Disasters Scenarios: Flooding

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Learning Objectives

• Identify remote sensing data and models relevant to flooding
• Monitor conditions before, during, and after a storm using remote sensing and modeled data
• Understand how remote sensing and modeled data can be used in decision-making activities
Flooding Impacts

• A 2015 report by the UN stated that 2.3 billion people were affected by flooding between 1995-2015*

• The report also indicated that flood trends are affecting larger areas and becoming more severe

* UNISDR
Flooding Impacts in the U.S.

Flood Fatalities in the U.S. Over the Last 30 Years

A 2016 flood in Louisiana, U.S.A. caused an estimated $10 Billion in damages

Chart Data Source: National Weather Service
ARSET Trainings of Interest

  – ARSET offered an advanced, online training in March 2016
  – Four hour training
  – Available at: https://arset.gsfc.nasa.gov/disasters/webinars/advfloodwebinar

• Applications of Remote Sensing to Soil Moisture and Evapotranspiration
  – Introductory, online training provided in September 2016
  – Five hour training
  – Available at: https://arset.gsfc.nasa.gov/water/webinars/apps-et-smap
Potential Problems to Address Before/During/After a Flood

- What are the areas at risk for flooding?
- How can flood risk maps be supplemented with satellite data?
- What areas are currently flooded?
- How fast is the water rising/receding?
- What is the flood extent?
- What is the flood damage?
Flood Risk Maps
FEMA Flood Risk Maps - USA

- FEMA provides flood maps to communities to set minimum floodplain standards
- Only covers the U.S.
- https://msc.fema.gov/portal/search

HOW IS A FLOOD MAP MADE?

1. Identify Area to Map or Re-Map
   A watershed is reviewed for development of a new map or to update/re-map the watershed.

2. Select the Project Area
   A watershed is selected for Discovery based on evaluations of risk, need, availability of elevation data, regional knowledge of issues, and input from the state, community, and other stakeholders.

3. Gather Information
   FEMA, state, local, and tribal officials collect current and historic flood-related data including:
   - Hydrology
   - Infrastructure
   - Hydraulics
   - Land use
   - Existing maps such as:
     - Floodplain
     - Base map
     - Flood Map, if existent
FEMA Flood Risk Map for Houston, Texas
Global Flood Risk Maps - World Resources Institute (WRI)

https://www.wri.org/

• Aqueduct Global Flood Analyzer
  – Assess river flood risks:
    – By country, river basin, or state
    – By population, GDP, or urban damage
    – Current or future (2030)

• Aqueduct Water Risk Atlas
  – https://www.wri.org/our-work/project/aqueduct
  – Online mapping tool that lets users combine 12 key indicators of water risk to create global overall water risk maps
Identifying Infrastructure at Risk
Terrain, Roads, and Population Data for Planning

- Terrain data from the Shuttle Radar Topography Mission (SRTM) can be accessed at [https://earthdata.nasa.gov/](https://earthdata.nasa.gov/). Covers land surfaces between 60°N and 56°S latitude, 30 m spatial resolution. Raster size is 1 degree tiles.

- ASTER Global Digital Elevation Maps (GDEM) can also be accessed at [https://earthdata.nasa.gov/](https://earthdata.nasa.gov/). Covers land surfaces between 83°N and 83°S latitude, 30 m spatial resolution.

- NASA’s Socioeconomic Data and Applications Center (SEDAC) makes global man-made impervious surface & settlement extent data available, generated from Landsat (global coverage, 30 m spatial resolution)
  
  Importing data from both of those sites into geospatial software (e.g., QGIS) allows you to identify areas susceptible to flooding.

