
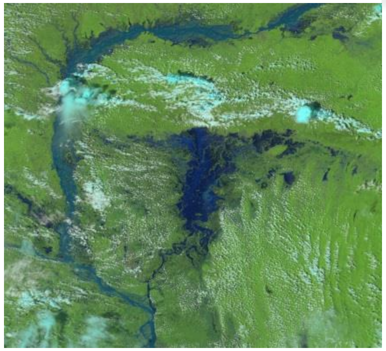
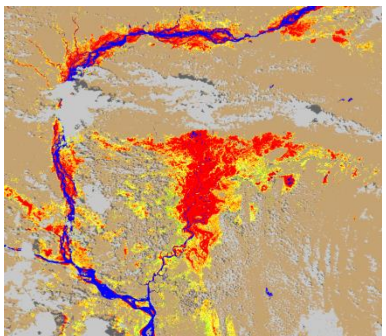

Automatic Near Real-time Flood Detection using SNPP/VIIRS Imagery

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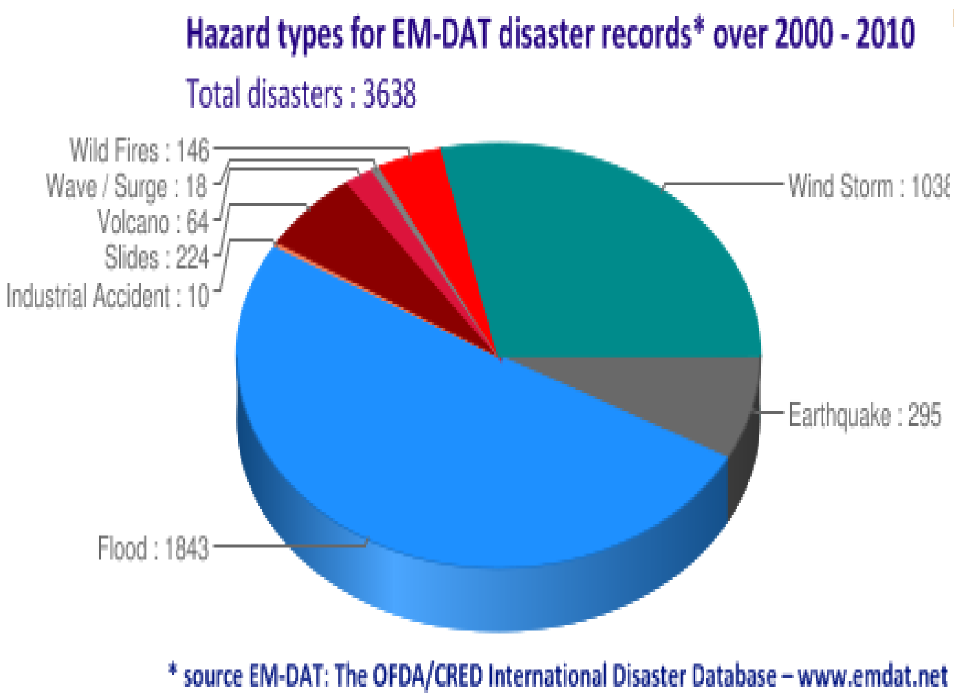
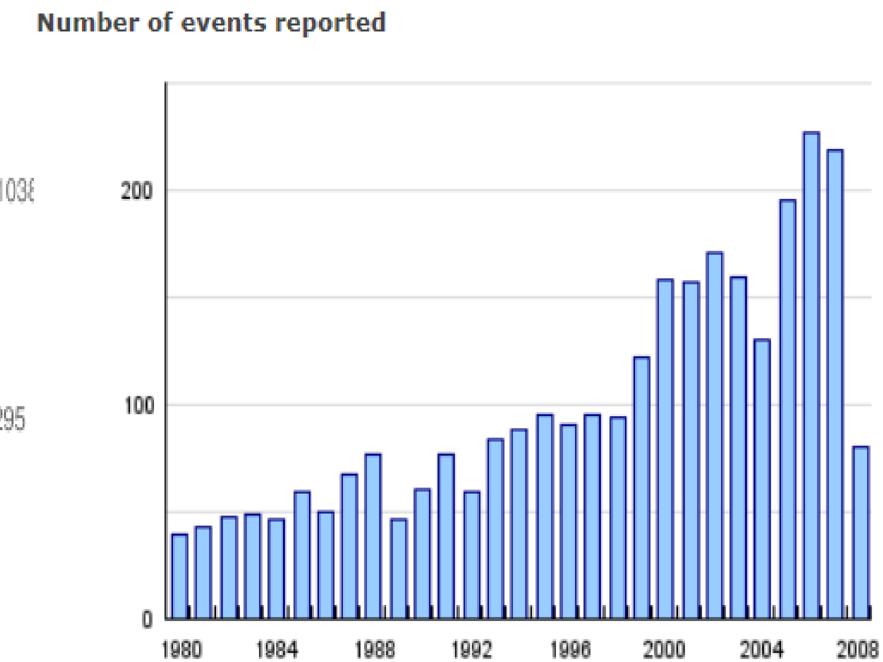
National Water Center, June 22, 2016

Outline

- Background (Why flood?)
- SNPP/VIIRS Flood Detection
  - Principles
  - Challenges & Solutions
  - Algorithm flow
- Evaluation & Application
- 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

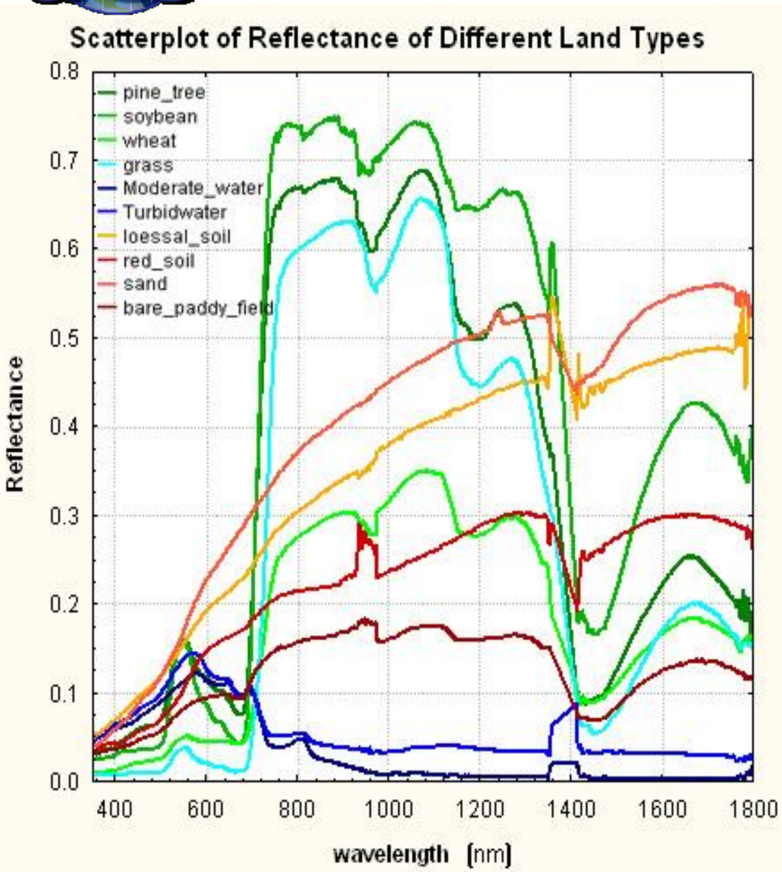
Galena, AK ice-jam flood in 2013: 90% buildings were destroyed.

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

Background

- Most floods occur with vegetation/bare soil underlying conditions--supra-veg/bare land floods.
- 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.

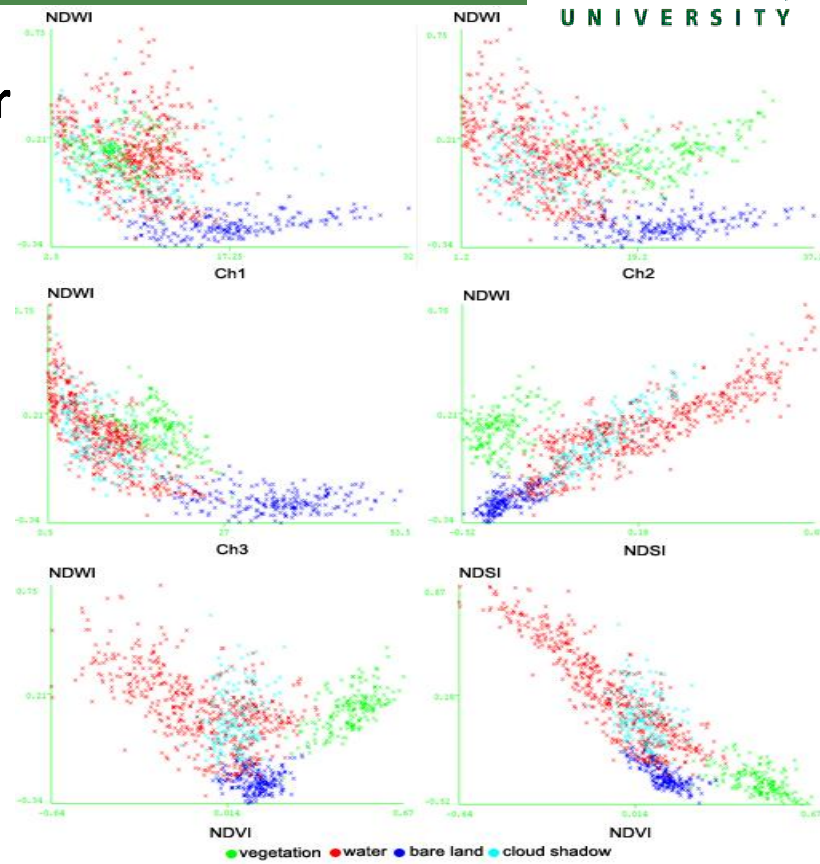
Principles - basic flood type



- Without contamination from sun glint, open water surface has higher reflectance in visible (VIS) (VIS) than in near-infrared (NIR) and short-wave infrared (SWIR) channels.
- Reflectance of clean water in SWIR channel is close to zero.
- Reflectance of water surface changes with suspending matter content: clean<moderate turbid<turbid<severe turbid.
- Most flood water is a mixture of open water and other land types such as vegetation, bare soils or snow/ice. Hence, reflectance of flood water is also a combination of open water and its mixture.

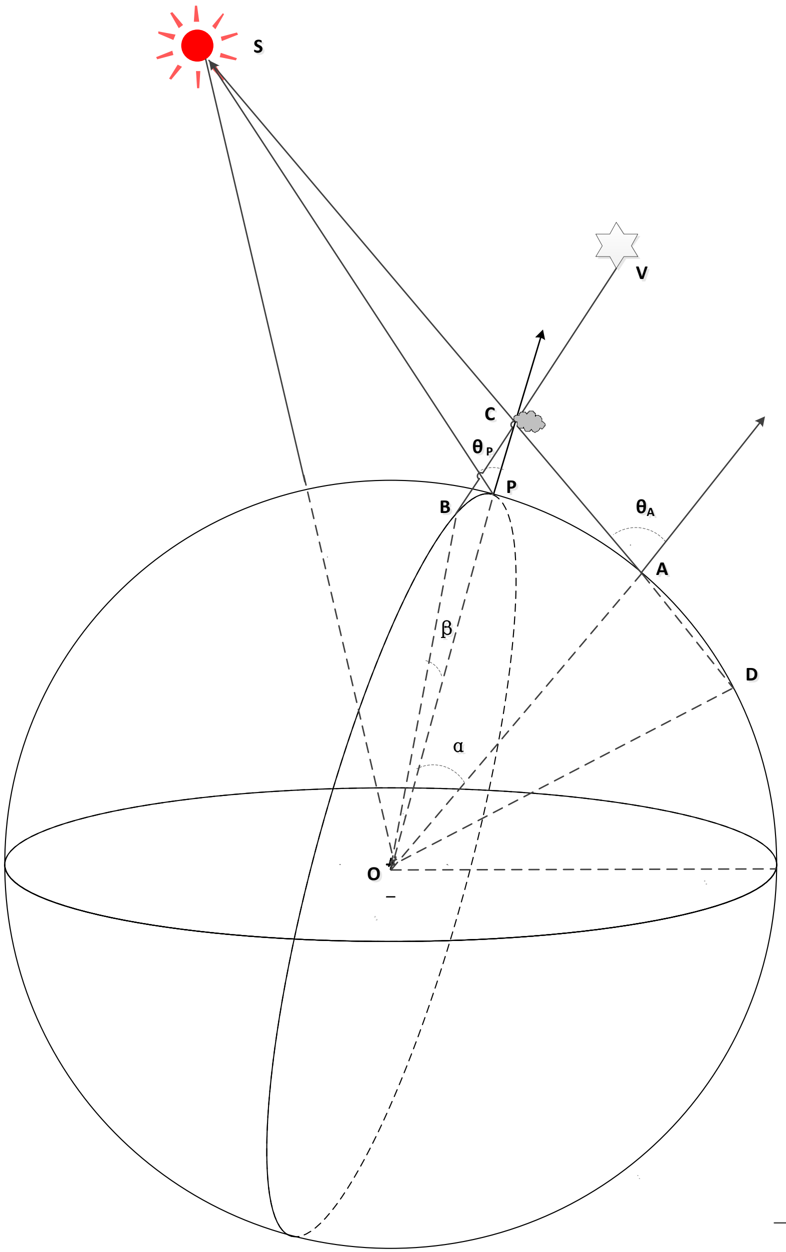
Challenges & Solutions

- **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.

