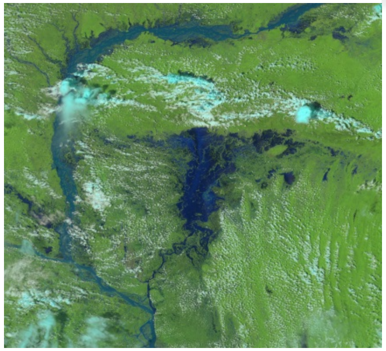
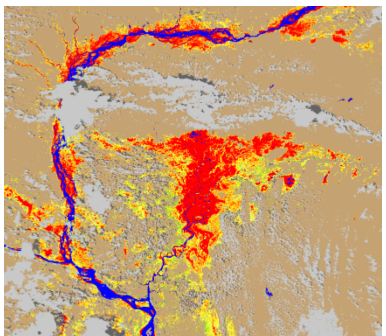
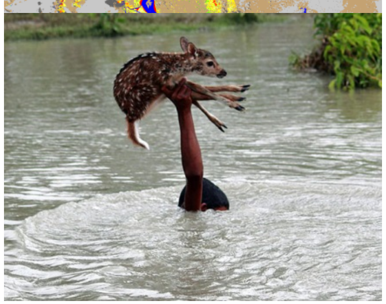






Flood Mapping Using Suomi-NPP VIIRS

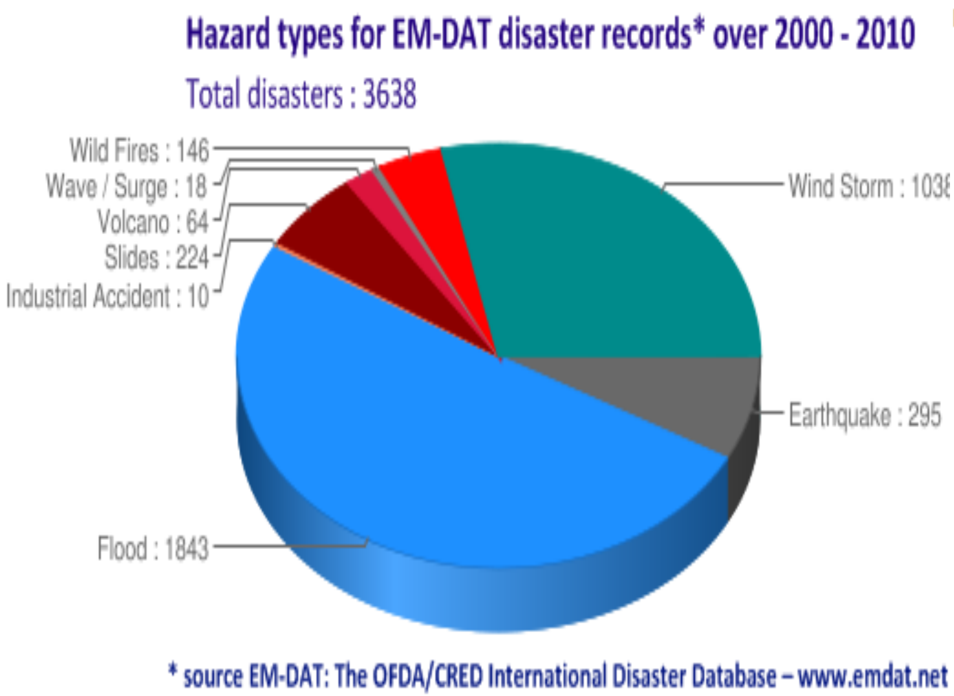
Donglian Sun Sanmei Li
George Mason University, USA
Mitch Goldberg Bill Sjoberg
NOAA JPSS Program Office, USA
David Santek Jay Hoffman
Space Science and Engineering Center, USA

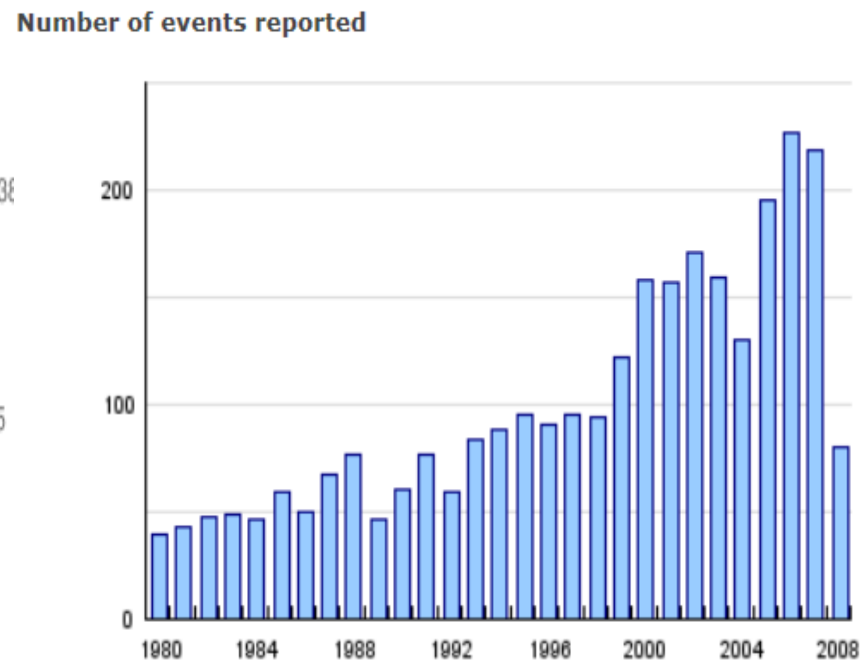
October 28, 2016

Outline

- Background (Why flood?)
- Challenges & Solutions
- Applications
- Validations/Evaluations
- Discussions
- Summary
- Reference

Why flood?





Floods are the most frequent natural disasters around the globe. With climate change, floods become more and more frequent

Why flood?

Mississippi River flood in 2011:
392 killed, economic loss: $2.8B

New York flood in 2012:
233 killed, economic loss: $75B

Galena, AK ice-jam flood in 2013: 90% buildings were destroyed.

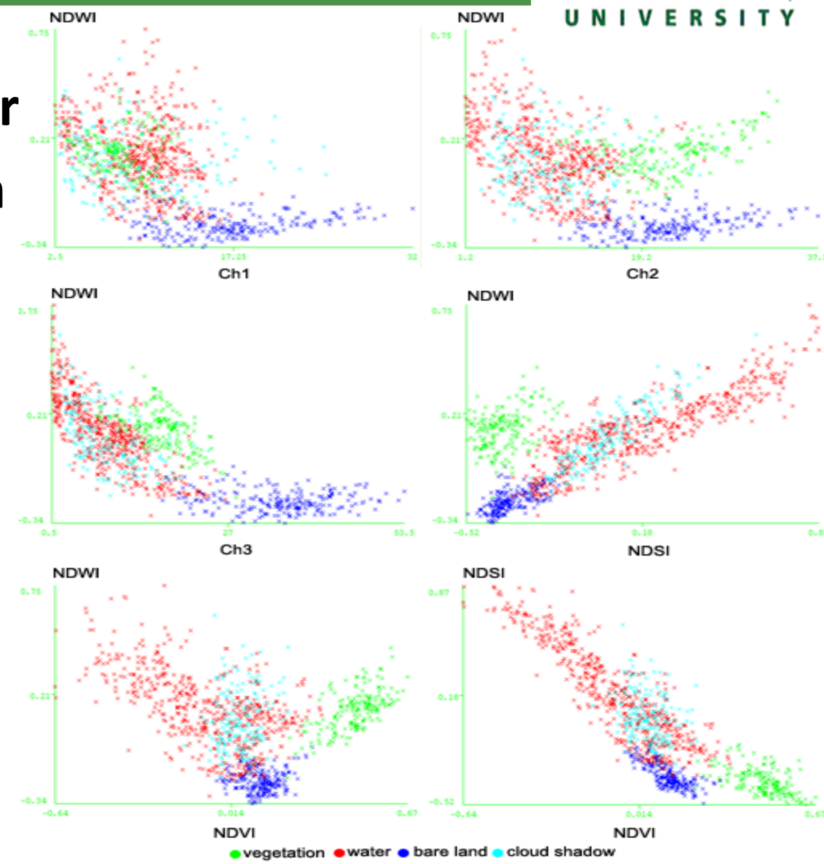
In the U. S., floods caused more loss of life and property than other types of severe weather events.

Background

- SNPP/VIIRS data show special advantages in flood detection.
  - ✓ 3000km swath without gaps even at the equator and constant 375-m spatial resolution across the scan in Imager bands
  - ✓ Multiple observations per day in high latitudes
  - ✓ Particularly excellent at snow-melt and ice-jam floods due to less contamination from cloud cover than floods caused by intensive rainfall
- Initialized by JPSS Proving Ground & Risk Reduction Program, flood detection algorithms have been developed to generate near real-time flood products from SNPP/VIIRS imagery.

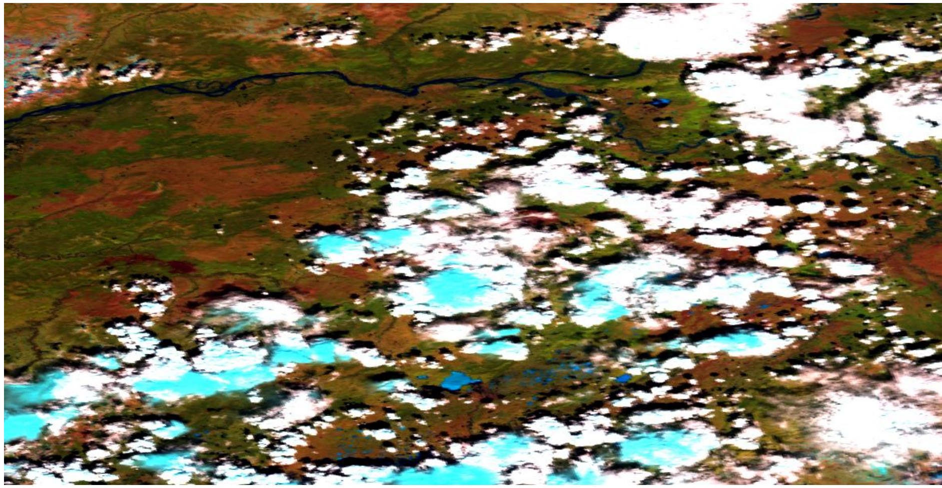
Challenges & Solutions

- **Cloud shadow is the biggest challenge for automatic near real-time flood detection using optical satellite imagery.**
  - ✓ Cloud shadows share spectral similarity to flood water, and thus it is unable to be removed based on spectral features.
  - ✓ Geometry-based method provides a good solution but still suffers with uncertainty of cloud height and cloud mask.

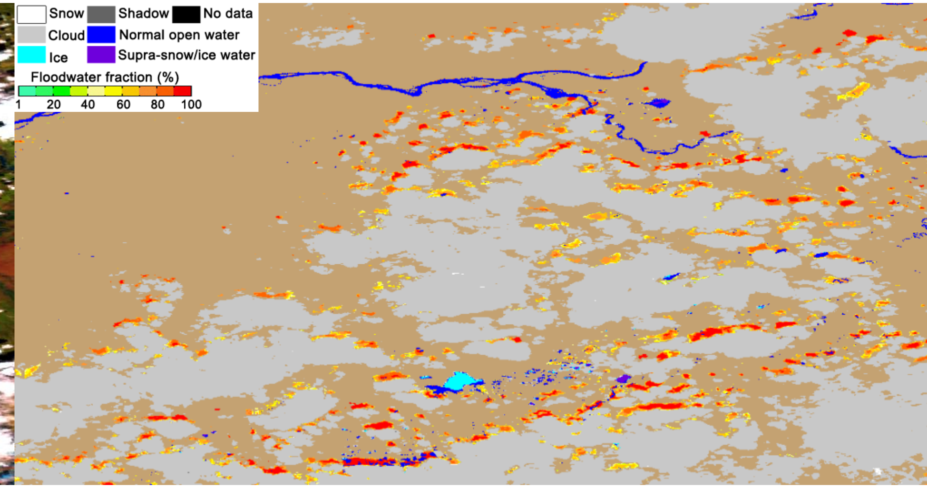


- **Solution:** cloud shadow removal from water pixels based on geometry-based method (Li. et al., 2013).
  - ✓ Based on geometric relationship between cloud and cloud shadows over spherical surface
  - ✓ An iteration method is applied to decrease uncertainty of cloud heights

Cloud Shadow Removal

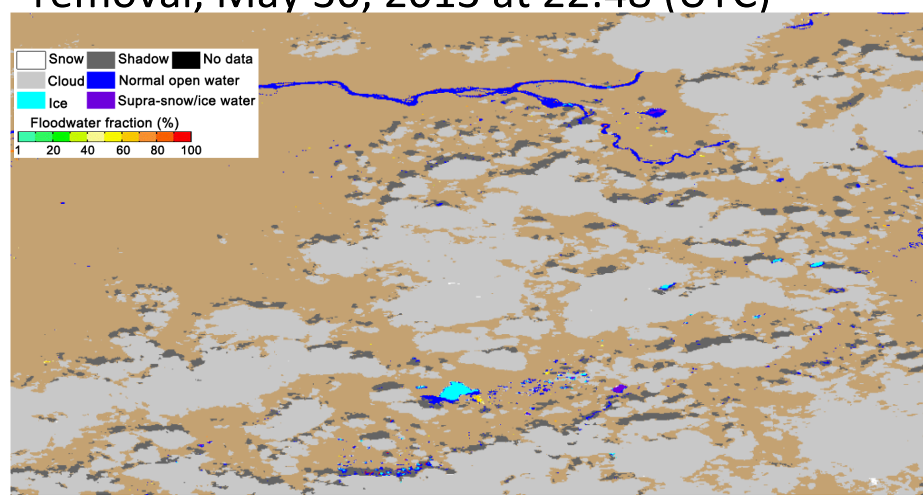


VIIRS false-color composited image, May 30, 2013 at 22:48 (UTC)



VIIRS flood map without cloud shadow removal, May 30, 2013 at 22:48 (UTC)

- In VIIRS false-color image (Top left), cloud shadows look very similar to open water and they are easily miscassified as flood water and further retrieved in large water fractions (Top right).
- After cloud shadow removal, these shadows are removed from VIIRS flood map (Bottom right).