- All above sites require a NASA Earth Observing System Data and Information System (EOSDIS) login to download data.
Data Acquisition: SRTM Global 1 Arc Second DEM

- Log into NASA’s Earth Data Search: [https://search.earthdata.nasa.gov/search](https://search.earthdata.nasa.gov/search)
  - (If you don’t have an account, you will need to create one)
  - Type “srtm 1 arc second” into the search box
  - Hover your mouse over the spatial icon and select “Rectangle”
  - For coordinates enter “SW: 27.5, -97.5 NE: 30.5, -89.5”
- This places a bounding box around the TX and LA coast
Data Acquisition: SRTM Global 1 Arc Second DEM

– In matching collections at the bottom of the screen select “NASA Shuttle Radar Topography Mission Global 1 arc second V003”
– There should be 24 granules selected for download. Click “Download All.”
– Select Data Access Method and click Submit
Data Acquisition: SRTM Global 1 Arc Second DEM

- Click “View/Download Data Links”
- This takes you to a FTP site to download each file using the links provided

• Bring downloaded files into QGIS and merge these into a single mosaic file to get a seamless dataset for study area
Data Acquisition: Impervious Surface Data

  – (If you don’t have an account, you will need to create one)
  – Using the window “Impervious Surface Percentage (GMIS)” click on “Download View”

- Click on the bubble next to “Tile” and then click “Download by Tiles”
Data Acquisition: Impervious Surface Data

- Download data from tiles 14R and 15R by clicking on each tile, checking the box for “Impervious Surface Percentage (GMIS)” and click “Save”
- Open the files using QGIS
- For more information on Global Man-made Impervious Surface (GMIS) dataset, refer to the link below: http://sedac.ciesin.columbia.edu/data/set/ulandsat-gmis-v1
SRTM DEM + Impervious Surface Data: Hurricane Harvey

Higher elevation

Lower elevation

Impervious surfaces (e.g., more paved areas)

Percent Impervious

0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
SRTM DEM + Impervious Surface Data: Hurricane Harvey
Soil Moisture in High Risk Areas
Soil Moisture

- Flood severity can be impacted by how wet soils are before a rainstorm
  - High soil moisture can increase the chance of inundation
- The National Weather Service’s flash flood guidance is updated at least every 24 hours based on surface soil moisture
- NASA’s Soil Moisture Active Passive (SMAP) mission makes measurements of surface soil moisture globally every 3 days
NASA’s Soil Moisture Active Passive (SMAP) Mission

• Measures moisture in the top 5 cm of the soil globally every 3 days
• Uses a microwave remote sensing instrument
• Easily accessible data:
  – surface soil moisture (9 km, 36 km)
  – root zone soil moisture (9 km, 36 km)
Accessing SMAP Data

https://worldview.earthdata.nasa.gov/

https://nsidc.org/data/smap/smap-data.html
Accessing SMAP Surface Soil Moisture
Accessing SMAP Root Zone Soil Moisture
Visualizing SMAP Soil Moisture on Worldview
Downloading and Displaying SMAP Soil Moisture Data

SMAP Soil Moisture (L3 – Radiometer – 9km) for Aug. 24, 2017

Soil Moisture (cm$^3$/cm$^3$)
SMAP Soil Moisture Before and During Hurricane Harvey
Tracking Flooding
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 hours with about a 10 hour latency
  - accumulated rain over 24, 72, and 168 hours
  - streamflow rates and flood intensity at 1/8th 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
Map Navigation
Zoom in/out
Select individual grid point for time series data
Plot different variables
Animation
GFMS: Flooding from Hurricane Harvey
GFMS: Flood Forecasts

Click on "next time step" to view 4-5 day forecasts.
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 (up to the previous day) flood mapping since Jan 2013
# MODIS NRT Global Flood Mapping: Available Quantities

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

<table>
<thead>
<tr>
<th>Products</th>
<th>Available Downloads</th>
</tr>
</thead>
<tbody>
<tr>
<td>MODIS Flood Map</td>
<td>MFM png</td>
</tr>
<tr>
<td>MODIS Flood Water</td>
<td>MFW shapefile (.zip)KMZ</td>
</tr>
<tr>
<td>MODIS Surface Water</td>
<td>MSW shapefile (.zip)KMZ</td>
</tr>
<tr>
<td>MODIS Water Product</td>
<td>MWP geotiff</td>
</tr>
<tr>
<td>README</td>
<td></td>
</tr>
<tr>
<td></td>
<td>pdf txt</td>
</tr>
</tbody>
</table>
MODIS NRT Global Flood Mapping: Houston Area, Post Harvey

