State of Wisconsin International Charter and EagleVision Report of the June 2008 Midwest Floods

October 2008

Introduction

In June of 2008, Wisconsin and other Midwest states saw an unprecedented amount of rain fall on the region. A series of storms dating from June 5 - 12 caused widespread flooding that resulted in damage to thousands of homes, businesses and roads. Many local climate records were broken with up to 17-inches of rain in some parts of the state. Thirty counties were declared a "state of emergency" by Governor Doyle and eventually 31 counties received federal disaster declarations.

Partners

On June 10, the Wisconsin Department of Military Affairs (DMA) requested the US Geological Survey (USGS) to activate the International Charter. By June 30 DMA determined that no more remote sensing support was needed and that the International Charter could be deactivated.

During the activation, three major partners were involved in supporting DMA's request.

- **DMA** – DMA was the requester. The State Emergency Operation Center (EOC) and the Wisconsin National Guard Joint Operation Center (JOC) are both located at DMA and were activated in response to the flooding. The GIS coordinator for the agency coordinated all mapping activities for both the EOC and JOC and was named the project manager for the international charter activation.
- **USGS –** USGS provided access to imagery. DMA communicated daily with the emergency response team at the EROS data center as well as receiving support from the Wisconsin USGS liaison.
- **WisconsinView –** WisconsinView, a remote sensing consortium from the University of Wisconsin-Madison, focuses on research education and outreach for the application of innovative technologies in science, government and business. WisconsinView provided support in processing and analysis of all the scenes collected. WisconsinView is a member of the AmericanView consortium and during the flooding event, tapped into its nationwide network of remote sensing experts to aid in the analysis.

Process

Acquisition

Once the charter was activated, DMA provided the USGS coordinates of the impacted areas. The main objective was to identify flood polygons, which provided emergency responders a "bird's eye" view of the floods. It also provided information for long term efforts to aid other agencies with future planning and mitigation activities.

USGS then analyzed our needs and made suggestions on what imagery would be most helpful. RADARSAT-1 product was suggested to meet our short term needs while the multispectral sensor available on the SPOT and Landsat would meet our longer term needs. The ability to utilize several sensors also provided for confirmation between sensors as well as refinement of the final products.

Analysis

The analysis of satellite imagery included imagery from several systems such as Landsat-5, SPOT-2, SPOT-4, SPOT-5, and RADARSAT-1. The goals were to:

- differentiate water from land.
- differentiate flood water from “normal” water.
- generate a GIS vector data layer (multi-polygon) in a standard projection for overlay with other GIS data.

Each of the satellite systems collected data in different ways and produce data with different characteristics. Landsat and SPOT are passive optical systems that measure surface-reflected sunlight. The radiance is recorded by onboard radiometric sensors sensitive to specific wavelengths of light at specific spatial resolutions. RADARSAT is an active microwave system that sends radar waves to the surface of the earth and records the reflected energy that returns to the satellite.

These two basic techniques, optical and radar, produce useful data because the surface features of the earth (water, soil, vegetation, urban surfaces, etc) produce different and distinguishable amounts of reflected energy. In the case of optical return, the differences are measures of red, green, blue, and infrared radiation or spectra. In the case of radar systems, the return represents different textures of surface features through “backscatter.”

There are a number of limitations inherent in both of these approaches to environmental remote sensing. Satellite systems and initial signal processing systems are designed to geo-locate the data as it is received and processed. However, even with careful post-processing, data products often include geo-location errors, especially if the processing is expedited. There are also basic trade-offs between spatial resolution (amount of detail in the data) and area of extent (how many images required to cover an area). Higher resolution imagery (e.g. 4-meter pixels) may require a dozen images to cover the same area of as single moderate resolution scene (e.g. 30-meter pixels). With optical sensors, these images may take days, weeks, or even months to collect.