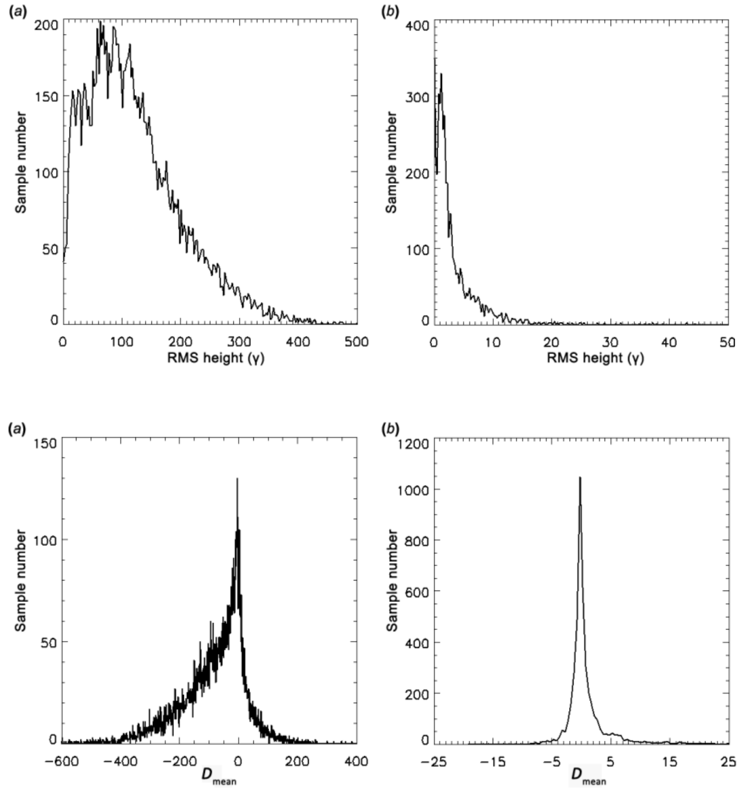


VIIRS flood map after cloud shadow removal, May 30, 2013 at 22:48 (UTC)

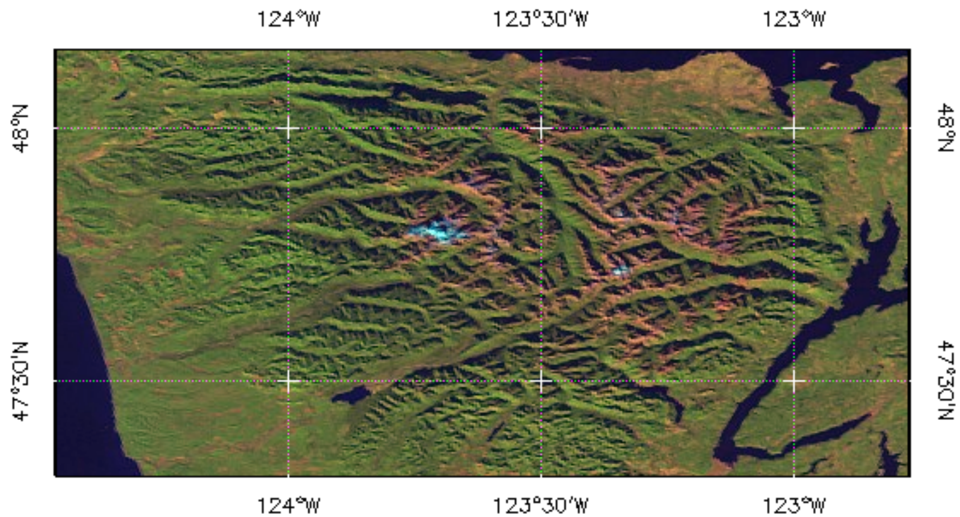
Challenges & Solutions

- **Terrain shadow is the second biggest challenge for automatic near real-time flood detection.**
  - ✓ Unable to be removed based on spectral features because of spectral similarity to flood water.

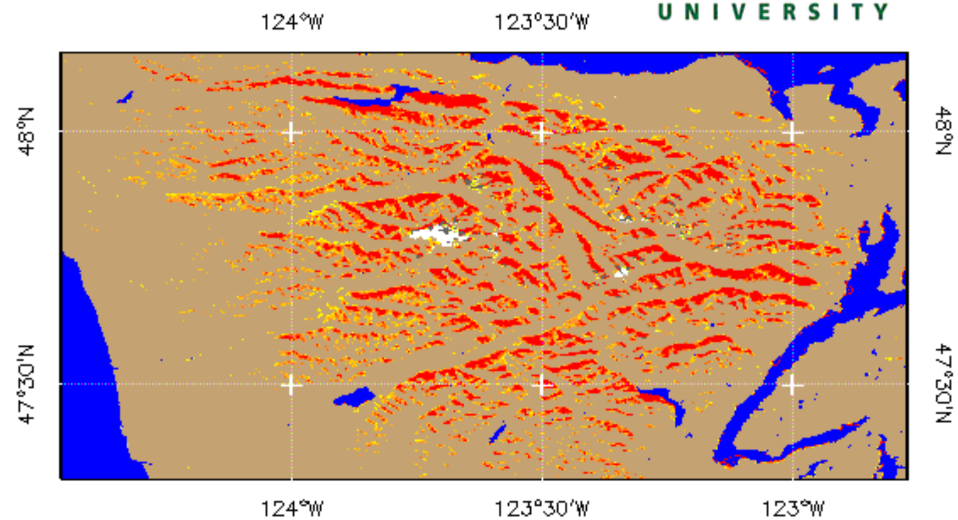
- **Solution:** Object-based method to remove terrain shadows from flood maps (Li. et al., 2015).
  - ✓ Full application of surface roughness analysis:
  - ✓ Object-based instead of pixel-based.



Terrain Shadow Removal

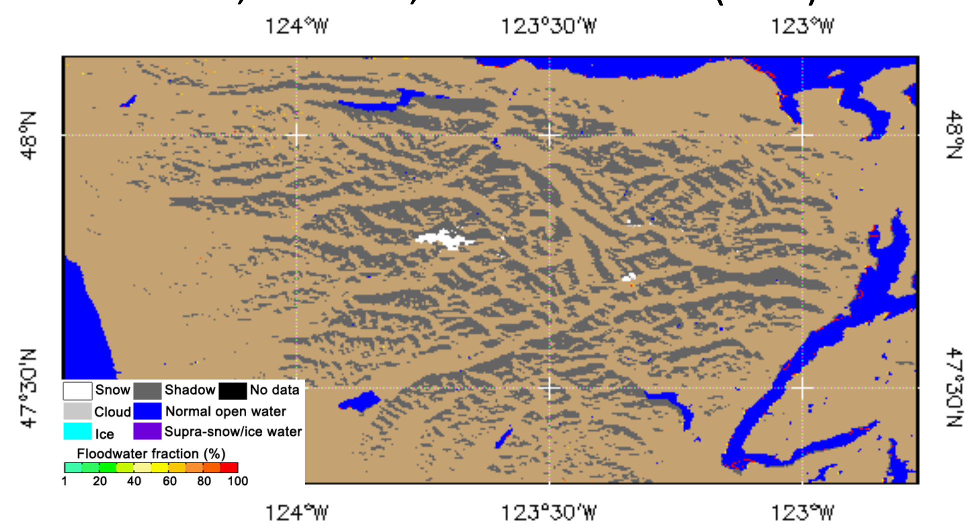


VIIRS false-color composited image, Nov. 15, 2014 at 21:02 (UTC)



VIIRS flood map without terrain shade removal, Nov. 15, 2014 at 21:02 (UTC)

- Without terrain shadow removal, most terrain shadows are detected as flood water with large water fractions (Top right).
- After terrain shadow removal, these terrain shadows are removed from flood map (Bottom right).



VIIRS flood map after terrain shadow removal, Nov. 15, 2014 at 21:02 (UTC)

Challenges & Solutions

- **Moderate spatial resolution of VIIRS imagery**
  - ✓ Limited to detect minor floods
  - ✓ Requires flood water fraction retrieval for better representation of flood extent than simple water/no water mask
- **Solution:**
  - ✓ Application of change detection to detect minor floods.
  - ✓ Dynamic Nearest Neighboring Searching method for water fractions by considering the mixing structure of sub-pixel land portion (Li. et al., 2012)
  - ✓ Downscale model to enhance the resolution of VIIRS flood map.

Challenges & Solutions – Downscaling model

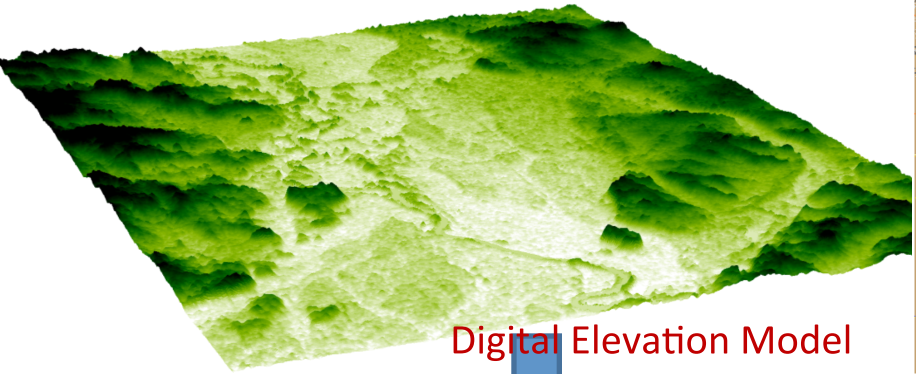
- The inundation mechanism can be expressed as:

$$A = \int_{\min\_h}^{\max\_h} \int_{1}^{N} w_i(h) f_i(h)\, di dh$$

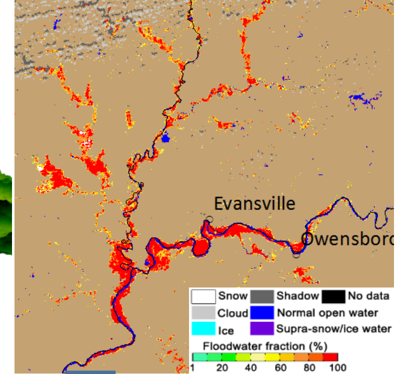
Where, A is satellite-based total water area between the minimal surface elevation, $\min\_h$, and maximal inundated surface elevation, $\max\_h$, $w_i(h)$ is the weight of land type i at height h in a VIIRS 375-m pixel, and $f_i(h)$ is the total area of land type i at height h.

  - ✓ $\max\_h$: flood water surface level (the most important variable).
  - ✓ Flood water depth: $\max\_h$ - h.

- Network analysis.
  - ✓ To make river flow smoothly from upstream to downstream.
  - ✓ To guarantee the accuracy of flood water surface level.



Digital Elevation Model



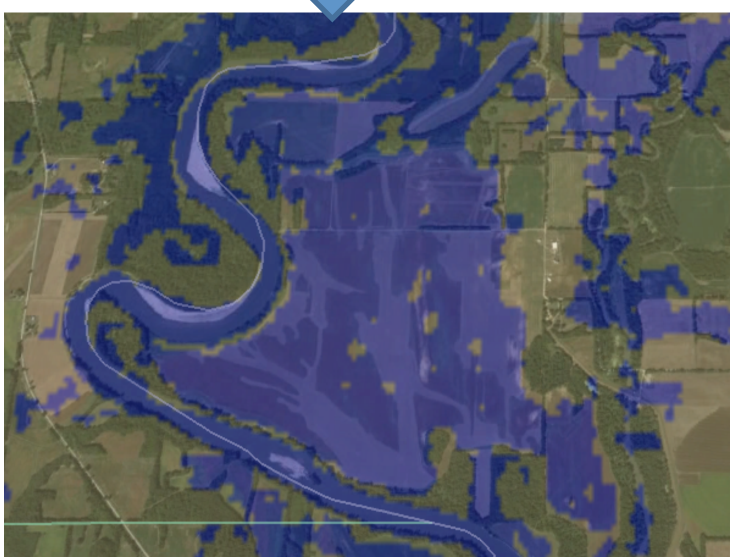
Can we see more from 375-m SNPP/ VIIRS flood maps?

Integration, Downscaling

Flood Mapping Tool

Scientific models

Computer systems



VIIRS downscaled 30-m flood map: provide more flood details

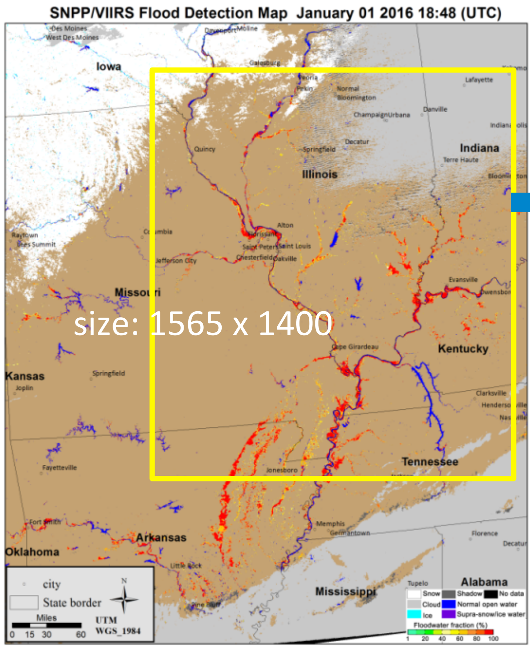
375-m VIIRS flood maps provide macro flooding information, but are limited to address any details. Flood mapping tool helps the moderate-spatial-resolution satellite imagers “see” more details of floods.

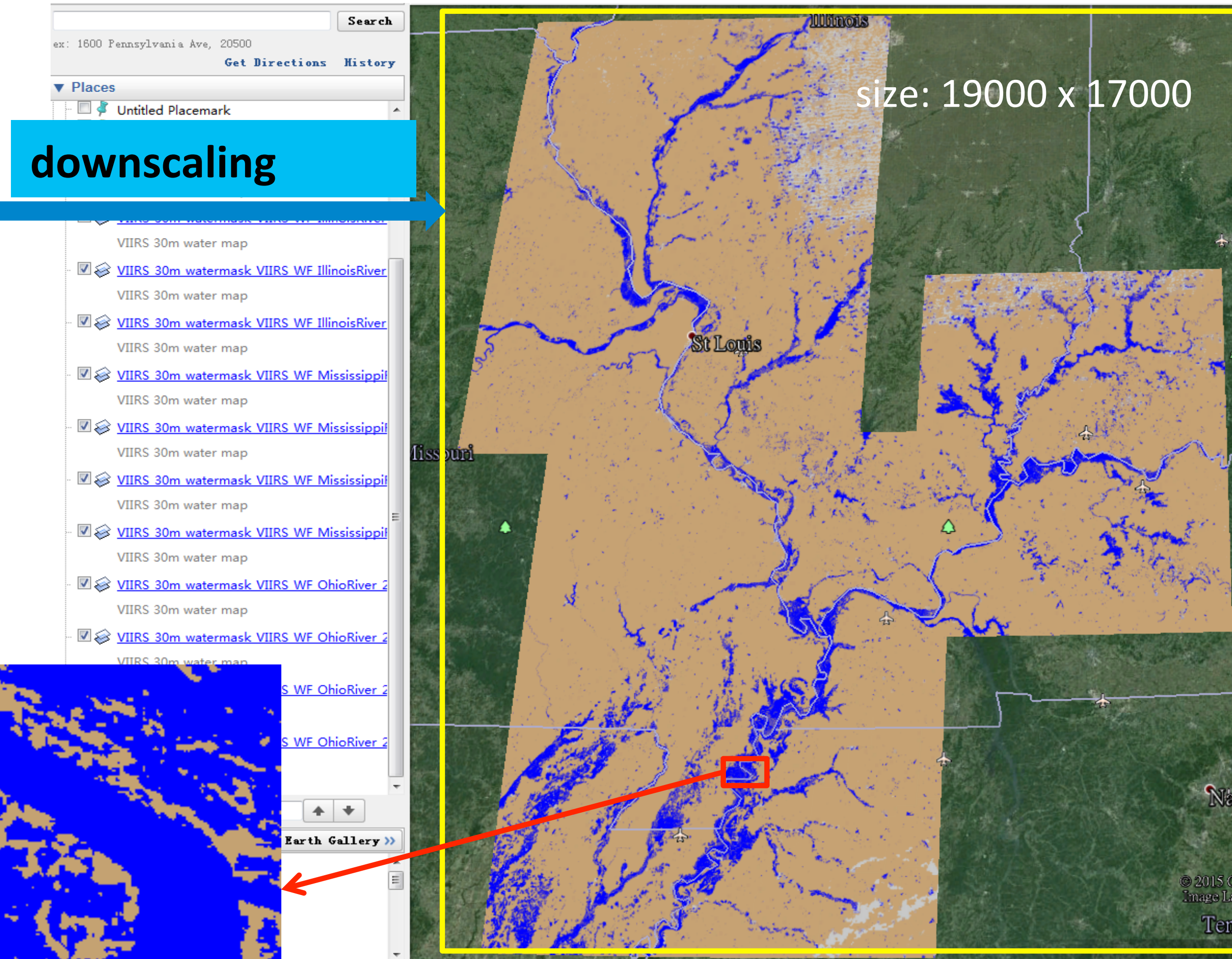
Challenges & Solutions – Downscaling model

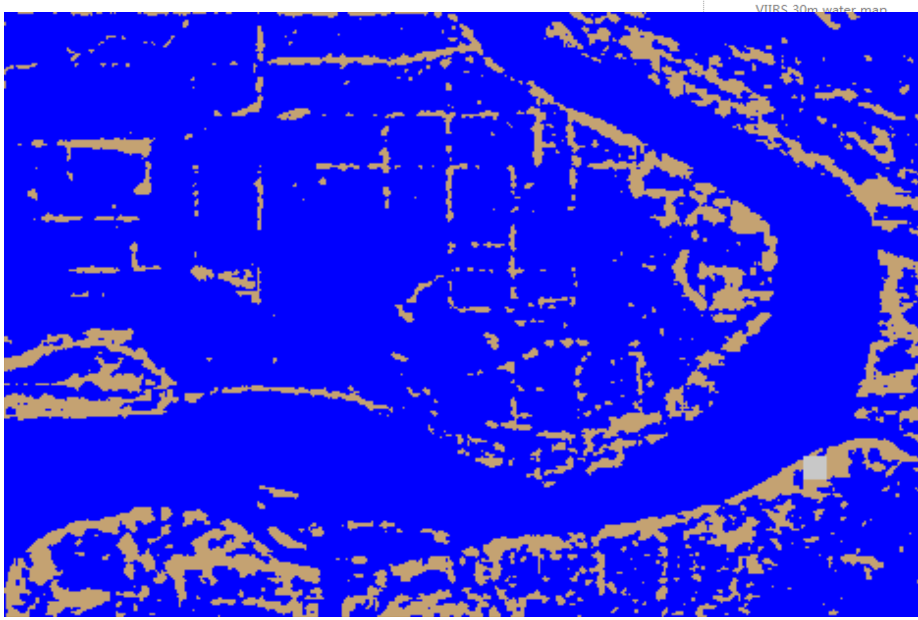
- **Downscaling model:** It is a model to enhance the spatial resolution of VIIRS flood maps from 375 meters to 30 meters or 10 meters using high resolution DEM and VIIRS 375-m flood water fraction product.

