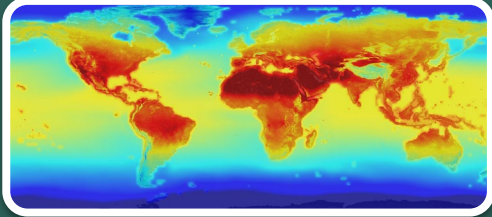


Workshop Agenda



Session I: Introduction to Climate Change

- Overview of climate change
- Monitoring climate change drivers using NASA data



Session II: Earth Observations for Climate Change Impacts (Land & Atmosphere)

- Overview
- Focus Area: Drought
- Focus Area: Urban Heat Islands & Extreme Heat
- Focus Area: Wildfires & Smoke



Session III: Earth Observations for Climate Change Impacts (Ocean & Ice)

- Overview
- Focus Area: Sea Level Rise



Session IV: Climate Models, Policy & Decision making

- Climate Modeling
- NASA ESO

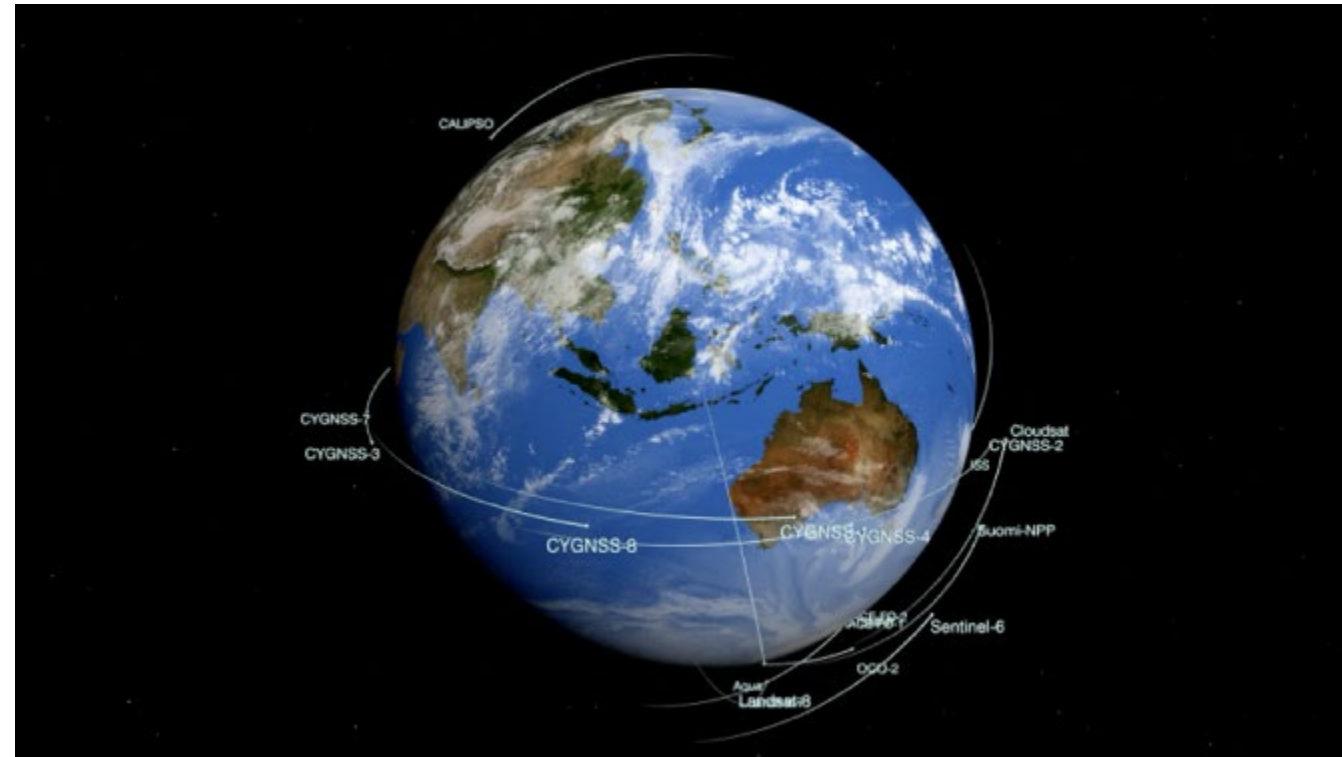




Session II: Earth Observations for Climate Change Impacts (Land & Atmosphere)

Role of Earth Observations in Climate Change Assessment

- NASA Earth observing satellites observe changes across the entire planet, from the atmosphere, biosphere, hydrosphere, cryosphere, and lithosphere.
- They provide consistent, timely, global, accurate measurements, from the tropics to the polar regions.
- NASA conducts a program of breakthrough research on climate science, enhancing the ability of the international scientific community to advance globally-integrated Earth system science.



NASA's Earth Observing Fleet (2021). Credit: [NASA's Scientific Visualization Studio](https://climate.nasa.gov/nasa_science/history/)





Phenology & Agriculture

Phenology

- The study of plant and animal life cycles in relation to the seasons.
- Phenological events change from year to year.
- Timing of events (phenophase) such as flowering, leafing, migration, and insect emergence can impact how plants and animals thrive in their environment.

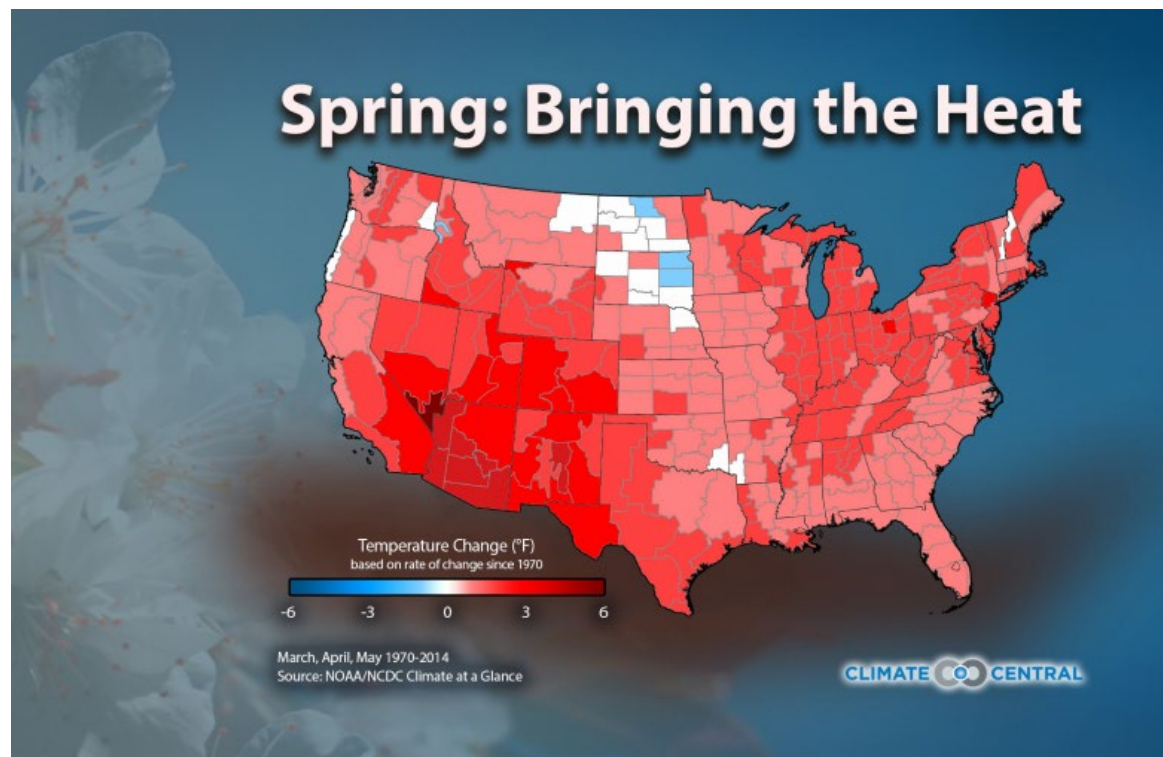


Seasonal cycle of a tree. Image Credit: USGS/NPN)



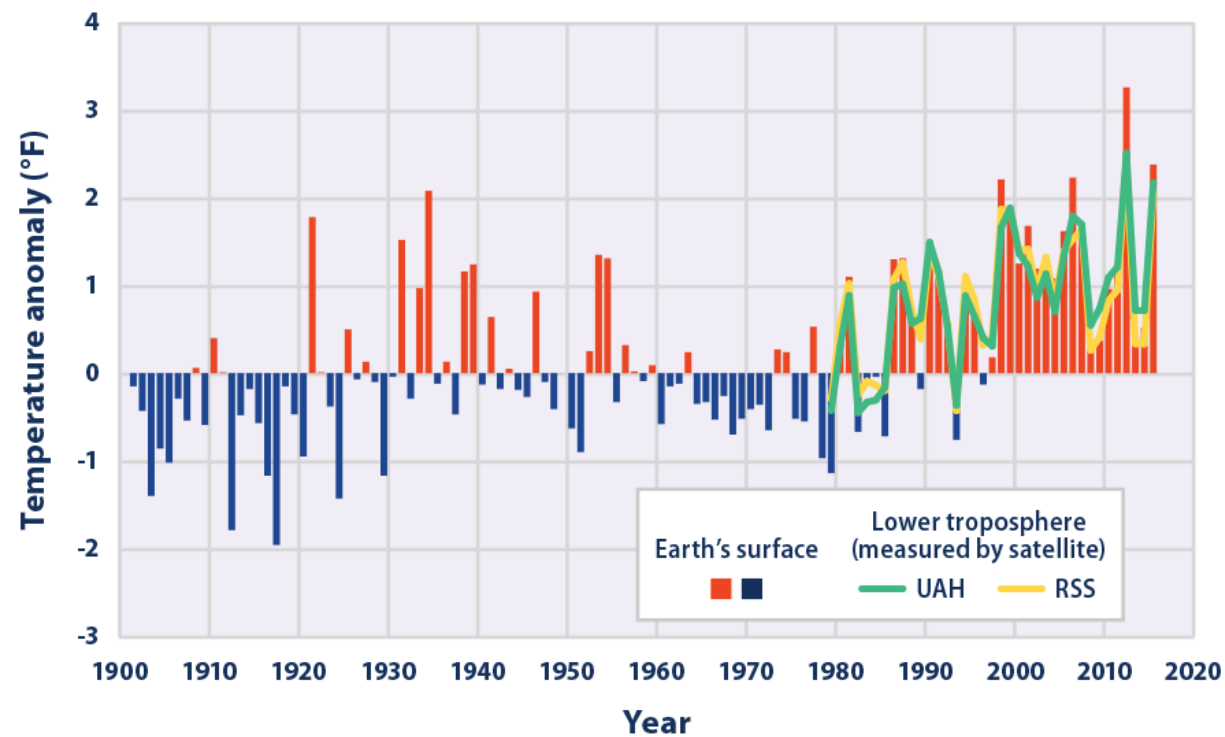
Drivers of Phenology

Temperature



Spring Temperature Change from 1970–2014, Based on Rate of Change from 1970

Image Credit: [Climate Central](https://www.climatecentral.org/).



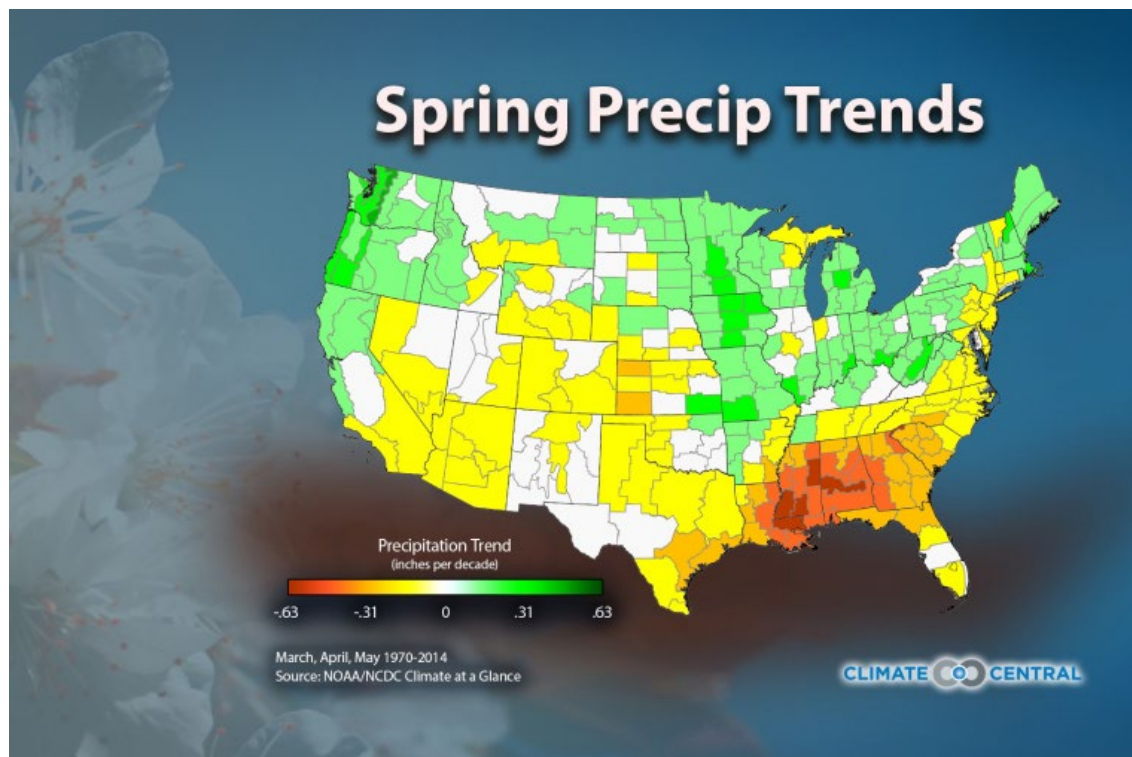
Annual Average Temperatures in the Contiguous 48 States from 1901–2016

Image Credit: [NOAA, 2016](https://www.noaa.gov/).



