Development of the Global GEO-LEO 3-D Flood Mapping System

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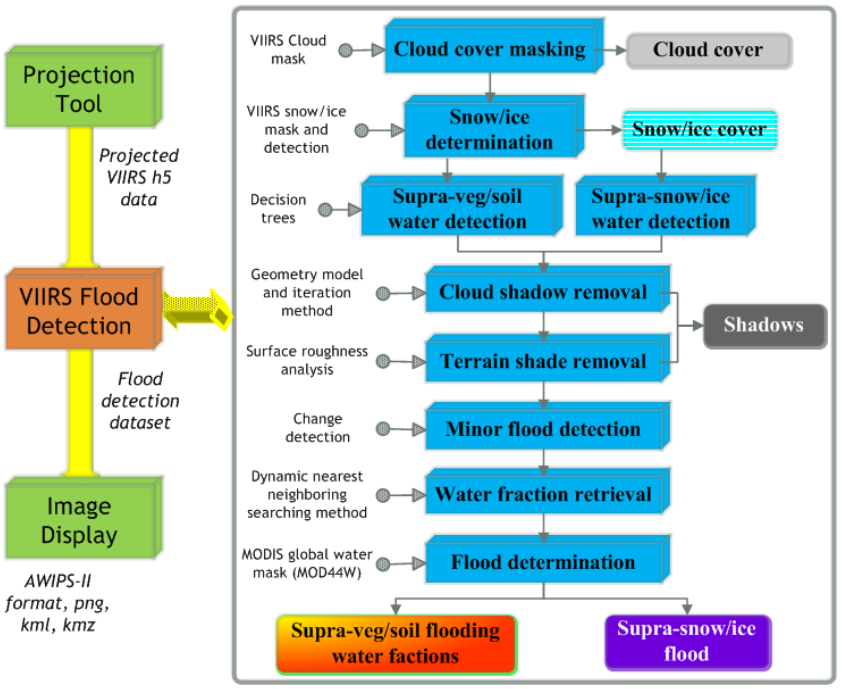
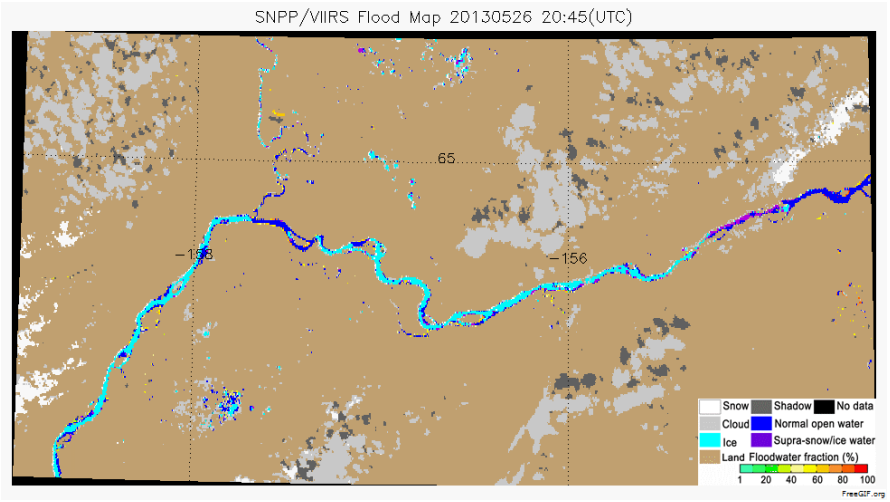
Outline

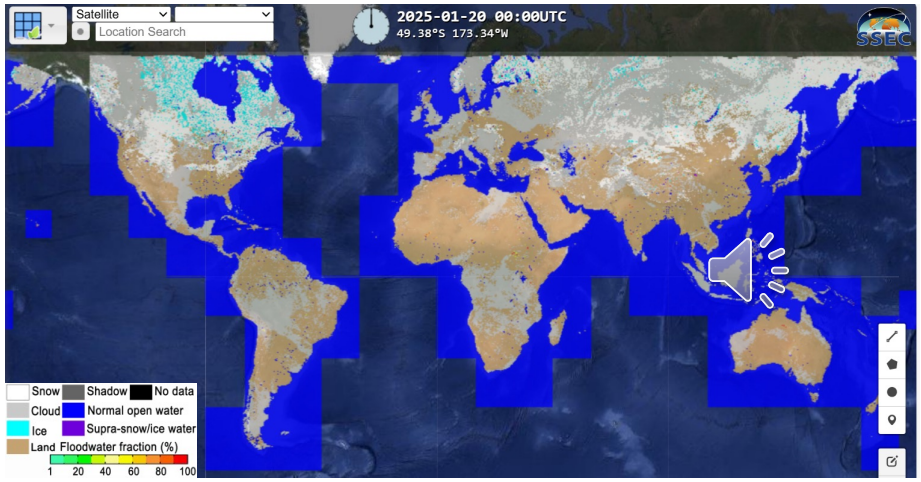
- LEO flood mapping
- GEO flood mapping
- Joint GEO-LEO flood mapping
- 3D GEO-LEO flood mapping
  - ✓ VIIRS Downscaling model
  - ✓ Validation and examples
  - ✓ Apply the downscaling model to ABI 1-km flood product
- Future's plan
- Web access to the current GEO-LEO flood products

LEO Flood Mapping – VIIRS

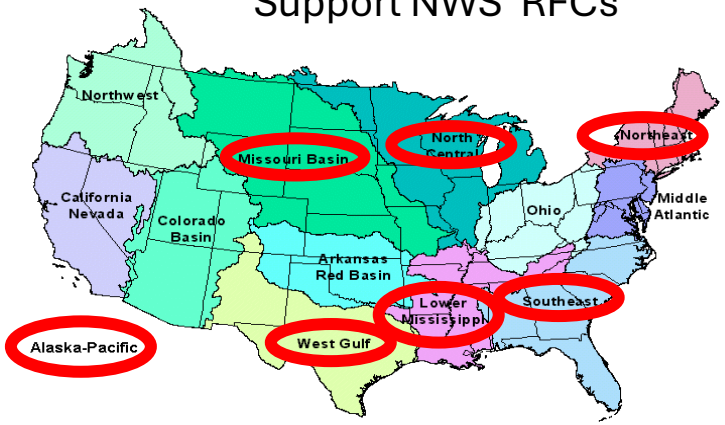


- In 2015, the first version of VIIRS flood mapping software was released to produce VIIRS flood product under a demonstration mode.
- In 2021, NOAA declared the operational production of VIIRS global flood products. A global flood mapping system has been developed using the VIIRS imagery on-boarding SNPP, NOAA-20 and NOAA-21 to detect flood in any land regions between 80°S and 80°N under solar zenith angles less than 85°.





Support NWS' RFCs

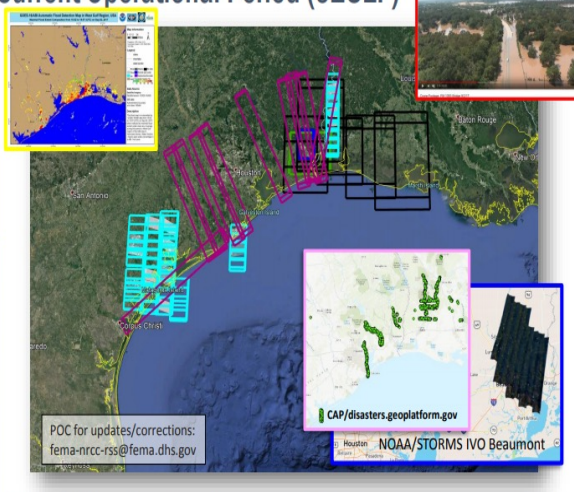


Support FEMA

MDARNG
FEMA Collection Synchronization – Current Operational Period (02SEP)

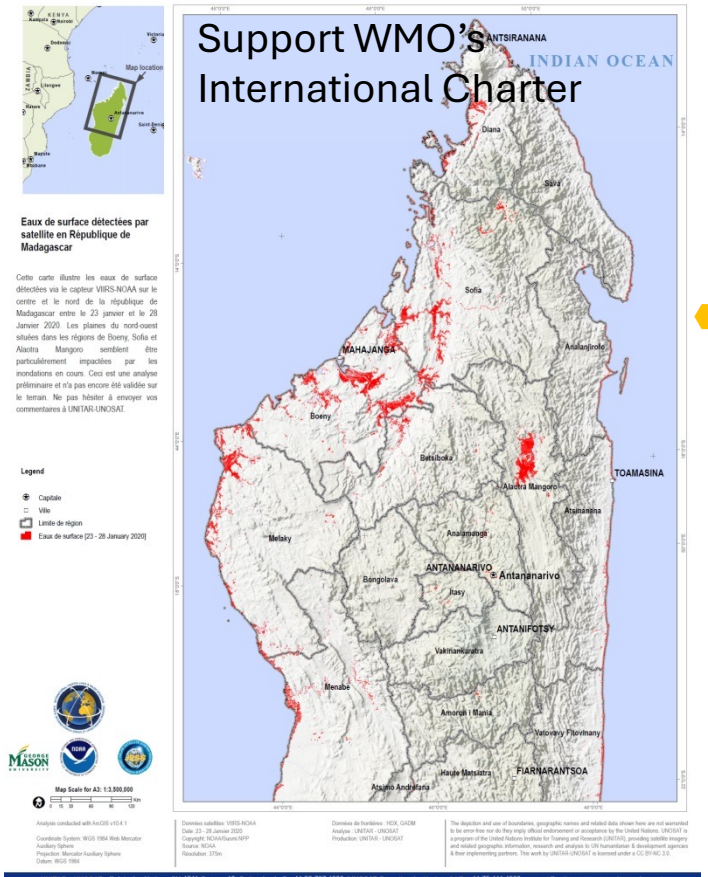
2	How many residences have been impacted and to what degree have they been impacted?
3	How has critical infrastructure been impacted (including list of critical sites, oil rigs, power, transportation, chemical spills)?
4	What are the flood extents of reservoirs and rivers in the AOI?
5	What is the impact of the Arkema chemical facility explosion?

Satellite Platforms	PED	Collection Information	PIR
COSMOSKYMED	Copernicus	1 SAR Product Available	2
RADARSAT-2	NASA/JPL	No Action	2
PALSAR	NASA/JPL	No Action	2
TERRASAR-X	NASA/JPL	No Action	2
WORLDVIEW-1	UNKNOWN	No Action	2
WORLDVIEW-2	UNKNOWN	No Action	2
WORLDVIEW-3	UNKNOWN	Over 100 MSI/PAN Collects	2
WORLDVIEW-4	UNKNOWN	No Action	2
SENTINEL-1	NASA/JPL	No Action	2
SENTINEL-2	NASA/JPL	No Action	2
SPOT-6	NASA/JPL	32 MSI/PAN Collects	2
LANDSAT-7	UNKNOWN	No Action	2
LANDSAT-8	UNKNOWN	No Action	2
GEOEYE-1	UNKNOWN	No Action	2
UKDMC-2	UNKNOWN	No Action	2
GOES-16 & JPSS	NOAA & GMU	Flood Detection	2



Airborne Platforms	PED	Collection Information	PIR
Civil Air Patrol	FEMA/States	Operational (Cumulative Imagery Displayed Above)	4
NOAA (N68RF King Air)	FEMA/States	Operational	2
NOAA (N48RF Twin Otter)	FEMA/States	No Action	2
NASA/JPL (UAVSAR)	NASA/JPL	Operational	2
National Guard (3X RC-26)	TX NG	Operational (focused on SAR)	1
EPA (ASPECT)	EPA	Operational	5
DOI BLM (Small UAS)	Unknown	Operational	1

Support WMO's International Charter



- VIIRS flood products have been applied in flood operations especially in situational awareness and loss assessment.

Support media

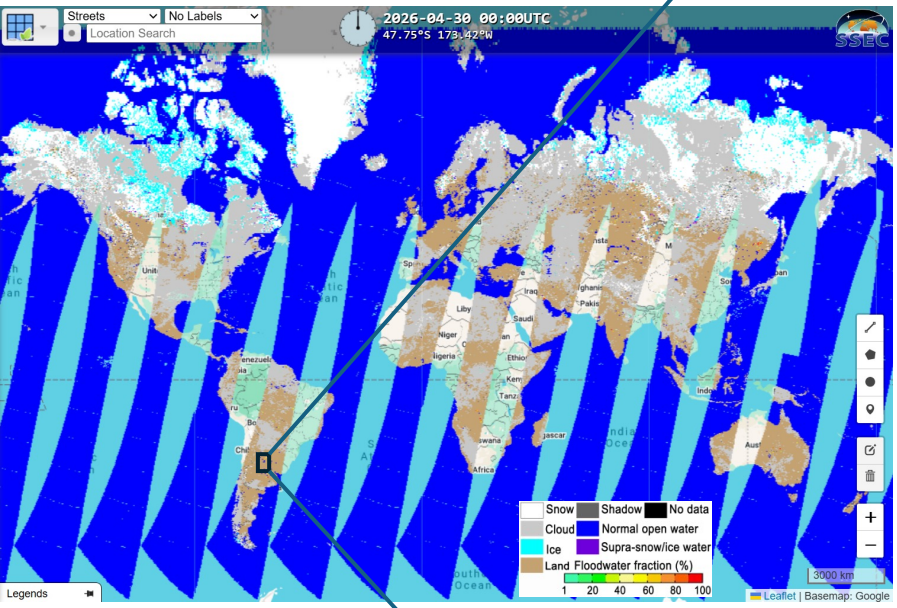
nytimes.com/interactive/2019/09/11/us/midwest-flooding.html

The New York Times

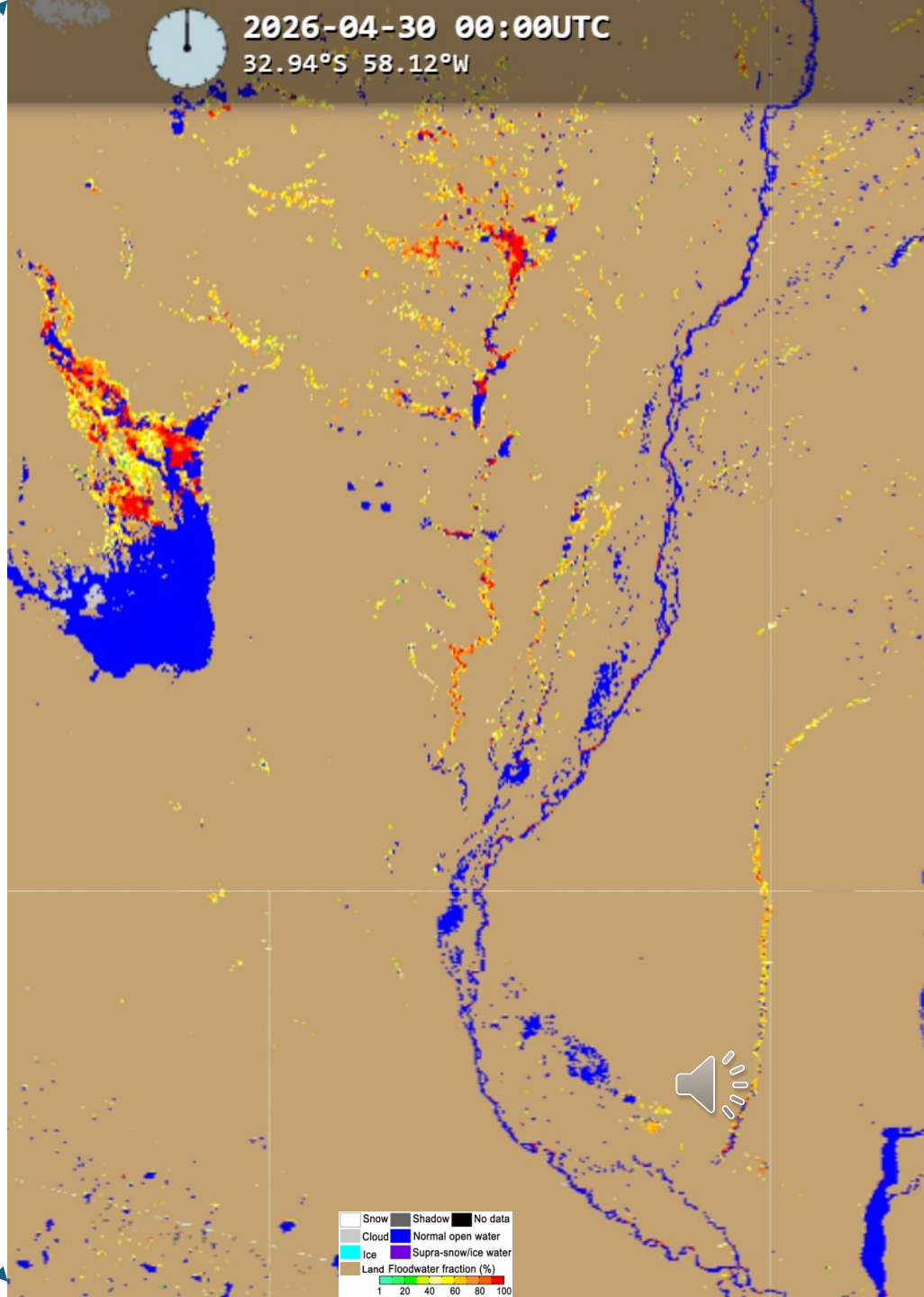
The Great Flood of 2019: A Complete Picture of a Slow-Motion Disaster