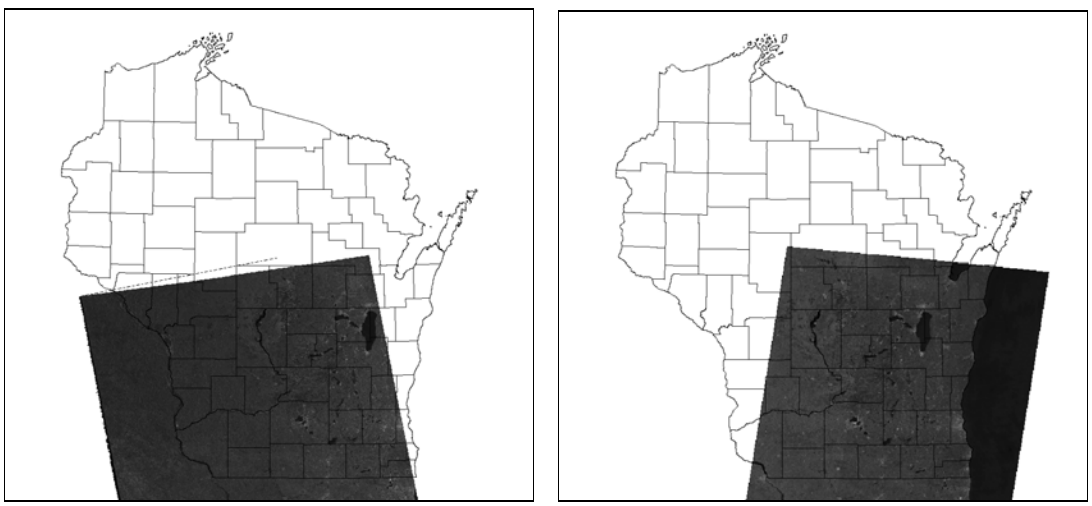
There are also sensor-specific limitations. Cloudy days limit optical systems with direct interference to the line of sight, but also by cloud shadows that interfere and limit reflectance. For example, water absorbs infrared radiation and returns a very weak signal. Cloud shadows also return a weak infrared signal and can cause confusion during spectral signature classification. Radar systems penetrate clouds and can operate at night giving them an advantage for timely delivery of imagery. However, surface features such as hill “shadows” and smooth fields can return values similar to water surfaces.

The analysis included the following imagery sets:

Platform	Sensor	Dates	Resolution	No. of Scenes
RADARSAT-1	SAR	6/15, 6/16	25m	2
Landsat	TM	6/18	30m	1
SPOT-2	MSI	6/14, 6/19	20m	9
SPOT-4	MSI	6/14, 6/17, 7/4	20m	8
SPOT-5	MSI	6/21, 6/28, 7/1	10m	10

RADARSAT-1

The first images WisconsinView received were RADARSAT-1 scenes from June 15 and 16, 2008. These were transferred to and processed immediately by Dr. Jonathan Chipman, former WisconsinView scientist and now with the Dartmouth College. One of the scenes was acquired in an ascending "night" orbit. The other was in a descending "daytime" orbit. The imagery was similar enough in area extent and quality that Dr. Chipman elected to proceed first with the June 15 image. He had discovered that both images almost completely covered the entire area of southern Wisconsin affected by the flooding. However, both were geographically skewed in the northern area. Given the time that would be required to correct the distortion, he decided to crop the top of the image to proceed with the resulting subset of geographically correct data.



RADARSAT-1 imagery from June 15 (left) and June 16, 2008 (right) showing area of coverage relative to Wisconsin counties.

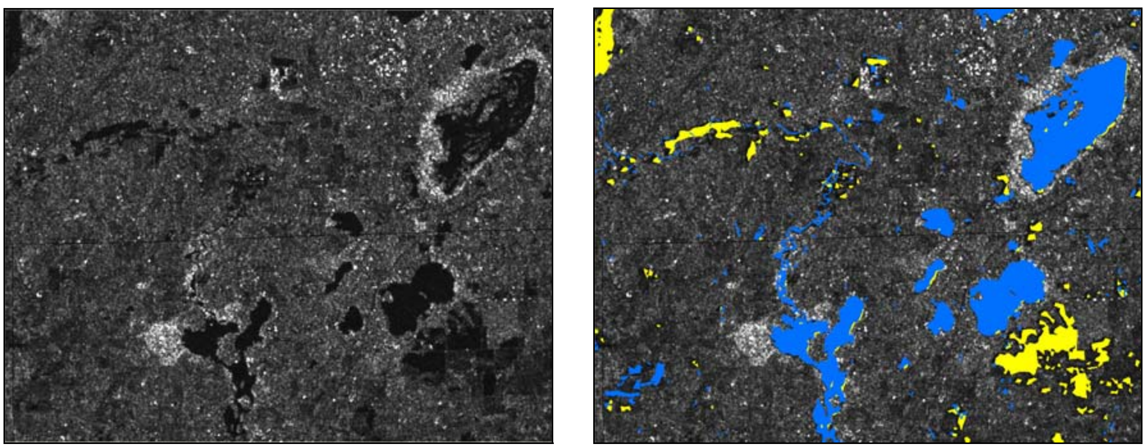
Dr. Chipman used ENVI/IDL to process the imagery and produced a single shapefile showing all water as either normal water or flood water. These are the steps he used:

(1) Adjusted coordinates to fit more closely with 1:24k maps (affine shift needed).
(2) Reprojected from UTM zone 15 to WTM83 (Wisconsin State Standard).
(3) Subset Wisconsin area (image overlapped parts of Illinois, Iowa, Minnesota).
(4) Ran an "enhanced frost filter" (5x5 kernel) to reduce impact of speckle noise.
(5) Classified pixels with values in the range of 1-35 as water.

