Flood Mapping with Satellite Images and its Web Service

BY Jie Shan, Ejaz Hussain, KyoHyouk Kim, and Larry Biehl

Introduction

During the 20th century, floods were the number-one natural disaster in the United States in terms of number of lives lost and property damage (*Charles Perry,* http://ks.water.usgs.gov/pubs/fact-sheets/fs.024-00.html). In the U.S., the Midwest is the center of agriculture and bio fuel production. However, it is also the region often subject to record flood damages. In central Indiana, for example, four 100-year flood events have occurred over the last 15 years (http://in.water.usgs.gov/flood/). Recent record floods include the ones in Indiana (June 2008 and March 2009), Minnesota and North Dakota (March 2009), and Georgia (September 2009). The damages resulting from these disasters are devastating. Taking the Indiana June 2008 flood as an example, the Governor declared a state of emergency in 23 counties, and 39 counties were declared major disaster areas by the President. A total of 51 counties were affected by the flood with an initial estimated loss of about $126 million.

Remote sensing images provide a useful data source to detect, determine, and estimate the flood extent, damage and impact. Since November 2008, Landsat images have been a free data source. However, two factors limit their broad usage and popularity in flood mapping. The revisit time of one Landsat satellite is about two weeks. Despite the combined use of the two operating Landsat satellites, the revisit time of one week may still easily miss the flooding events. Besides, the optical nature of Landsat images does not allow for cloud penetration, which considerably hinders their usefulness during the flood event.

Recently, we have used temporal optical and synthetic aperture radar images to map the flood extents. By using other ancillary data, we were able to estimate the potential damages or impact to major standing crops, roads and streets, and evaluate the designated floodplains. In addition, the flood mapping results could be published on the Web through the Google Earth API with data visualization and query capabilities (Shan *et al.,* 2009). This helps the authorities and the general public to visualize the geospatial distribution and extent of floods in a timely way and take any necessary remedial actions.

Satellite Image Sources

As one of the most important data sources, the International Charter – Space and Disasters intends to promote cooperation among its member space agencies and industries in the use of disaster related satellite data (Stryker and Jones, 2009). It facilitates the provision of relevant data to the affected countries or regions to enable them to effectively manage the rescue, relief and rehabilitation efforts during and after disasters. As discussed in Stryker and Jones, 2009, when a major disaster occurs, the Charter is activated by the authorized users. In such situations, member space agencies look for archive data or plan for appropriate spacecrafts to take new acquisition over the disaster areas. Satellite data are quickly made available to the project managers, who then make further distribution to the end users and value added data handlers such as universities, government agencies and the emergency response centers. The project managers ensure the quick processing of the available data, extraction of the valuable information and its immediate delivery to the end users. As of April 2009, the Charter has been activated more than 135 times in response to various flood and hurricane related events (Figure 1), including the recent Indiana flood in March 2009 and the Georgia flood in September 2009. The Charter provided various SPOT, DMC, Landsat, IRS, CBERS optical images, and ENVISAT, ERS, RADARSAT, ALOS radar images. Some commercial high resolution images were also provided and used during the aforementioned floods.