	Spatial resolution	Swath width	Global coverage
SNPP/VIIRS Imagery	375 m	3000 km	every day
Downscaled VIIRS flood maps	10 m or 30 m	3000 km	every day
Landsat-8 OLI imagery	30 m	189 km	16 days

The downscaling model makes SNPP equivalent to more than 15 Landsat-8 satellites in flood mapping.







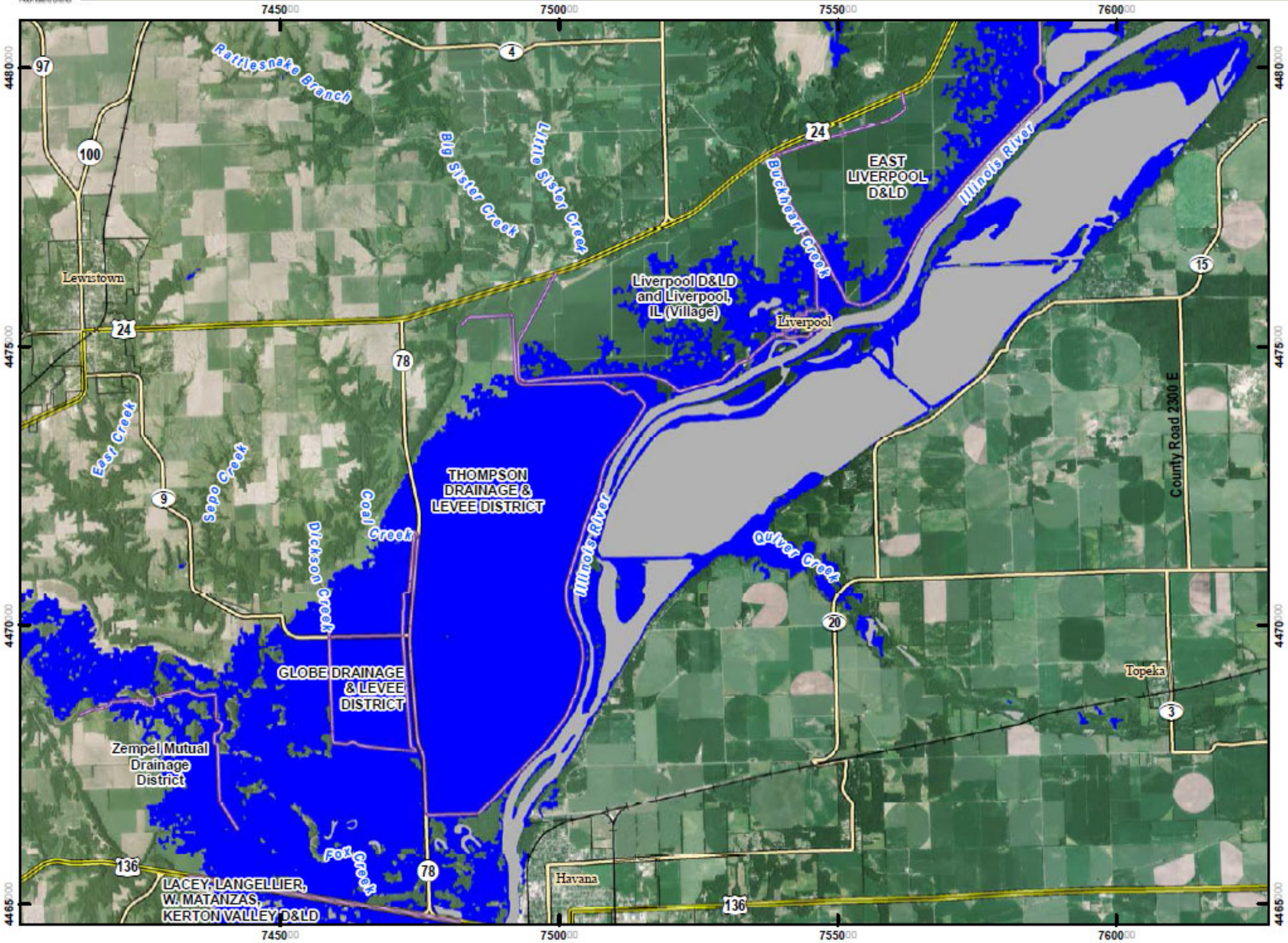
It takes about 10 minutes to finish the downscaling process within the yellow rectangular region in a 1-core-CPU computer.

Fast processing speed guarantees the near-real-time capability.

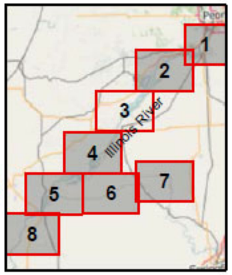
28 DEC 2015 FLOOD EVENT - NOAA VIIRS IMAGERY

05 Jan 2016 @ 1044 HRS

US Army Corps of Engineers



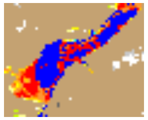
INCIDENT LOCATION



The background image is experimental satellite imagery collected by NOAA's Suomi NPP, using the Visible Infrared Imaging Radiometer Suite (VIIRS). It shows the extent of surface water as of 01 JAN 2016. It has been downscaled to 30 meter resolution and packaged into KML files by NOAA. MVR extracted the KML images for import into GIS on 02 JAN 2016.

NOTE: Surface water behind a levee should not be categorically interpreated as an overtopping. The surface water detected could be due to many situations including, but not limited to, levee seepage/boils, pre-existing surface water, or ponding due to precipation.

Rock Island District
Emergency Management
28 DEC 2015

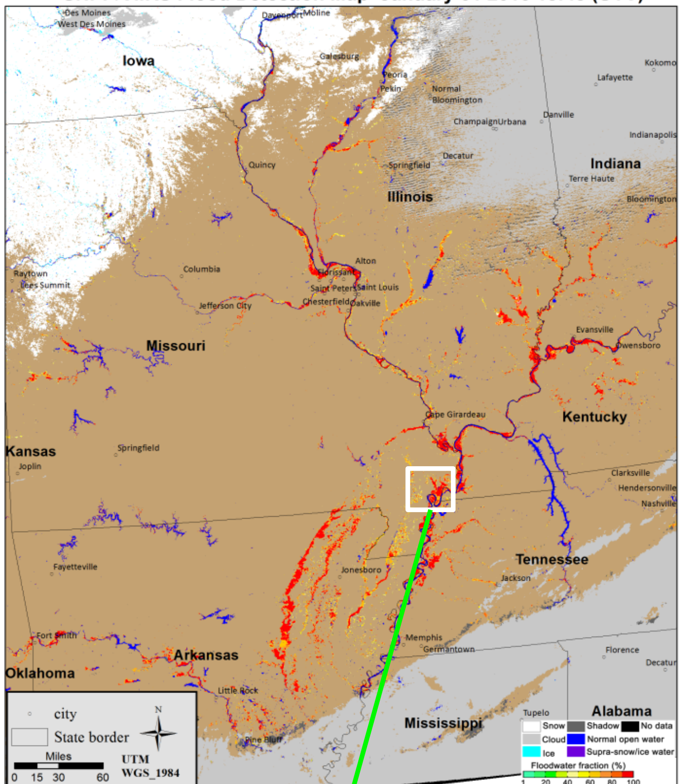


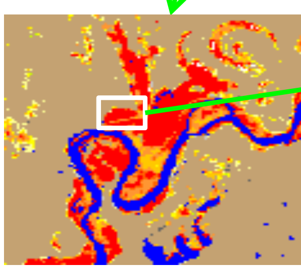
VIIRS 375-m flood map

Great flood details from VIIRS 30-m flood maps provide incredible information for flood investigation and evaluation.

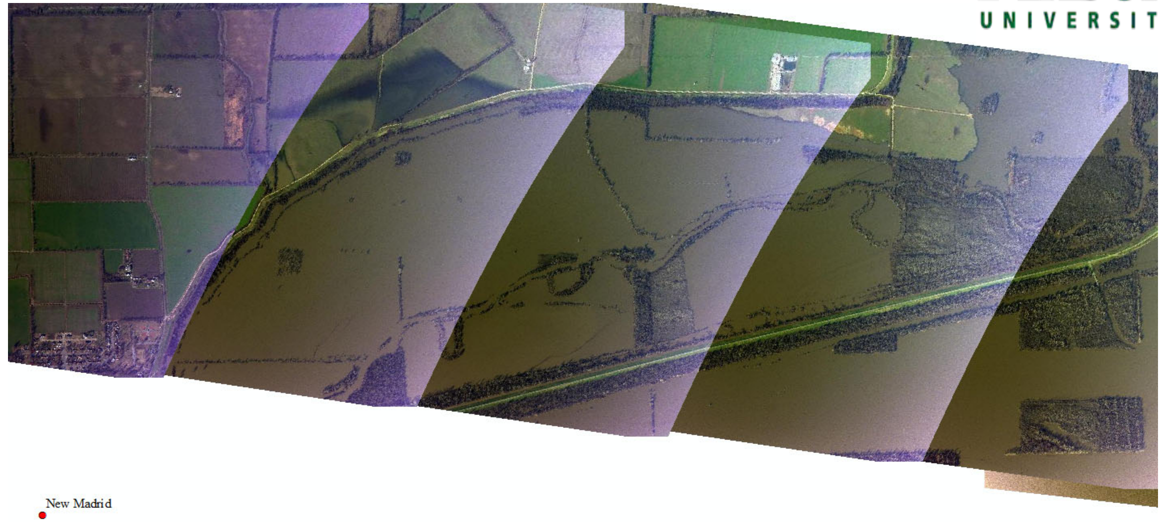
Comparing with aerial photography

SNPP/VIIRS Flood Detection Map January 01 2016 18:48 (UTC)