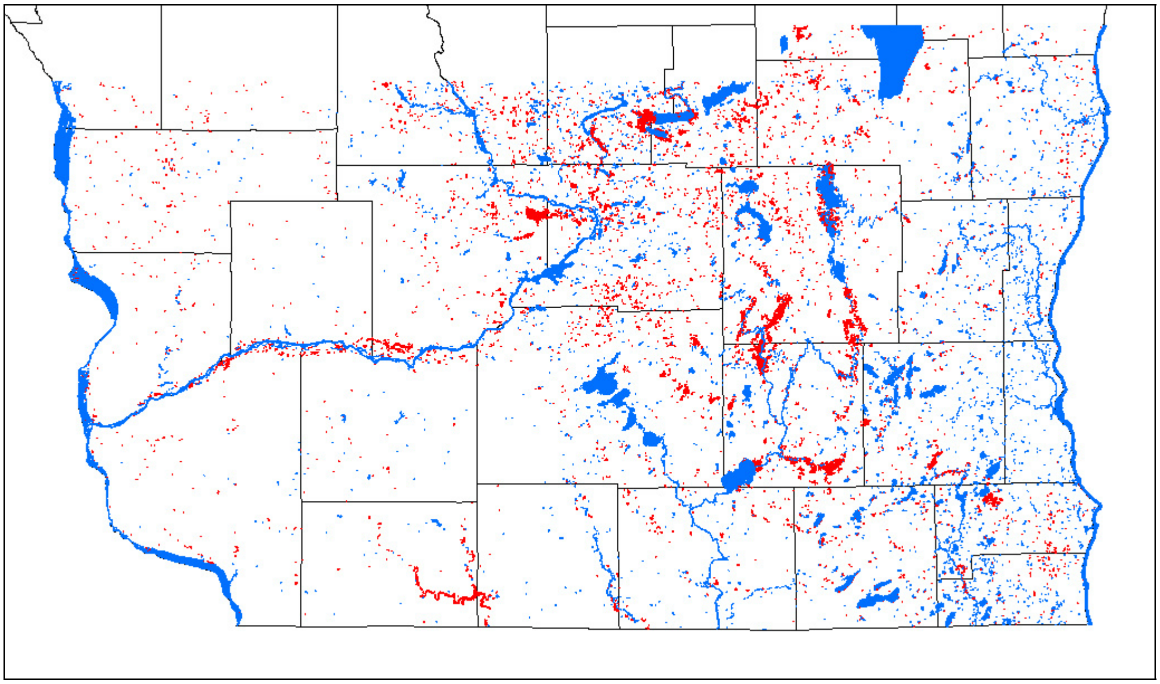
(6) Distinguished flooding from "normal" water pixels (lakes, etc.) using WISCLAND land cover data set (1992 data published in 1998).
(6a) Eliminated any "flooding" on steep slopes (radar hill shadows).
(7) Discarded any "clumps" smaller than 5 pixels.
(8) Exported to GeoTIFF (blue = normal water, red = potential flooding).
(9) Exported to shapefile and layer file.

Dr. Chipman merged the two images and repeated these steps for the final version.

In general the RADARSAT-1 analysis did a good job of differentiating water from land. There were errors of omission and errors of commission. Omissions seems to have happened where the noise filtering eliminated clusters of features deemed too small or too narrow to be trusted. Sometimes this effected depiction of flood plain areas along rivers that formed nearly linear features (this happened along some rivers in southwestern Wisconsin). Commission occurred when the texture signature of very smooth agricultural fields were identified as water during processing. Areas in which tree canopy obscured flooded land were omitted. More sophisticated techniques can identify water under tree canopy, but these require significantly more time than was deemed acceptable.



RADARSAT-1 imagery can be processed to differentiate between land and water. The image on the left is shows "backscatter" from June 15. In the image on the right, pixels identified as water are represented in blue (expected normal water features) and yellow (flood water).