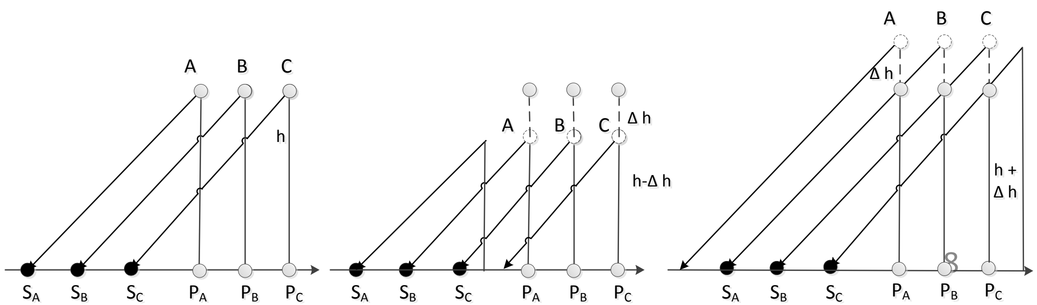


- **Solution:** post cloud shadow removal from water pixels based on geometry-based method (Li. et al., 2013).
  - ✓ Based on geometric relationship between cloud and cloud shadows over spherical surface
  - ✓ An iteration method is applied to decrease uncertainty of cloud heights

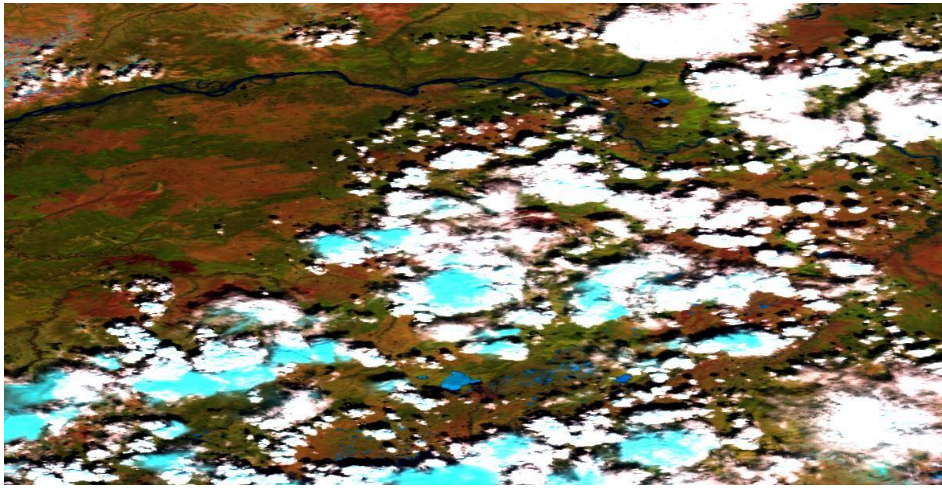
Challenges & Solutions



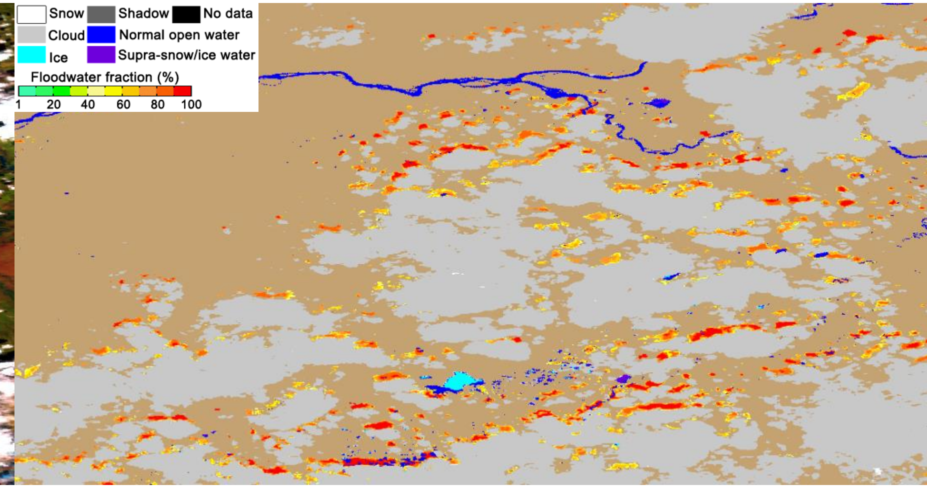
- Geometry-based method to remove cloud shadows from water pixels (Li. et al., 2013)
  - ✓ Based on geometric relationship between cloud and cloud shadows over spherical surface
  - ✓ An iteration method is applied to decrease uncertainty of cloud heights



Cloud Shadow Removal

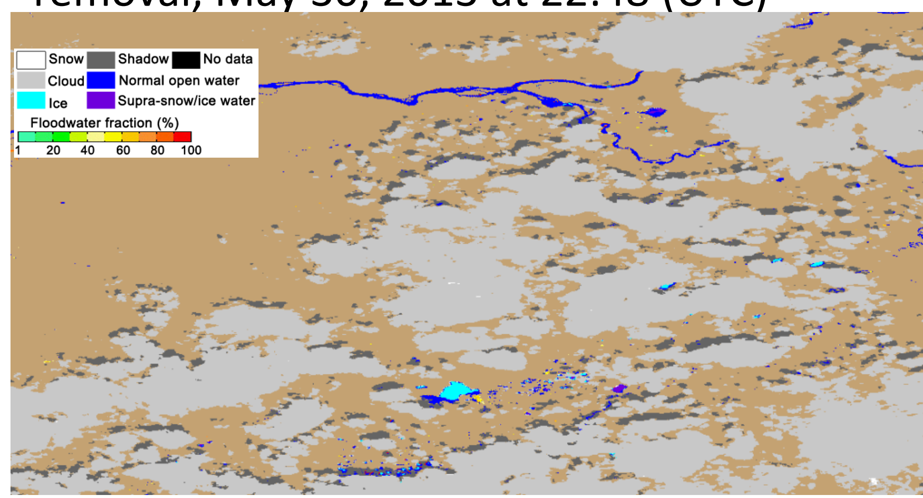


VIIRS false-color composited image, May 30, 2013 at 22:48 (UTC)



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

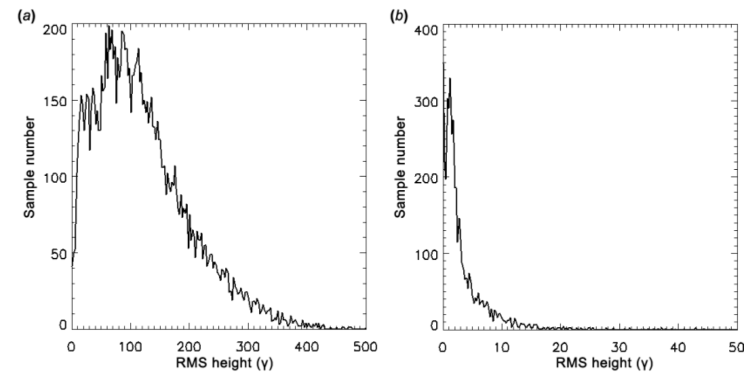
- In VIIRS false-color image (Top left), cloud shadows look very similar to open water and they are easily detected as flood water and further retrieved in large water fractions (Top right).
- After cloud shadow removal, these shadows are removed from VIIRS flood map (Bottom right).

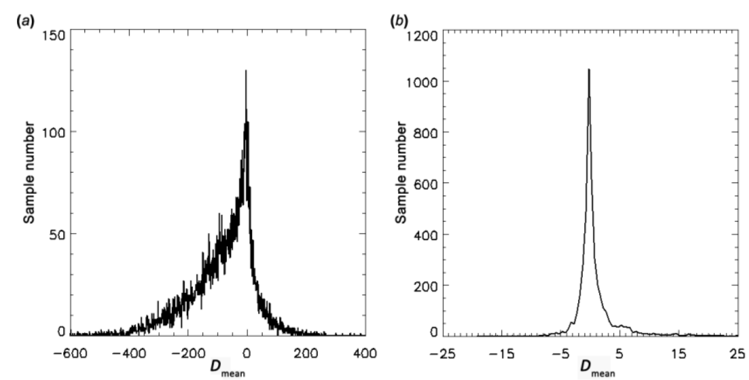


VIIRS flood map after cloud shadow removal, May 30, 2013 at 22:48 (UTC)

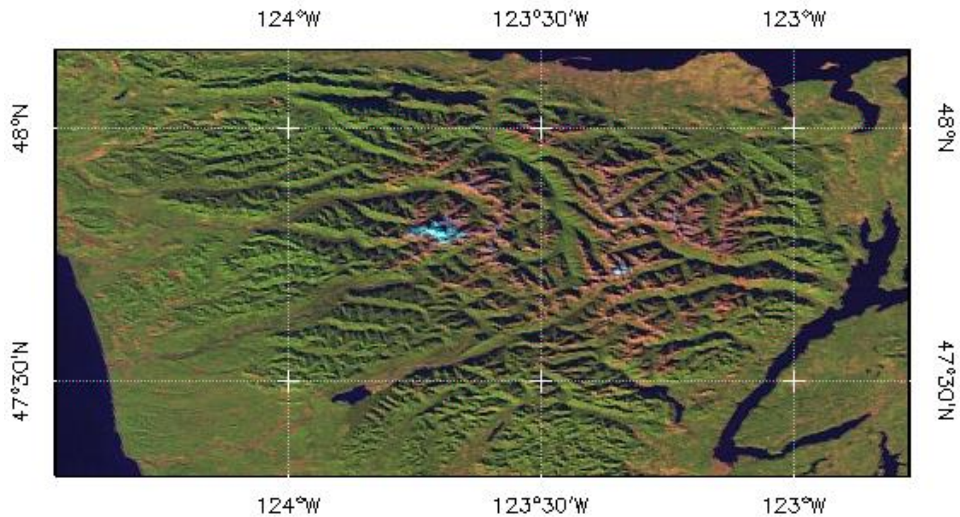
Challenges & Solutions

- **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:
    - Terrain shadows are formed in mountainous areas with large surface roughness
    - Flood water accumulates in low-lying areas with small surface roughness
  - ✓ Object-based instead of pixel-based.