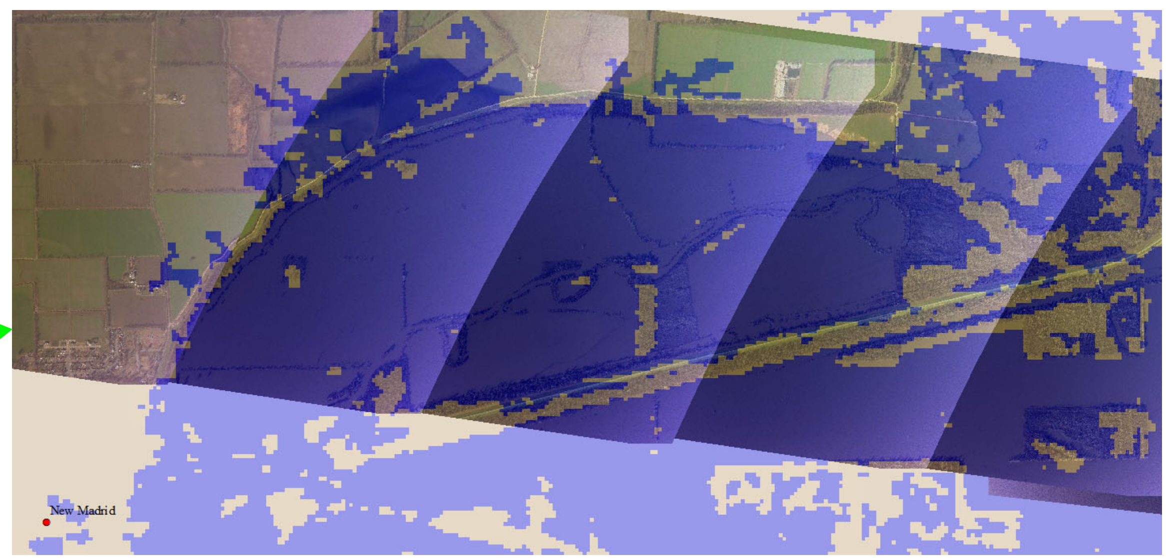




VIISR 375-m flood map



Aerial photo on Jan. 02, 2016 near New Madrid

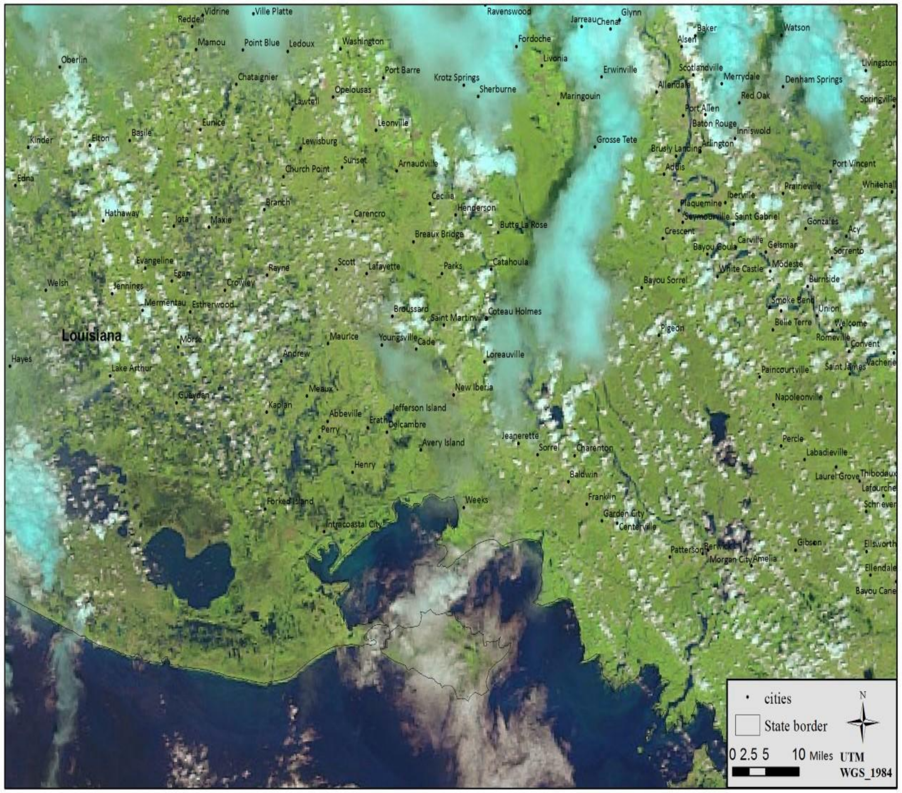


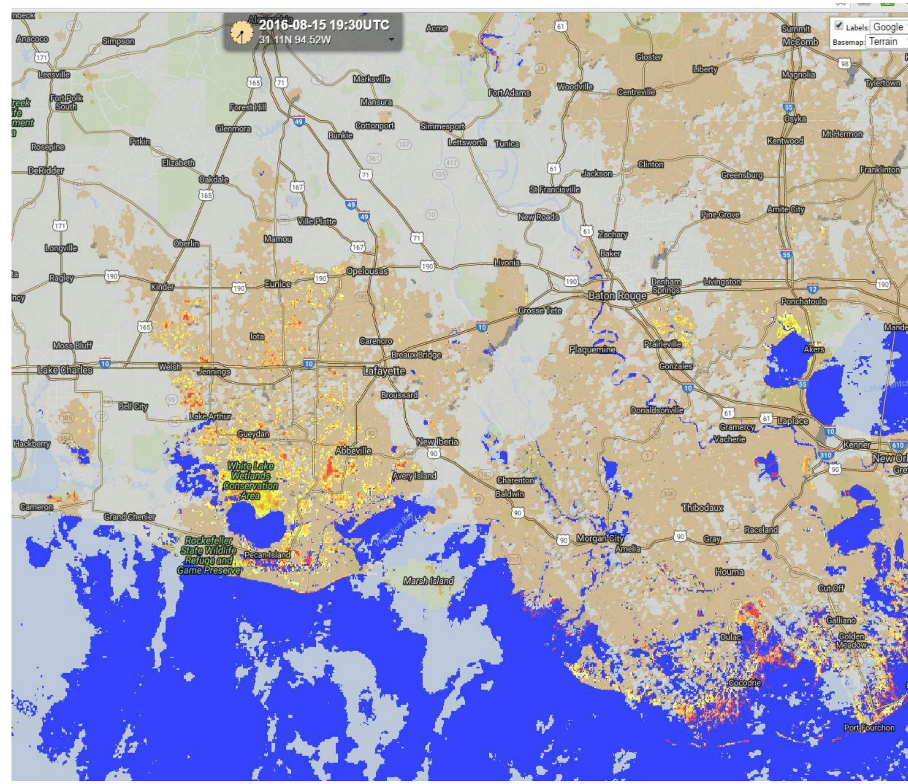
VIIRS 30-m flood map on Jan. 01, 2016 (overlapping on the top aerial image, light purple is flood water)

APPLICATION: SEVERE FLOODING IN LOUISIANA IN AUGUST 2016

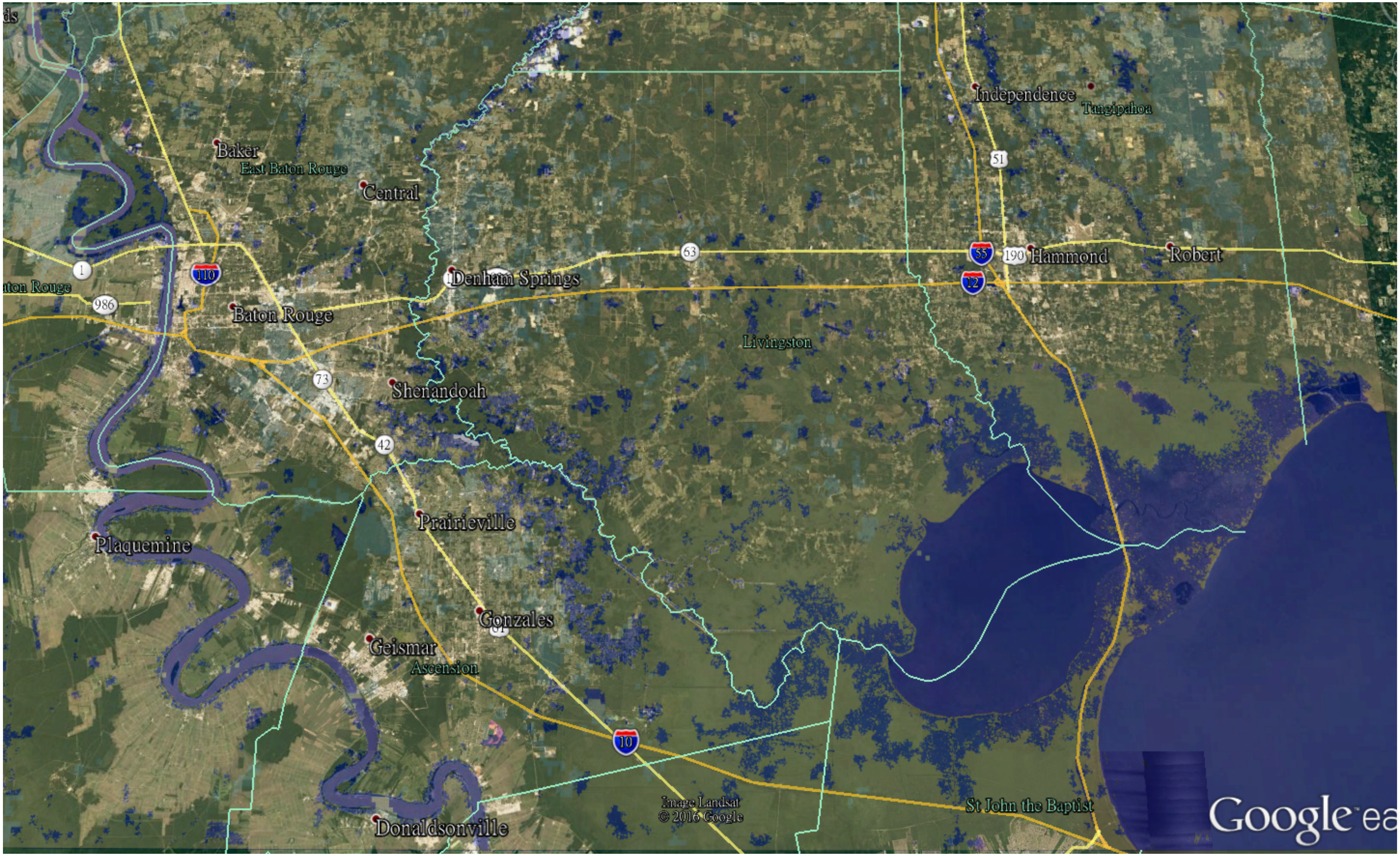
In August 2016, a slow moving low pressure system combined with copious amounts of tropical moisture led to very heavy rainfall and significant flooding over portions of the central Gulf Coast region. On August 11, a mesoscale convective system flared up in southern Louisiana and remained nearly stationary, and as a result, torrential downpours occurred in the areas surrounding Baton Rouge and Lafayette. Prolonged rainfall in southern Louisiana resulted in catastrophic flooding that submerged thousands of houses and businesses. Louisiana's governor, John Bel Edwards, called the disaster a "historic, unprecedented flooding event" and declared a state of emergency. The flood has been called the worst US natural disaster since Hurricane Sandy in 2012. It was thought over 40,000 homes were damaged in Louisiana. Thirteen people have been confirmed dead because of the flooding.

SNPP/VIIRS false-color image in southern Louisiana August 15, 2016 19:28 (UTC)

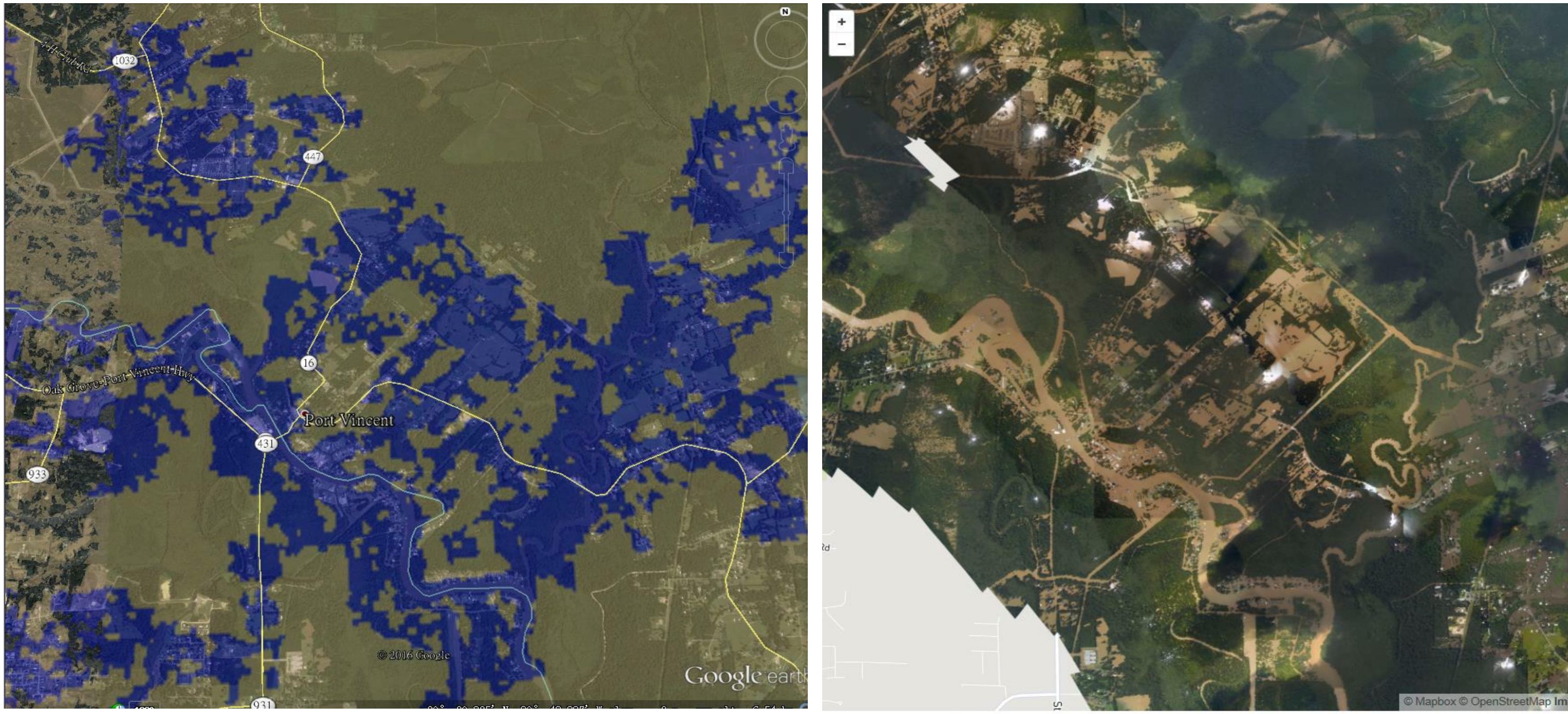




The Visible Infrared Imaging Radiometer Suite (VIIRS) onboard the NPP satellite captured the false color image (left), and the flood map derived from VIIRS on August 15, 2016 (right).



An Overview of flooding water near Baton Rouge using VIIRS 30-m flood map composited from August 15 and August 17, 2016. Light purple is water.



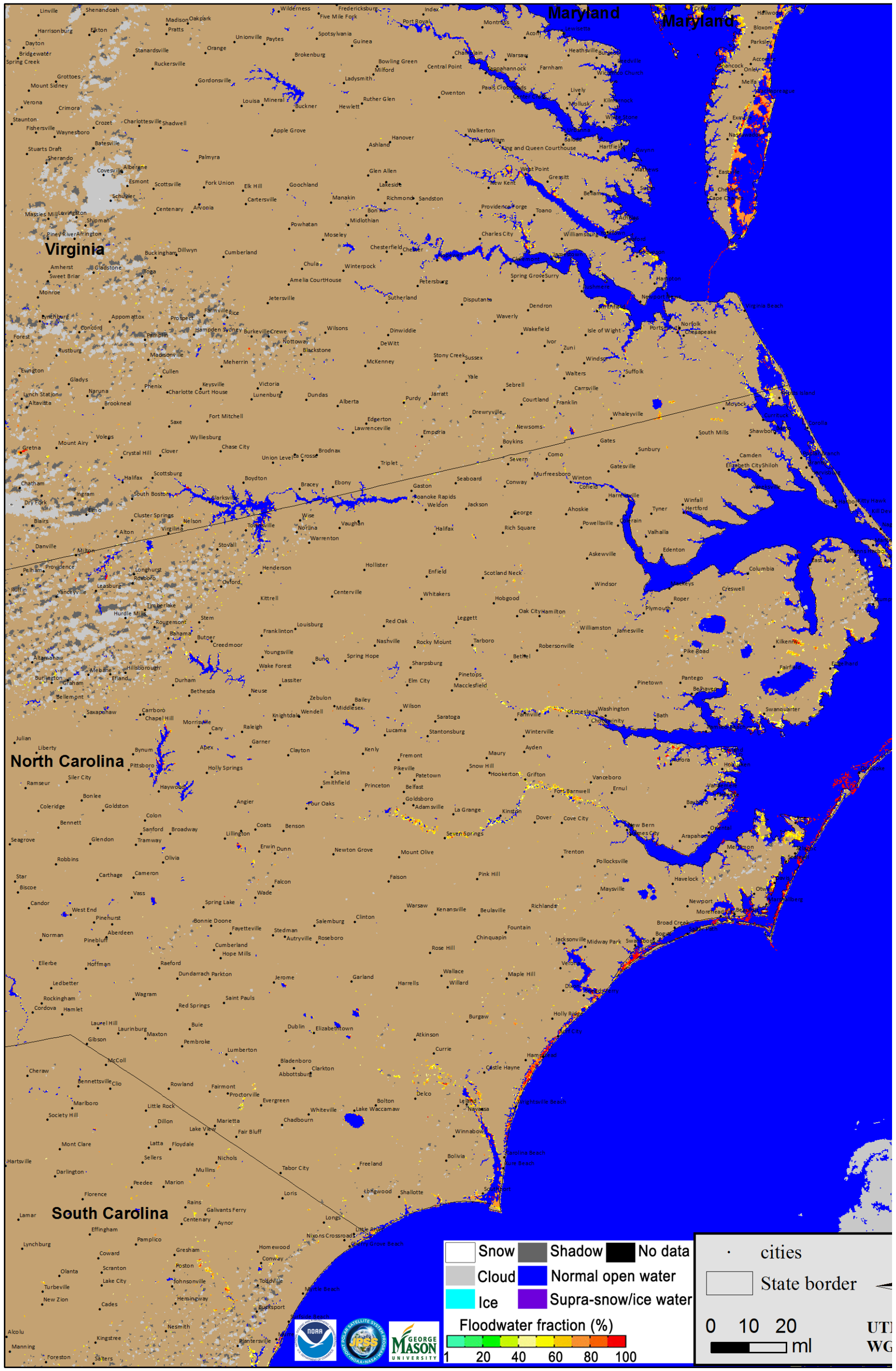
VIIRS downscaled 30-m flood map composited from results on August 15 and August 17, 2016 (left). Compared with the aerial images taken on August 15, 2016 (right). Image courtesy: NOAA Remote Sensing Division

