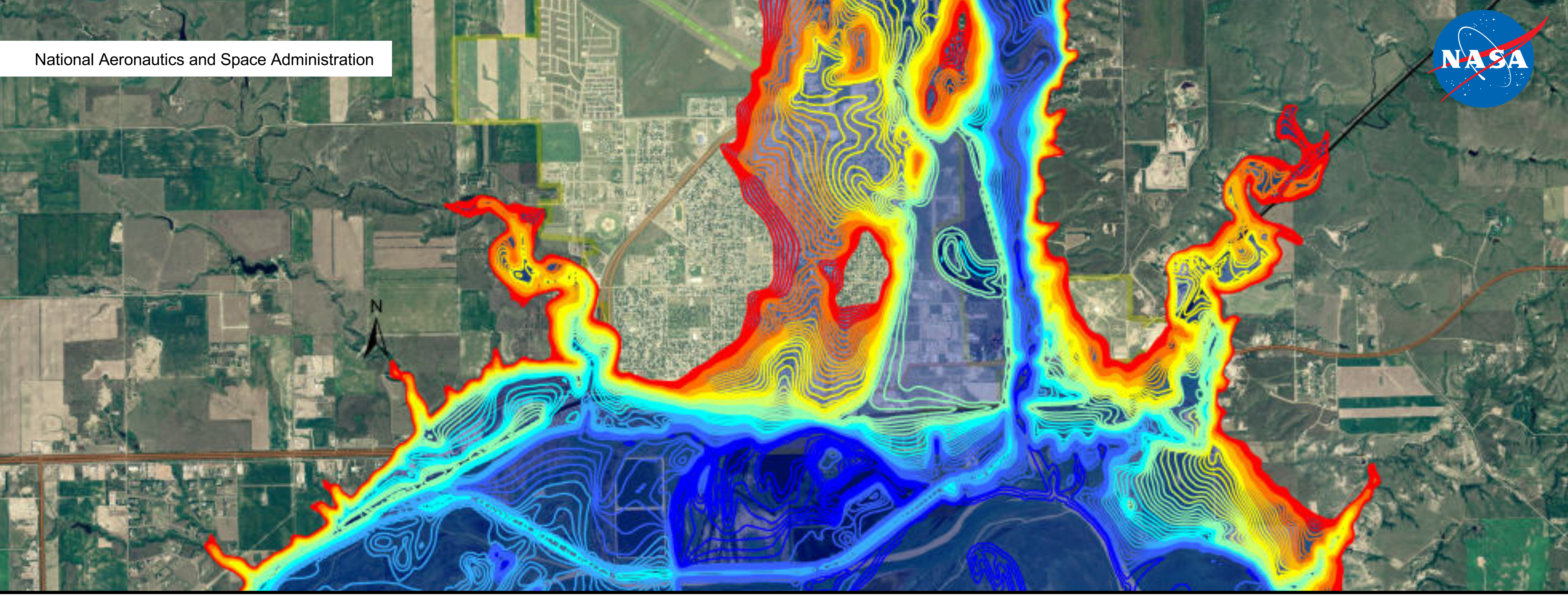
National Aeronautics and Space Administration



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

August 1

Access and Analysis of Remote Sensing Observations for Urban Flood Monitoring

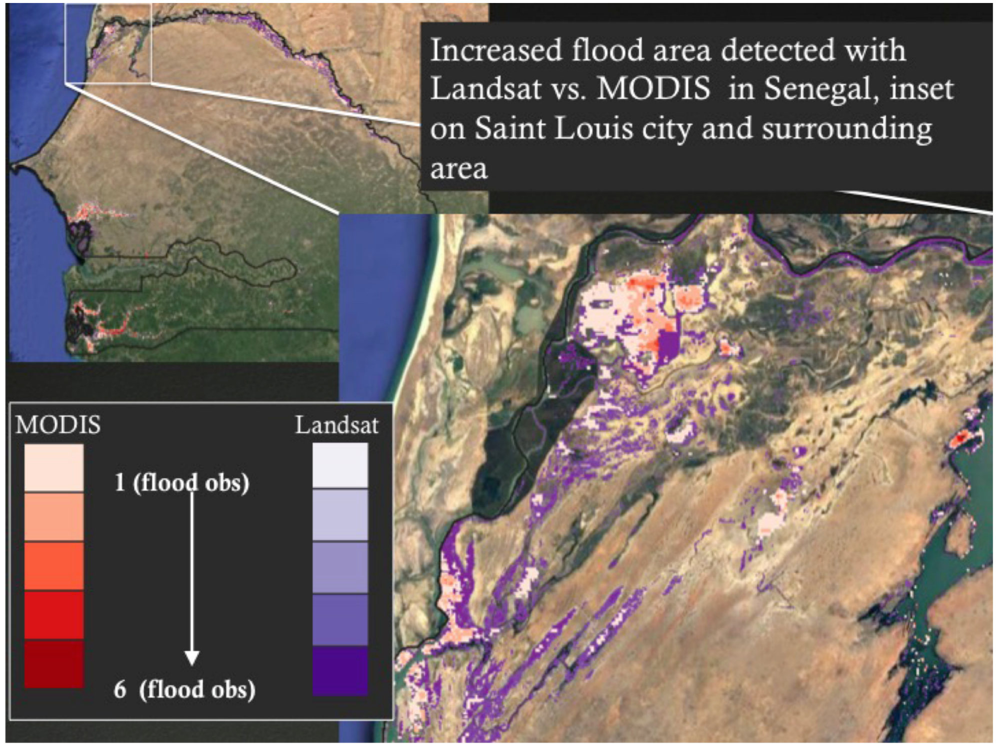


Image Credits: (left) https://blogs.worldbank.org/taxonomy/term/14333; (right)

Homework and Certificates

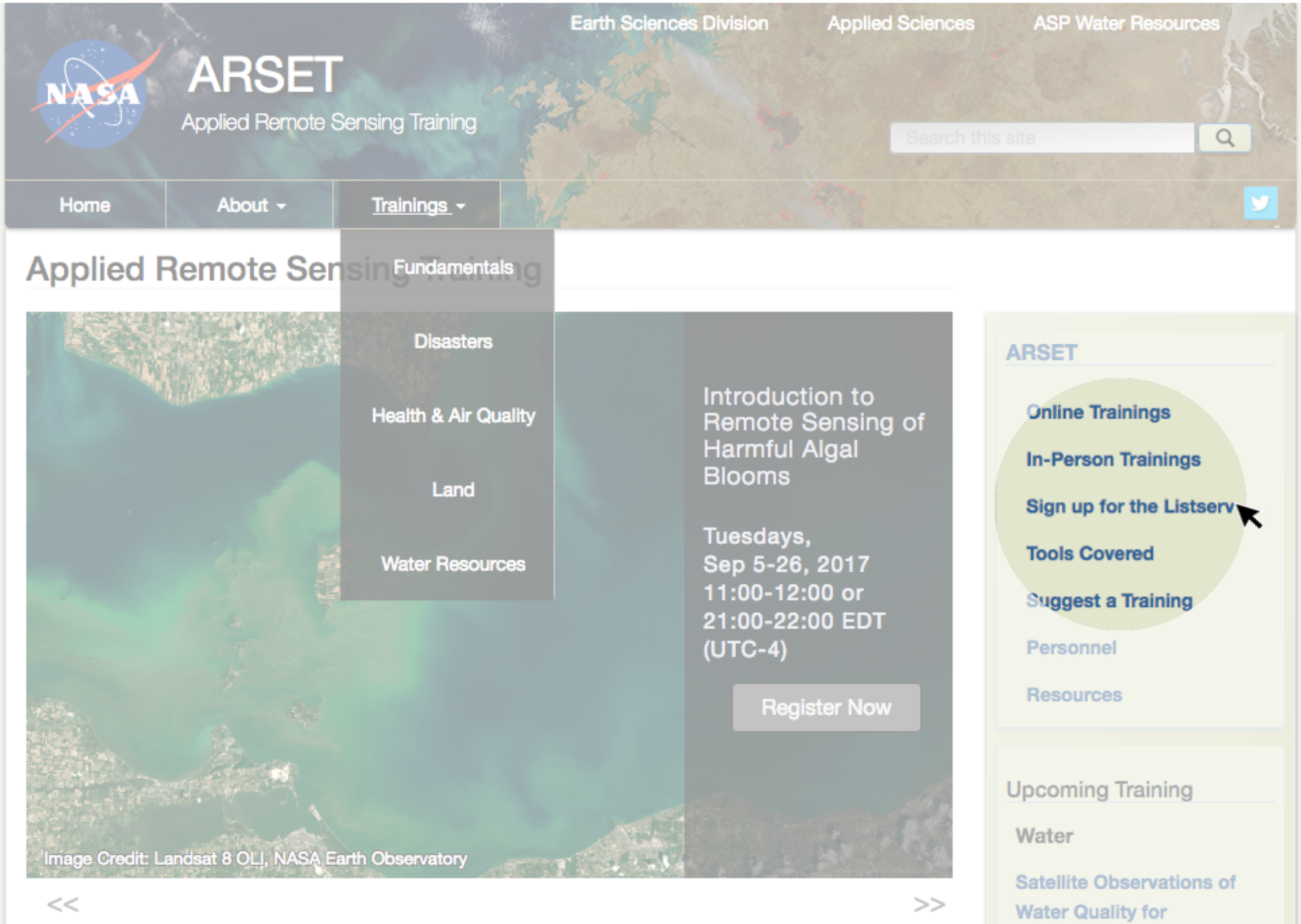
- Homework will be available after Session-1 and Session-2 from https://arset.gsfc.nasa.gov/water/webinars/
- **Answers must be submitted via Google Form**
- Certificate of Completion:
  - Attend both webinars
  - Complete the homework assignment by the deadline (15 August 2018)
  - You will receive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

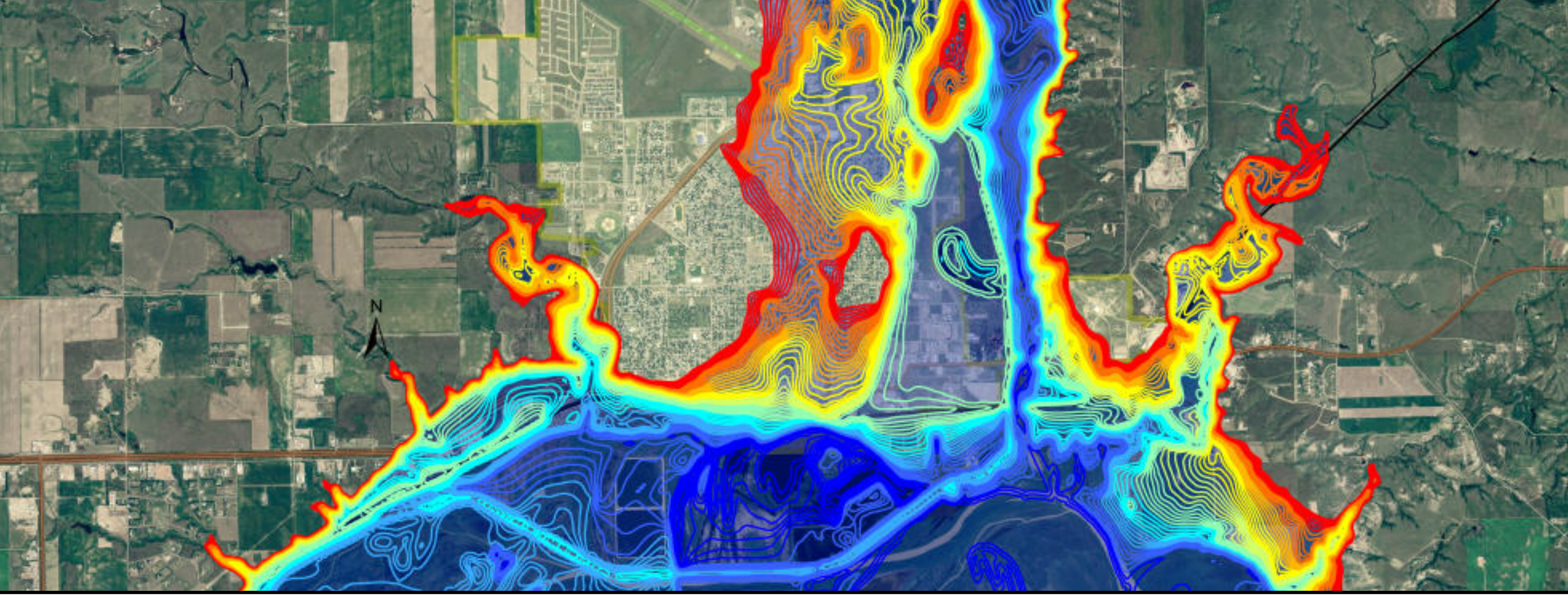
Outline for Session 2

- 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/

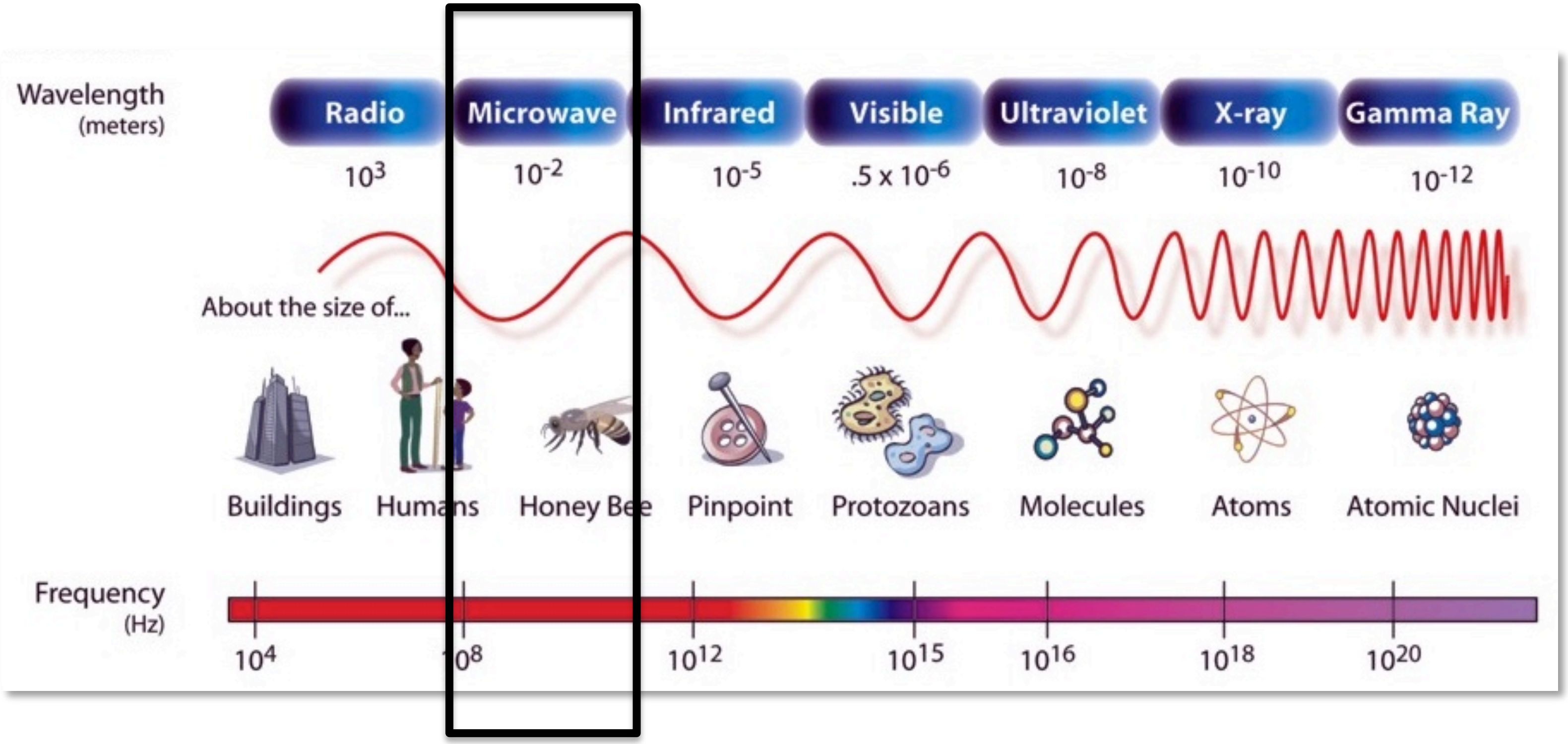




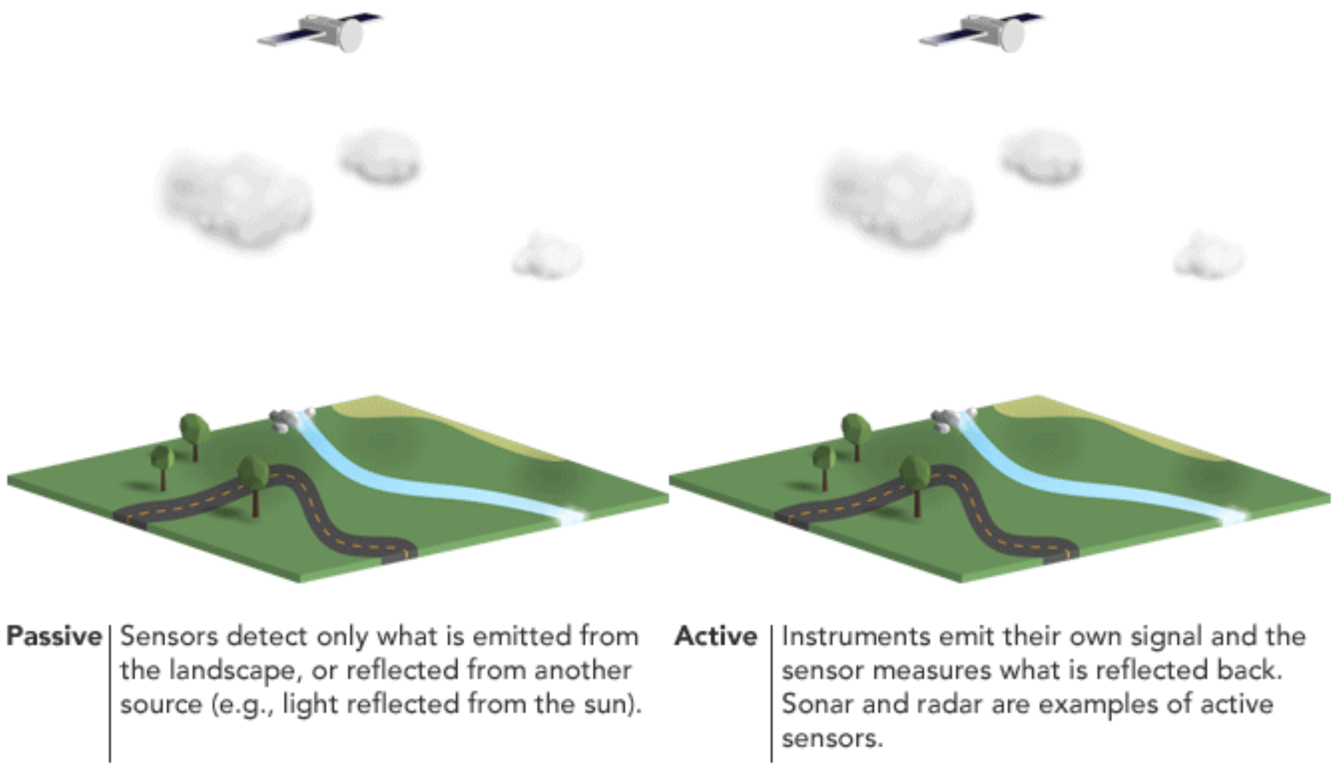
SAR-Based Urban Flood Monitoring

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:

- 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

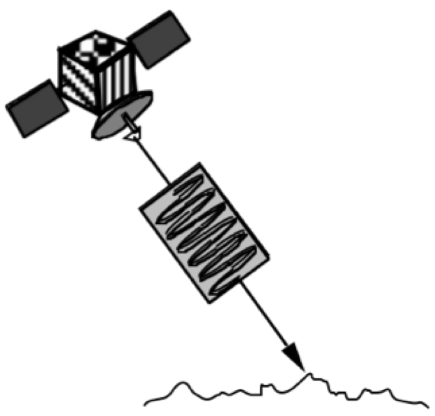
- Nearly all weather capability
- Day or night capability
- Penetration through the vegetation canopy
- Penetration through the soil
- Minimal atmospheric effects
- Sensitivity to dielectric properties (liquid vs. frozen water)
- Sensitivity to structure

Disadvantages

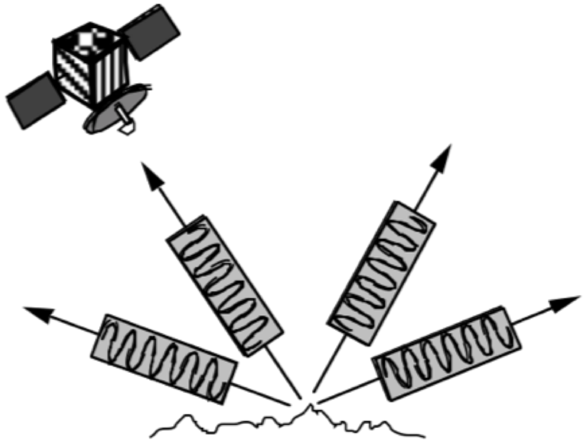
- Information content is different than optical and sometimes difficult to interpret
- Speckle effects (graininess in the image)
- Effects of topography

Review of Radar Image Formation

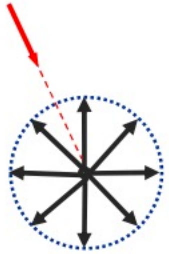
1. Radar can measure amplitude (the strength of the reflected echo) and phase (the position of a point in time on a waveform cycle)
2. Radar can only measure the part of the echo reflected back towards the antenna (backscatter)
3. Radar pulses travel at the speed of light
4. The strength of the reflected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



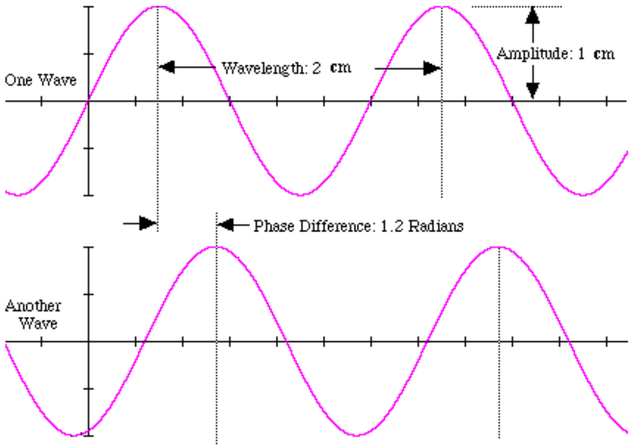
RADAR TRANSMITS A PULSE



MEASURES REFLECTED ECHO (BACKSCATTER)

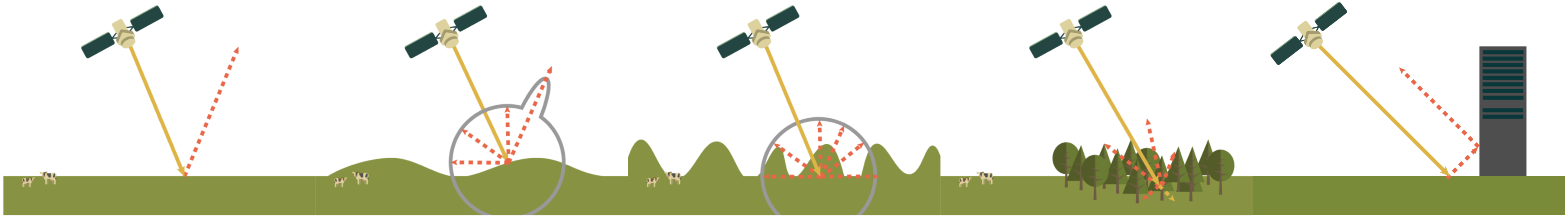


Isotropic scatterer



Radar Signal Interaction

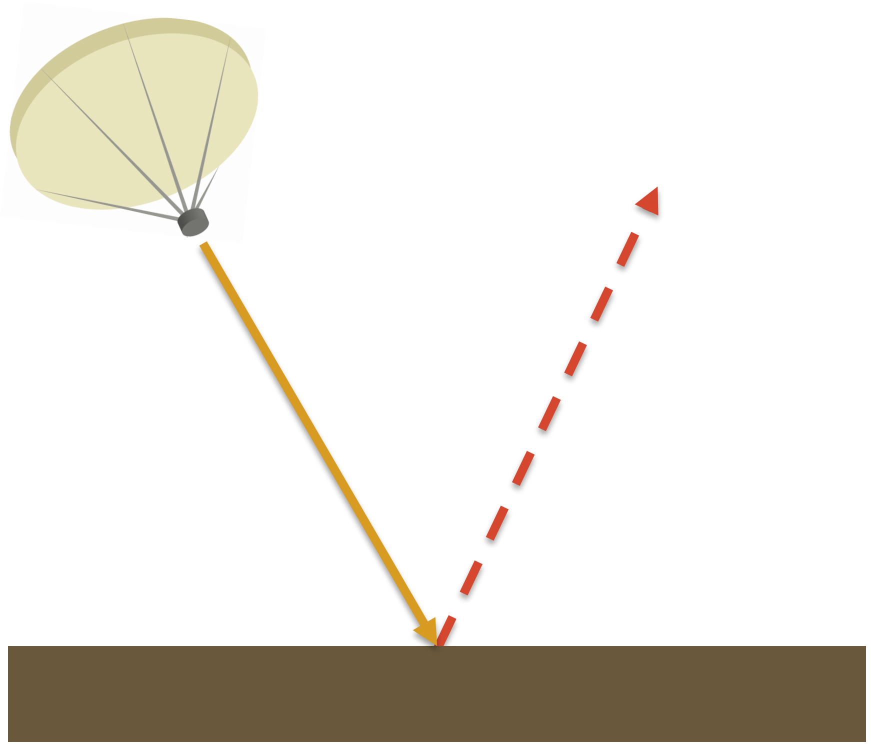
Backscattering Mechanism



Smooth Surface | Rough Surface | Rougher Surface | Volume Scattering | Double Bounce

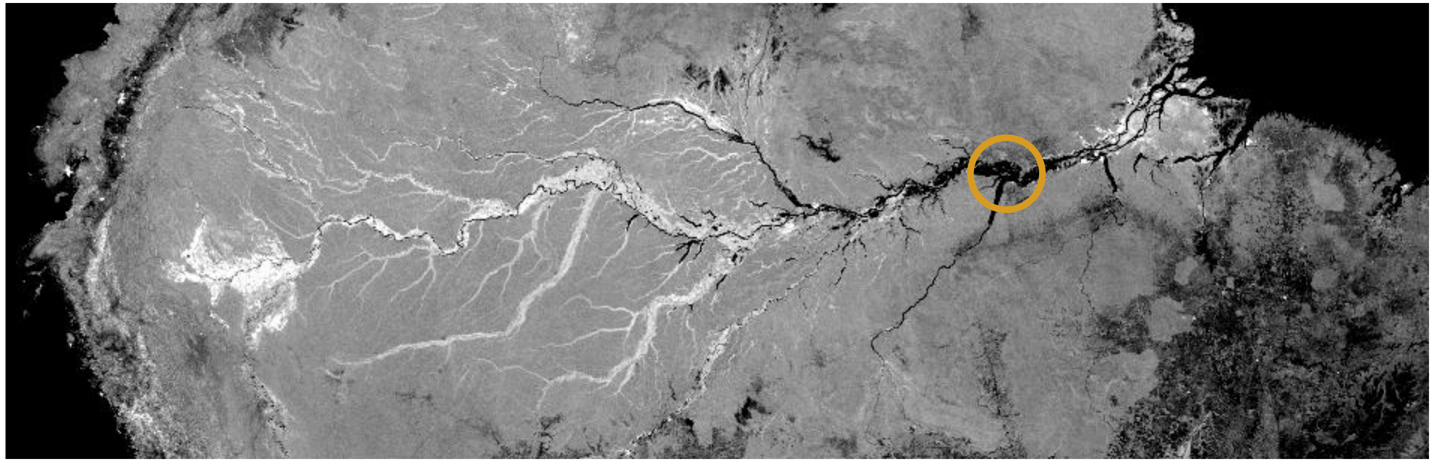
Examples of Radar Interaction

Smooth Surface Reflection (Specular Reflection)



Smooth, Level Surface
(Open Water, Road)

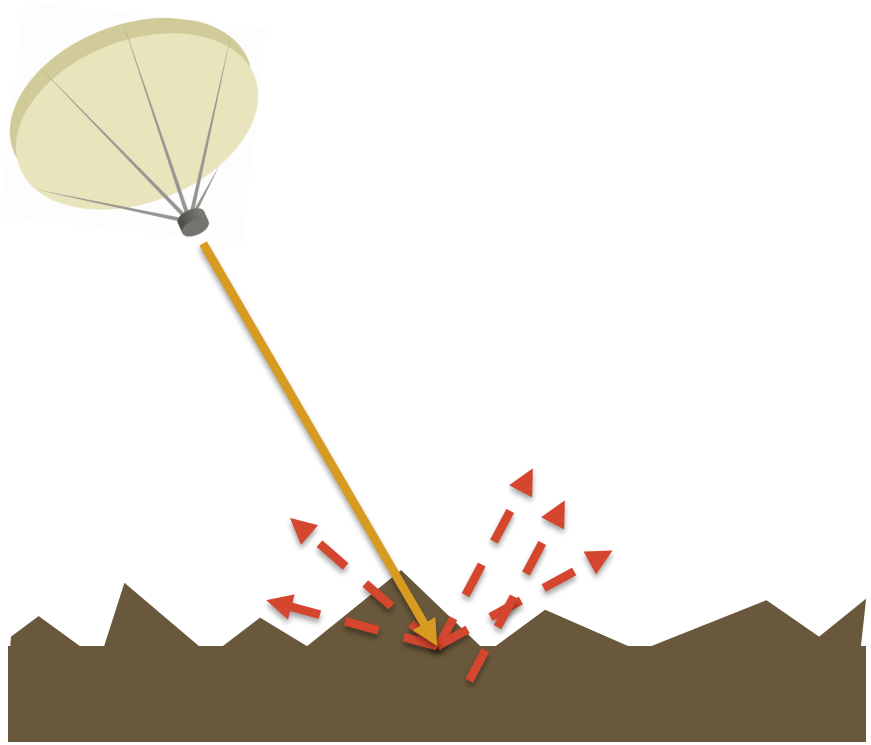
SMAP Radar Mosaic of the Amazon Basin April 2015 (L-band, HH, 3 km)



Pixel Color

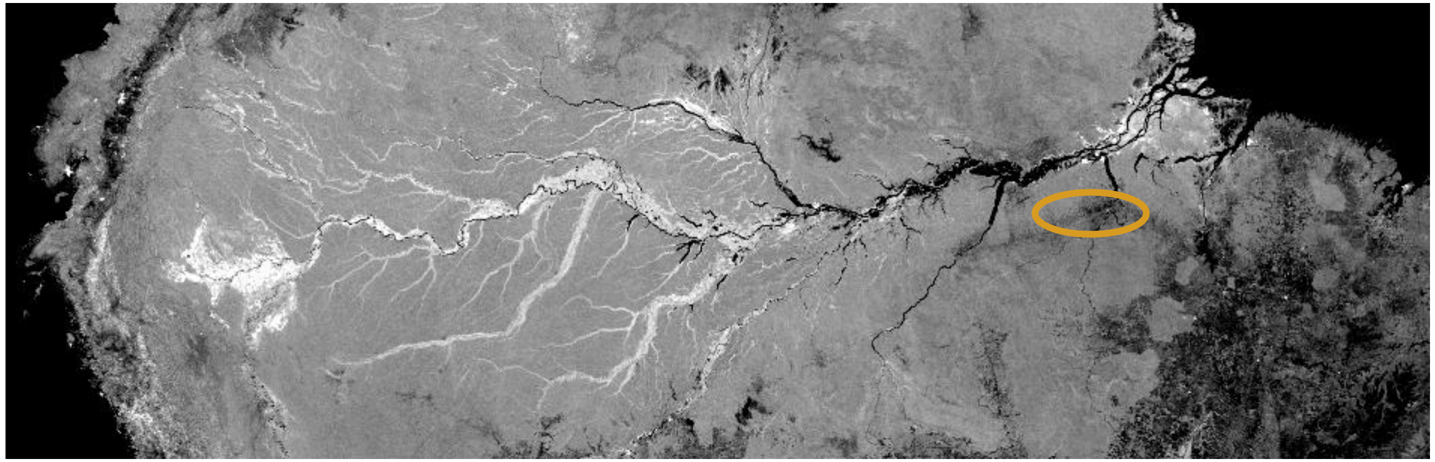
Examples of Radar Interaction

Rough Surface Reflection



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

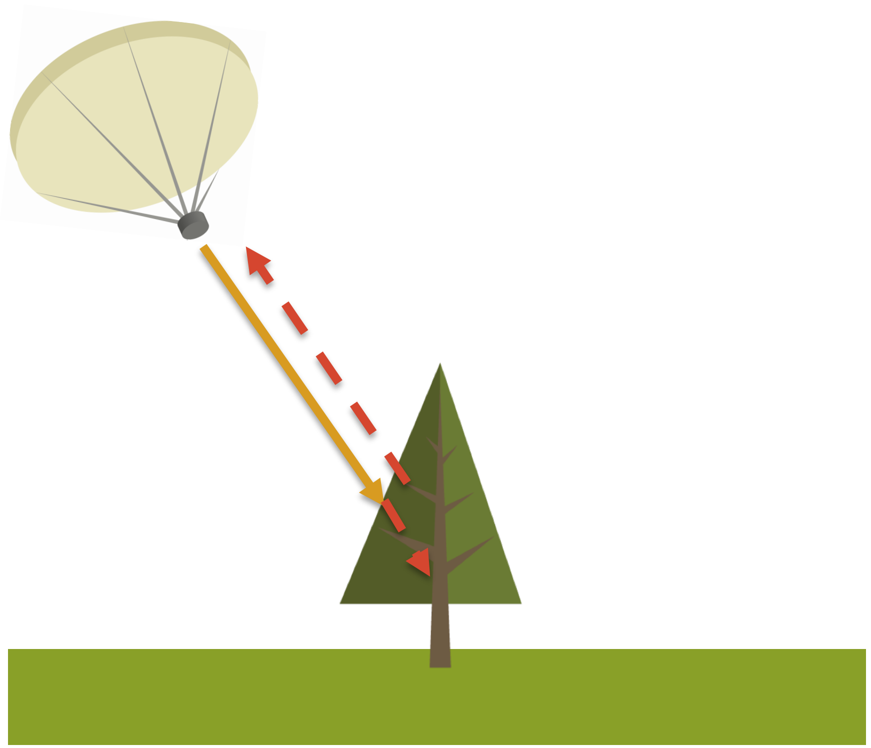
SMAP Radar Mosaic of the Amazon Basin April 2015 (L-band, HH, 3 km)