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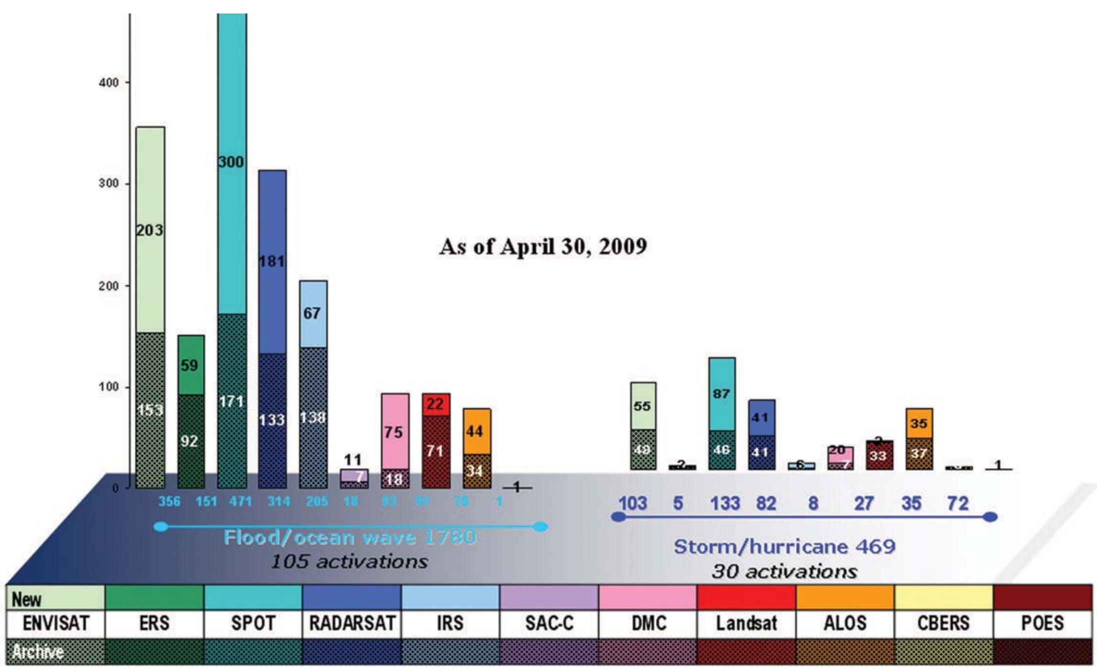

Figure 1. Charter images used for flood related mapping (Courtesy Brenda Jones, USGS).

Opposite: Part of QuickBird image collected on June 18, 2008 about one week after the Indiana flood (Courtesy DigitalGlobe). The flooding water remained in Knox and Gibson counties in southwestern Indiana.

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Data Processing

Data processing involves three steps: registration, flood extent determination, and damage assessment.

The Charter provided images are often georeferenced by the data providers. However, such georeference may not be precise enough when they are overlaid with other reference data, such as road maps and high resolution images. Therefore, it is necessary to carefully evaluate the input images with reference to other data sources to ensure their correct geographic reference. When processing the images of the floods in Indiana and Georgia, such mis-registration of the input images was determined to be a few meters to as much as a few hundred meters. Google images and road networks were used as reference to rectify the input images before further processing. The rectified images included ALOS PALSAR, ENVISAT, WorldView-1, SPOT, RADARSAT 2, and DMC. The input Landsat images seem to have minimum mis-registration.

Water extent was determined through automated image classification, possibly combined with or followed by some data fusion steps. Object based image classification technique was used (Benz *et al.*, 2004) with two sequential steps: image segmentation and classification of the segmented objects. The image segmentation step divides an image into contiguous, disjoint, and homogeneous regions or objects. At the second step, these objects are classified through fuzzy inference using their spectral, contextual and textural properties. This process needs to repeat for both the during-flood images and the pre-flood images.

Additional information must be used to find out the flood extent. This needs to use priori flood images collected at the same season or as close as possible to the flood period. The extent of normal water bodies can be identified by using the aforementioned approach. The removal of normal water from the during-flood images gives the flood extent. This process is straightforward if optical multispectral images, such as Landsat images, are used since detecting water in those images is relatively easy. However, if radar images have to be used due to cloud coverage or limited availability of optical images, certain advanced fusion steps must be involved. Due to the similar reflectance of water, forestry, grass, and even roads on radar images, the detected water class usually has a lot of false alarms, which must be further removed. In our work, we used available pre-flood Landsat images to determine forest and normal water, which were then removed from the results obtained from the during-flood radar images. The remaining was considered to be the flood extent.

Assessment on potential damages is the next task to carry out. One typical interest is crops and road infrastructure. Annual crop data are provided by the United States Department of Agriculture. Every year the National Agricultural Statistics Service, along with the Farm Service Agency and the participating State governments, record and produce the Cropland Data Layer (CDL) for major crops (http://www.nass.usda.gov). The CDL program annually focuses on corn, soybean, and cotton agricultural regions in the participating states to produce digitally categorized, geo-referenced output products for crop acreage estimation. Vector road maps are available from the county or state GIS repository. Such CDL layers and road maps can be used for damage assessment through overlaying with the detected flood extent to determine the affected crops and roads and their statistics, such as type, area, or length (Shan *et al.*, 2009). Figure 2 shows an example of the Indiana June 2008 flood mapping results.