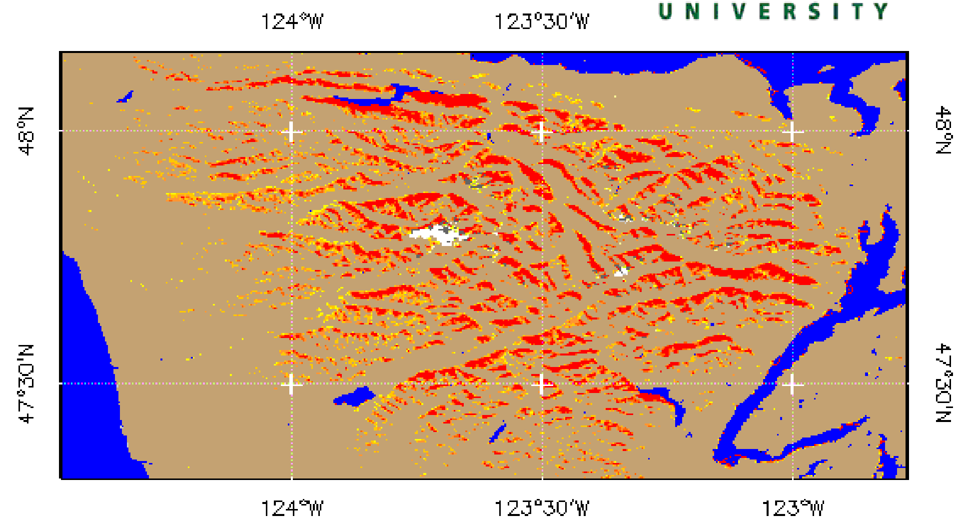




Terrain Shadow Removal

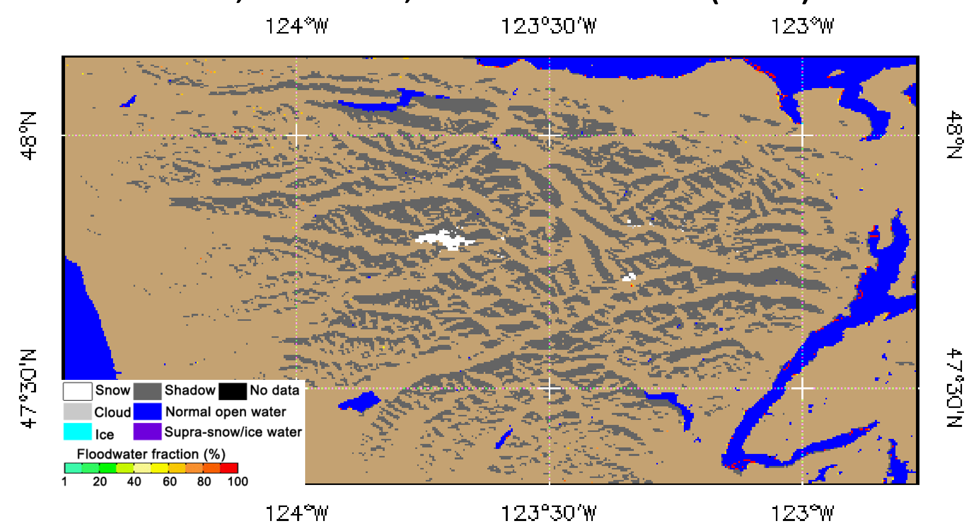


VIIRS false-color composited image, Nov. 15, 2014 at 21:02 (UTC)



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

- **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.

Challenges & Solutions – Downscaling model

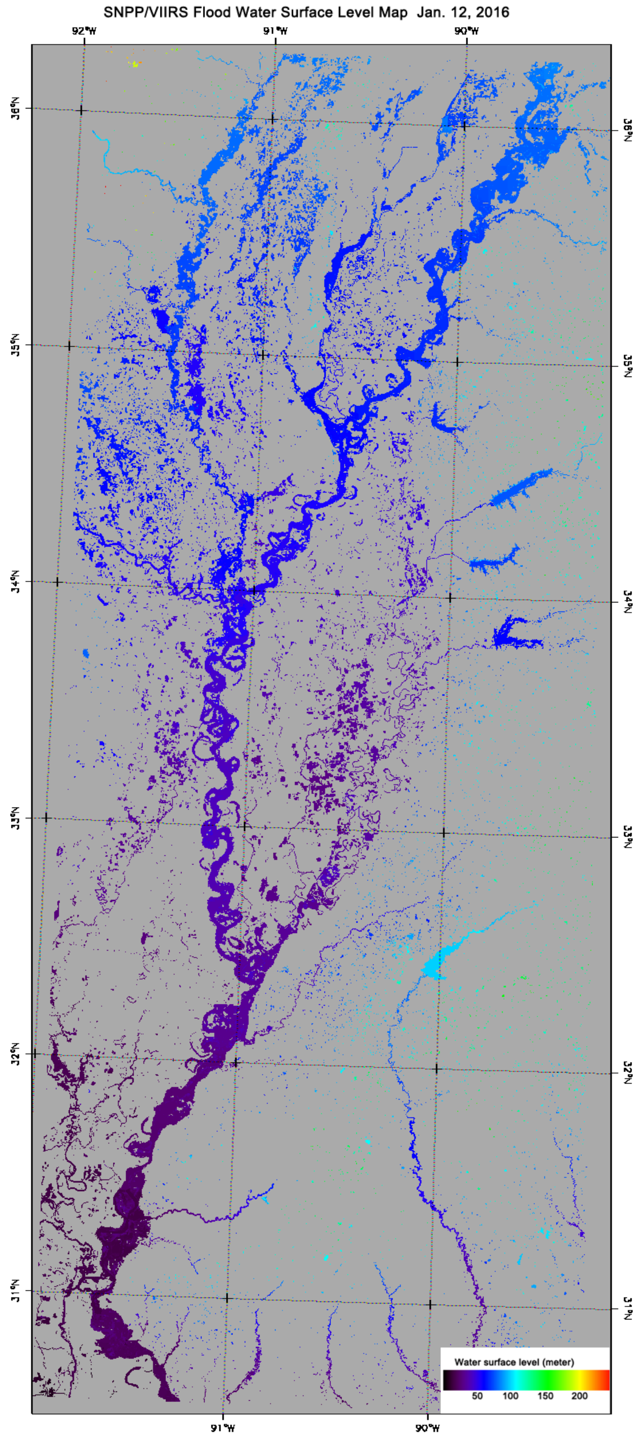
- The inundation mechanism can be expressed as:

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

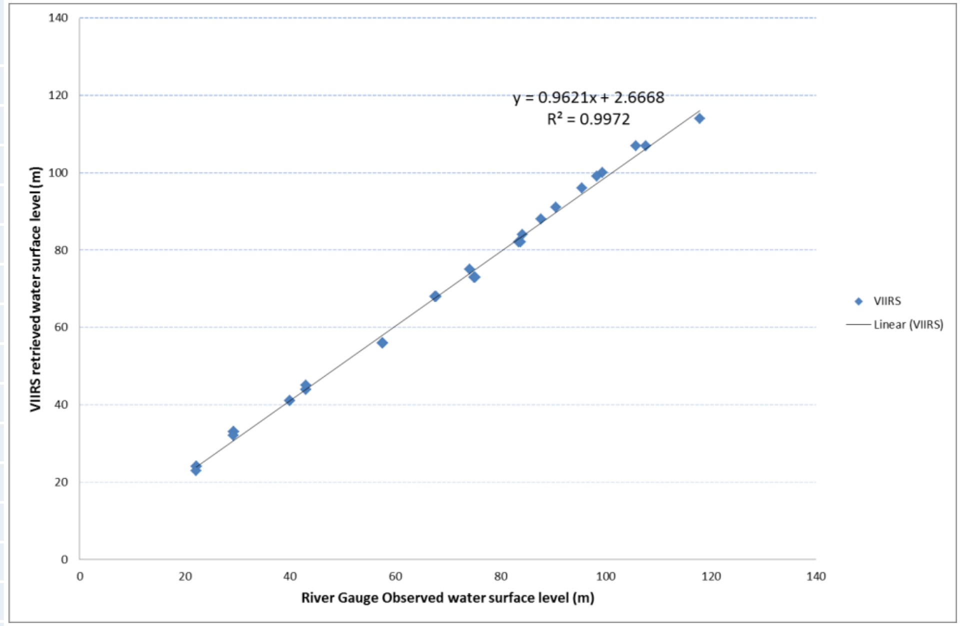
Where, A is satellite-based total water area between the minimal surface elevation, $\min\_h$, and maximal inundated surface elevation, $\max\_h$, $w_i(h)$ is the weight of land type i at height h in a VIIRS 375-m pixel, and $f_i(h)$ is the total area of land type i at height h.

  - ✓ $\max\_h$: 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.



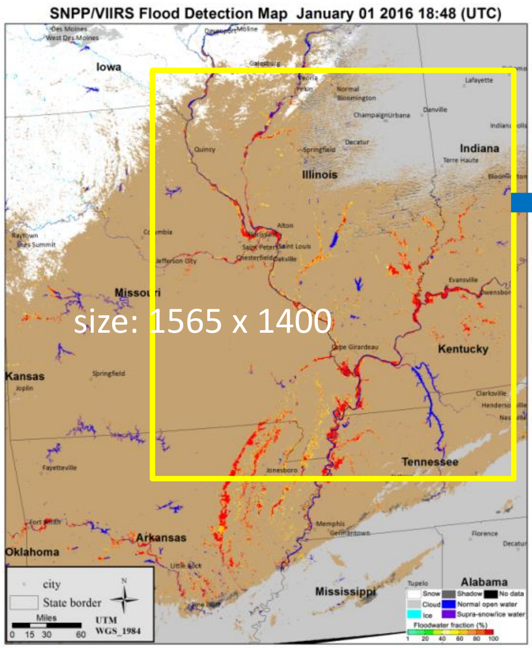
River Gauge	VIIRS
117.86616	114
107.5944	107
105.7656	107
99.392232	100
98.365056	99
95.487744	96
90.580464	91
87.703152	88
84.152232	84
74.197464	75
83.786472	82
75.233784	73
67.729608	68
57.63768	56
42.949368	44
39.940992	41
29.178504	33
22.122384	24
83.512152	82
75.020424	73
67.485768	68
57.54624	56
42.964608	44
39.95928	41
29.269944	33
22.213824	24
83.786472	82
75.233784	73
67.729608	68
57.63768	56
42.949368	45
39.940992	41
29.178504	32
22.122384	23



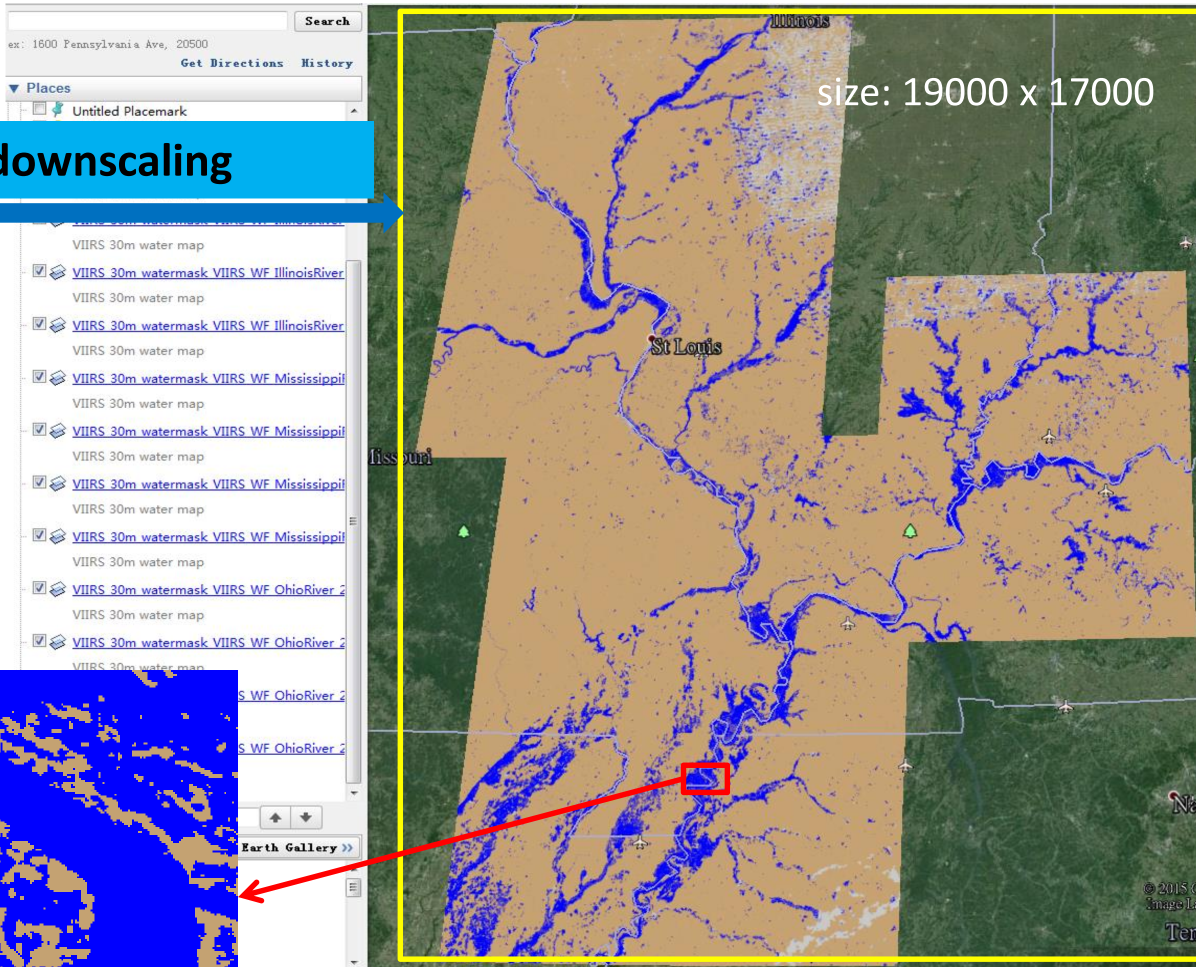
Validate VIIRS flood water surface level product with water levels from river gauges

