

Urban Flood Monitoring Using Remote Sensing Observations

Erika Podest and Amita Mehta

1 August 2018



Course Outline

July 25

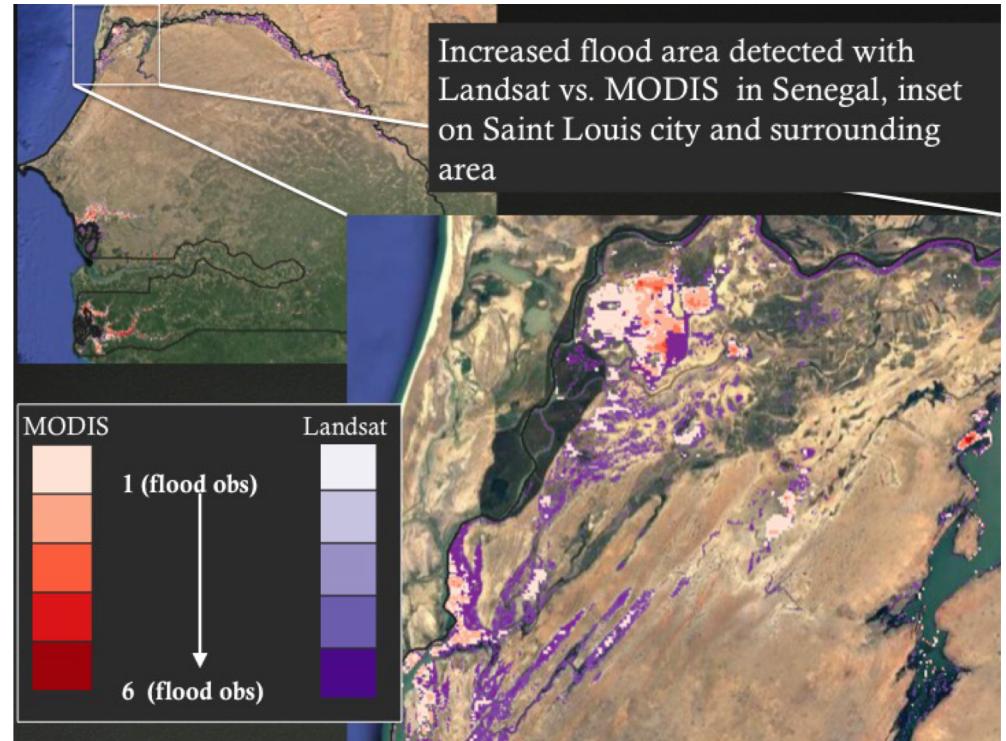
Overview of Remote Sensing Data for
Urban Flooding



Image Credits: (left) <https://blogs.worldbank.org/taxonomy/term/14333>; (right)

August 1

Access and Analysis of Remote Sensing
Observations for Urban Flood Monitoring



Homework and Certificates

- Homework will be available after Session-1 and Session-2 from <https://arset.gsfc.nasa.gov/water/webinars/>
- **Answers must be submitted via Google Form**
- Certificate of Completion:
 - Attend both webinars
 - Complete the homework assignment by the deadline (15 August 2018)
 - You will receive certificates approx. two months after the completion of the course from: marines.martins@ssaihq.com



Outline for Session 2

- SAR-based Urban Flood Monitoring
- About LIDAR Data for Urban Floodplain Detection
- Overview and Data Access of Landsat-based Urban Data and Socioeconomic Data
- Overview of Flood Mapping Tools: MODIS, DFO, GFMS
- Demonstration of Monitoring Urban Floods For Decision Making
- Challenges in Monitoring Urban Flooding
- Summary

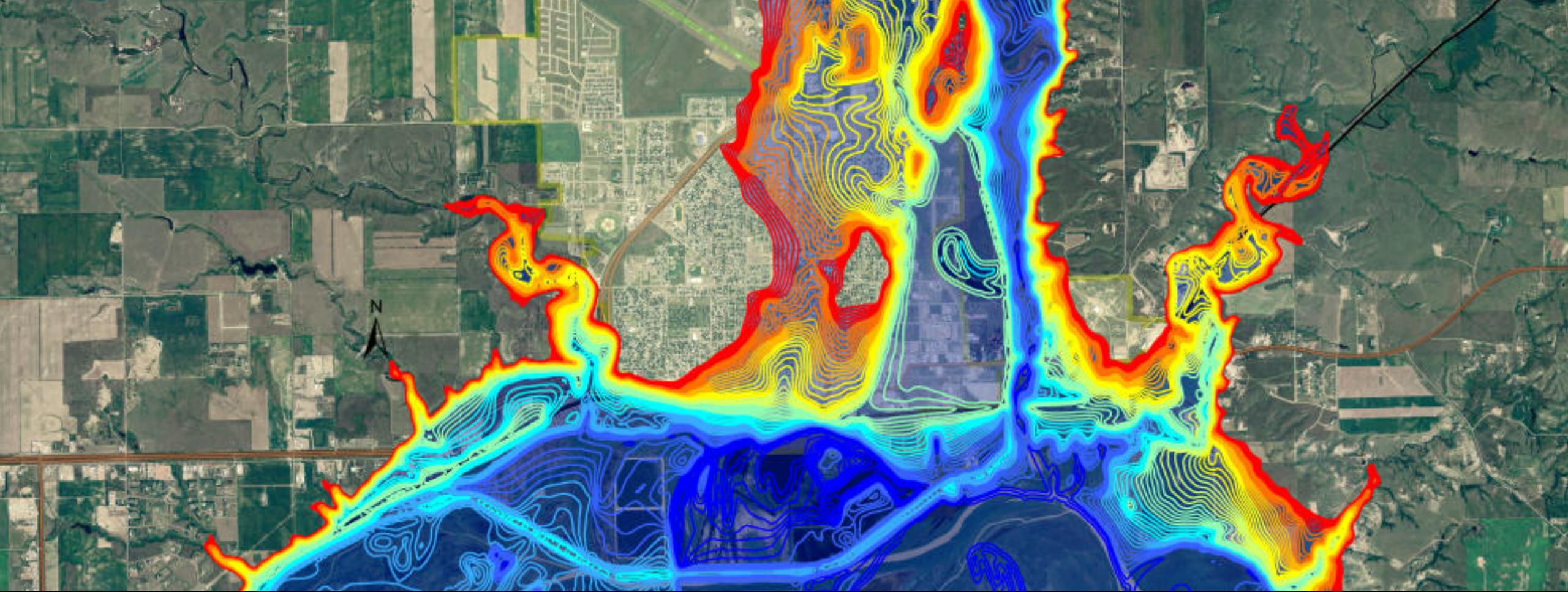


ARSET Website & Listserv

<http://arset.gsfc.nasa.gov/>

The screenshot shows the ARSET website homepage. At the top, there's a navigation bar with links for Home, About, Trainings, Earth Sciences Division, Applied Sciences, and ASP Water Resources. A search bar and a Twitter icon are also present. The main content area features a large image of a coastal area with green algae. Overlaid on this image is text for a training titled 'Introduction to Remote Sensing of Harmful Algal Blooms' scheduled for Tuesdays, Sep 5-26, 2017, from 11:00-12:00 or 21:00-22:00 EDT (UTC-4). A 'Register Now' button is visible. To the right, a sidebar titled 'ARSET' contains links for Online Trainings, In-Person Trainings, Sign up for the Listserv (which has a mouse cursor pointing at it), Tools Covered, Suggest a Training, Personnel, and Resources. Below this is another section titled 'Upcoming Training' with links for Water and Satellite Observations of Water Quality for.

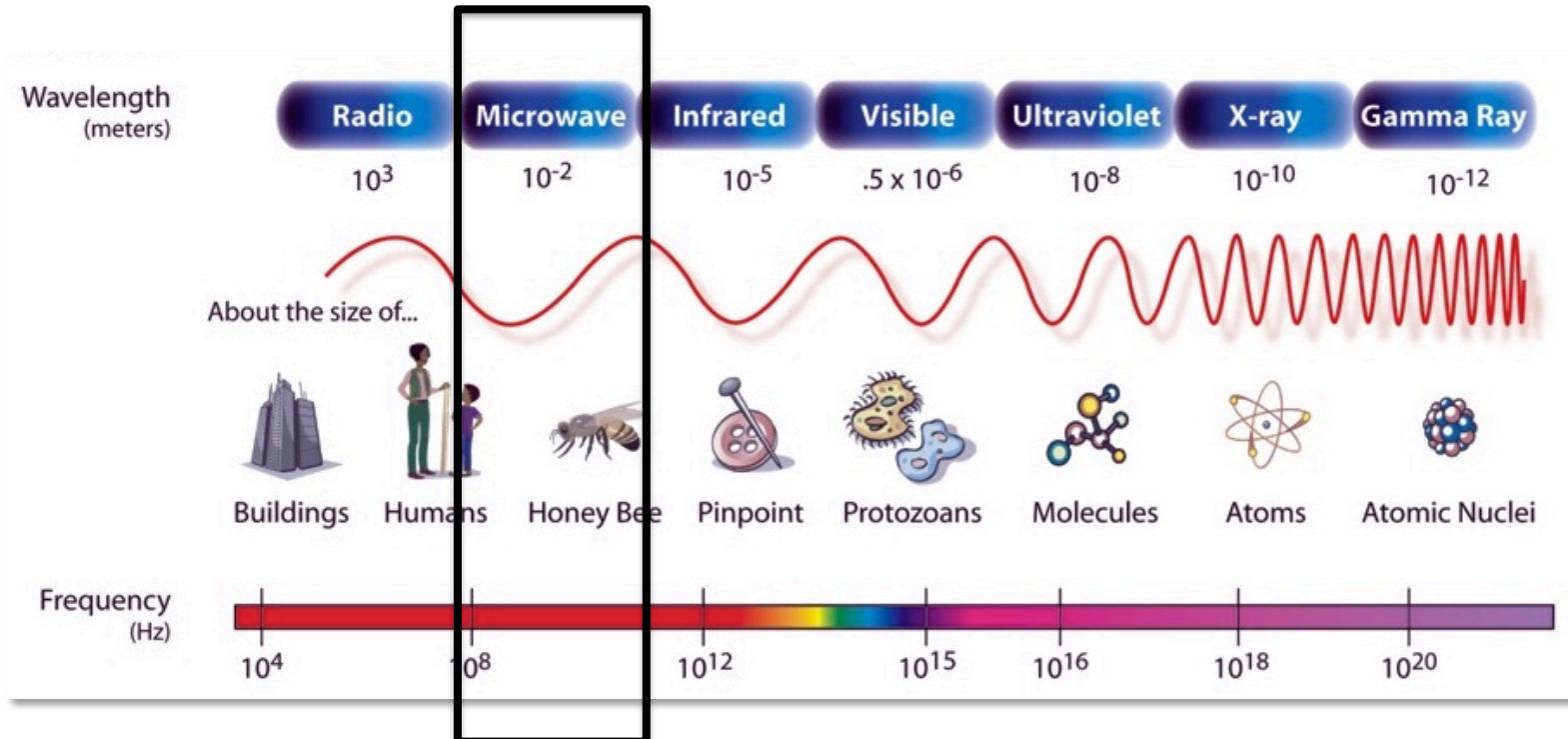




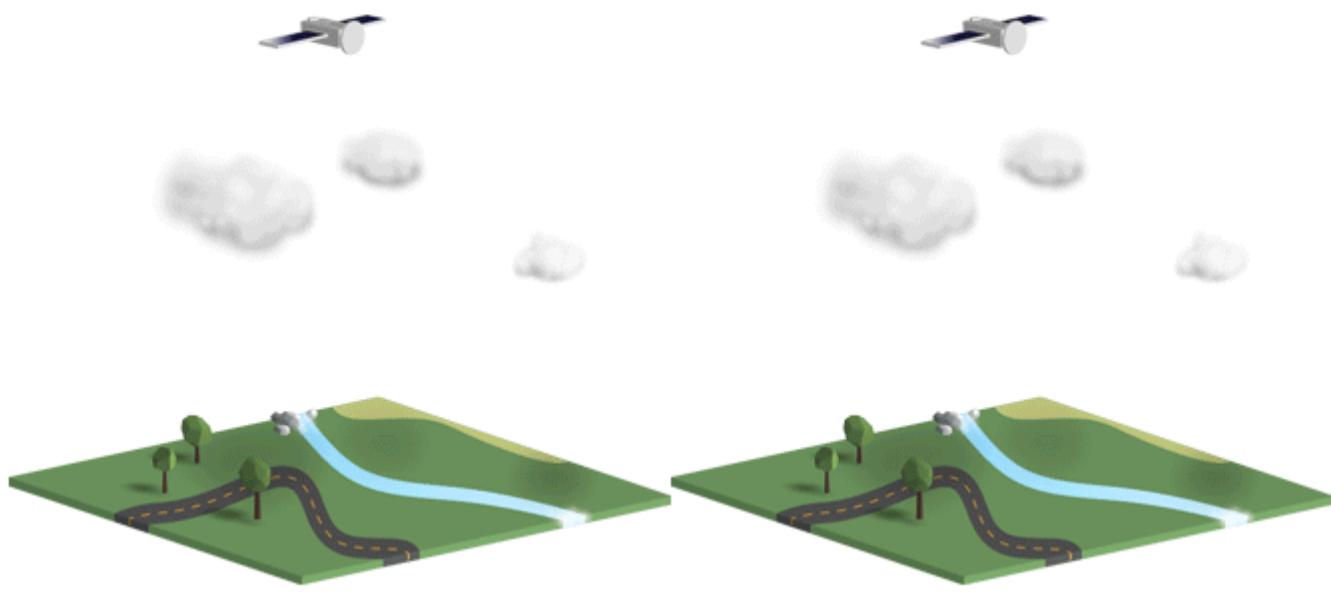
SAR-Based Urban Flood Monitoring

The Electromagnetic Spectrum

- Optical sensors measure reflected solar light and only function in the daytime
- The surface of the Earth cannot be imaged with visible or infrared sensors when there are clouds
- Microwaves can penetrate through clouds and vegetation, and can operate in day or night conditions



Active & Passive Remote Sensing



Passive Sensors detect only what is emitted from the landscape, or reflected from another source (e.g., light reflected from the sun).

Active Instruments emit their own signal and the sensor measures what is reflected back. Sonar and radar are examples of active sensors.

Passive Sensors:

- The source of radiant energy arises from natural sources
- e.g. the sun, Earth, other “hot” bodies

Active Sensors

- Provide their own artificial radiant energy source for illumination
- e.g. **radar, synthetic aperture radar (SAR), LIDAR**



Advantages and Disadvantages of Radar Over Optical Remote Sensing

Advantages

- Nearly all weather capability
- Day or night capability
- Penetration through the vegetation canopy
- Penetration through the soil
- Minimal atmospheric effects
- Sensitivity to dielectric properties (liquid vs. frozen water)
- Sensitivity to structure

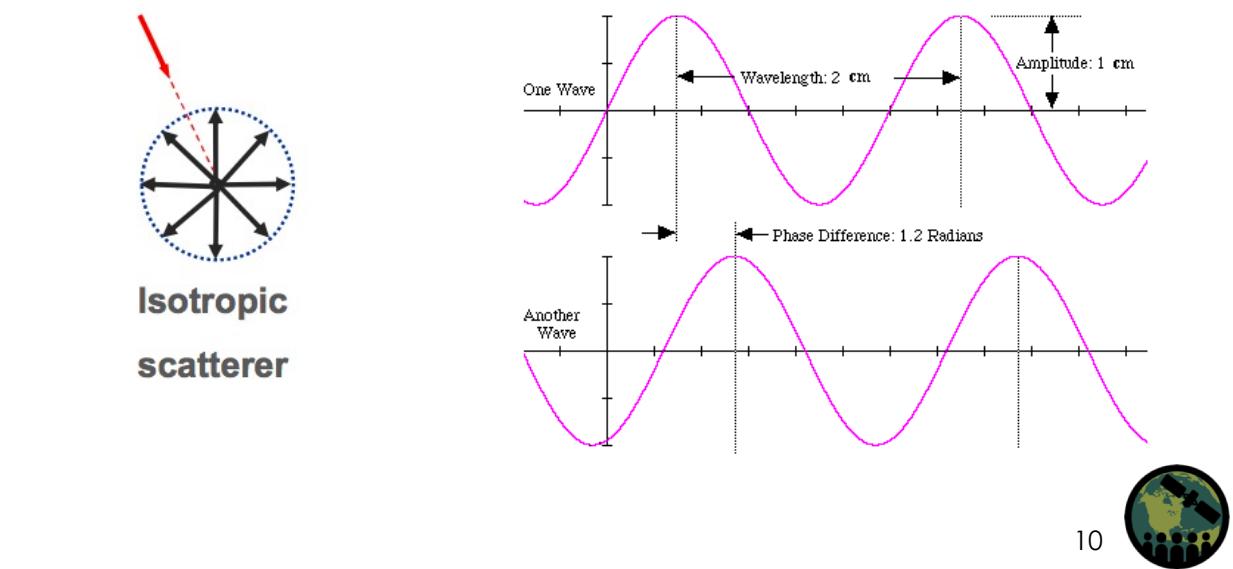
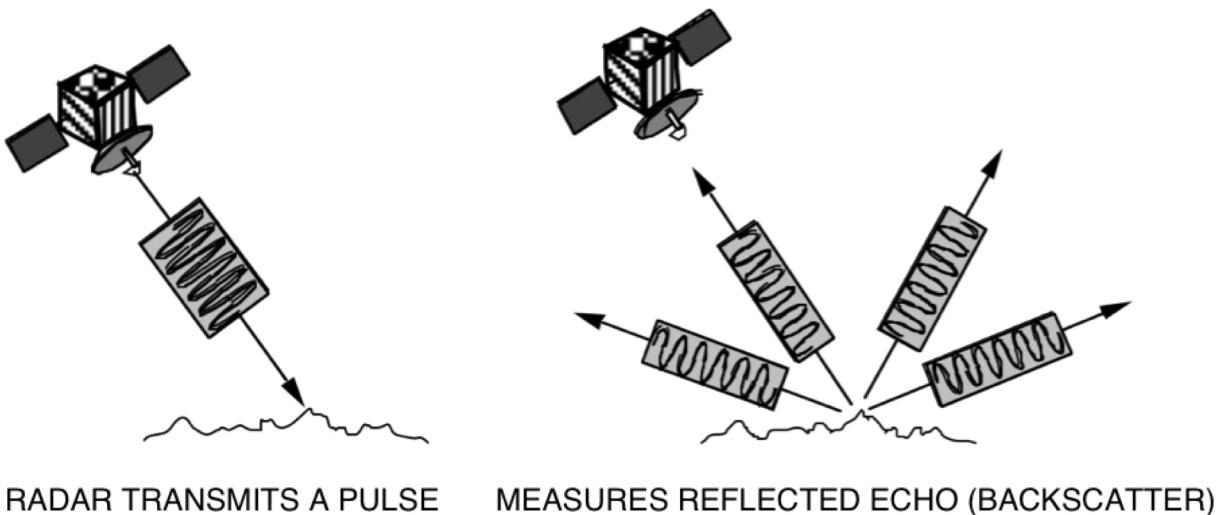
Disadvantages

- Information content is different than optical and sometimes difficult to interpret
- Speckle effects (graininess in the image)
- Effects of topography