By Sarah Almukhtar, Blacki Migliozzi, John Schwartz and Josh Williams Sept. 11, 2019

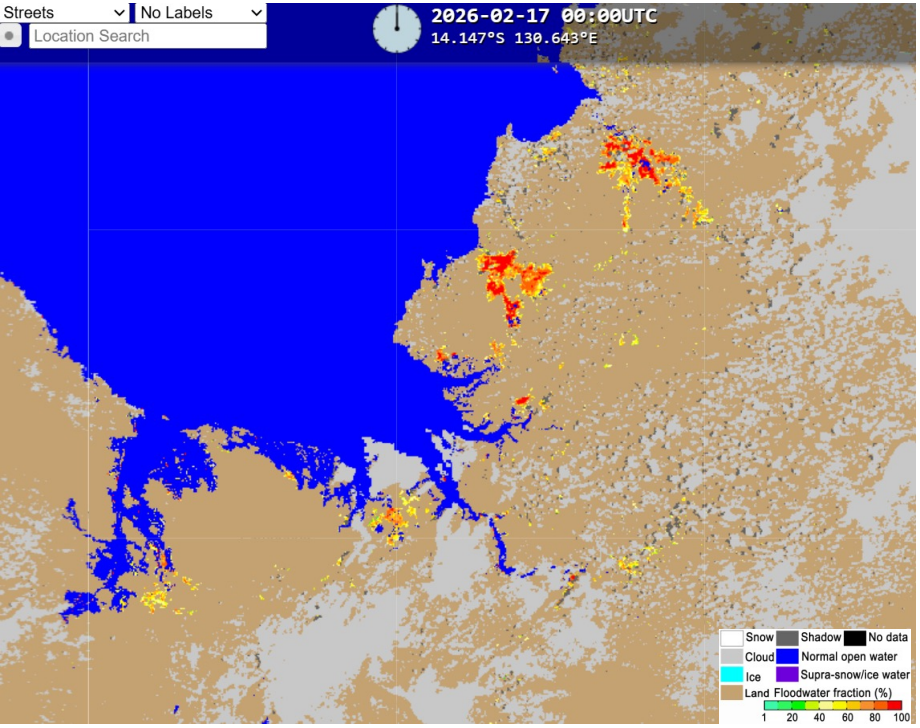
LEO Flood Mapping — SLSTR



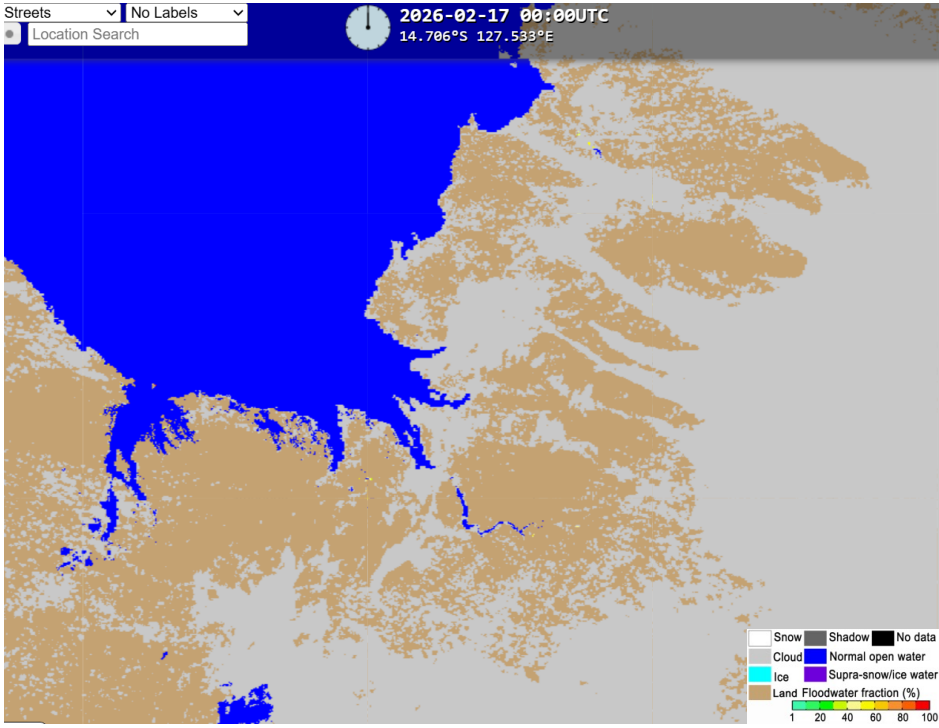
- Sentinel-3A/SLSTR global flood product provides 500-m flood maps in near real time: https://floods.ssec.wisc.edu/?products=SLSTR-flood
- As a morning satellite, Sentinel-3A can make up the deficiency of VIIRS with overpasses in the afternoon.



SLSTR vs VIIRS



Sentinel-3A/SLSTR flood map in Australia on Feb. 17, 2026



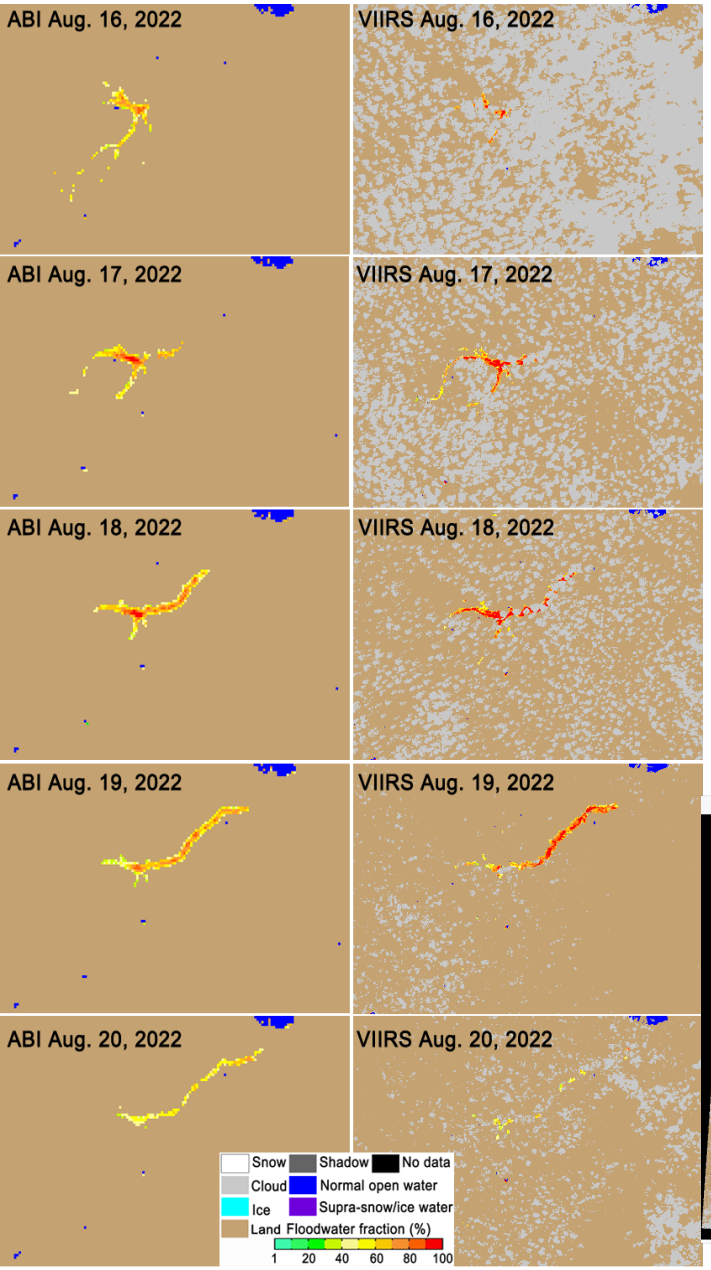
VIIRS flood map in Australia on Feb. 17, 2026

- Although Sentinel-3A data are with gaps in mid-low latitudes, the morning overpasses are still excellent data sources for flood mapping with better time manners.
- The 300-m Sentinel-3A/OLCI imagery can provide even better data sources for flood mapping together with SLSTR data.

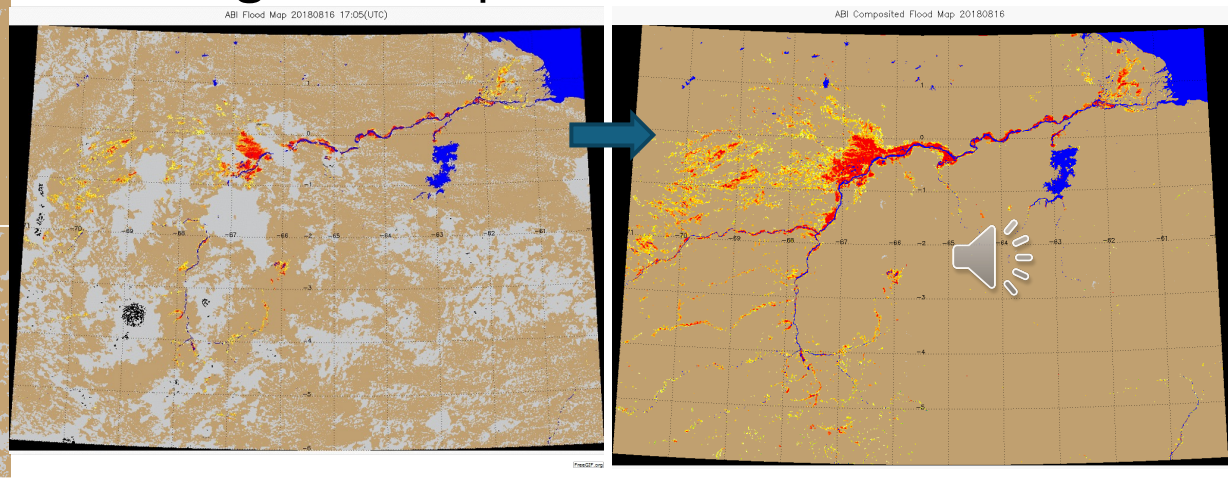
Advantages and Limitations of LEO Flood Mapping

- Advantages:
  - ✓ VIIRS imagery is with 3000km swath width without gaps even at the equator and constant 375-m spatial resolution across the scan in Imager bands (each satellite provides complete daily global coverage).
  - ✓ Other LEO sensors such as SLSTR and OLCI can provide morning observations for flood mapping.
  - ✓ 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
- Limitations:
  - ✓ Easily affected by clouds (hard to provide continuous monitoring on floods. Miss most flash floods caused by rainfall.
  - ✓ Limited observations during daytime in mid-low latitudes,
  - ✓ Moderate spatial resolution from 300 to 500 meters (unable to capture most minor floods)

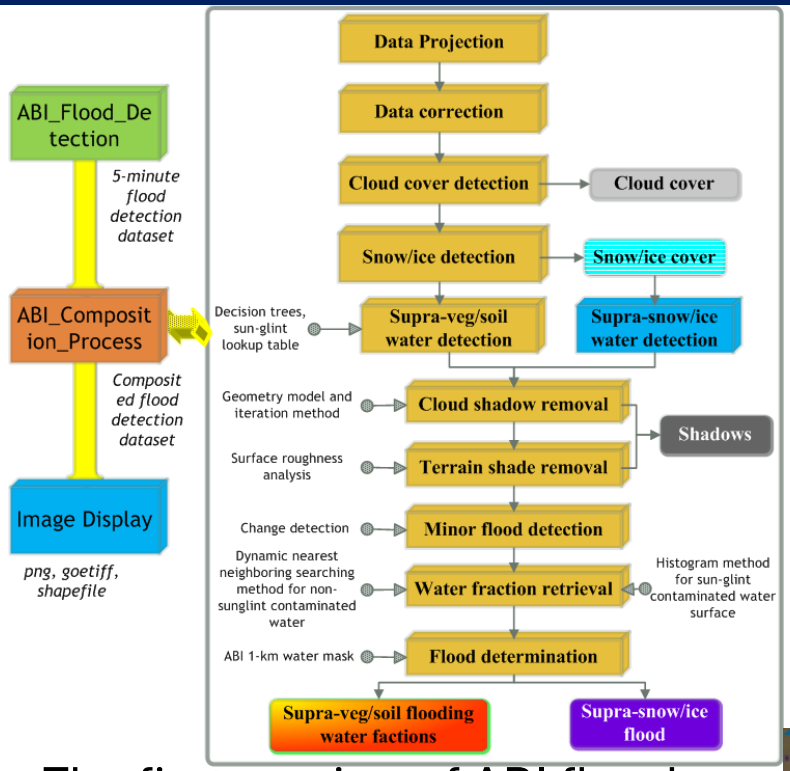
GEO Flood Mapping

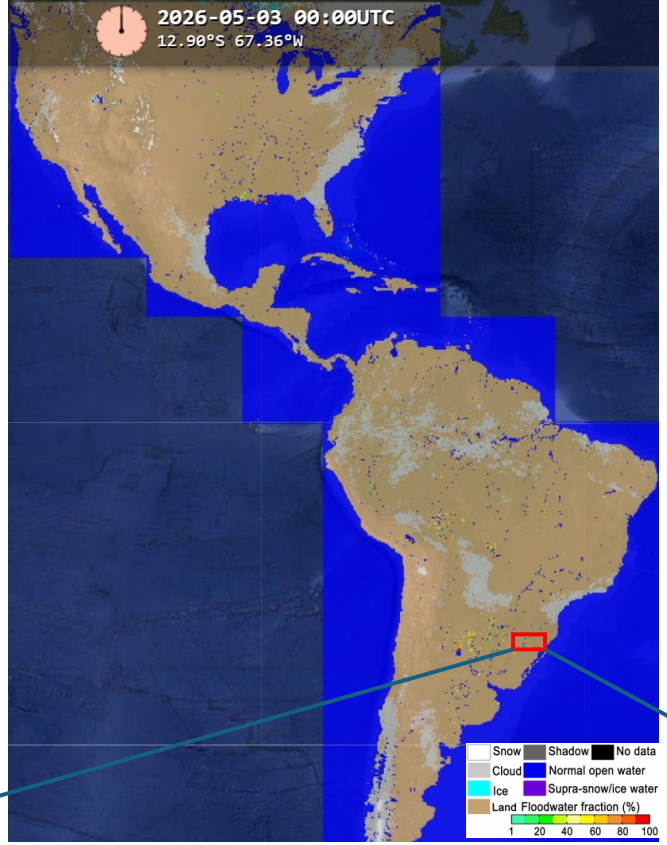


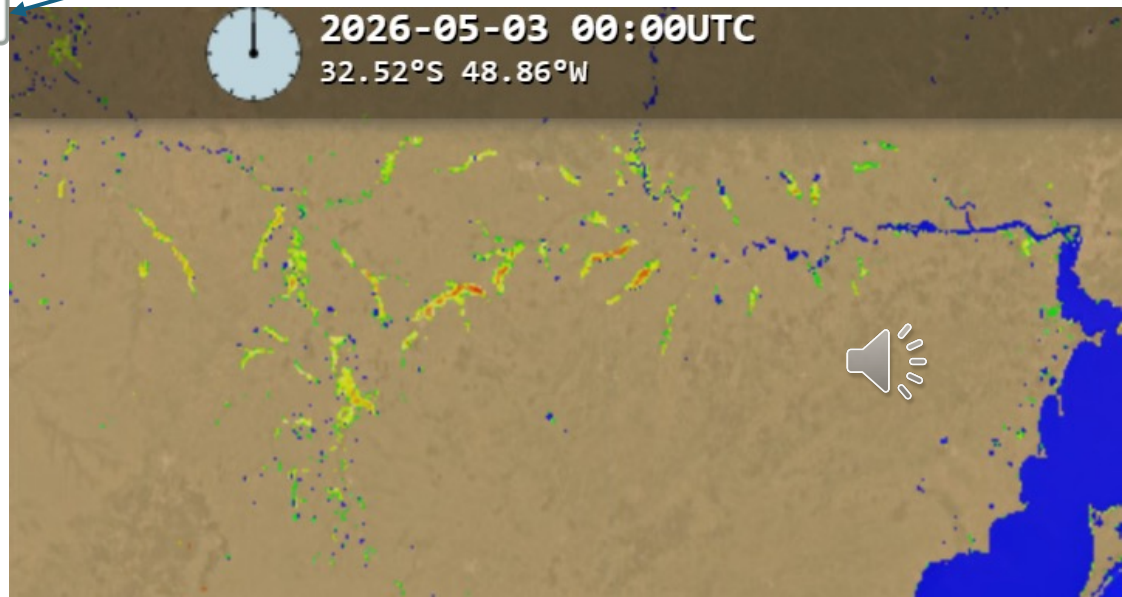
- With frequent observations every 5 or 10 minutes, GEO satellite imagery provide near real-time flood maps from early morning to late afternoon with the best time manners.
- Through a rolling composition process, the maximal clear-sky coverage during a day can be derived for flood mapping, which provides the most complete flood extent among all the optical satellites.