Application: Flood due to Hurricane Mathew

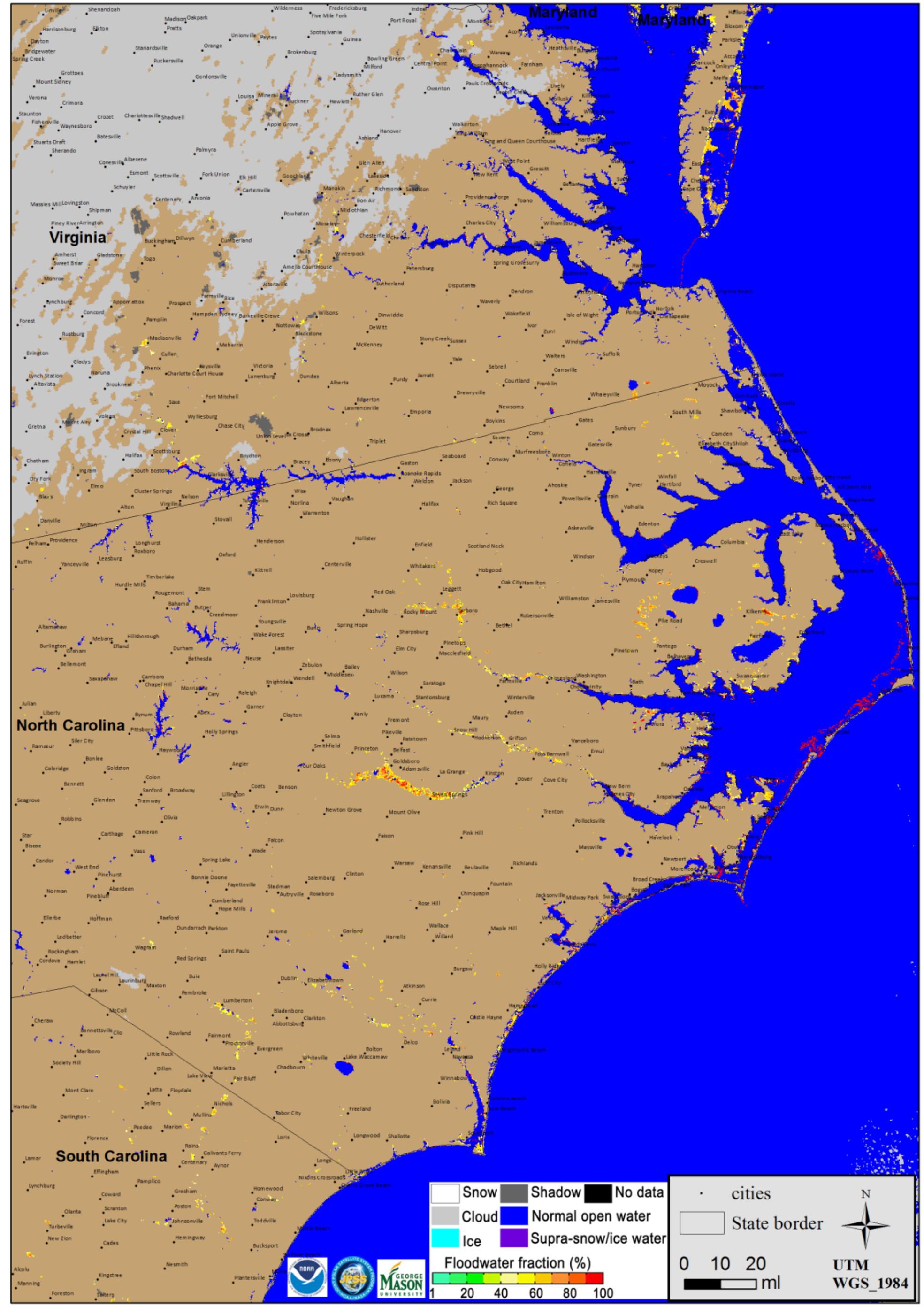
Hurricane Mathew has killed 46 people in the US, including 26 in North Carolina, 12 in Florida, 3 in Georgia, 4 in South Carolina, and 1 in Virginia.[102][129] Early estimates indicate total economic losses of at least US $4–6 billion in the southeastern United States, prior to the widespread flooding in North Carolina.[130]

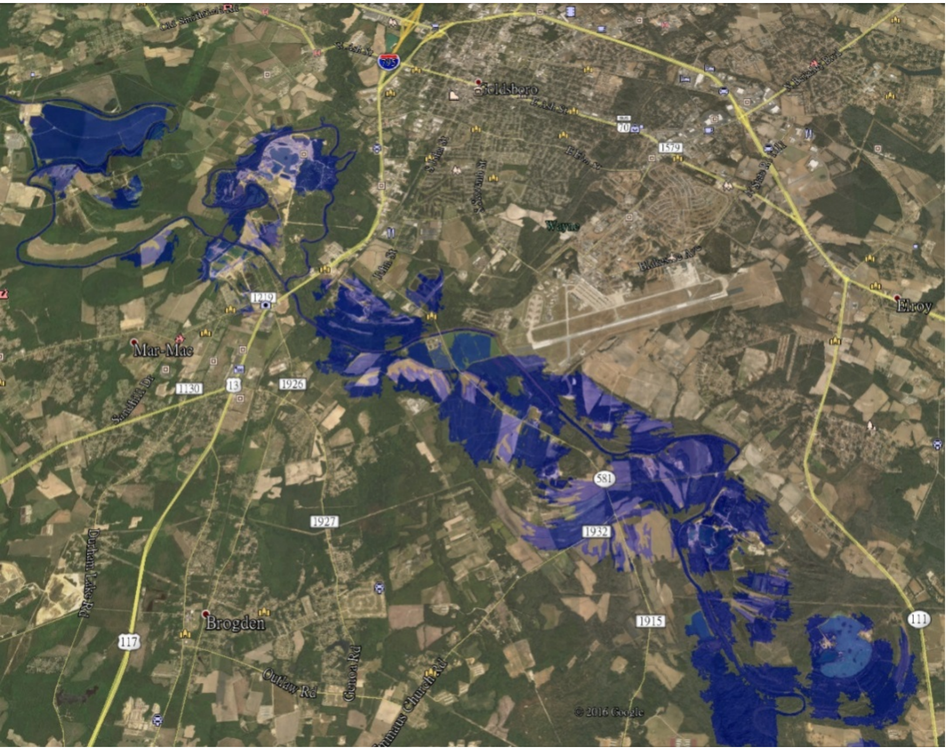
Sections of Interstate 95 in South Carolina and in North Carolina had to be shut down as a result of hurricane flooding.[144] After 10 in (25 cm) of rain fell in the Lumberton area on September 28 causing flooding, Matthew dumped another 10 in (25 cm) to 14 in (36 cm),[146] and as a result the Lumber River reached a record 24 ft (7.3 m) in the south end of Lumberton, breaking the record of 20.5 ft (6.2 m) feet.[147] In Kinston, the Neuse River crested at 28.31 ft (8.63 m), a foot higher than the record set byHurricane Floyd.[148] Preliminary estimates indicate that roughly 100,000 structures were flooded across the state and damage reached US $1.5 billion.[150]

SNPP/VIIRS Automatic Flood Detection Map 17 Oct. 2016 18:04(UTC)

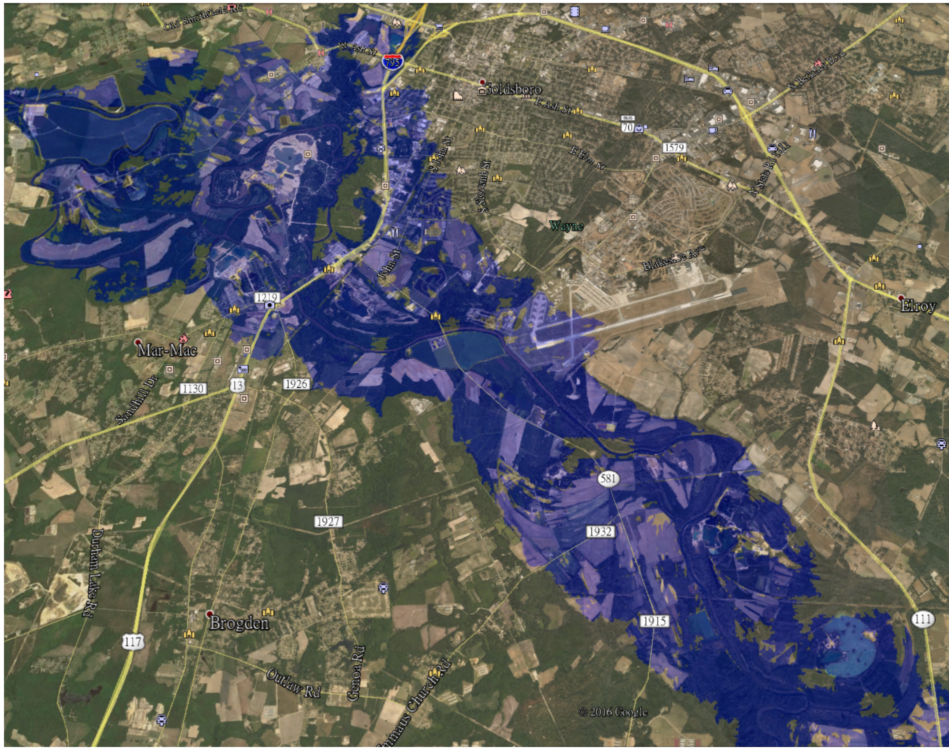


SNPP/VIIRS Automatic Flood Detection Map 13 Oct. 2016 17:37(UTC)



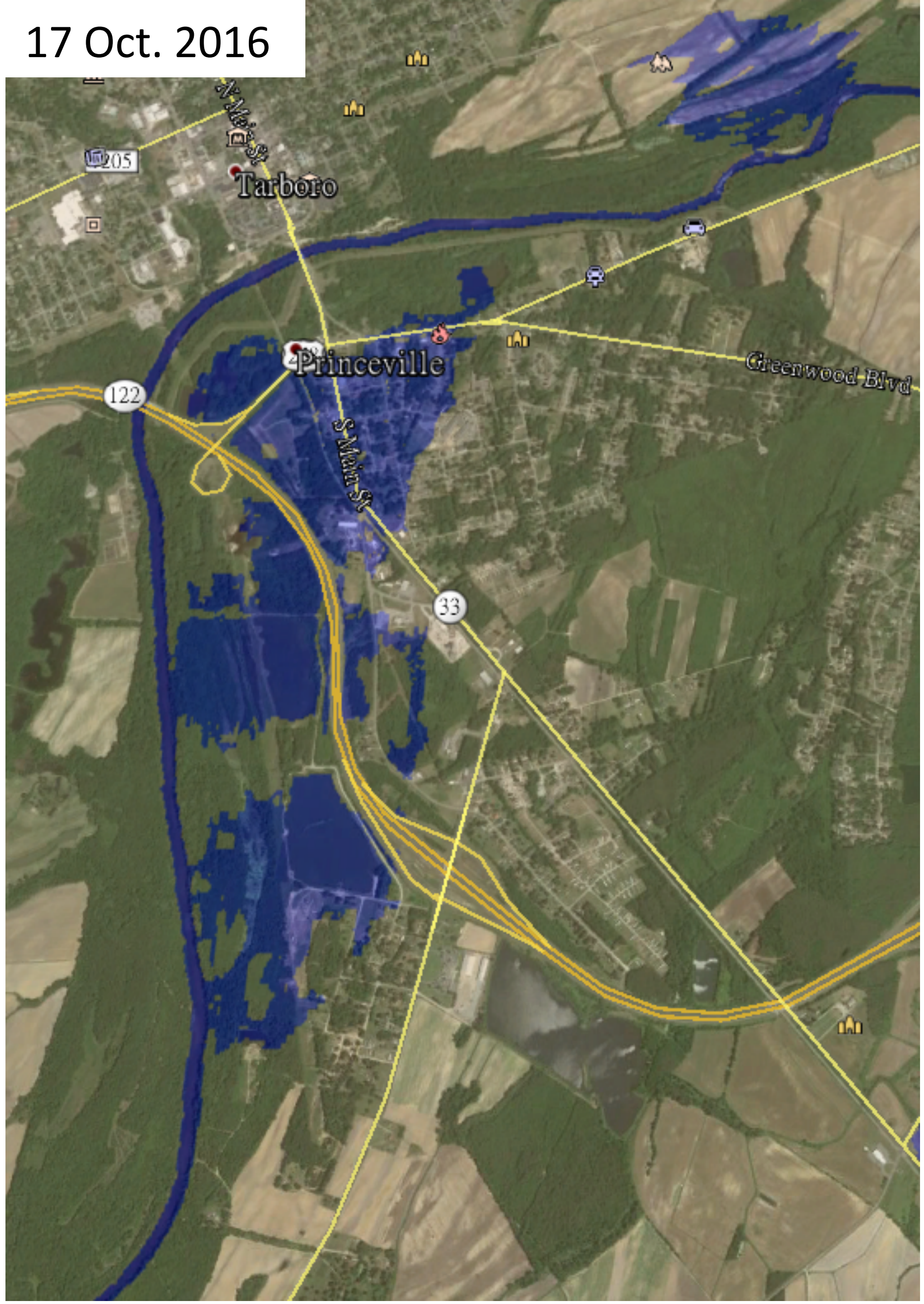


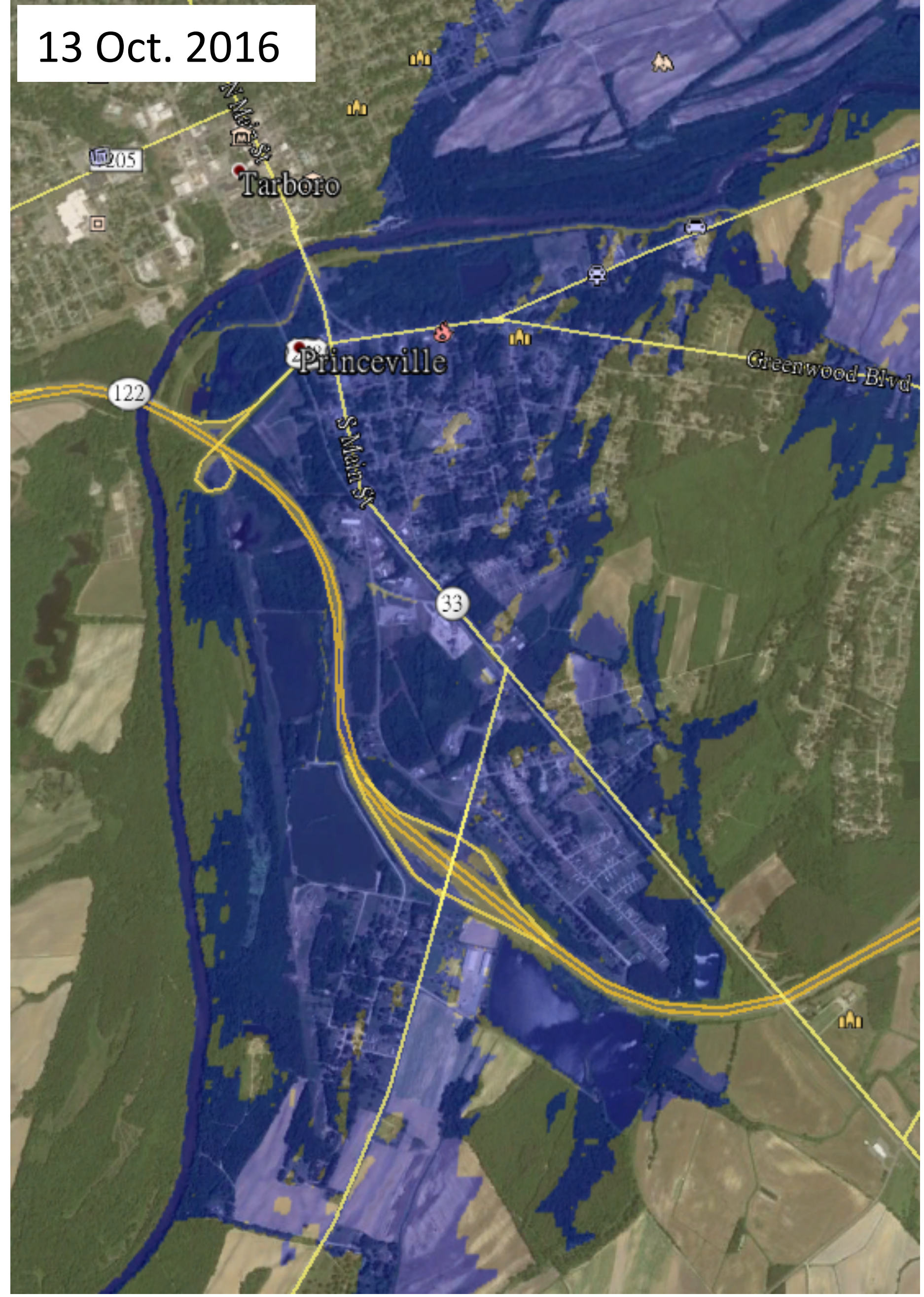
VIIRS downscaled 9-m flood map near Goldsboro, NC on 17 Oct. 2016