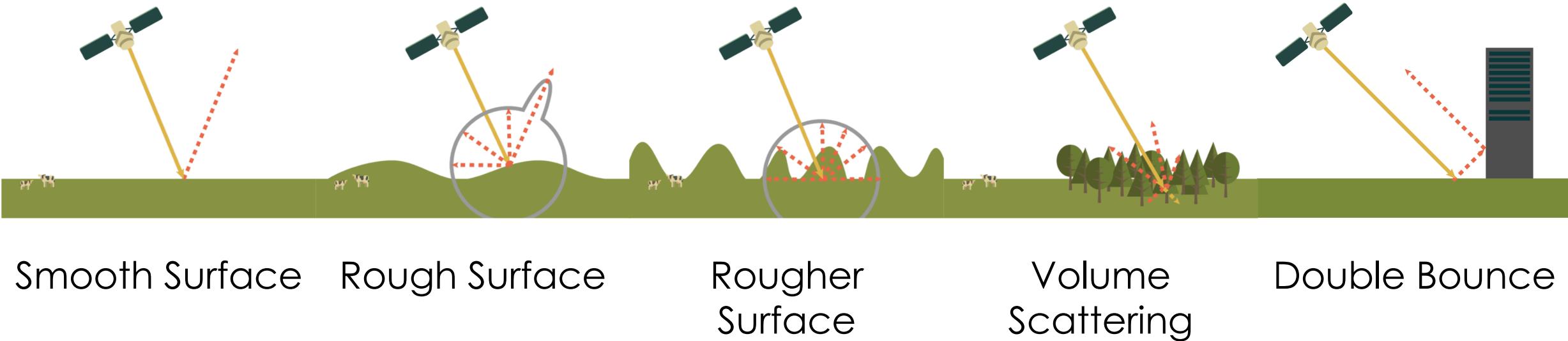
Review of Radar Image Formation

1. Radar can measure amplitude (the strength of the reflected echo) and phase (the position of a point in time on a waveform cycle)
2. Radar can only measure the part of the echo reflected back towards the antenna (backscatter)
3. Radar pulses travel at the speed of light
4. The strength of the reflected echo is the backscattering coefficient (sigma naught) and is expressed in decibels (dB)



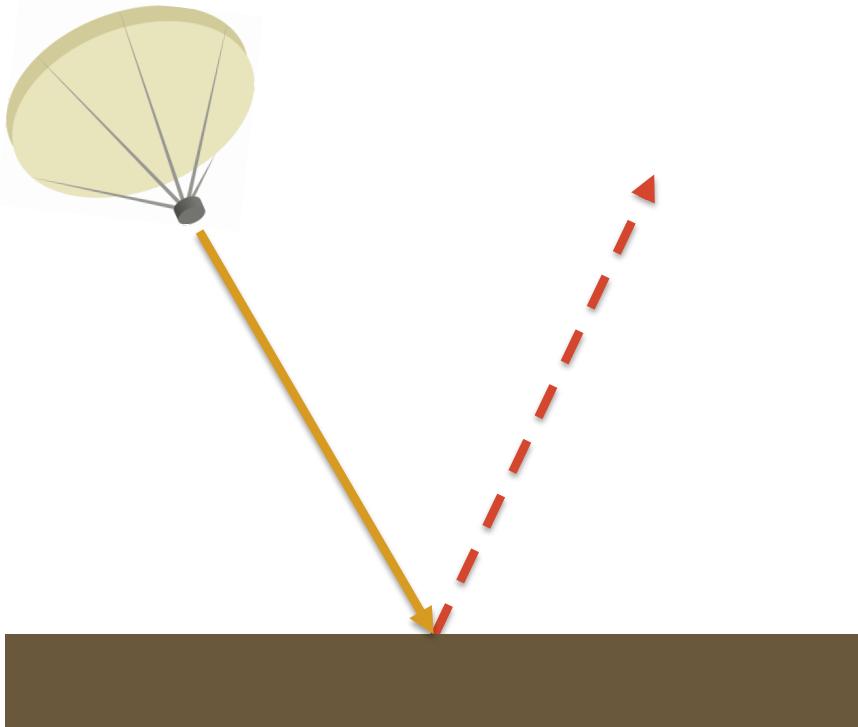
Radar Signal Interaction

Backscattering Mechanism



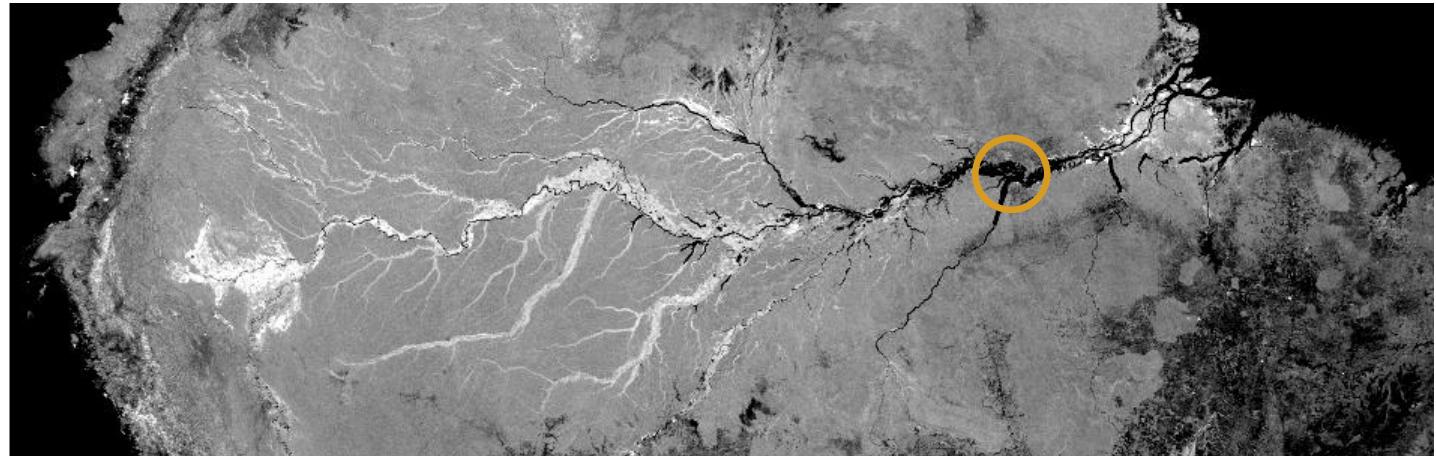
Examples of Radar Interaction

Smooth Surface Reflection (Specular Reflection)



Smooth, Level Surface
(Open Water, Road)

SMAP Radar Mosaic of the Amazon Basin
April 2015 (L-band, HH, 3 km)

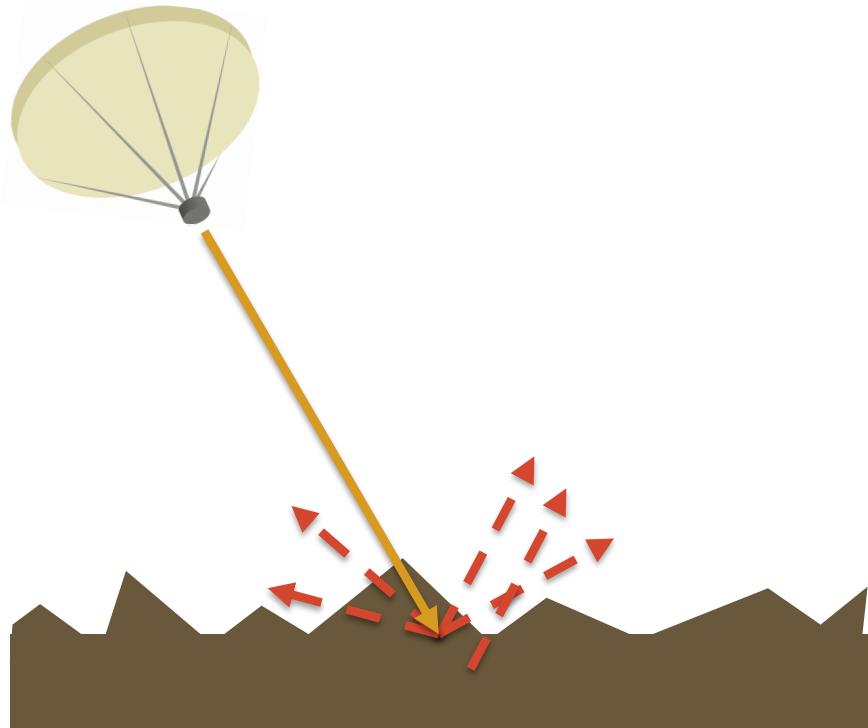


Pixel Color



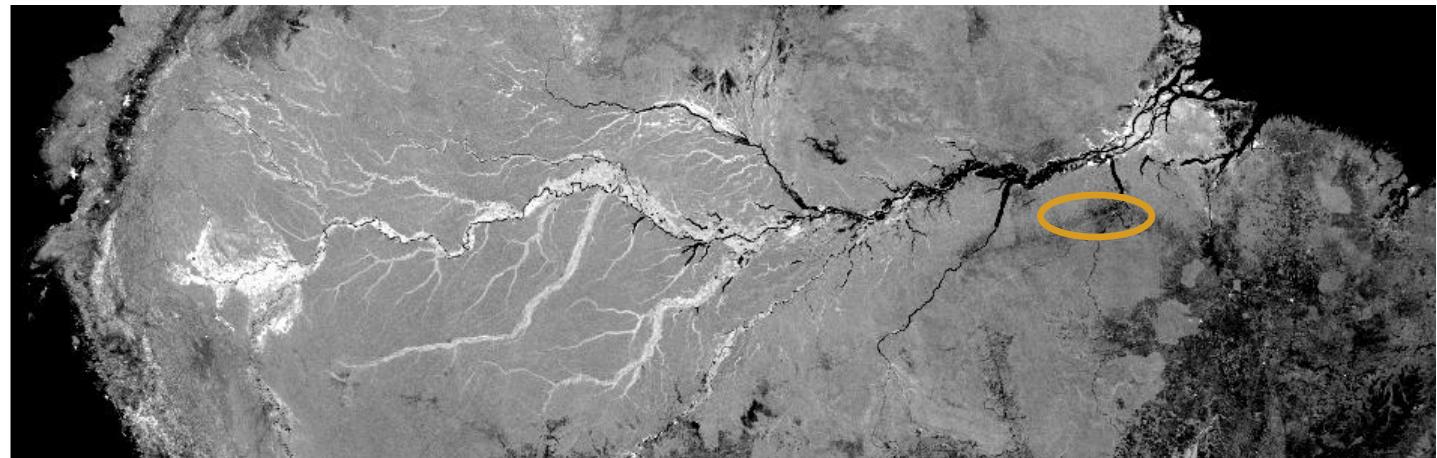
Examples of Radar Interaction

Rough Surface Reflection



Rough, Bare Surface
(deforested areas, tilled
agricultural fields)

SMAP Radar Mosaic of the Amazon Basin
April 2015 (L-band, HH, 3 km)

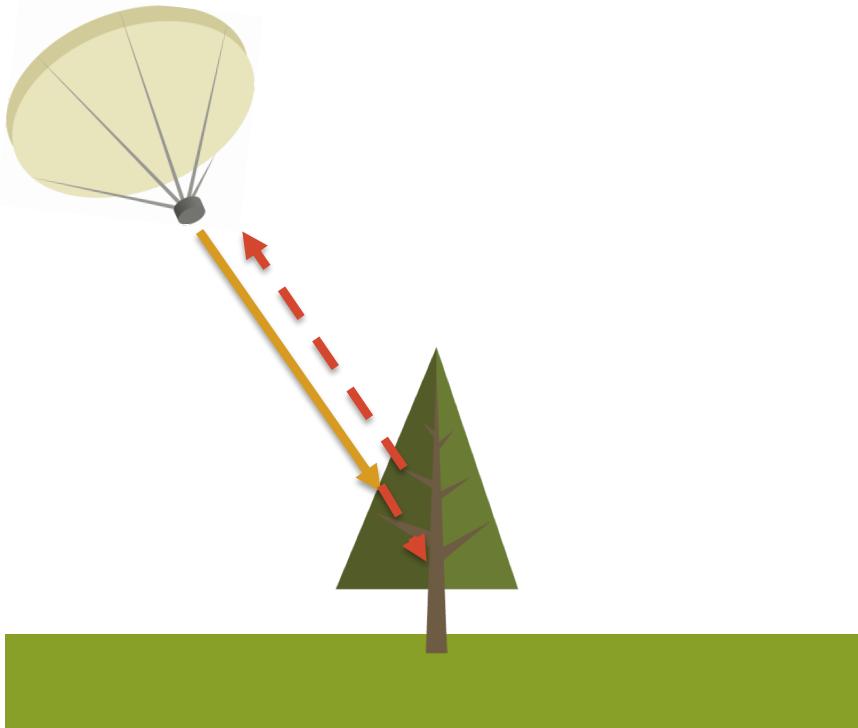


Pixel Color



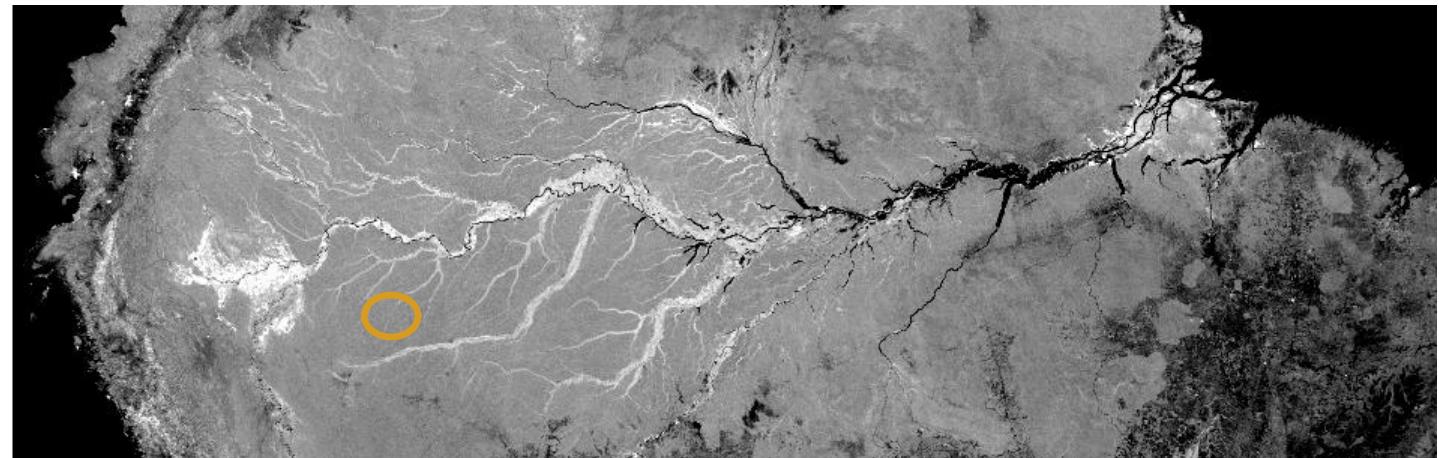
Examples of Radar Interaction

Volume Scattering by Vegetation



Vegetation

SMAP Radar Mosaic of the Amazon Basin
April 2015 (L-band, HH, 3 km)