The detected flood extent can also be used to evaluate general flood plain products, which are often produced based on certain flood modeling. Such maps are produced by Federal Emergency Management Agency and often made available through the state GIS repository. Figure 3 shows that most detected flood areas using satellite images are within the predicted flood plain maps, however, some are indeed outside, which suggests a certain amount of underestimation of the flood plain modeling process.

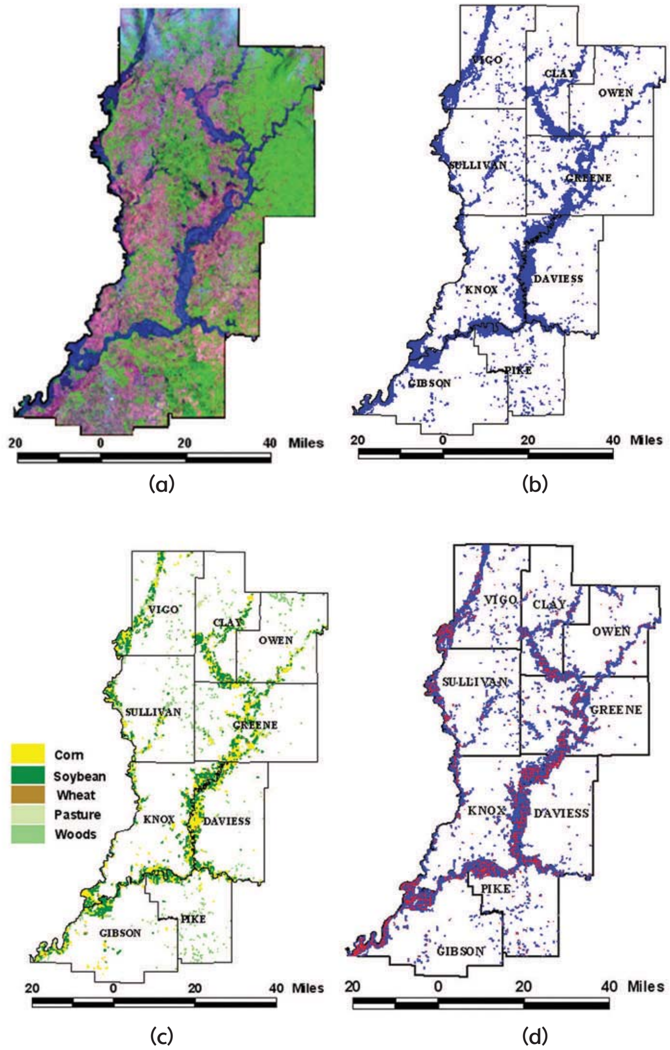

Figure 2. During flood Landsat image (a), flood extent map (b), flood affected crops (c) and flood affected roads (d) for the southwestern Indiana June 2008 floods. Reprint from *Shan et al.,* 2009 with permission.

Web Mapping Service

The satellite derived flood maps can be visualized and accessed on the Internet through web mapping techniques. A prototype tool was developed based on a Google Earth plug-in. Through a web browser, one can visualize the flood extent with reference to the background data provided by Google Earth, such as images, roads, boundary, thematic layers, and property map. This way the general public and governments have an easier and more convenient way to evaluate the flood situation and can be more informed and updated as to any new developments. Figure 4 illustrates the interface of the prototype tool with detected 2008 Indiana flood extent overlaid atop Google Earth reference data. Figure 5 shows the flood extent detected from ALOS PALSAR images (blue) during the Georgia flood in September 2009. Landsat images prior to the flood were used to remove the false water bodies detected on the ALOS images. It should be noted that there was heavy cloud coverage for several weeks during the Georgia flood and the first cloud-free Landsat images were collected about one week after the flood, which makes them less useful in this study.

Conclusion

The value and usefulness of timely collected and processed satellite images are demonstrated through the mapping activities in recent floods in Indiana and Georgia. In addition to the free Landsat images, which have limitations in timely revisits and cloud cover requirements, the other images, such as radar images, from the International Charter are a valuable data source. Archived images and GIS data are needed to detect reliable flood extent and estimate potential crop and infrastructure damages. The combined use of temporal optical and radar images is often necessary to achieve this objective. Web mapping capability provides the general public and government agencies with an effective tool for situation awareness and development update.