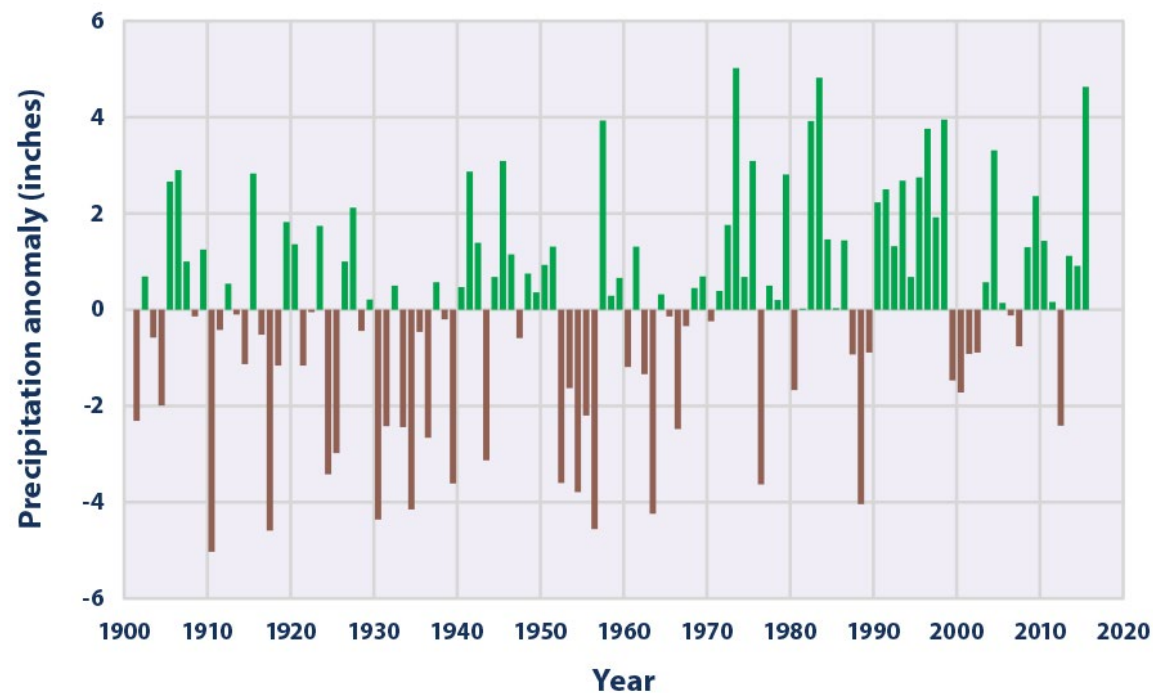
Drivers of Phenology

Water Availability



Precipitation Trend in Inches per Decade
from 1970–2014

Image Credit: [Climate Central](#).



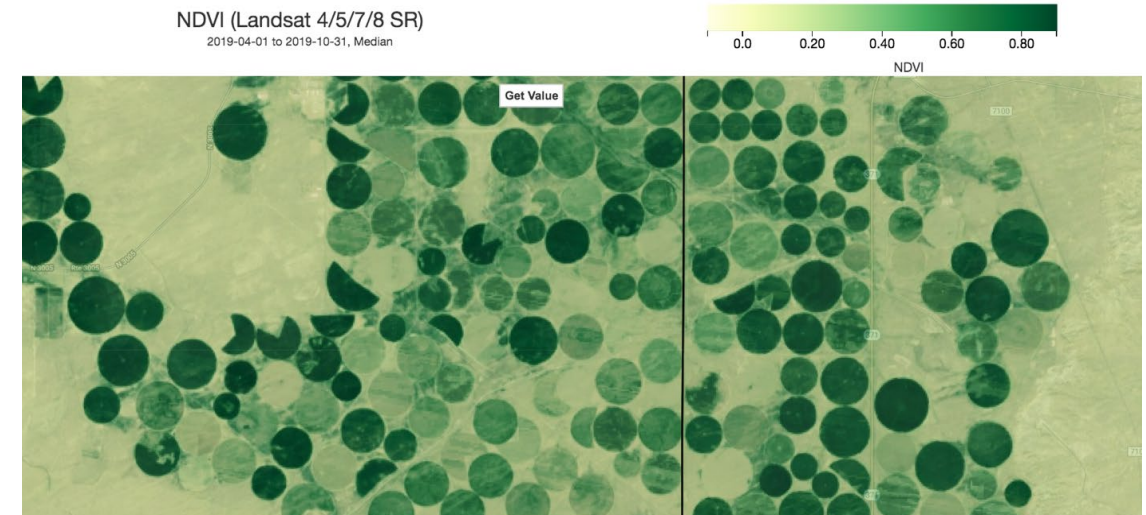
Total Annual Precipitation Anomaly in
the Contiguous U.S. from 1901

Image Credit: [NOAA, 2016](#).



Remote Sensing of Phenology

- Use of satellites and sensors to track seasonal patterns of variation in vegetated land surfaces
- **Land Surface Phenology (LSP)**
 - Regular monitoring of the entire global land surface
 - Gather information on entire ecosystems: broad scale trends
- Most useful when linked to ground observation networks
- Uses Include:
 - Crop Health Assessments
 - Drought Severity
 - Wildfire Risks
 - Invasive Species and Pest Tracking
 - Mapping Infectious Disease Risk

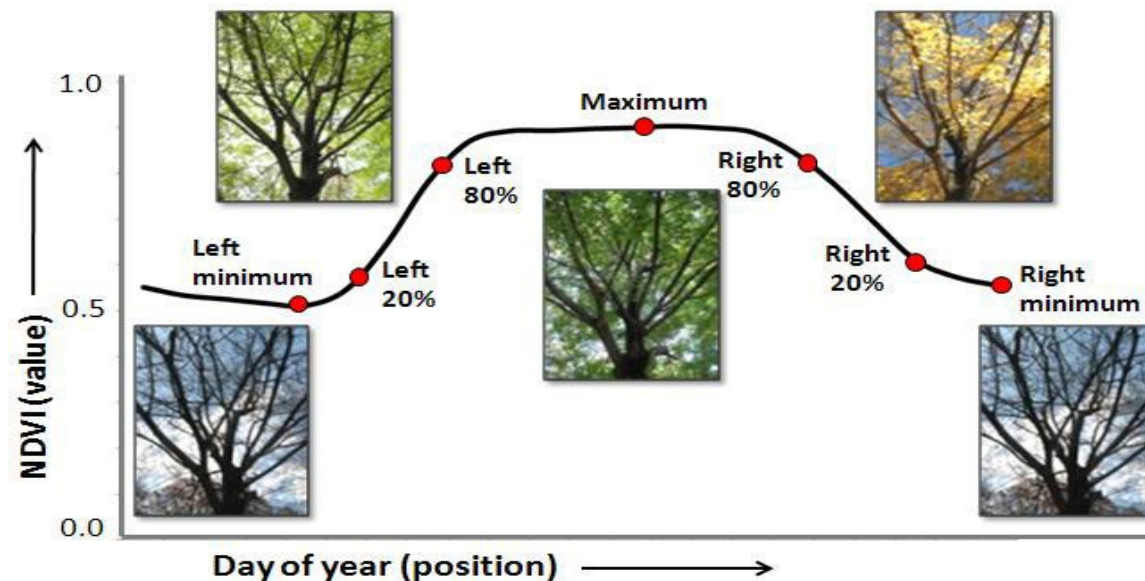


Center pivot irrigation with NDVI displayed.
Image Credit: NASA/DRI [DSET](#).



NDVI and Seasonality

- Remote sensing is used to track the seasonal changes in vegetation.
- Monthly NDVI images from MODIS or Landsat can be used to monitor phenology.



North America NDVI Images in Winter and Summer

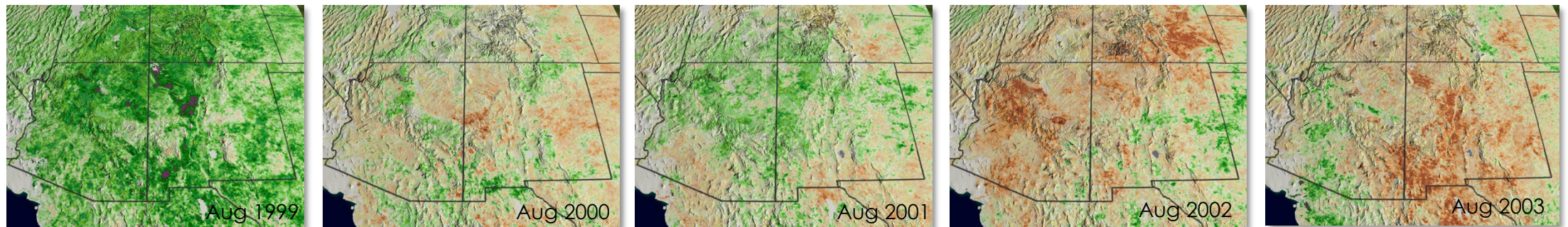
Credit: spacegrant.montana.edu



NDVI: Anomalies

- Departure of NDVI from the long-term average, normalized by long-term variability
- Generated by subtracting the long-term mean from the current value for that month of the year for each grid cell
- Indicates if vegetation greenness at a particular location is typical for that period or if the vegetation is more or less green

NDVI Anomalies in the Southwestern United States



Phenological Metrics

- Key variables estimated with remote sensing:
 - Start of Season (SOS)
 - End of Season (EOS)
 - Maximum NDVI
 - Duration
 - Amplitude

Start of Season (SOS) for Kansas, 2018

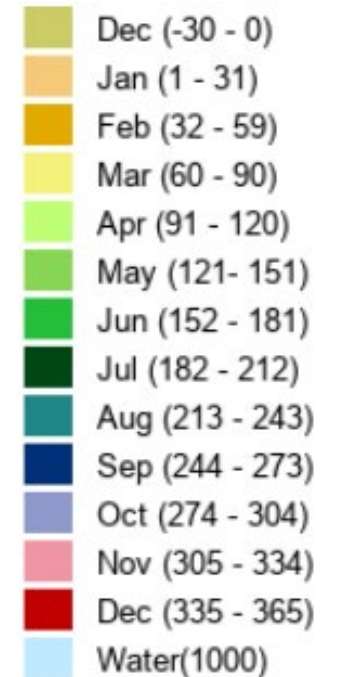
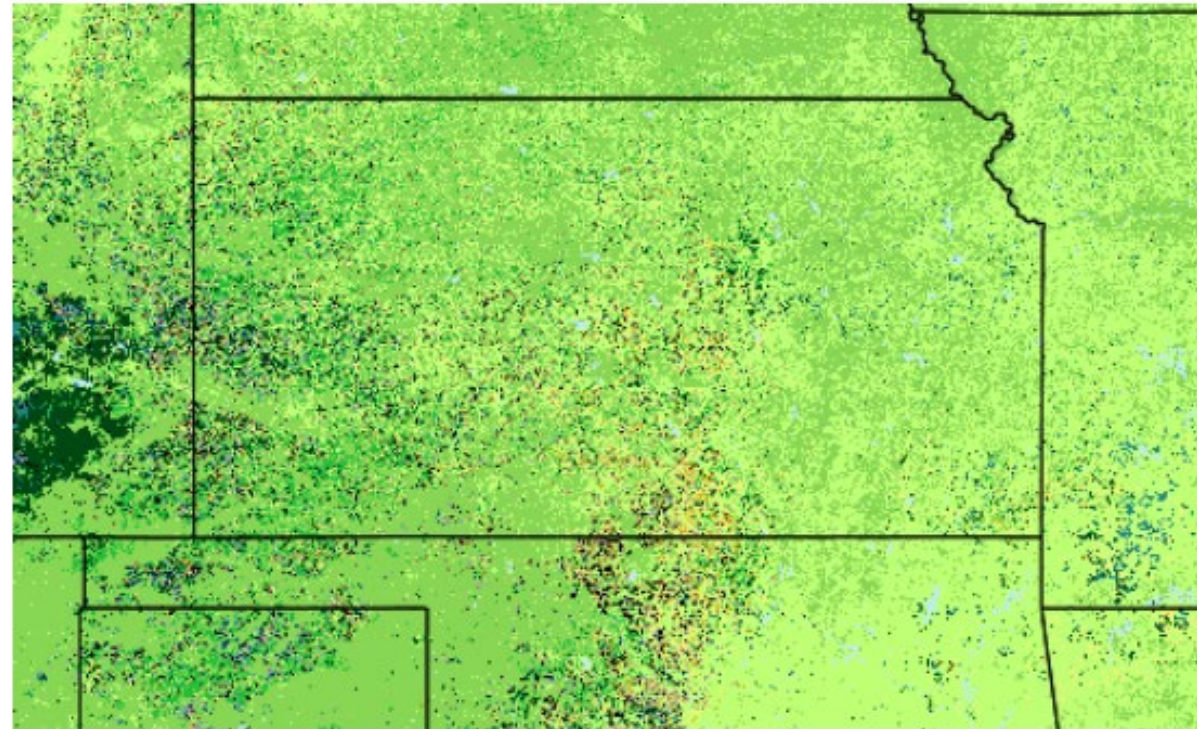


Image Credit: [USGS](https://www.usgs.gov/)



Start of Season

- **Start of Season Time (SOST)**
 - Day of year identified as having a consistent upward trend in time series NDVI
- **Start of Season NDVI (SOSN)**
 - NDVI value (or baseline) identified at the day of year identified as a consistent upward trend in time series NDVI