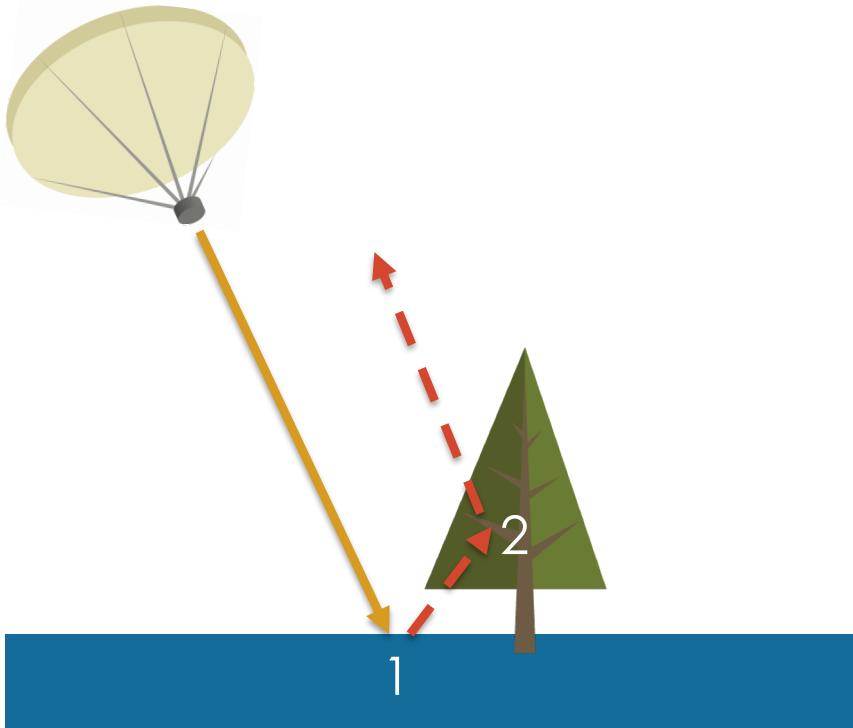


Pixel Color



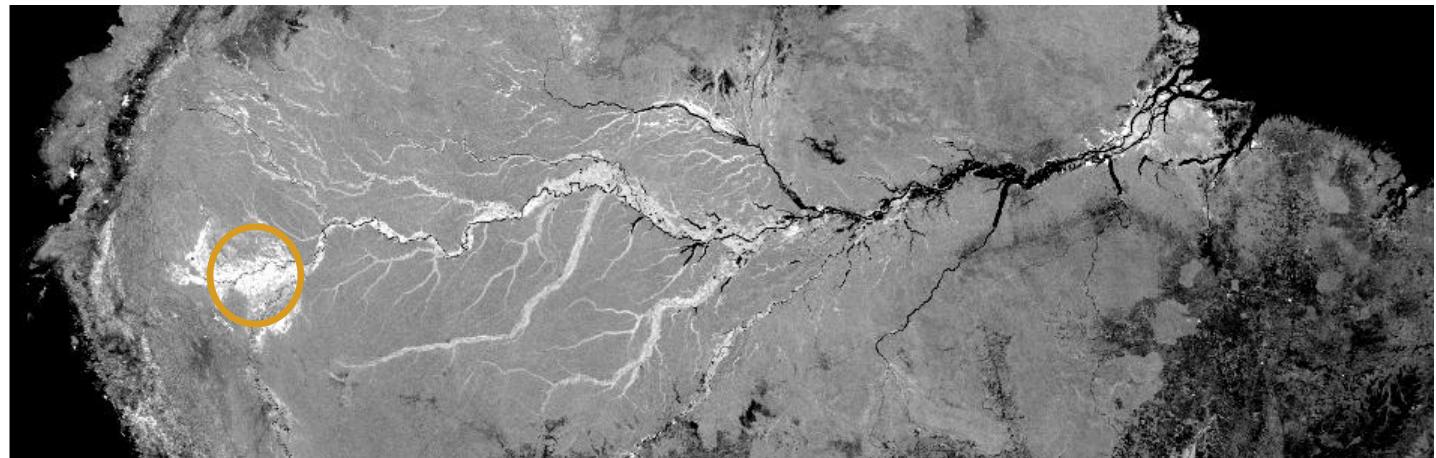
Examples of Radar Interaction

Double Bounce



Inundated Vegetation

**SMAP Radar Mosaic of the Amazon Basin
April 2015 (L-band, HH, 3 km)**

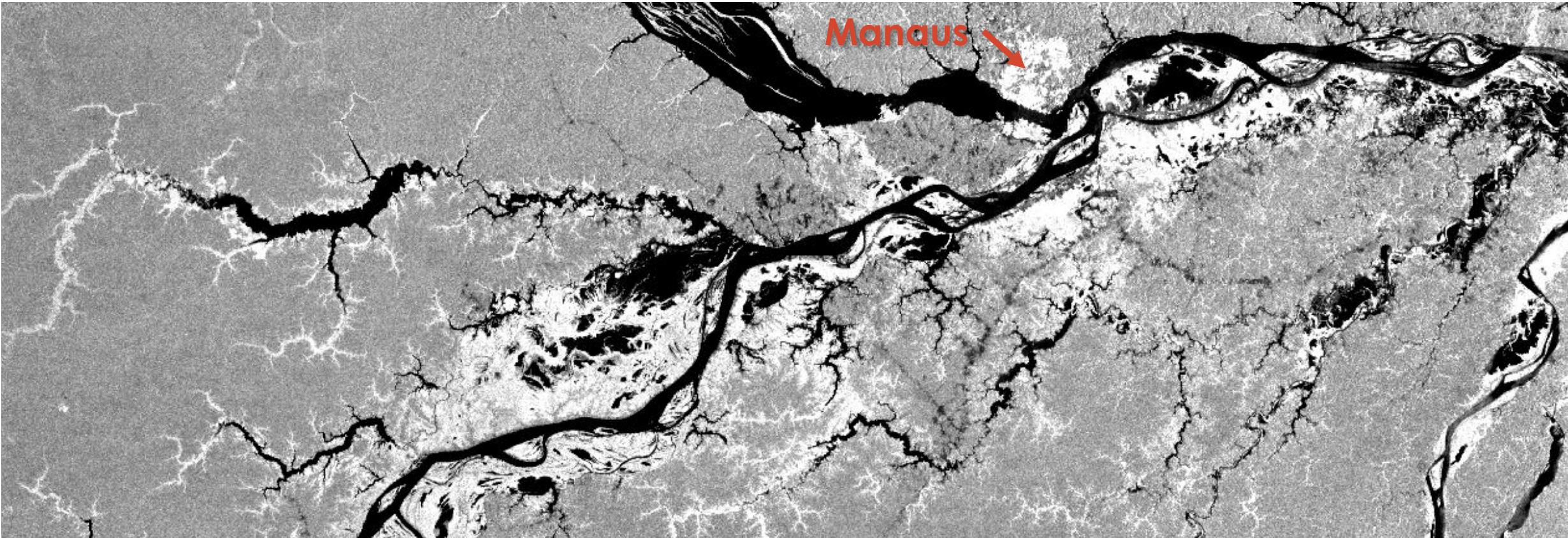


Pixel Color



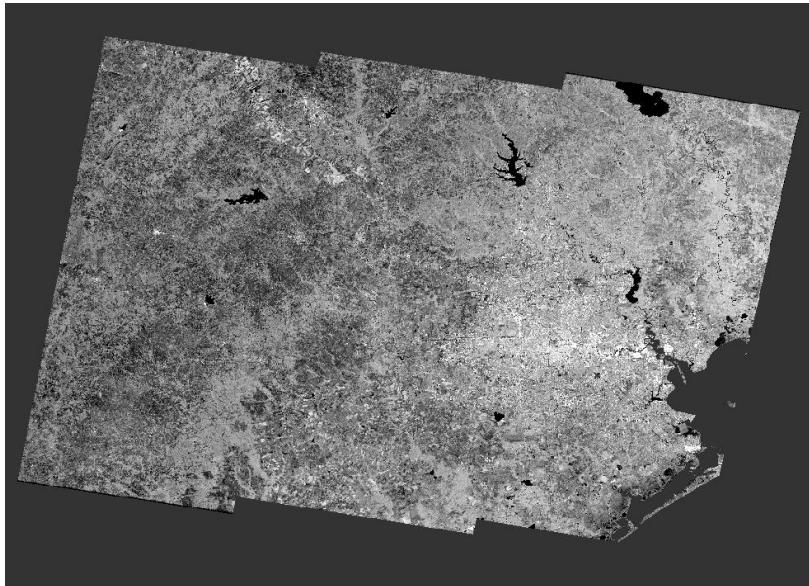
Source of Confusion: Urban Areas with Flooded Vegetated Areas

HH Image from Palsar (L-band) of Manaus, Brazil and its surroundings

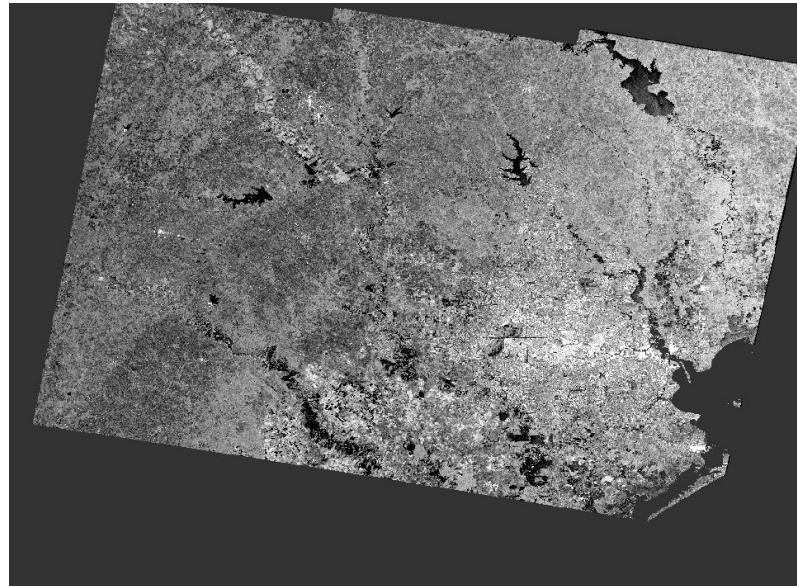


Hurricane Harvey in Houston Texas – August 2017

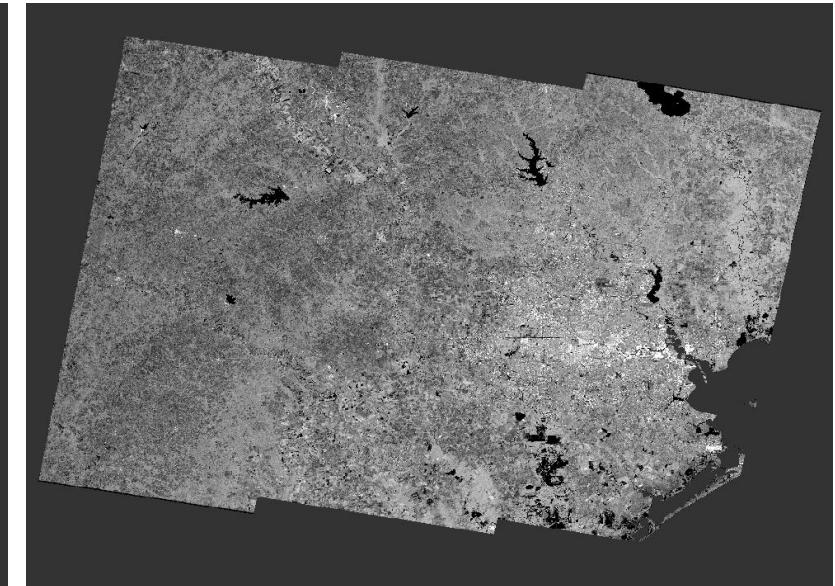
Aug 18, 2017
(Before the Event)



Aug 30, 2017
(During the Event)

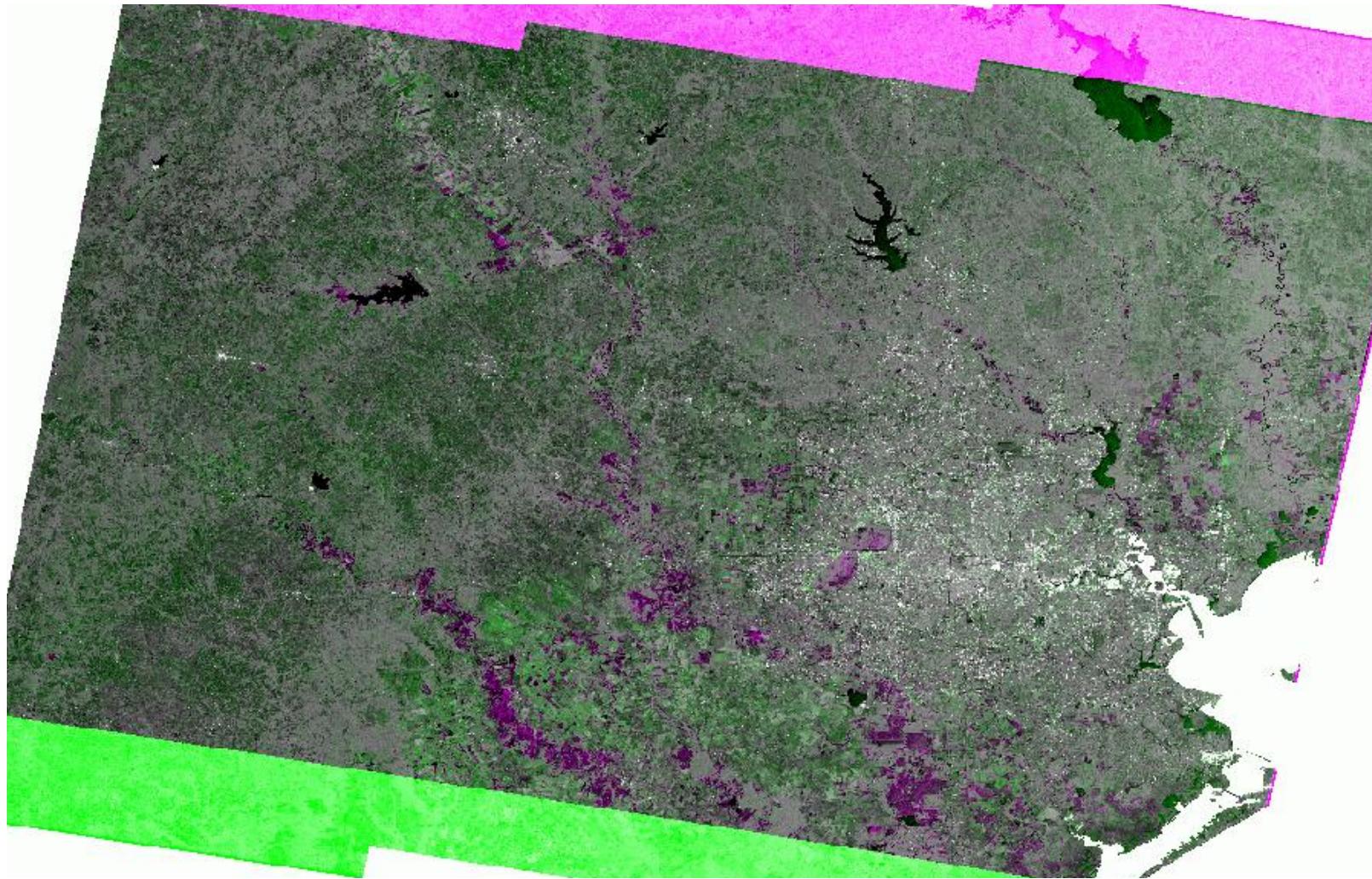


Sep 5, 2017
(After the Event)



Hurricane Harvey in Houston Texas - Before and During the Event

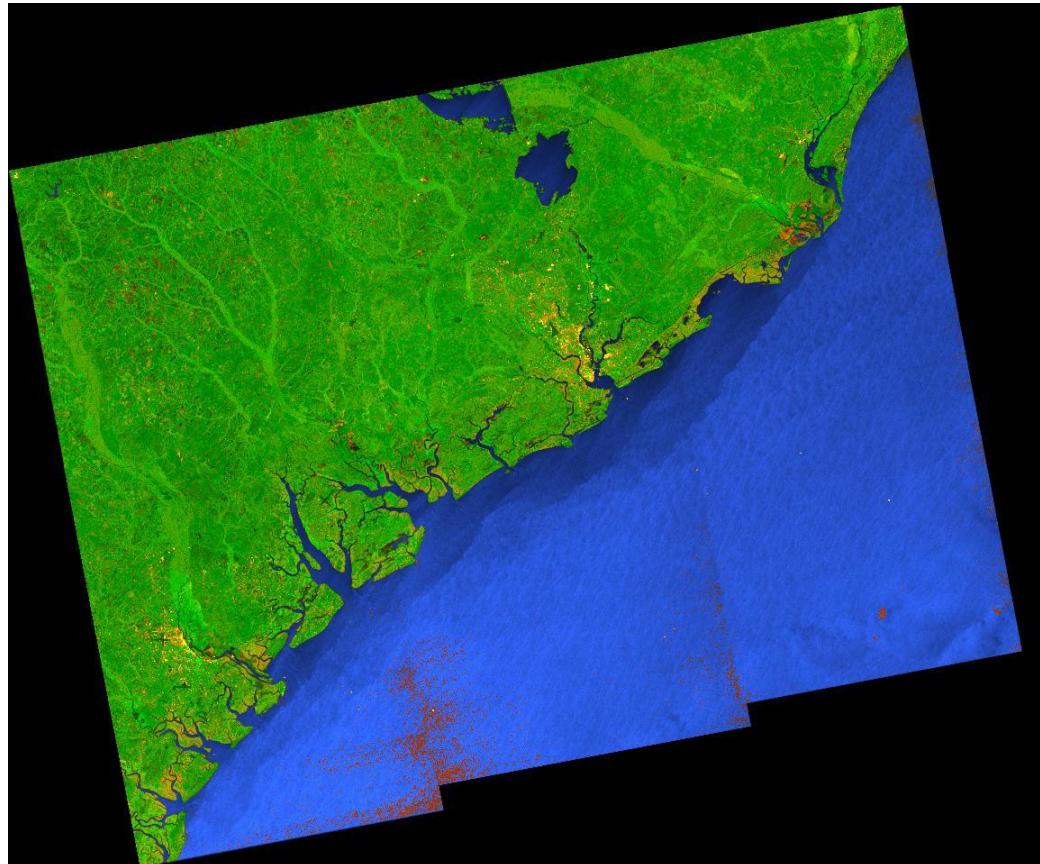
Sentinel-1 Radar Images, RGB: Aug 30 (R), Aug 18 (G), Aug 30 (B)



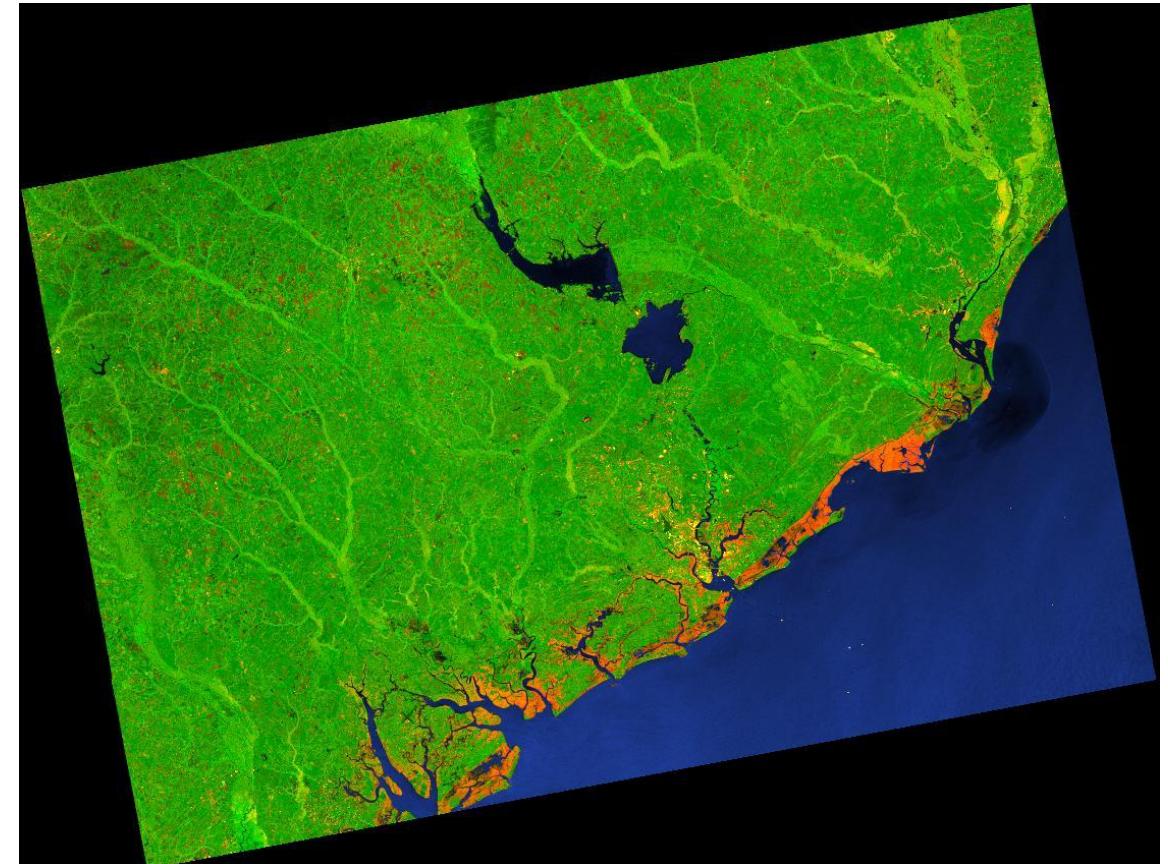
Hurricane Matthew on the East Coast of the U.S. – Coastal Flooding

Sentinel-1 Radar Images

Oct 4, 2016
(Before the Event)

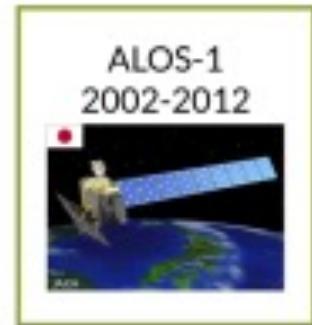


Oct 16, 2016
(After the Event)

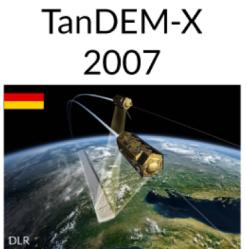


Radar Data from Different Satellites

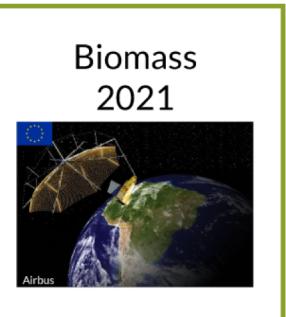
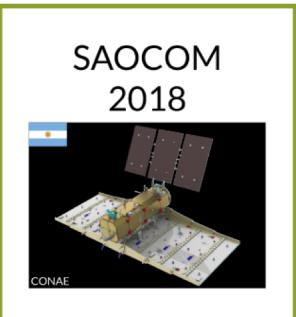
Legacy:



Current:



Future:



 freely accessible

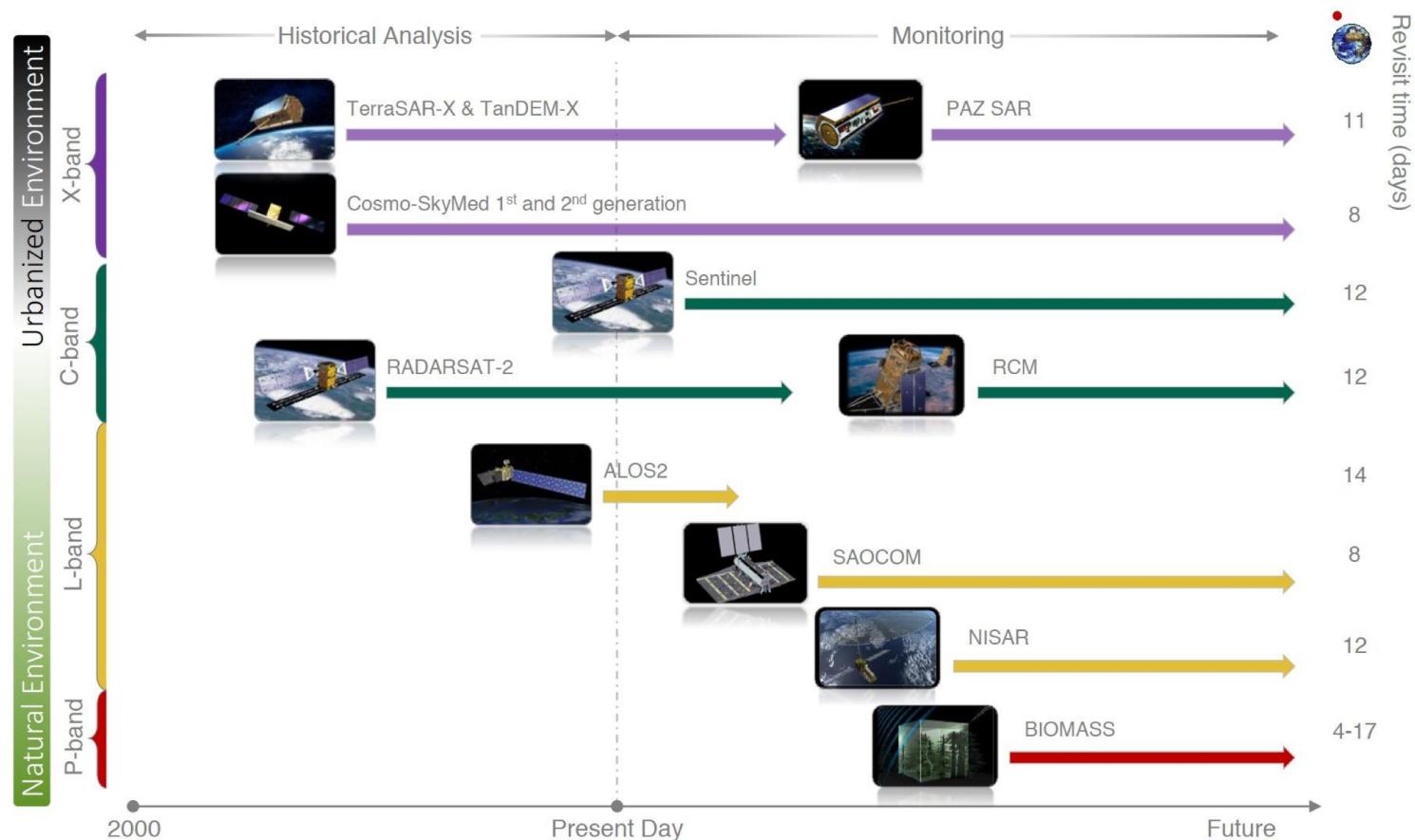
Credit: Franz Meyer, University of Alaska, Fairbanks



Current and Future SAR Satellites

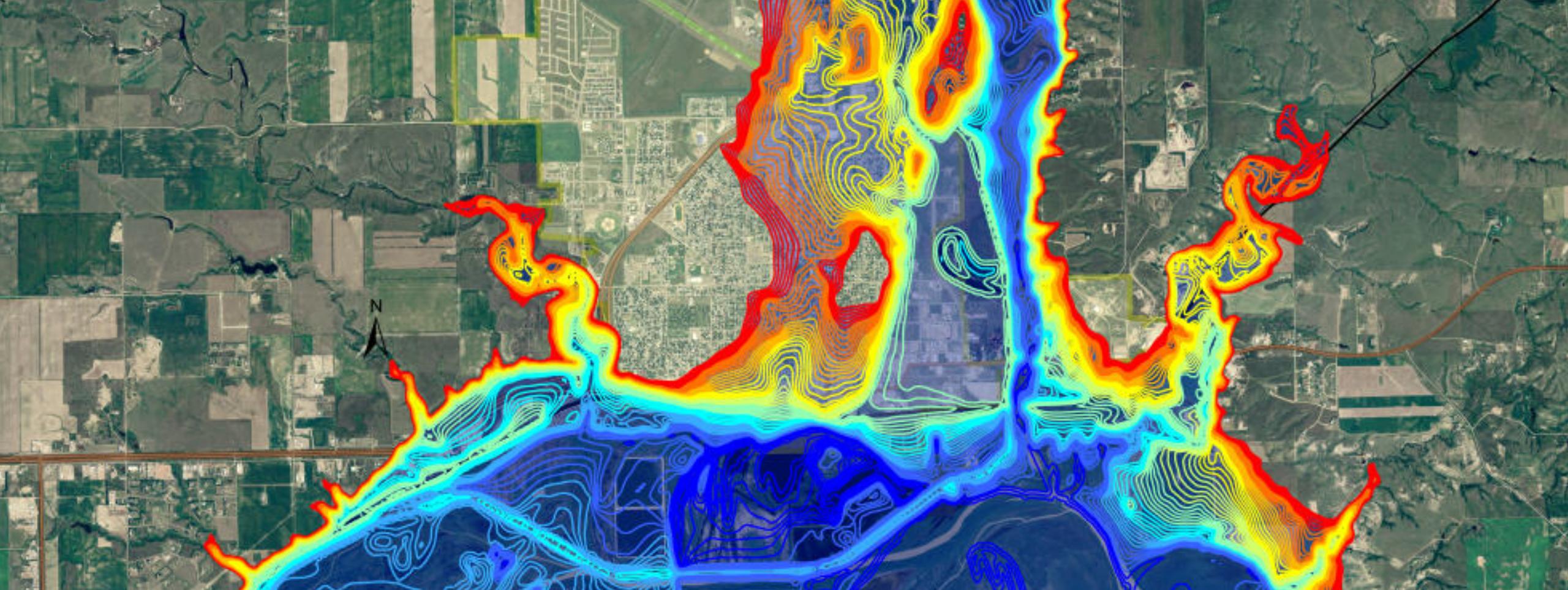


Current and Future SAR Satellites



Credit: Franz Meyer, University of Alaska, Fairbanks



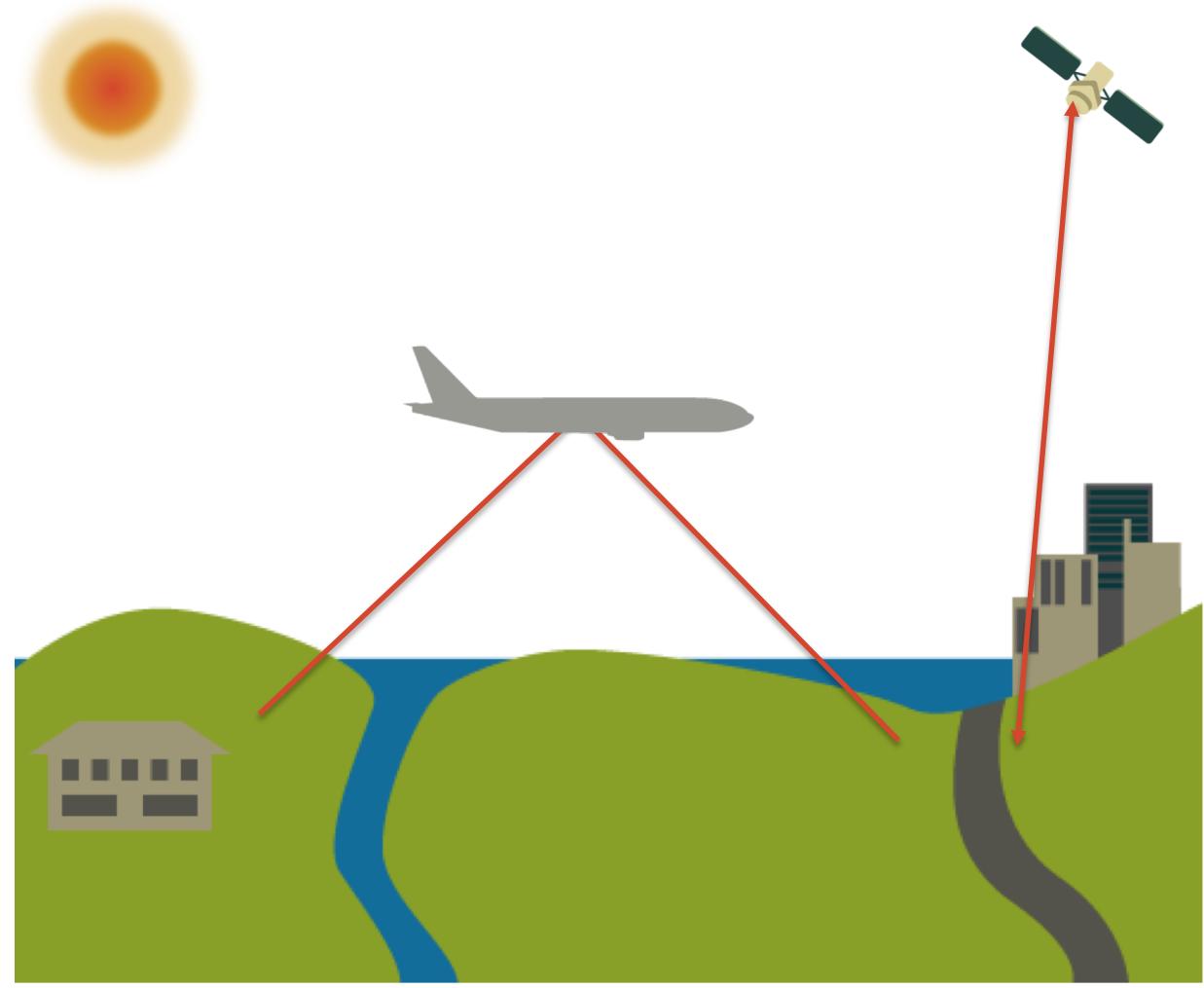


About LIDAR Data for Urban Floodplain Detection

What is LIDAR?

<https://www.nasa.gov/centers/langley/news/factsheets/RemoteSensing.html>

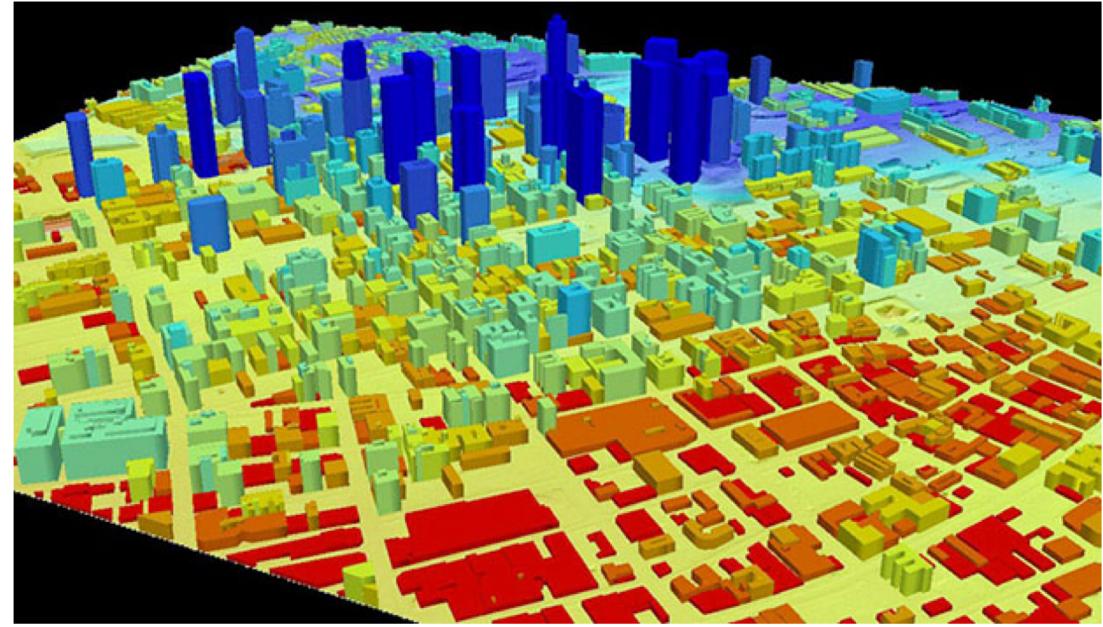
- LIDAR - Light Detection And Ranging is an active remote sensing instrument that emits a pulse of light and measures the reflected pulse
- LIDAR are used to observe surface and atmospheric features
- LIDAR can be flown on aircraft or satellites



What is LIDAR?

<https://lasersdbw.larc.nasa.gov/tutorials/lidar/>

- There are three types of LIDAR: Ranging, Differential Absorption, and Doppler
 - Ranging LIDAR measures the time between emitted and reflected light pulses to determine the distance of an object
 - Differential Absorption LIDAR uses two wavelengths to measure the temperature, density, and pressure of trace gases and aerosols in the atmosphere
 - Doppler LIDAR senses shift in wavelength due to motion of the target and is used to measure wind velocity



LIDAR can map out the size and shape of objects

Image Credit: Leidos



What is LIDAR?

<https://oceanservice.noaa.gov/facts/lidar.html>

- Ranging LIDAR is used to generate three-dimensional information about the shape of the characteristics of the Earth's surface
- There are two types of Ranging LIDAR:
 - Topographic LIDAR with near-Infrared wavelength is used to map the land
 - Bathymetric LIDAR with green light used to measure seafloor and riverbed elevations

Washington, DC

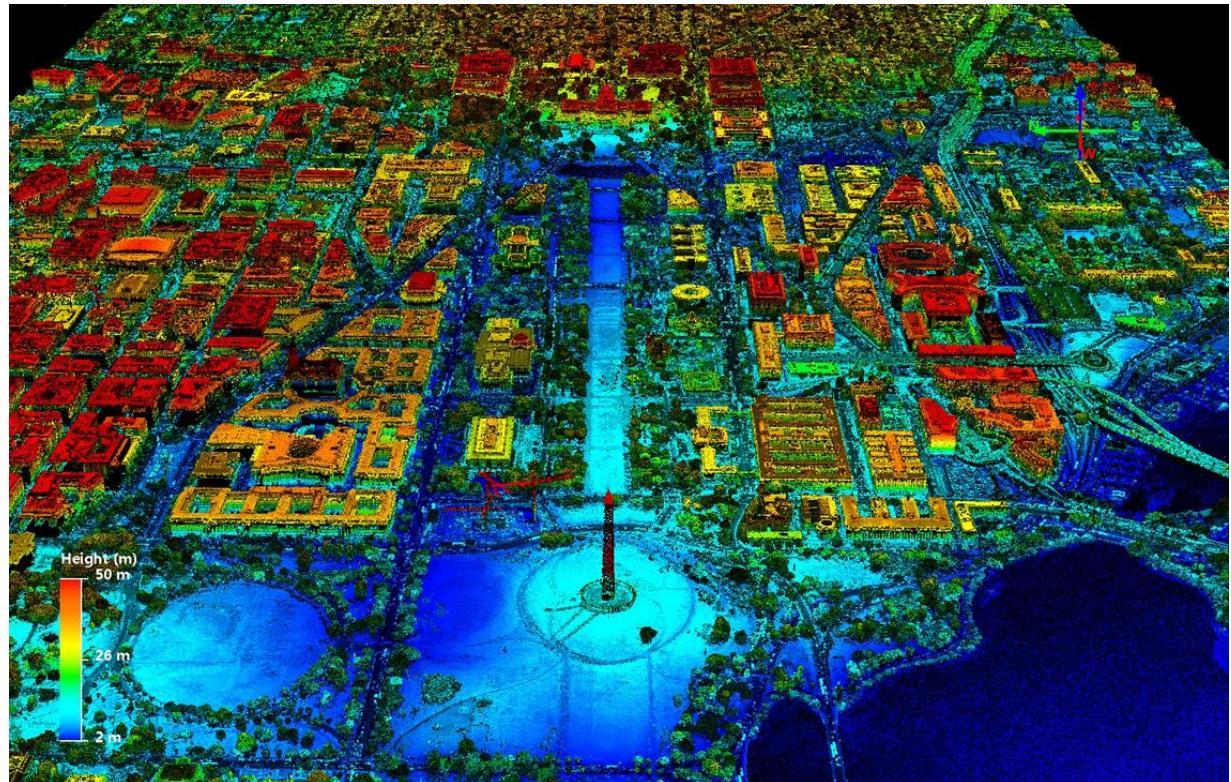


Image Credit: USGS



LIDAR Topography Data

https://nationalmap.gov/3DEP/3dep_whatis.html

- USGS 3D Elevation Program (3DEP) is set up to provide open source, high resolution elevation data based on LIDAR
- The elevation data are available at multiple spatial resolutions (1 meter to 30 m)

Data

Elevation Products (3DEP)

Product Search Filter

All Subcategories

1 arc-second DEM
[Show Availability](#)

1 meter DEM
[Show Availability](#)

1/3 arc-second DEM
[Show Availability](#)

1/9 arc-second DEM
[Show Availability](#)

2 arc-second DEM - Alaska
[Show Availability](#)

5 meter DEM (Alaska only)
[Show Availability](#)

Contours (1:24,000-scale)
[Show Preview](#)

Data Extent [Select Data Extent.](#)

1 x 1 degree

10000 x 10000 meter

15 x 15 minute (1:48,000/1:62,500/1:63,360)

Varies

[Hide All Availability](#)

Availability legend

	1 arc-second
	1 meter
	1/3 arc-second
	1/9 arc-second
	1/9 arc-second Coastal Zone
	2 arc-second

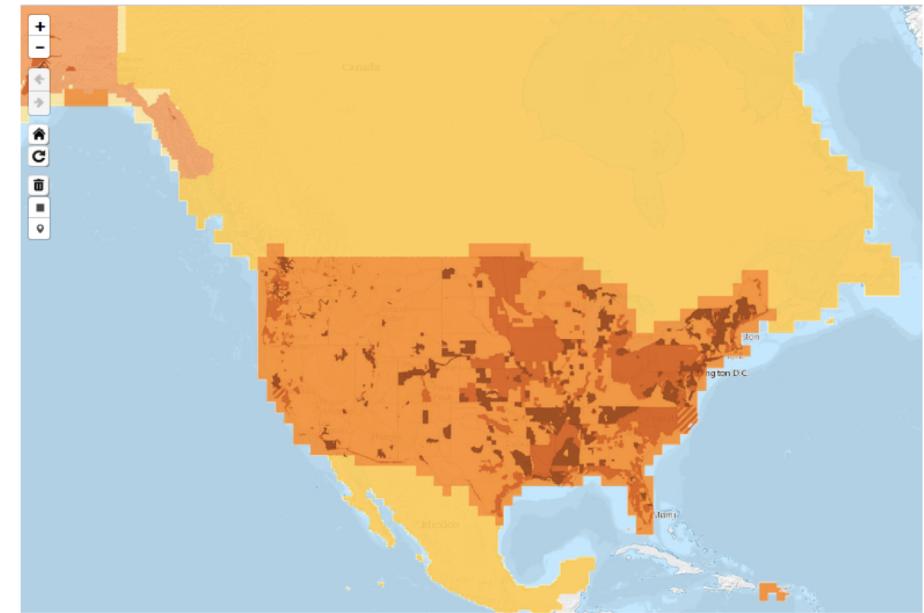


Image Credits: https://nationalmap.gov/3DEP/3dep_whatis.html



LIDAR Topography Data

<https://coast.noaa.gov/inventory/>

NOAA Coast Watch provides US Inter-agency LIDAR products

DATA INVENTORY CURRENT AS OF MARCH 2018

- Topographic Lidar
- Topobathy Shoreline Lidar
- IfSAR Data
- Bathymetric Lidar
- NOAA Hydrographic Surveys
- USACE Hydrographic Surveys
- Trackline Bathymetry
- Multibeam Bathymetry