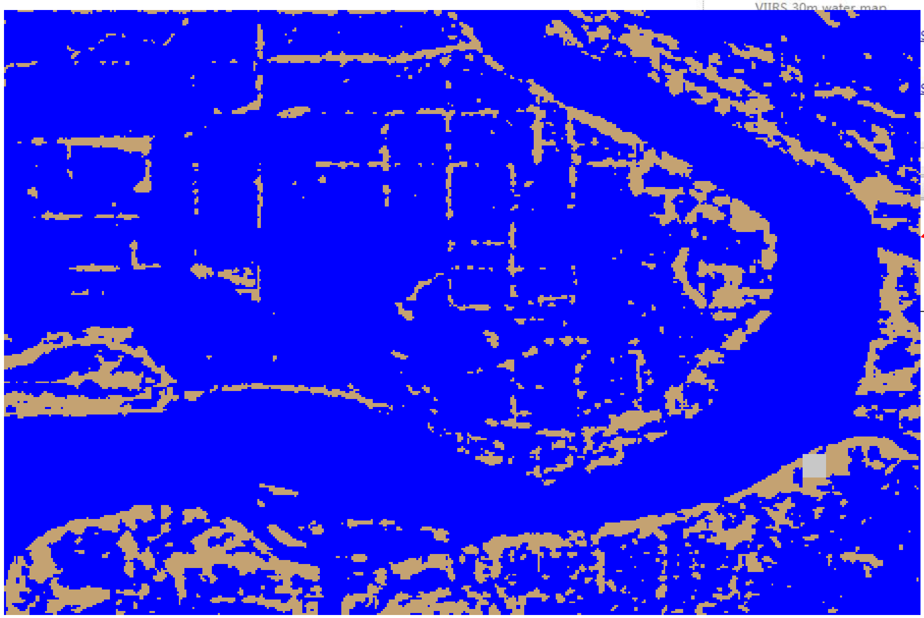
Model outputs:

- 30-m or 10-m flood areal extent
- 30-m or 10-m flood water depth
- 375-m flood water surface level product.



downscaling

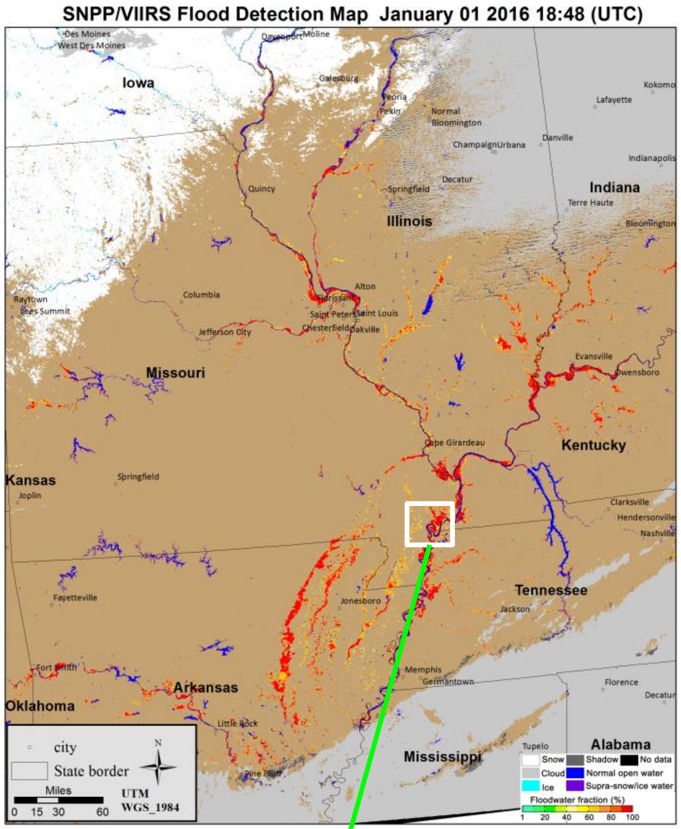


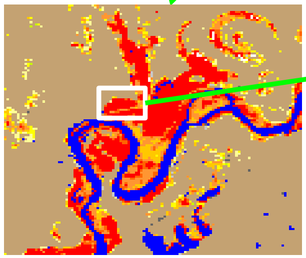


It takes about 10 minutes to finish the downscaling process within the yellow rectangular region in a 1-core-CPU computer.

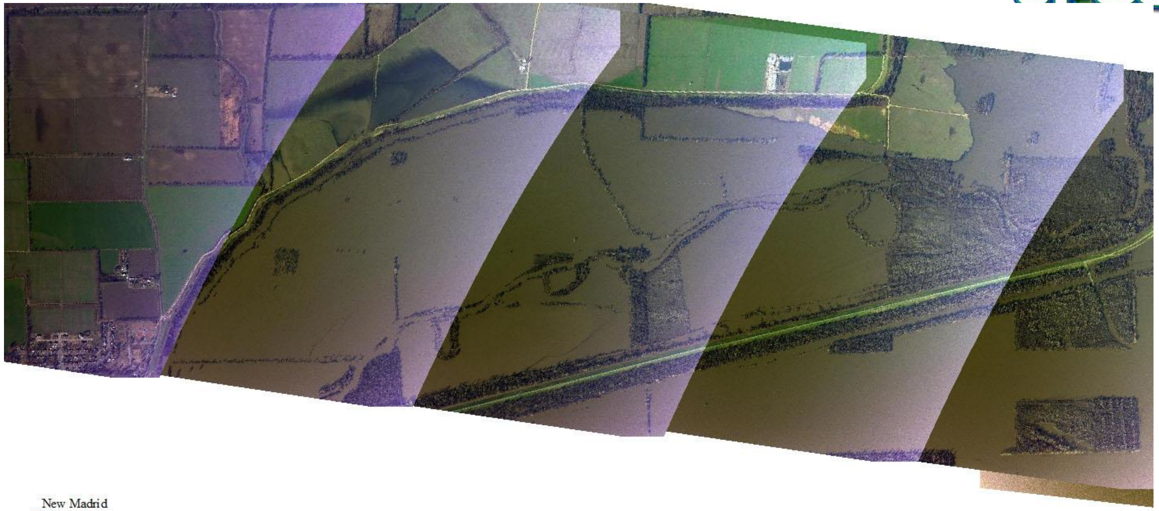
Fast processing speed guarantees the near-real-time capability.