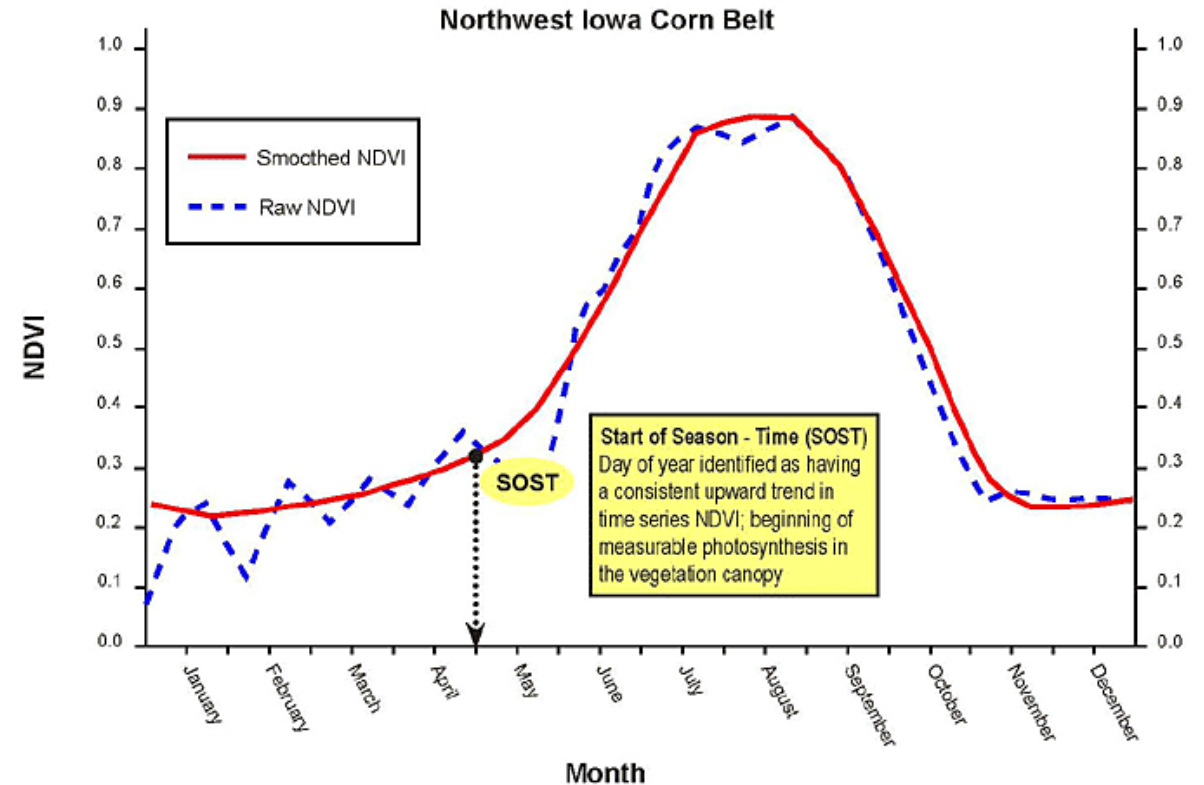


Image Credit: [USGS](https://www.usgs.gov/)



End of Season

- **End of Season Time (EOST)**
 - Day of year identified at the end of a consistent downward trend in time series NDVI
- **End of Season NDVI (EOSN)**
 - NDVI value corresponding with the day of year identified at the end of a consistent downward trend in time series NDVI

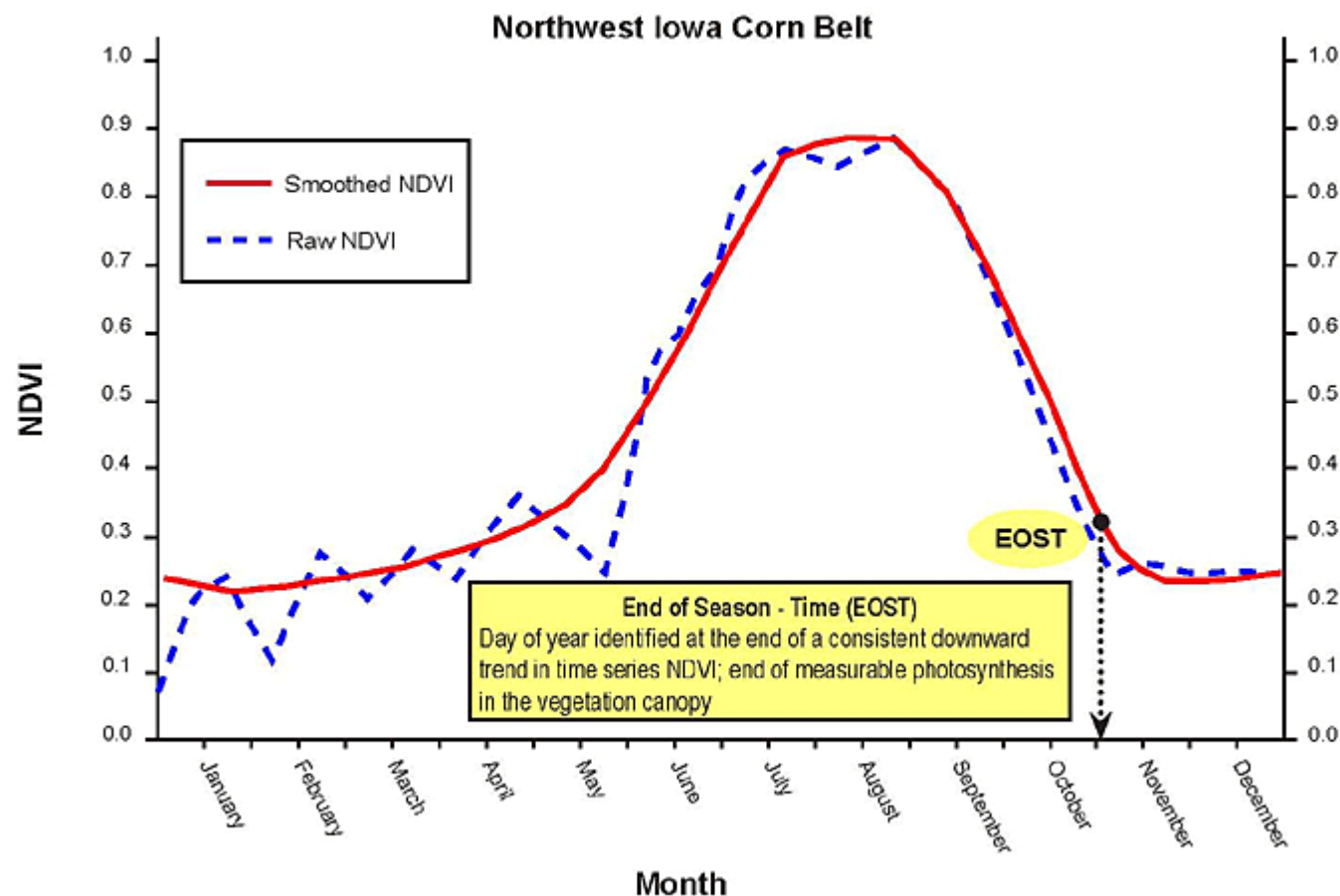


Image Credit: [USGS](#)



Max, Duration, Amplitude

- **Maximum NDVI (MAXN)**
 - Maximum NDVI in an annual time series
- **Duration (DUR)**
 - Number of days from the Start of Season Time (SOST) until the End of Season Time (EOST)
- **Amplitude (AMP)**
 - Difference between Maximum NDVI (MAXN) and Start of Season NDVI (SOSN)

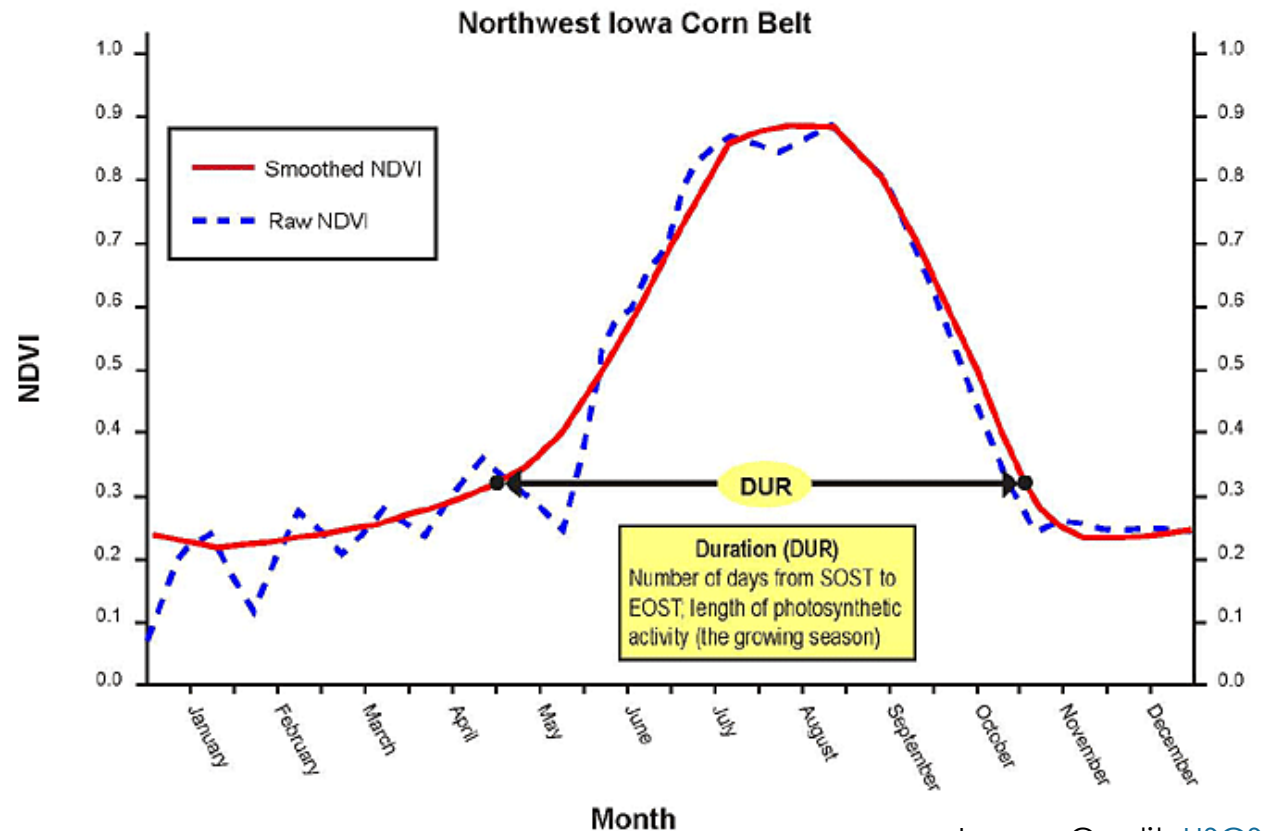


Image Credit: [USGS](https://www.usgs.gov/)



NPN Overview

<https://www.usanpn.org/>

*Collect • Store • Share
Phenology Data and Information*

*Advance Science
Inform Decisions
Communicate & Connect*



NPN Overview

<https://www.usanpn.org/>

Primary Goal

- *Create a standardized dataset for use in multiple types of research.*

Mission

- Make phenology data, models, and related information available.
- Encourage people of all ages and backgrounds to observe and record phenology.

UNDERSTAND HOW SPECIES
AND LANDSCAPES ARE
RESPONDING TO CLIMATE
CHANGE.



Photo Credit: C. Enquist





Demo: National Phenology Network

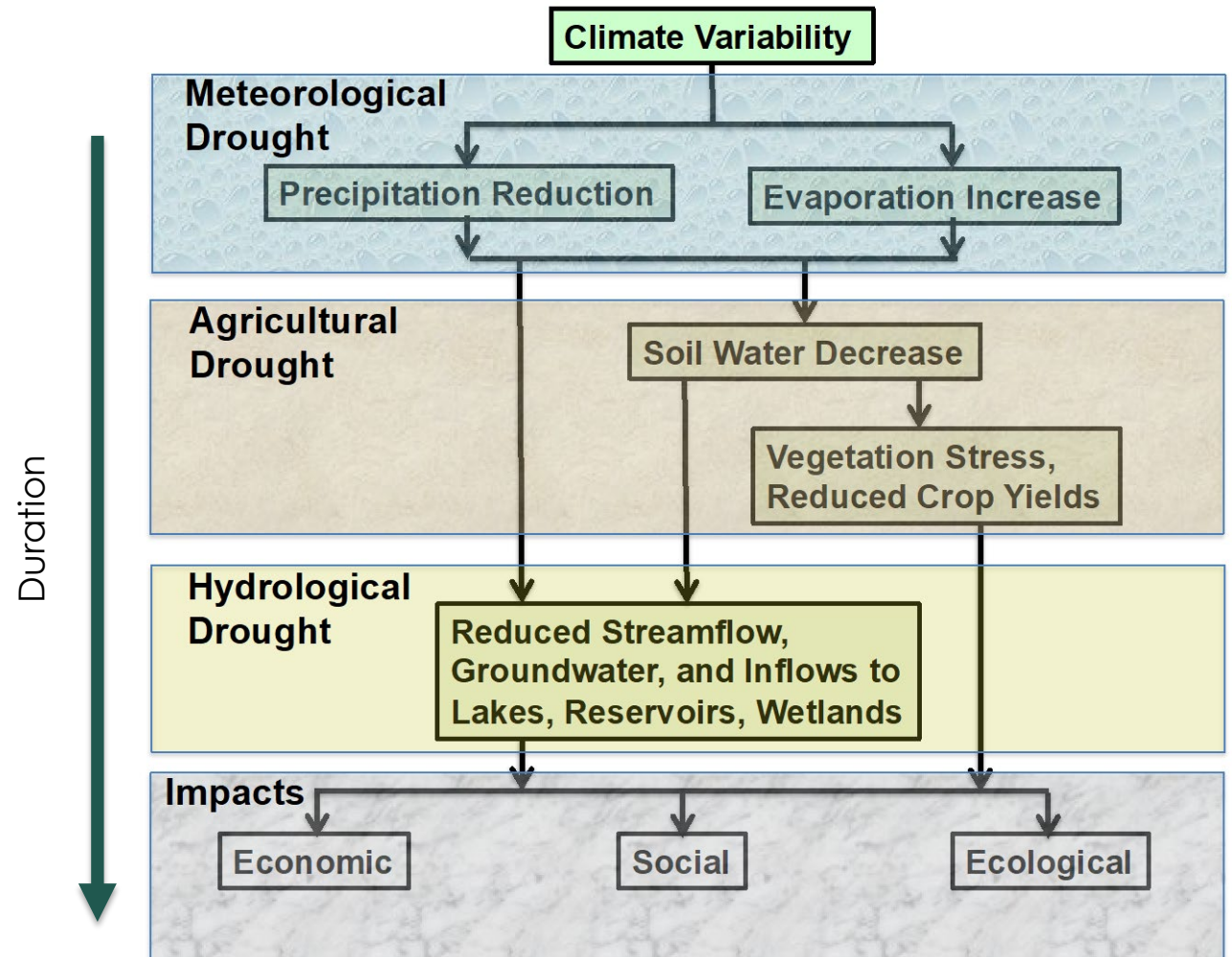


Drought

Types of Droughts

All droughts originate from “below normal” precipitation.