GEO Flood Mapping – ABI

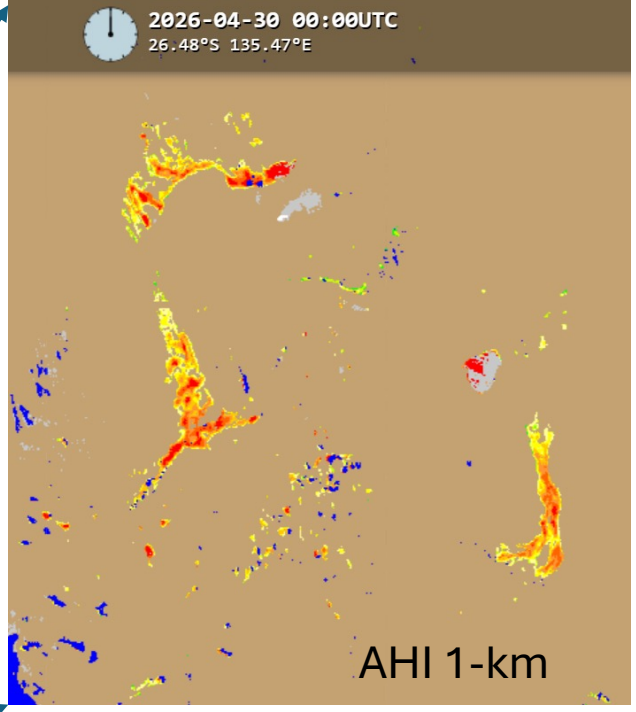


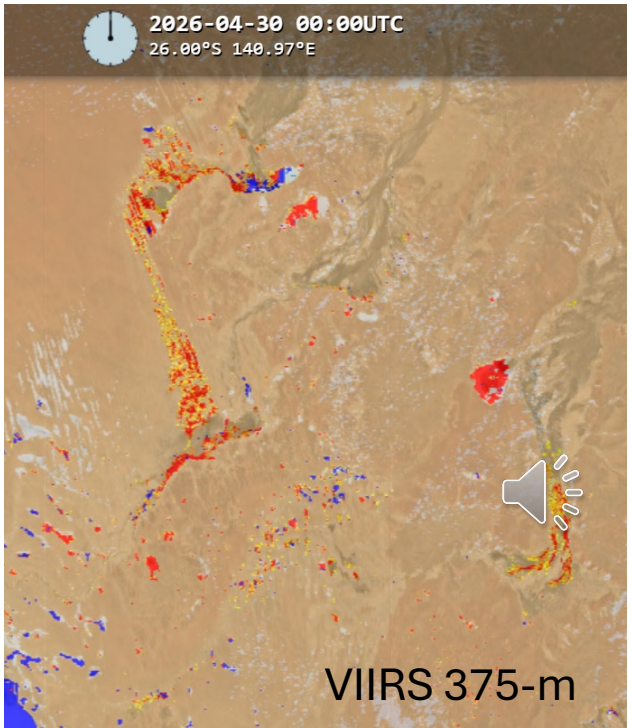




- The first version of ABI flood mapping software was released in 2018, and in 2023, NOAA declared the operational production of ABI flood product.
- Averagely, ABI flood product derives ~20% more clear-sky coverage than VIIRS flood product.

GEO Flood Mapping – AHI and FCI



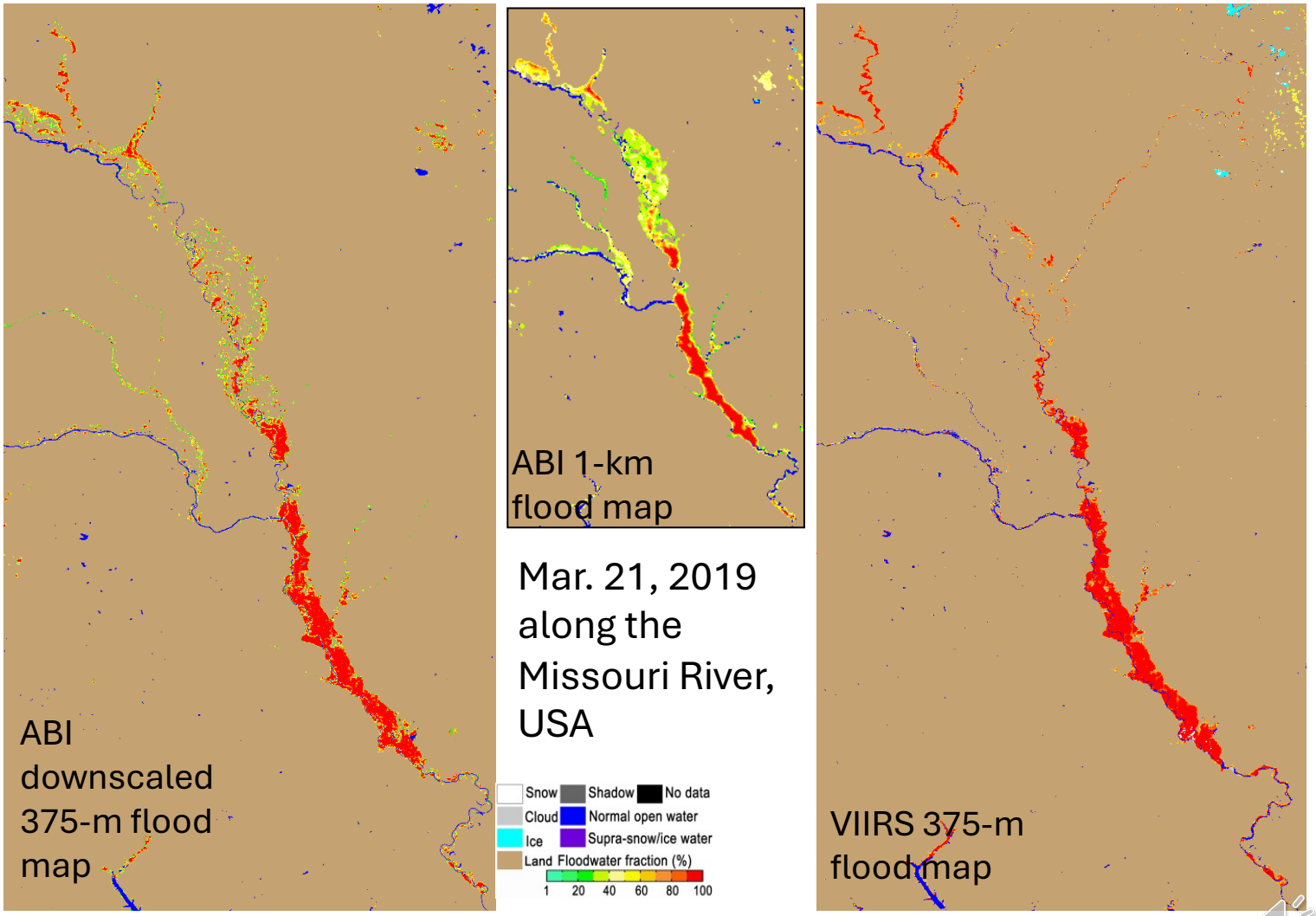


- Other GEO satellite data such as Himawari-8&9/AHI and MTG/FCI imagery can also been applied in flood mapping.

Advantages and Limitation of GEO Flood Mapping

- Advantages:
  - ✓ Dense observations every 5 to 10 minutes
  - ✓ Best time manners: data are available from early morning to late afternoon, which makes it possible to capture floods as earliest as possible.
  - ✓ Provide maximal clear-sky coverage for flood mapping: Averagely derives 20% extra clear-sky coverage than LEO imagery
- Limitations:
  - ✓ Can be affected by clouds (hard to provide continuous monitoring on floods. Miss most flash floods caused by rainfall.)
  - ✓ Coarse spatial resolution from 500 meters to 2 km at nadir region. Resolution decreases with the increase of distance to the nadir point.
    - ✓ unable to detect most minor floods
    - ✓ Data around North Pole and South Pole regions becomes unusable for flood mapping.

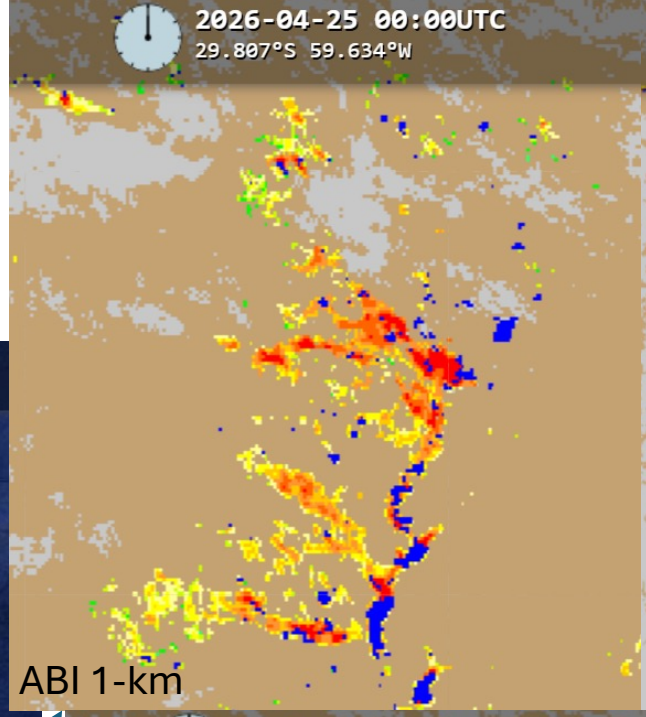
Joint GEO-LEO Flood Mapping



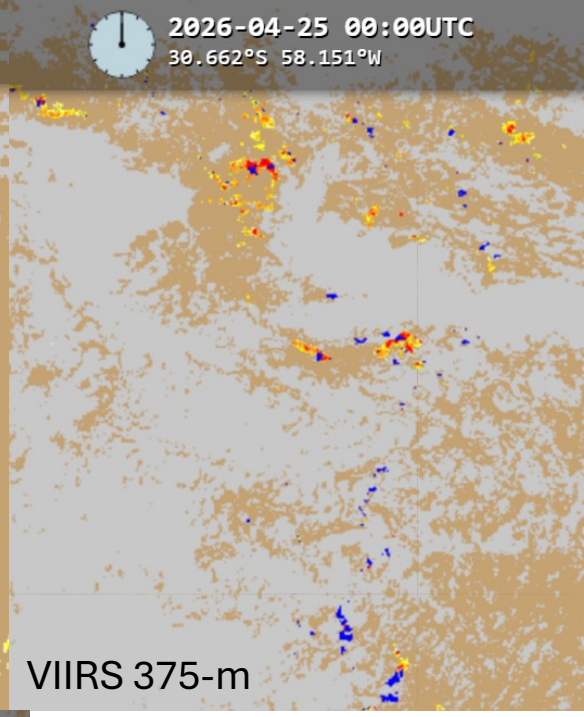
- With a simplified downscaling method, the ABI 1-km flood map can be downscaled into 375-m flood maps with similar quality of flood extent to VIIRS flood product. This makes it possible to fuse the GEO and LEO flood products into a joint flood product.

Joint GEO-LEO Flood Mapping — VIIRS/ABI

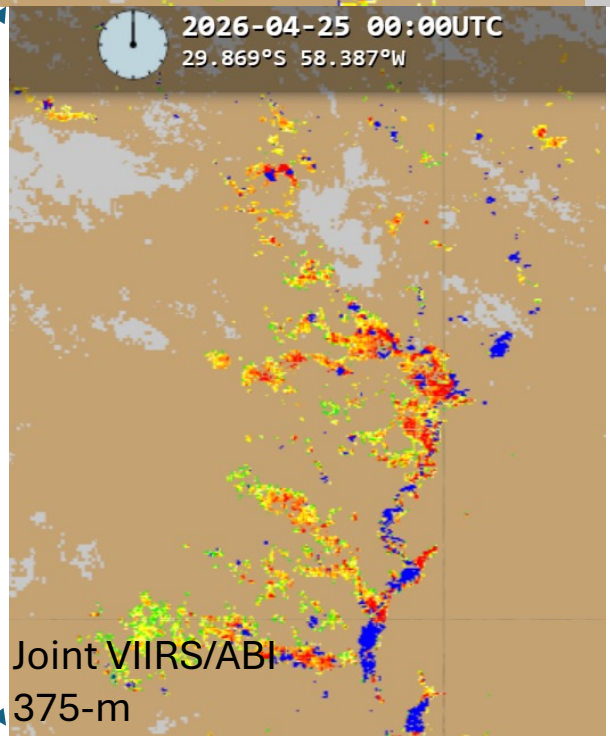
Joint VIIRS/ABI 375-m flood map on April 25, 2026



ABI 1-km



VIIRS 375-m

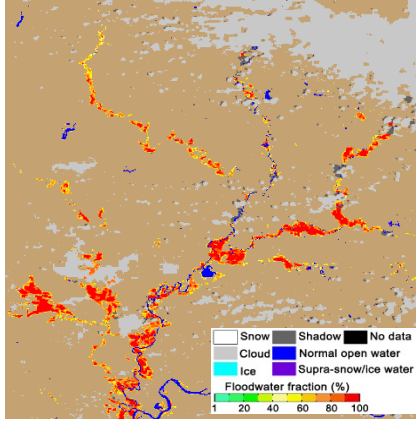


Joint VIIRS/ABI 375-m

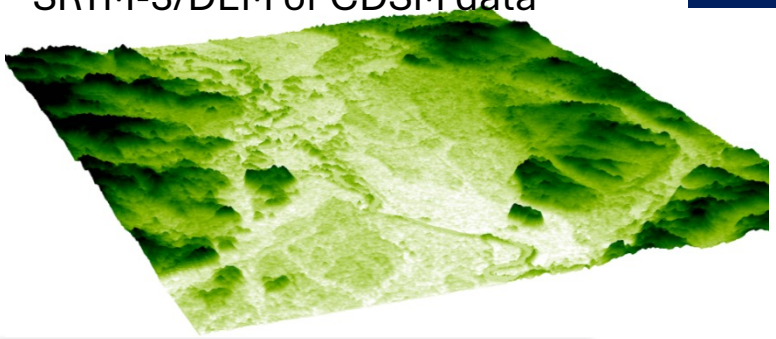
- The joint GEO-LEO flood products have the maximal clear-sky coverage from GEO imagery and finer spatial resolution from LEO imagery, which shows better flood extent than either GEO or LEO flood products.