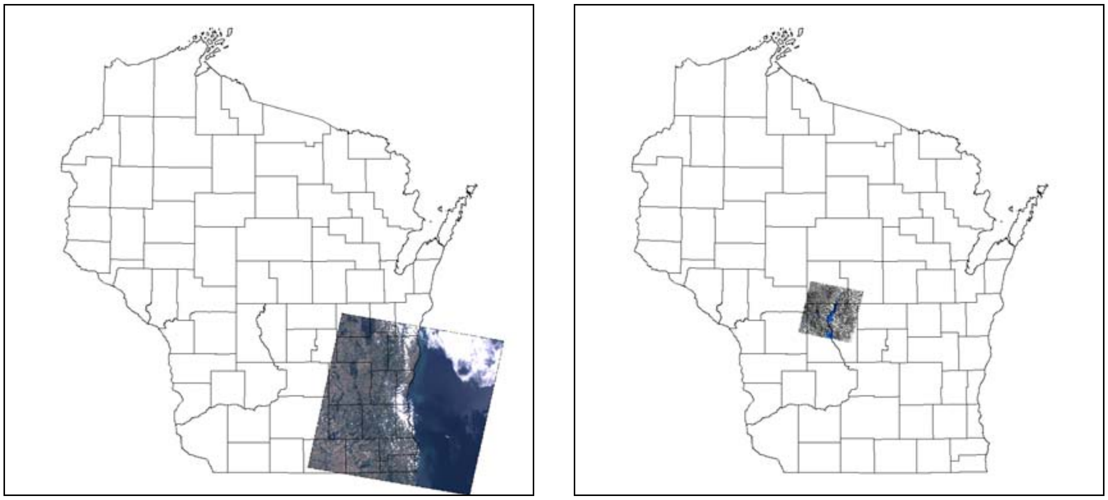
Water features extracted from both the June 15 and June 16, 2008 RADARSAT-1 imagery represented in blue (normal water) and red (flood water) in shapefile format.

Dr. Chipman chose to use the WISCLAND data set to establish existing water and to differentiate it from flood water. This was done largely out of convenience. The 1992 WISCLAND is regrettably the best, most recent, comprehensive land cover data set easily available for Wisconsin in WTM projection and raster format. Alternatives such as the National Land Cover Data (NLCD) produced by the Multi-Resolution Land Characteristics Consortium (MRLC) in 1992 and 2001 (2006 update in preparation) would seem to be better choices. However, these national datasets often have significant regional inaccuracies and require significant amounts of pre-processing in preparation for use in state-specific projects. In retrospect the Wisconsin DNR 24k hydro vector dataset may have been a better choice for its accuracy. However, its use would also have required pre-processing or a change in protocol.