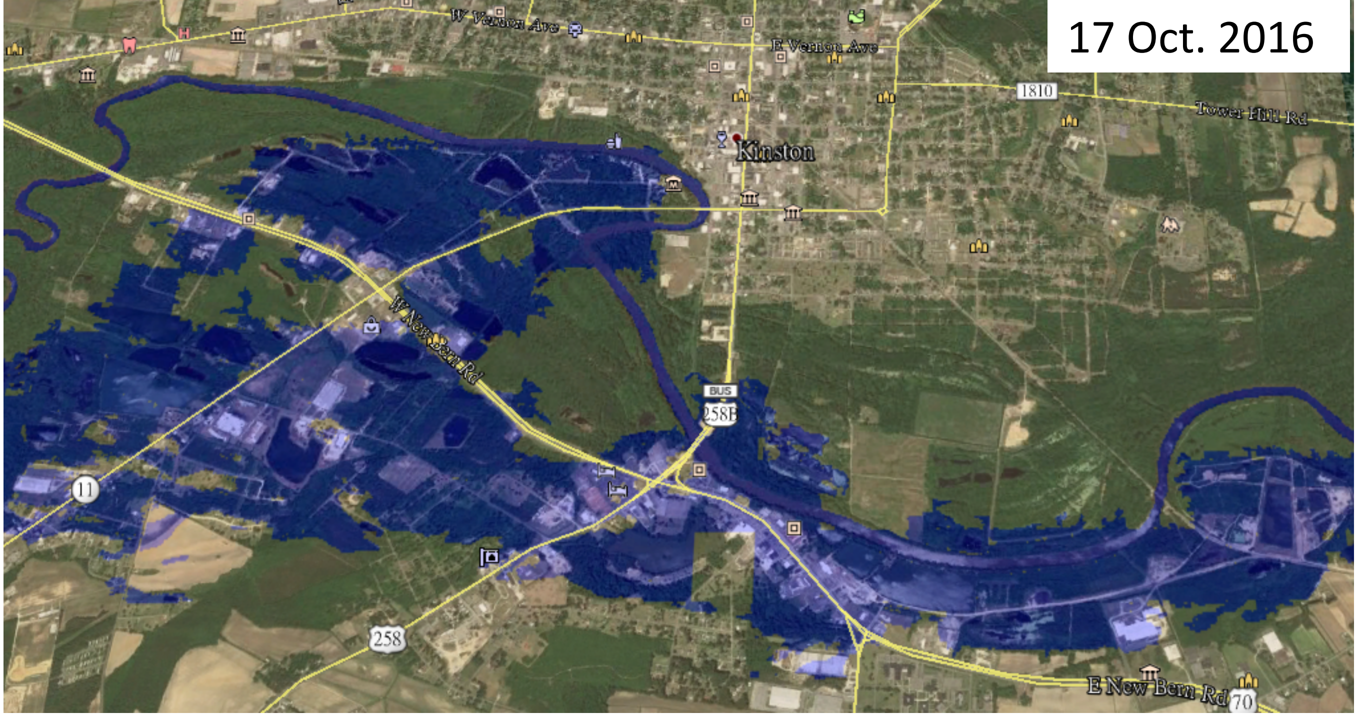
VIIRS downscaled 9-m flood map near Goldsboro, NC on 13 Oct. 2016

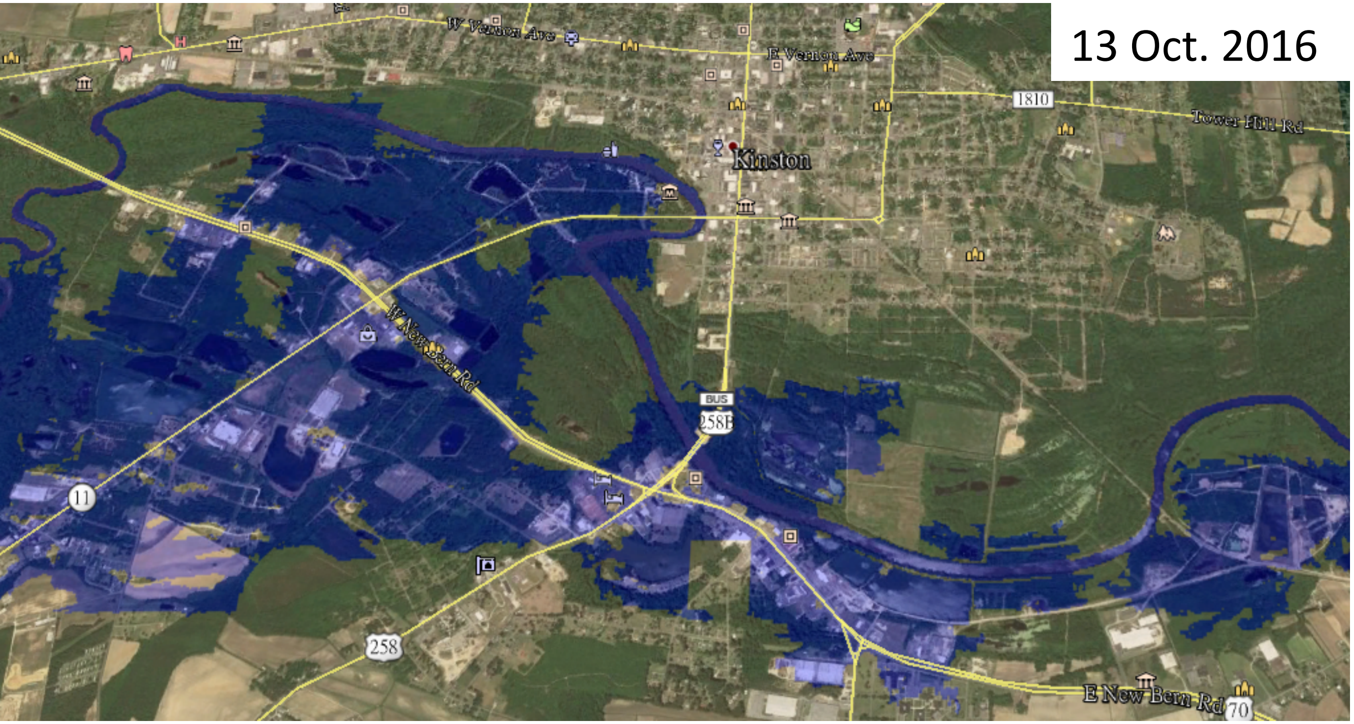
Flooding water along the Neuse River near Goldsboro receded a lot comparing to the result on Oct. 13 2016.



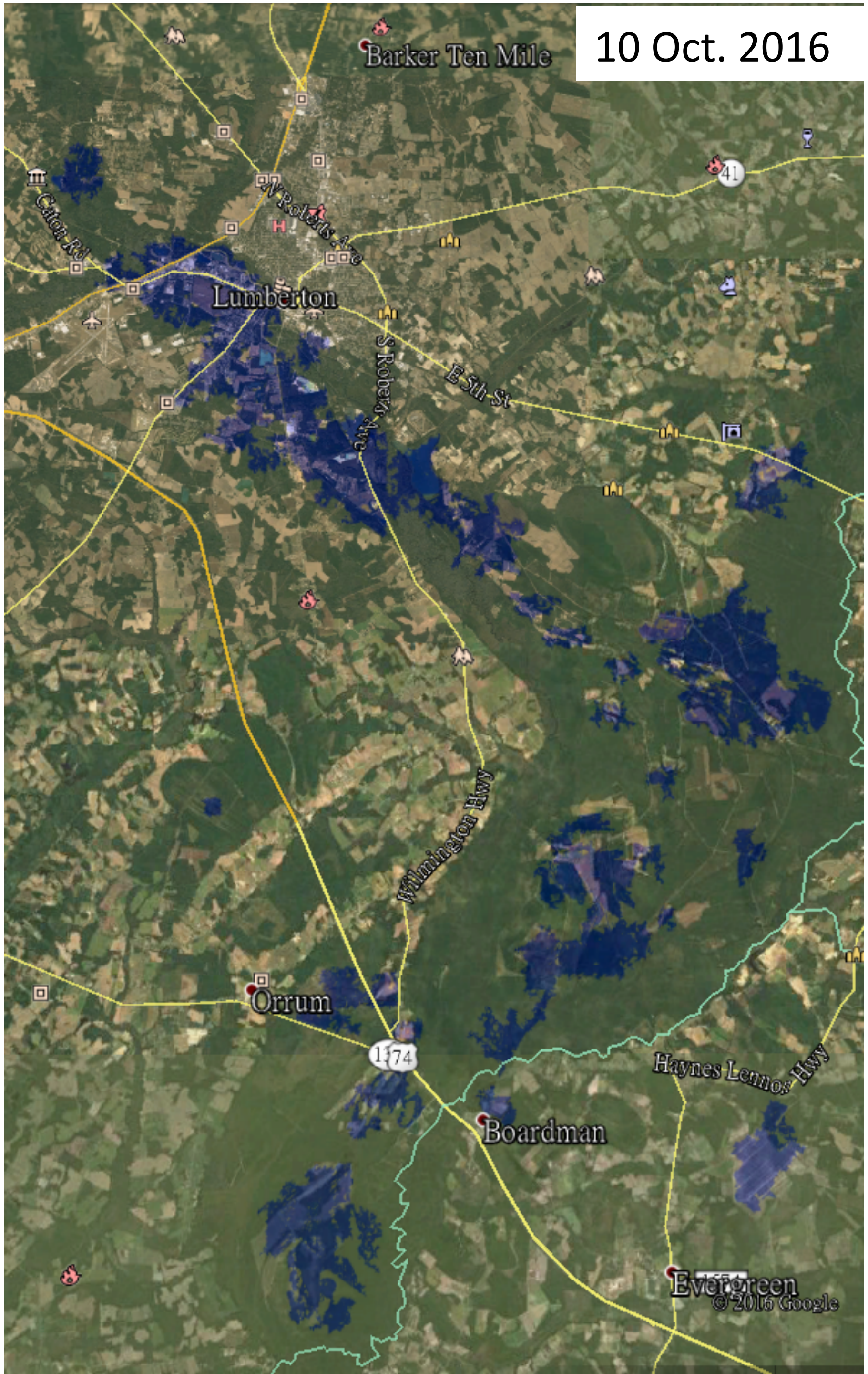


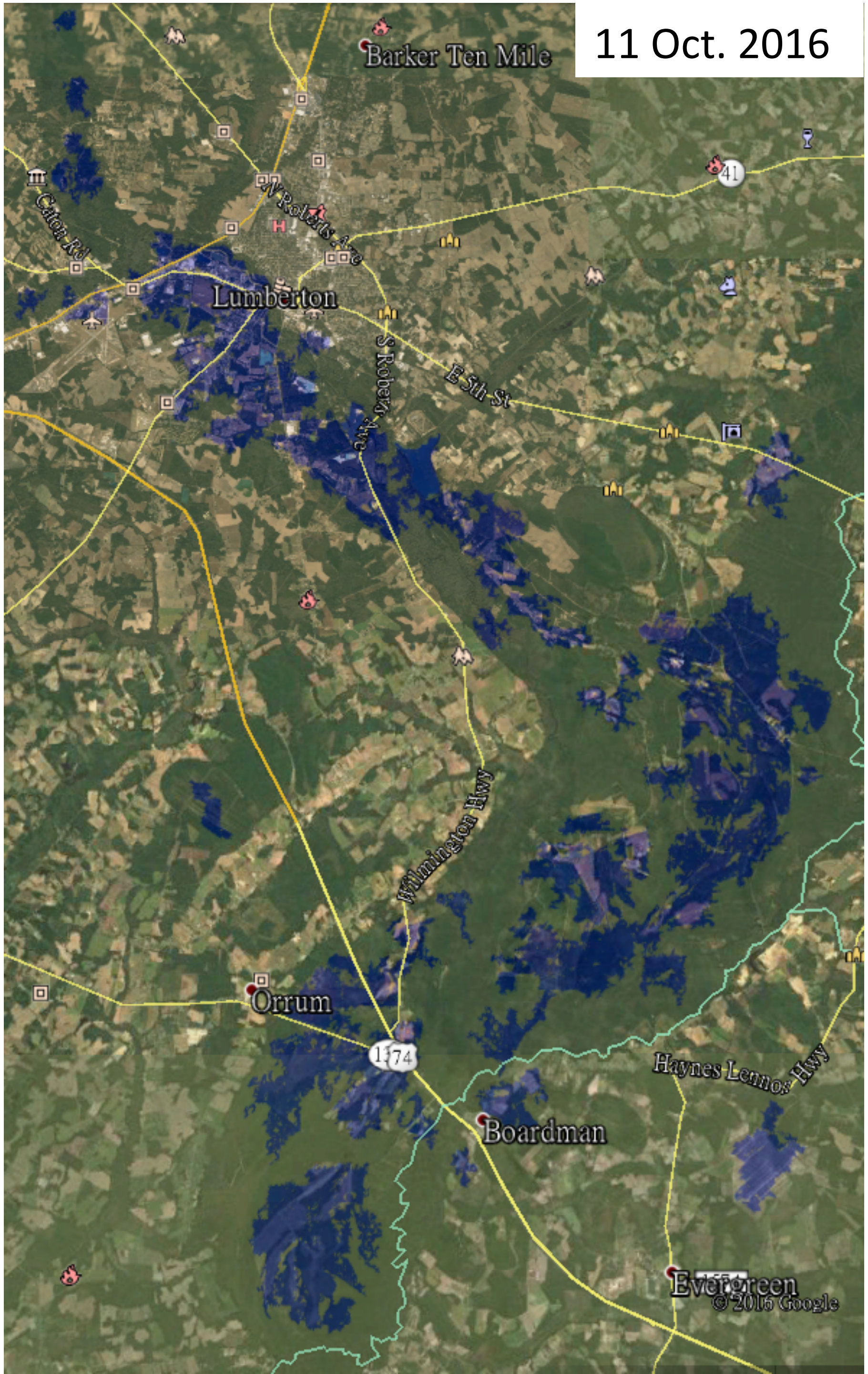
Some flooding water could be found in Princeville on Oct. 17th, but receded substantially comparing to 13 Oct. 2016.