MAINTAINED BY

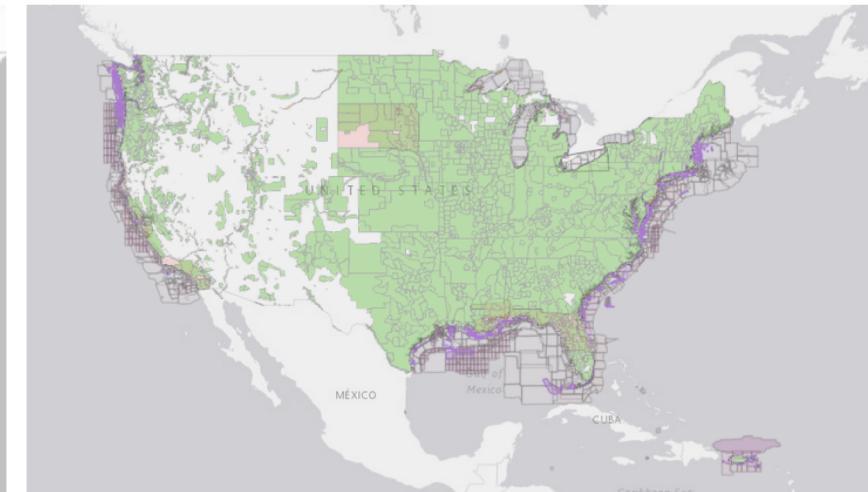
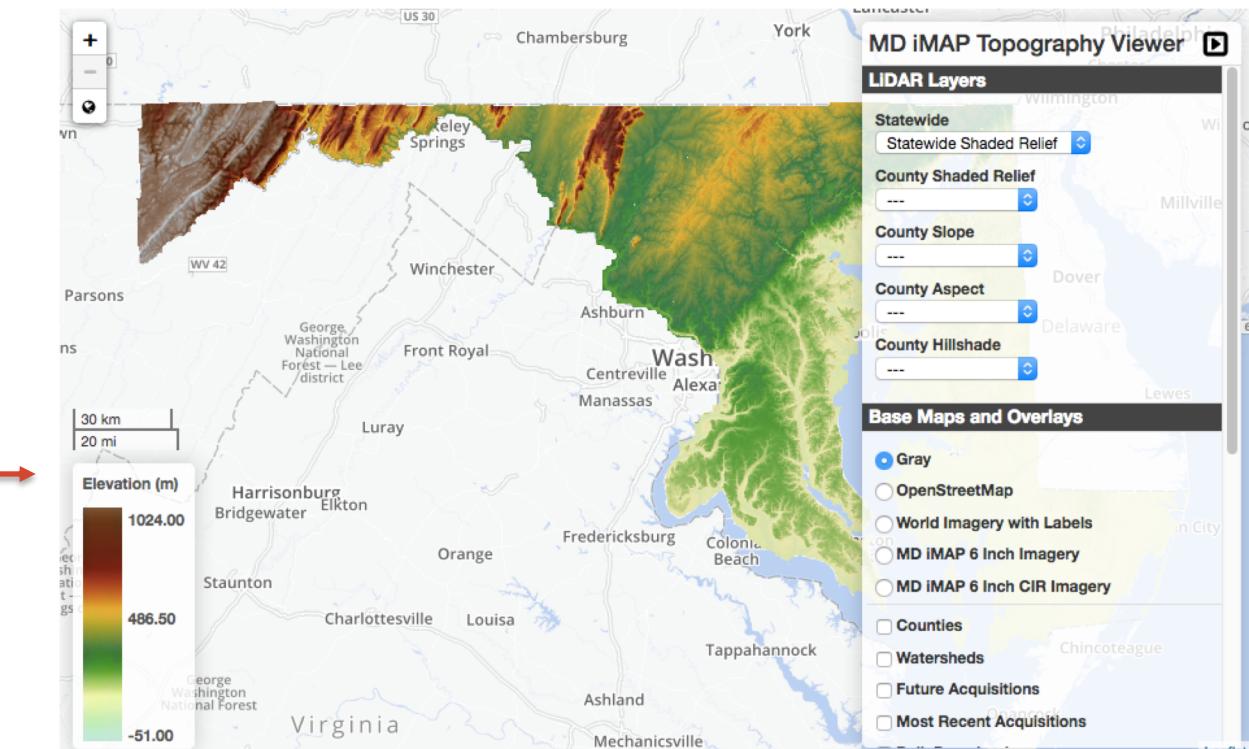


Image Credit: <https://coast.noaa.gov/dataviewer/#/lidar/search/>



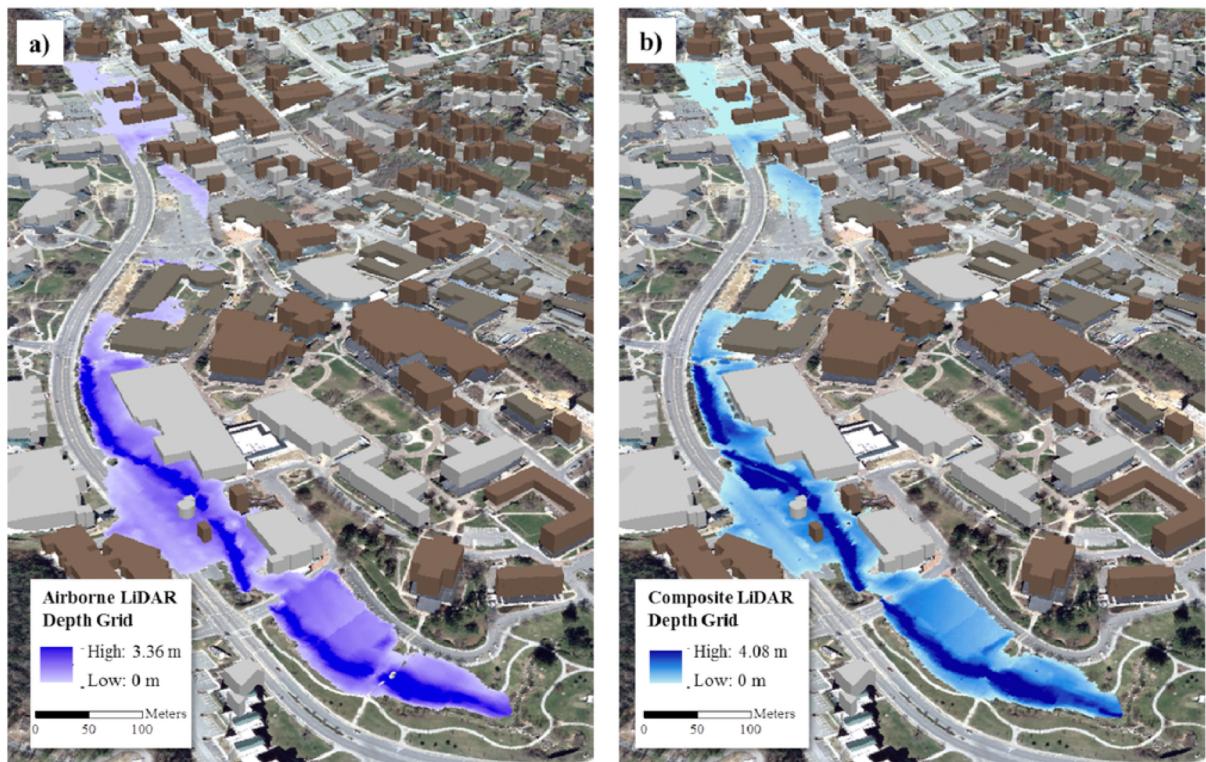
LIDAR Topography Data

- FEMA also has aircraft-based LIDAR data for elevation mapping in various areas: <https://bit.ly/2L9C4H1>
- There are also other regional data, commercial and open source, available from various sources
 - e.g. state of Maryland LIDAR data: <http://imap.maryland.gov/Pages/lidar-topography-viewer.aspx>



LIDAR Data Applications for Urban Flooding

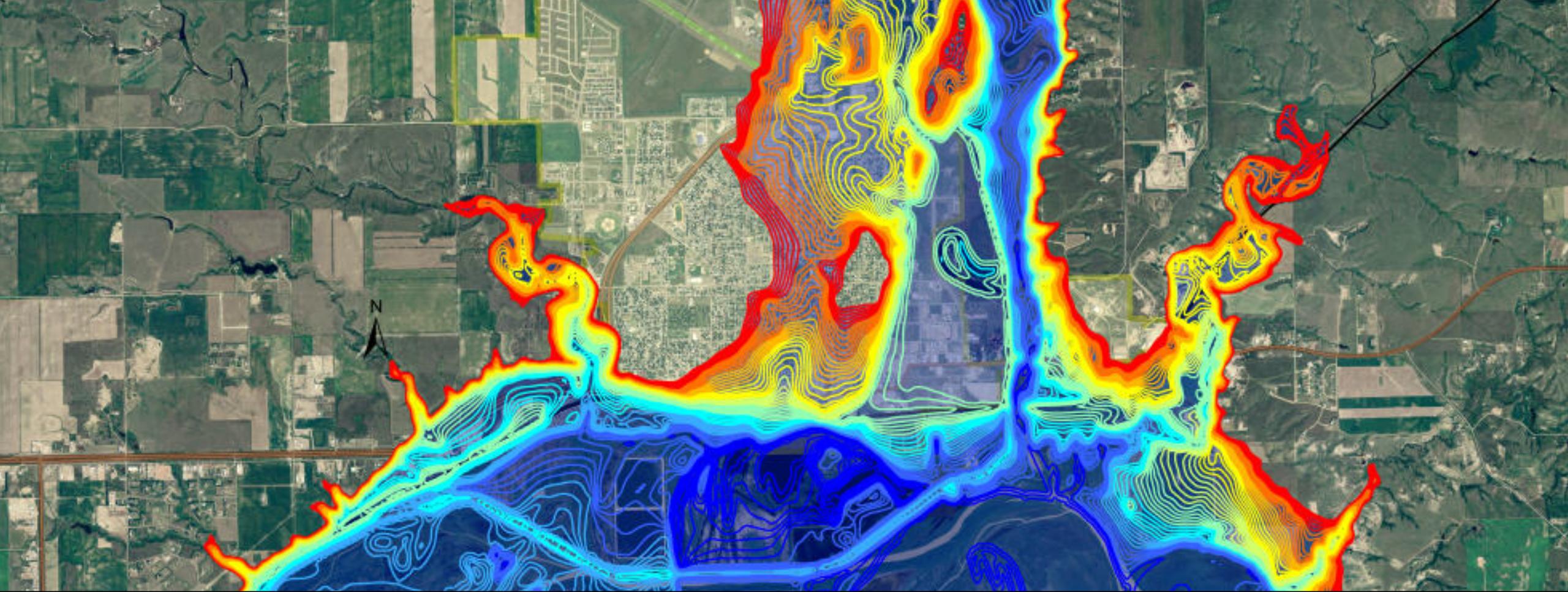
- FEMA uses LIDAR elevation to detect floodplains and for flood risk analysis
 - <https://bit.ly/2m9v3en>
- UNESCO uses LIDAR elevation data for flood modeling
 - <https://bit.ly/2JiTIBs>
- LIDAR-based regional flood modeling studies are a topic of exploration and research



Boone Creek Sub-Basin, NC

Turner et al., 2013: Flood Modeling Using a Synthesis of Multi-Platform LiDAR Data, Water, 5(4), 1533-1560; doi:[10.3390/w5041533](https://doi.org/10.3390/w5041533)





Overview of Landsat-Based Urban Data and Socioeconomic Data

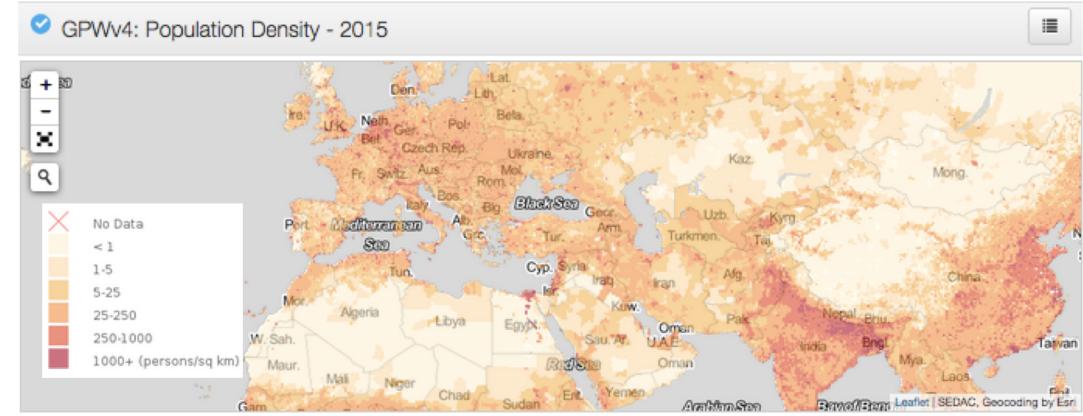
Socioeconomic and Urban Data

<http://sedac.ciesin.columbia.edu/>

The screenshot shows the homepage of the Socioeconomic Data and Applications Center (SEDAC). The header features the NASA logo and the text "SOCIOECONOMIC DATA AND APPLICATIONS CENTER (SEDAC)" followed by a subtitle "A Data Center in NASA's Earth Observing System Data and Information System (EOSDIS) — Hosted by CIESIN at Columbia University". Below the header is a navigation bar with links for DATA, MAPS, THEMES, RESOURCES, SOCIAL MEDIA, ABOUT, and HELP. A search bar and user account icons are also present. The main content area is titled "Data Collections (41)" and displays a grid of 12 dataset cards. The datasets include:

- Anthropogenic Biomes**: Describes 21 global anthropogenic biomes based on population density, land use, and vegetation cover, grouped into six categories: dense settlements, villages, croplands, rangeland, forested, and wildlands.
- Archive of Census Related Products (ACRP)**: A collection of value-added georeferenced data files derived from the 1990 U.S. Census, spanning the United States and its territories.
- China Dimensions**: A wide range of data from circa 1990, including administrative boundaries, population and agricultural census data, and other statistics, covering the administrative regions of China.
- Climate Effects on Food Supply**: Assessments of potential climate change impacts of temperature and precipitation on global staple crop production (wheat, rice, and maize), with a focus on quantitative estimates of yield changes based on multiple climate scenarios.
- Compendium of Environmental Sustainability Indicators**: A compilation of sustainability indicators from multiple sources incorporating multiple country codes. Methodological summaries are contained in an accompanying metadata database.
- Energy Infrastructure**: Data on the locations and status of nuclear power facilities along with estimates of the population residing near locations with at least one operating reactor.
- Environmental Performance Index (EPI)**: Released every two years since 2006, the EPI groups performance indicators into two policy categories, environmental health and ecosystem vitality, in order to gauge how close countries are to reaching established environmental policy goals.
- Environmental Sustainability Index (ESI)**: Released four times between 2000 and 2005, and based on a compilation of indicators derived from underlying data sets, the ESI measures overall progress towards environmental sustainability for 146 countries.
- Environmental Treaties and Resource Indicators (ENTRI)**: Information on treaty participation by country, environmental treaty texts, and a Conference of Party (COP) decision search tool for major multilateral environmental agreements.
- Georeferenced Population Data sets of Mexico**: Administrative boundaries, settlement locations and populations, and gridded population data for Mexico circa 1990. Includes place names, geographic coordinates of more than 30,000 urban and metropolitan places, and elevation data for
- Global Agricultural Lands**: Combines satellite data with agricultural inventory data to estimate the proportion of land area in cropland and pasture for the year 2000.
- Global Fertilizer and Manure, v1**: Global gridded data sets of fertilizer application rates and manure production of nitrogen and phosphorus for circa 2000.