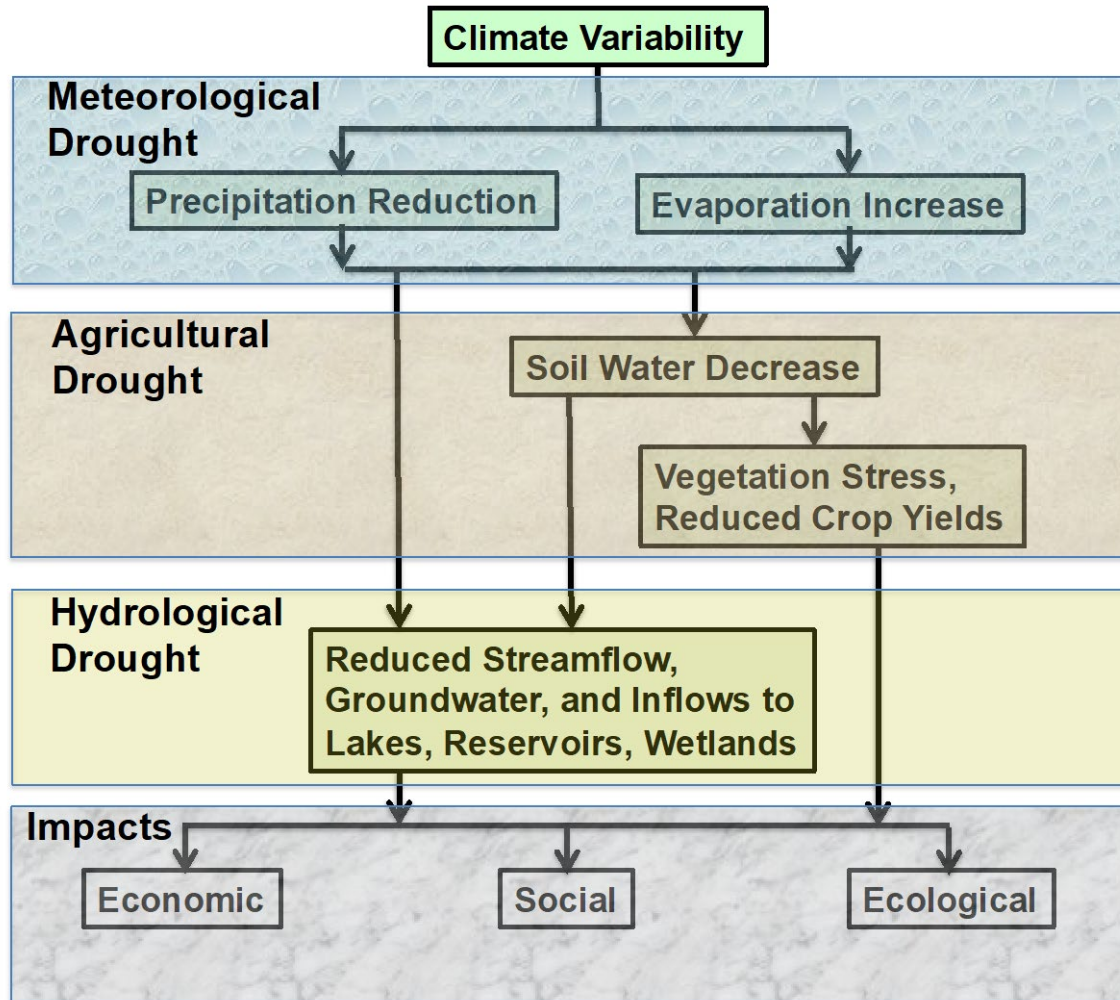
- Meteorological Drought
- Agricultural Drought
- Hydrological Drought
- Socioeconomic Drought



Wilhite, D.A.; and M.H. Glantz. 1985. Understanding the Drought Phenomenon: The Role of Definitions. *Water International* 10(3):111–120
Figure: Mehta, V.M., 2017: Natural Decadal Climate Variability: Societal Impacts. CRC Press, Boca Raton, Florida, 326 pp.



Types of Droughts



- **Meteorological Drought**
 - related to supply and demand of precipitation
 - weather systems that create precipitation shortages
 - multiple scientific and biological systems
 - social and economic changes
- **Agricultural Drought**
 - related to various conditions that affect water supply
 - precipitation shortage
 - evapotranspiration and surface water supply
 - affects agricultural drought

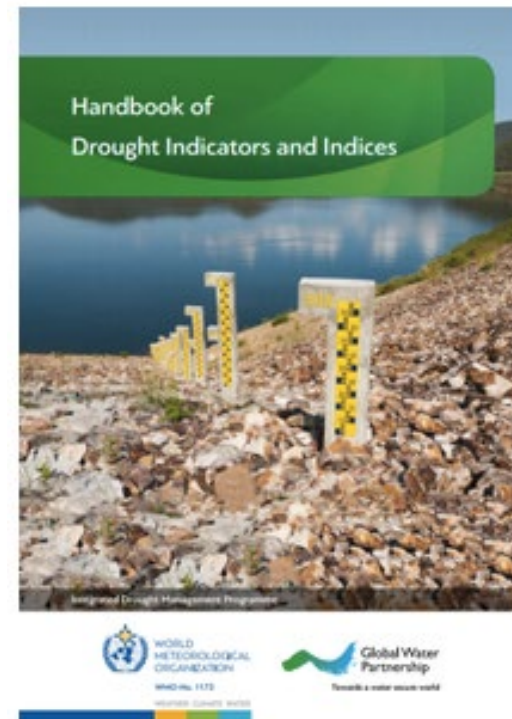


Precipitation-Based Drought Indices

- Drought indices are mathematical representations of water deficit (and excess) compared to historical data.
 - Help decide when to start implementing water conservation or drought response measures
 - Can be used to analyze drought frequency, severity, and duration for a given location and period
- Commonly used operational drought indices are:
 - Standardized Precipitation Index (SPI)
 - Palmer Drought Severity Index (PDSI)

Source: [National Drought Mitigation Center](#);

Image: [Handbook of Drought Indicators & Indices](#)



Standardized Precipitation Index (SPI)

<http://www.cpc.ncep.noaa.gov/products/Drought/Monitoring/spi.shtml>

- Primarily defined to characterize meteorological drought
- Mathematically, historical rainfall data at any location fitted with gamma distribution represent cumulative probability function
- If a rainfall event is a low probability on the cumulative probability function, it is indicative of a drought event
- The SPI values can be interpreted as the number of standard deviations by which the observed rainfall anomaly deviates from the long-term mean

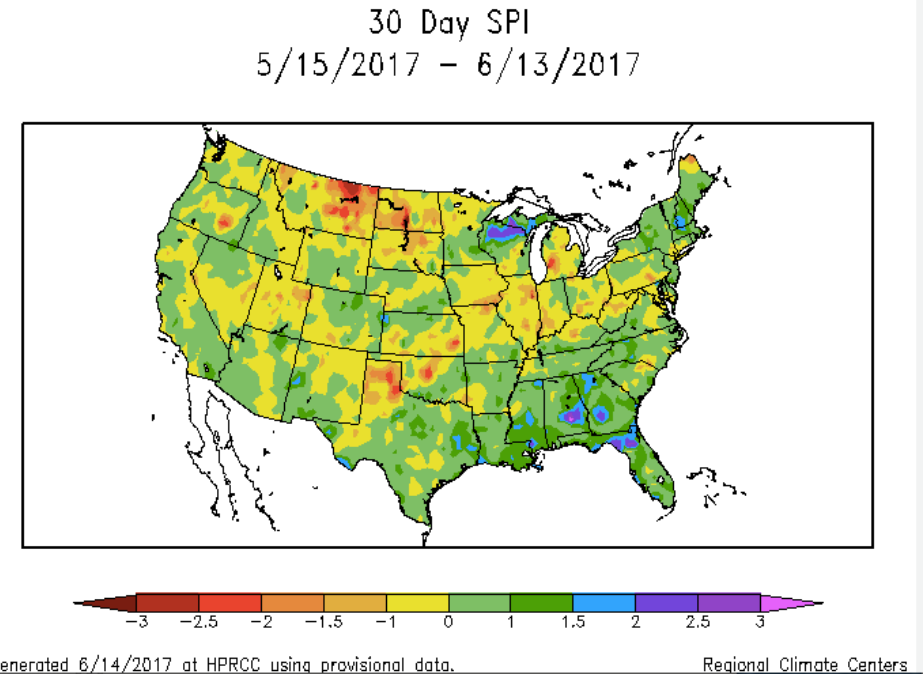


Image Credit: HPRCC ACIS Climate Map
<http://hprcc.unl.edu/maps.php?map=ACISClimateMaps#>

Text Source: [NCAR/UCAR Climate Data Guide](#)



Palmer Drought Severity Index (PDSI)

<http://climatedataguide.ucar.edu/climate-data/palmer-drought-severity-index-pdsi>

- An index for evaluating the severity and frequency of prolonged periods of abnormally dry or wet conditions
- Uses **temperature** and **precipitation** data and a physical water balance model to estimate relative dryness
- A standardized index that goes from -10 (dry) to +10 (wet)

$$PDSI(m) = PDSI\{m-1 + [Z(m)/3 - 0.103 PDSI(m-1)]\}$$

m = month index

Z(m) = moisture anomaly index (based on a water balance model)

Learn more:

http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/cdus/palmer_drought/wpdanote.shtml

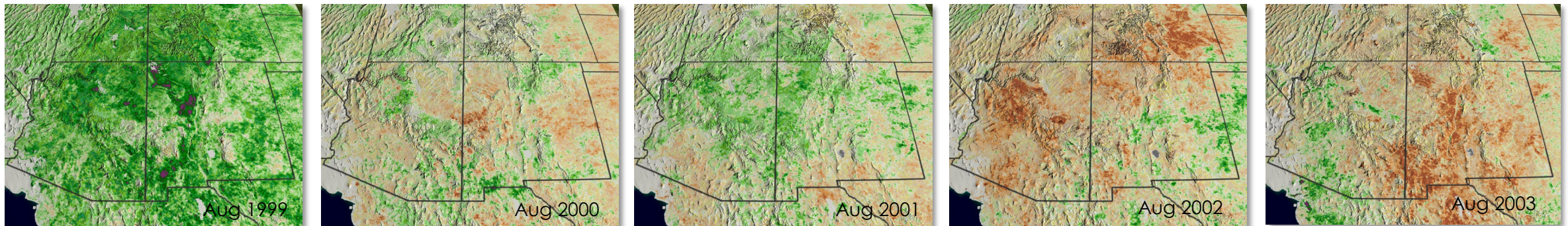
Palmer, W. C., 1965: Meteorological drought. Research Paper 45, U.S. Dept. of Commerce, 58 pp.

Dai, A., K. E. Trenberth, and T. Qian, 2004: A global data set of Palmer Drought Severity Index for 1870-2002: Relationship with soil moisture and effects of surface warming. J. Hydrometeorology, 5, 1117-1130.



NDVI Anomalies

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- Generated by subtracting the long-term mean from the current value for that month of the year for each grid cell.
- Indicates if vegetation greenness at a particular location is typical for that period or if the vegetation is more or less green



NDVI Anomalies in the southwestern United States. Image Credit: NASA/Goddard Space Flight Center Scientific Visualization Studio.



National Integrated Drought Information System (NIDIS)

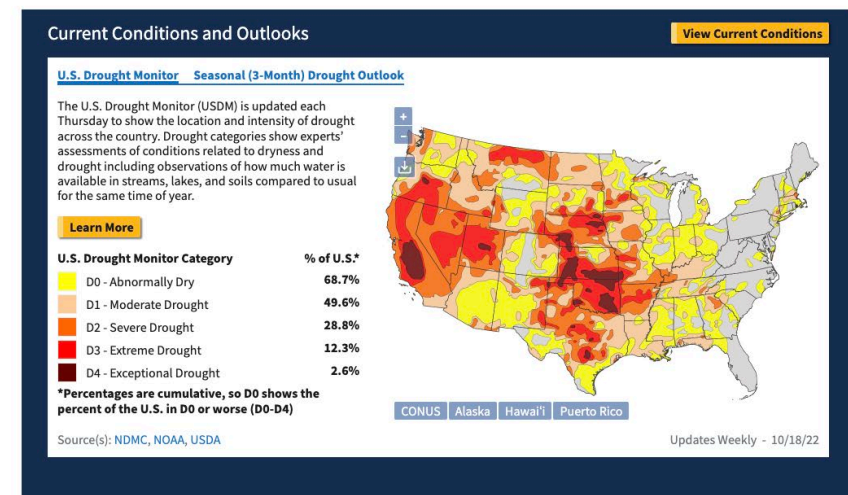
<http://www.drought.gov/>

- Multi-agency partnership that coordinates drought monitoring, forecasting, planning, and information at national, tribal, state, and local levels
- Provides a one-stop shop for data, decision-support products, resources, and information on drought—from drought monitoring and prediction, to planning and preparedness, to applied research.
- Local drought information down to the city and county level
- Interactive, easily shareable maps & data

How is drought affecting your neighborhood?

Advancing Drought Science and Preparedness Across the Nation

The National Integrated Drought Information System (NIDIS) is a multi-agency partnership that coordinates drought monitoring, forecasting, planning, and information at national, tribal, state, and local levels.



Climate Engine

<https://climateengine.com/>

- Partnership between the Desert Research Institute, University of Idaho, and Google that started through a Google Faculty Research award White House Climate Initiative.
- Climate Engine enables users to quickly process and visualize satellite Earth observations and gridded weather data for environmental monitoring and to improve early warning of drought, wildfire, and crop-failure risk.
- Instead of processing entire archives, focus on data discovery and answers.