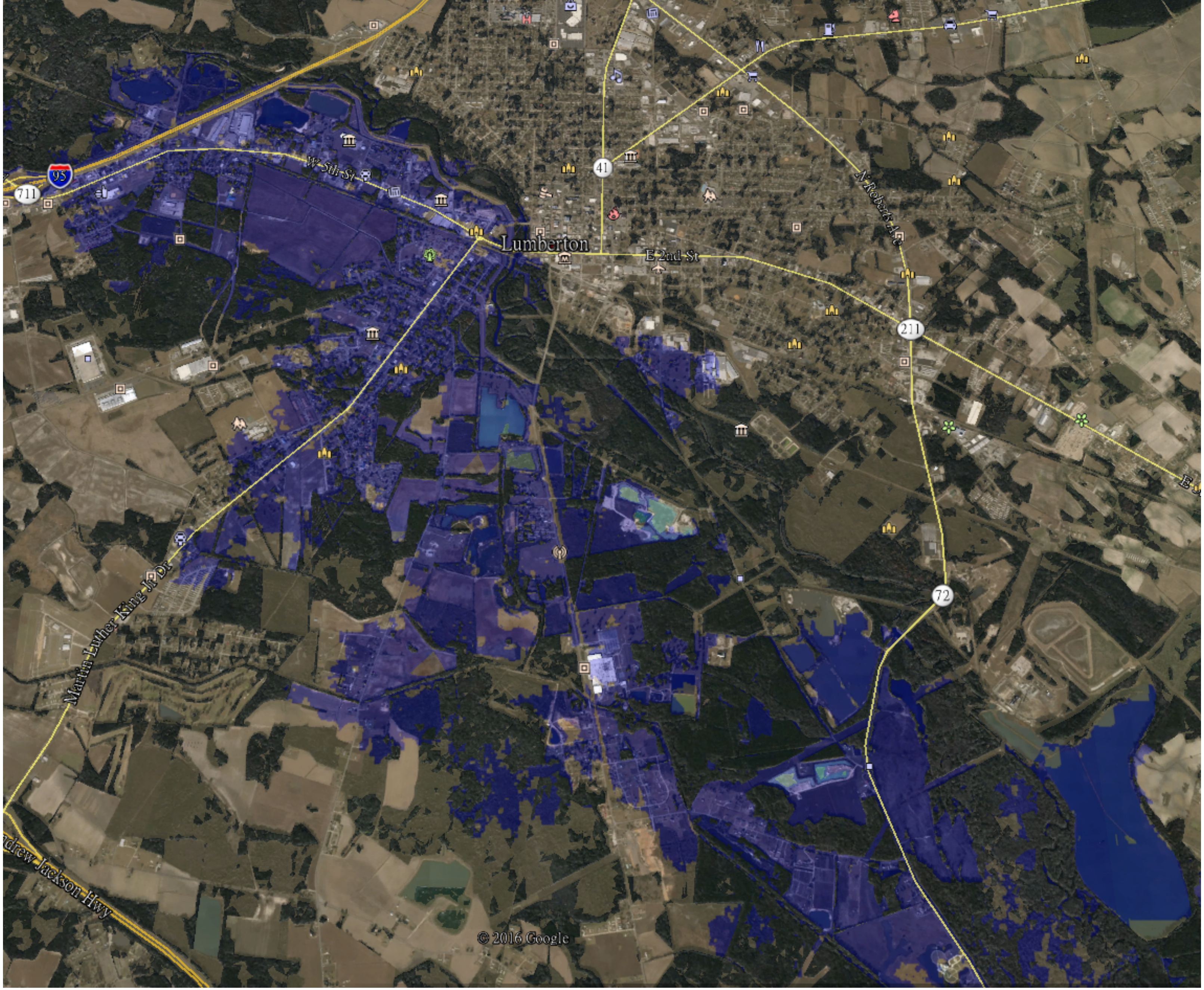




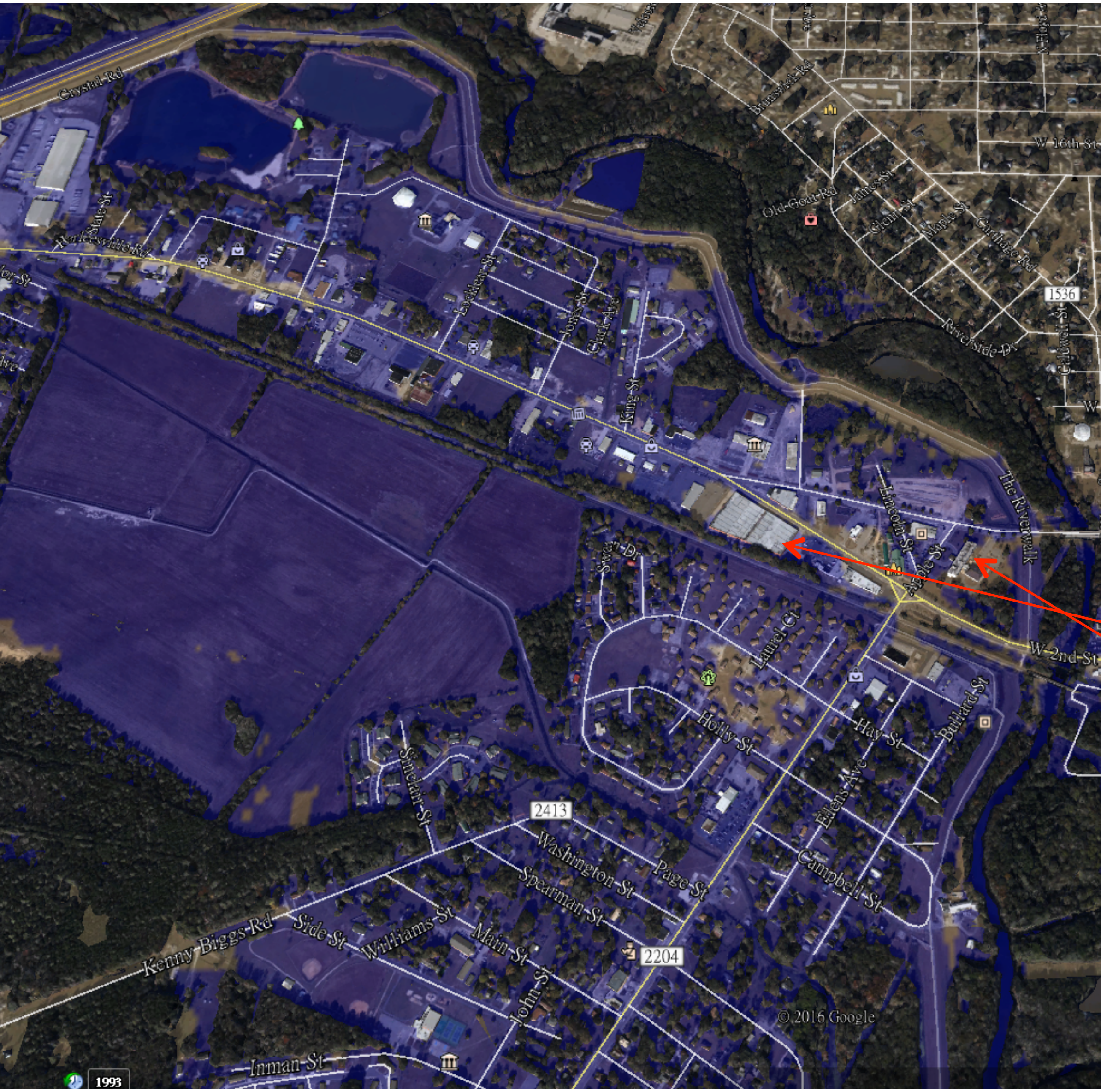
The Neuse River keeps large flooding water near Kinston, but receded a bit comparing to 13 Oct. 2016.


10 Oct. 2016
Barker Ten Mile
Lumberton
N Roberts Ave
S Roberts Ave
E 5th St
Caton Rd
Wilmington Hwy
Orrum
Boardman
Haynes Lennon Hwy
Evergreen
© 2016 Google


11 Oct. 2016
Barker Ten Mile
Lumberton
N Roberts Ave
S Roberts Ave
E 5th St
Caton Rd
Wilmington Hwy
Orrum
Boardman
Haynes Lennon Hwy
Evergreen
© 2016 Google



VIIRS downscaled 9-m flood map in Lumberton, NC on 10 Oct. 2016



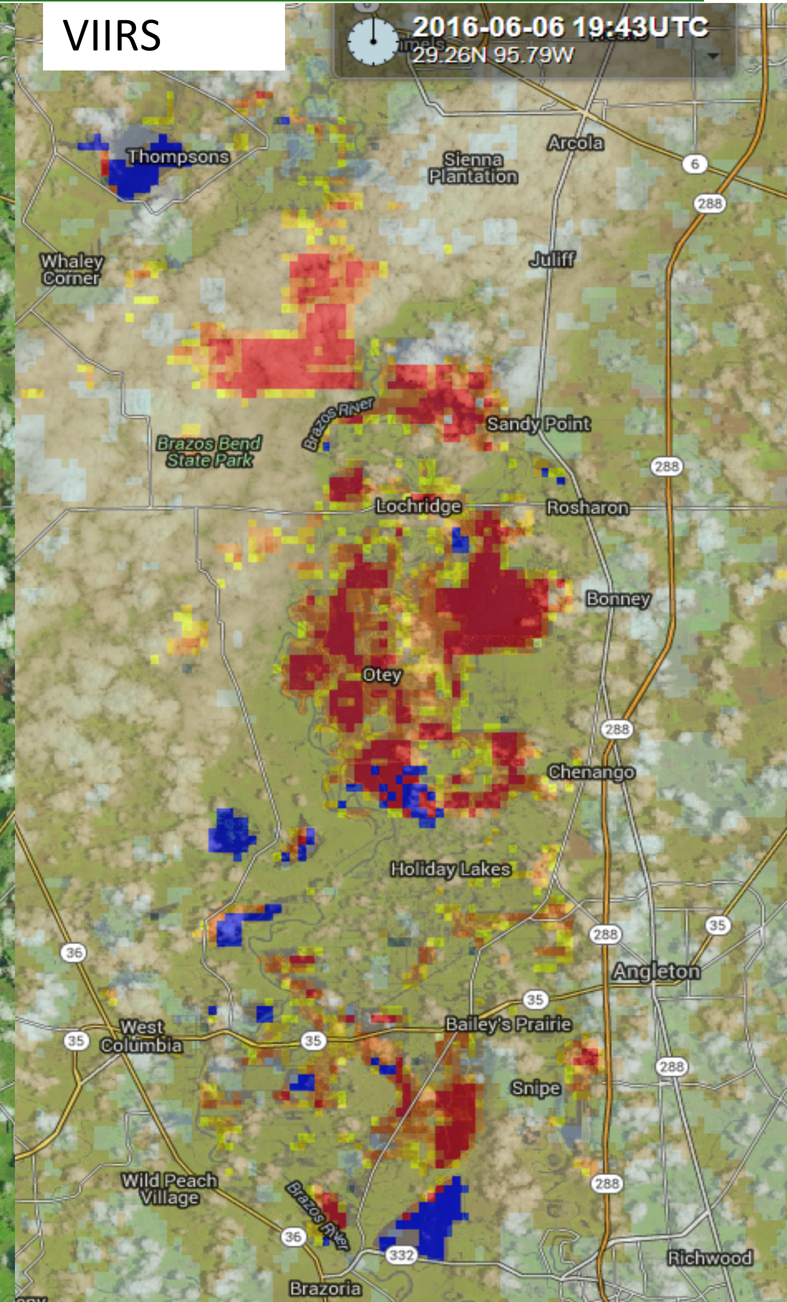
Days after Hurricane Matthew flooding is still at its peak. Along west 5th Street in Lumberton the flood waters stretch about 3 miles down the road. And in that three miles, hundreds of people's lives have been destroyed due to the waters.

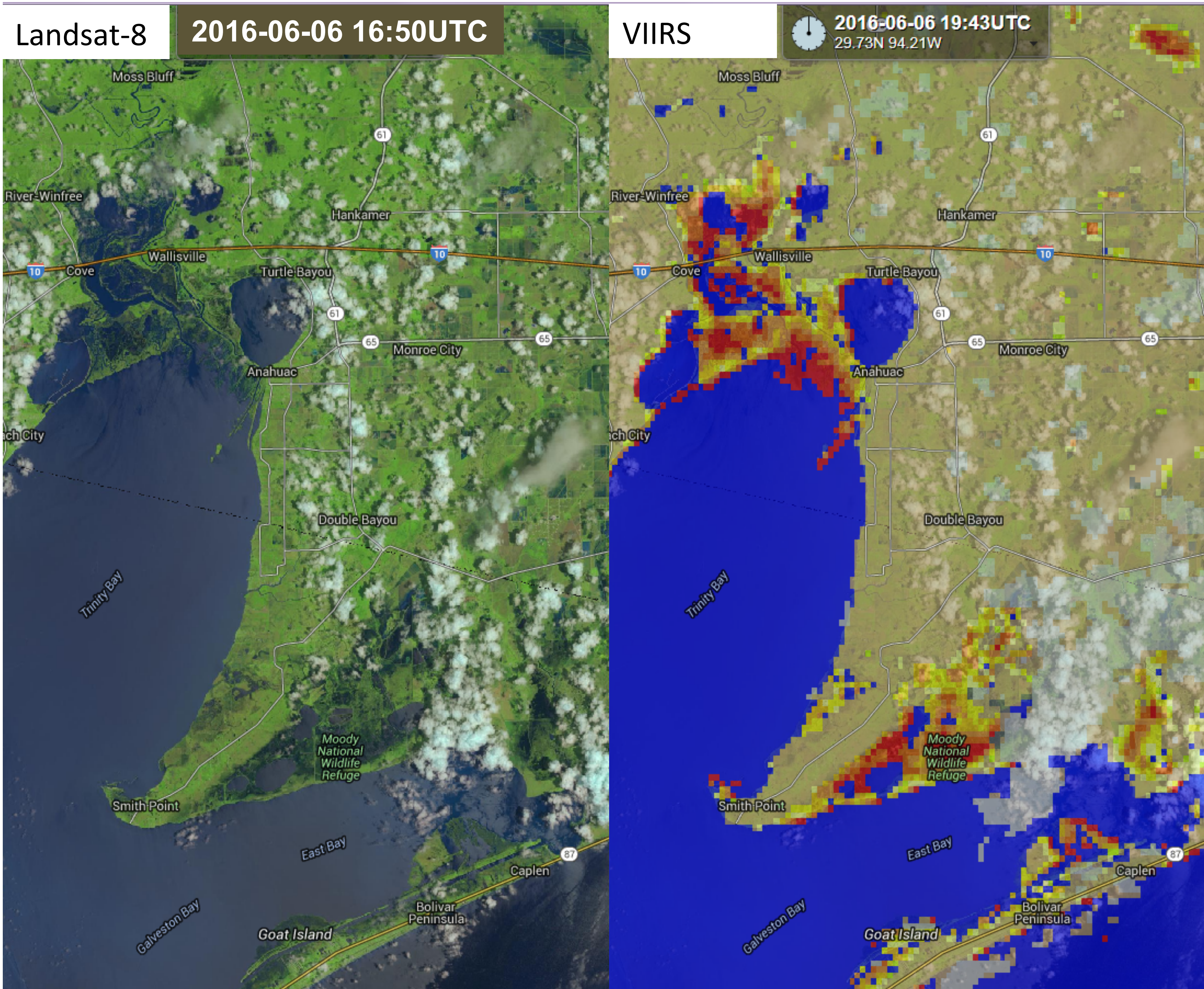
John Dzienny

This photo shot by a drone shows how widespread flooding is in Lumberton, North Carolina, on Wednesday, Oct. 12, 2016.

