the VIIRS flood product, and the processed SAR flood product.



(a) (b) (c)

Fig. 2. A flood event in Bangladesh identified by the Aqua/Terra MODIS 2-day flood product [9], the Suomi NPP/NOAA 20 VIIRS 5-day flood product [10], and a flood product created using Sentinel-1 SAR data [13]. (a) The flood event identified in the Aqua/Terra MODIS 2-day flood product [9]. Land is indicated by green/brown pixels, permanent water is indicated by light blue pixels, unknown/cloud cover is indicated by gray pixels, and flooding is indicated by red pixels. (b) The flood event identified in the Suomi NPP/NOAA 20 VIIRS 5-day flood product [10]. Land is indicated by light brown pixels, permanent water is indicated by blue pixels, unknown/cloud cover is indicated by gray pixels, and flooding of increasing severity is indicated by yellow, orange, and red pixels. (c) The flood event identified in a mosaic of Sentinel-1 SAR data files [13] converted into a flood product. White pixels indicate flooding and black pixels indicate all else.

We then use a voting system to automatically combine the flood targets from each source into an ordered queue for the high-resolution sensors to observe. This minimizes the effects of the individual weaknesses of each data source.

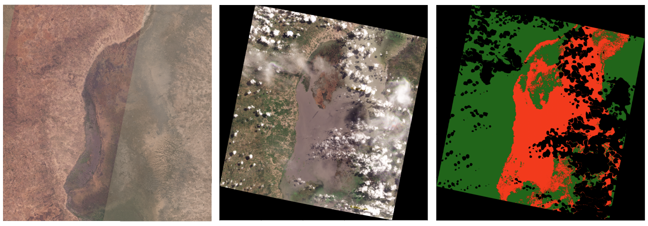
3.2. Automatic tasking of Planet SkySat for high-resolution imagery

After collecting and analyzing MODIS, VIIRS, and SAR data, our sensorweb automatically tasks the Planet SkySat constellation to observe the flooded areas in high resolution. SkySat captures high-resolution images with approximately 0.597 m/pixel spatial resolution [14].

One limitation of the SkySat constellation is the relatively long execution time, which is caused by incoming cloud cover, competing tasking requests, the relatively low orbit altitude of 400-450 km [15] of SkySat satellites, and other operational constraints. To mitigate this constraint, we also automatically search for other high-resolution data in our areas of interest, including imagery from the PlanetScope Dove constellation, which achieves a 3 m/pixel spatial resolution [16] and covers almost all of the land of the earth on a daily basis [17], as well as SkySat data tasked by other users.

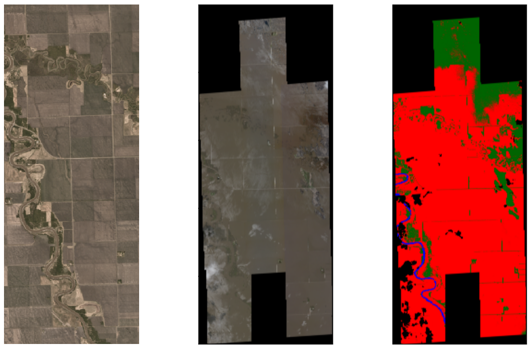
3.3. Automatic surface water extent product generation using high-resolution imagery

After our SkySat orders have been fulfilled, we automatically retrieve a surface reflectance product generated by Planet [18] and then create a surface water extent product using a visible spectrum band ratio to identify water and a global surface water map [19] to mask out permanent water. The resulting map, along with statistics regarding the extent of each type of pixel, are then saved (Fig. 3, Fig. 4). Table 1 quantitatively describes the results that we have obtained so far. In theory, the sensorweb would gather and analyze one SkySat image and approximately 1120 Dove images per week. Due to implementation issues (workflow, intermediate storage), we have not been able to achieve these rates yet.



(a) (b) (c)

Fig. 3. Our automated sensorweb pipeline detects a flood in Tabora, Tanzania, retrieves Dove images of it, and generates a surface water extent product of the flooded area. (a) The corresponding area without flooding captured by the Dove constellation, taken 06/24/2019. (b) Automatically retrieved Dove image of the region during the flood, taken 05/02/2022. (c) Automatically generated surface water extent product of the region during the flood. Green indicates land, blue indicates permanent water, black indicates cloud cover/unknown, and red indicates flooding.
Permanent Water Map Source: EC JRC/Google.



(a) (b) (c)

Fig. 4. Our automated sensorweb pipeline detects a flood in the Red River, Minnesota, USA, tasks SkySat to image it, and generates a surface water extent product of the flooded area. (a) The corresponding area without flooding captured by the Dove constellation, taken 05/28/2021. (b) Automatically tasked SkySat image of the region during the flood, taken 05/22/2022. (c) Automatically generated surface water extent product of the region during the flood. Green indicates land, blue indicates permanent water, black indicates cloud cover/unknown, and red indicates flooding.
Permanent Water Map Source: EC JRC/Google.

Table 1. Current summary of flood sensorweb results

Alert files generated per week	56
Total flood alerts generated per week	1120
Total SkySat flood event images tasked and analyzed	3
Dove flood event images retrieved and analyzed	85

4. FUTURE WORK

Although our sensorweb relies primarily on MODIS, VIIRS, and SAR data for flood detection, we are working to add other flood detection sensors to our sensorweb. Specifically, we want to use more cloud penetrating SAR from other sources such as Uninhabited Aerial Vehicle Synthetic Aperture Radar (UAVSAR). We are also working on collecting data from the Tropical Rainfall Measuring Mission (TRMM) and the Global Precipitation Measurement (GPM) mission to estimate where precipitation is heavy, and thus where floods are likely occurring. Additionally, we are working to incorporate data and alerts from in-situ sources, like water gauges, forecasts from weather stations, and alerts from official environmental monitoring sources. This will increase our confidence in the floods that we task SkySat to image. We also plan to combine these data with hydrological models to predict future flood locations and thus reduce latency in flood observation.

Finally, we plan to improve our output by constructing an additional water depth product. As demonstrated in [2], derivation of water depth and volume for flooded pixels can be accomplished automatically using a digital elevation model.

5. CONCLUSIONS

Flooding is a problem that can have devastating effects on humans, but effective space-based monitoring of floods can provide valuable information that helps improve our understanding of their size, impact, and causes. However, floods are sparsely dispersed on the surface of the earth, and with the scarcity of high-resolution assets, we need a way to monitor flooding at high resolution without using these assets to locate floods. We have described an ongoing effort to combine several moderate-resolution and high-resolution remote sensors into a sensorweb that performs high-resolution flood monitoring at a global scale. We are also working to append other sensors and hydrological models to the sensorweb to further mitigate cloud cover and latency. Nevertheless, our sensorweb has achieved worldwide, high-resolution flood monitoring while using only moderate-resolution assets for flood detection, thus improving global flood analysis.

6. ACKNOWLEDGEMENTS

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