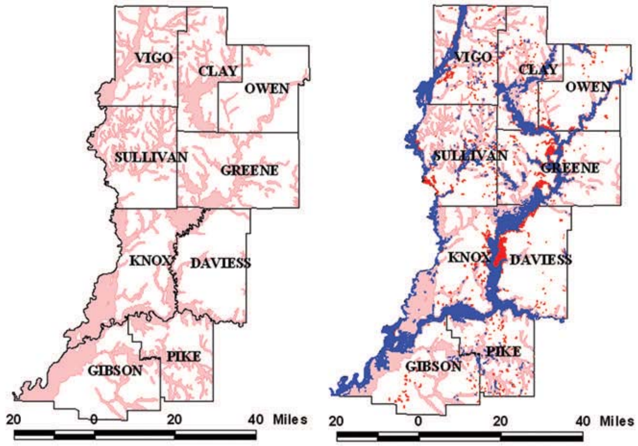

Figure 3. General flood plains (left, light red) and the actual flood extents from the Landsat image (right, blue for flood water within flood plains and dark red for flood water outside flood plains). Reprint from Shan *et al.,* 2009 with permission.

References

Benz, U.C., P. Hofmann, G. Willhauck, I. Lingenfelder, and M. Heynen, 2004. Multi-resolution, object-oriented fuzzy analysis of remote sensing data for GIS ready information. *Journal of Photogrammetry and Remote Sensing,* Vol. 58, pp. 239–258.

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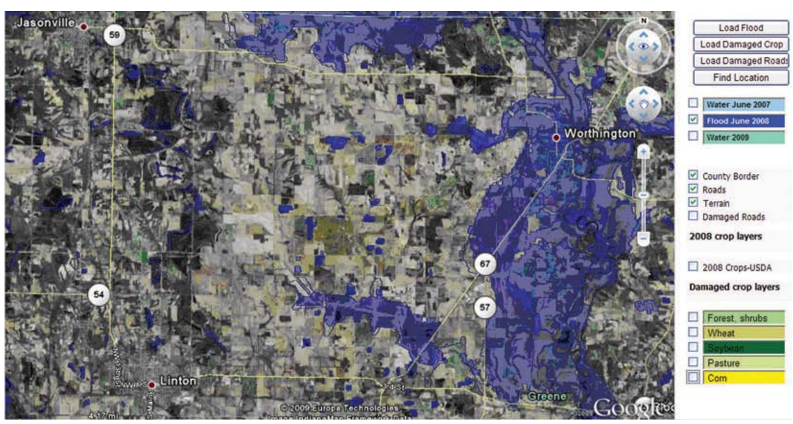

Figure 4. Indiana June 2008 flood extents (blue) derived from Landsat images overlaid atop the Google Earth images and the functions for display and damage assessment (the panel to the right) https://engineering.purdue.edu/CE/floodmaps/main.htm.

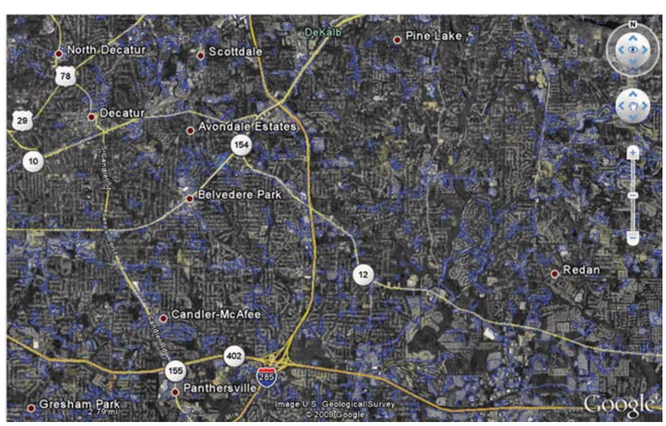

Figure 5. Georgia flood extents (blue) derived from ALOS PALSAR images overlaid atop the Google Earth images. Courtesy JAXA for the ALOS images.