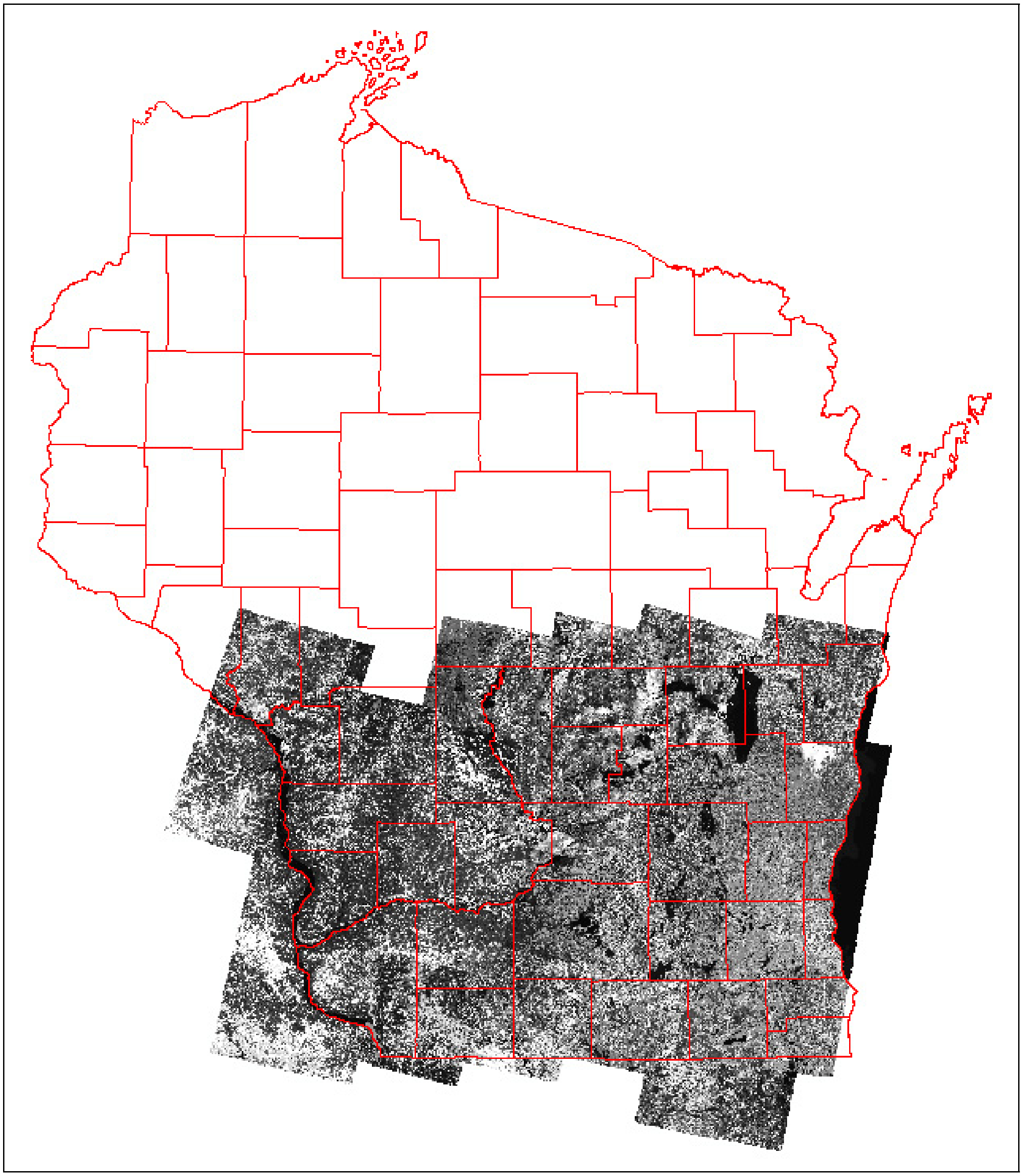
Generally it appears that the RADARSAT imagery processing produced a low estimate of actual flooding. This is partly because the snapshot came early in the flooding event. The Rock River did not crest until late June. It is also because the protocol eliminated clusters of pixels too small to be considered accurate within the resolution of the sensor (25m).

Landsat & SPOT

WisconsinView downloaded the one reasonably cloud-free Landsat 5 Thematic Mapper (TM) image available and 27 multi–spectral (MSI) SPOT images from a USGS server. These were processed by Dr. Sam Batzli of the University of Wisconsin-Madison. Dr. Batzli used Leica Geosystems' ERDAS IMAGINE to perform unsupervised classification of the 28 images and mosaicked the results together into a single shapefile showing all water.



Landsat imagery (left) covers an area about nine times larger than a typical SPOT image (right). Only one Landsat image from one satellite had sufficiently few clouds to be useful. More than two dozen SPOT images from three different satellites were available with low or no clouds.



One Landsat and 27 SPOT images were used to cover the southern part of the state(only the SPOT scenes are displayed here).

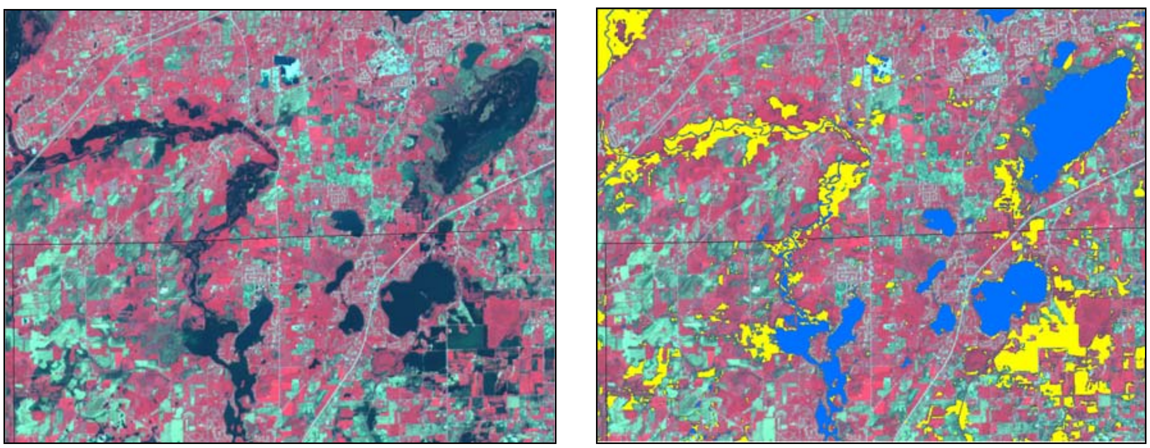
Dr. Batzli used the following protocol:

Data Prep:

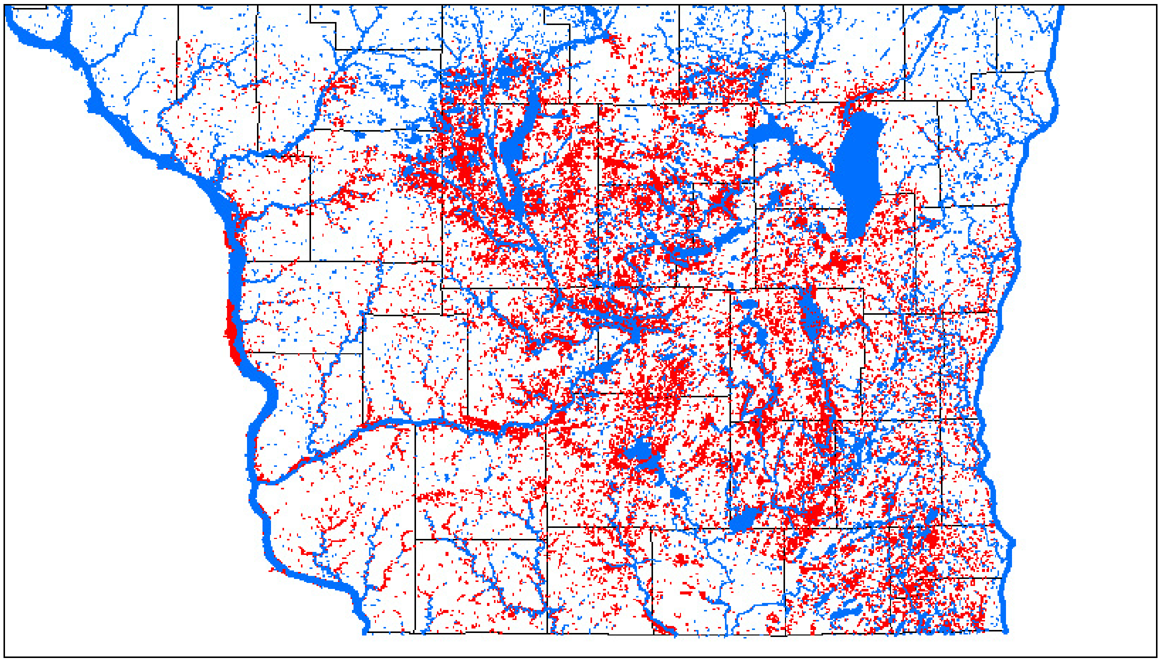
1) Identify potentially useful images (rejecting cloudy images and misnamed tiles).
2) Identify scene location (using provided shapefile – incomplete).
3) Download and unzip images to local drive.
4) Evaluate spatial integrity (three SPOT images poorly geo-corrected).

Data Analysis:

5) Run unsupervised classification (30-60 classes – more if haze or clouds were present, 10 iterations, .95-.99 convergence).
6) Open resulting new image in ArcGIS 9.3 – ArcMap.
7) Visually inspect raster output overlaid on original imagery for water classes (usually 4-8 classes).
8) Re-classification with ArcMap Spatial Analyst to produce an image with three classes (water, land, no-data).
9) Run a "raster to feature" process with ArcMap Spatial Analyst to generate polygon shapefile, and export the water polygons to a final shapefile.
10) Overlay shapefile on original image to identify and remove obvious errors of commission such as cloud shadows and edge effects. Re-process with more classes, iterations and/or higher convergence, if necessary.
11) Modify attribute table to indicate polygon source and size: platform, sensor, resolution, date, area (meters).
12) Merge adjacent polygon fragments to simplify shapefile.
13) Mosaic shapefiles from all 28 scenes to produce single "all-water" shapefile.



The SPOT-2 image on the left shows water as darker than land. On the right, normal water (blue) is differentiated from flood water (yellow) after processing.



Final SPOT flooding shapefile (red) with existing water (blue) from DNR open-water or "hydrshai" layer overlaid on top.