3D Flood Mapping

- The downscaling model is developed to build the 3-D inundation structure from 2-D LEO and GEO flood products by using the high-resolution DEM and the fluid features of floodwater.

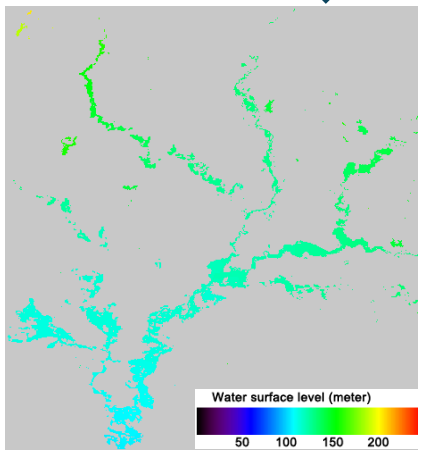


Digital Elevation Model: 30-m SRTM-3/DEM or CDSM data

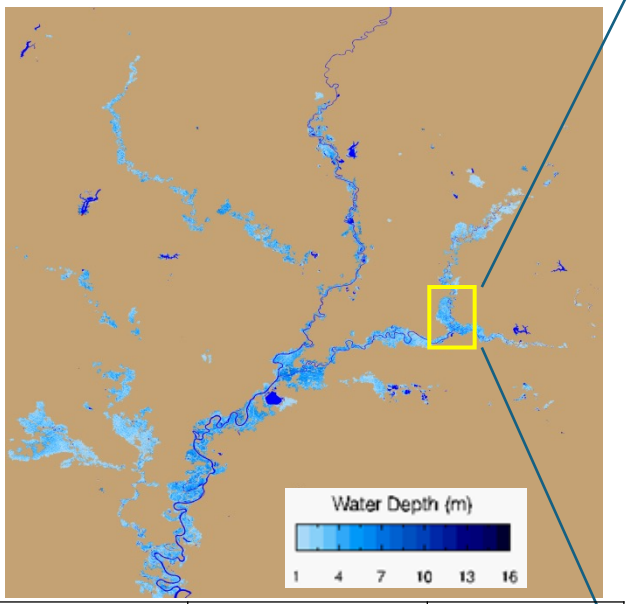


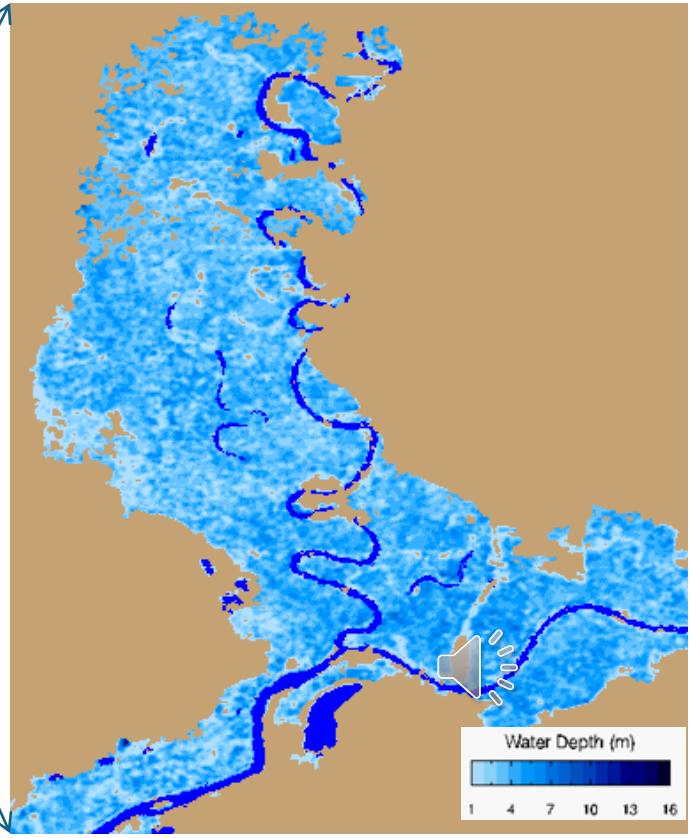
VIIRS 375-m floodwater fractions

Downscaling



VIIRS 375-m floodwater surface levels





VIIRS 30-m floodwater depth

Gauge No.	Gauge Name	Gauge Height (m)	VIIRS height(m)
3381495	Little Wabash river@Main ST, Carmel, IL	114.54	114
3381500	Little Wabash river a@ Carmel, IL	113.96	113
3377500	Wabash River @ MT, Carmel ,IL	121.65	121
3374100	White River @ Hazleton, In	124.61	126

Downscaling Model

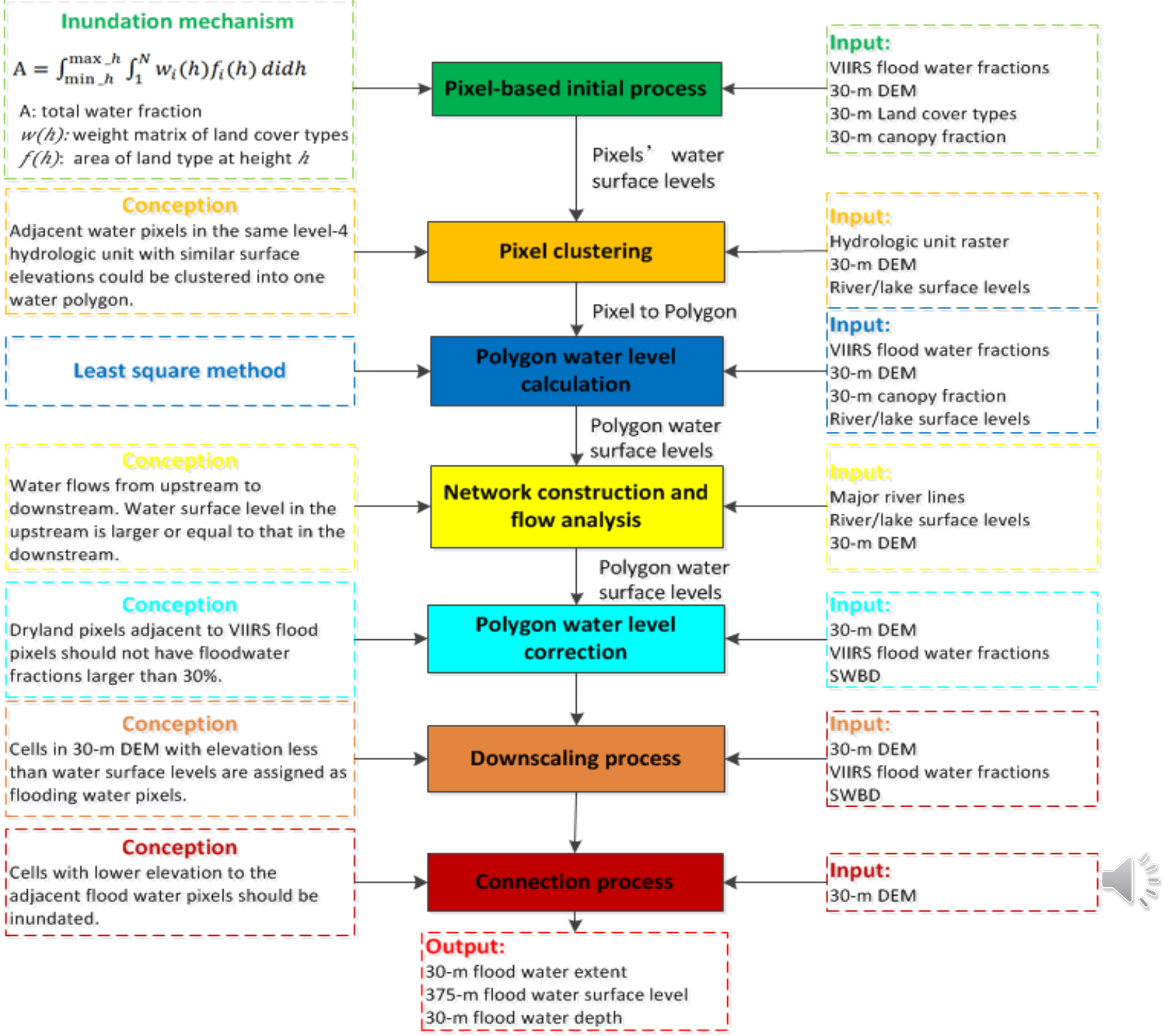
- The inundation mechanism can be expressed as:

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

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.

- ✓ $\max\_h$: floodwater surface level
- ✓ Flood water depth: $\max\_h$ - h

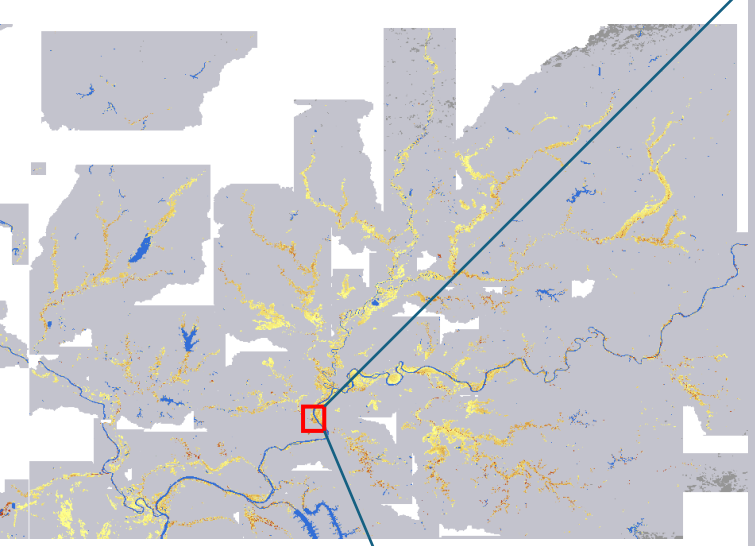
- River network analysis:
  - ✓ To make river flow smoothly from upstream to downstream.
  - ✓ To decrease the uncertainties of floodwater surface levels of a single floodwater polygon by using the floodwater surface levels along a river.


Inundation mechanism
$A = \int_{min\_h}^{max\_h} \int_{1}^{N} w_i(h) f_i(h)\, didh$
A: total water fraction
w(h): weight matrix of land cover types
f(h): area of land type at height h
Pixel-based initial process
Input:
VIIRS flood water fractions
30-m DEM
30-m Land cover types
30-m canopy fraction
Pixels' water surface levels
Conception
Adjacent water pixels in the same level-4 hydrologic unit with similar surface elevations could be clustered into one water polygon.
Pixel clustering
Input:
Hydrologic unit raster
30-m DEM
River/lake surface levels
Pixel to Polygon
Least square method
Polygon water level calculation
Input:
VIIRS flood water fractions
30-m DEM
30-m canopy fraction
River/lake surface levels
Polygon water surface levels
Conception
Water flows from upstream to downstream. Water surface level in the upstream is larger or equal to that in the downstream.
Network construction and flow analysis
Input:
Major river lines
River/lake surface levels
30-m DEM
Polygon water surface levels
Conception
Dryland pixels adjacent to VIIRS flood pixels should not have floodwater fractions larger than 30%.
Polygon water level correction
Input:
30-m DEM
VIIRS flood water fractions
SWBD
Conception
Cells in 30-m DEM with elevation less than water surface levels are assigned as flooding water pixels.
Downscaling process
Input:
30-m DEM
VIIRS flood water fractions
SWBD
Conception
Cells with lower elevation to the adjacent flood water pixels should be inundated.
Connection process
Input:
30-m DEM
Output:
30-m flood water extent
375-m flood water surface level
30-m flood water depth

3D Flood Mapping from LEO and GEO

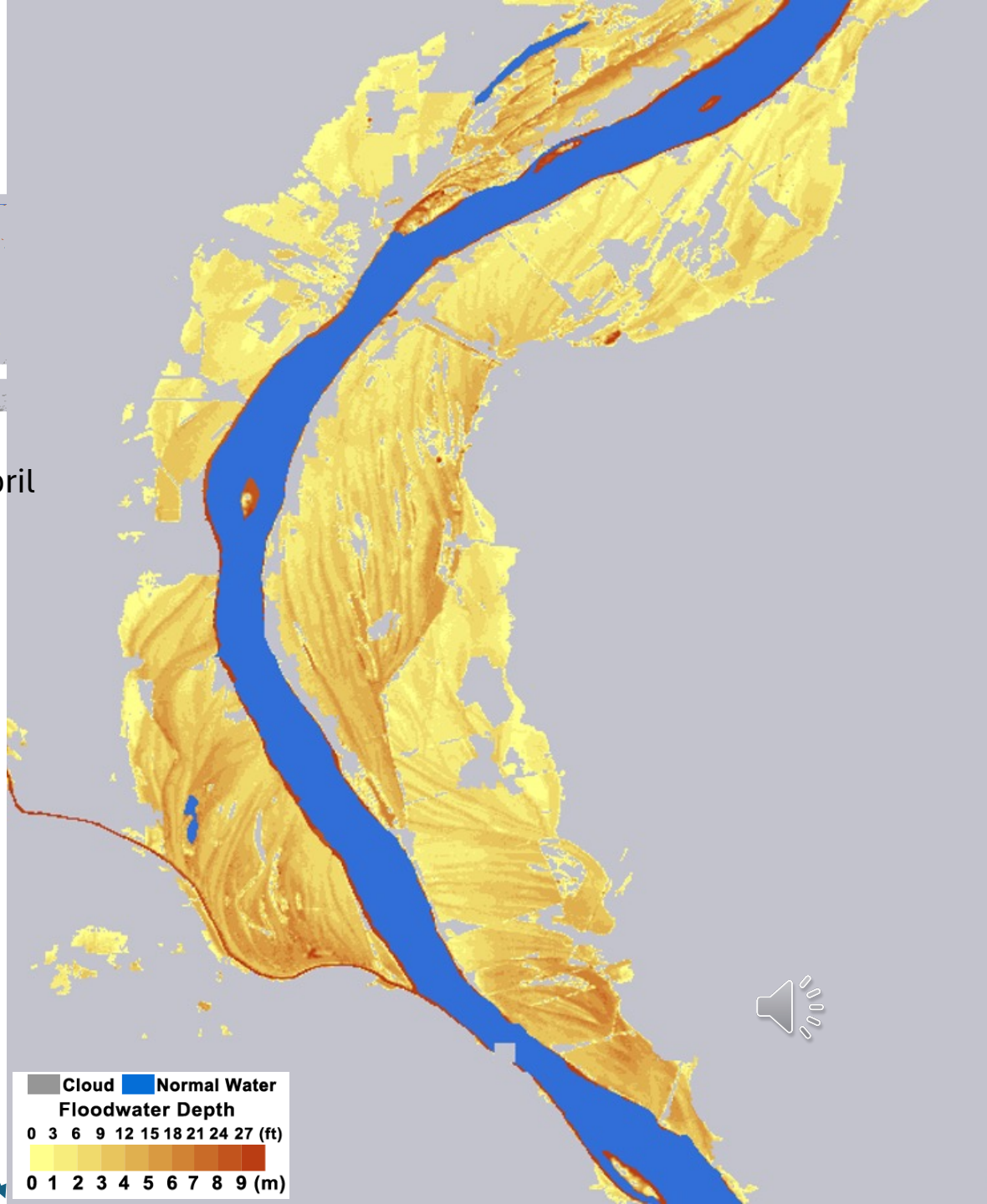
	Spatial resolution	Global coverage	Flood detection
LEO/GEO Imagery	300 m~2km	10 minutes or daily	2-D flood extent
3D LEO/GEO flood maps	30 m	10 minutes or daily	flood depths, floodwater surface levels
Landsat-8 OLI imagery	30 m	16 days	2-D flood extent

- Provide much larger-scale 30-m flood maps than high-resolution satellite images such as Landsat-8.
- Provide continuous 3-D inundation information (flood extent, floodwater surface levels and floodwater depth) rather than 2-D flood extent and discrete gauge height observations.
- A balance of low cost (daily global data availability), fast process (~10 minutes for one river basin) and reasonable accuracy.
- Provide possibility and base products for flood simulation and forecasting from LEO and GEO imagery.