Comparing with aerial photography

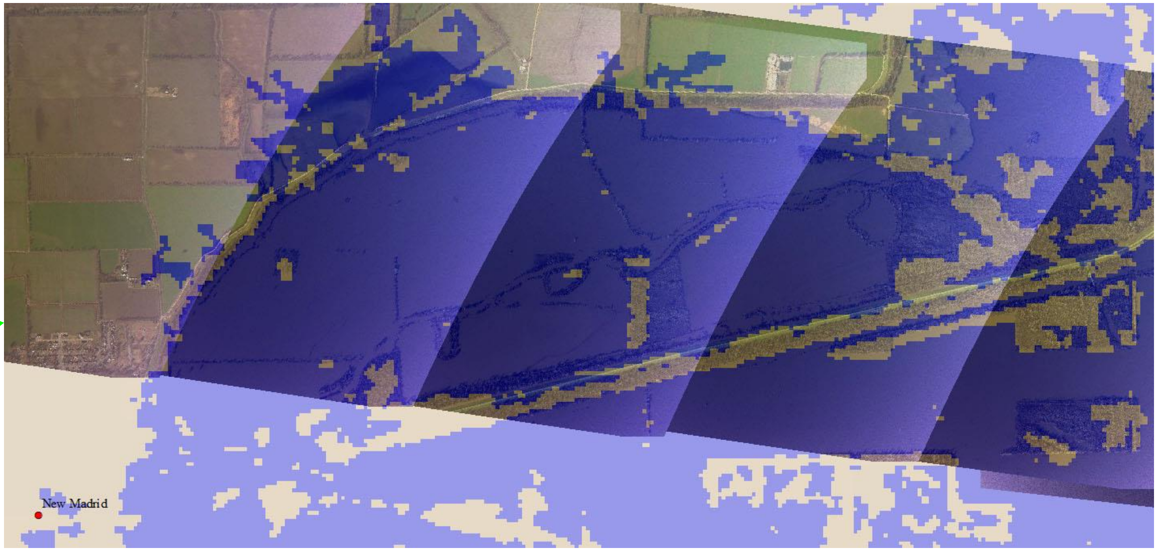




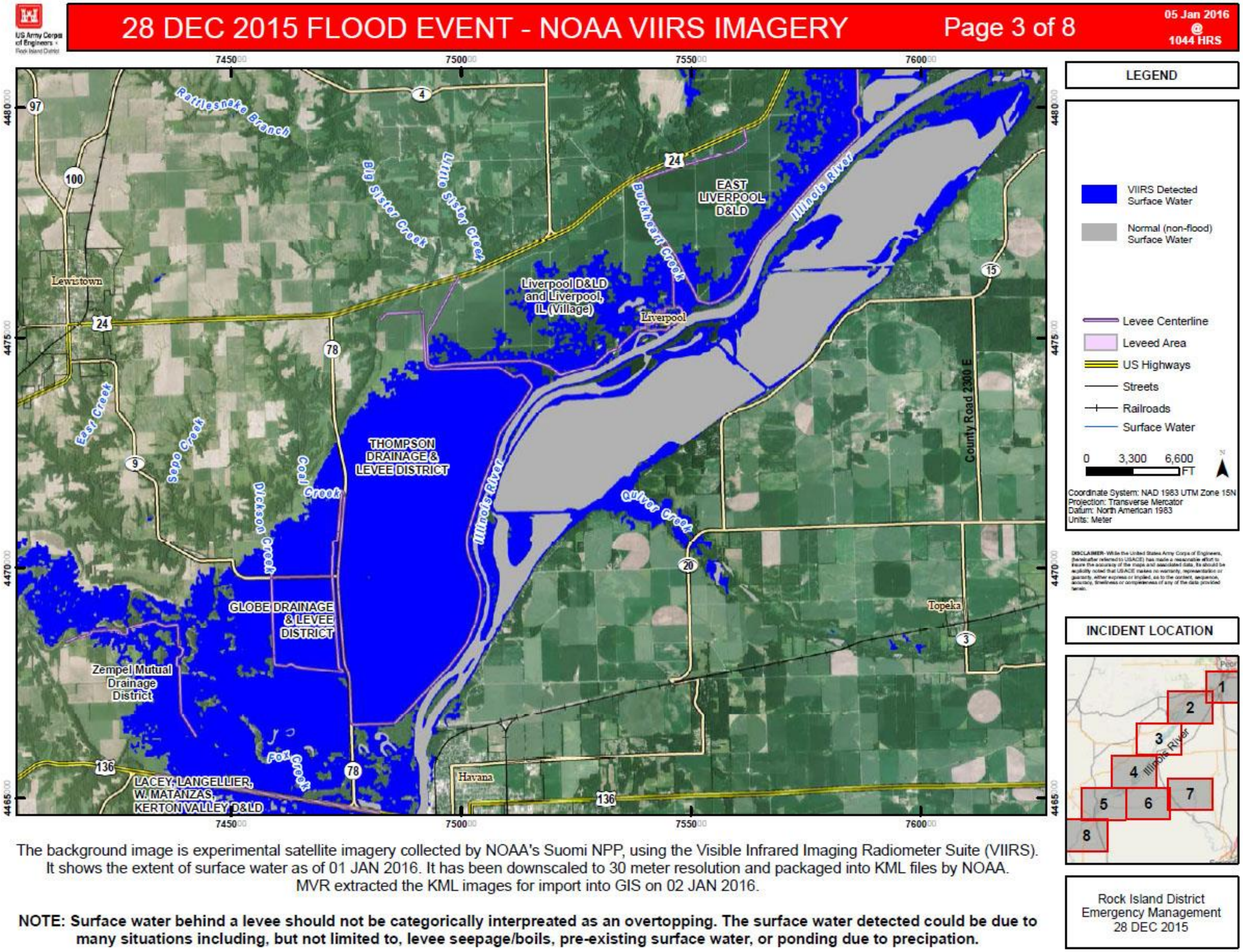
VIISR 375-m flood map

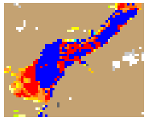


Aerial photo on Jan. 02, 2016 near New Madrid



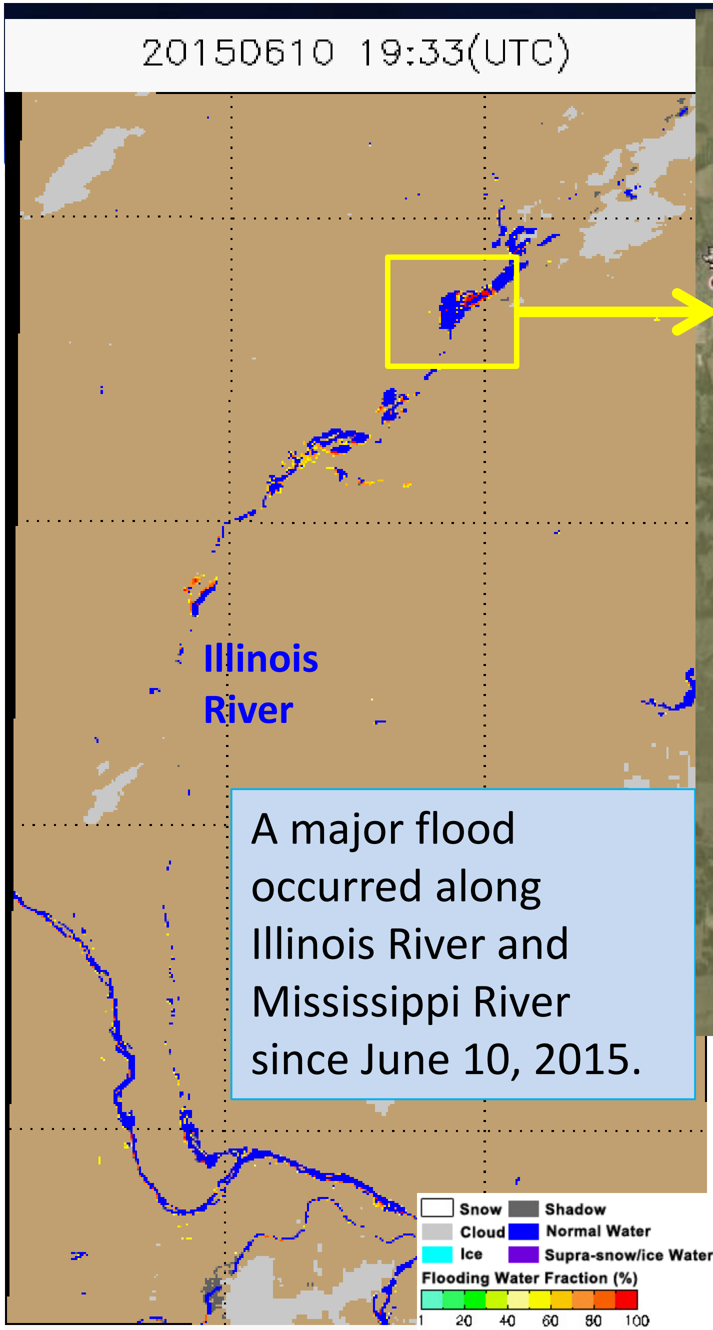
VIIRS 30-m flood map on Jan. 01, 2016 (overlapping on the top aerial image, light purple is flood water)





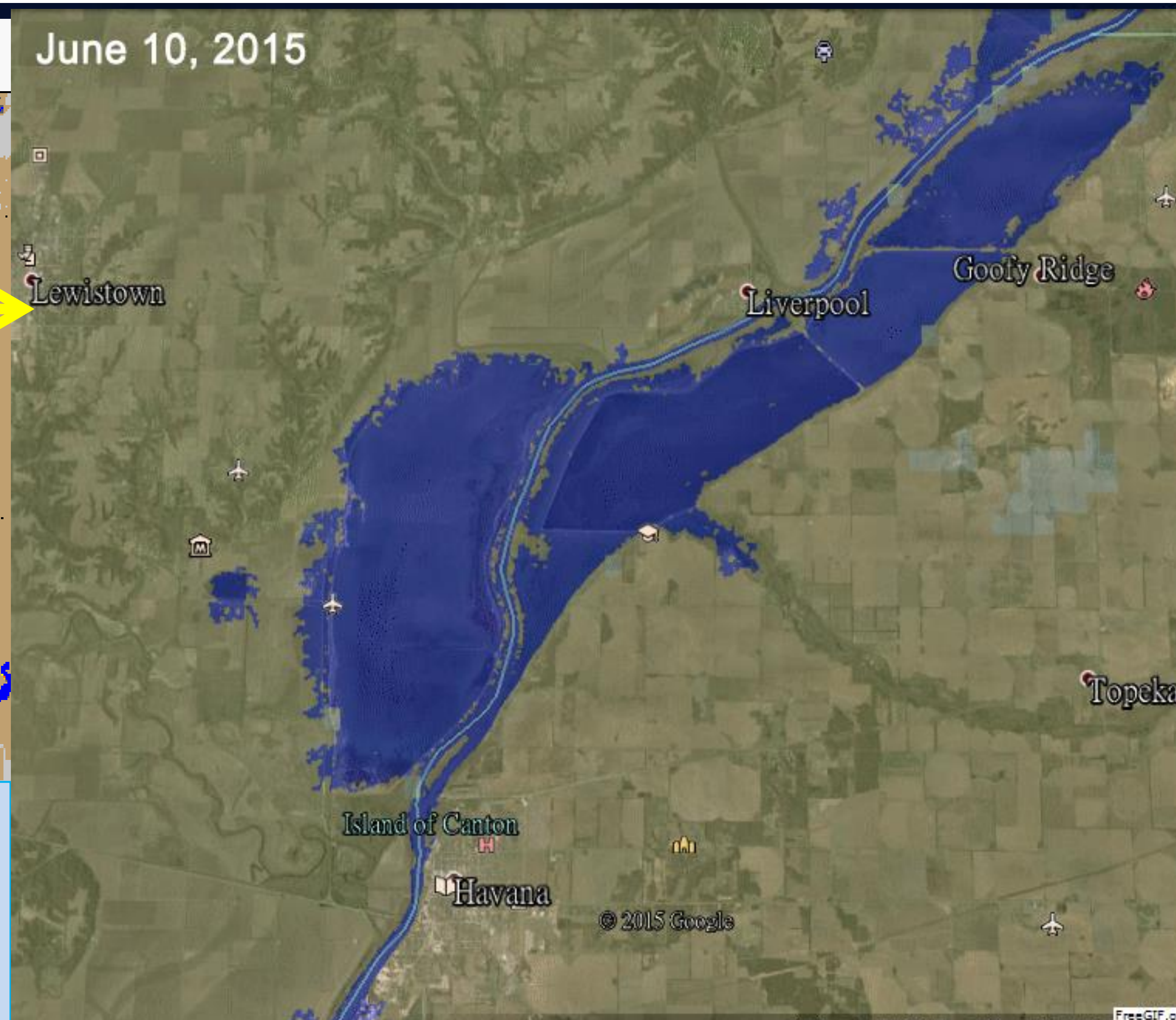
VIIRS 375-m flood map

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



A major flood occurred along Illinois River and Mississippi River since June 10, 2015.

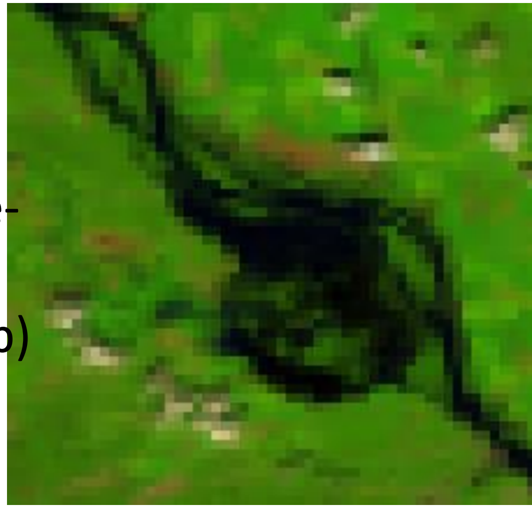
VIIRS 375-m flood maps along Illinois River

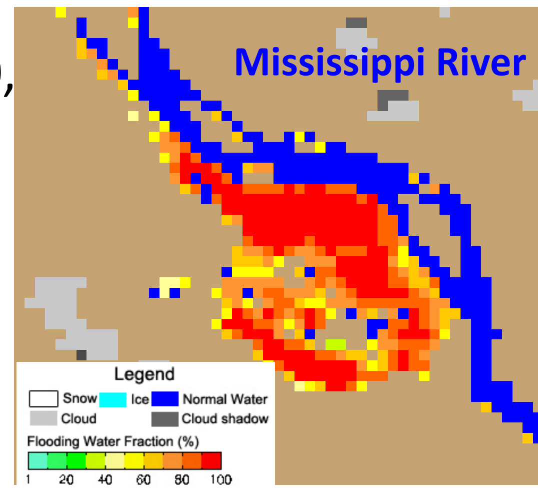


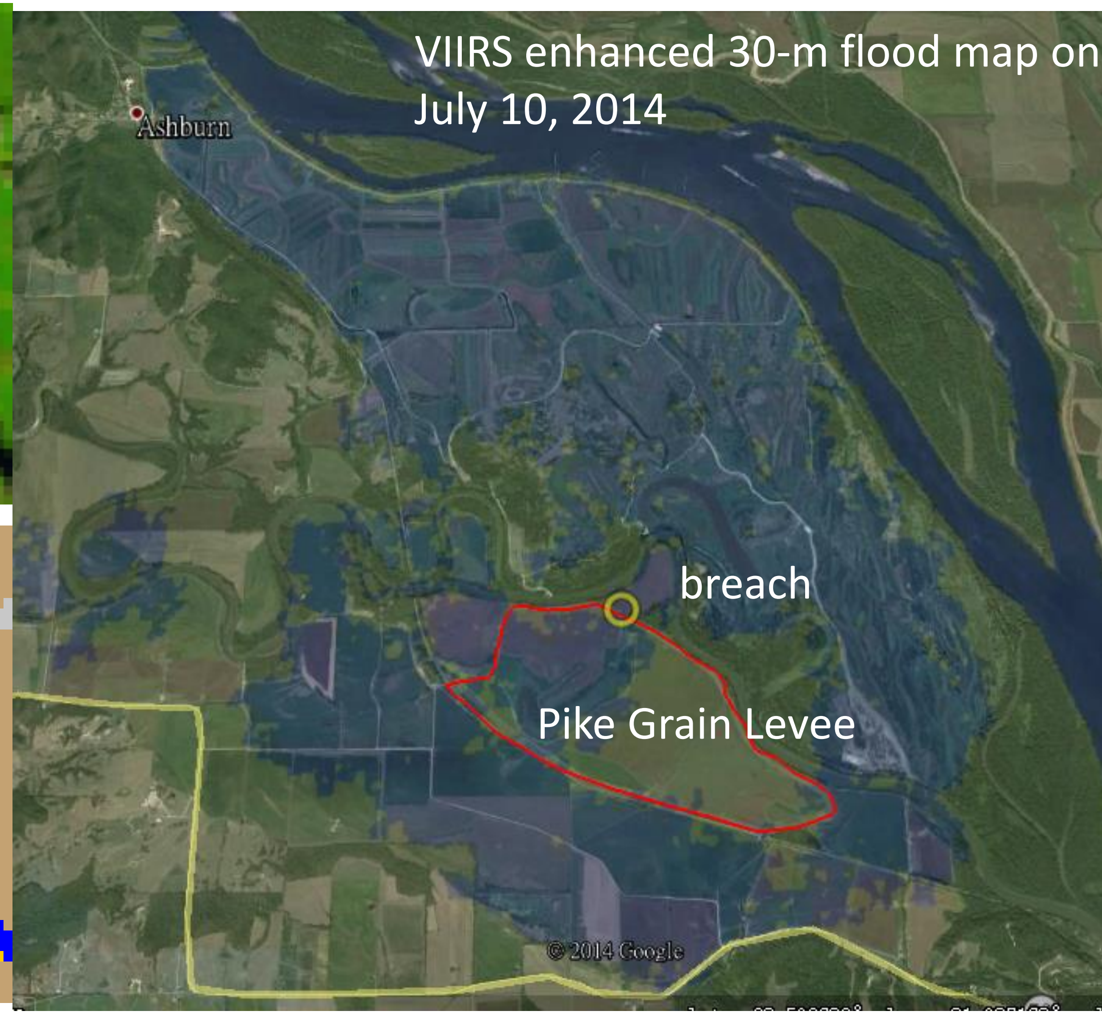
VIIRS enhanced 30-m flood maps along Illinois River

Near real-time flood extent monitoring.