Pixel Color

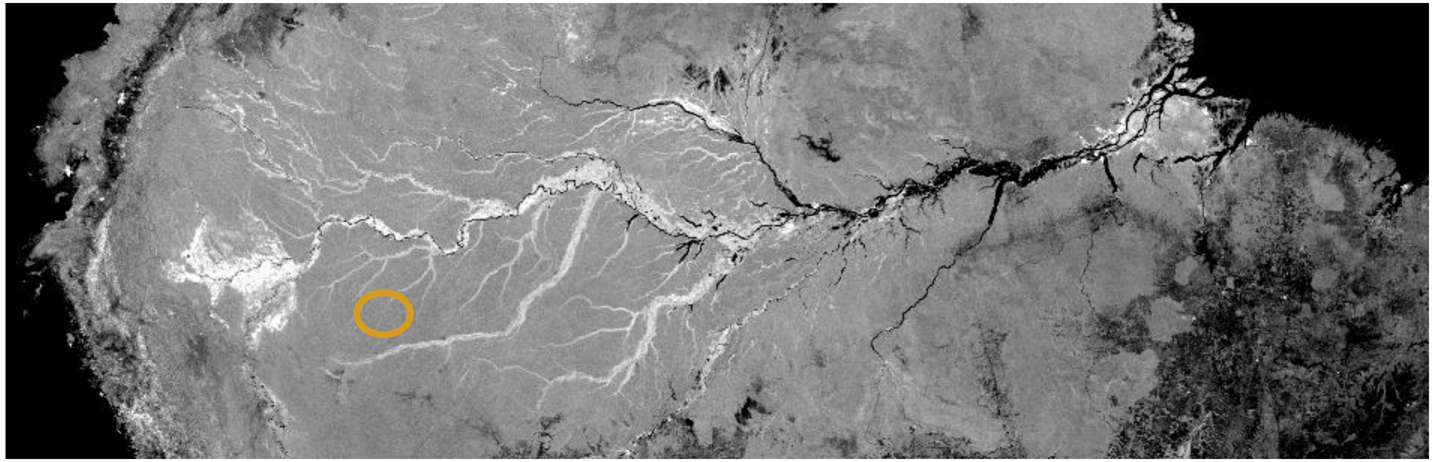
Examples of Radar Interaction

Volume Scattering by Vegetation



Vegetation

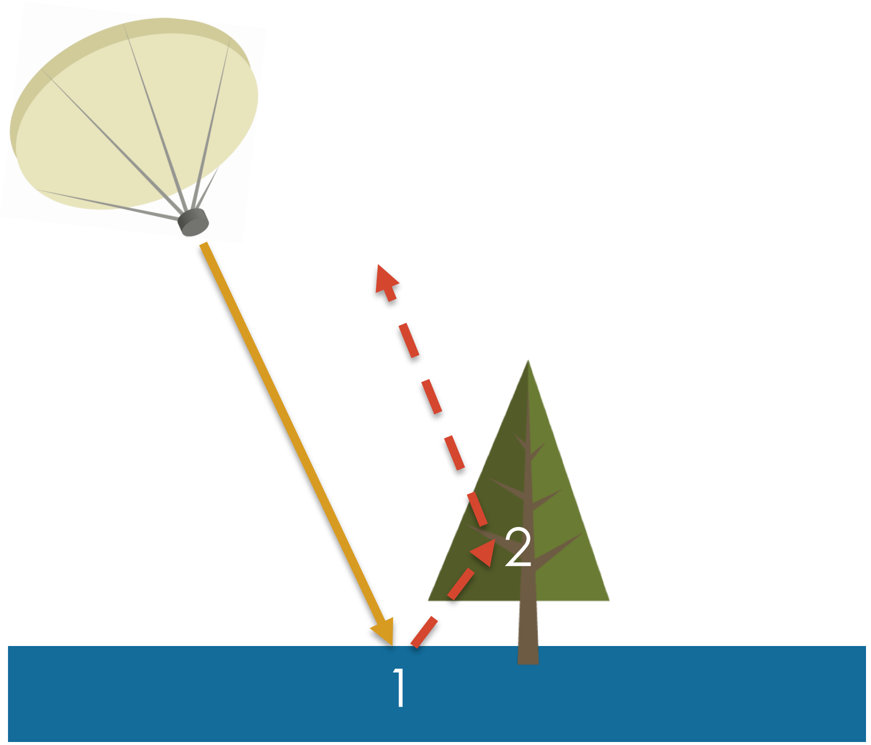
SMAP Radar Mosaic of the Amazon Basin
April 2015 (L-band, HH, 3 km)



Pixel Color

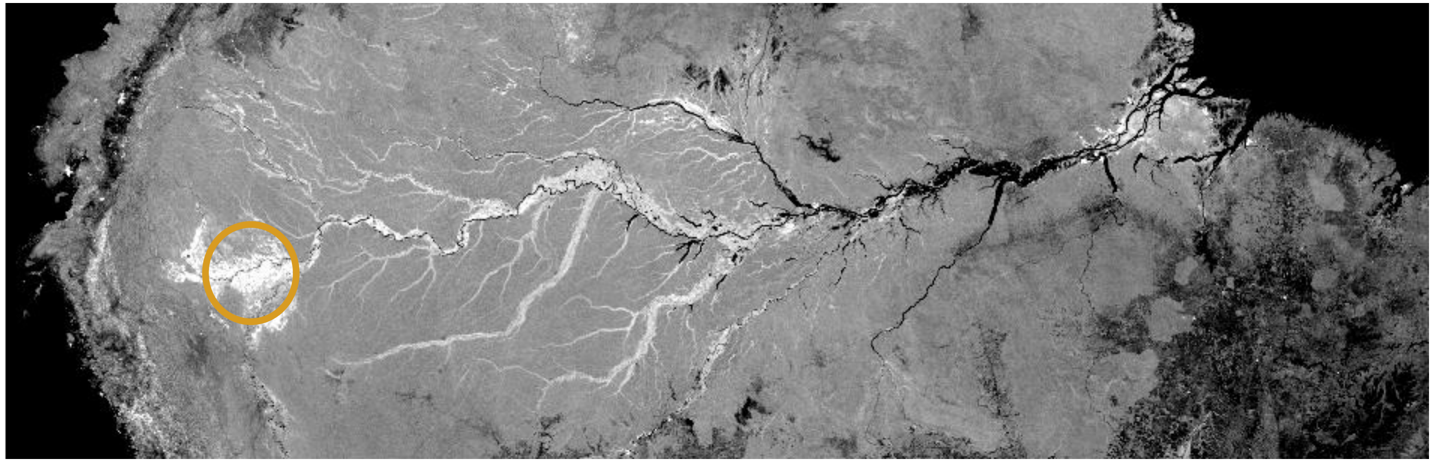
Examples of Radar Interaction

Double Bounce



Inundated Vegetation

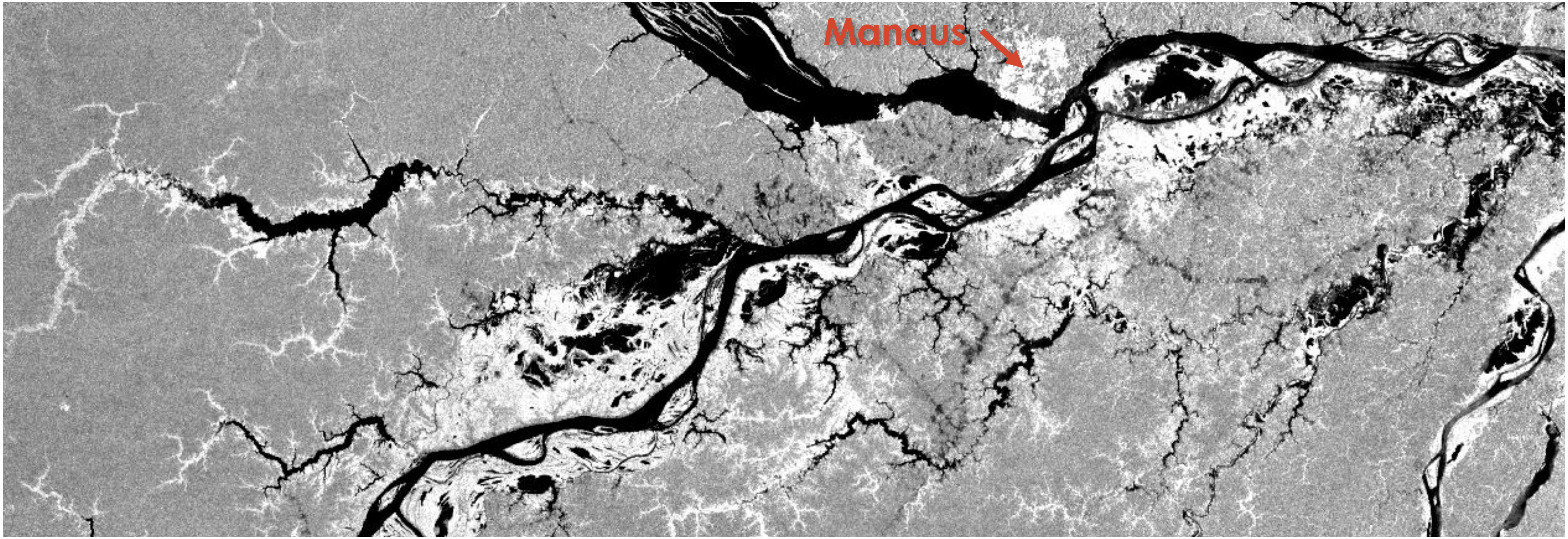
SMAP Radar Mosaic of the Amazon Basin April 2015 (L-band, HH, 3 km)



Pixel Color

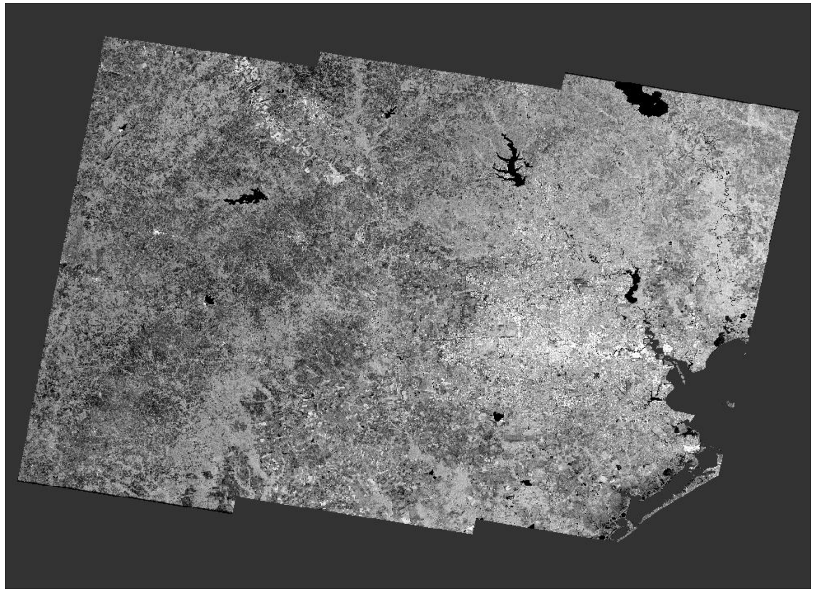
Source of Confusion: Urban Areas with Flooded Vegetated Areas

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

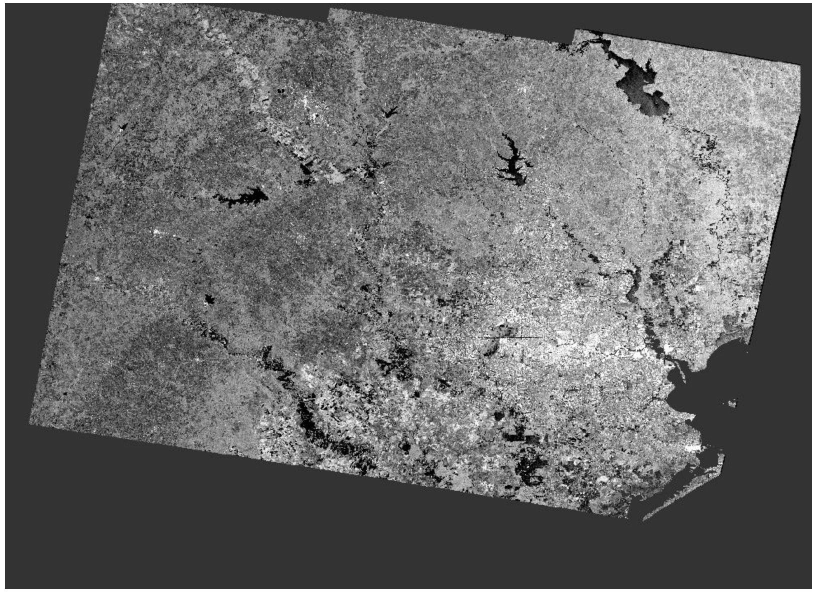


Hurricane Harvey in Houston Texas – August 2017

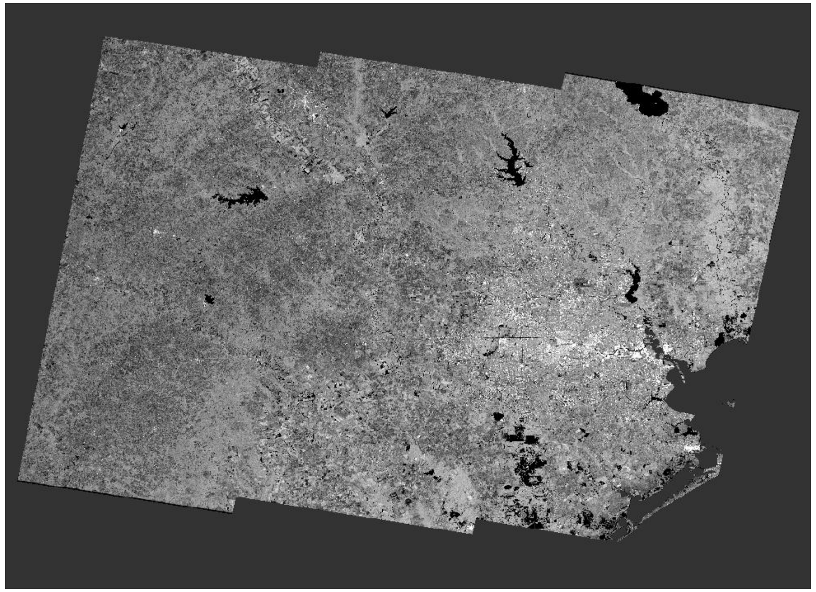
Aug 18, 2017
(Before the Event)



Aug 30, 2017
(During the Event)

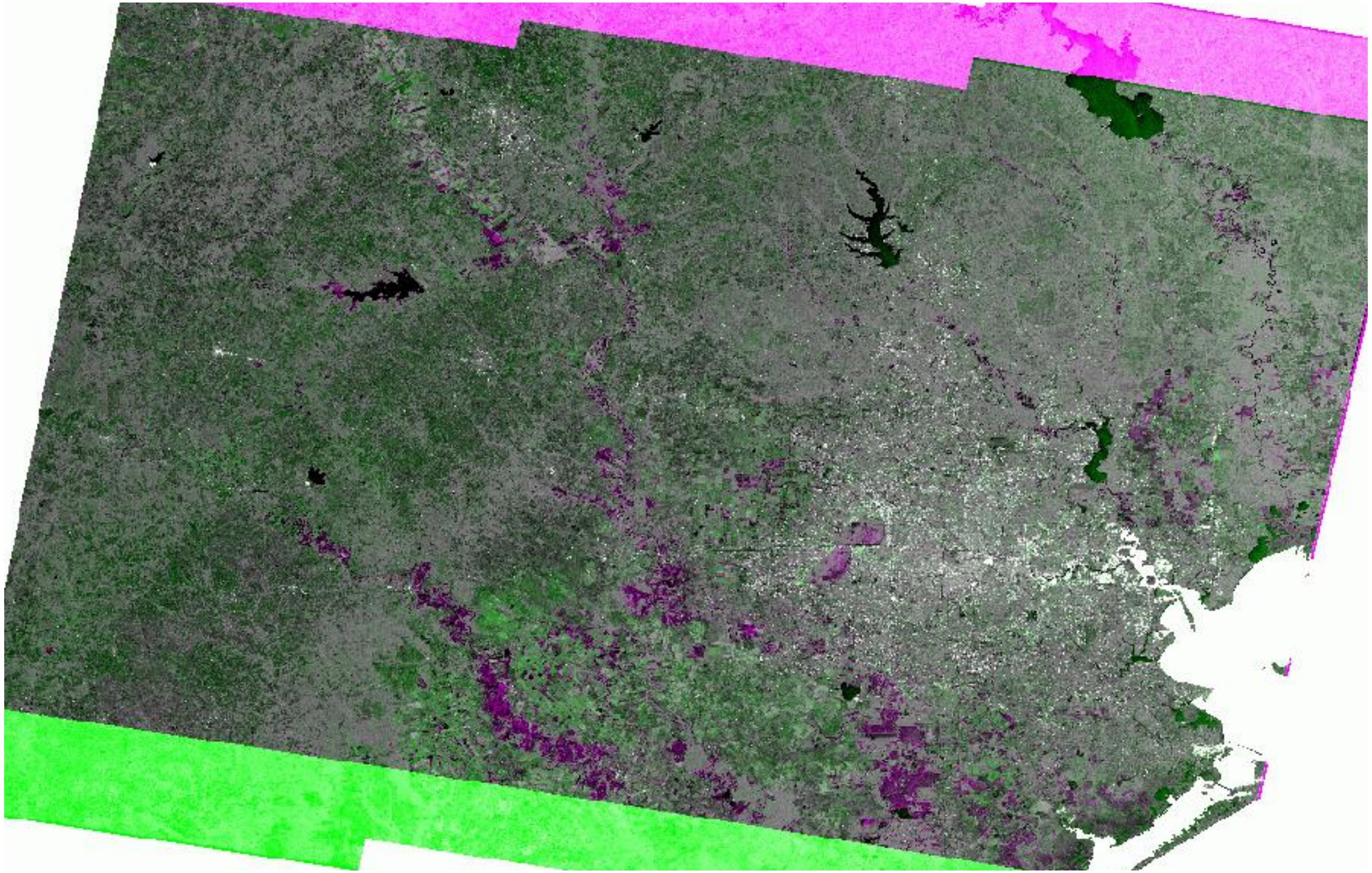


Sep 5, 2017
(After the Event)