Climate Engine® Solutions Data Resilience + Google PARTNERSHIPS

From Science to Finance:

Earth Insights for Economic Resilience

Data driven insights to support financial and operational resilience for a changing planet

01 Solutions
Transform your organization by leveraging insights generated from satellite data

02 Data
Integrate climate and environmental information into your decision making

03 Resilience + Google
Learn how Climate Engine + Google build financial and operational resilience





Demo: Climate Engine



Hands-on – Climate Engine



Flooding

Remote Sensing-Based Flood Detection

There are several approaches to using remote sensing observations for flood monitoring:

- Detecting flood water on previously dry land surfaces using satellite-derived land cover observations
- Hydrology models that derive streamflow and runoff using precipitation and weather data from satellites and models
- Inferring flooding conditions using satellite-derived precipitation rate and amount, and soil moisture conditions using statistical methodology

Note: Each flooding approach also uses model and/or surface-based data in addition to satellite data.



Remote Sensing-Based Flood Detection

There are several approaches to using remote sensing observations for flood monitoring:

- **Detecting flood water on previously dry land surfaces using satellite-derived land cover observations**
- Hydrology models that derive streamflow and runoff using precipitation and weather data from satellites and models
- Inferring flooding conditions using satellite-derived precipitation rate and amount, and soil moisture conditions using statistical methodology

Based on this approach multi-year time series of flood maps are available from:

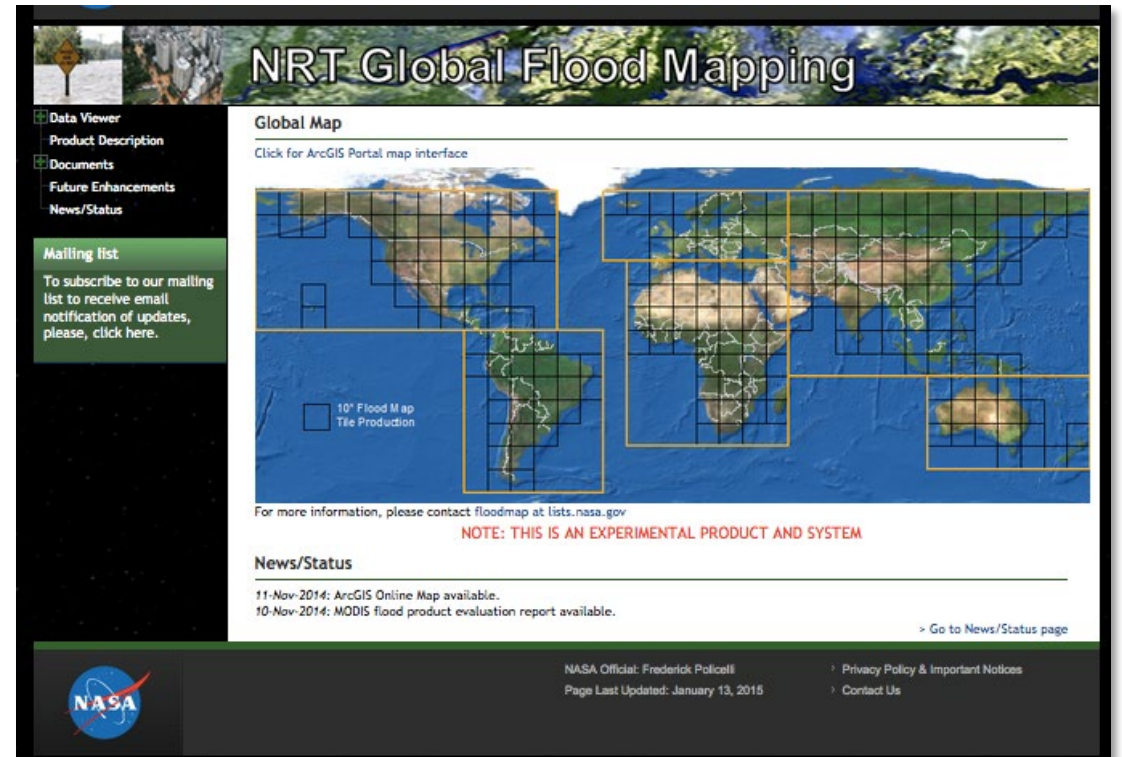
- **Aqua and Terra MODIS (2013 to present)**
- **Sentinel-1 SAR (2014 to present)**



MODIS Global Flood Mapping Web-Tool (2013–2021)

<https://floodmap.modaps.eosdis.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 and archived flood mapping from 2013–2021.



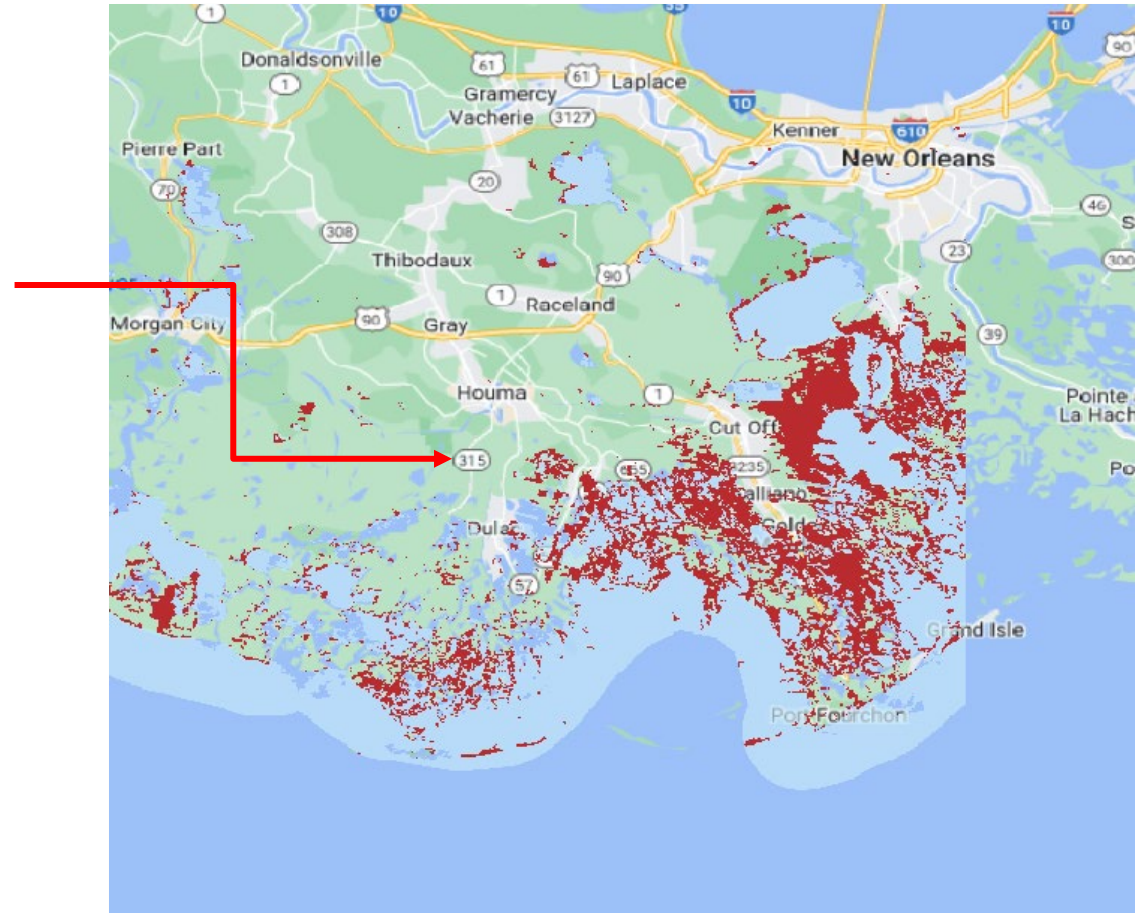
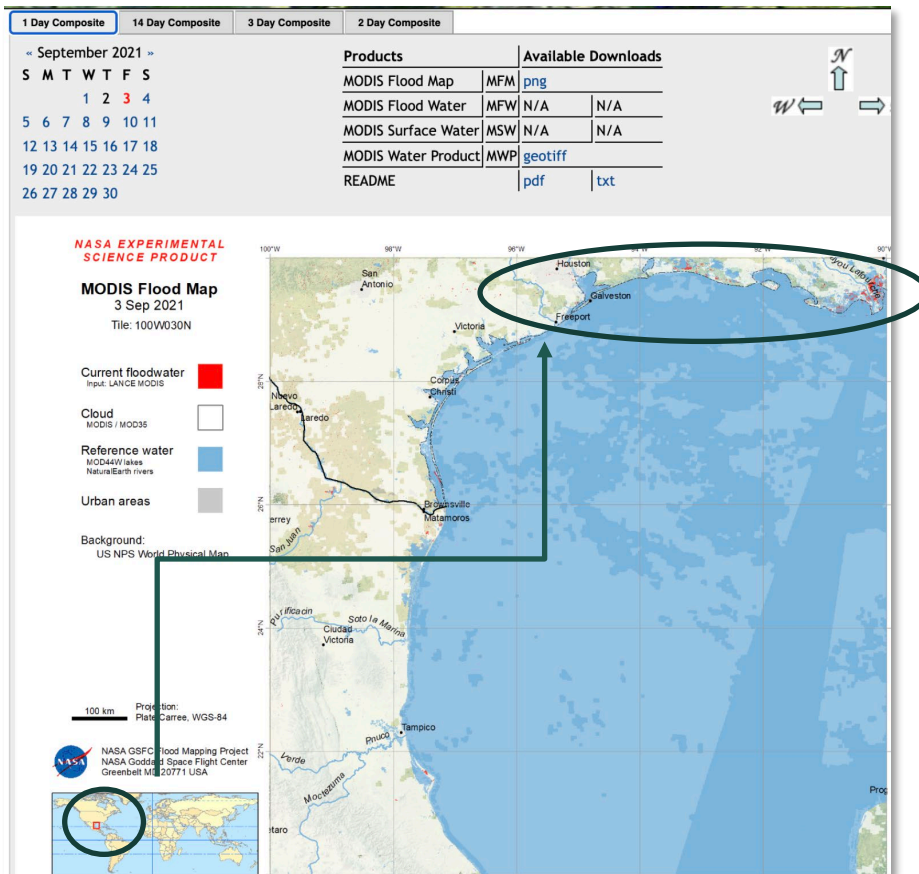
<https://earthobservatory.nasa.gov/images/88624/flooding-on-the-ganges-river>



MODIS Global Flood Mapping (2013–2021)

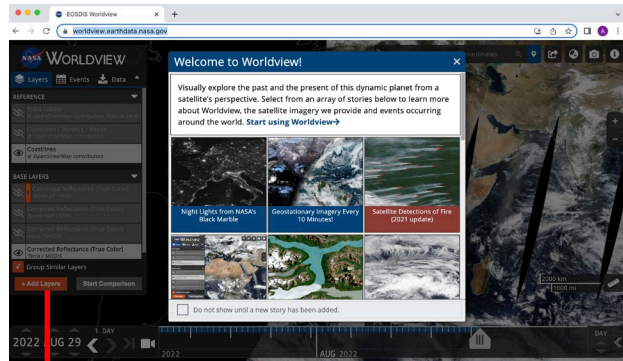
<https://floodmap.modaps.eosdis.nasa.gov/readme.php>

Flooding due to Hurricane Ida (3 September 2021)

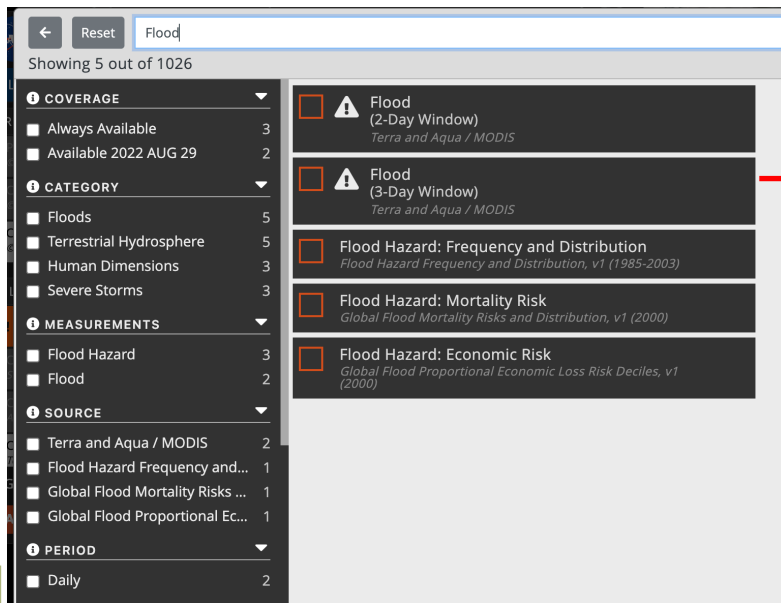
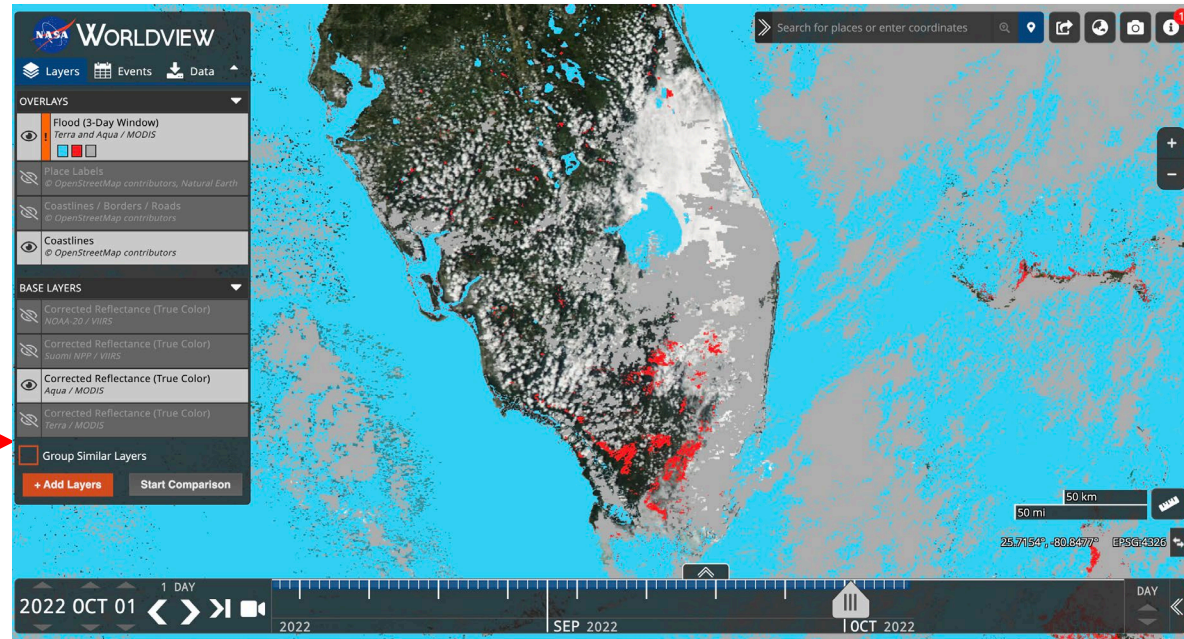