VIIRS false-color image (top) and flood map (bottom) on July 10, 2014





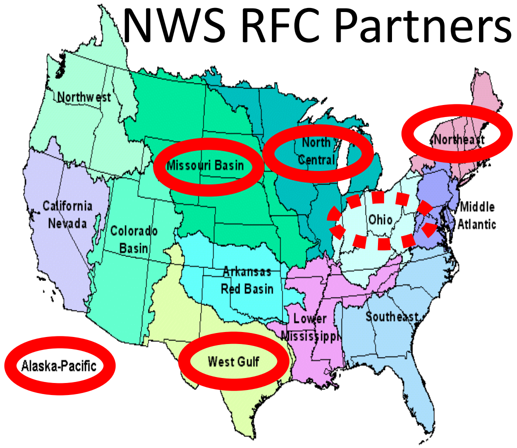


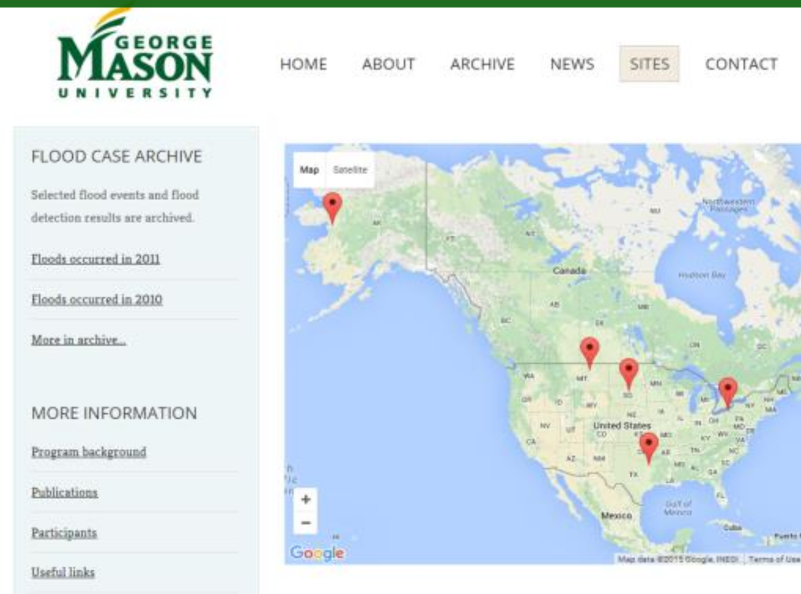
Application: Levee monitoring and management.

- ✓ Provide dynamic flood information around levees, which could assist river forecasters to investigate flood status and risks of levees.
- ✓ Downscaled flood maps based on flood extent products provide more details of levees such as breach, flooding water volume.

VIIRS Near Real-time Flood Products

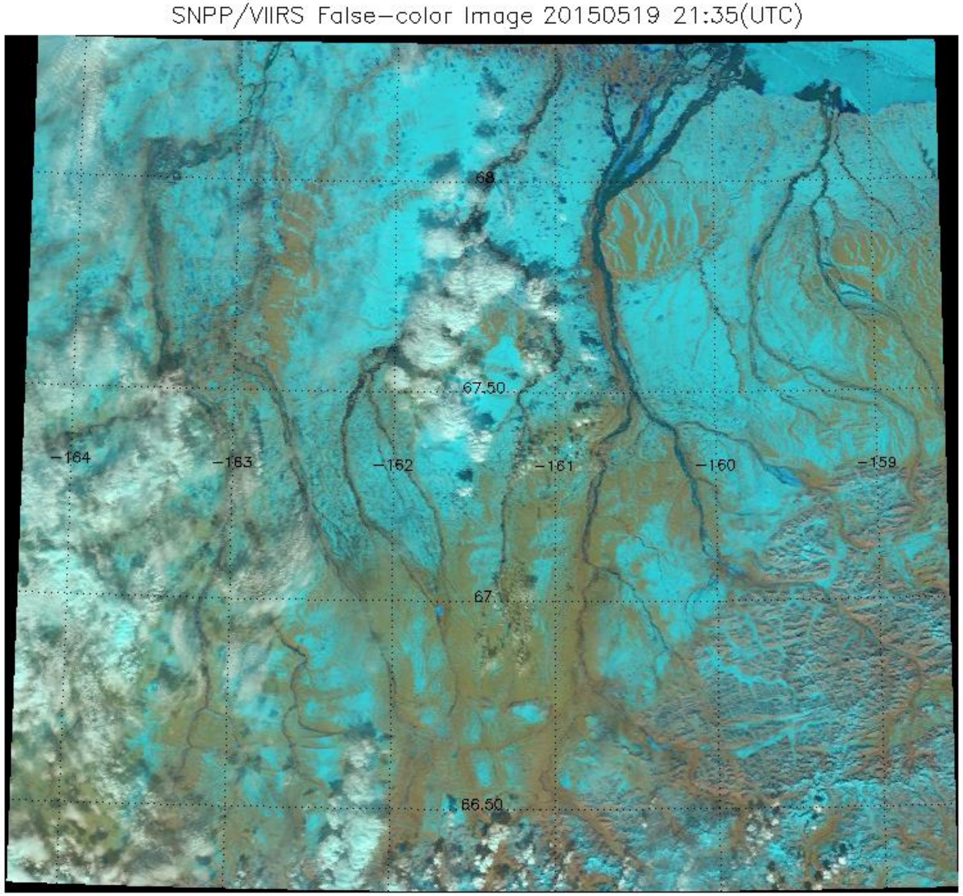
NWS RFC Partners

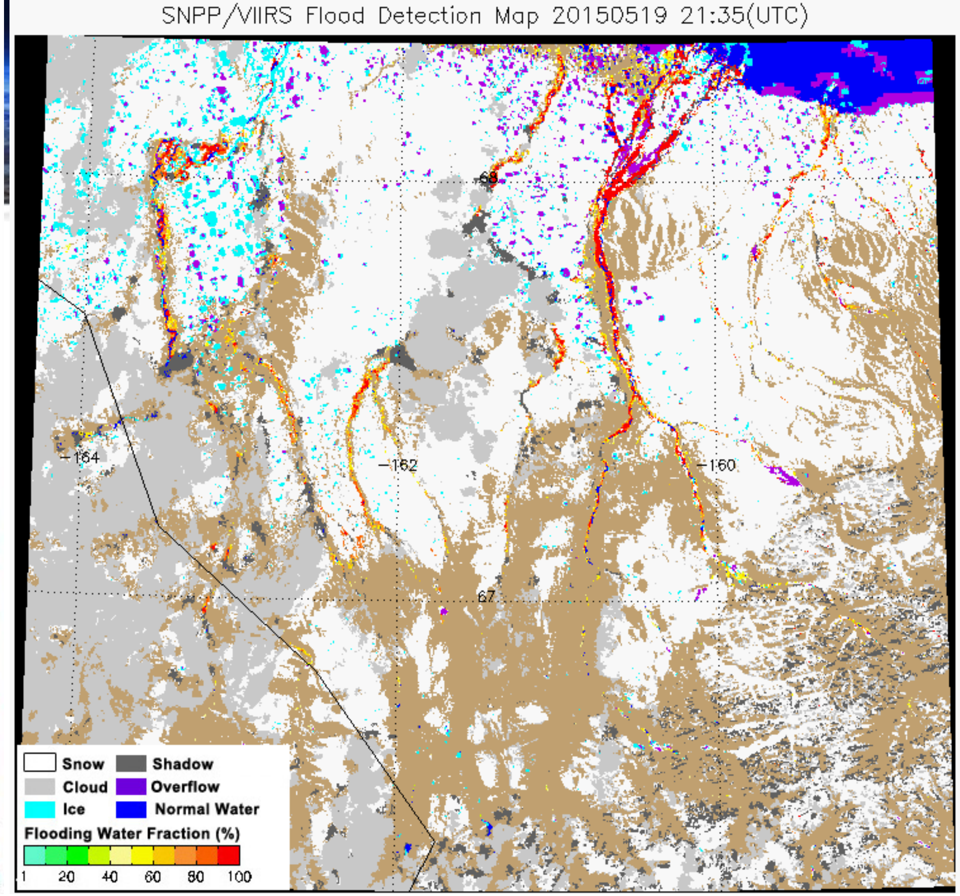




Interface to browse near-real-time flood products for the five river forecast centers: http://rs.gmu.edu http://realearth.ssec.wisc.edu/

- The software is routinely running at SSEC and GINA, which have access to direct broadcast SNPP/VIIRS data, to generate near-real-time flood maps for five River Forecast Centers (RFCs) in USA.
- VIIRS near real-time flood products can be accessed for these five RFCs in Real Earth and AWIPS-II.