For the processing of optical imagery (Landsat and SPOT) there were three basic problems. The first, and perhaps easiest to fix, was in the data prep phase. It proved difficult to identify relevant imagery on the USGS website. Shapefile foot prints were not always up to date. There were only a few "quick-look" images to help determine cloud cover. The naming convention did not always make sense or contained errors. For example one scene was identified in the file name as Madison, Wisconsin but was actually centered over Madison, Indiana. In other cases, overlap into Iowa and Illinois created some confusion over which images were required to create a complete mosaic of Wisconsin. At least two of the SPOT images were badly georeferenced and required significant amount of correcting to render them useful. Several other were simply too cloudy.

The second issue involved the ambitious nature of the task. Making a mosaic of 28 different images from four different sensors at three different resolutions with a two week difference in acquisition (changing ground and atmospheric conditions) is not a trivial task. The unevenness of the results represents each of these differences to varying degrees.

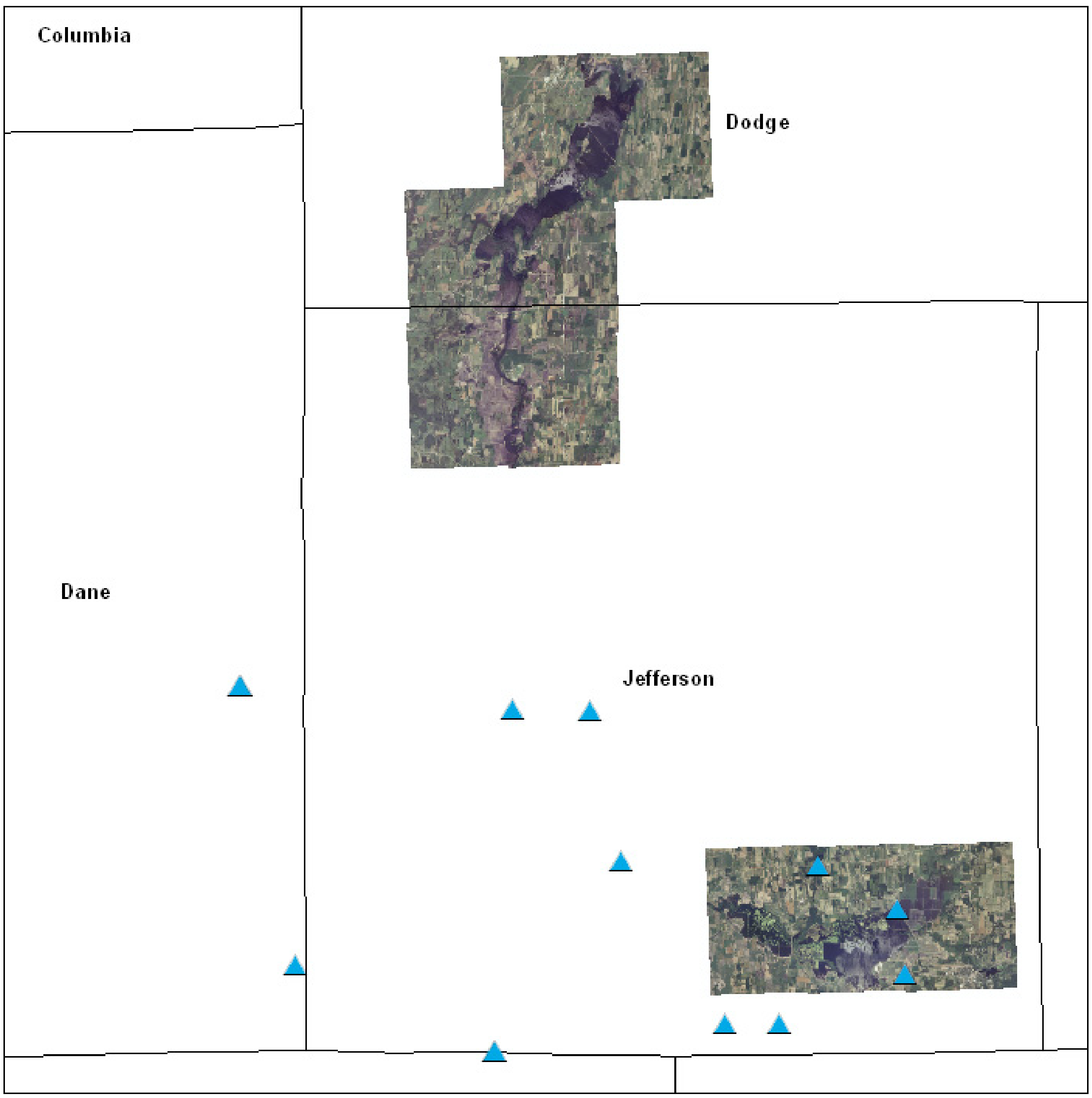
The third problem involved human resources. This task was voluntarily undertaken on a overload schedule by a single individual under extreme time pressures. Had a processing protocol been in place prior to the event along with a more coordinated network, the effort could have been more easily shared. Lessons learned from this event will be brought forward in the work of WisconsinView.