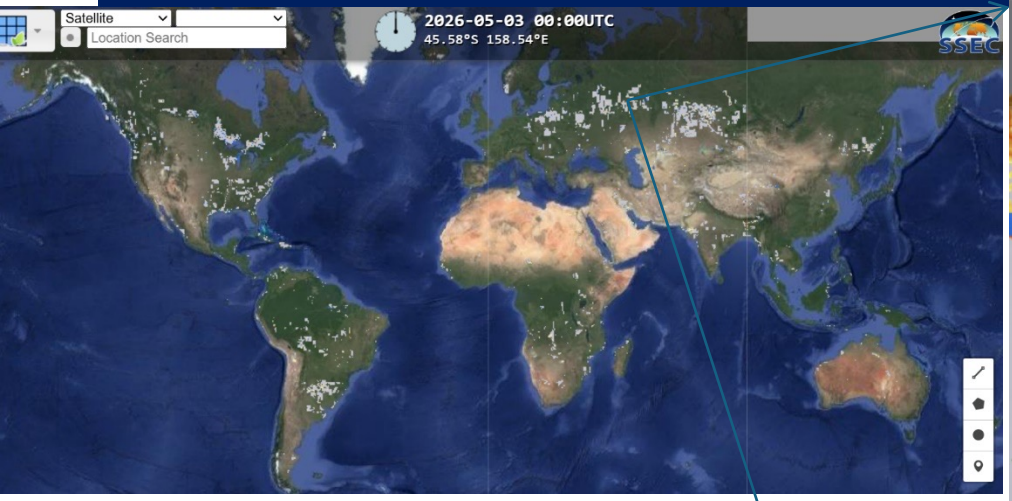


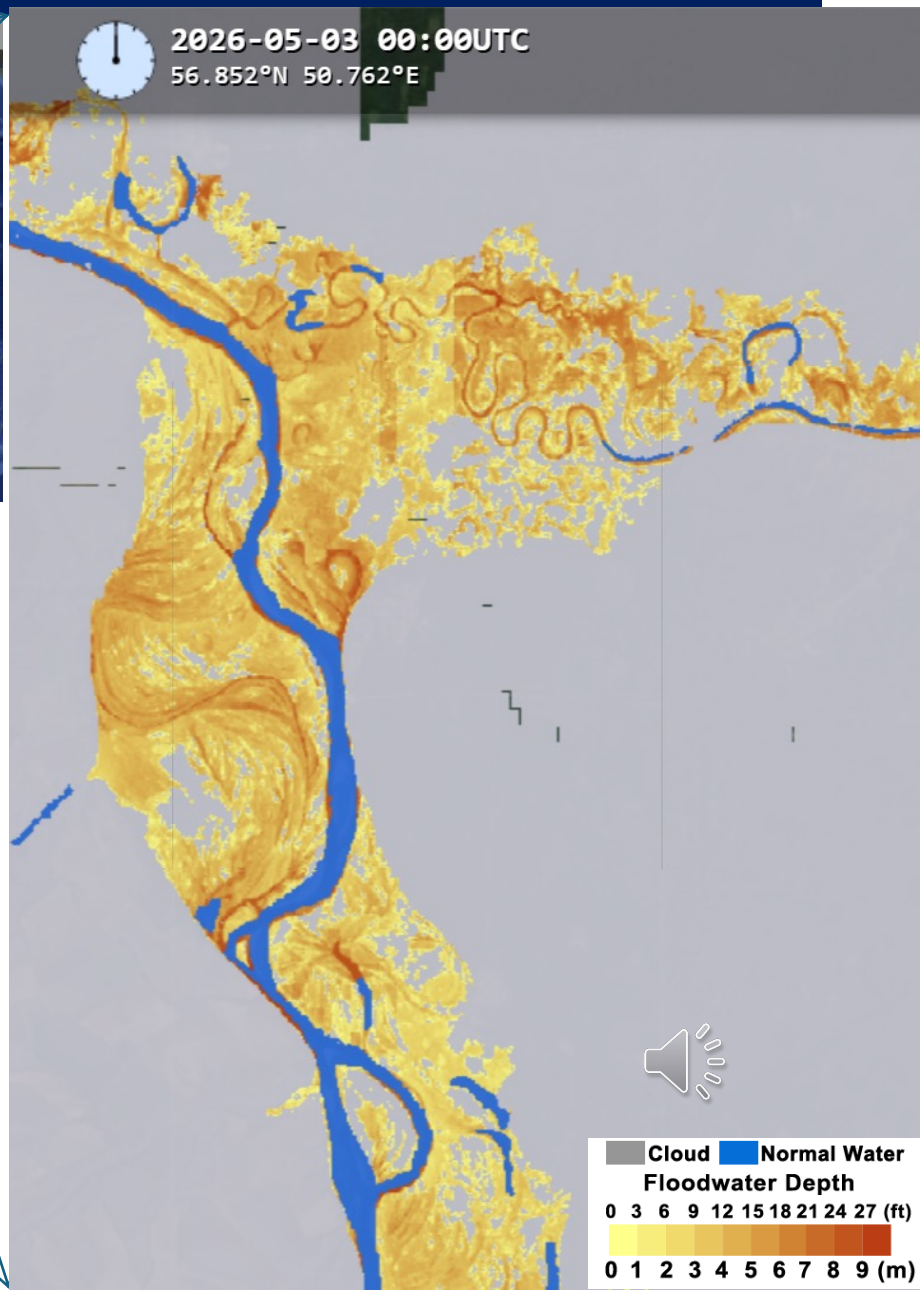
VIIRS 30-m floodwater depth map on April 07, 2025 in the Ohio River Basin, USA

- Fast process: It takes half an hour to derive a 30-m floodwater depth map covering the entire Ohio River Basin.
- Ground survey may take days to derive a complete set of images covering the river basin.
- High-resolution satellites such as Landsat-8&9 have narrow swath width and long revisiting interval.



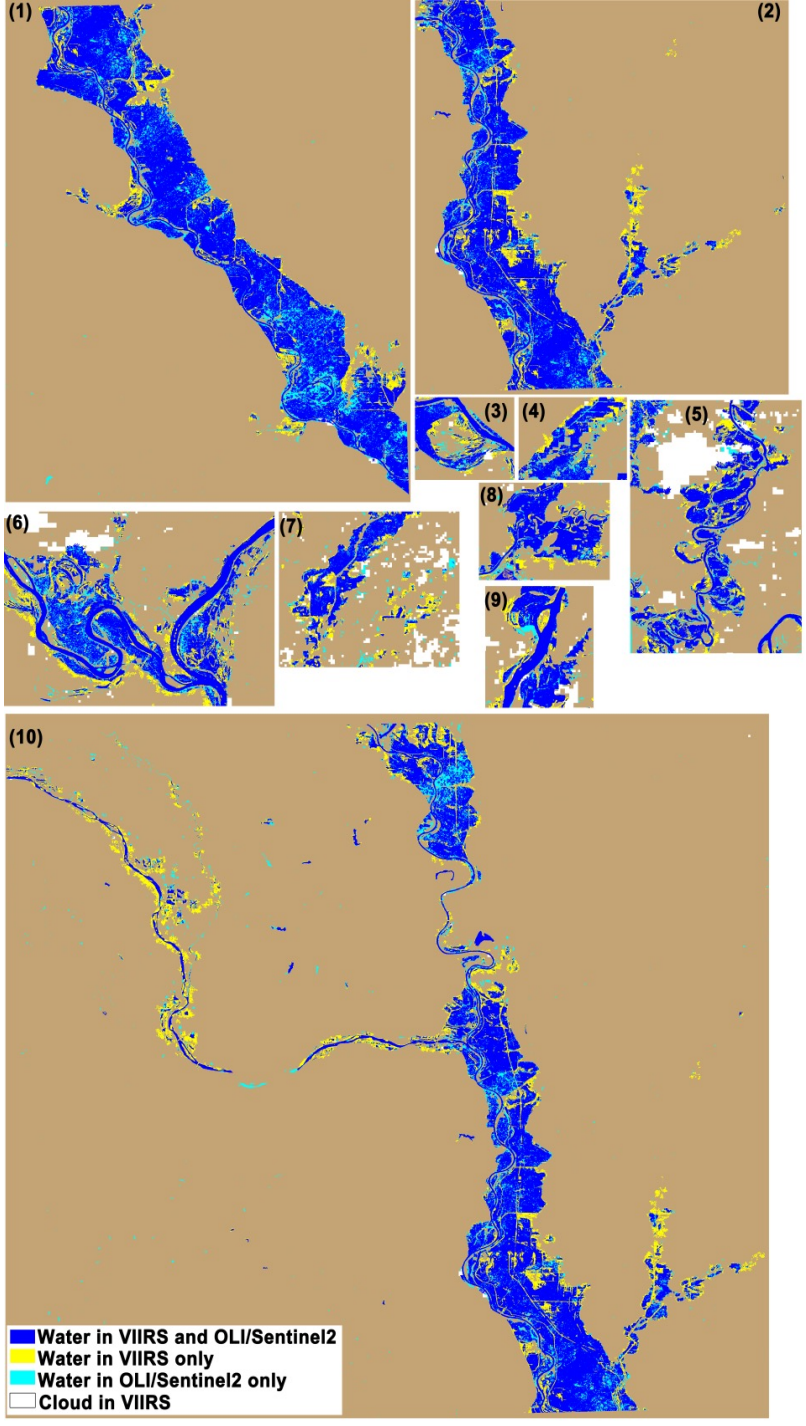
Global VIIRS 30-m floodwater depth Product





VIIRS global daily 30-m floodwater depth maps are now available in Real Earth: http://floods.ssec.wisc.edu/?products=VIIRS-3Dflood

Validation



Validation results of VIIRS downscaled flood maps with SRTM/DEM against Landsat-8 OLI/Sentinel-2 images

	N_{V_L}	N_V	N_L	N_C	$N_{V\_no\_L}$	$N_{L\_no\_V}$	P_C(%)	P_O(%)	P_E(%)
Region 1	596352	716416	691474	663	120064	94459	86.33	13.67	16.76
Region 2	812215	913102	985795	1123	100887	172457	82.49	17.51	11.05
Region 3	65090	84323	81459	633	19233	15736	80.53	19.47	22.81
Region 4	69809	87533	89489	100	17724	19580	78.10	21.90	20.25
Region 5	236899	307180	301031	11528	70281	52604	81.83	18.17	22.88
Region 6	338667	438637	429267	3539	99970	87061	79.55	20.45	22.79
Region 7	107318	153145	138532	2686	45827	28528	79.00	21.00	29.92
Region 8	114364	138825	132284	11	24461	17909	86.46	13.54	17.62
Region 9	119518	143968	136457	1329	24450	15610	88.45	11.55	16.98
Region 10	855633	1129690	1037143	761	274057	176780	82.56	17.06	24.26

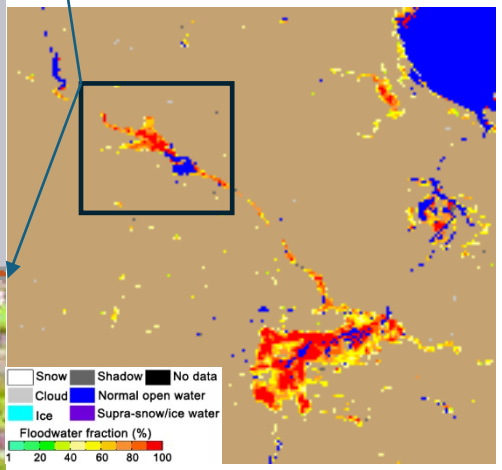
Validation

VIIRS 30-m floodwater depth map on May 20, 2020

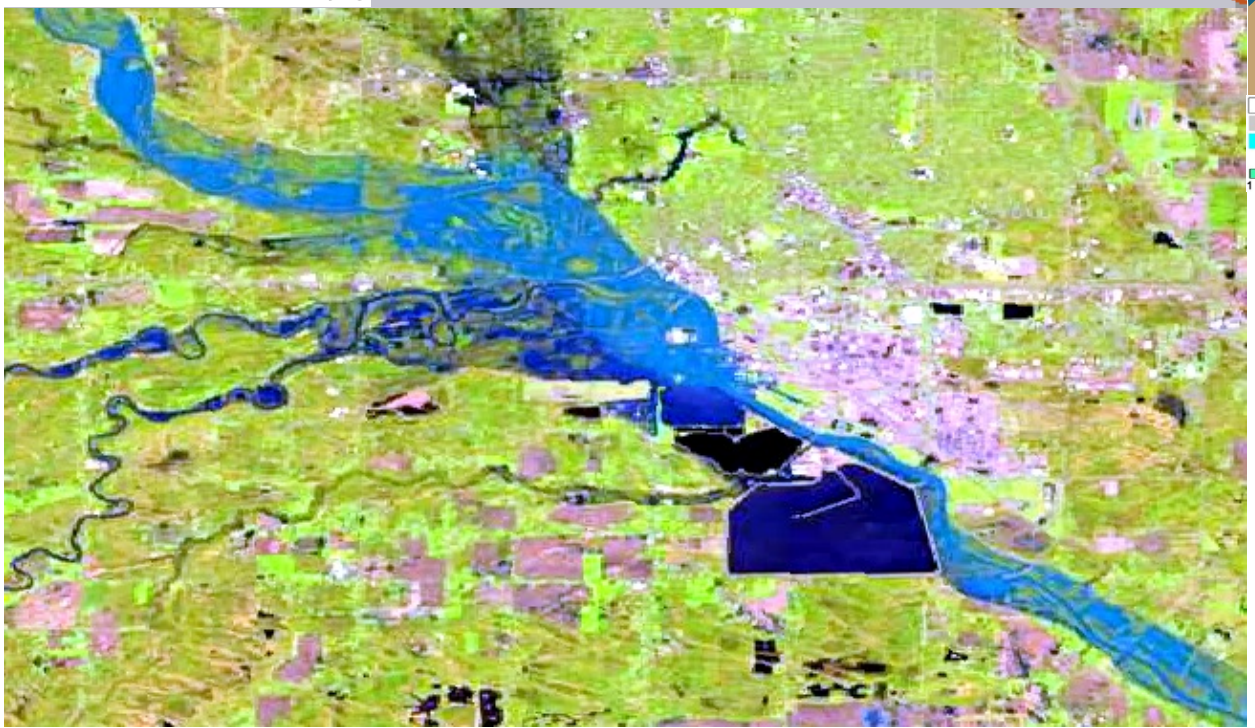
Midland

Cloud Normal Water
Floodwater Depth
0 3 6 9 12 15 18 21 24 27 (ft)
0 1 2 3 4 5 6 7 8 9 (m)