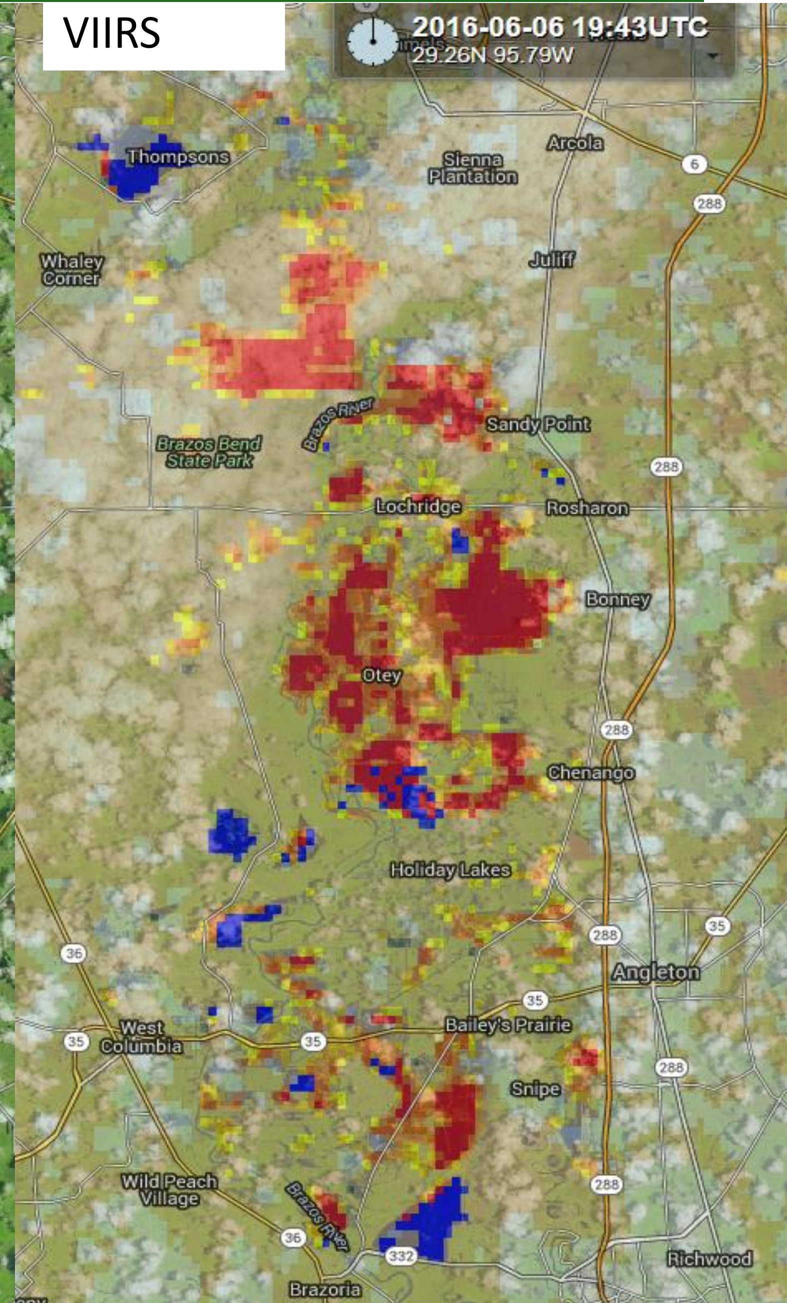


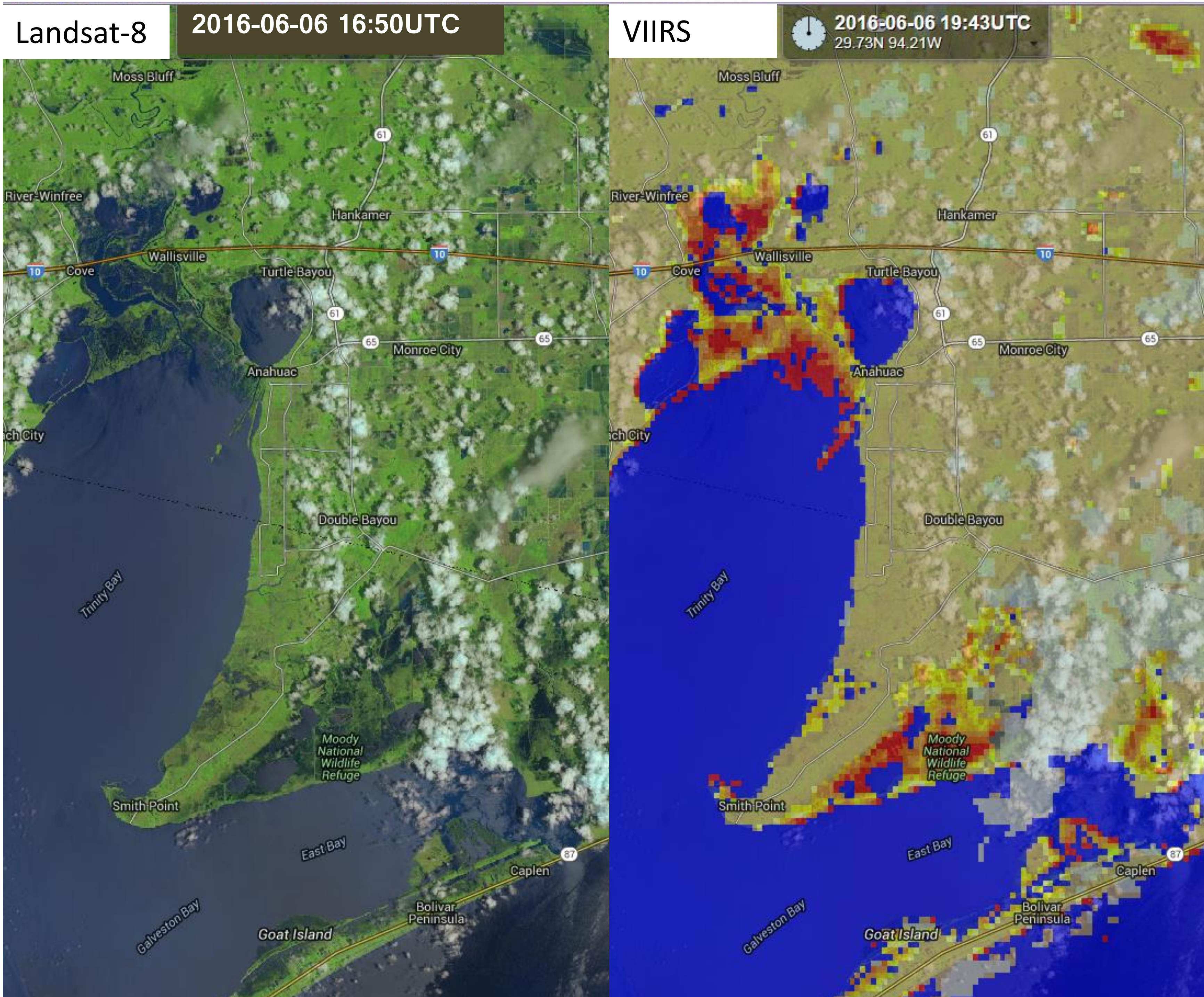


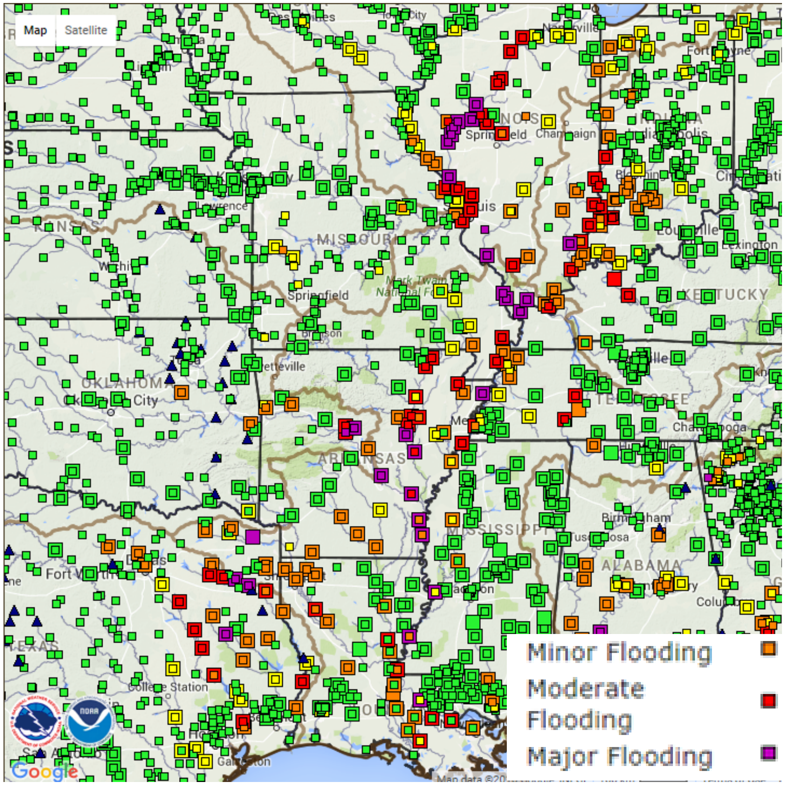
Near real-time flood extent monitoring.

- ✓ **Coverage:** any regions between 80° S and 80° N.
- ✓ **Spatial resolution:** 375-m
- ✓ **Flood types:** supra-veg/bare soil flood and supra-snow/ice flood.
- ✓ **Flood maps**: In a flood map, there are cloud, snow, River/lake ice, shadow (cloud shadow and terrain shades), supra-snow/ice flood cover, normal open water and flooding water fractions of supra-veg/bare soil floods.

Evaluations

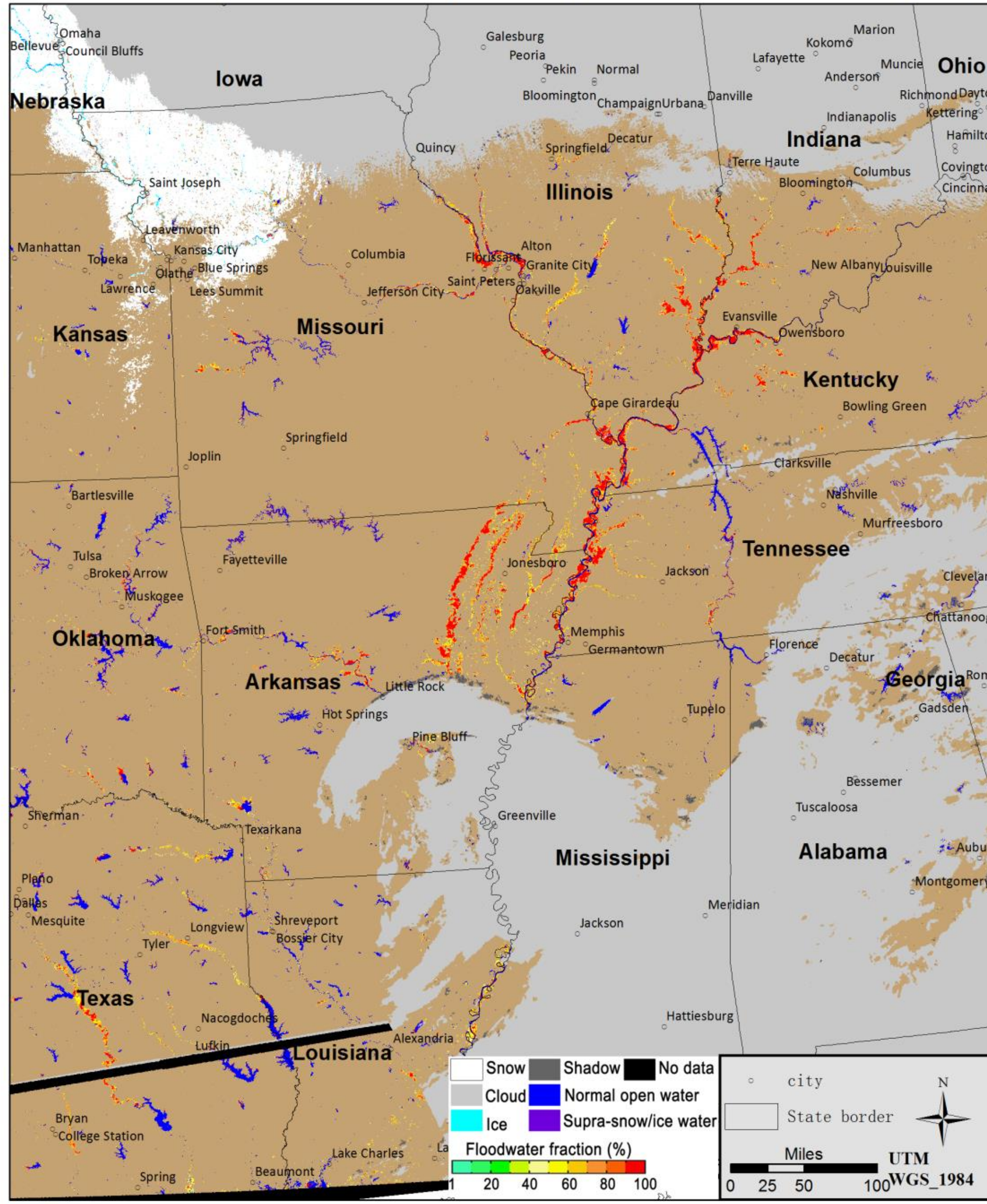



Landsat-8
2016-06-06 16:50UTC
VIIRS
2016-06-06 19:43UTC
29.73N 94.21W
Moss Bluff
River-Winfree
Hankamer
Wallisville
Cove
Turtle Bayou
Monroe City
Anahuac
Double Bayou
Trinity Bay
Moody National Wildlife Refuge
Smith Point
East Bay
Caplen
Bolivar Peninsula
Goat Island
Galveston Bay



River gauge map on Jan. 03, 2016

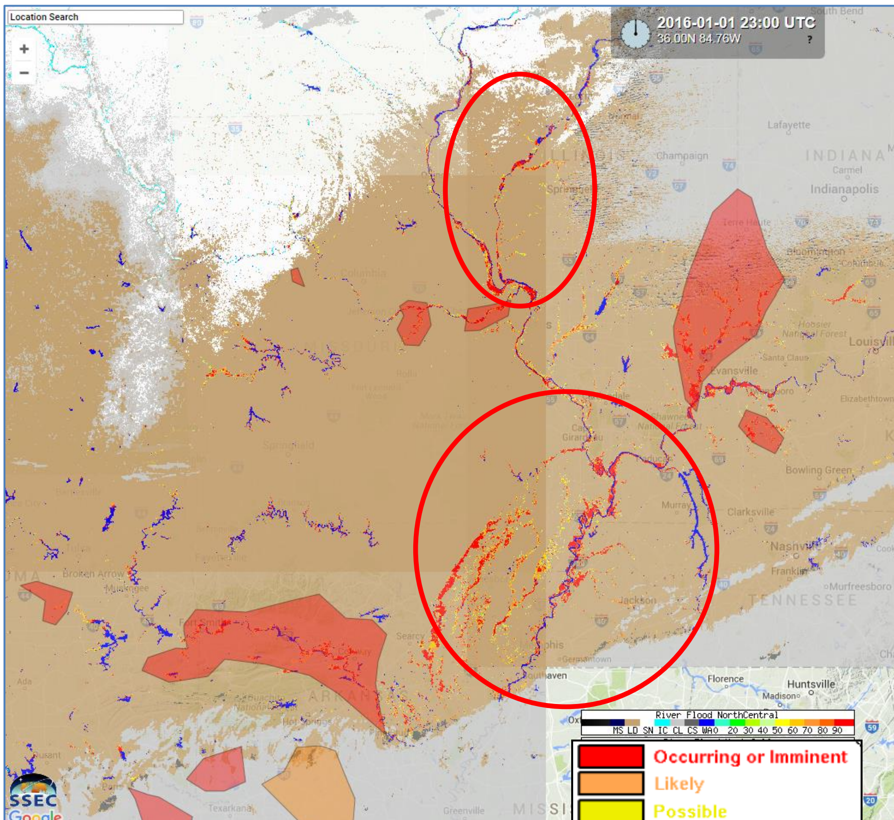
SNPP/VIIRS Flood Detection Map January 03 2016 18:03 & 19:50 (UTC)