NASA Worldview (2022)

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



3-Day Composite Flooding from MODIS Flooding due to Hurricane Ian



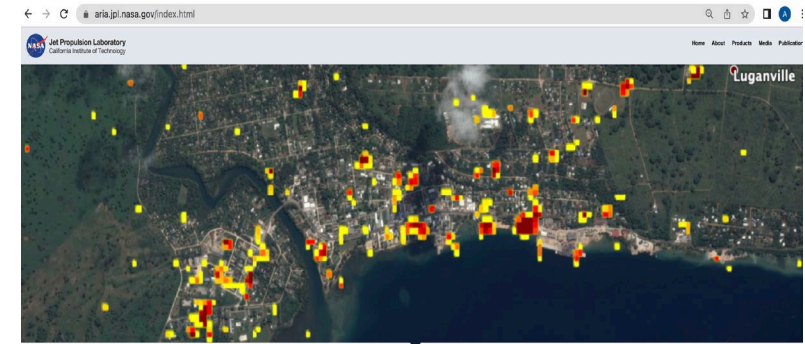
Replacing the MODIS NRT Flood Map Portal
<https://floodmap.modaps.eosdis.nasa.gov/>



ARIA

<https://aria.jpl.nasa.gov/index.html>

- A collaboration between JPL and Caltech to exploit radar and optical remote sensing, GPS, and seismic observations for hazard science and response.
- ARIA investigates the processes and impacts of multiple natural hazards.
- Primarily focused on ground deformation change measurements, also include flood damage proxy maps.



Products

Overview

Below is a schematic showing what Level 2 (L2) and Level 3 (L3) data sets are available. Available products are in blue, and clicking on them will take you to additional information about the product specifications and background.

	Science Products		Urgent Response Products
Product	InSAR	GPS	SAR
Level 2	Standard Displacement Products	PS Time-Series	
Level 3	Time Series		Damage Proxy Maps (DPM)
	Coseismic	GPS Coseismic Offsets	Flood Proxy Maps (FPM)



ARIA Flood List (2014 to Present)

<https://aria-share.jpl.nasa.gov/>

Jet Propulsion Laboratory
California Institute of Technology

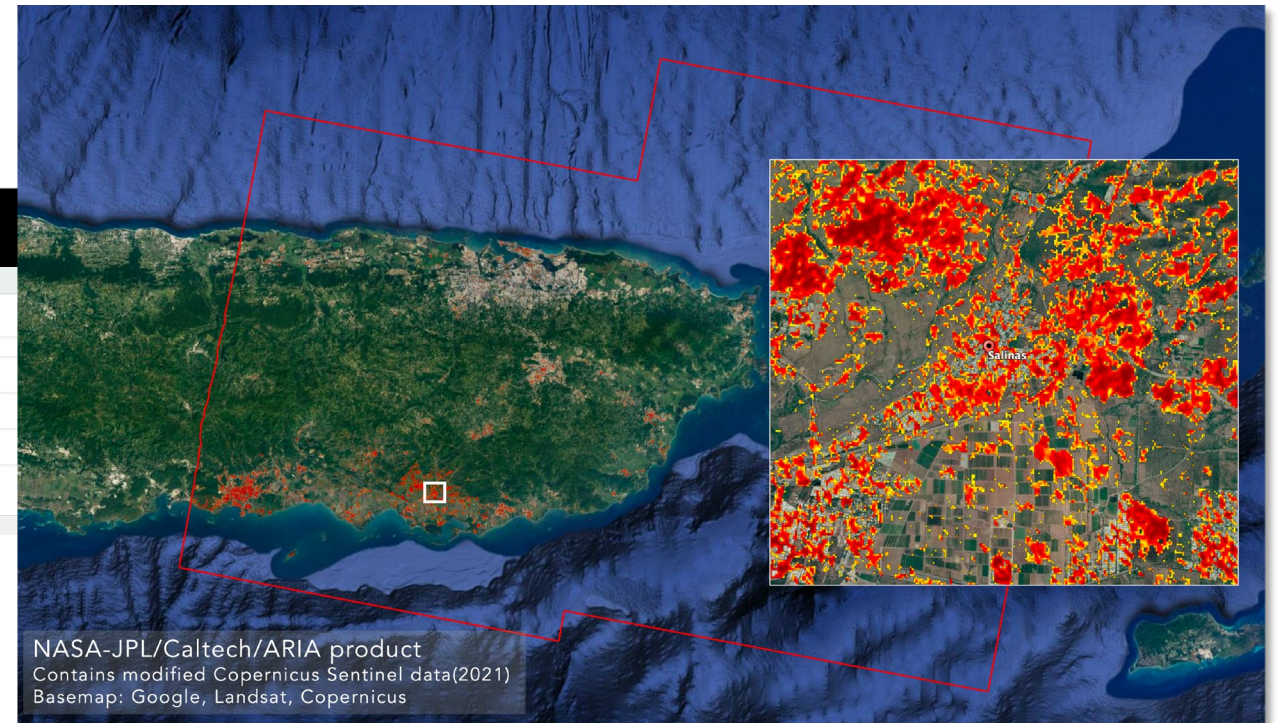
ARIA Share

Location: /
Name *
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20140512-galileo_guardian/ EQ
20140814-wash_watf/ EQ
20150425-Neqal_EQ/ EQ
20150910-Himal_Citic_EQ/ EQ
20151004-Bermuda_Hurricane_Isaquin/ EQ
20160111-US_Midwest_Flood/ EQ
20160414-Kyushu_EQ/ EQ
20160415-Kyushu_EQ/ EQ
20160607-Cambodia_Bong/ EQ
20160816-Luxemburg_Flood/ EQ
20160816-Dan_EQ/ EQ
20161026-Iraq_EQ/ EQ
20161030-Dan_EQ/ EQ
20161113-Netherlands_EQ/ EQ
20170107-Mexico_Flood/ EQ
201708-Hurricane_Irene/ EQ
201709-Hurricane_Sirma/ EQ
201709-Hurricane_Maria/ EQ
20170906-Quebec_Chicago_Mexico_EQ/ EQ
20170919-ITF_1_Rakos_Mexico_EQ/ EQ
20171004-NorCal_Fire/ EQ
20171210-SocCal_Fire/ EQ
201801-Tonga_Cyclone_Gita/ EQ
20180504-Hurricane_Michael-eruption-EQ/ EQ
20180603-Puerto_Rico/ EQ
20180605-Lombok_Indonesia_EQ/ EQ
201809-Hurricane_Florence/ EQ
20180905-Hokkaido_EQ/ EQ
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20180920-Suawesi_EQ/ EQ
201810-Hurricane_Thomas/ EQ
201810-Super_Typhoon_Yutu/ EQ
201811-Camp_Fire/ EQ
201811-Wildfire_Fire/ EQ
20181118-Archangel_Maska_EQ/ EQ
2018-07-Alaska_Fire/ EQ
201903-Cyclone_Sai/ EQ
201904-Cyclone_Kammit/ EQ
201904-Lahar_Batavia/ EQ
201904-Quake_Flood/ EQ
201906-Tripoli_Flood/ EQ
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201910-Army_Fire/ EQ
201910-Typhoon_Hagibis_Japan/ EQ
20191008-Philippines_EQ/ EQ
20191124-Alabama_EQ/ EQ
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20200203-Hawaii_Tornado/ EQ
20200318-Magna_EQ/ EQ
20200312-Tripoli_EQ/ EQ
20200410-Cyclone_Harold_Fiji/ EQ
20200520-Madani_Dam_Break_Flood/ EQ
20200623-Oman_Floods_EQ/ EQ
202007-Tropical_Storm_Sales_Dominican_Republic/ EQ
20200804-Brazil_Brazil/ EQ
202009-Robot_Fire/ EQ
202009-Creek_Fire/ EQ
20200903-California_LML_Lighting_Complex_Fire/ EQ
202009-Hurricane_Laura_EOS_ARIA-SG/ EQ
20201010-Spanish_Island_EQ/ EQ
202011-Hurricane_Eta/ EQ
202011-Hurricane_Sofia/ EQ
202012-Cyclone_Yani/ EQ
202103-Australia_Flood/ EQ
20210403-Lithuania_Milano/ EQ
20210710-Hurricane_Patsy_EQ/ EQ
20210814-Haiti_EQ/ EQ
20210829-Hurricane_Ipsa_USA/ EQ
20210907-Australia_EQ/ EQ
20210915-Lithuania_Vilnius/ EQ
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20220918-Hurricane_Puerto_Rico/ EQ

home up refresh

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ARIA_DPMraw_Sentinel-1_D25_20220919.tif

Hurricane Ian Flooding, Puerto Rico



The Flood Observatory (DFO River Watch: 1998–Present)

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

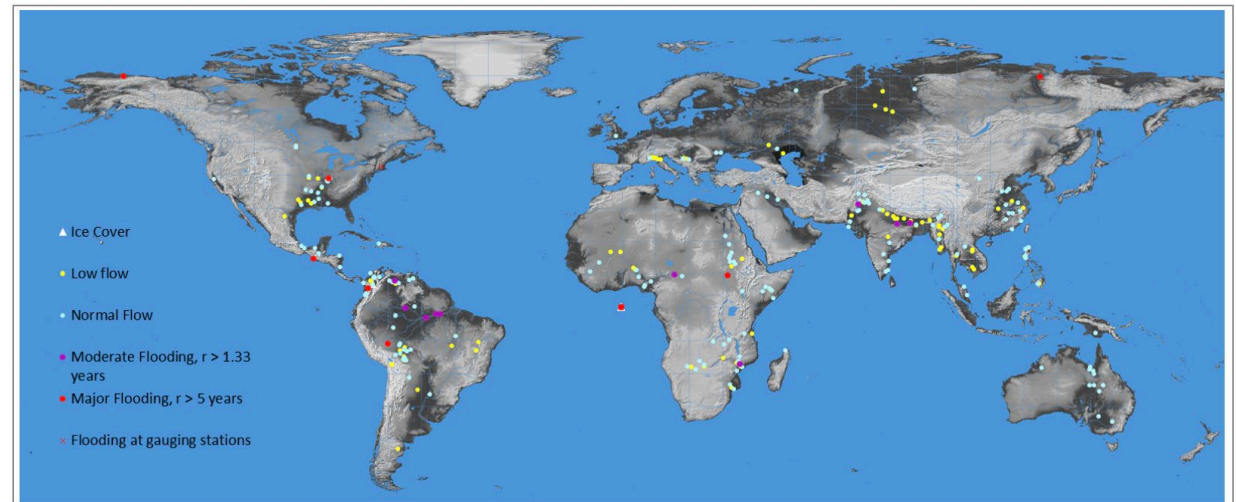
- Based on passive microwave observations from TRMM/GPM and river gauge measurements.
- Currently, a new version and validation of river discharge methodology is underway.
- Provides river discharge and monthly and annual runoff time series.

River and Reservoir Watch (Under revision to Version 4.5)

DFO's River and Reservoir Watch provides experimental, fully-automated satellite-based river discharge and reservoir area measurements. Only Version 4.5 has been fully validated to specified error limits.

Twice-daily updates at 2:30 and 14:30 Local Denver Time

See sample [Movie of this Display](#).

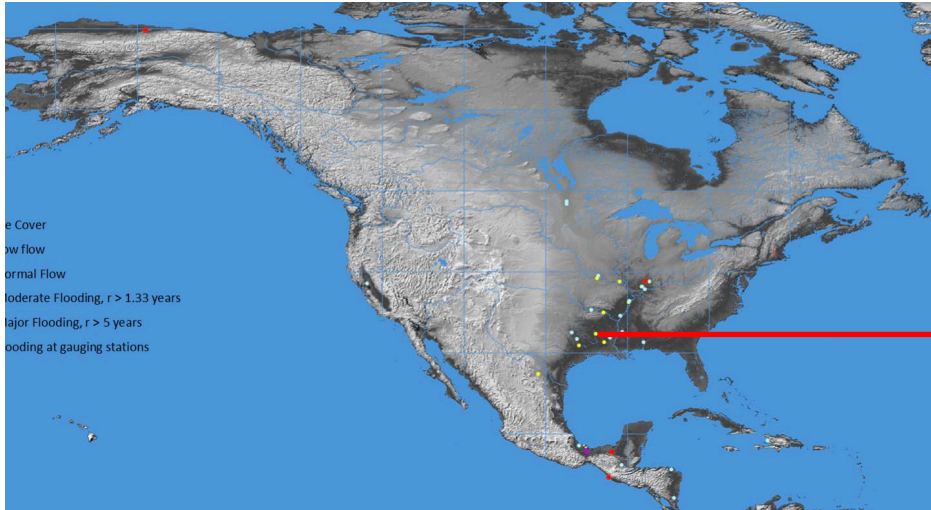


<https://floodobservatory.colorado.edu/DischargeAccess.html>



The Flood Observatory (DFO River Watch: 1998 – Present)

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



Arkansas River Watch

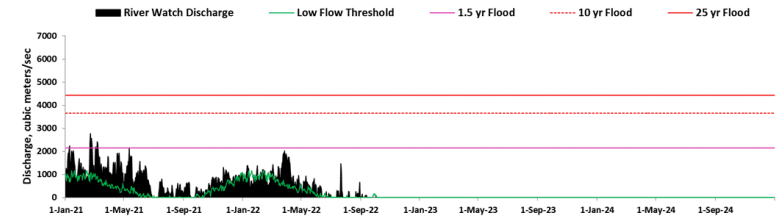
River and Reservoir Watch Version 4.5

River Discharge and Reservoir Storage Changes Using Satellite Microwave Radiometry