Flood due to Sanford dam failure in central Michigan on May 20, 2020

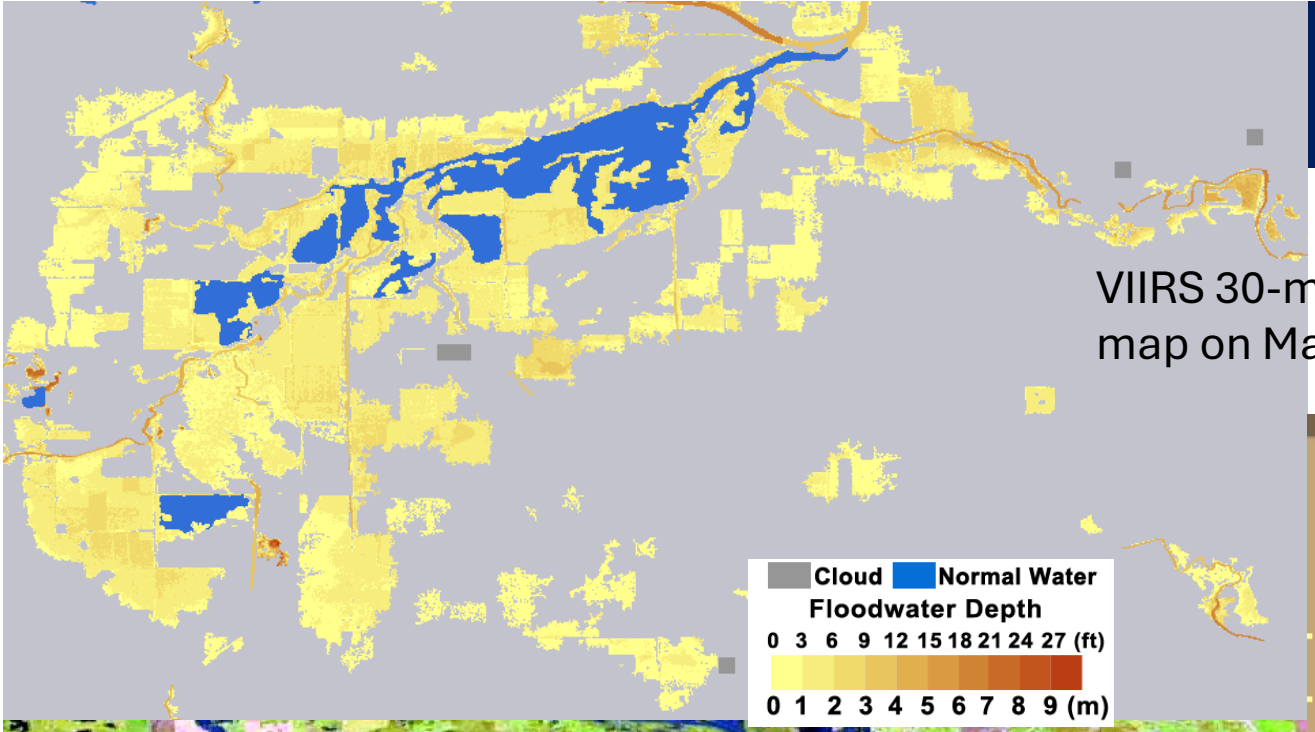


VIIRS 375m flood map on May 20, 2020

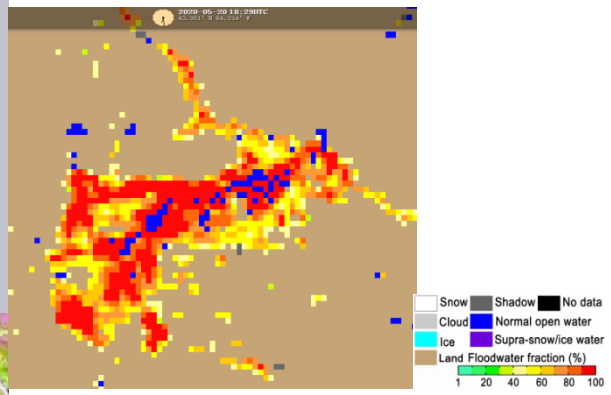


Landsat-8/OLI May 20, 2020

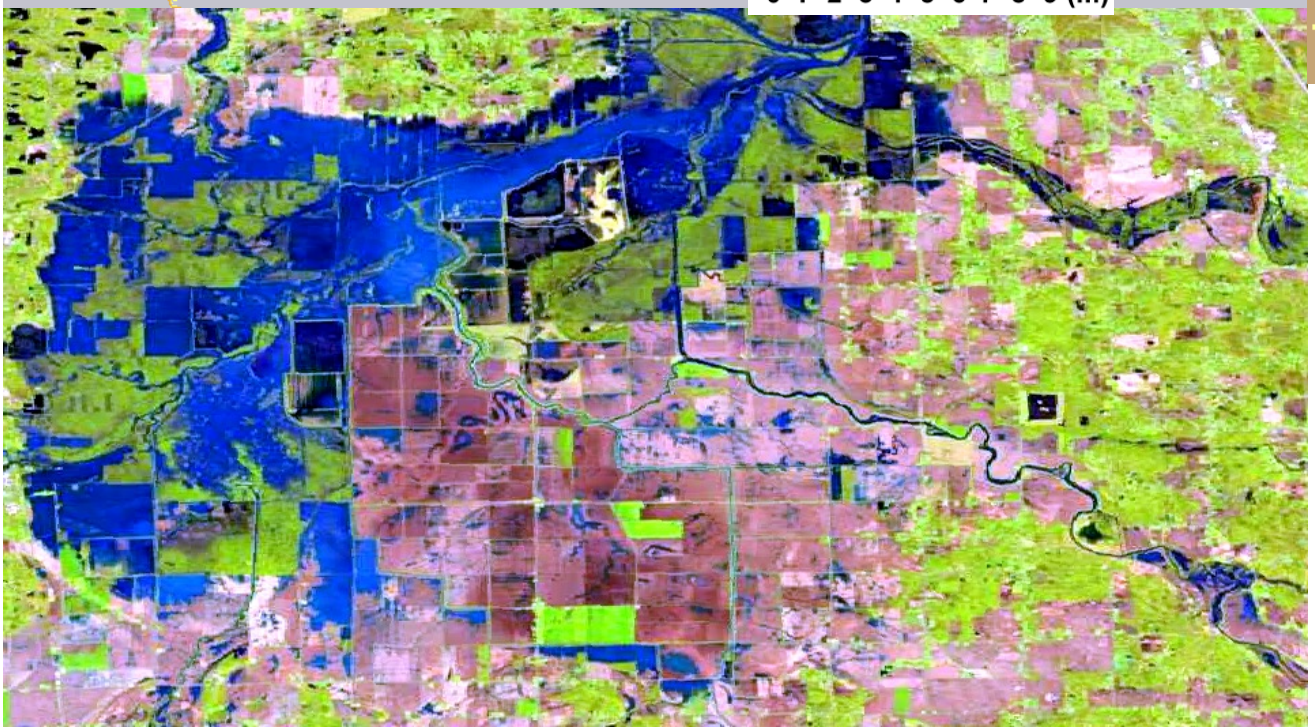
Validation



VIIRS 30-m floodwater depth map on May 20, 2020



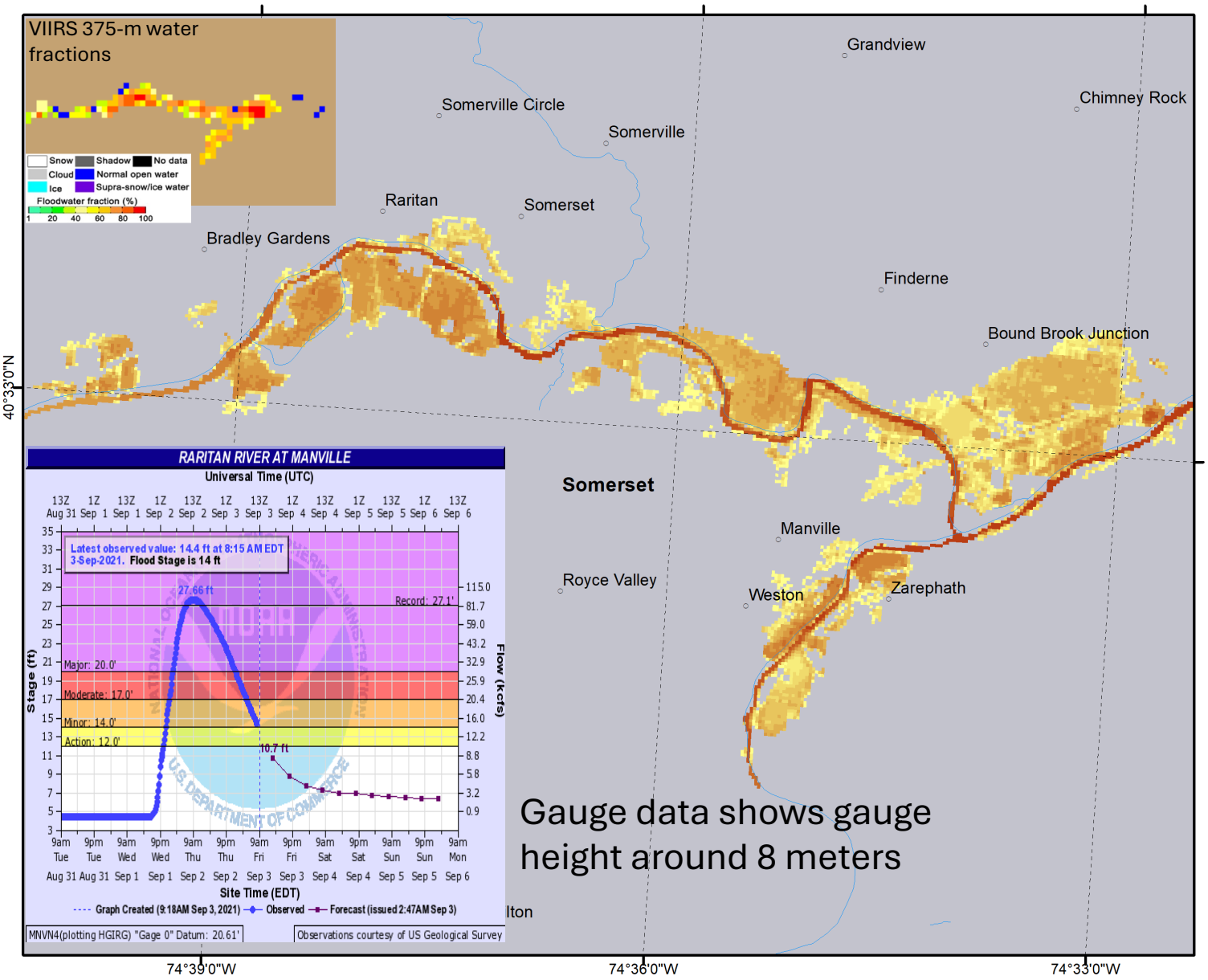
VIIRS 375m flood map on May 20, 2020



Landsat-8/OLI May 20, 2020

Suomi-NPP&NOAA-20/VIIRS Downscaled 30-m Flood Map in New Jersey, USA

Downscaled 30-m Floodwater Depth on Sep.02, 2021



Map Information

Miles
0 0.5 1

N

Projection: UTM, Zone 19 N
Coordinate System: GCS WGS1984
Unit: meters

Legend

- cities
- river
- County border
- Cloud
- Normal Water

Floodwater Depth (m)

0 1 2 3 4 5 6 7 8 9 ≥10

Data Source

Satellite Imagery

Satellite/sensor:
Suomi-NPP&NOAA-20/VIIRS

GIS data

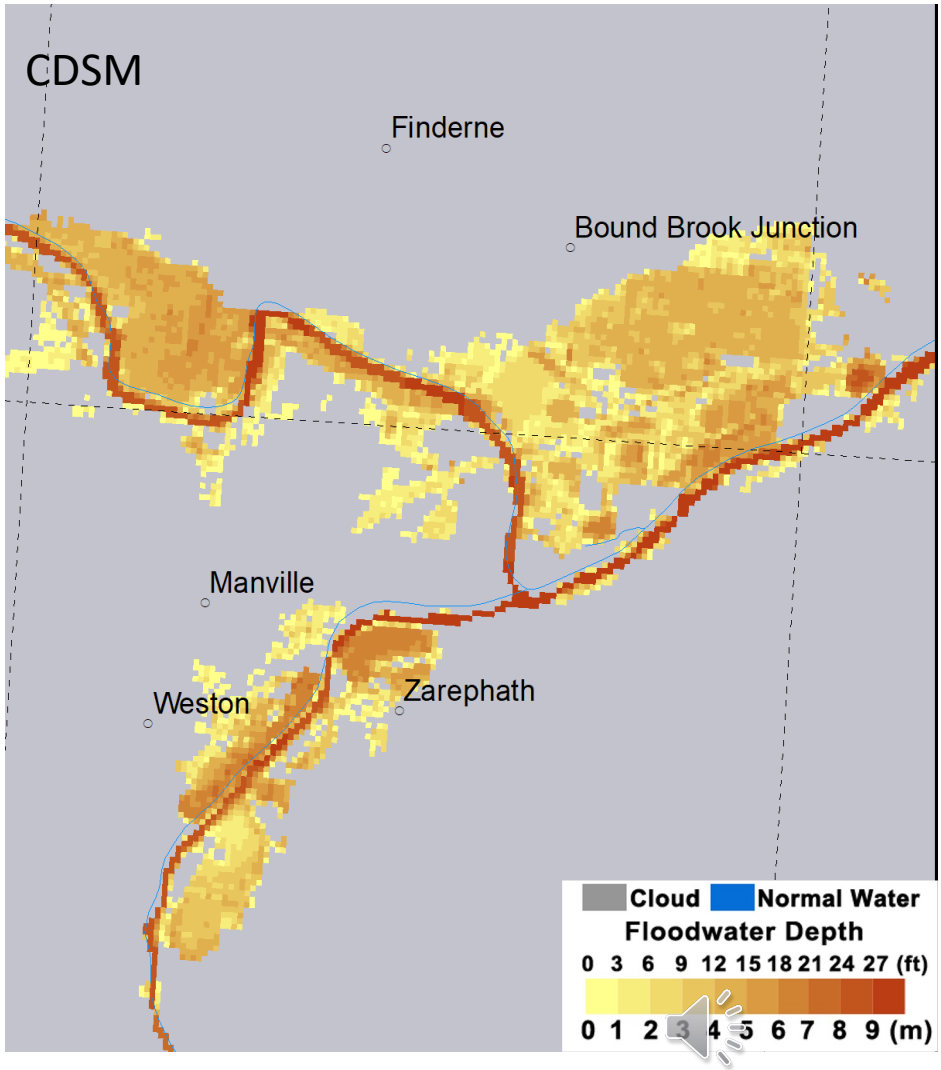
Adminstrative boundary and cities: GDAM

Description

This flood map is a 30-m flood water depth map downscaled from Suomi-NPP&NOAA-20 VIIRS image on Sep. 02, 2021, which reflects the flood extent and water depth under clear-sky coverage in New Jersey due to Hurricane Ida.

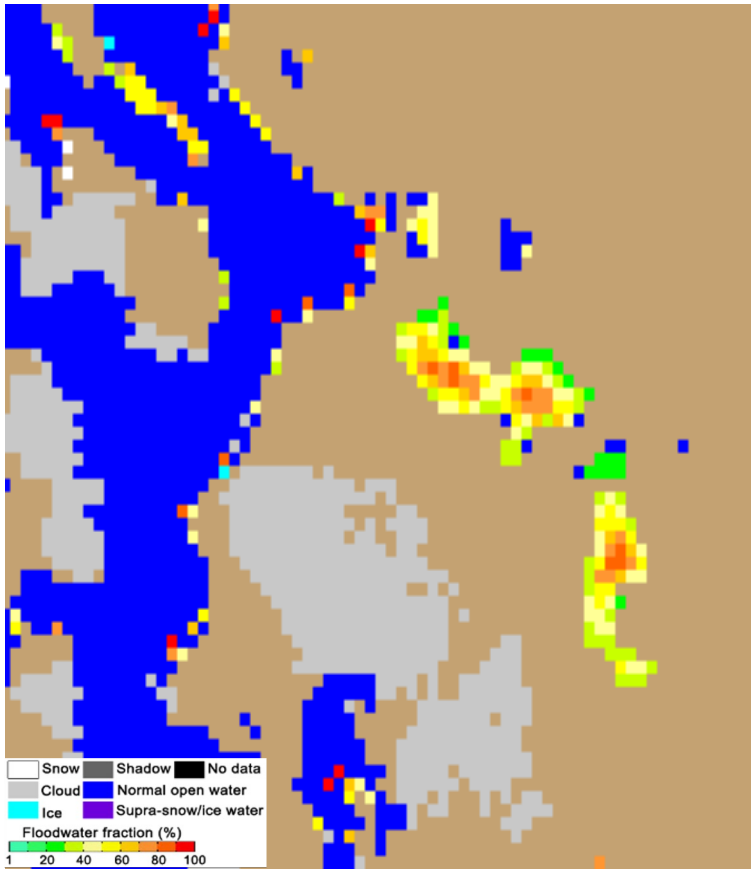
Validation

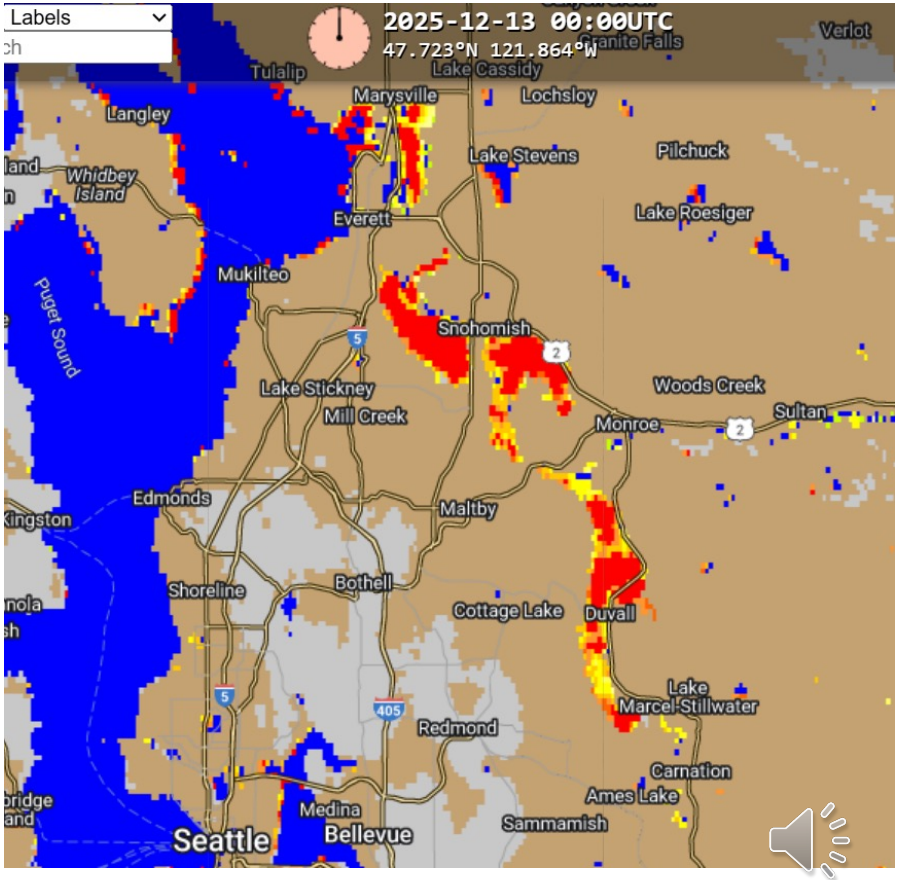
Geo-Eye image on Sep. 02, 2021



VIIRS 30-m floodwater depth map on Sep. 02, 2021

Is it possible to downscale the ABI 1-km flood product to 30-m floodwater depth product?