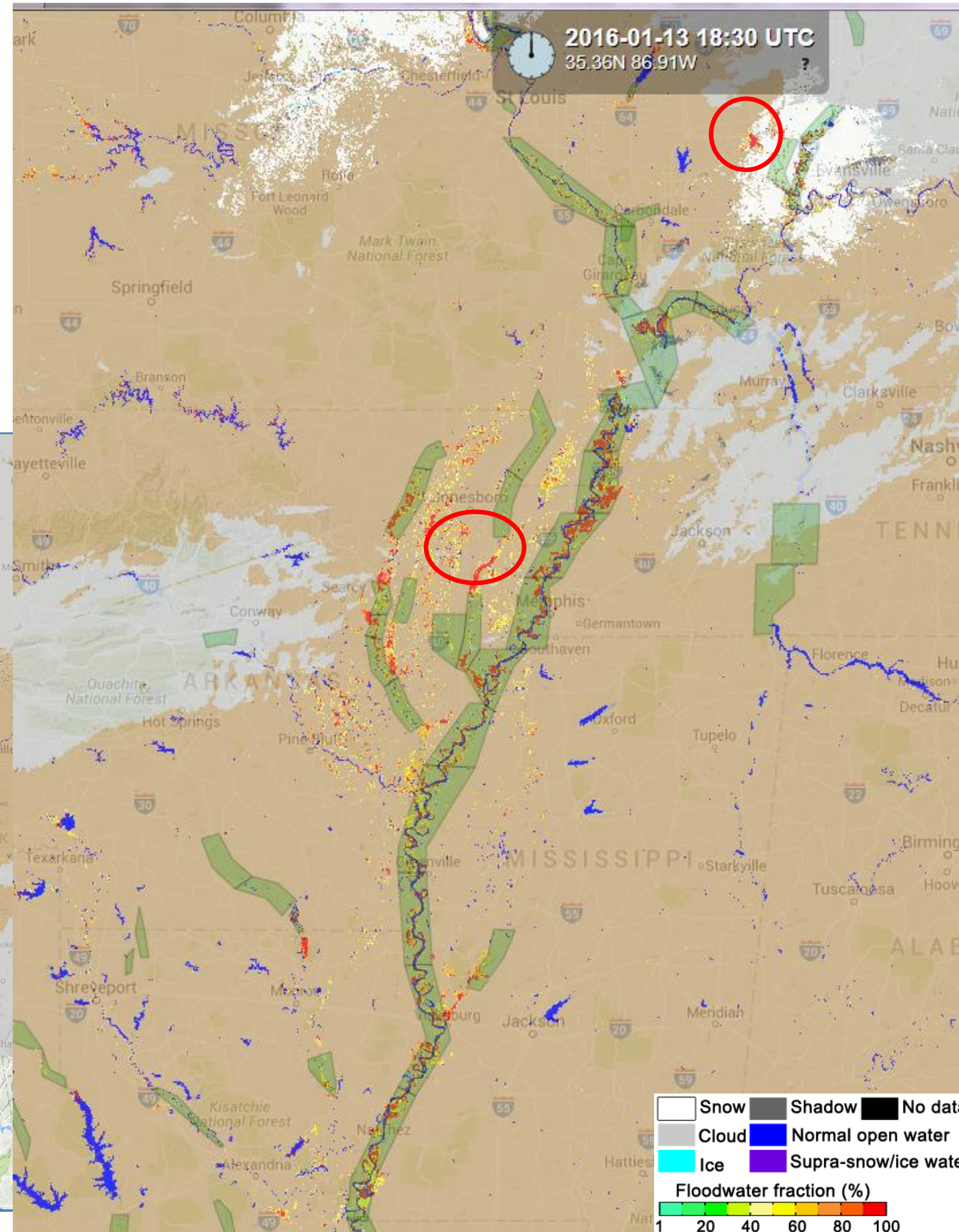
Evaluations against river gauge observations.

- ✓ 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



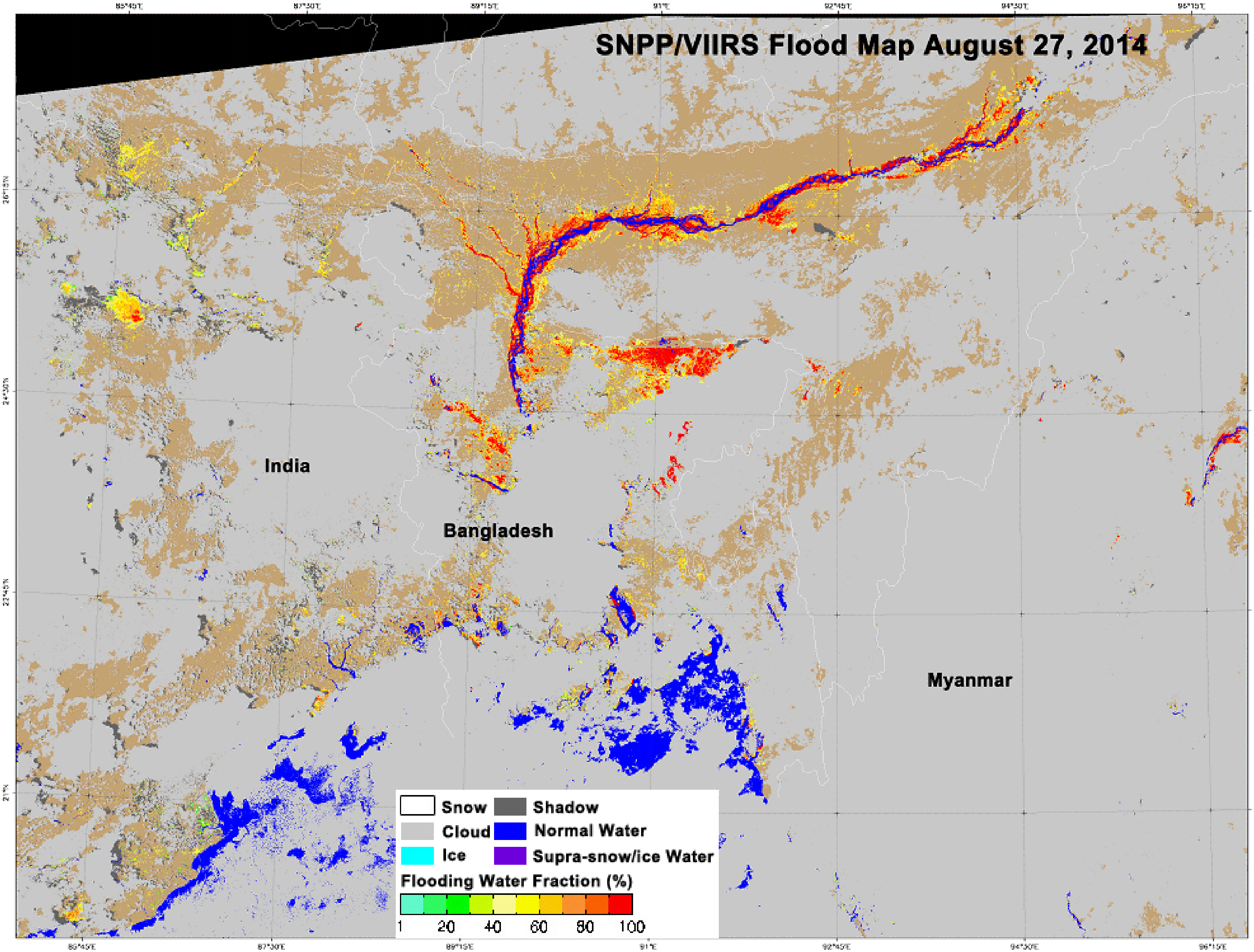
Comparing with flood outlook product



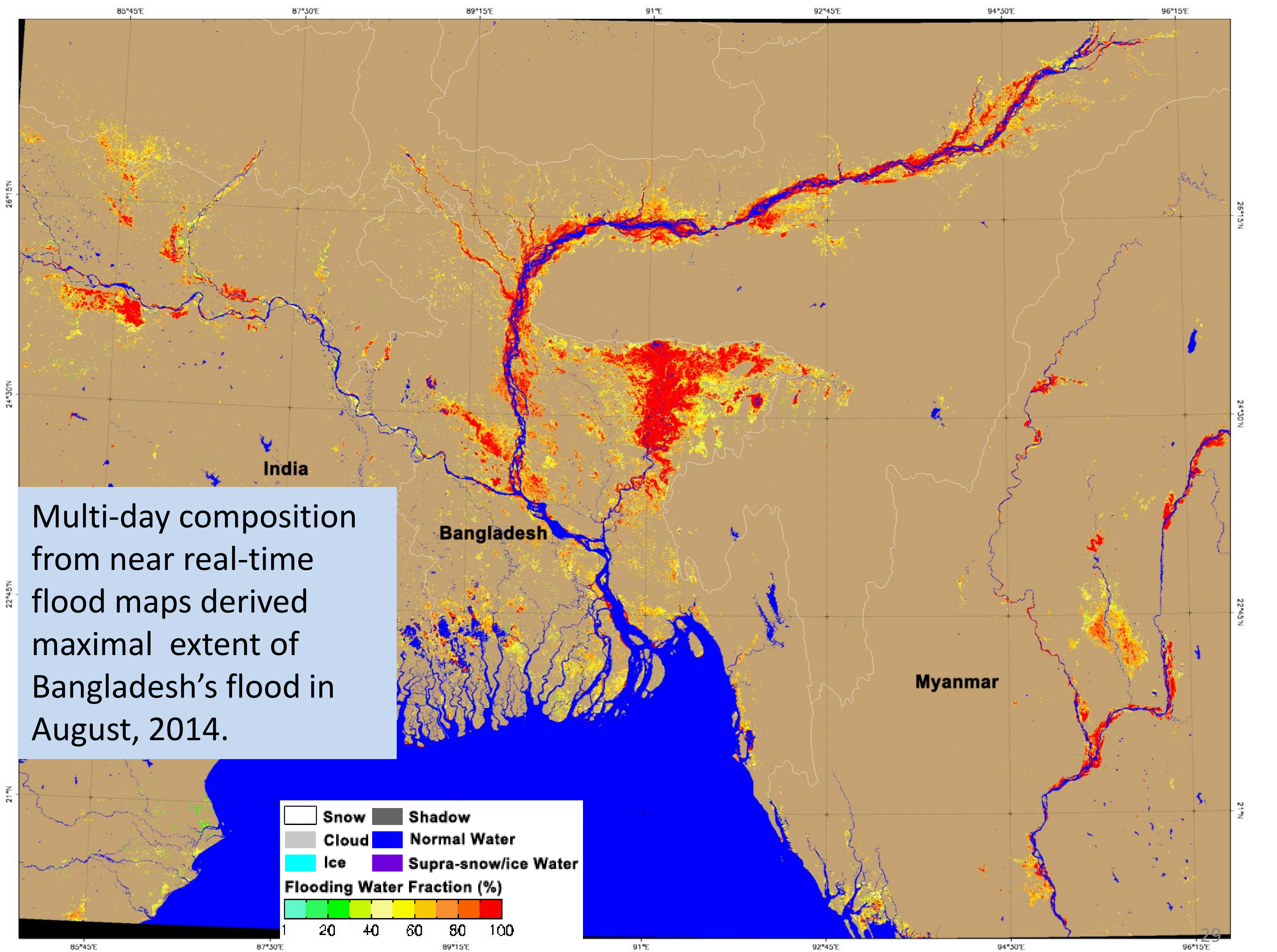
Comparing with flood warning product

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.



Cloud cover prevents a complete overview of flood water from near real-time flood maps during Bangladesh's flood event in August, 2014.



Multi-day composition from near real-time flood maps derived maximal extent of Bangladesh's flood in August, 2014.

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.

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Thanks!

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Any Questions ?