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

Tile 100W 30N

Aug. 31, 2017

Note: MODIS cannot see the surface when clouds are present

Inundated Surface Post-Hurricane Harvey
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
DFO: Flooding Due to Hurricane Harvey

https://floodobservatory.colorado.edu/Events/2017USA4510/2017USA4510.html

Flood Map (Hurricane Harvey)
Red is flooding mapped from NASA MODIS, ESA Sentinel 1, ASI Cosmo SkyMed, and Radarsat 2 data. Blue is a reference normal water extent.
NASA Disasters Portal

https://disasters.nasa.gov/home
**ARIA Flood Extent Map**


- This map is derived from Synthetic Aperture Radar (SAR) amplitude images from the Japan Aerospace Exploration Agency's (JAXA) ALOS-2 PALSAR-2 satellite, taken before (Jul 30, 2017) and after (Aug 27, 2017) Hurricane Harvey made landfall.

- The map covers an area of 135 km². Each pixel measures about 538 ft². Local ground observations provided anecdotal preliminary validation.

- This flood proxy map should be used as guidance to identify areas that are likely flooded, and may be less reliable over urban areas. ALOS-2 data were accessed through the International Charter

Text Credit: ARIA; Credit: NASA/J PL-Caltech/J AXA/METI/Google Earth
Synthetic Aperture Radar (SAR) Imagery For Flood Detection

https://arset.gsfc.nasa.gov/disasters/webinars/intro-SAR

- SAR is an active sensor operating in microwave frequencies - collect backscattered signal
- The backscatter signal is primarily sensitive to surface structure
- The scale of the objects on the surface relative to the wavelength determine how rough or smooth they appear to the radar signal and how bright or dark they will appear on the image

<table>
<thead>
<tr>
<th>Frequency band</th>
<th>Frequency range</th>
<th>Application Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>VHF</td>
<td>300 KHz - 300 MHz</td>
<td>Foliage/Ground penetration, biomass</td>
</tr>
<tr>
<td>P-Band</td>
<td>300 MHz - 1 GHz</td>
<td>biomass, soil moisture, penetration</td>
</tr>
<tr>
<td>L-Band</td>
<td>1 GHz - 2 GHz</td>
<td>agriculture, forestry, soil moisture</td>
</tr>
<tr>
<td>C-Band</td>
<td>4 GHz - 8 GHz</td>
<td>ocean, agriculture</td>
</tr>
<tr>
<td>X-Band</td>
<td>8 GHz - 12 GHz</td>
<td>agriculture, ocean, high resolution radar</td>
</tr>
<tr>
<td>Ku-Band</td>
<td>14 GHz - 18 GHz</td>
<td>glaciology (snow cover mapping)</td>
</tr>
<tr>
<td>Ka-Band</td>
<td>27 GHz - 47 GHz</td>
<td>high resolution radars</td>
</tr>
</tbody>
</table>

Backscattering Mechanisms

Smooth Surface

Rough Surface
Radar Data from Different Satellites

The Legacy:
- SeaSAT 1978 (USA)
- ERS 1/2 1991-2011 (Europe)
- ENVISAT 2002-2012 (Europe)
- ALOS-1 2006-2011
- Radarsat-1 1995-2013 (Canada)

The New:
- TanDEM-X 2007 (Germany)
- Radarsat-2 2007 (Canada)
- COSMO-SkyMed 2007 (Italy)
- Sentinel-1 2014 (Europe)
- SAOCOM 2018 (Argentina)
- PAZ SAR 2018 (Spain)

The Future:
- RCM 2019 (Canada)
- NISAR 2021 (USA)
- Biomass 2021 (Europe)

Credit: Franz Meyer, University of Alaska

NASA’s Applied Remote Sensing Training Program
SAR Applications

1. Wetland Ecosystems
2. Vegetation Studies
3. Disaster Monitoring
4. Ground Subsidence
5. Cryosphere
6. Oceans
7. Urban Area/Infrastructure Change

Unlike optical sensors, such as MODIS and VIIRS, microwave SAR can see through clouds!