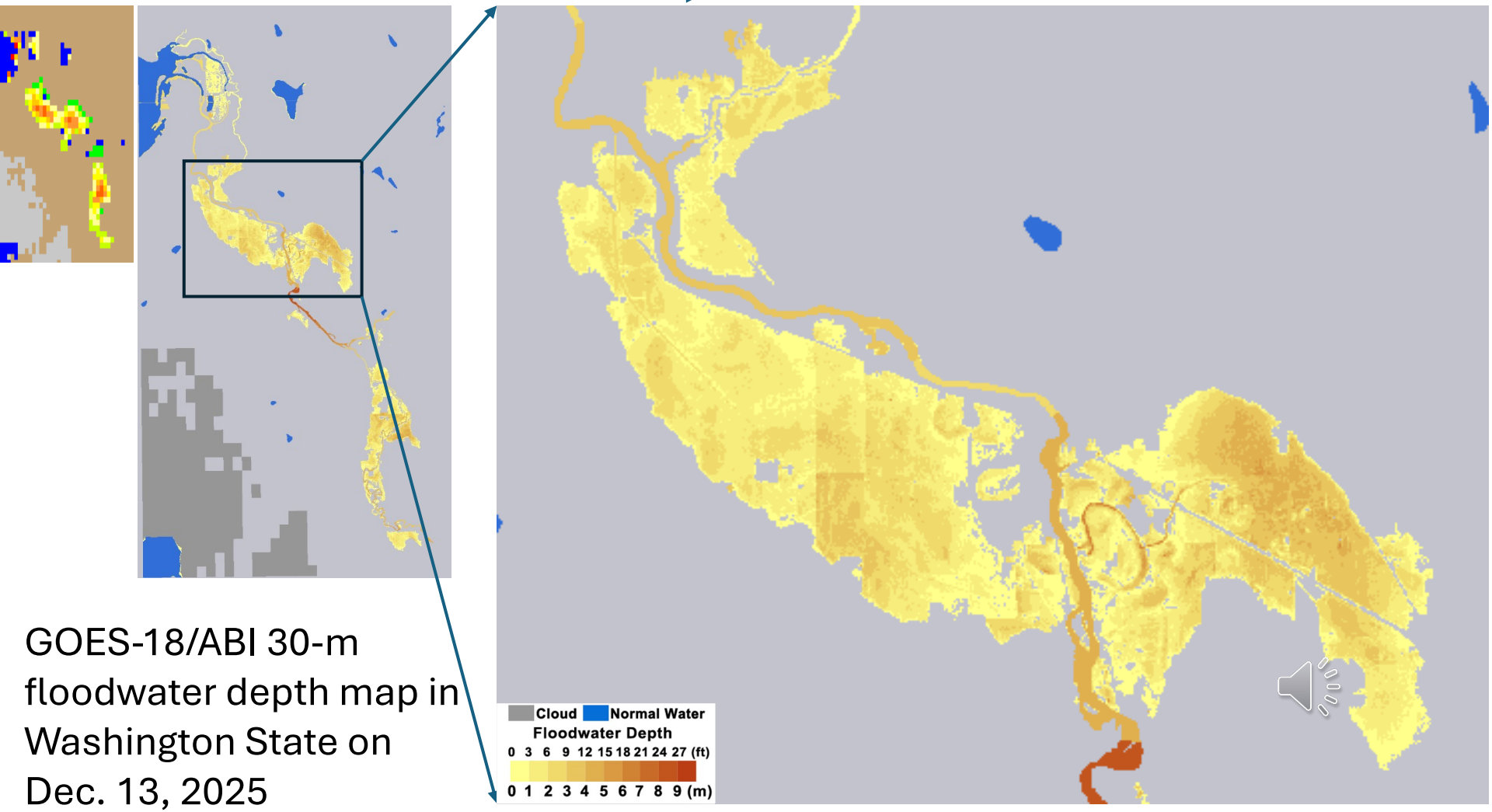




Comparison between flood maps on Dec. 13, 2025 in Washington State, USA, left: GOES-18/ABI 1-km , right: VIIRS 375-m

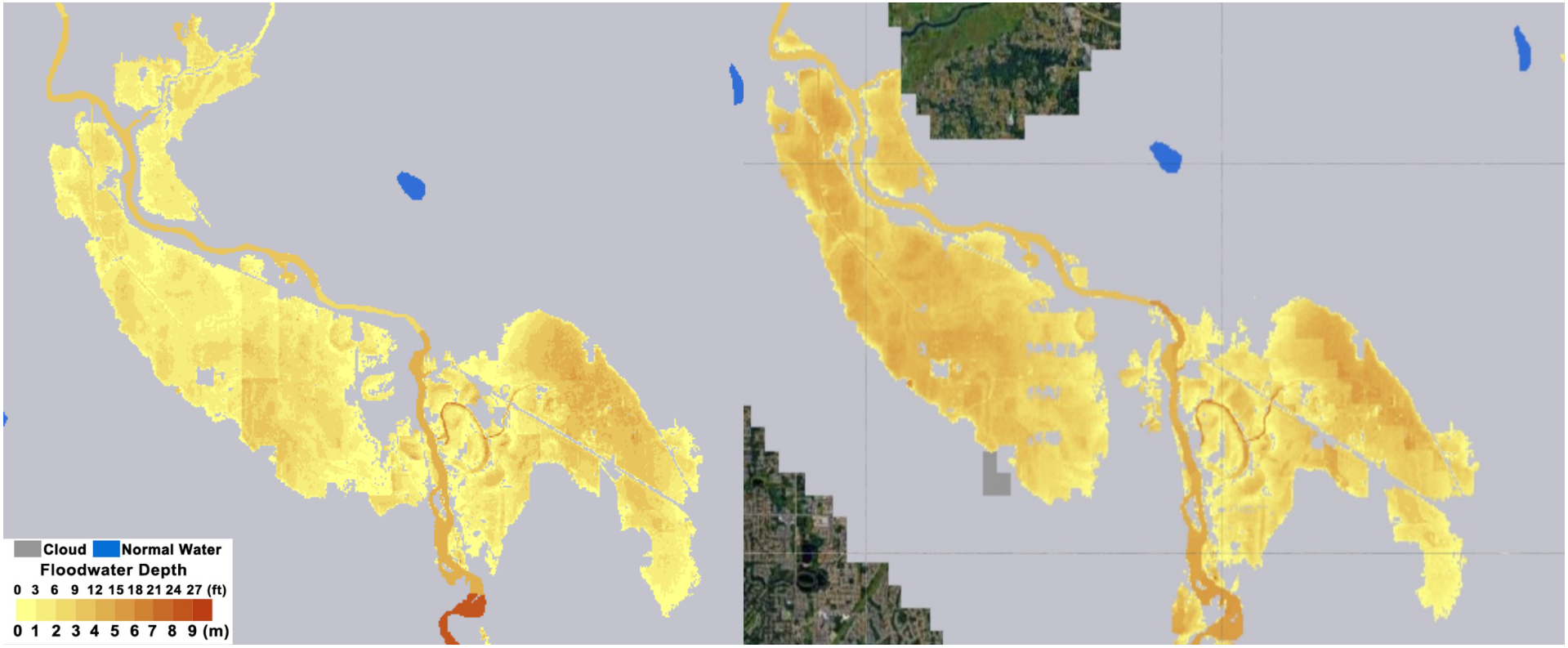
ABI Downscaling Process

From 1-km to 30-m



GOES-18/ABI 30-m floodwater depth map in Washington State on Dec. 13, 2025

ABI 30m vs VIIRS 30m

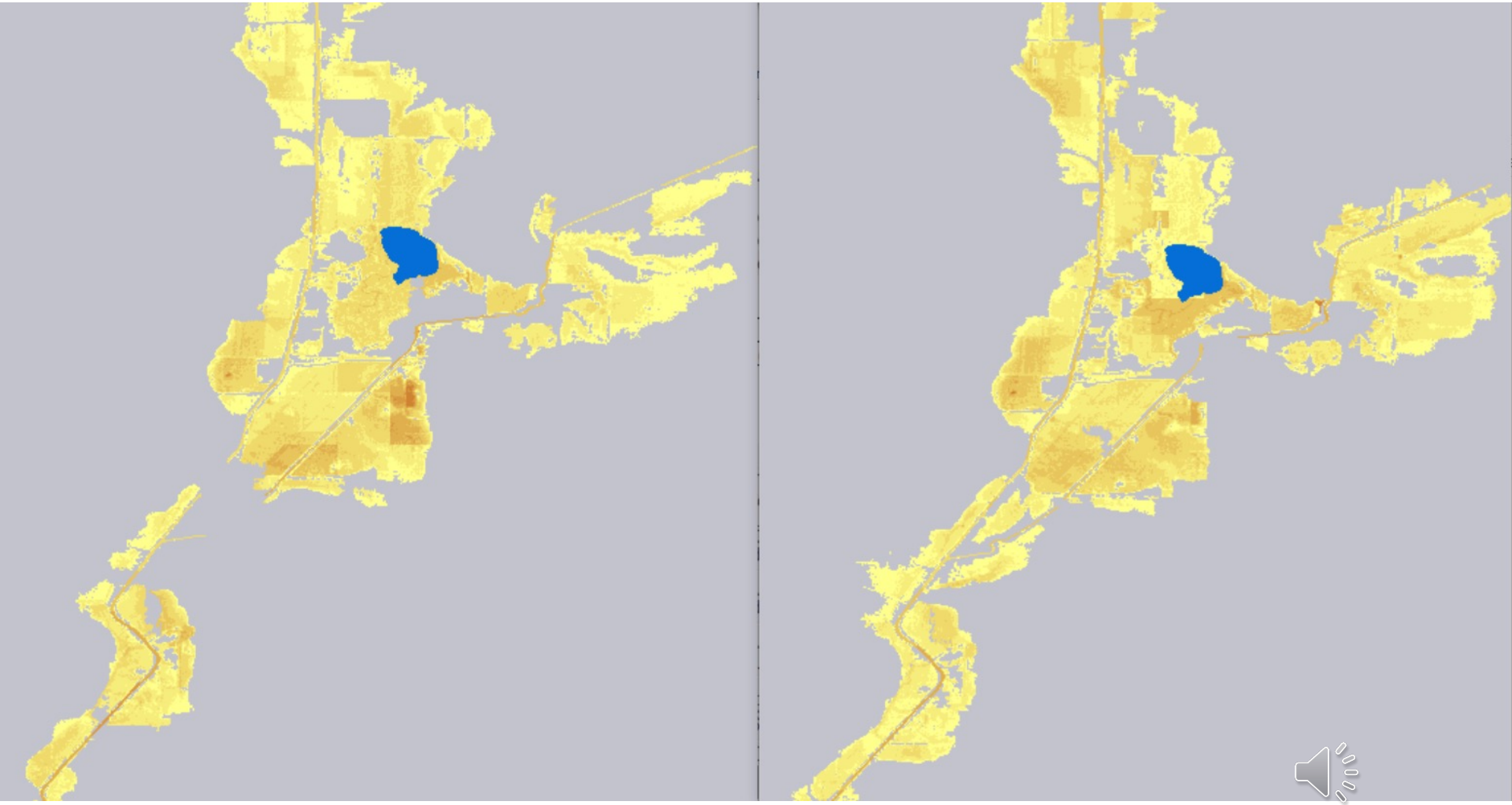


G18/ABI 30-m floodwater depth map on Dec. 13, 2025

VIIRS 30-m floodwater depth map on Dec. 13, 2025

ABI 30-m floodwater depth map (left) in WA, USA on Dec. 13, 2025 from a preliminary test shows consistent flood extent to the VIIRS result (right).