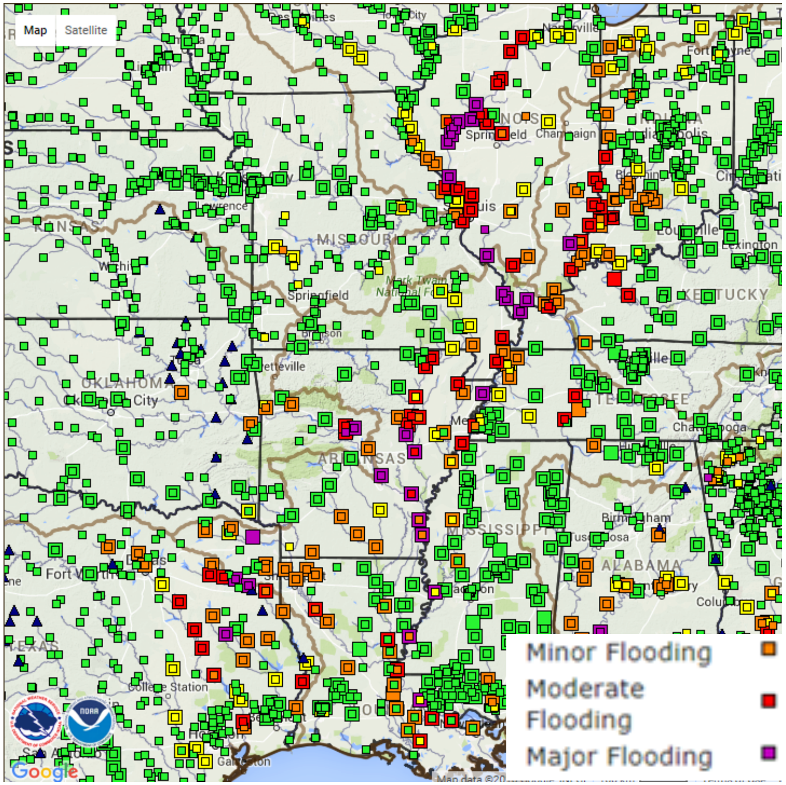
VIIRS downscaled 9-m flood map in Lumberton, NC on 10 Oct. 2016

Validations/Evaluations





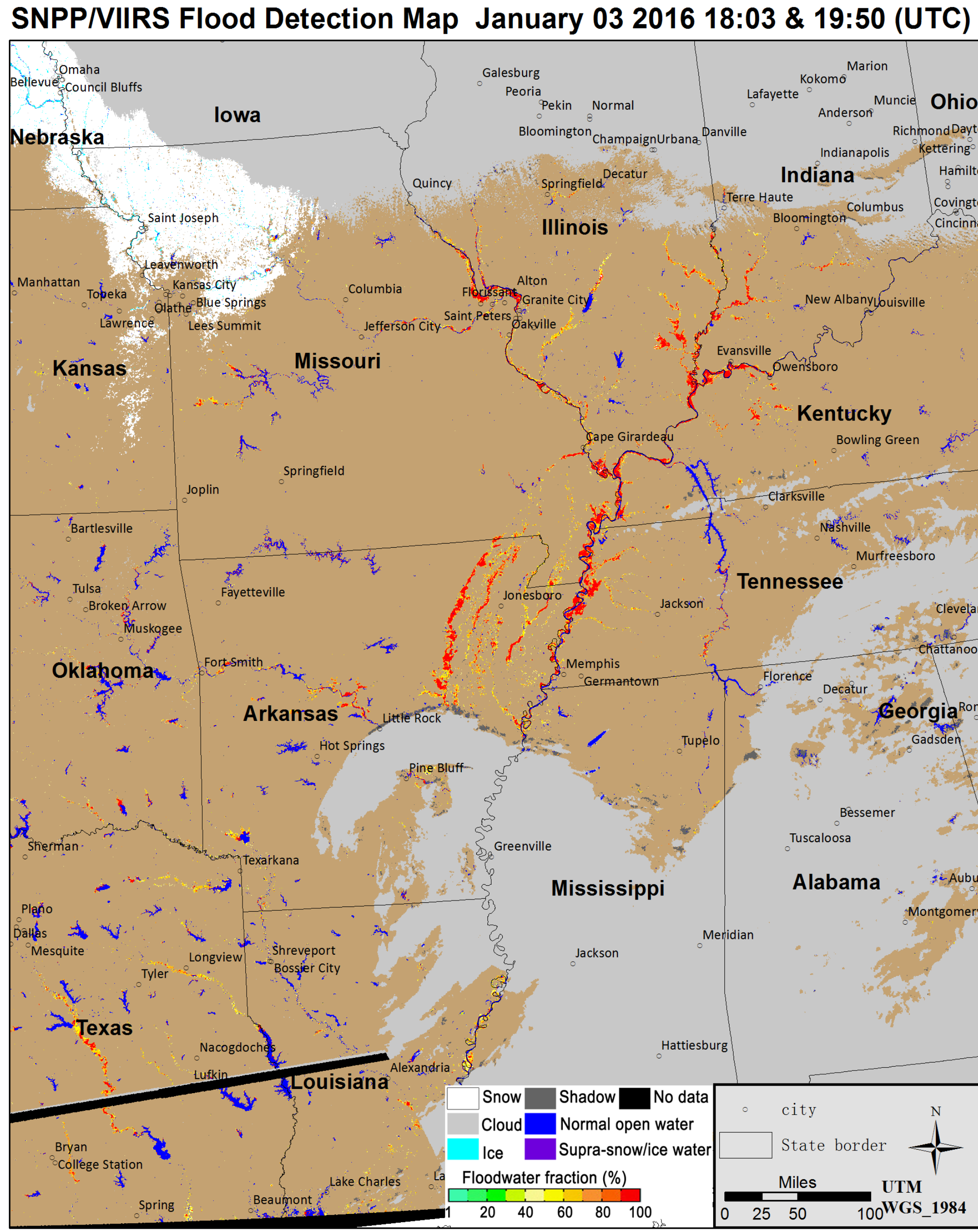
Landsat-8
2016-06-06 16:50UTC
VIIRS
2016-06-06 19:43UTC
29.73N 94.21W
Moss Bluff
River-Winfree
Hankamer
Wallisville
Cove
Turtle Bayou
Monroe City
Anahuac
Double Bayou
Trinity Bay
Moody National Wildlife Refuge
Smith Point
East Bay
Caplen
Bolivar Peninsula
Galveston Bay
Goat Island



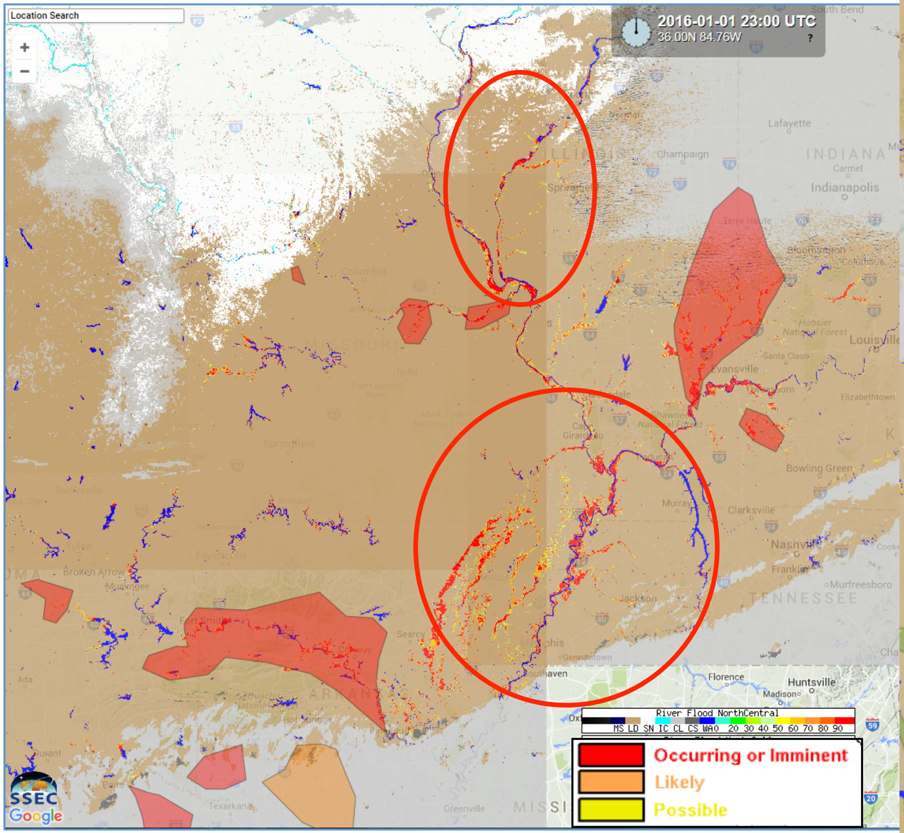
River gauge map on Jan. 03, 2016

Evaluations against river gauge observations.

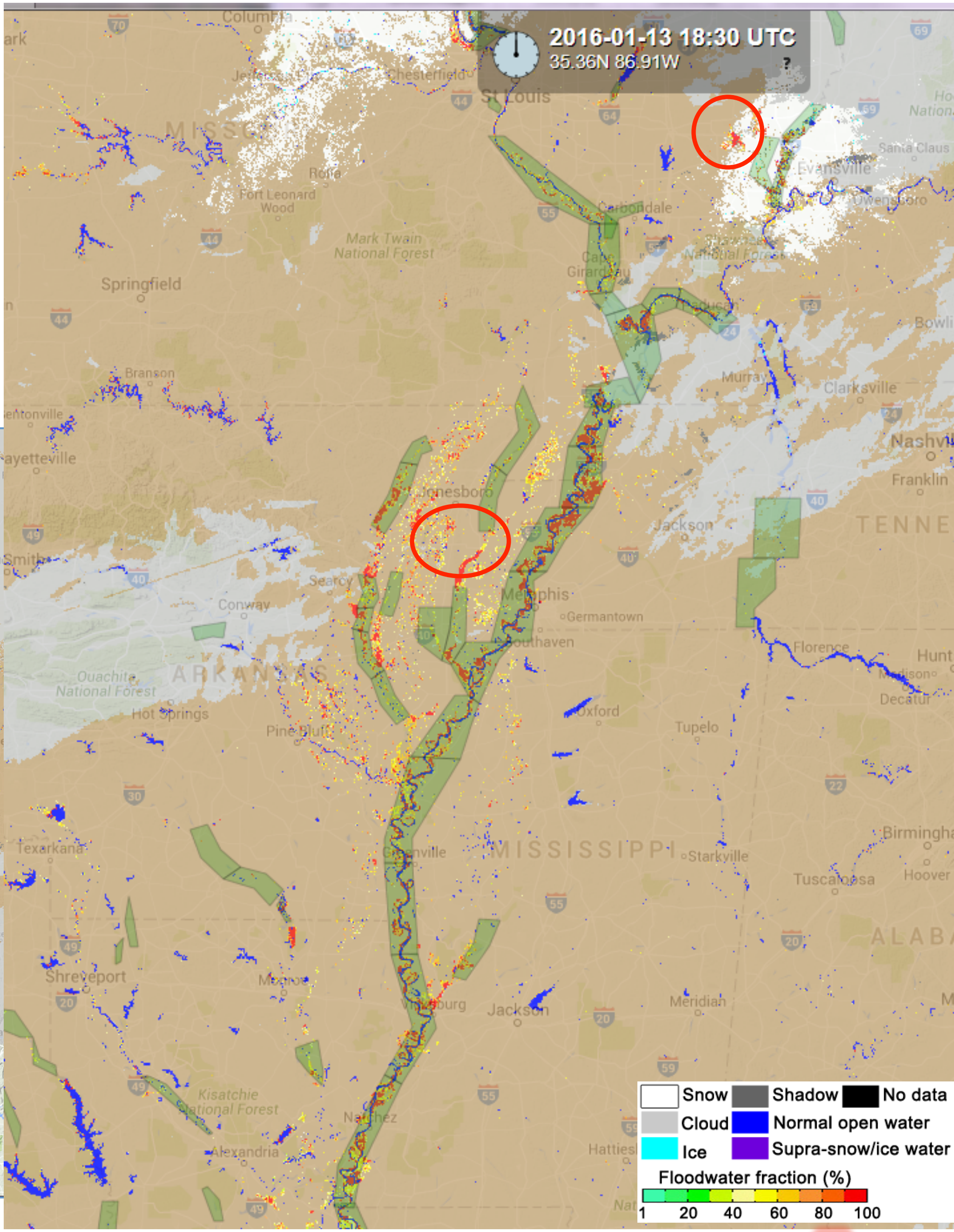
✓ VIIRS flood map can provide spatial flood extent not only showing flood locations but also showing what floods look like.



Evaluations against flood forecast models



Comparing with flood outlook product



Comparing with flood warning product

Discussions

- Cloud cover is the biggest limitation for flood detection using VIIRS imagery, which prevents continuous detection on flood water and causes latency to detect flood water from intensive rainfall.
  - ✓ The contradiction is: no clouds, no rainfall, and then no floods.

    Solution: microwave (ATMS) (Sun et al., 2015)
  - ✓ Latency may prevent the product from flood prediction, but is still okay for flood extent investigation and loss assessment.
- Multi-day composition from near real-time flood maps can obtain maximal flood extent during a flood event, and thus reduce the impact from cloud cover.

Summary

- We have solved the critical issues, like cloud shadow and terrain shade problems, and made near real time flood products become possible.
- The high temporal and wide coverage of environmental satellites, including meteorological satellites like NPP/JPSS, made them attractive for disaster monitoring and detection, but their moderate spatial resolution may limit their wide applications. We developed downscale model and enhanced the capability of these moderate-to-course resolution sensors.
- Meanwhile, our model made 3-D flood products including flood water surface level, flood water depth, and high resolution flood maps become possible.

Reference

- Sun, D., Y. Yu, and M. D. Goldberg (2011). Deriving water fraction and flood maps from MODIS images using a decision tree approach. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*. **4** (4), 814 – 825.
- Sun, D., Y. Yu, R. Zhang, S. Li, and M. D. Goldberg (2012). Towards Operational Automatic Flood Detection Using EOS/MODIS data. *Photogrammetric Engineering & Remote Sensing*, **78** (6).
- Li, S., D. Sun, Y. Yu, I. Csiszar, A. Stefanidis, and M. D. Goldberg (2012). A New Shortwave Infrared (SWIR) Method for Quantitative Water Fraction Derivation and Evaluation with EOS/MODIS and Landsat/TM data. *IEEE Transactions on Geoscience and Remote Sensing*, **51** (3).
- Li, S., D. Sun, M. Goldberg and A. Stefanidis (2013). Derivation of 30-m-resolution Water Maps from TERRA/MODIS and SRTM. *Remote Sensing of Environment,* **134**, 417–430.
- Li, S., D. Sun and Y. Yu (2013). Automatic cloud-shadow removal from flood/standing water maps using MSG/SEVIRI imagery, *International Journal of Remote Sensing*, **34**(15), 5487-5502
- Sun D., S. Li · W. Zheng · A. Croitoru · A. Stefanidis, and M. D. Goldberg, 2015: Mapping floods due to Hurricane Sandy using NPP VIIRS and ATMS data and geotagged Flickr imagery, *International Journal of Digital Earth*, 06/2015; DOI: 10.1080/17538947.2015.1040474.
- Li, S., D. Sun, M. Goldberg and B. Sjoberg (2015). Object-based automatic terrain shadow removal from SNPP/VIIRS flood maps, *International Journal of Remote Sensing*, **36** (21), 5504–5522.

Thanks!

•

Any Questions ?