Hurricane Harvey in Houston Texas - Before and During the Event

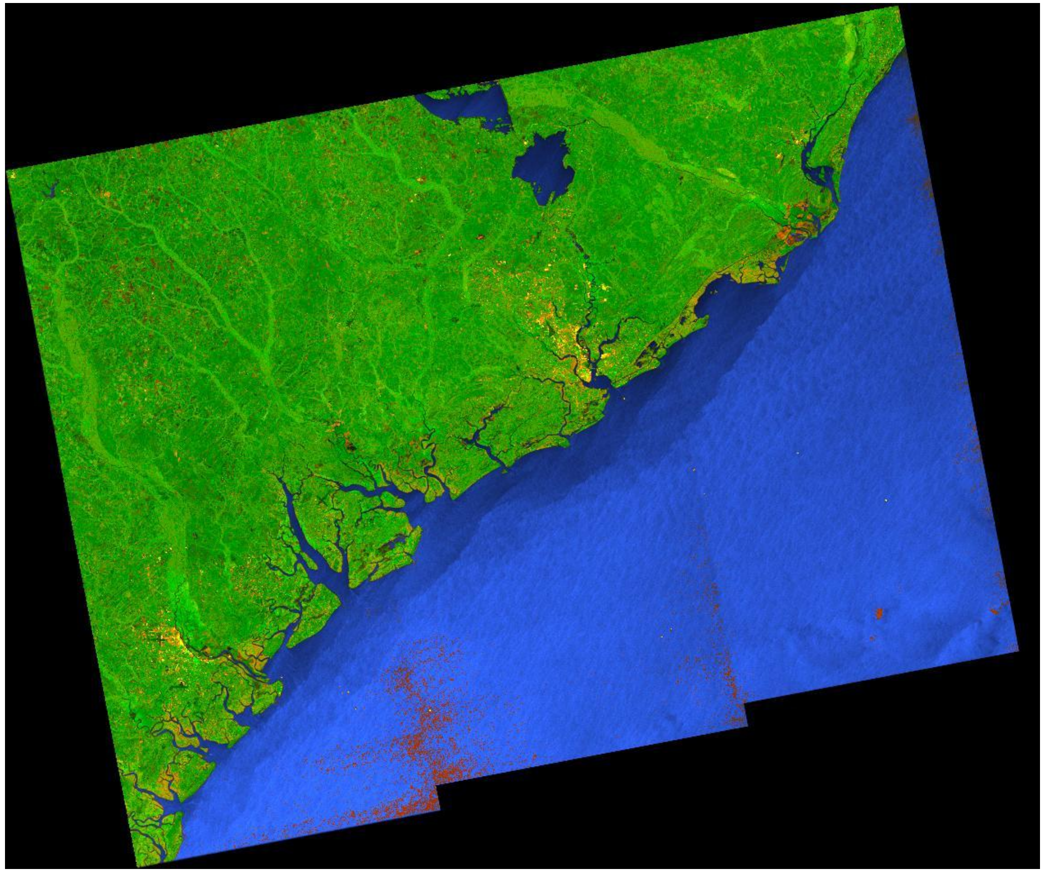
Sentinel-1 Radar Images, RGB: Aug 30 (R), Aug 18 (G), Aug 30 (B)



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

Sentinel-1 Radar Images

Oct 4, 2016
(Before the Event)

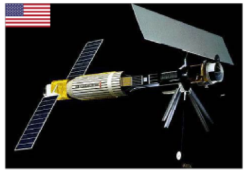


Oct 16, 2016
(After the Event)

Radar Data from Different Satellites

Legacy:

SeaSAT
1978



JERS-1
1992-1998

ERS 1/2
1991-2011

ENVISAT
2002-2012

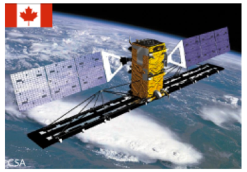
ALOS-1
2002-2012

Radarsat-1
1995-2013

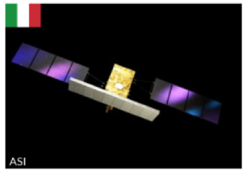
Current:

TanDEM-X
2007

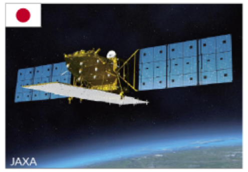
Radarsat-2
2007



COSMO-SkyMed
2007

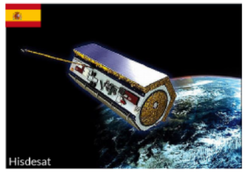


ALOS-2
2014



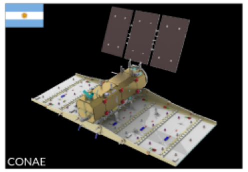
Sentinel-1
2014

PAZ SAR
2018

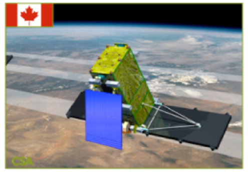


Future:

SAOCOM
2018

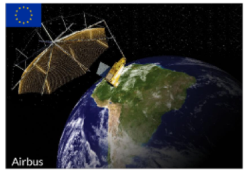


RCM
2018



NISAR
2021

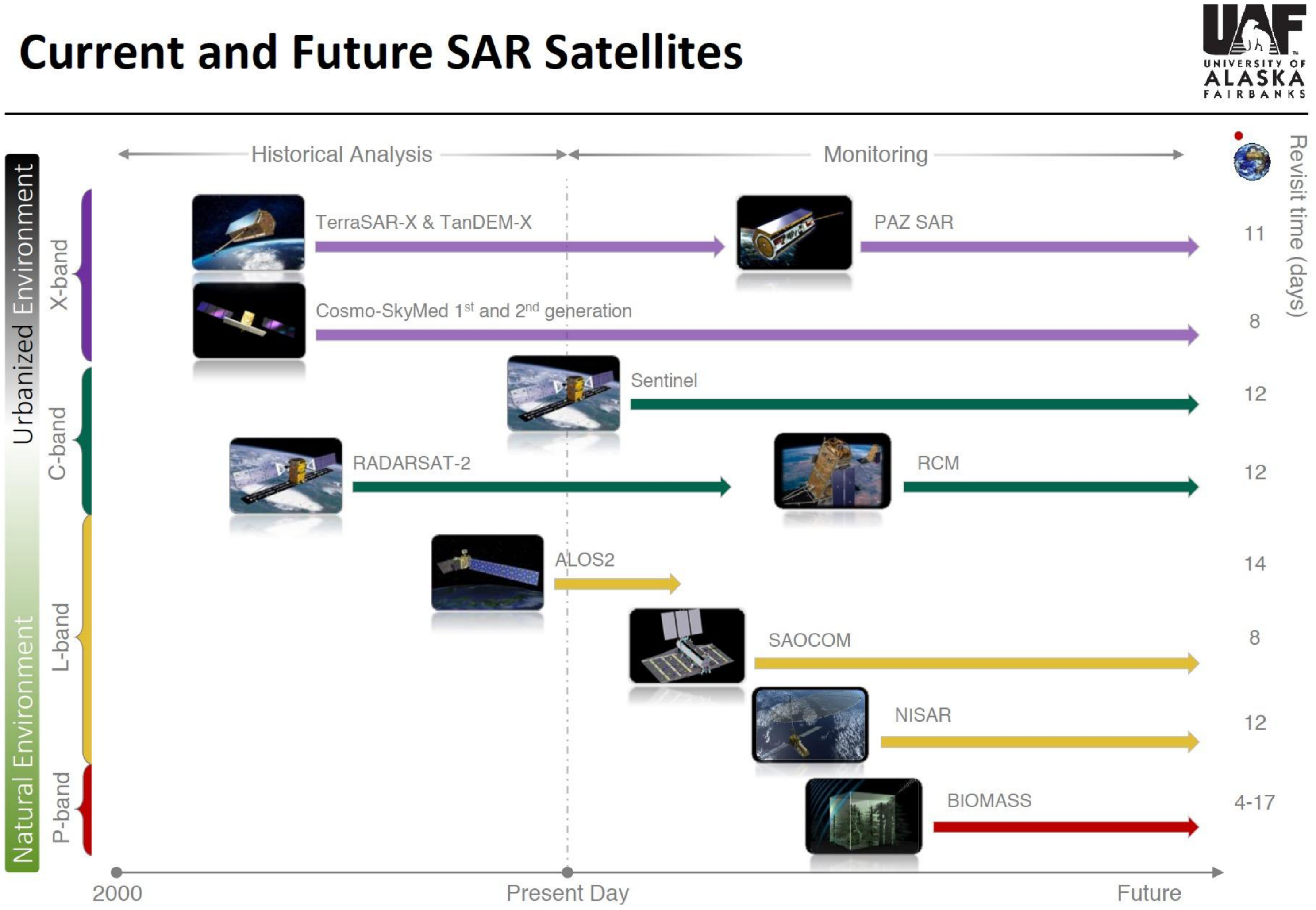
Biomass
2021



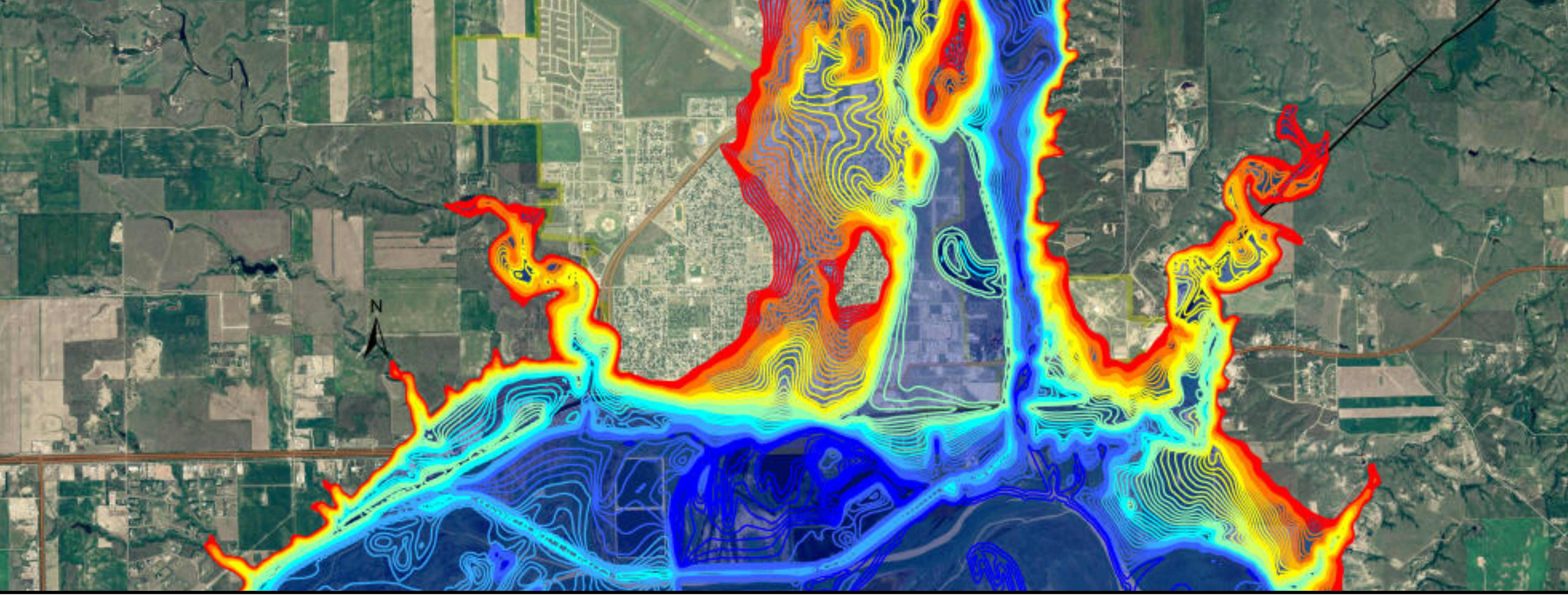
freely accessible

Credit: Franz Meyer, University of Alaska, Fairbanks

Current and Future SAR Satellites



Credit: Franz Meyer, University of Alaska, Fairbanks

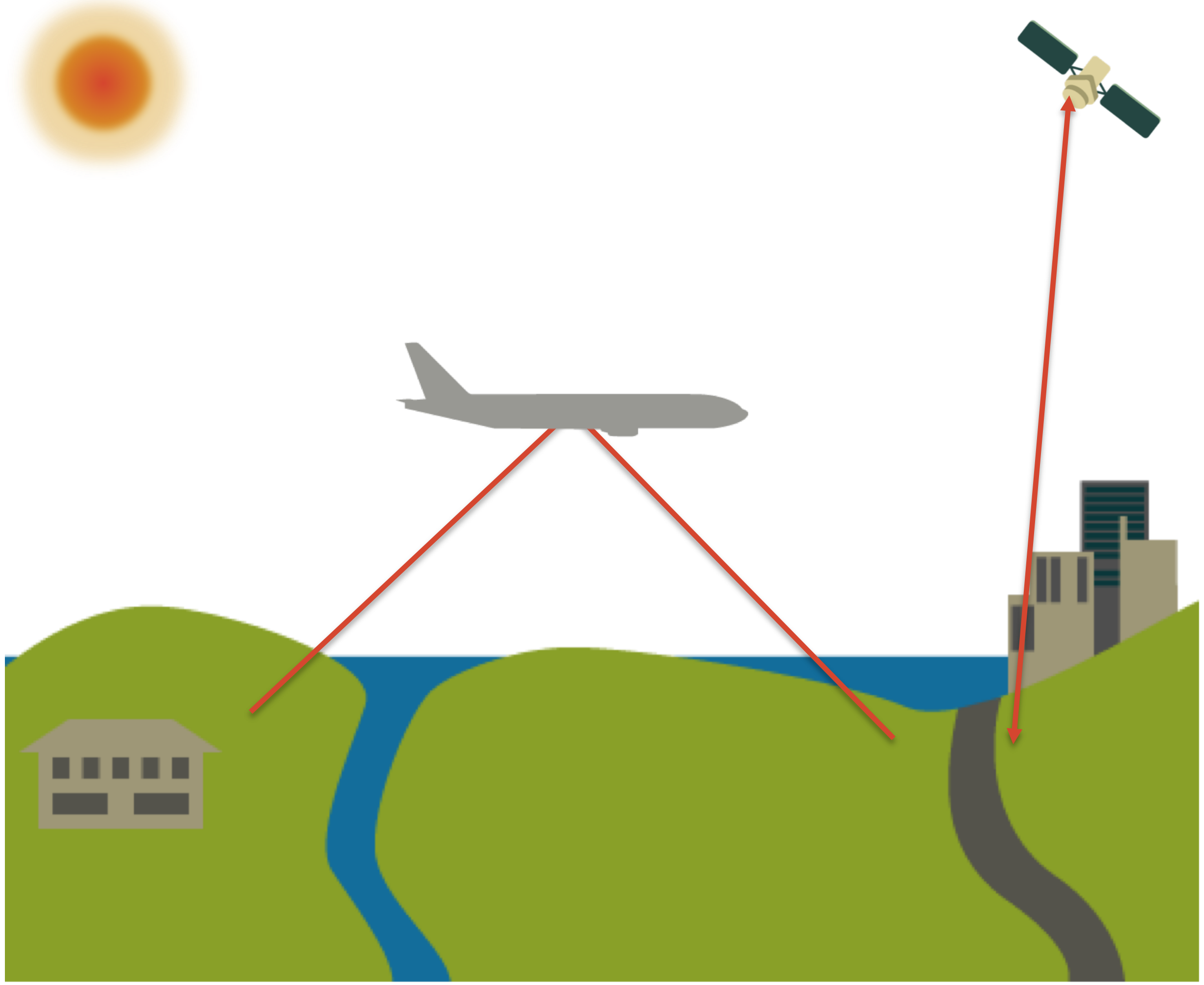


About LIDAR Data for Urban Floodplain Detection

What is LIDAR?

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

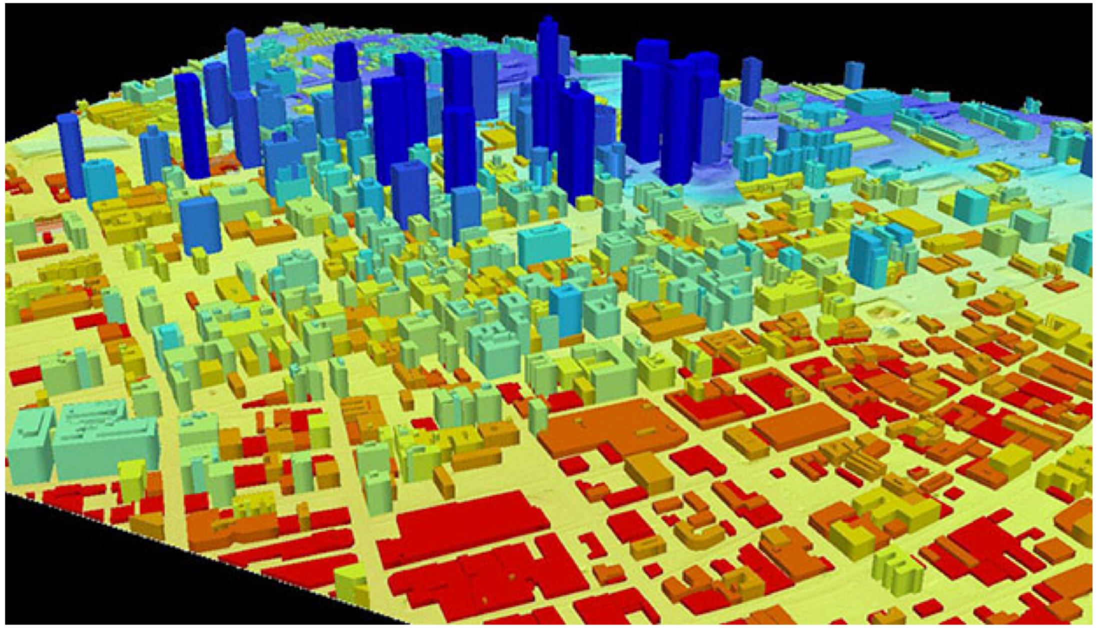
- LIDAR - LIght Detection And Ranging is an active remote sensing instrument that emits a pulse of light and measures the reflected pulse
- LIDAR are used to observe surface and atmospheric features
- LIDAR can be flown on aircraft or satellites



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 measures 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 measures 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 and bathymetric
  - 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