The WisconsinView network is growing but has not yet reached its full potential. There is hope that growing support for the parent consortium at the federal level

(AmericaView) will lead to restored budgets and growth in the future. As it grows, WisconsinView hopes to have processing protocols available at each of the UW system universities and regional offices of state and federal agencies where remote sensing capabilities and expertise exist. Then, when an emergency strikes anywhere in the state, and the International Charter is activated, there will be a trained workforce available, with instructions and protocols, to take on the task of processing imagery. To date, four of the 13 four-year institutions are members of WisconsinView.

Ground-Truthing

Two limited, but helpful efforts at "ground-truthing" were undertaken. The first involved a team of Wisconsin DNR employees using hand-held GPS receivers and digital cameras on the ground on June 20, 2008. The second involved access to a pre-release of 1-meter color-infrared 2008 National Agriculture Imagery Program (NAIP) imagery from the Wisconsin Farm Service Agency (WI-FSA) of the USDA.



Ground truthing inputs included 9 pre-released 2008 NAIP images and several GPS points (blue triangles)with accompanying ground photographs.

The top image is the June 2005 NAIP image of a portion of Jefferson County. The bottom image is the July 5, 2008 NAIP pre-release image. Flooded areas appear dark blue. Green triangles represent three ground truth locations (005A top left, 006A center right, 007A bottom right).

7/5/2008 NAIP Air Photo (1m)

Water form Landsat 6/18/2008 (30m)

Water from SPOT-4 6/14/2008 (20m)

Water from RADARSAT-1 6/16/2008 (25m)

Water from SPOT-2 6/14/2008 (20m)

View north from 007A (marked with red circle)

The ground truth aerial photography and GPS data provided an opportunity to compare satellite imagery analysis with more detailed imagery and on the ground information. The date of the 2008 NAIP imagery was July 5, 9, and 23, significantly after the main flooding event. However, it is possible to discern in the imagery areas where water stood prior to draining. In the examples provided here, the SPOT-4 imagery seems to correspond most accurately to the aerial imagery and ground truth GPS observations.

The GPS team documented standing water at site 007A. Only the RADARSAT and SPOT-4 imagery captured the standing water.

The ground truth data largely confirmed that areas suspected of being errors of commission were indeed flooded fields during the month of June. The satellite imagery and its analysis in general did a good job of identifying areas of suspected flooding. There were errors of omission with the coarse sensor resolutions (RADARSAT at 25m and Landsat at 30m) but because of their broad coverage area, the RADARSAT in particular, carried the advantage in getting a useable product out to emergency management within 48 hours of acquisition. The SPOT and Landsat composite took considerably longer to develop – weeks rather than days.

There is a basic trade-off between expediting image processing and the quality of the results. It can be hard to strike a balance between getting information out in a timely manner and getting information out that is accurate. Image processing is time consuming. The more elaborate the techniques are for filtering out spurious data the more time consuming the process. The more ground-truth inputs, the easier it is correct and improve the results. That being said, there is no other better source of overview information on land surface conditions than remote sensing imagery.

Conclusion

Access to these datasets proved invaluable in both a response and a recovery efforts. These dataset will also have an impact as mitigation and flood modernization activities progress forward in the coming months and years. While the assistance from the USGS and the WisconsinView program were very helpful, timely resources need to be identified to expedite processing and analysis of these products to ensure these products are used to their full capacity during both the response and recovery phases.

The Wisconsin Department of Military Affairs would like to thank the USGS, WisconsinView and Dartmouth College for their assistance in coordination, processing and analysis of the data. Also, thanks to International partners for providing these valuable products and to Surdex and the WI-FSA for providing pre-release 2008 NAIP Orthophotography, which aided in ground truthing. Lastly we would like to thank all who supported our mission during these floods including those who volunteered time in the state Emergency Operation Center or in the field collecting ground truth data.