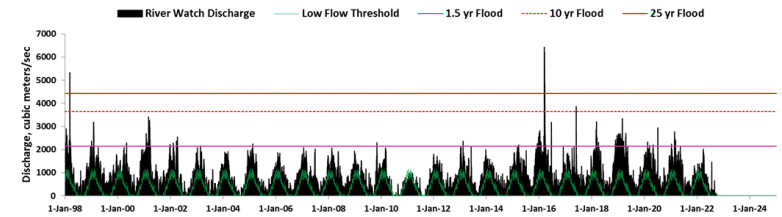
GFDS Area ID: 443
[GEE Time Series](#)
Last measured: 6-Oct-22
 Discharge: 0 m³/sec
 7-day Runoff: 0.0 mm
 Flood Magnitude: 0.0 Scale of 0-10

Arkansas USA
 Center: -93.599 Long. 32.399 Lat. 162786
 Signal/Noise: 7.0 Fair
 sq km WBM contributing area

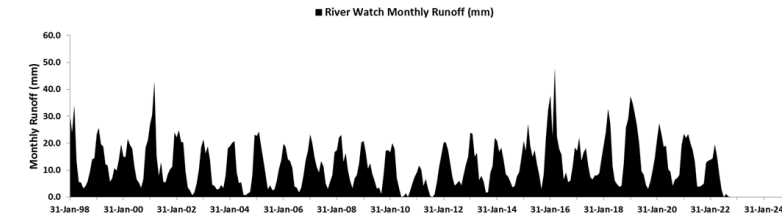
Status: 1 (1, low; 2, normal flow; 3, moderate flood; r > 1.5 y; 4, major flood; r > 5 y)
 (7-day runoff compared to 20 y average for this date, 2002-2021)
[Flood Magnitude Defined](#) [Technical Summary](#)



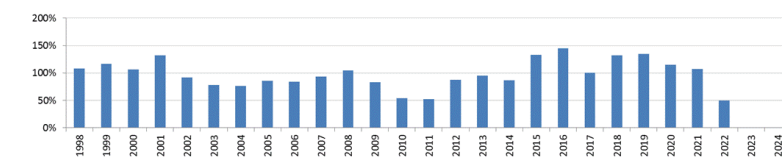
Notes: 7-day forward weighted moving average is applied. Geolocation correction, commencing April 1, 2012: 0
 Low flow is 20th percentile discharge for this day, 2003-2013.



[Log Pearson III computes recurrence intervals from 22 years of record \(1998-2019\)](#) Change in 10 yr flood discharge (2010-2021 / 1998-2009): 118.8%



Annual Runoff (percent of mean, 1998-2021)
 Mean discharge: 783 m³/s
 Mean Runoff: 152 mm

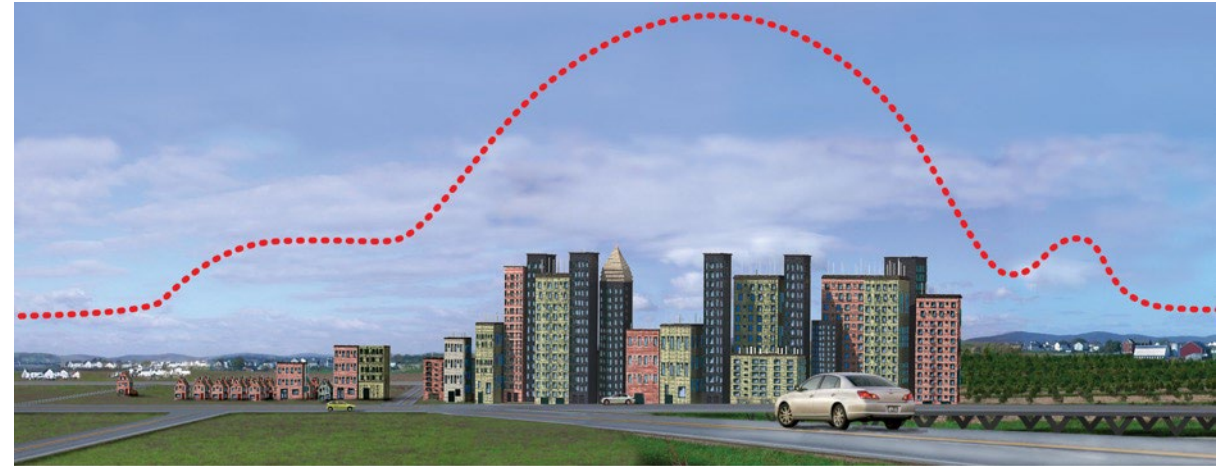




Urban Heat Islands

Urban Heat Islands

- Urban areas experience higher temperatures than outlying areas. This difference in temperature is what constitutes an urban heat island (UHI).
- Difference in temperature has to do with changes in radiative and thermal properties of impervious surfaces (i.e., heat-absorbing buildings and pavement).
- Temperatures vary within cities due to the spatial distribution of water, soil, vegetation, and impervious surfaces.

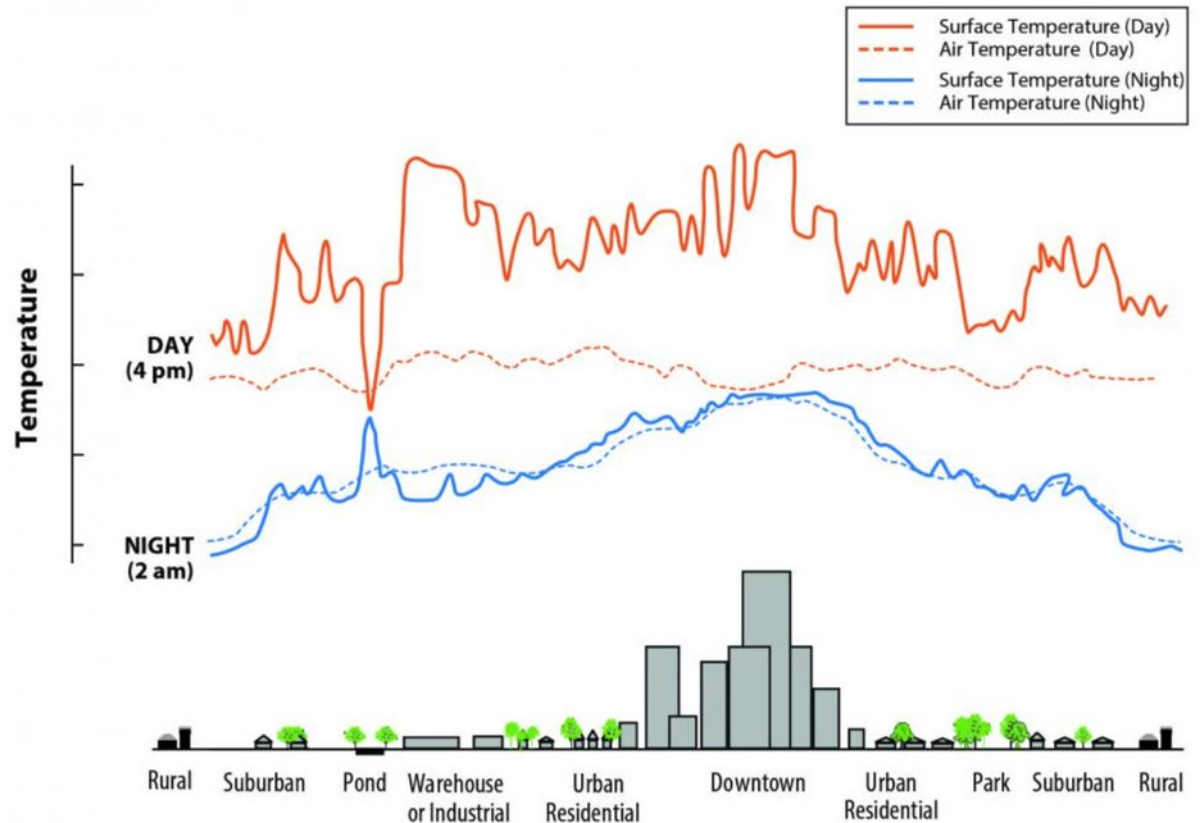


Land surface temperatures in cities, particularly densely-developed cities, tend to be elevated in comparison to surrounding areas. Credit: [NASA](#)



Urban Heat Islands

- Urban heat islands can form during the day or night, in small or large cities, and in any season.
- There are two types of urban heat islands:
 - Surface Urban Heat Islands
 - Atmospheric (i.e., air) Urban Heat Islands
- Surface temperatures vary more than air temperatures during the day, but they are generally similar at night.

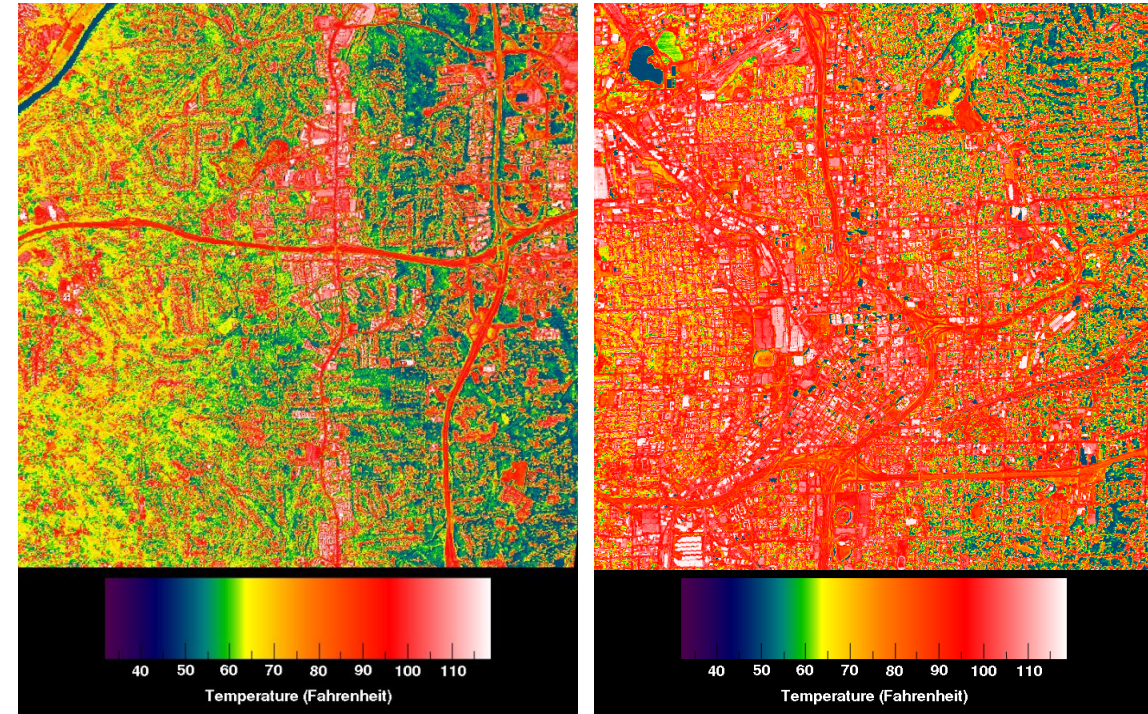


Parks, open land, and bodies of water can create cooler areas within a city. Temperatures are typically lower at suburban-rural borders than in downtown areas. Credit: [EPA](#)



Surface Urban Heat Islands

- Surface Urban Heat Islands (SUHI) represent the radiative temperature difference between impervious and natural surfaces.
 - SUHIs tend to be most intense during the day when the sun is shining.
 - Magnitude varies with seasons, but it is typically largest in the summer.
 - SUHIs are primarily measured by remote sensing in the thermal infrared (TIR) region of the electromagnetic (EM) spectrum.



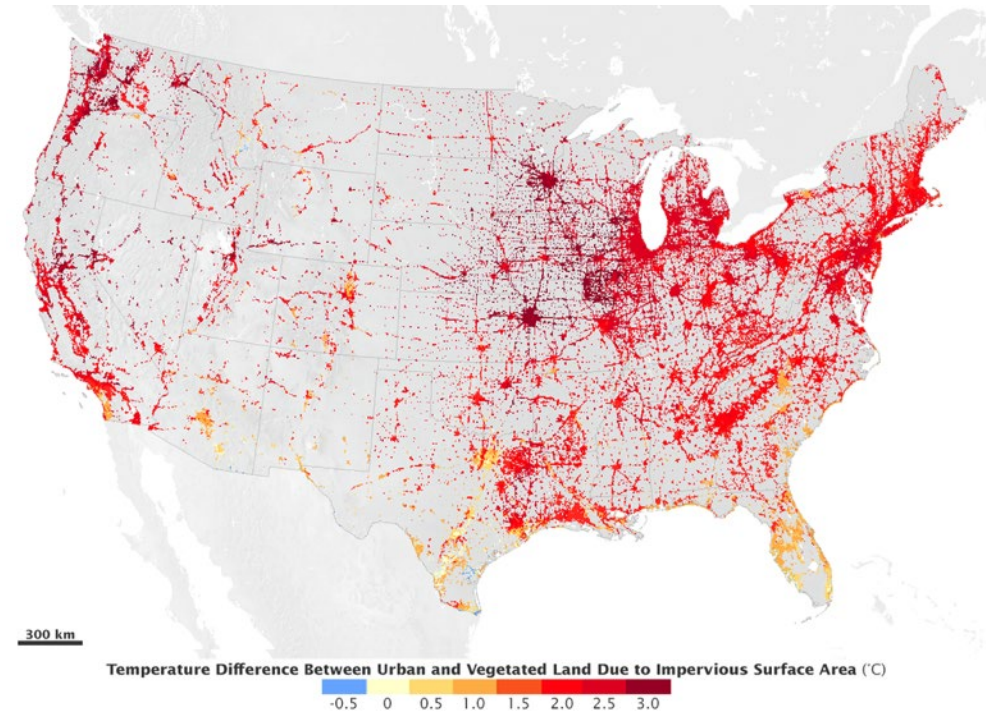
Satellite imagery of suburban (left) and urban (right) Atlanta, Georgia (USA) shows the differences in daytime heating, as caused by the urban heat island effect.