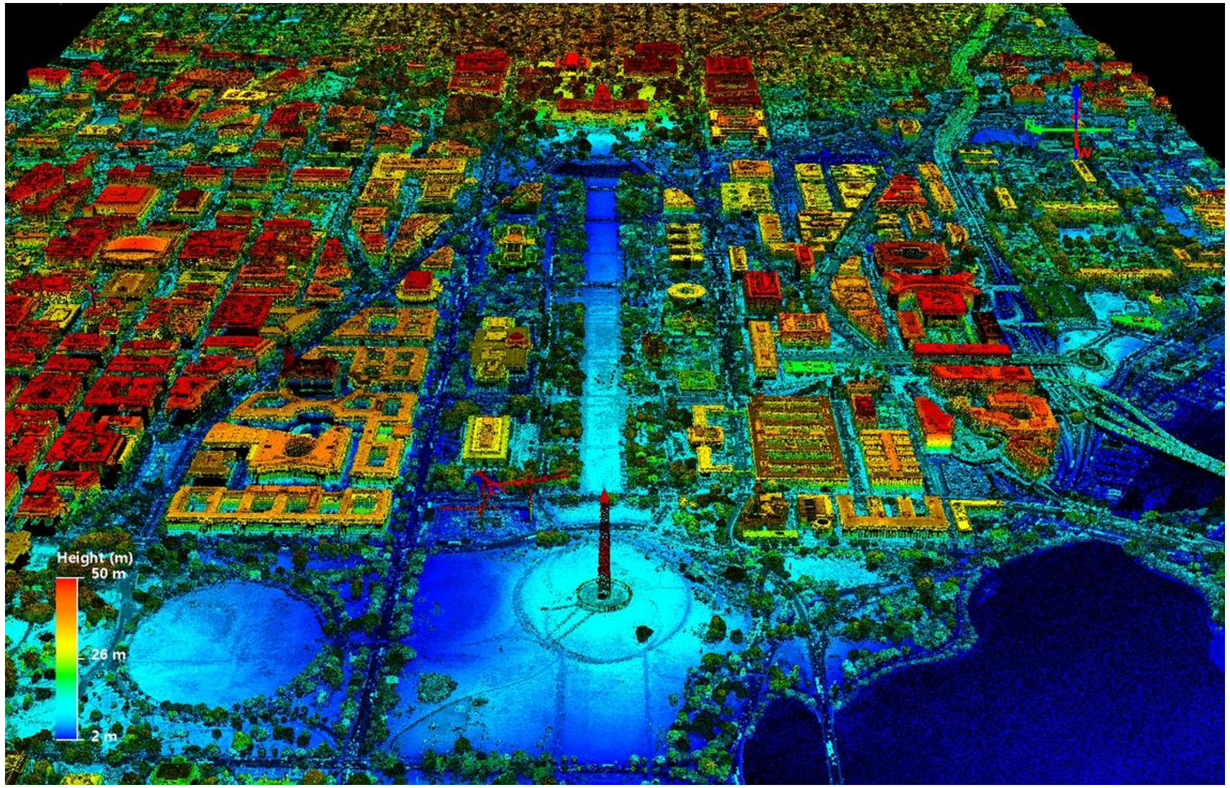
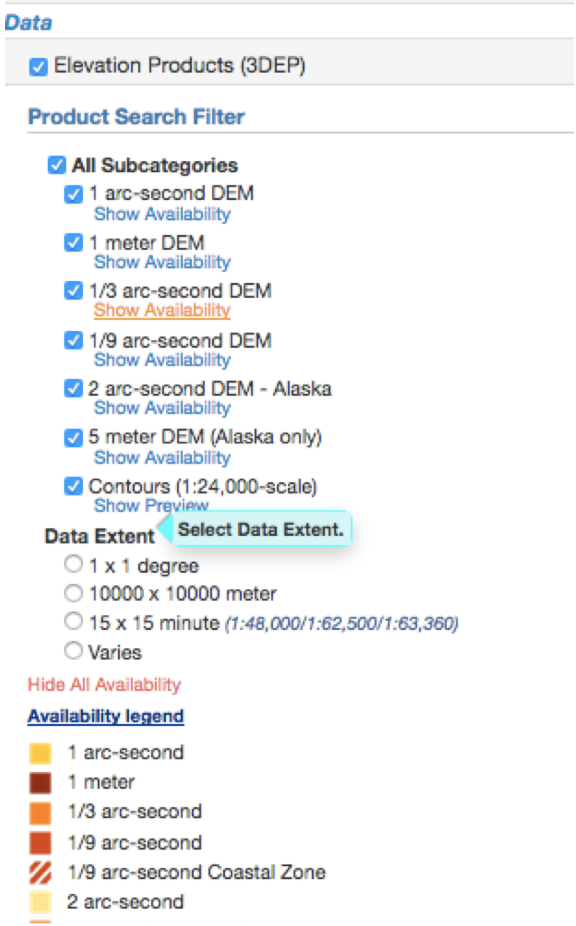


Image Credit: USGS

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)



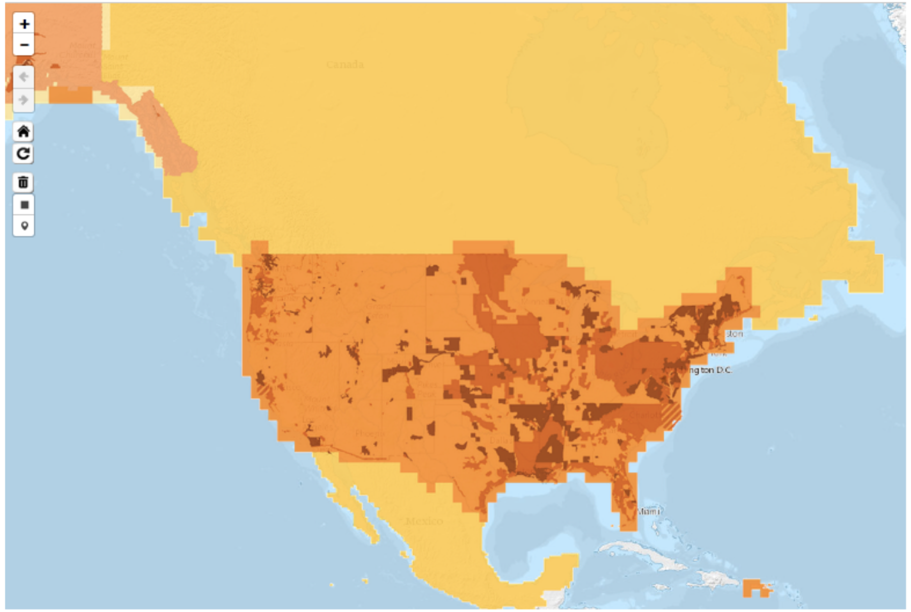
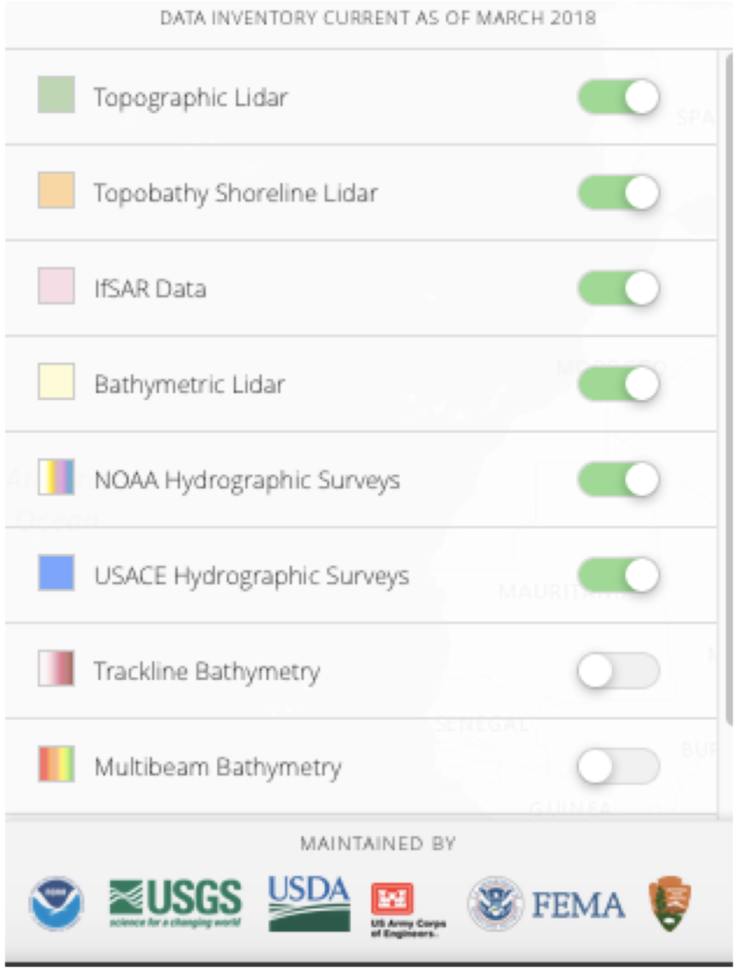


Image Credits: https://nationalmap.gov/3DEP/3dep_whatis.html

LIDAR Topography Data

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

NOAA Coast Watch provides US Inter-agency LIDAR products



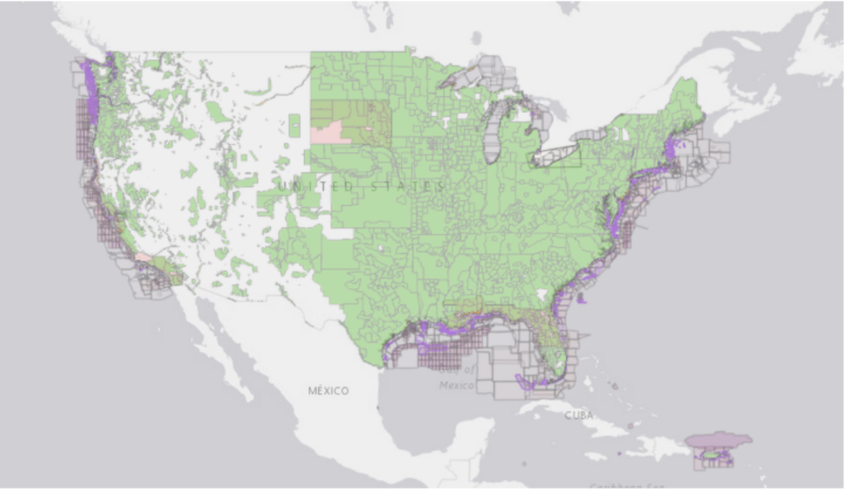
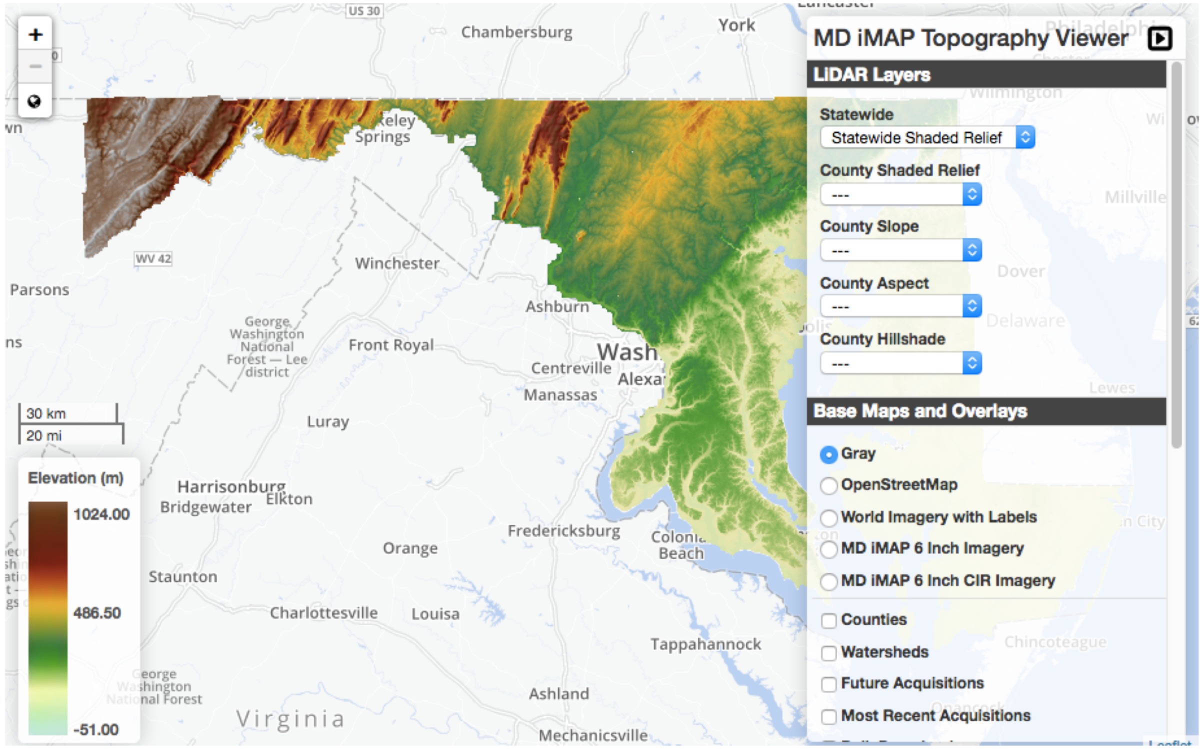


Image Credit: https://coast.noaa.gov/dataviewer/#/lidar/search/

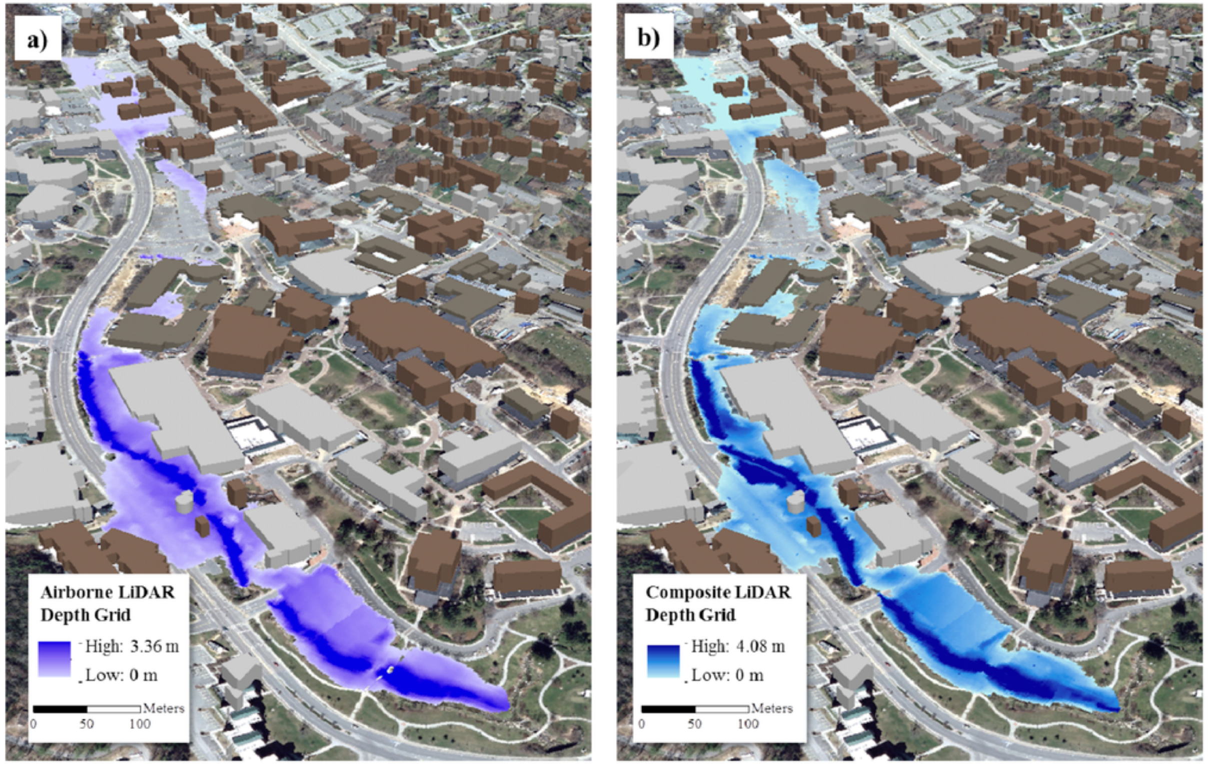
LIDAR Topography Data

- 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



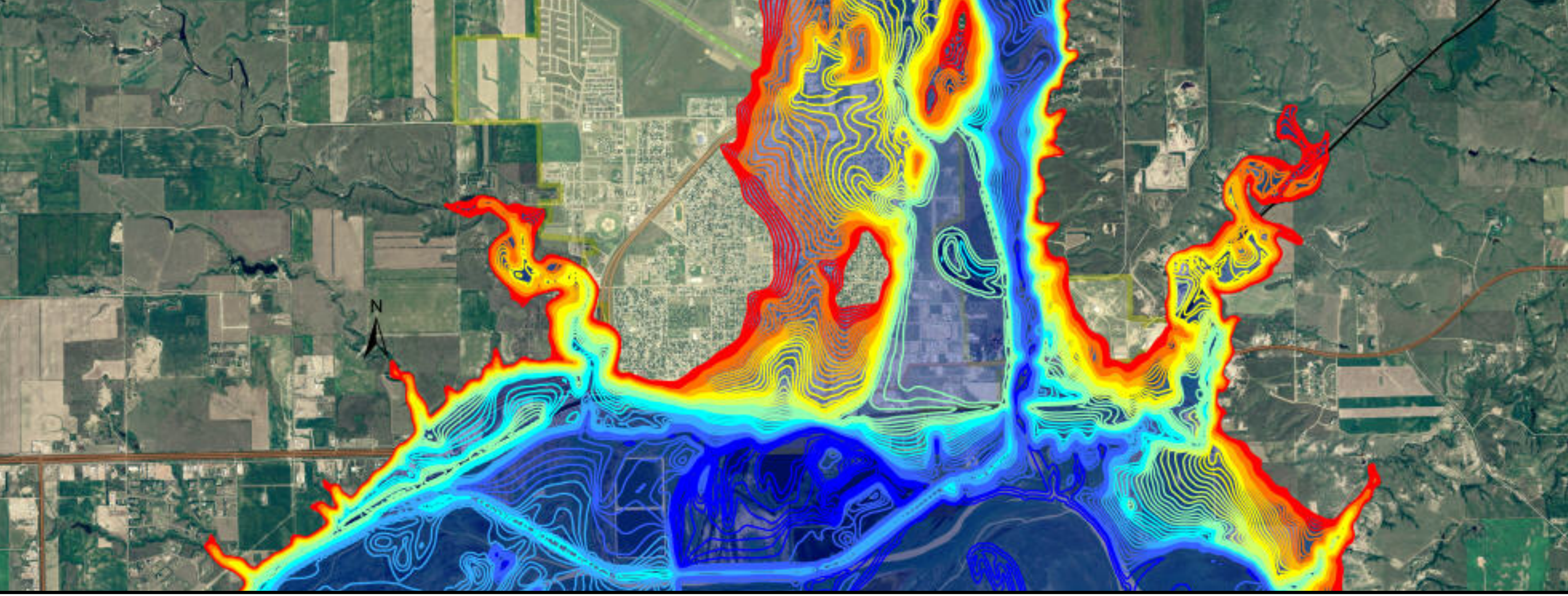
LIDAR Data Applications for Urban Flooding

- 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/2JiTTBs
- LIDAR-based regional flood modeling studies are a topic of exploration and research