Global Population Density



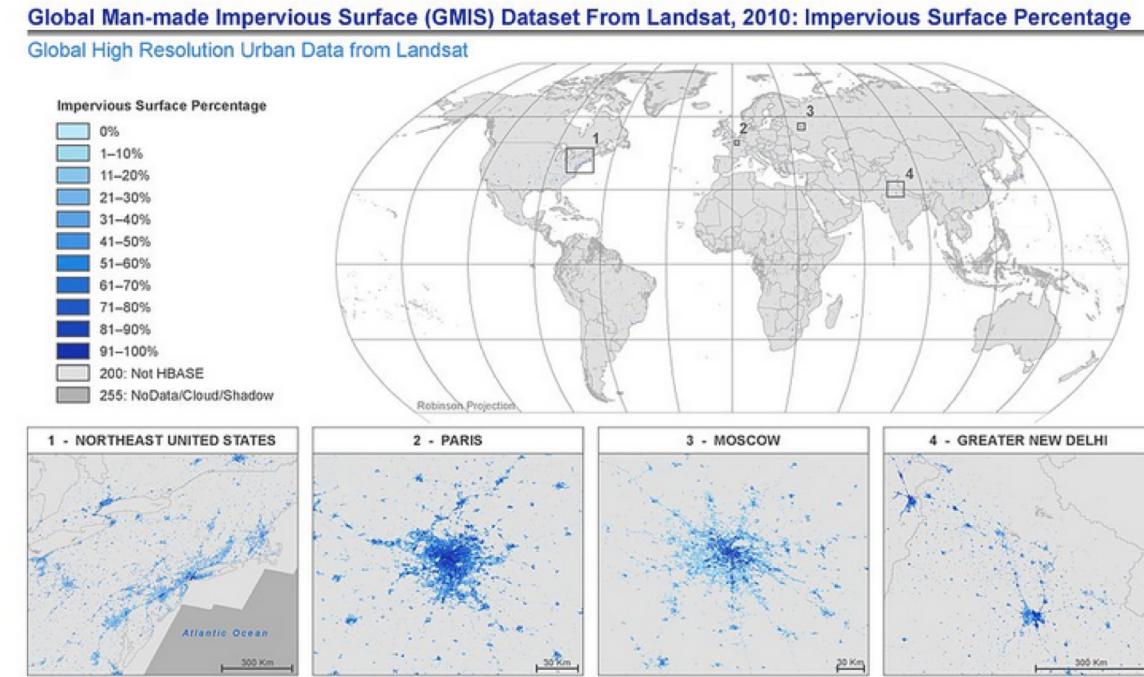
- Other Useful Datasets:
 - **Global urban data from the Landsat satellite**
 - **Global reservoirs and dams**
 - **Low elevation coastal zones**
 - **Global roads**
 - **Energy infrastructure**



Global Man-made Impervious Surface (GMIS) Dataset From Landsat

<http://sedac.ciesin.columbia.edu/data/set/ulandsat-gmis-v1>

- Derived from the Global Land Survey (GLS) Landsat data for 2010 used as target year
- Dataset includes:
 - percentage of impervious cover
 - per-pixel associated uncertainty for the impervious cover
- Spatial Resolution: 30 m
- A companion dataset to the Global Human Built-up And Settlement Extent (HBASE) dataset



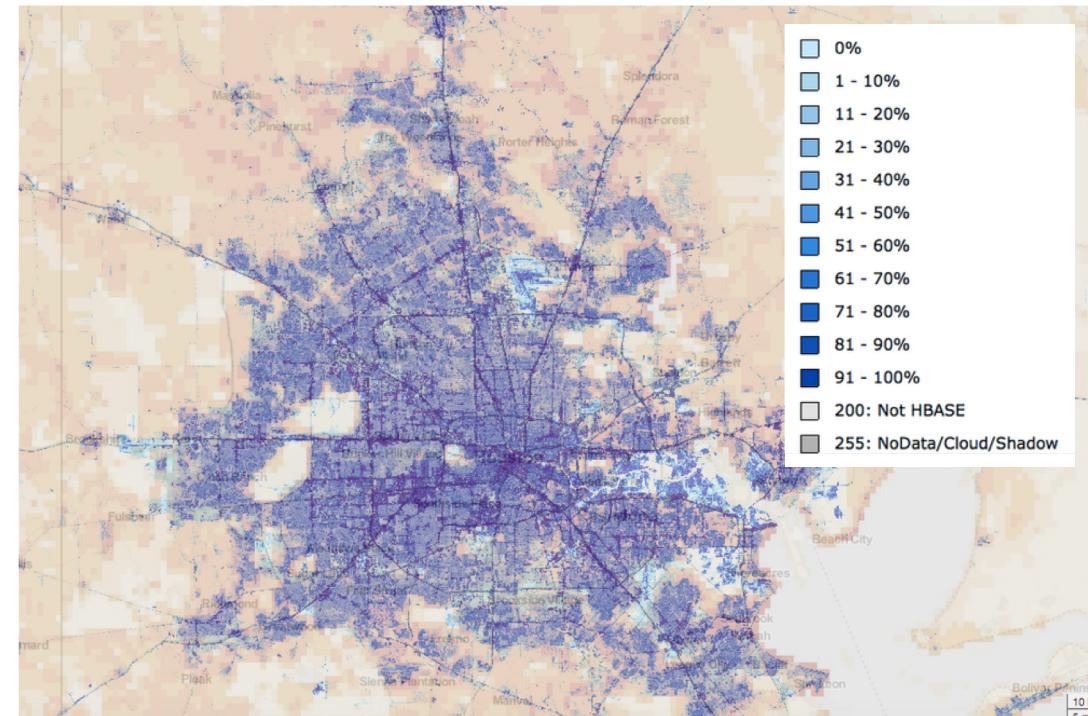
The Global Man-made Impervious Surface (GMIS) Dataset From Landsat, part of the Global High Resolution Urban Data from Landsat collection, consists of global estimates of fractional impervious cover derived from the Global Land Survey (GLS) Landsat dataset for the target year 2010. The GMIS dataset consists of two components: 1) global percent of impervious cover; and 2) per-pixel associated uncertainty for the global impervious cover. These layers are co-registered to the same spatial extent at a common 30m spatial resolution. The spatial extent covers the entire globe except Antarctica and some small islands. This dataset is one of the first global, 30m datasets of man-made impervious cover to be derived from the GLS data for 2010 and is a companion dataset to the Global Human Built-up And Settlement Extent (HBASE) dataset.

Brown de Colstoun, E. C., C. Huang, P. Wang, J. C. Tilton, B. Tan, J. Phillips, S. Niemczura, P.-Y. Ling, and R. E. Wolfe. 2017. Global Man-made Impervious Surface (GMIS) Dataset From Landsat. Palisades, NY: NASA Socioeconomic Data and Applications Center (SEDAC). <https://doi.org/10.7927/H4P55KKE>.



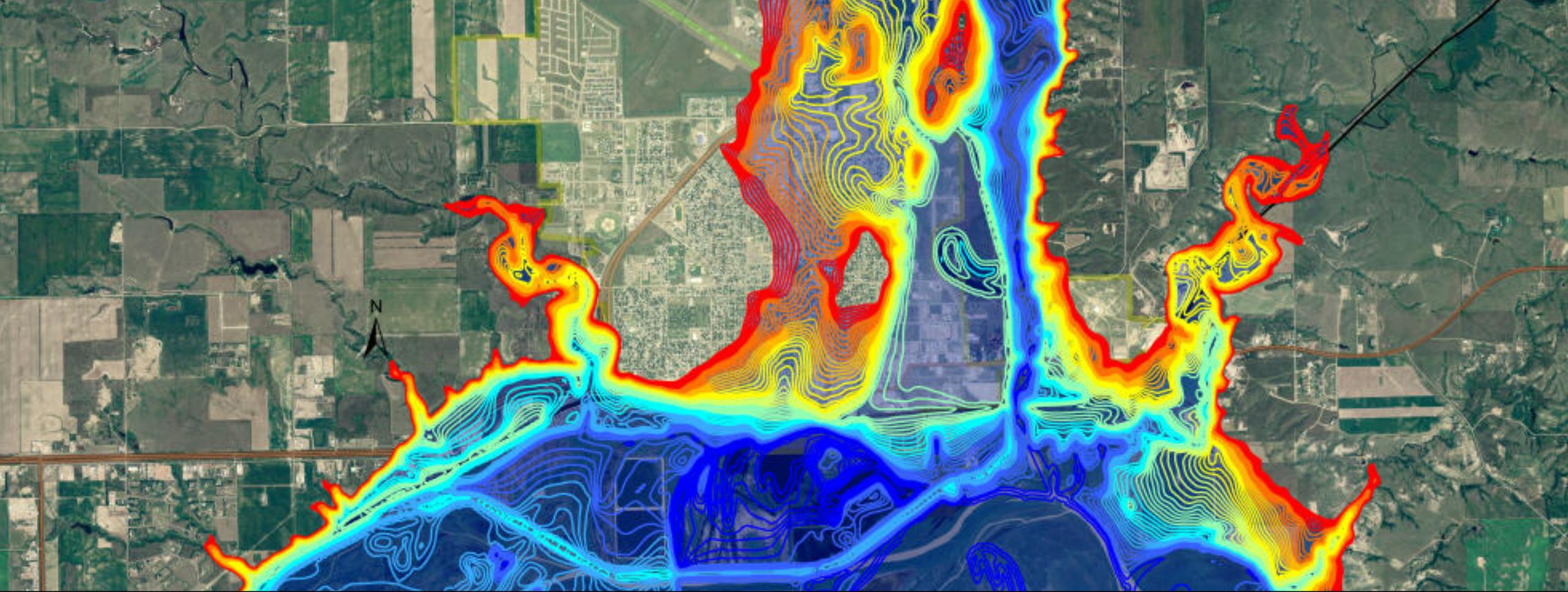
GMIS Data Application in Urban Flooding

- In an urban area, rainwater is removed by
 - runoff
 - infiltration into the ground
 - storm water drainage
- Estimates of impervious urban area from GMIS would help assess areas where no infiltration can be expected
- Combined with terrain/slope data, GMIS data can provide an indication of where waterlogging can occur during heavy rains, coastal surge or over-bank riverine flooding in a city
- Areas where pumping of water may be required if inundated

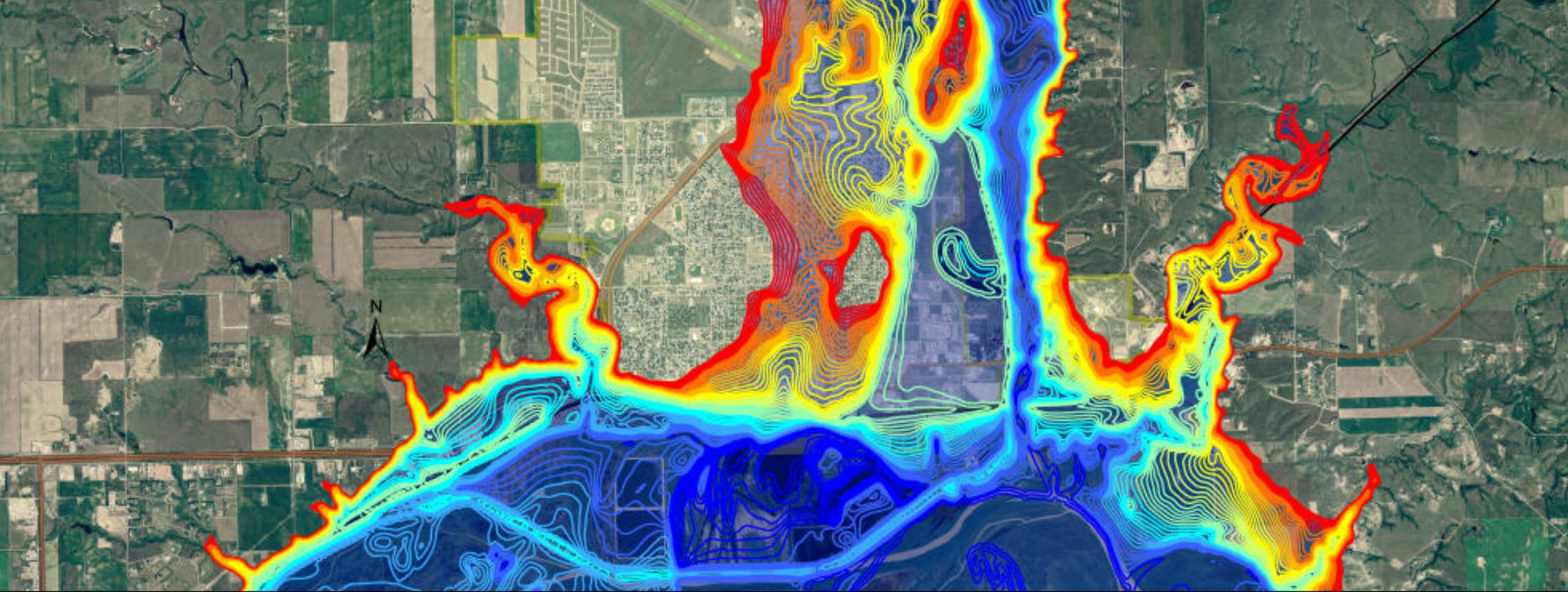


GMIS data for Houston





Demonstration of SEDAC/GMIS Data Access



Overview of Flood Mapping Tools: MODIS, DFO, GFMS, GDACS

Precipitation-Based Flood Tools

- ERDS uses GPM-IMERG data
- GFMS uses TRMM Multi-satellite Precipitation Analysis (TMPA) data
- GFMS will be transitioning to using GPM-IMERG data

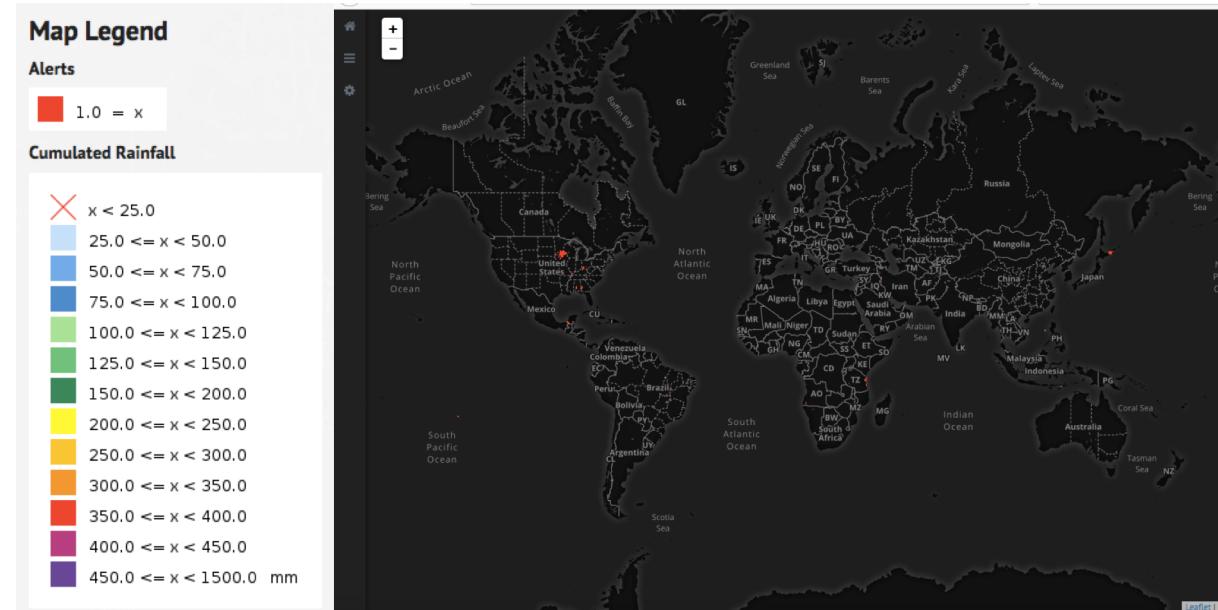


Extreme Rainfall Detection System (ERDS)

<http://erds.ithacaweb.org/>

- Uses near real-time GPM IMERG precipitation data and NOAA Global Forecasting System (GFS) rainfall for monitoring and forecasting accumulated rainfall
- Global Precipitation Climatology Center land-based rain gauge mean data are used as a reference to calculate extreme rainfall thresholds

- ERDS is one of the tools used by the UN World Food Programme (WFP) Emergency Preparedness Unit

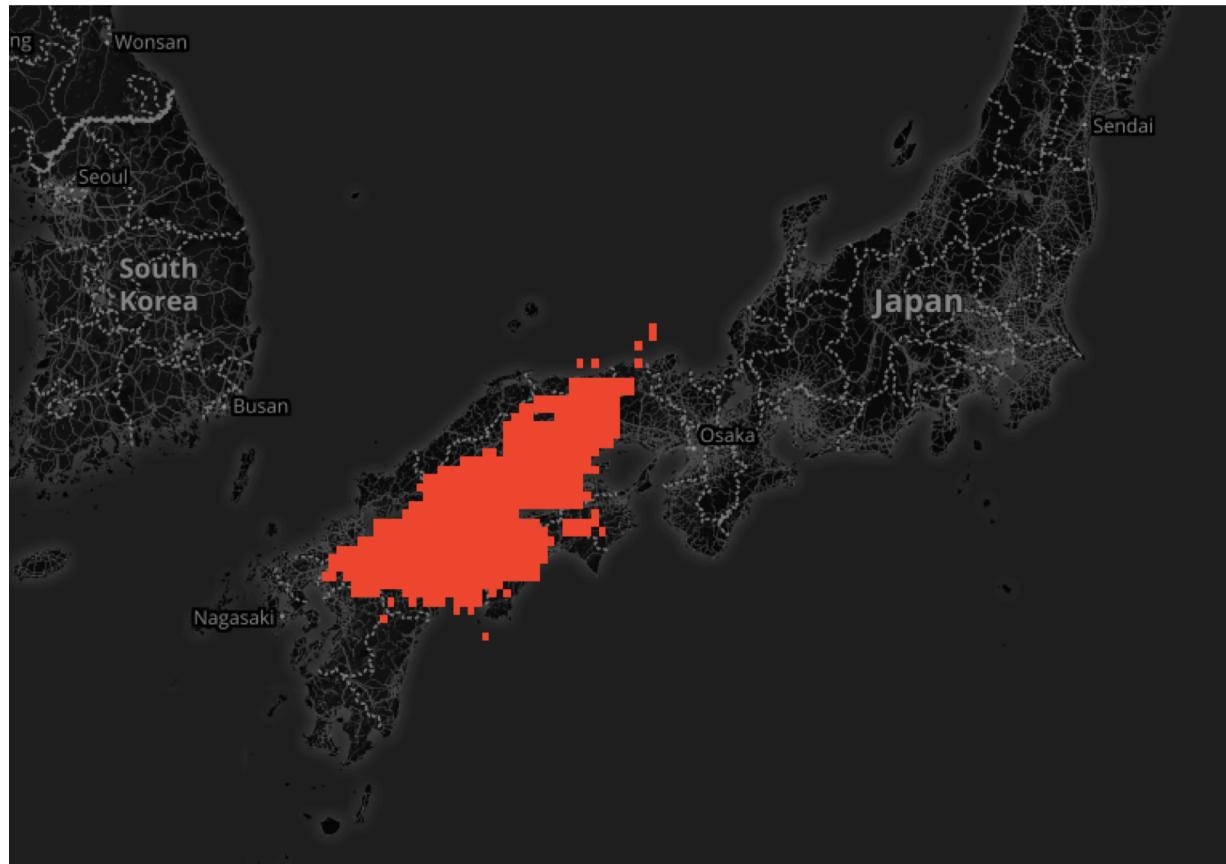


Extreme Rainfall Detection System (ERDS)

<http://erds.ithacaweb.org/>

- Provides cumulative precipitation based on near real-time IMERG data and 6-day GFS Forecast
- Provides alerts for extreme rainfall and potential flooding
- Experimental product – needs verification at local scale

Flood Alert in Japan
9 July 2018



Global Flood Monitoring System (GFMS)

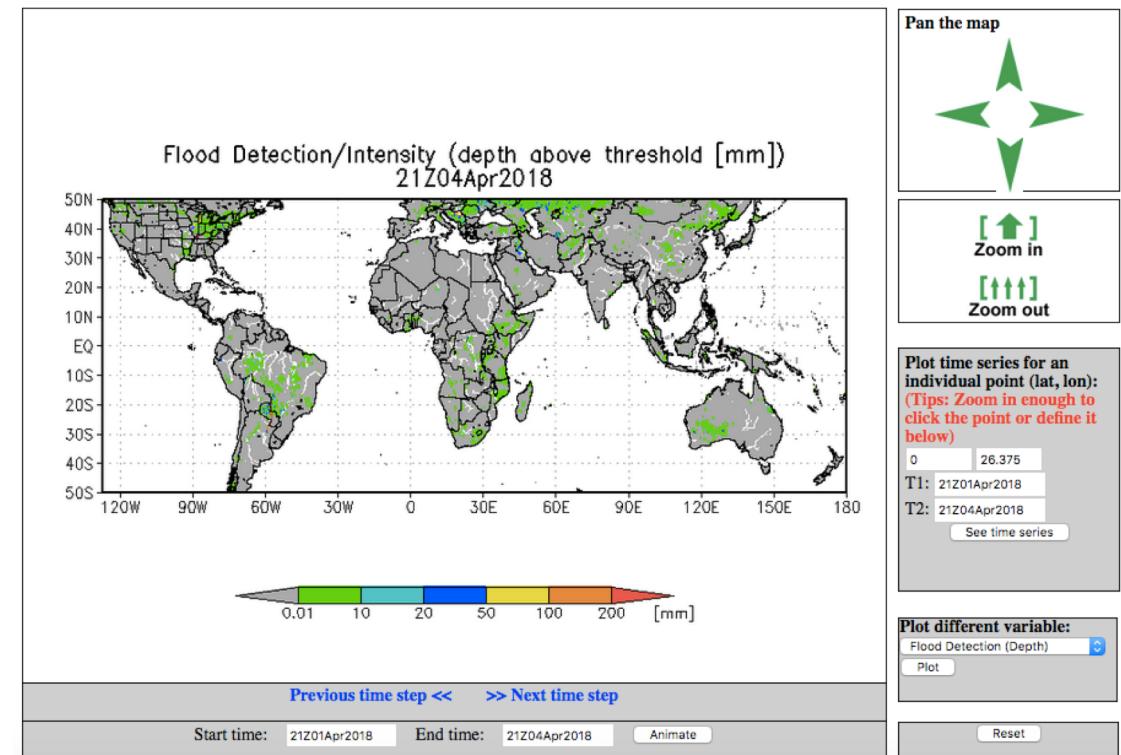
<http://flood.umd.edu/>

- Provides global maps, time series, and animations (50°S-50°N) of:
 - instantaneous rain rate every 3 hrs
 - accumulated rain over 24, 72, and 168 hrs
 - streamflow rates and flood intensity at $\frac{1}{8}$ th degree (~12 km) and 1 km
 - Near real-time and archives since 2013