Classification Based on SAR Observables

- **Green**: not inundated
- **Yellow & Orange**: inundated vegetation
- **Blue** (light & dark): open water
Sentinel 1 SAR Image Processing

- Sentinel-1 SAR data are available from:
  - https://vertex.daac.asf.alaska.edu/
- Sentinel-1 SAR data can be processed by using Sentinel-1 Application Toolbox (SNAP)
  - SNAP is an open source toolbox and can be downloaded from:
    - http://step.esa.int/main/download/
- Processing SAR images is complex and requires advanced training
- For more information see
  - https://arset.gsfc.nasa.gov/disasters/webinars/intro-SAR

ARSET hosted an advanced webinar on SAR data and applications in July 2018
Sentinel 1 SAR Images: Before and After Hurricane Matthew

Inundation in Coastal North Carolina
**Sentinel-1 Preprocessing on Google Earth Engine**

- Google Earth Engine uses the following preprocessing steps (as implemented by the Sentinel-1 Toolbox) to derive the backscatter coefficient in each pixel:
  
  - **Apply orbit file**
    - Updates orbit metadata with a restituted orbit file.
  
  - **GRD border noise removal**
    - Removes low intensity noise and invalid data on scene edges. (As of January 12, 2018)
  
  - **Thermal noise removal**
    - Removes additive noise in sub-swaths to help reduce discontinuities between sub-swaths for scenes in multi-swath acquisition modes. (This operation cannot be applied to images produced before July 2015)
  
  - **Radiometric calibration**
    - Computes backscatter intensity using sensor calibration parameters in the GRD metadata.
  
  - **Terrain correction** (orthorectification)
    - Converts data from ground range geometry, which does not take terrain into account, to $\sigma^0$ using the SRTM 30 meter DEM or the ASTER DEM for high latitudes (greater than 60° or less than -60°).
Google Earth Engine for Classifying Flood Extent with Sentinel-1

```javascript
new_flooding *
1 // Load Sentinel-1 images to map a flooding in Kerala in 2018.
2 // This script was originally written by Simon Ilyushchenko (GEE team)
3 // Default location
4 var geometry = {color: #d63000, _type: 'ee.Geometry.Point', coordinates: [76.40, 9.53]};
5 var pt = geometry;
6
7 // Load Sentinel-1 C-band SAR Ground Range collection (log scaling, VH co-polar)
8 var collection = ee.ImageCollection('COPERNICUS/S1_GRD').filterBounds(pt)
9 .filter(ee.Filter.listContains('transmitterReceiverPolarisation', 'VH'))
10 .filter(ee.Filter.eq('instrumentMode', 'IW'))
11 .filter(ee.Filter.eq('orbitProperties_pass', 'DESCENDING'))
12 .select('VH');
13
14 // Filter by date
15 var before = collection.filterDate('2018-07-04', '2018-07-06').mosaic();
16 var after = collection.filterDate('2018-08-21', '2018-08-23').mosaic();
17
18 // Threshold smoothed radar intensities to identify "flooded" areas.
19 var SMOOTHING_RADIUS = 100;
20 var DIFF_UPPER_THRESHOLD = -3;
21 var diff_smoothed = after.focal_median(SMOOTHING_RADIUS, 'circle', 'meters')
22 .subtract(before.focal_median(SMOOTHING_RADIUS, 'circle', 'meters'))
23 .diff_thresholded = diff_smoothed.lt(DIFF_UPPER_THRESHOLD);
24
25 // Display map
26 Map.centerObject(pt, 13);
27 Map.addLayer(before, {min:-30, max:0}, 'Before flood');
28 Map.addLayer(after, {min:-30, max:0}, 'After flood');
29 Map.addLayer(after.subtract(before), {min:-10, max:10}, 'After - before');
30 Map.addLayer(diff_smoothed, {min:-10, max:10}, 'diff_smoothed', 0);
31 Map.addLayer(diff_thresholded.updateMask(diff_thresholded),
32 {palette: "0000FF","flooded areas - blue",1});
```
Flood Mapping Results
Financial Loss
Financial Loss Potential Index for Hurricane Harvey, Sept. 1st 2017

Global Disaster Alert and Coordination System

http://www.gdacs.org/

Integrated Data and Information Portal

Includes:

- Near real-time and past storm information
- Data and maps from models and satellites
- Media reports and impacts
International Charter Space & Major Disasters

- Worldwide collaboration making satellite data available for disaster management
- Composed of global space agencies & space system operators
- 34 contributing satellites
- Available at: https://disasterscharter.org/