Boone Creek Sub-Basin, NC

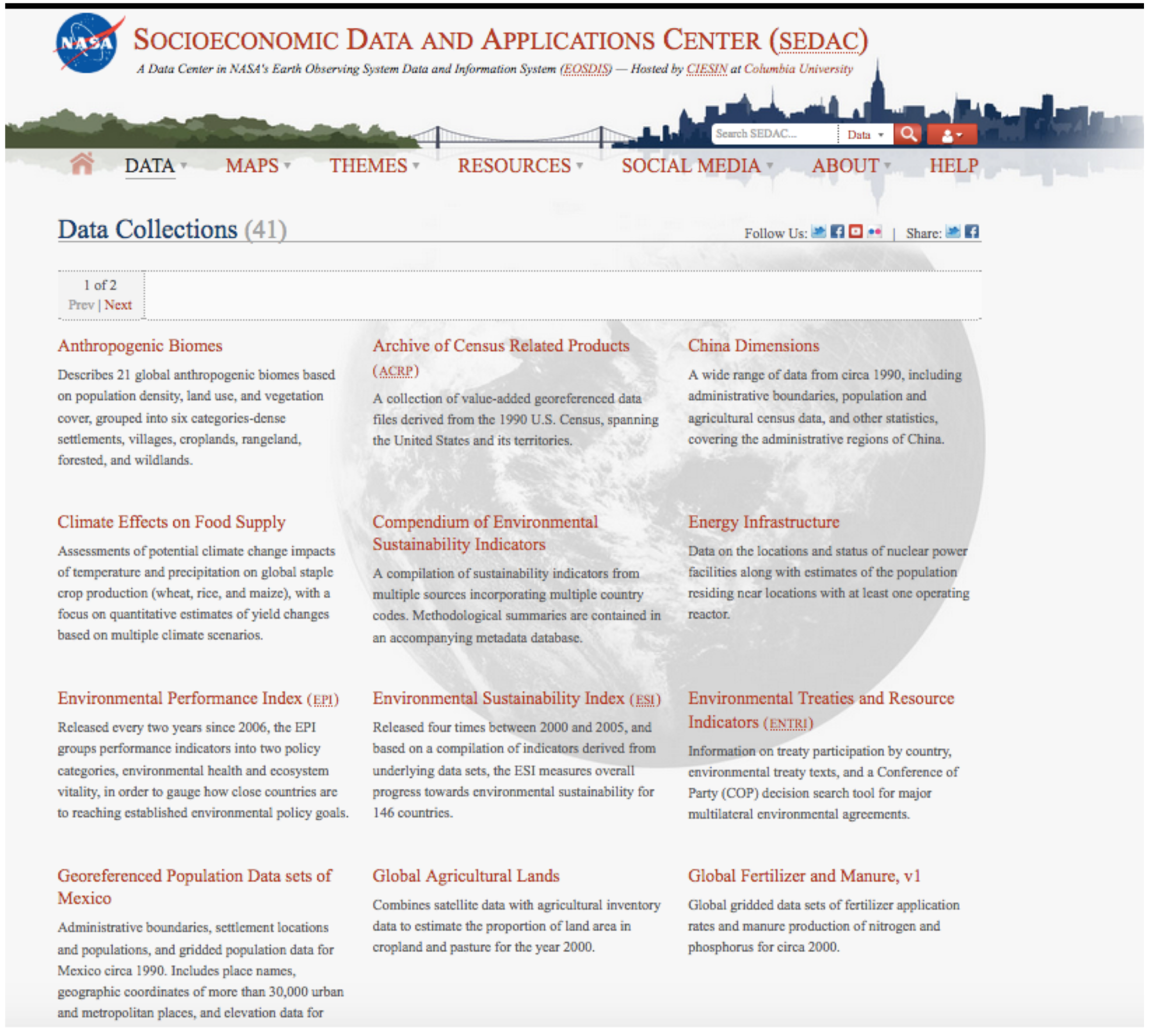
Turner et al., 2013: Flood Modeling Using a Synthesis of Multi-Platform LiDAR Data, Water, 5(4), 1533-1560; doi:10.3390/w5041533



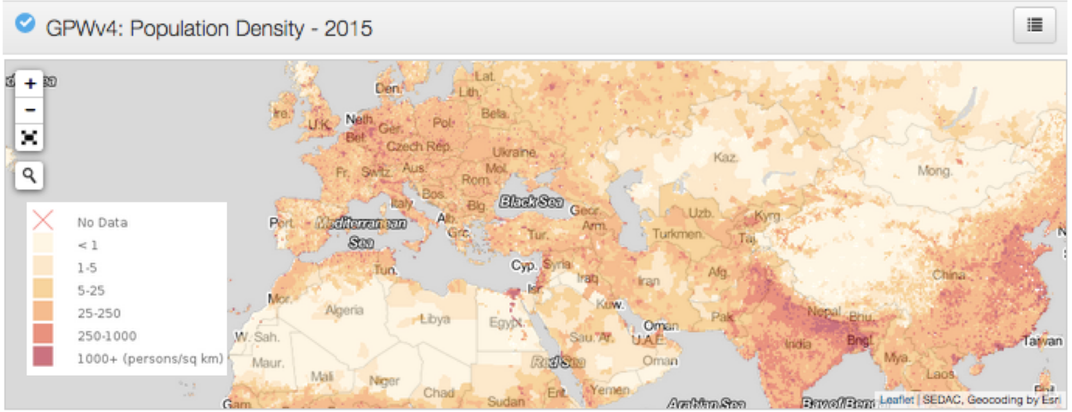
Overview of Landsat-Based Urban Data and Socioeconomic Data

Socioeconomic and Urban Data

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



Global Population Density

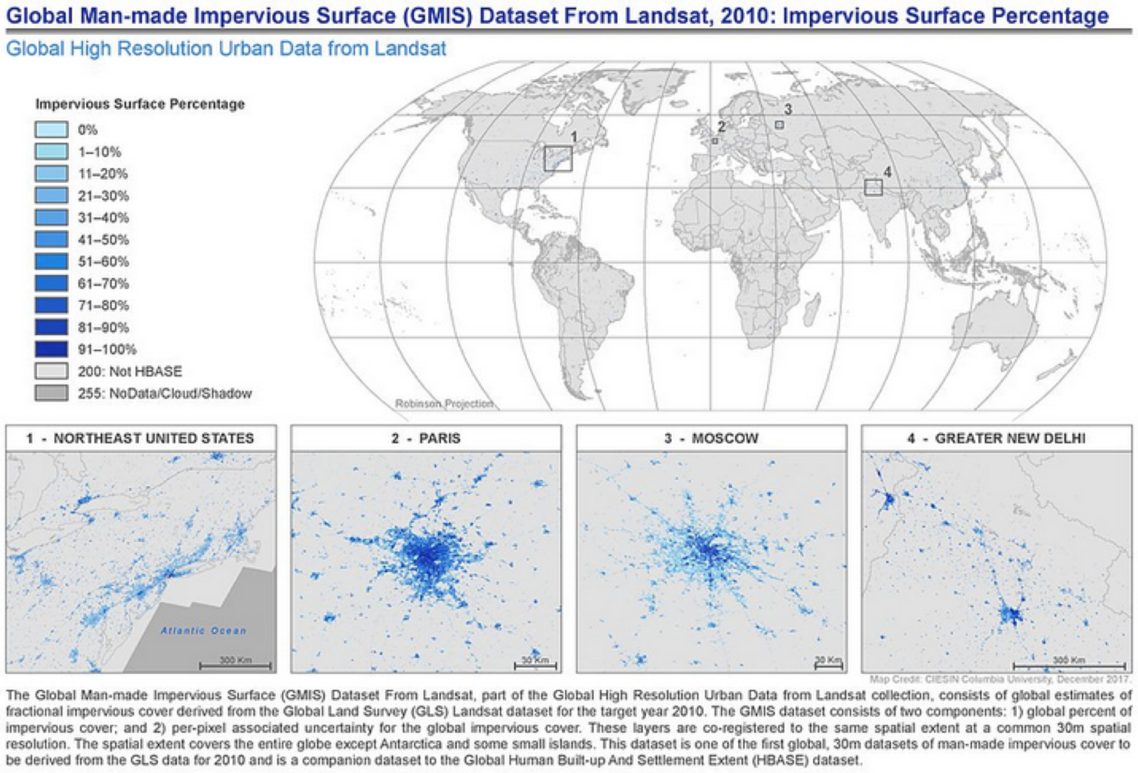


- Other Useful Datasets:
  - **Global urban data from the Landsat satellite**
  - Global reservoirs and dams
  - Low elevation coastal zones
  - Global roads
  - Energy infrastructure

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

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

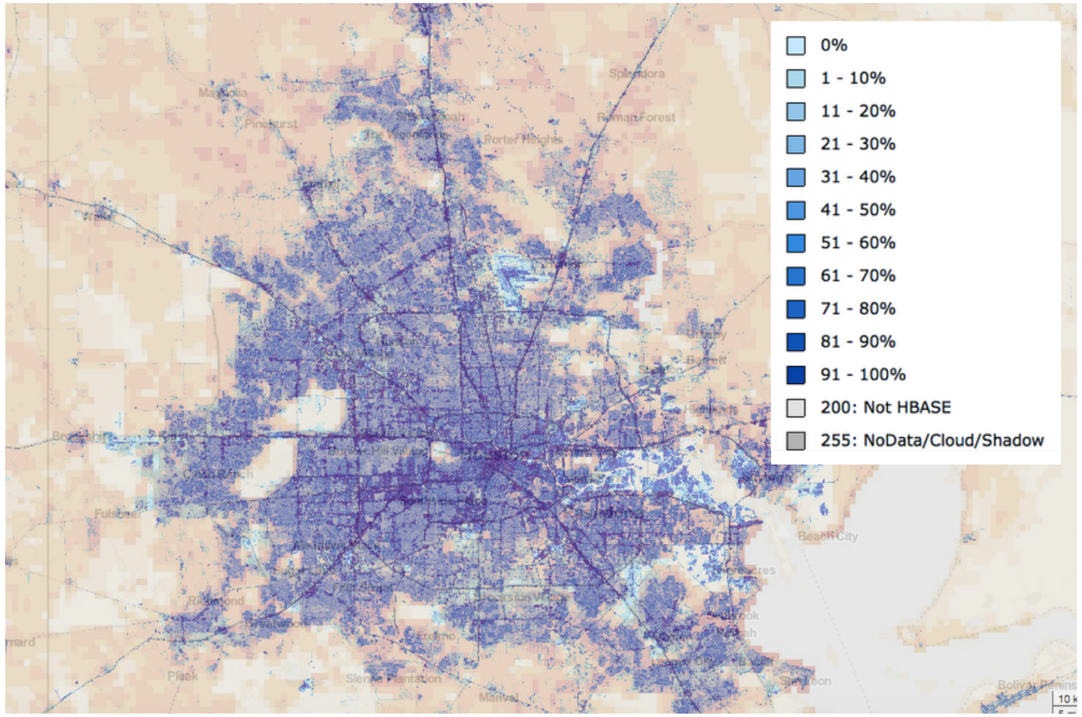
- Derived from the Global Land Survey (GLS) Landsat data for 2010 used as target year
- Dataset includes:
  - percentage of impervious cover
  - per-pixel associated uncertainty for the impervious cover
- Spatial Resolution: 30 m
- A companion dataset to the Global Human Built-up And Settlement Extent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



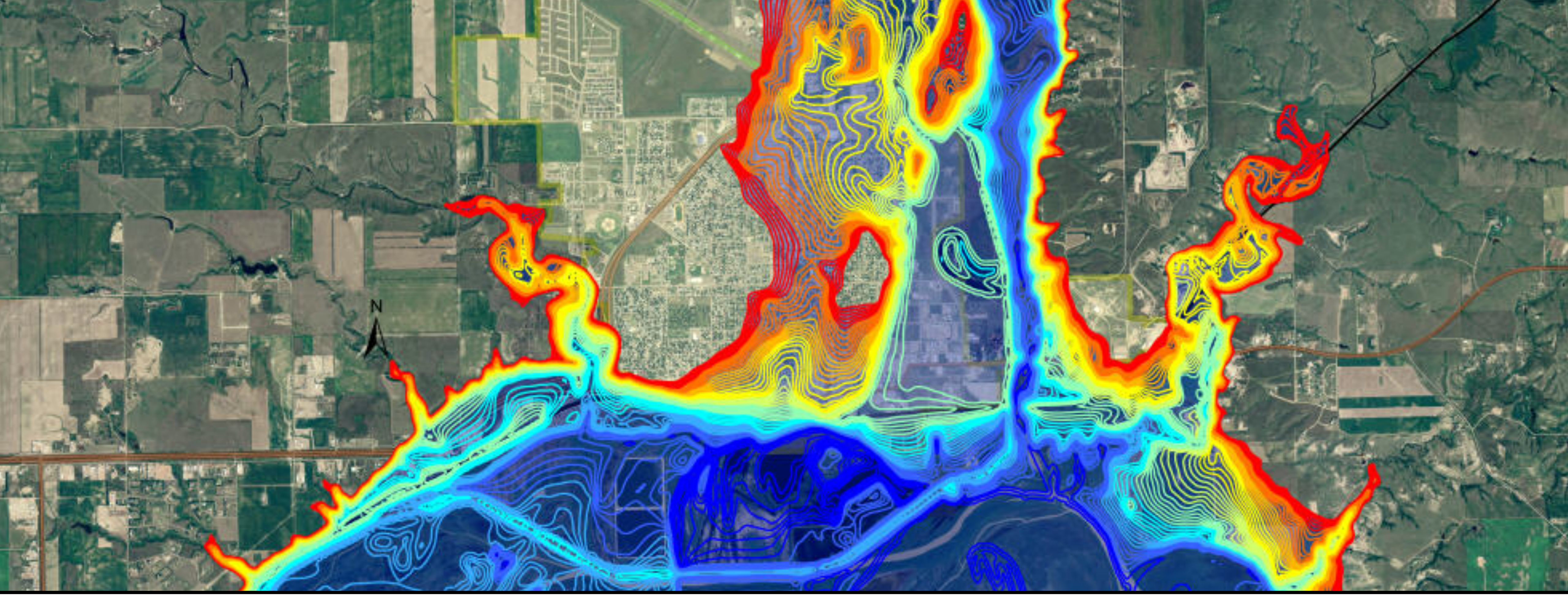
Brown de Colstoun, E. C., C. Huang, P. Wang, J. C. Tilton, B. Tan, J. Phillips, S. Niemczura, P.-Y. Ling, and R. E. Wolfe. 2017. Global Man-made Impervious Surface (GMIS) Dataset From Landsat. Palisades, NY: NASA Socioeconomic Data and Applications Center (SEDAC). https://doi.org/10.7927/H4P55KKF.

GMIS Data Application in Urban Flooding

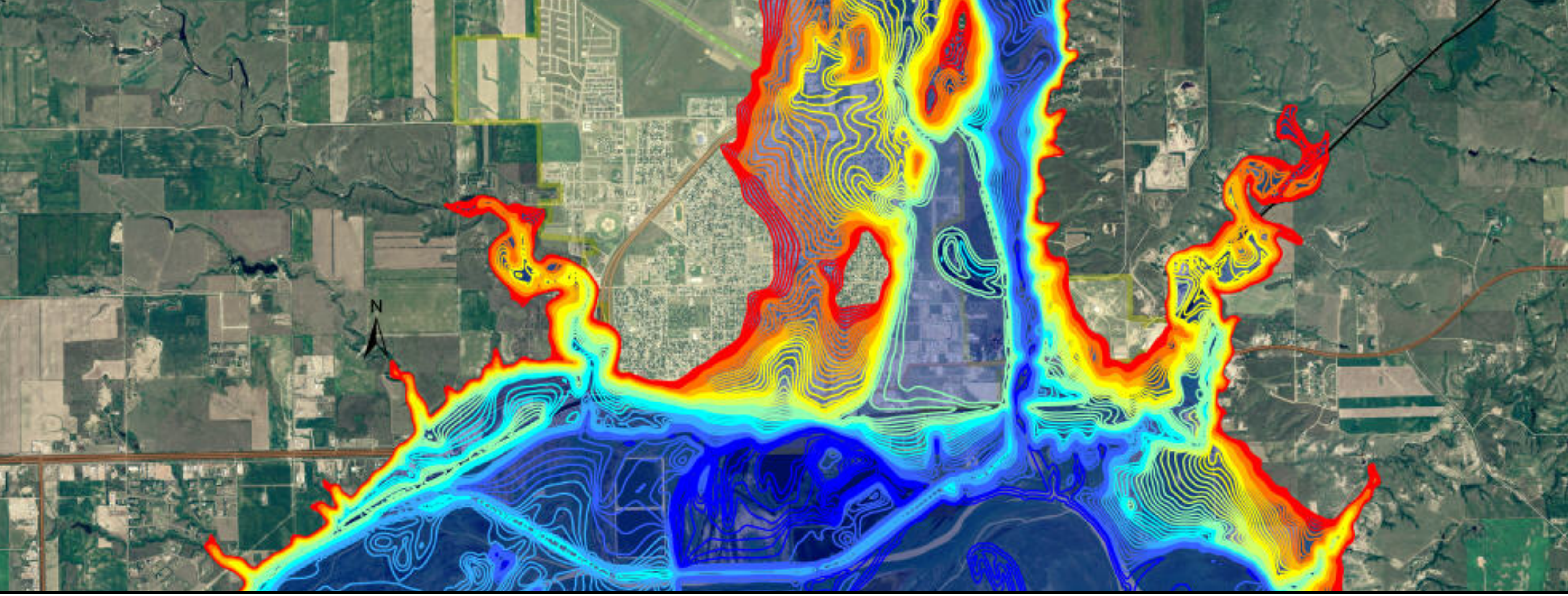
- In an urban area, rainwater is removed by
  – runoff
  – infiltration into the ground
  – storm water drainage
- Estimates of impervious urban area from GMIS would help assess areas where no infiltration can be expected
- Combined with terrain/slope data, GMIS data can provide an indication of where 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