Note: TRMM is no longer flying, but TRMM-based calibration is used to provide near real-time rainfall from a constellation of national & international satellites for flooding applications. Near real-time IMERG data available from:

<ftp://jsimpson.pps.eosdis.nasa.gov>

Interactive Features



GFMS

<http://flood.umd.edu/>

- Uses a hydrological model together with:
 - TMPA
 - Surface temperature and winds from NASA reanalysis model, Modern Era Retrospective Analysis for Research and Applications (MERRA)
 - Runoff generation from the UW Variable Infiltration Capacity (VIC) model
 - Runoff routing model from UMD

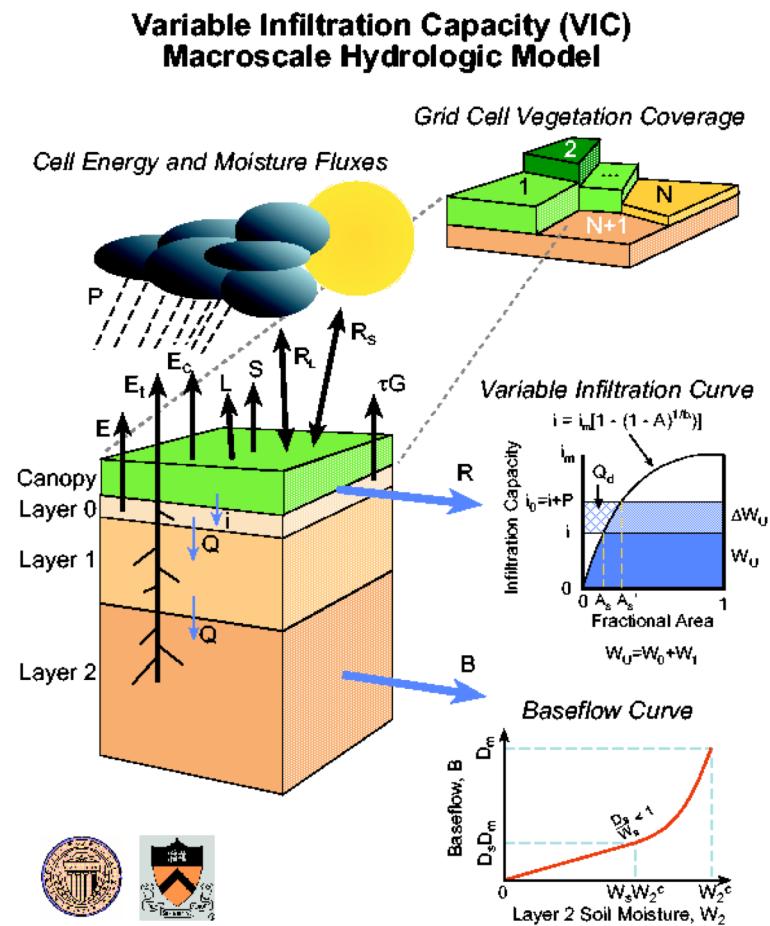
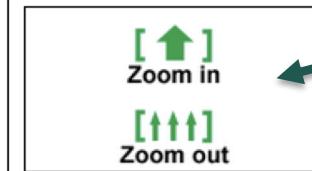
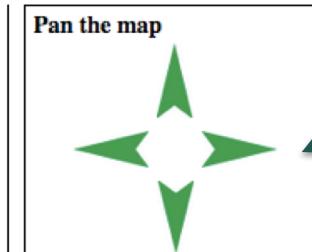
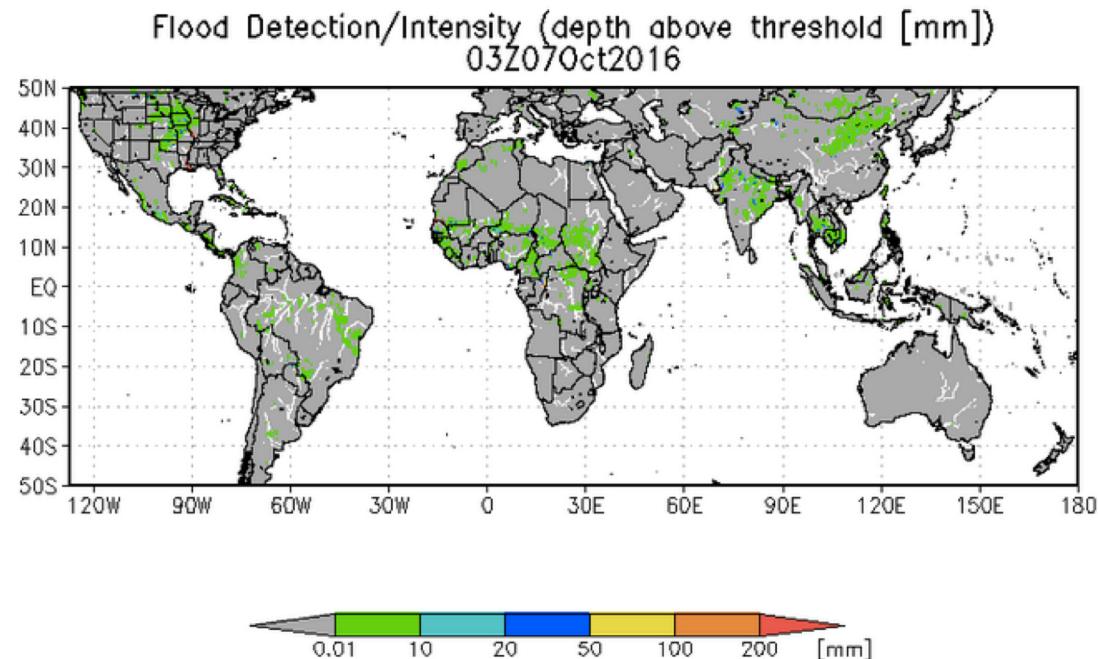


Image Credit: [UW VIC Macroscale Hydrologic Model](#); References: Wu, H., R. F. Adler, Y. Tian, G. J. Huffman, H. Li, and J. Wang (2014), Real-time global flood estimation using satellite-based precipitation and a coupled land surface and routing model, *Water Resour. Res.*, 50, 2693-2717, doi:10.1002/2013WR014710.; Wu H., R. F. Adler, Y. Hong, Y. Tian, and F. Policelli (2012), Evaluation of Global Flood Detection Using Satellite-Based Rainfall and a Hydrologic Model. *J. Hydrometeor*, 13, 1268-1284



GFMS

<http://flood.umd.edu/>



Plot time series for an individual point (lat, lon):
(Tips: Zoom in enough to click the point or define it below)

61.76 -152.4

T1: 03Z07Oct2016
T2: 21Z07Oct2016

See time series

Panel for plotting a time series for a specific point. It shows latitude (61.76), longitude (-152.4), start time (T1: 03Z07Oct2016), end time (T2: 21Z07Oct2016), and a "See time series" button.

Plot different variable:

Flood Detection (Depth)

Plot

Panel for selecting a different variable to plot. The "Flood Detection (Depth)" option is selected with a radio button.

Map Navigation

Zoom in/out

Select individual grid point for time series data

Plot different variables

Animation

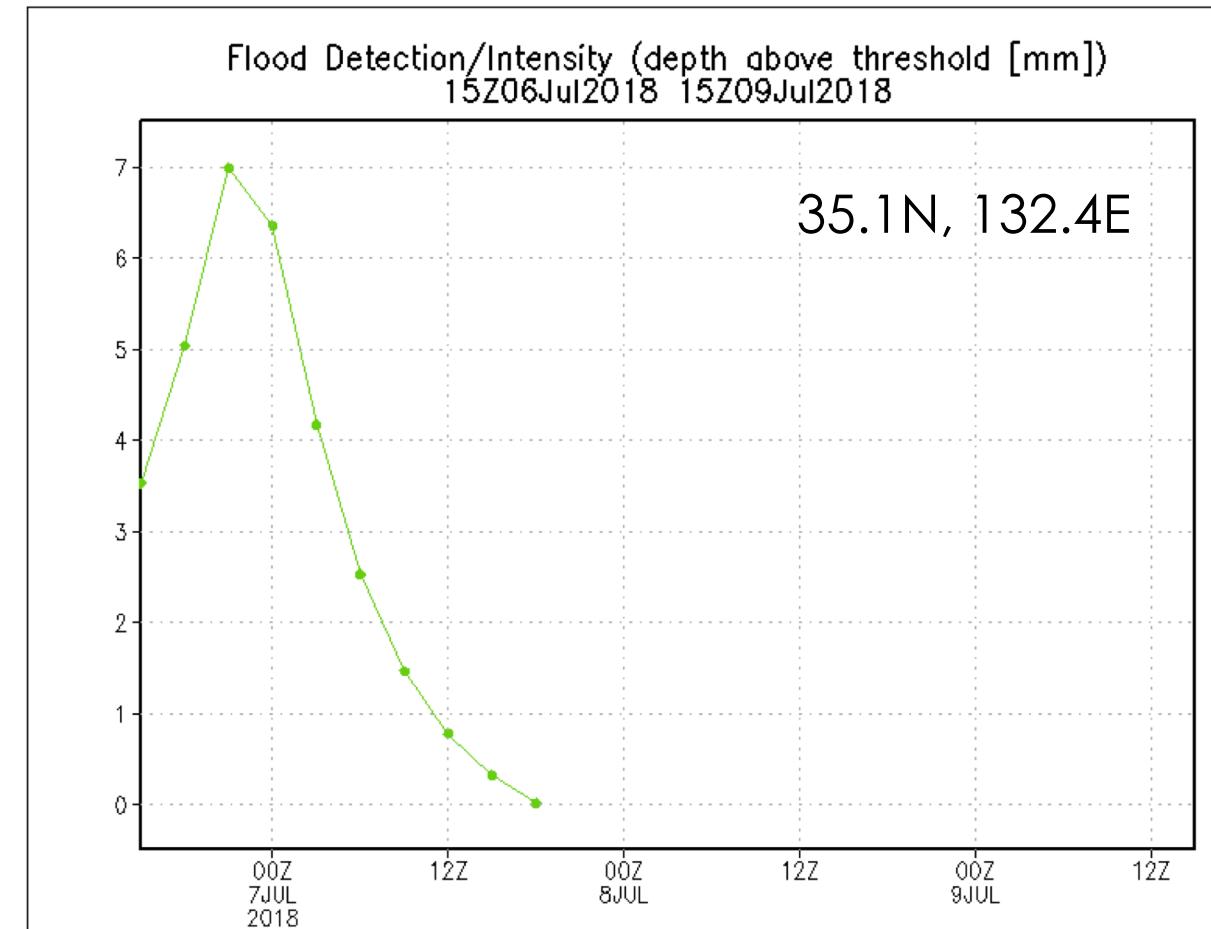
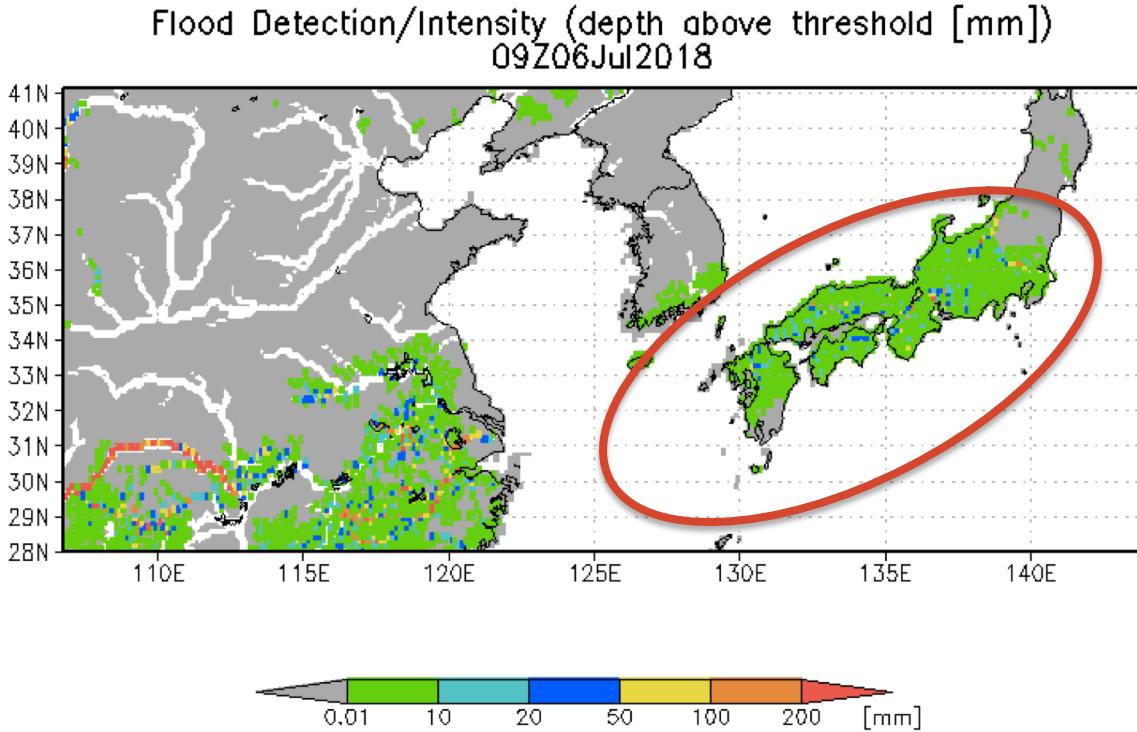
Previous time step << >> Next time step

Start time: 03Z07Oct2016 End time: 21Z07Oct2016 Animate

Reset



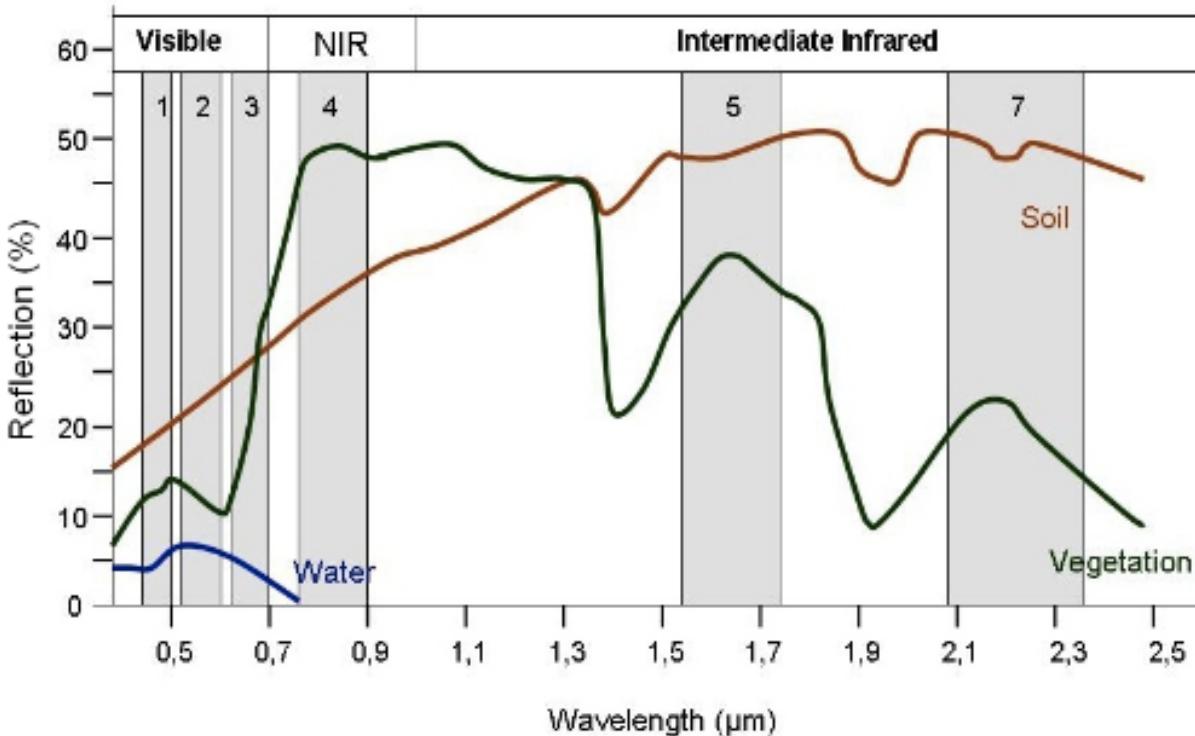
GFMS: Flooding in Japan July 2018



Land Cover Based Flooding Tools

Visible Radiation

- Reflected by the surface and depends on surface type



Used for Flood Mapping

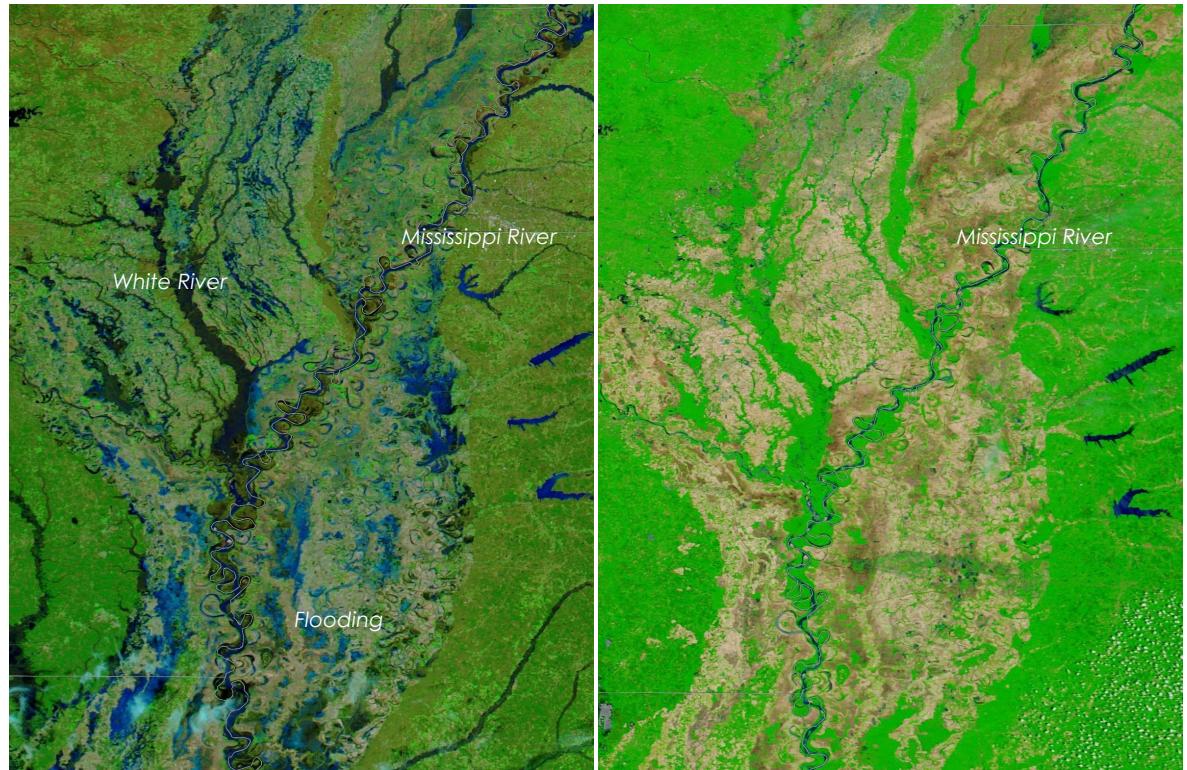
- Source
 - Terra/Aqua MODerate Resolution Imaging Spectroradiometer (MODIS) reflectance changes
- Tools
 - MODIS NRT Flood Mapping
 - Dartmouth Flood Observatory