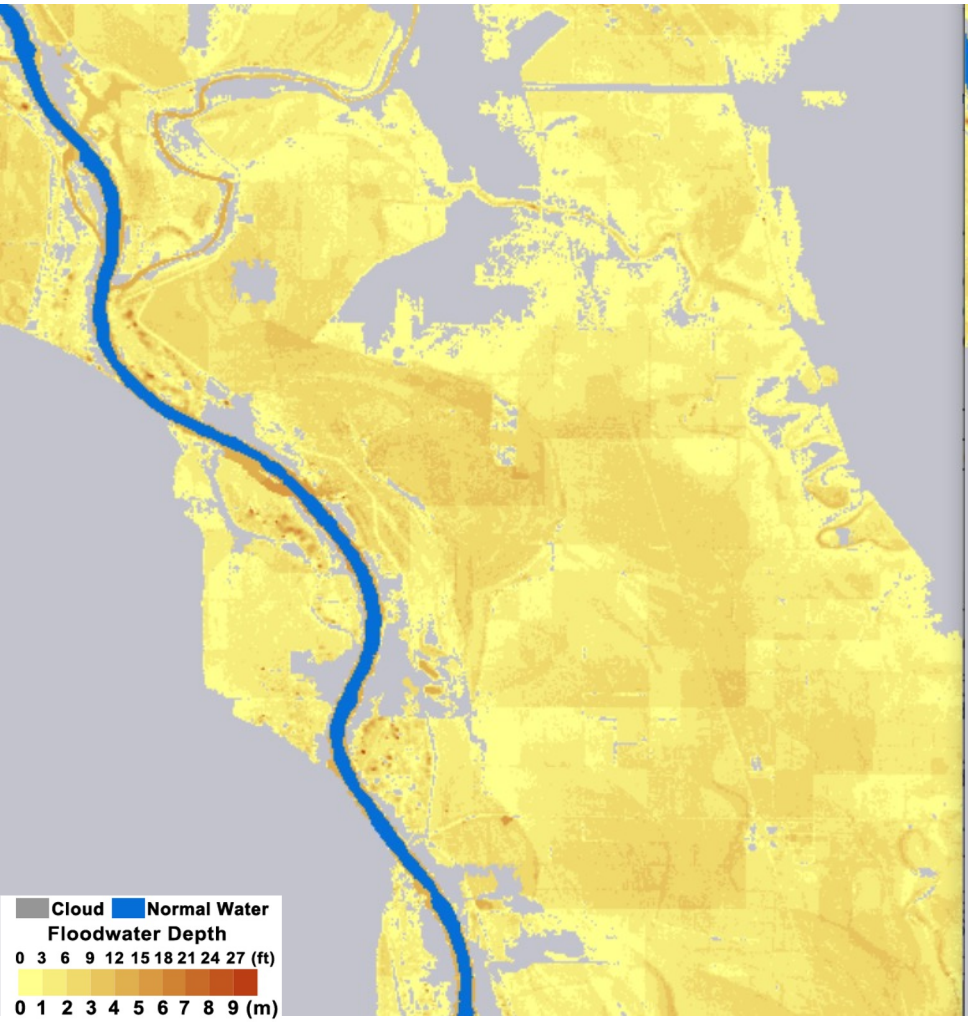
ABI 30m vs VIIRS 30m



ABI 30-m floodwater depth map on Mar. 21, 2019

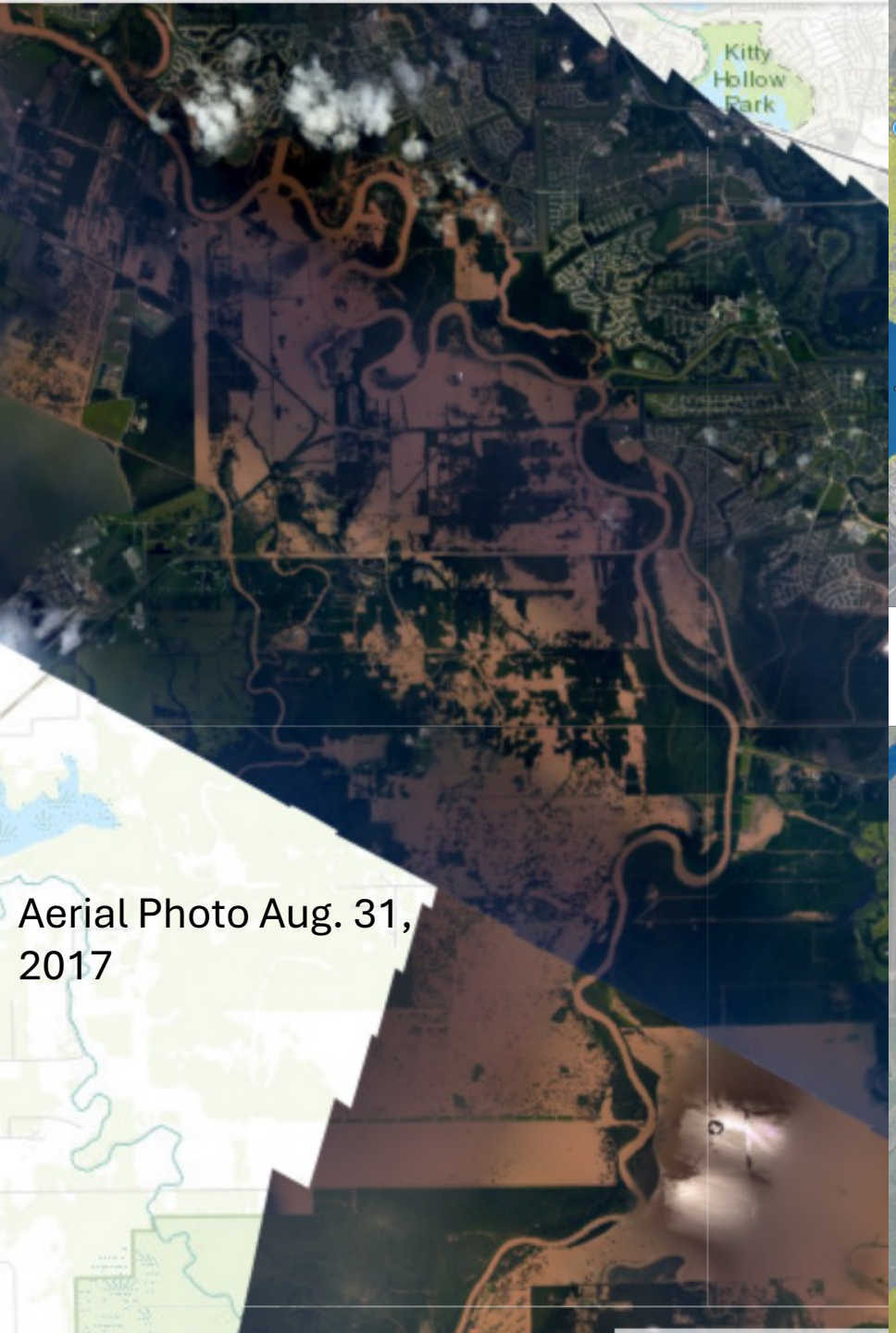
VIIRS 30-m floodwater depth map on Mar. 21, 2019

ABI 30m vs VIIRS 30m

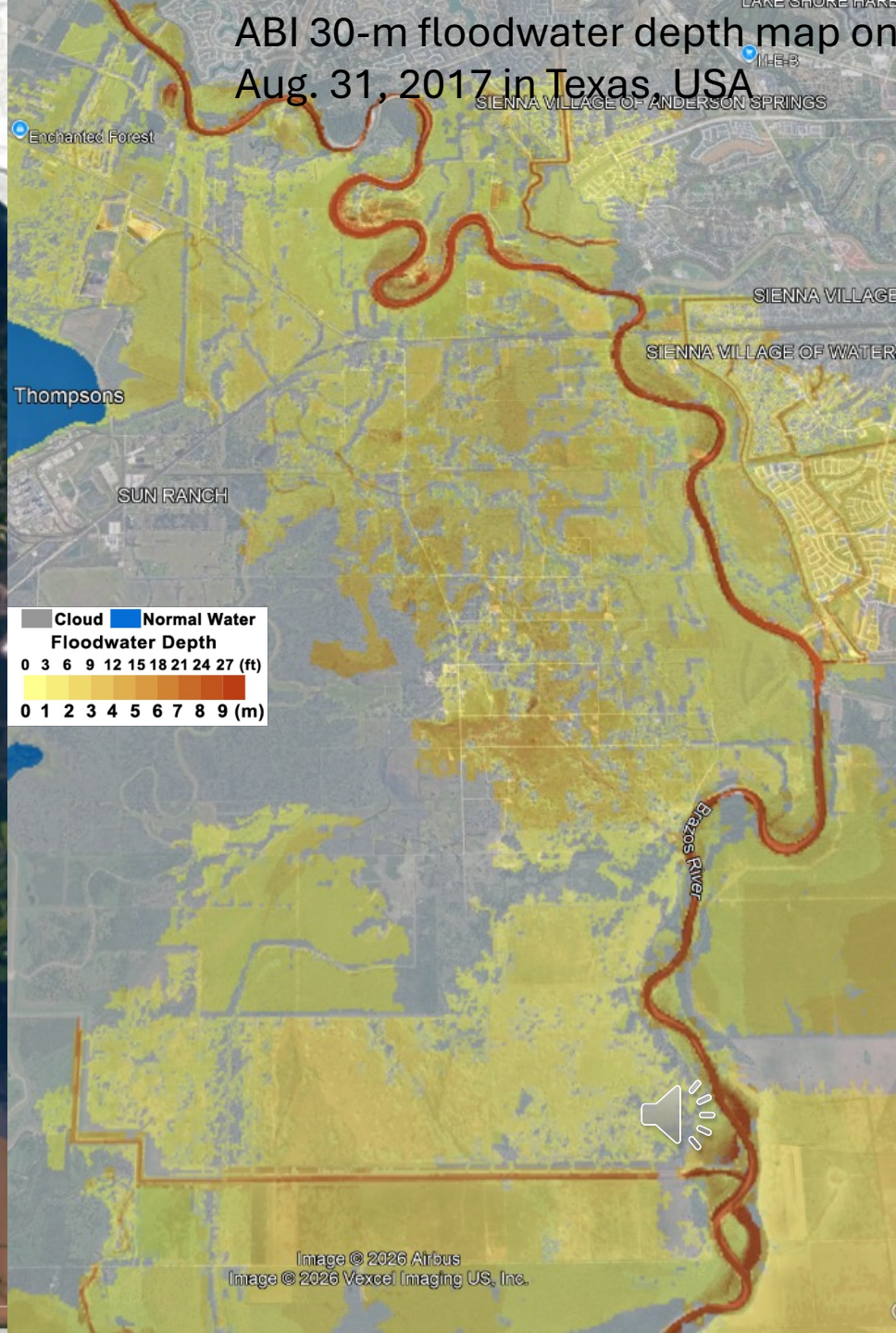


ABI 30-m floodwater depth map on Mar. 21, 2019

VIIRS 30-m floodwater depth map on Mar. 21, 2019

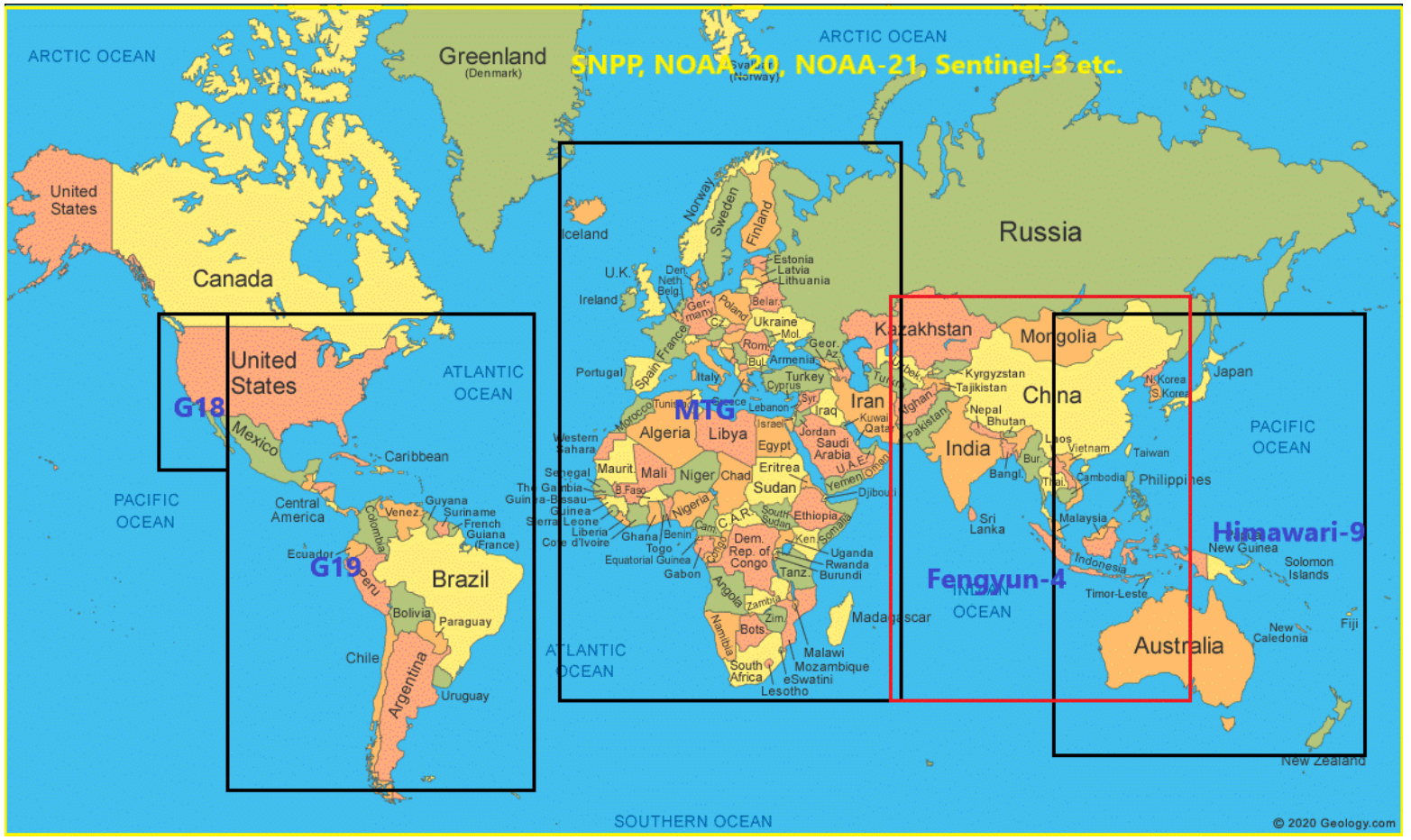


Aerial Photo Aug. 31, 2017



ABI 30-m floodwater depth map on Aug. 31, 2017 in Texas, USA

Coverage of GEO-LEO Satellites



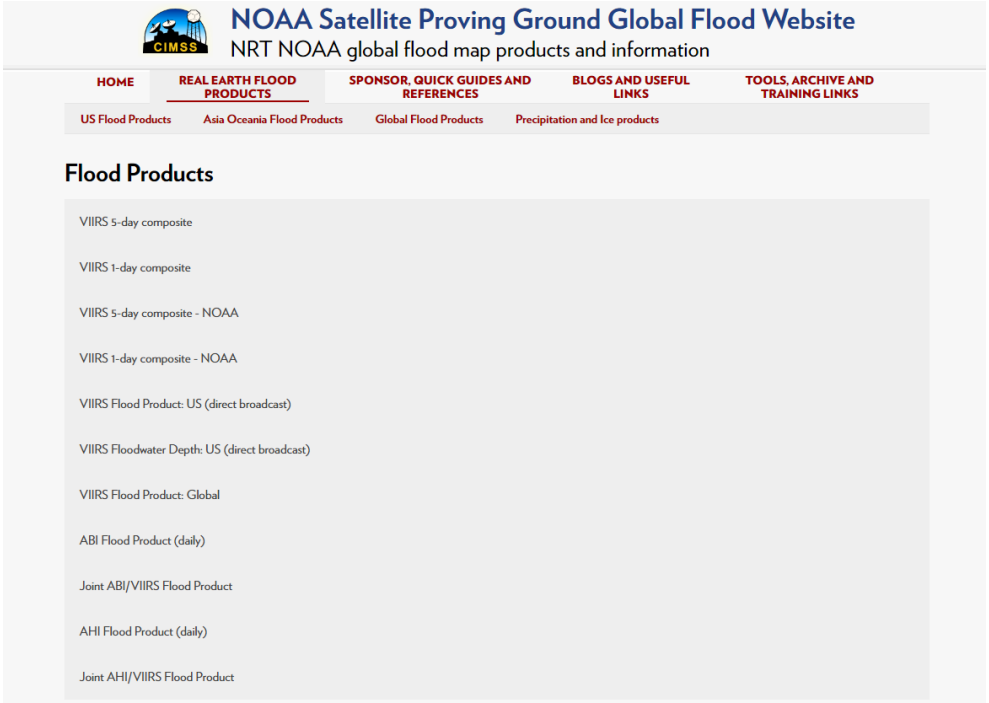
- Coverage of GEO-LEO satellites for flood mapping:
  - ✓ Global daily coverage from LEO satellites: SNPP, NOAA-20, NOAA-21, Sentinel-3
  - ✓ Coverage in mid-low latitudes for flood mapping from GEO satellites: GOES-18, GOES-19, MTG, Himawari-9, Fengyun-4 (not yet included)

Future's Plan — 3D GEO-LEO Flood Product

- Current joint GEO-LEO flood products: 375-m VIIRS/ABI and VIIRS/AHI floodwater fraction products
- Future joint GEO-LEO flood product: 30-m VIIRS/SLSTR/OLCI/ABI/AHI/FCI floodwater depth product:
  - ✓ Downscale VIIRS/SLSTR/OLCI floodwater fraction products (2D) to 30-m floodwater depth products (3D)
  - ✓ Downscale ABI/AHI/FCI floodwater fraction products (2D) to 30-m floodwater depth products (3D)
  - ✓ Merge the multiple 30-m floodwater depth products to derive a joint GEO-LEO 30-m floodwater depth product
    - ❑ maximal clear-sky coverage
    - ❑ daily global data availability
    - ❑ vertical inundation structures in flood depths and water surface levels
    - ❑ high spatial resolution at 30m

Web Access to the current LEO/GEO Flood Products

- Archived data:
  - ✓ NOAA CLASS: https://www.aev.class.noaa.gov/ River and Surface Flood Mapping Products (RSVFM)
  - ✓ AWS bucket: https://noaa-jpss.s3.amazonaws.com/index.html#JPSS_Blended_Products/
- Visualization web interface: https://www.ssec.wisc.edu/flood-map-demo/flood-products/



Reference

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Thanks!

Any questions? please contact me: sanmei.li@noaa.gov