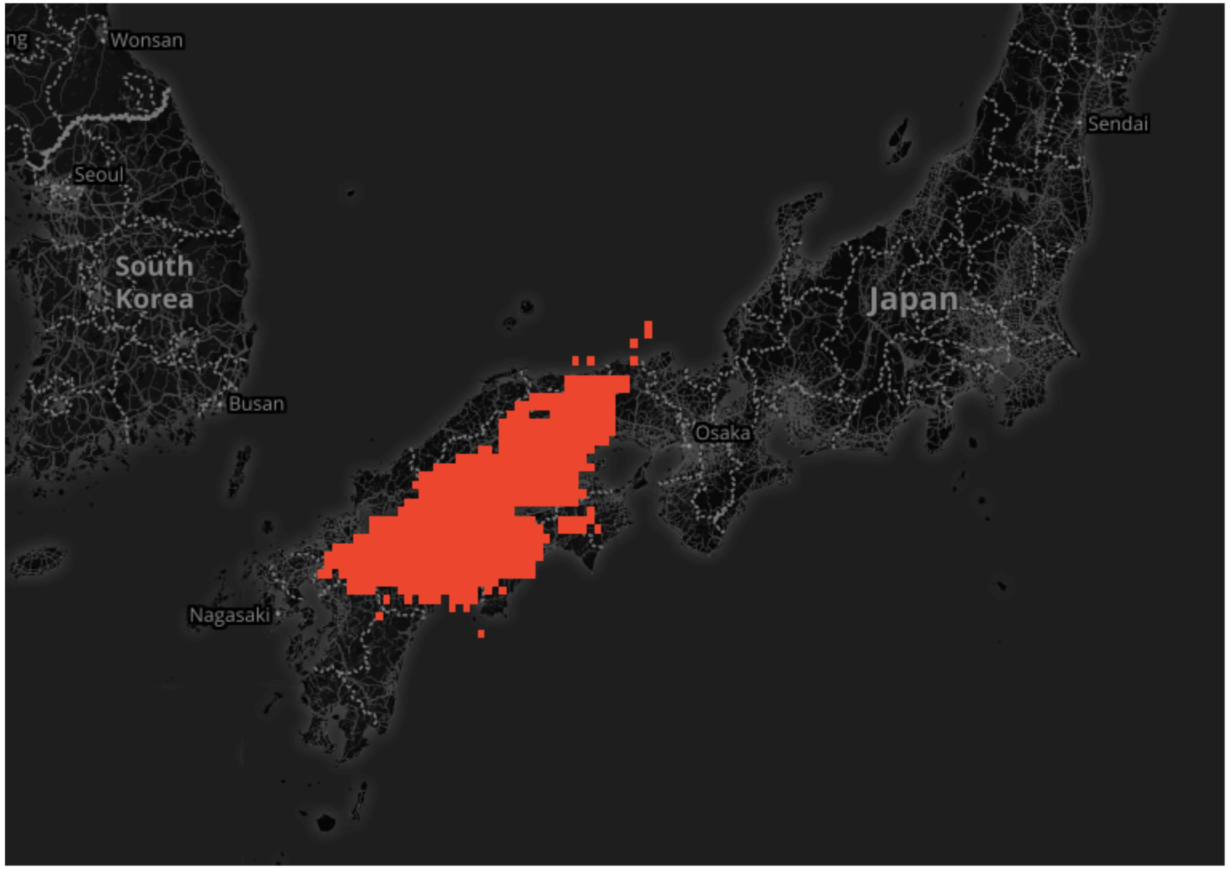
- ERDS is one of the tools used by the UN World Food Programme (WFP) Emergency Preparedness Unit

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



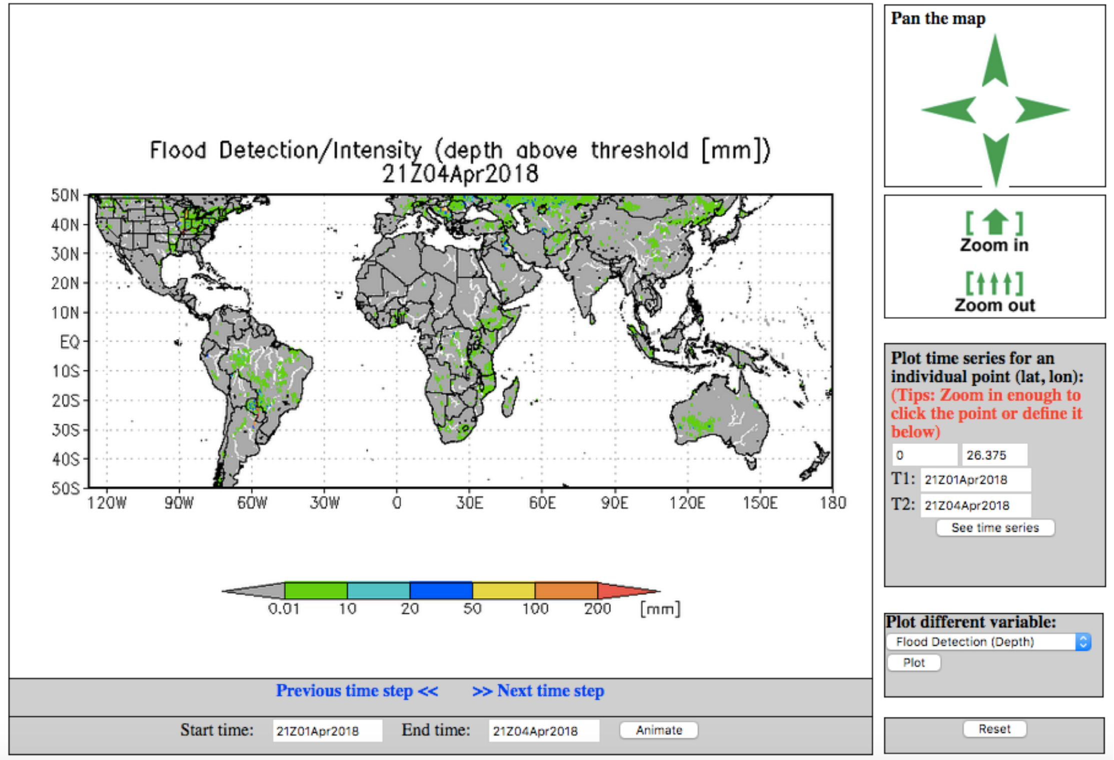
Global Flood Monitoring System (GFMS)

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 ⅛th 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

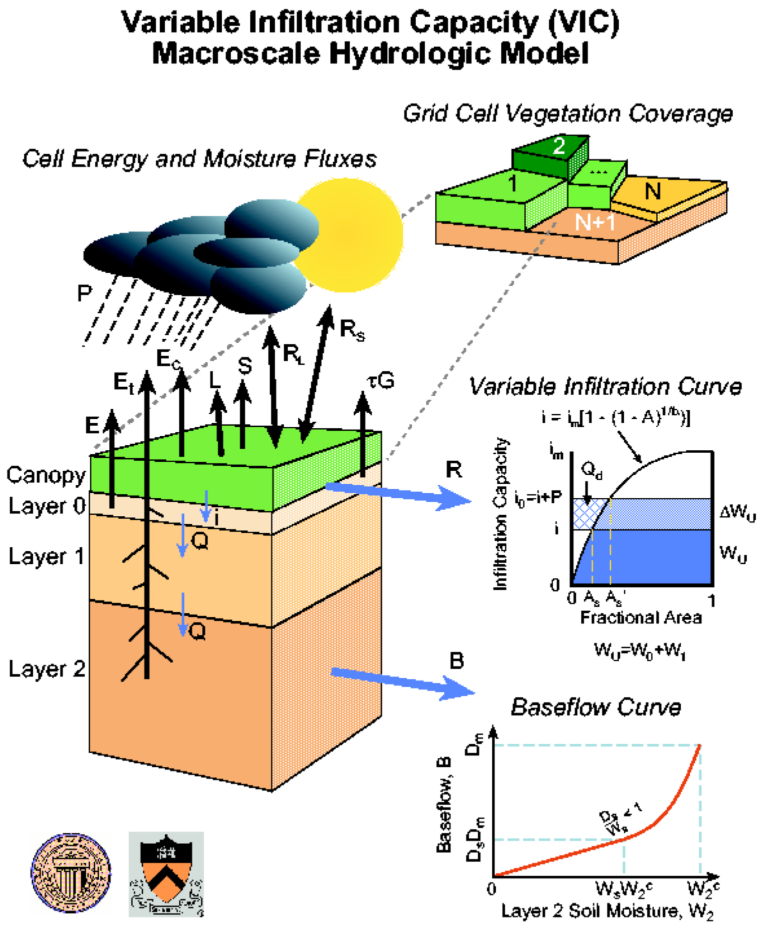
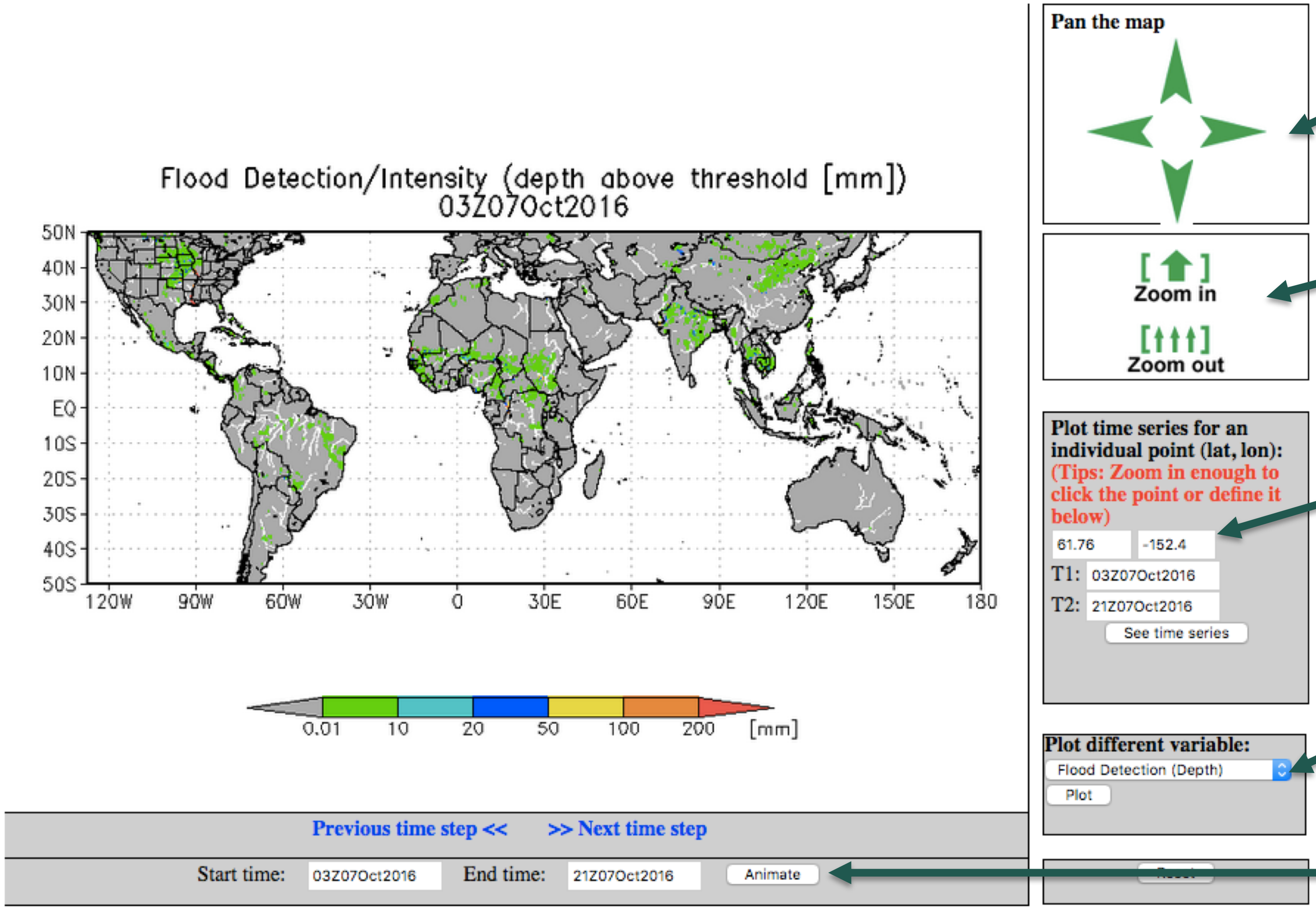


Image Credit: UW VIC Macroscale Hydrologic Model; References: Wu, H., R. F. Adler, Y. Tian, G. J. Huffman, H. Li, and J. Wang (2014), Real-time global flood estimation using satellite-based precipitation and a coupled land surface and routing model, Water Resour. Res., 50, 2693.2717, doi:10.1002/2013WR014710.; 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/



Map Navigation

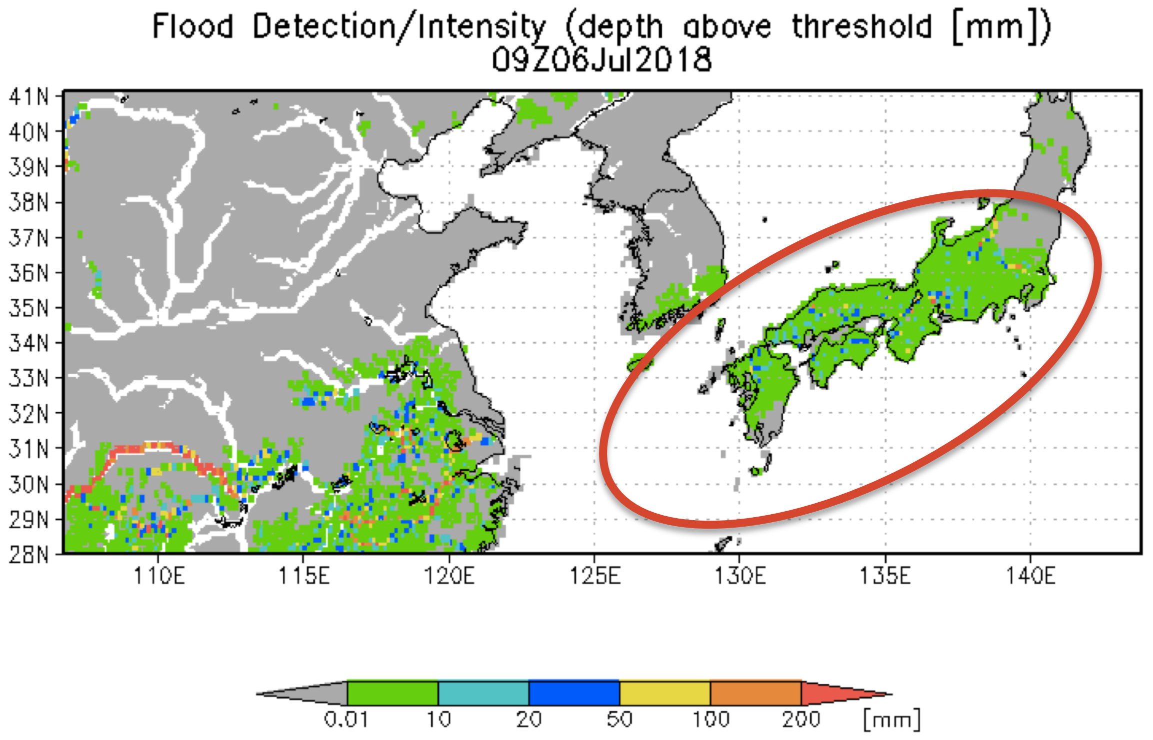
Zoom in/out

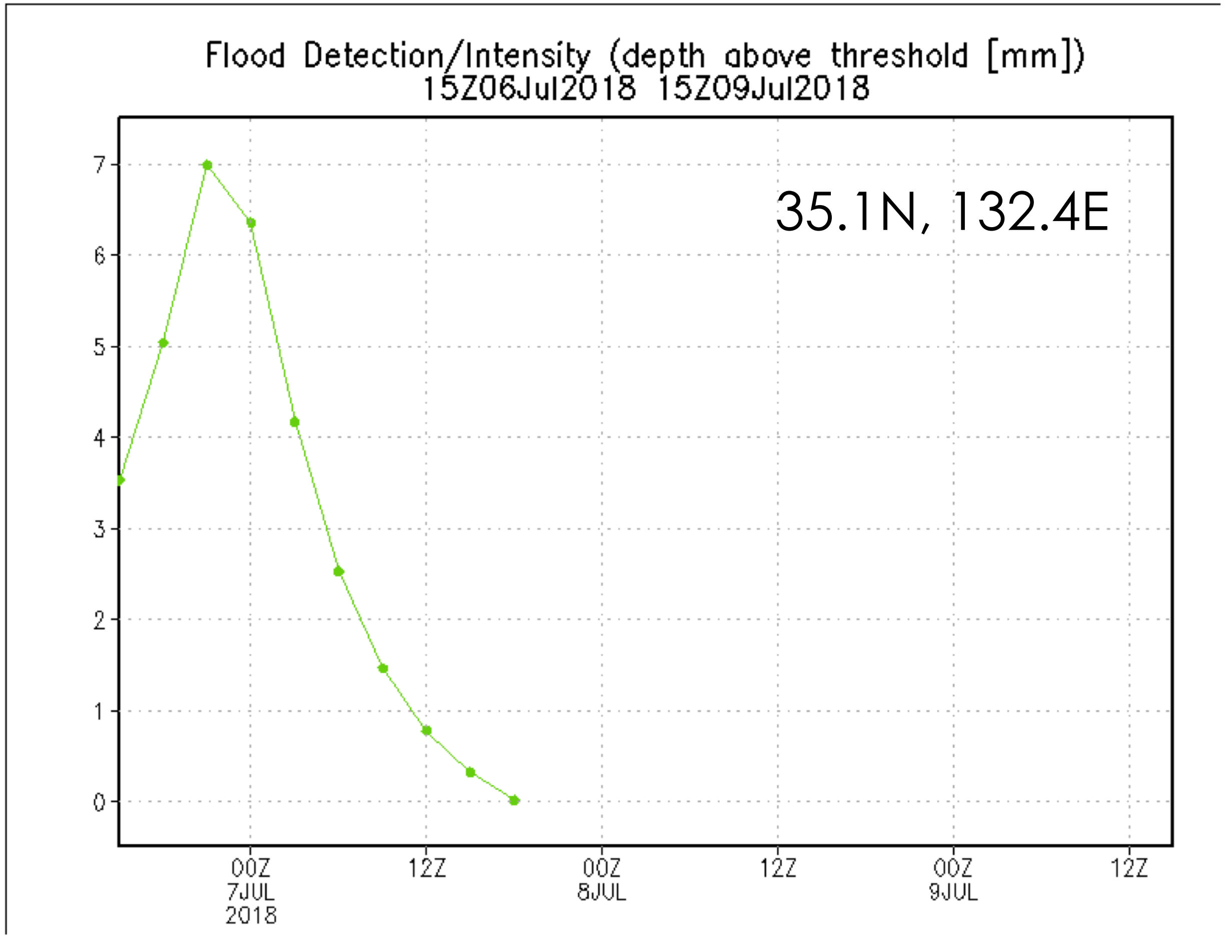
Select individual grid point for time series data