MODIS-Based Inundation Mapping

- MODIS provides observations 1-2 times per day
- Certain bands indicate water on previously dry surfaces:
 - Band 1: 620-670 nm
 - Band 2: 841-876 nm
 - Band 7: 2105-2155 nm
- Mapped with respect to a global reference database of water bodies
- MODIS cannot see the surface in the presence of clouds

Mississippi River Flooding 2016



MODIS (Aqua)
Mar 15, 2016

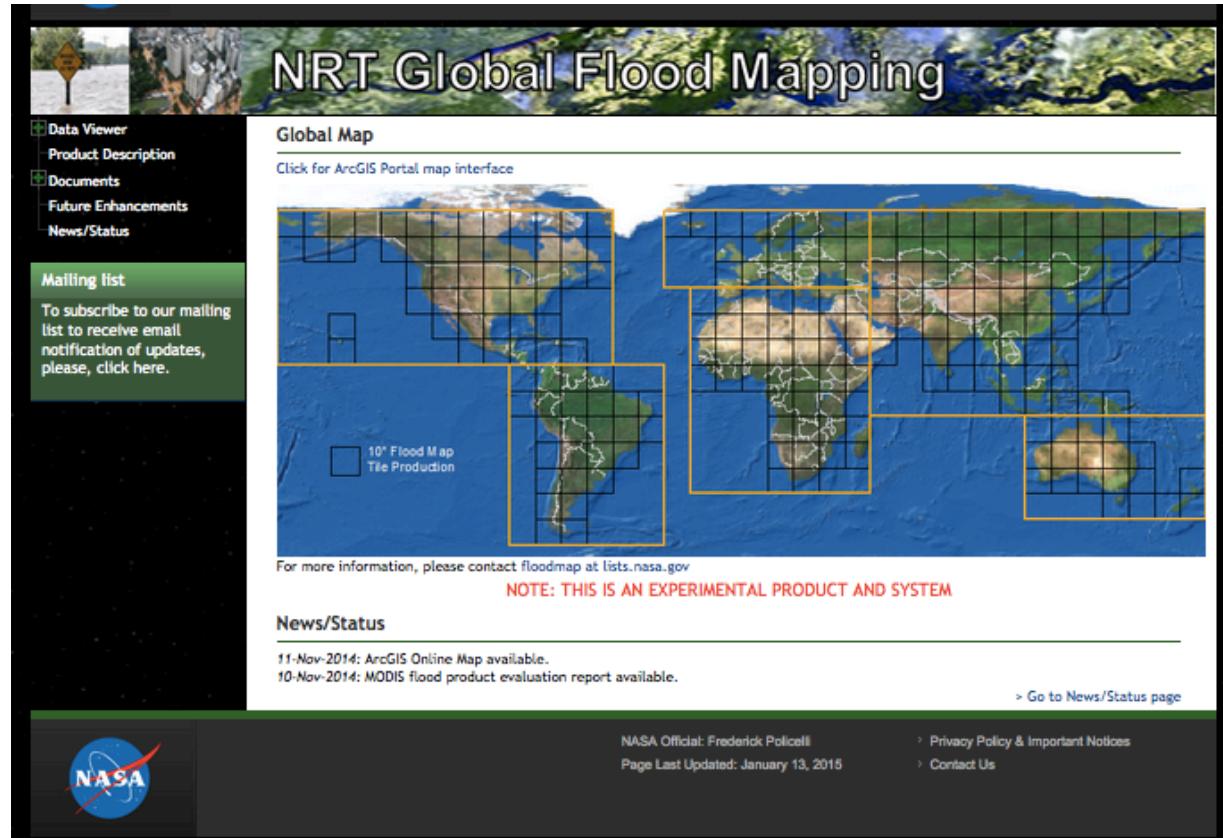
MODIS (Terra)
May 13, 2016



MODIS NRT Global Flood Mapping

<http://oas.gsfc.nasa.gov/>

- Based on MODIS reflectance at 250 m resolution composited on 2, 3, and 14 days
- Flood maps available on $10^\circ \times 10^\circ$ tile
- Permanent and surface flood water data available
- Cloud or terrain shadows can be misinterpreted as surface water
- Provides near real-time flood mapping since Jan 2013



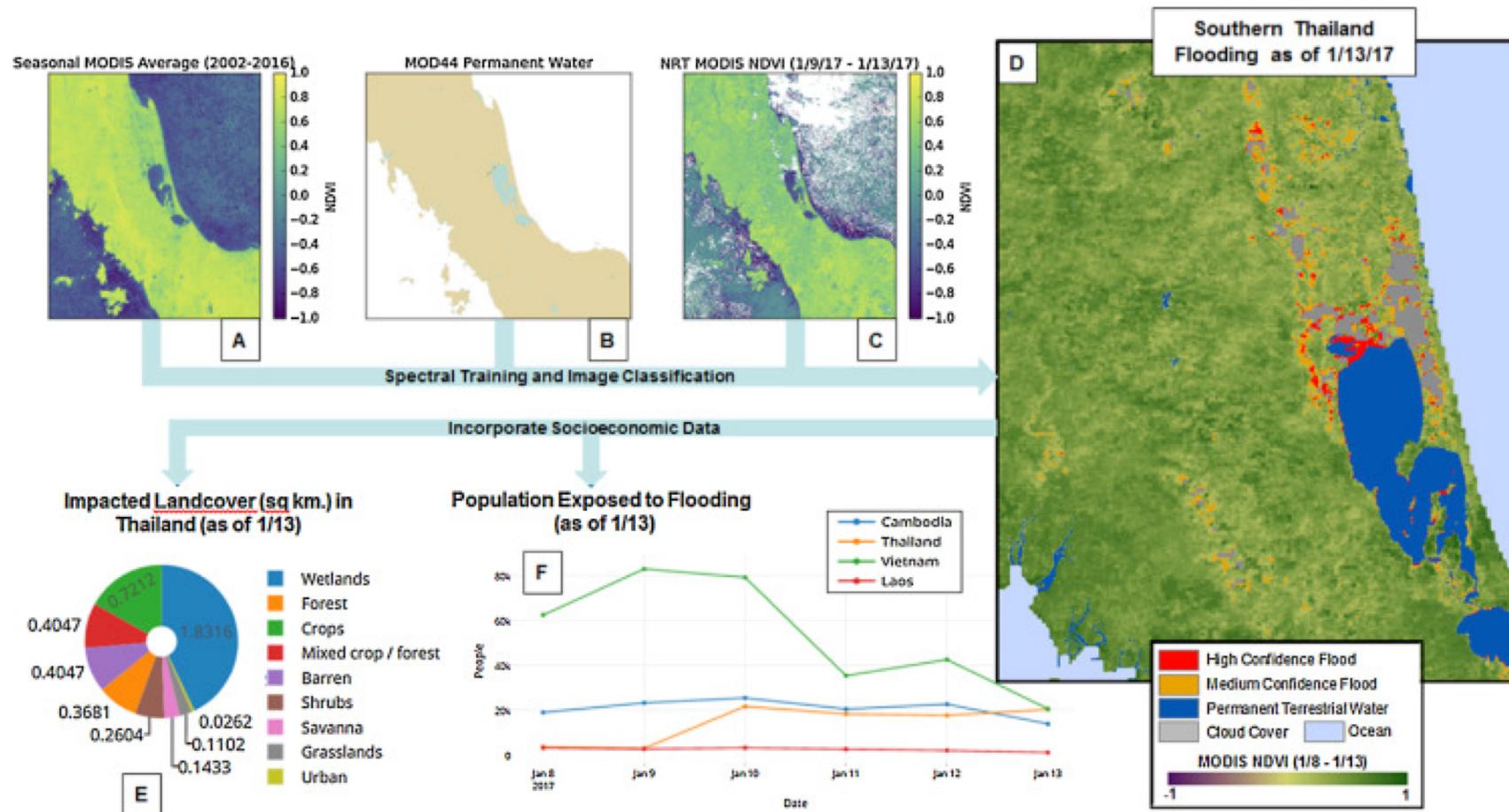
MODIS NRT Global Flood Mapping: Available Quantities

<http://oas.gsfc.nasa.gov/>

Products		Available Downloads
MODIS Flood Map	MFM	png
MODIS Flood Water	MFW	shapefile (.zip) KMZ
MODIS Surface Water	MSW	shapefile (.zip) KMZ
MODIS Water Product	MWP	geotiff
README		pdf txt



MODIS Inundation Map: Japan



- Shows a few flooded areas – not all flooded areas are observed due to the presence of clouds
- May require supervised reflectance threshold for improved inundation detection (e.g. Ahamed and Bolten, 2017)

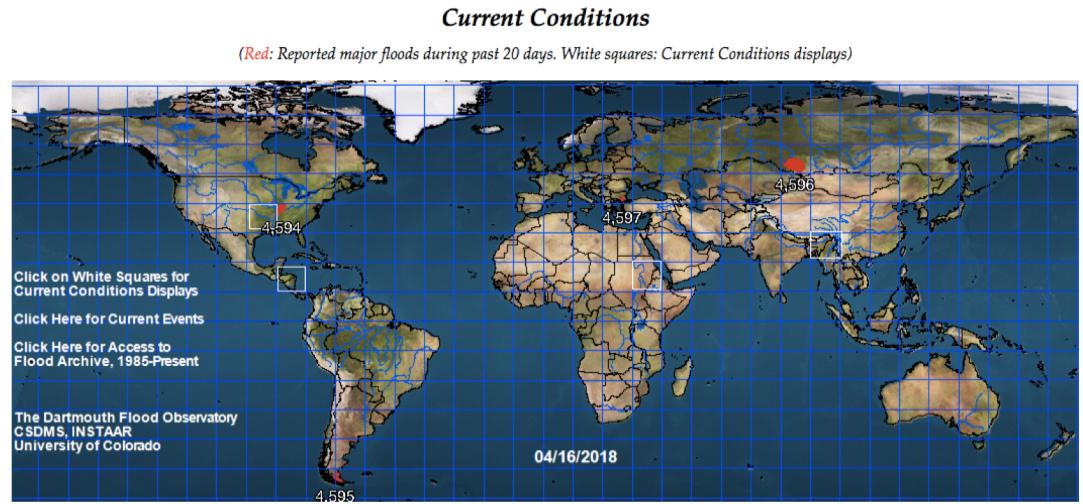
Ahamed, A., and J. Bolten, 2017: A MODIS-based automated flood monitoring system for southeast Asia, International Journal of Applied Earth Observations and Geoinformation, 62, 104-117.



Dartmouth Flood Observatory (DFO)

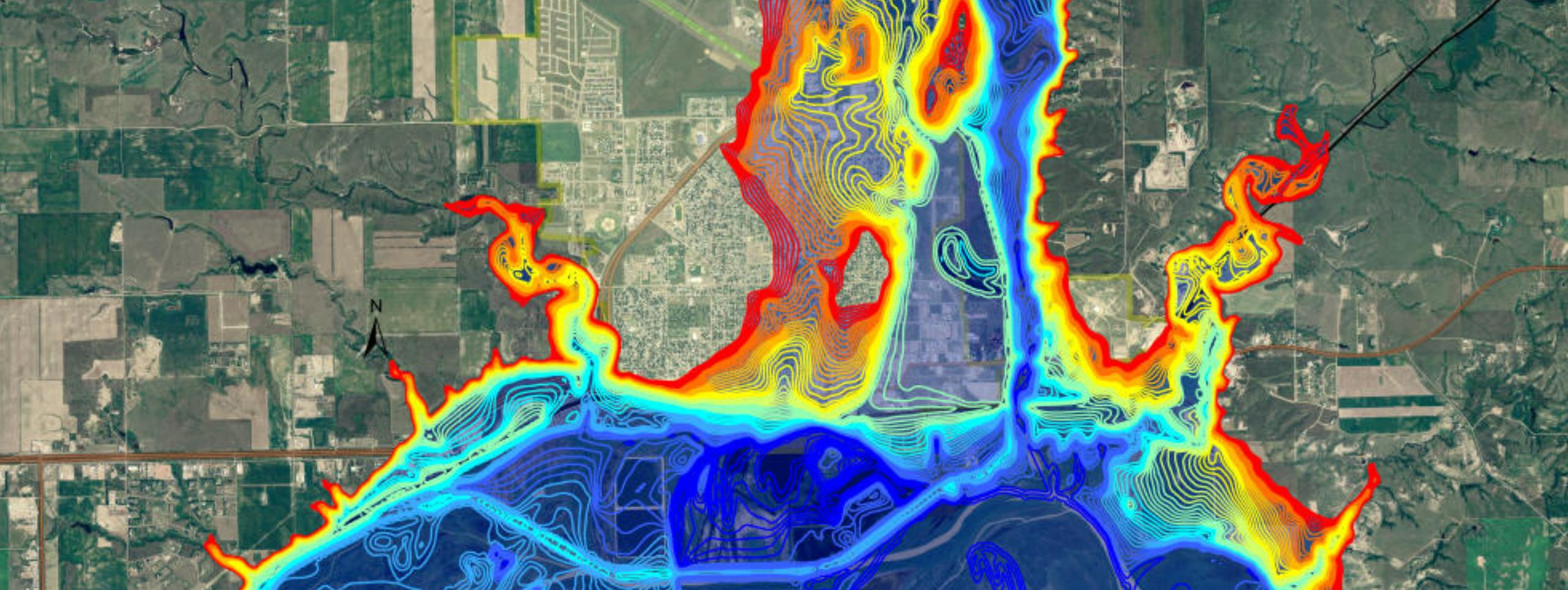
<http://floodobservatory.colorado.edu/>

- Uses flood mapping based on MODIS reflectance
 - same as MODIS NRT
- Also uses Landsat 8, EO-1, and ASTER images
 - uses COSMO-SkyMed and Sentinel-1 synthetic aperture radar (SAR) when available)
- Current flood events are analyzed with multiple data sources, including media report



- Provides near real-time, current, and past flood event mapping
- Red areas (above) indicate inundated surfaces



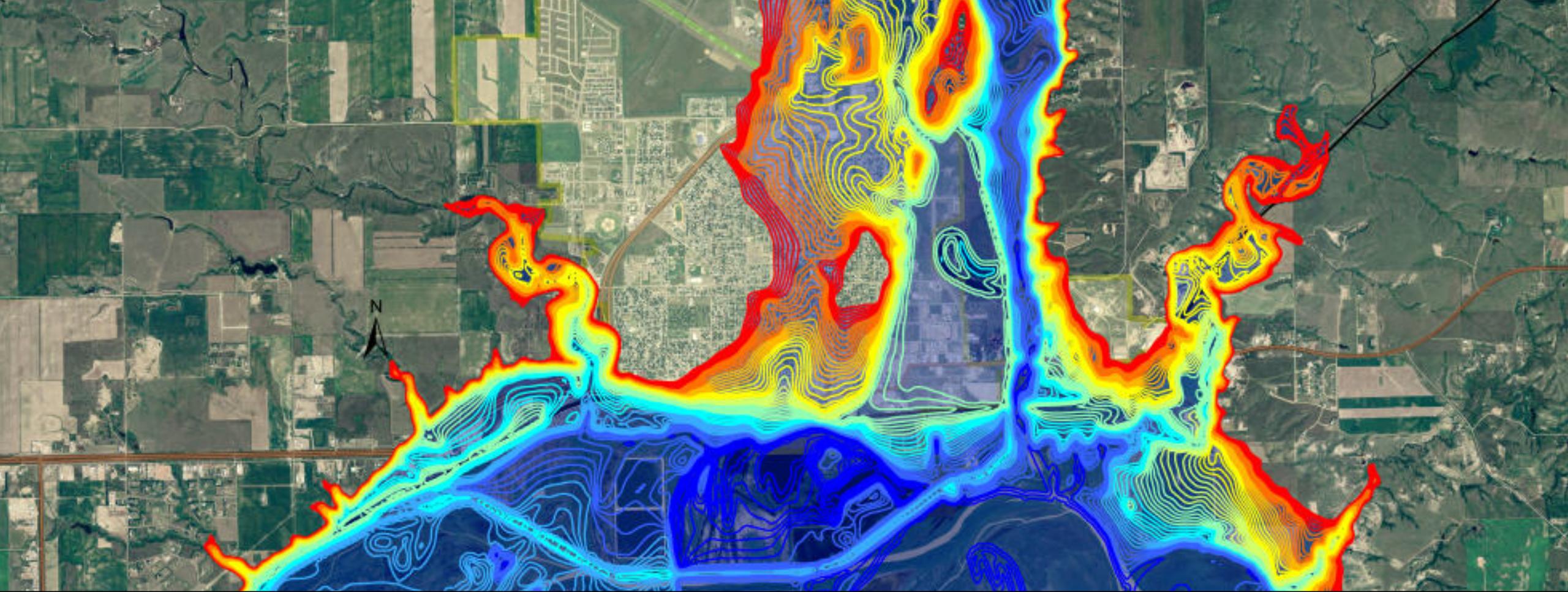


Demonstration of Monitoring Urban Floods For
Decision Making

Urban Flood Cases

- Ellicott City, Maryland
 - Flash Flood occurred on May 27, 2018
- Houston, Texas
 - Heavy rain caused flooding on July 4, 2018





Challenges in Monitoring Urban Flooding

Urban Flood: Data and Information Challenges

- Low spatial resolution of Remote sensing-based precipitation (~10 km), weather forecast (~35 km x 50km), runoff and streamflow (~12 km)
- Medium spatial resolution of surface inundation from MODIS (250 m)
- Landsat-based inundation can have 30 m resolution but swath size is 185 km and temporal resolution is 16 days
- Sentinel-1 SAR data have high spatial resolution (5 m) but 12-day temporal resolution
- Optical data (MODIS, Landsat) cannot see the surface inundation in the presence of clouds
- Terrain data from SRTM are at 30m resolution, available globally whereas high resolution LIDAR data (~5 to 10 m) do not have global coverage
- Flooding in smaller urban areas may not be resolved by remotely-sensed data alone



Urban Flood Management

- Each urban area is unique and flood management requires special solutions
- In addition to the rainfall, terrain, and urban extent data, urban planning, storm water removal, and drainage system capacity and design play a crucial role in urban flood management
- A combination of remote sensing-based information, in situ observations, and urban flood modeling is required for effective urban flood monitoring and decision making





Thank You!