Plot different variables

Animation

GFMS: Flooding in Japan July 2018

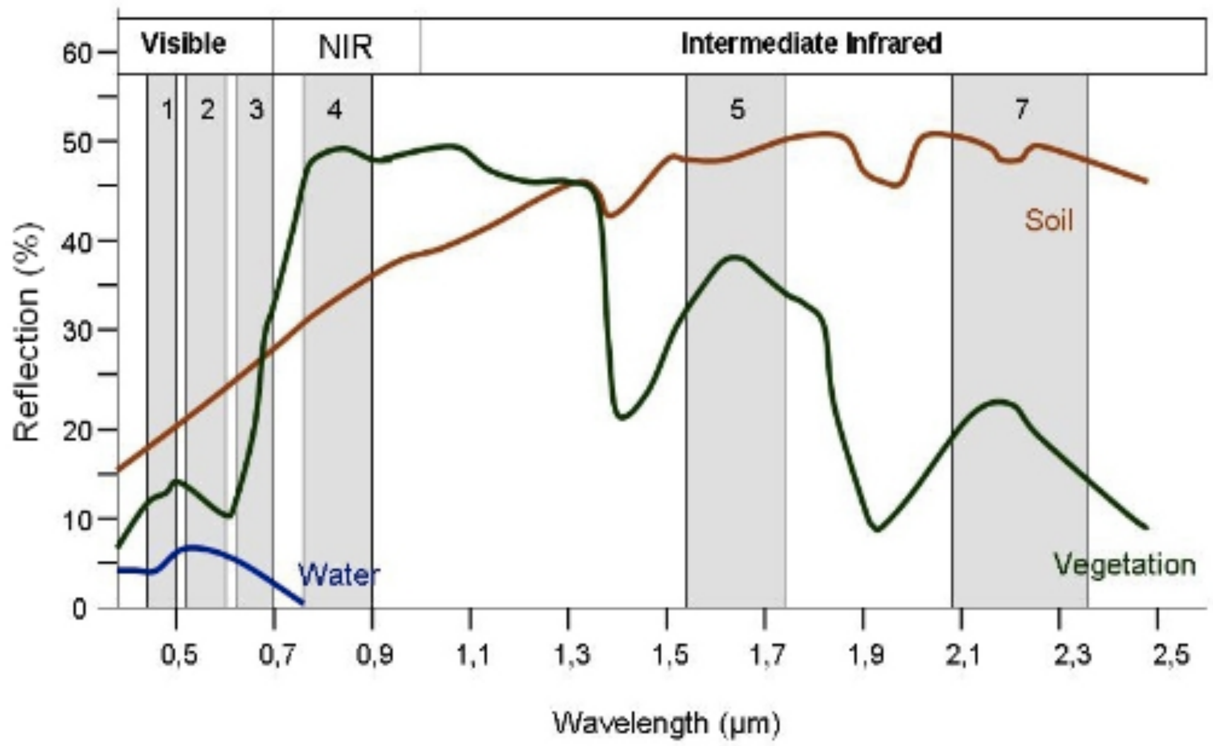




Land Cover Based Flooding Tools

Visible Radiation

- Reflected by the surface and depends on surface type



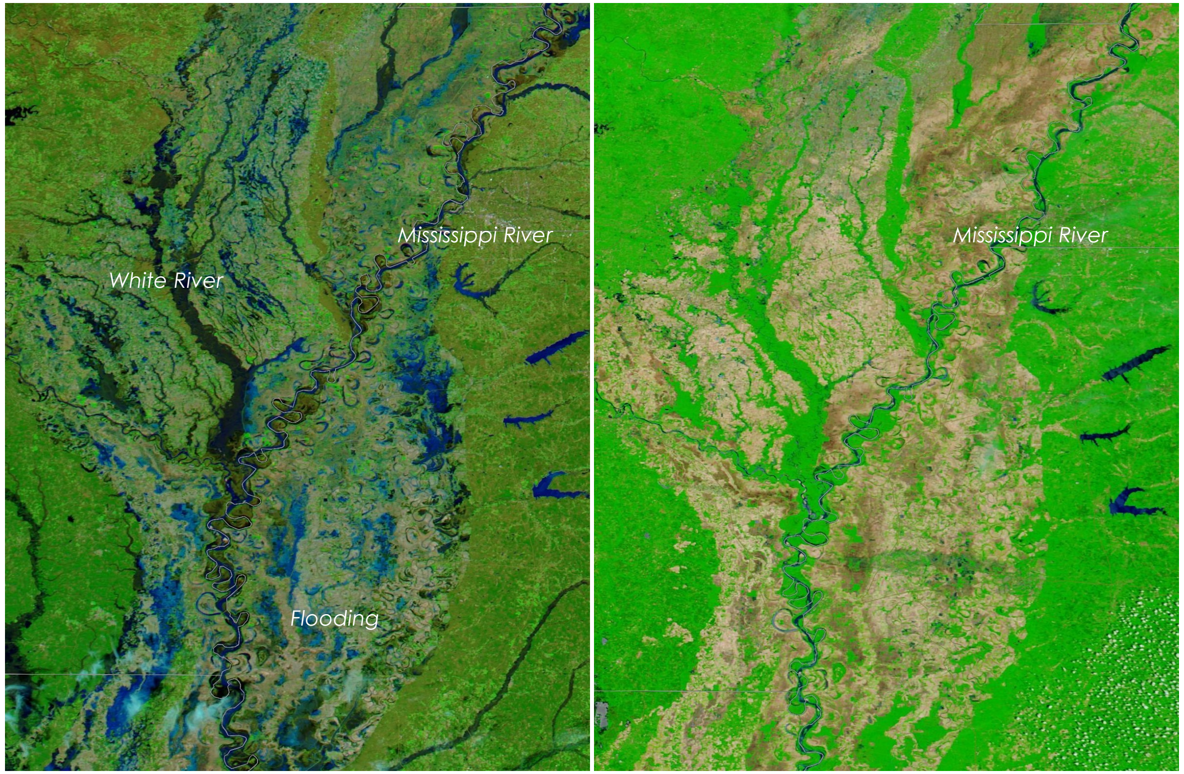
Used for Flood Mapping

- 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/

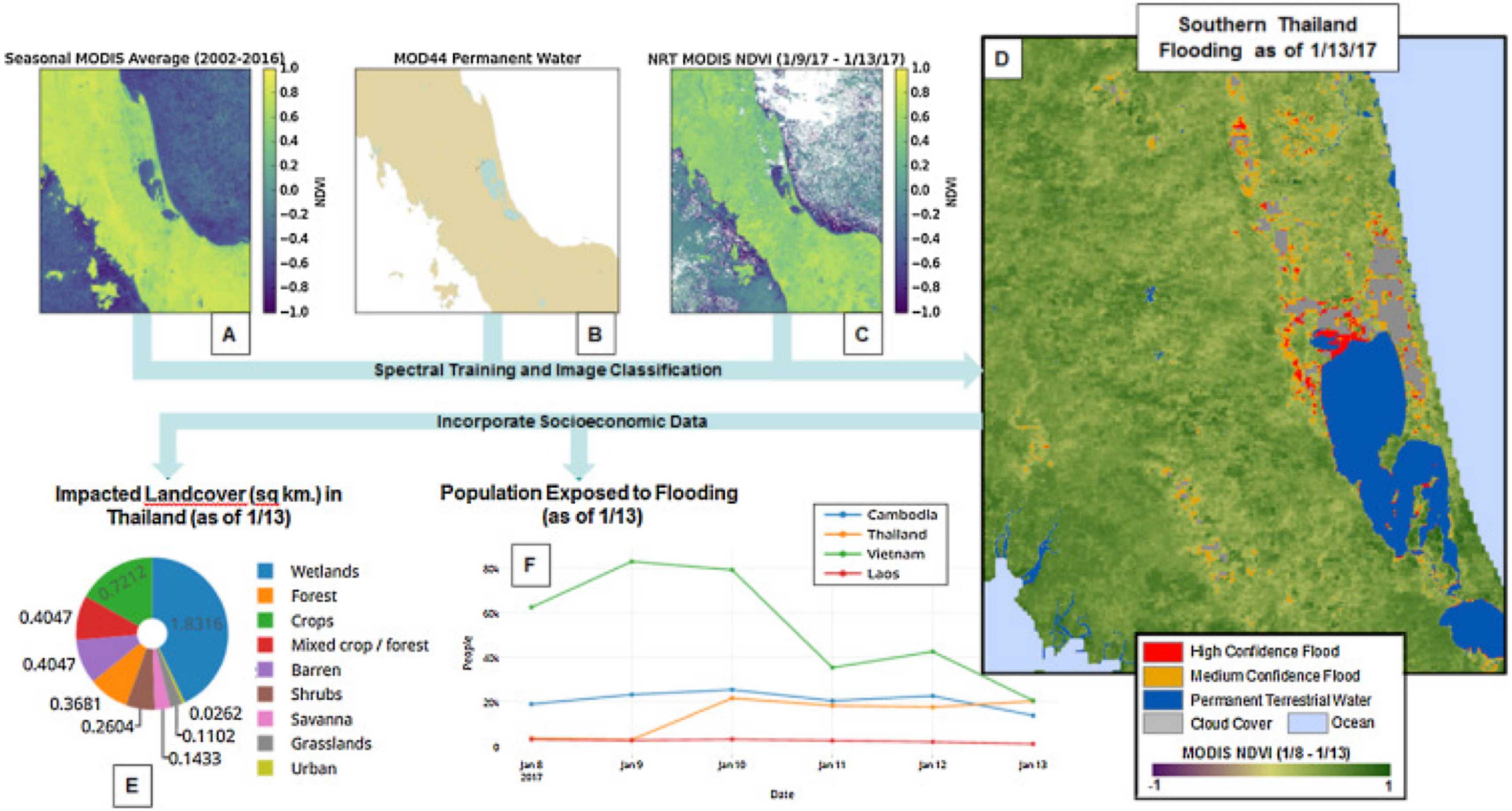
- Based on MODIS reflectance at 250 m resolution composited on 2, 3, and 14 days
- Flood maps available on 10°x10° tile
- Permanent and surface flood water data available
- Cloud or terrain shadows can be misinterpreted as surface water
- Provides near real-time flood mapping since Jan 2013

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



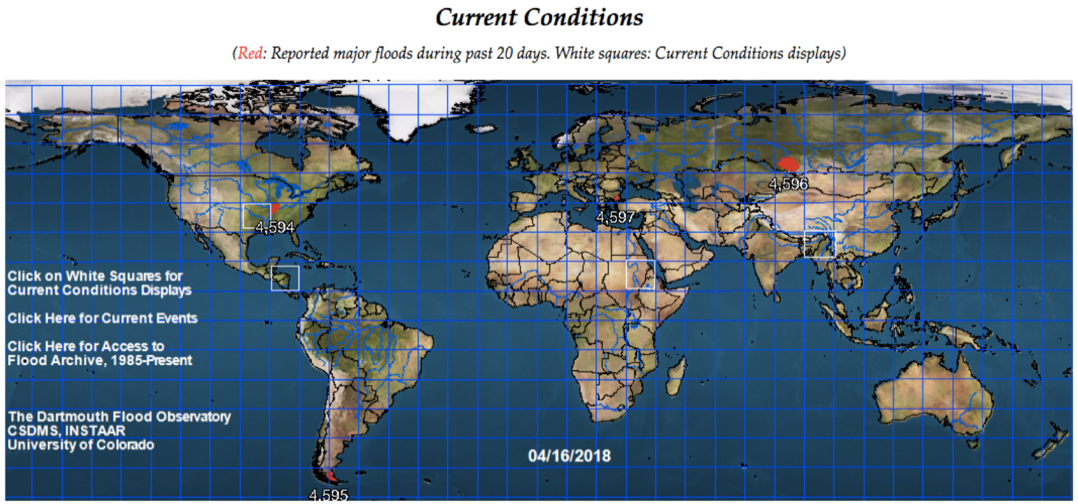
- Shows a few flooded areas – not all flooded areas are observed due to the presence of clouds
- May require supervised reflectance threshold for improved inundation detection (e.g. Ahamed and Bolten, 2017)

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.

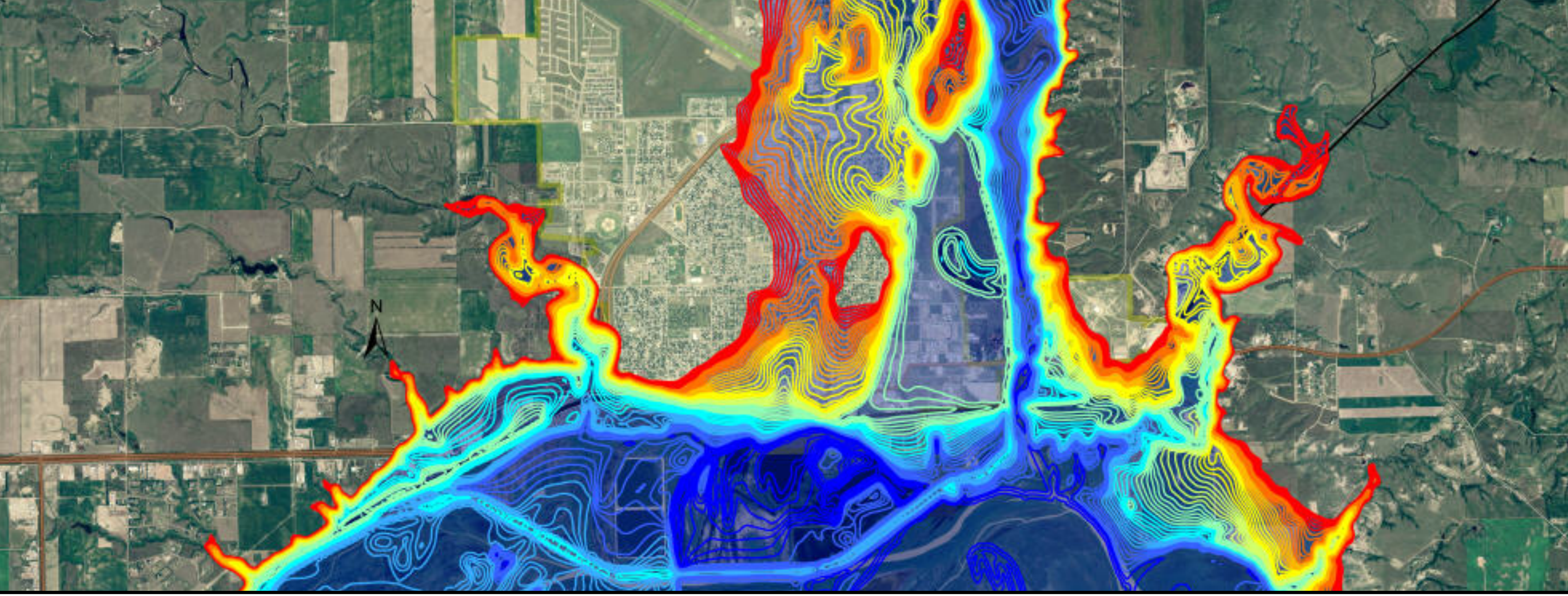
Dartmouth Flood Observatory (DFO)

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



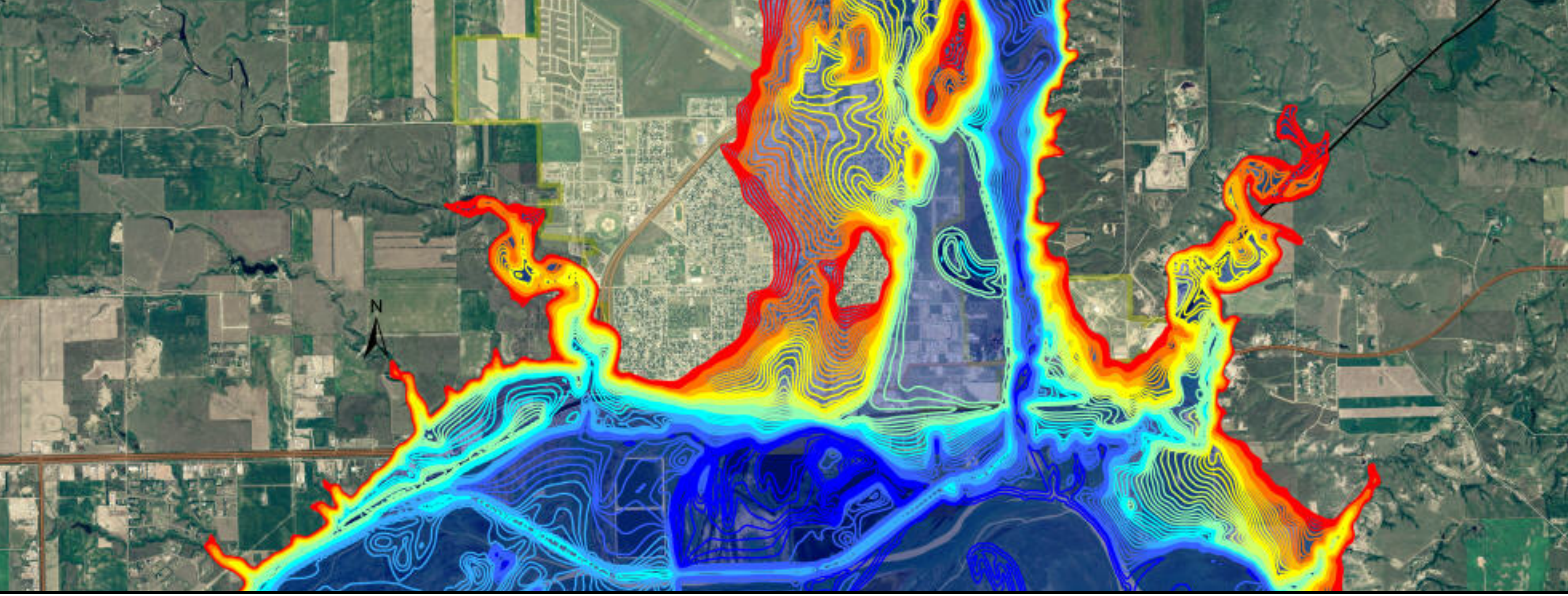
- Provides near real-time, current, and past flood event mapping
- Red areas (above) indicate inundated surfaces



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 to10 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!