Credit: [NASA Goddard Scientific Visualization Studio](#)



Monitoring Urban Heat Islands – SUHI

- Satellite thermal remote sensing measures SUHI and provides consistent and repeatable observations of the Earth's surface.
- Remote sensing offers the ability to study the urban thermal environment at various spatial (from local to global) and temporal (diurnal, seasonal, and inter-annual) scales (Weng, 2009).



Credit: [NASA](#)



Monitoring Urban Heat Islands – SUHI

- Surface Urban Heat Islands (SUHI) represent the difference of land surface temperature (LST) in urban relative to non-urban areas, as well as “hot spots” within urban areas, and are usually measured using satellite data.

$$\Delta T_{U-r} = T_U - T_r$$

- where ΔT_{U-r} is UHI intensity, T_U is urban temperature and T_r is rural temperature.
- The intensity of the heat island is the simplest quantitative indicator of the thermal modification imposed by urban relative to non-urban areas.

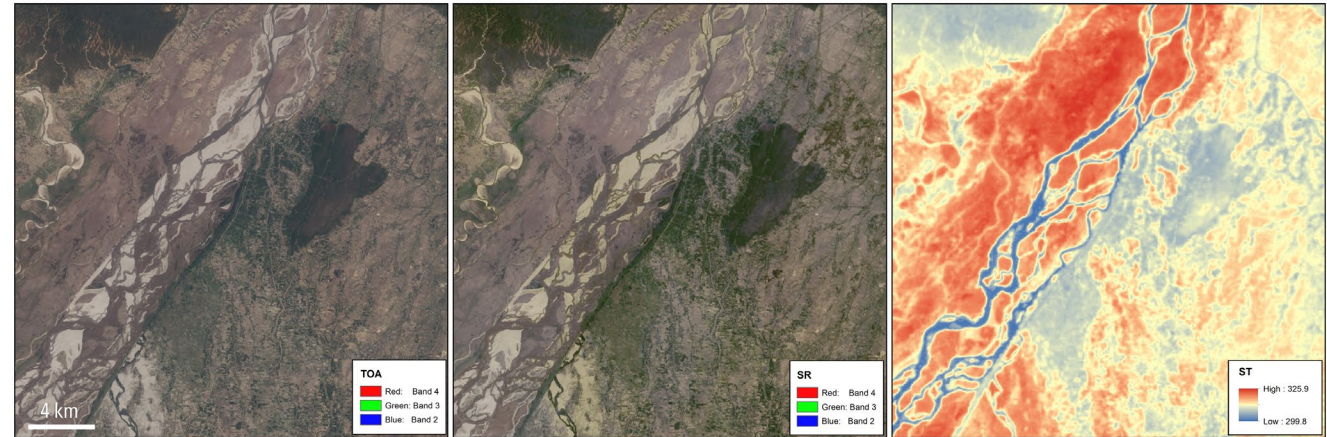


Landsat Collection 2

Second major reprocessing effort of the Landsat archive

- Global Level-2 Science and Atmospheric Auxiliary Products:
 - Surface Reflectance
 - **Surface Temperature**
- Improved Geometric Accuracy
- Improved Digital Elevation Modeling
- Improved Radiometric Calibration
- Consistent Quality Assessment Bands
- Updated and Consistent Metadata Files
- Cloud Optimized File Format

<https://www.usgs.gov/landsat-missions/landsat-collection-2>



Left: Landsat 8 Collection 2 level-1 top of atmosphere reflectance image, Center: Landsat 8 Collection 2 level-2 atmospherically corrected surface reflectance image, and Right: Landsat 8 Collection 2 level-2 surface temperature image for an area over the Sapta Koshi River in Bairawa, Nepal acquired on May 3, 2013. Credit: [USGS](https://www.usgs.gov/)



Landsat Collection 2 – Surface Temperature

- Measures the Earth's surface temperature in Kelvin
- Useful for monitoring:
 - Crop and vegetation health
 - Heat waves
 - Natural disasters (e.g., volcanic eruptions, wildfires)
 - **Urban heat island effects**
- Product availability:
 - Landsat 9: February 2022 to present
 - Landsat 8: April 2013 to present
 - Landsat 7: July 1999 to April 2022
 - Landsat 5: March 1984 to May 2012
 - Landsat 4 : August 1982 to December 1993



Land surface temperature for Providence, Rhode Island (USA) collected by Landsat ETM+ on July 31, 2002. The highest temperatures are shown in yellow, while cool temperatures are shown in deep purple. Credit: [NASA](#)



Limitations of Satellite Remote Sensing for Urban Heat Islands

- Data acquisition times of sun-synchronous satellites usually do not coincide with the time of day where the SUHI is at a minimum or maximum.
- Most widely used satellite for SUHI detection (i.e., Landsat) only has daytime data.
- Optical sensors cannot penetrate clouds or vegetative cover, which can lead to data gaps or a decrease in data utility.
- The accuracy of land surface temperature (LST) estimates depends strongly on corrections for atmospheric effects and an accurate estimate of surface emissivity.
- Radiances received by sensors are influenced by the sensor-viewing angle.
- It is difficult to obtain high spectral, spatial, and temporal resolution with the same instrument.
- A large amount of data exists in various spatial and temporal resolutions, file formats, sizes, and from multiple sources.



Computing Land Surface Temperature in GEE

Below are 3 scripts for assessing urban heat islands using satellite data.

- **Landsat_LST_Time_Series_Pixel.js**

- Example code showing how to graph a **LST time series** from Landsat 8 & 9
- <https://code.earthengine.google.com/2eae305edb229ae171391b341094fa81>

- **Landsat_LST_SUHI.js**

- Example code showing how to process **Landsat-derived SUHI** over Washington, DC (USA)
- <https://code.earthengine.google.com/8f8a363aa18fa9d16c1fe84991aa4154>

- **MODIS_LST_Day_Night.js**

- Example code showing how to process **MODIS-derived SUHI** for **day** and **night** over Washington, DC (USA)
- <https://code.earthengine.google.com/63c37316806efa35321f7e8651429bb2>



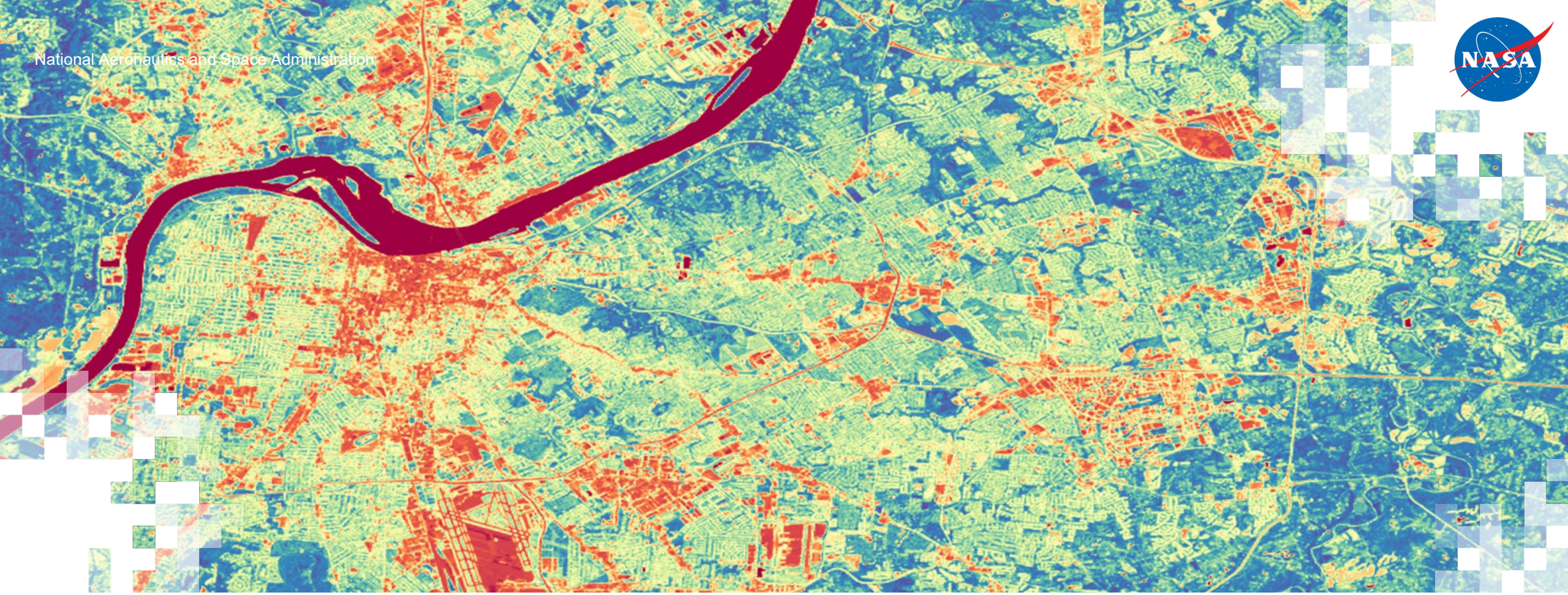
Computing Land Surface Temperature in GEE

- To modify the different scripts for your study area, users will need to change the following parameters:

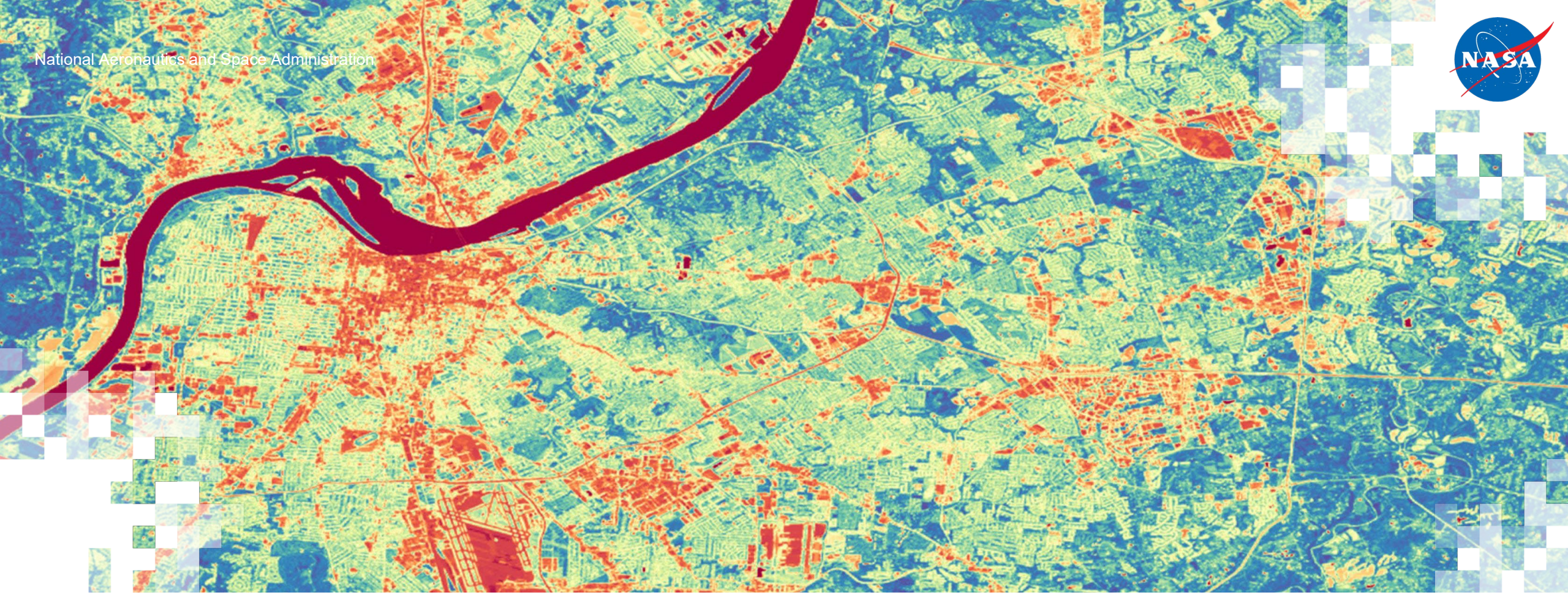
- DATE_RANGE
- YEAR_RANGE
- STUDYBOUNDS
- DISPLAY
- point: Longitude/Latitude for area of interest
- aoi: Delineated rectangle for area of interest
- Rural: Delineated polygon(s) for rural areas
- Urban: Delineated polygon(s) for urban areas

```
// Assign a variable to filter the day of year from July 1 t
// Adjust the DATE_RANGE for your own UHI study.
var DATE_RANGE = ee.Filter.dayOfYear(182, 243);
// Assign a variable to filter years from 2010 – 2022.
// Adjust the YEAR_RANGE for your own UHI study.
var YEAR_RANGE = ee.Filter.calendarRange(2010, 2022, 'year');
// Assign a variable to delineate your area of interest
// Create your own aoi using the Geometry tools in the map w
var STUDYBOUNDS = aoi;
// Assign a variable to display images in the map window
var DISPLAY = true;
```





Demo – Measuring Land Surface Temperature from Landsat



Hands On – Measuring Land Surface Temperature from Landsat



Wildfires & Smoke

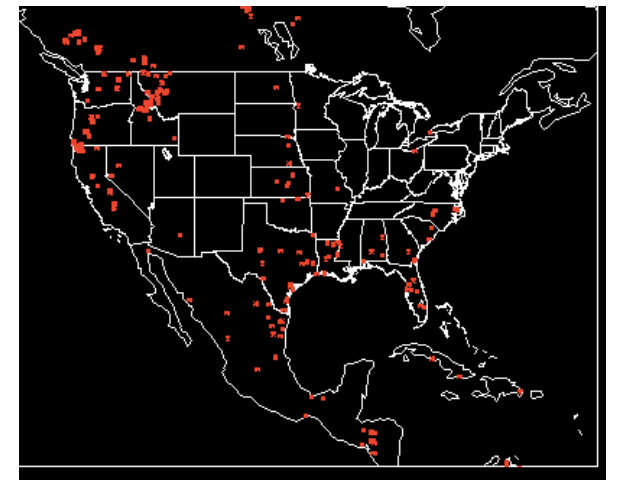
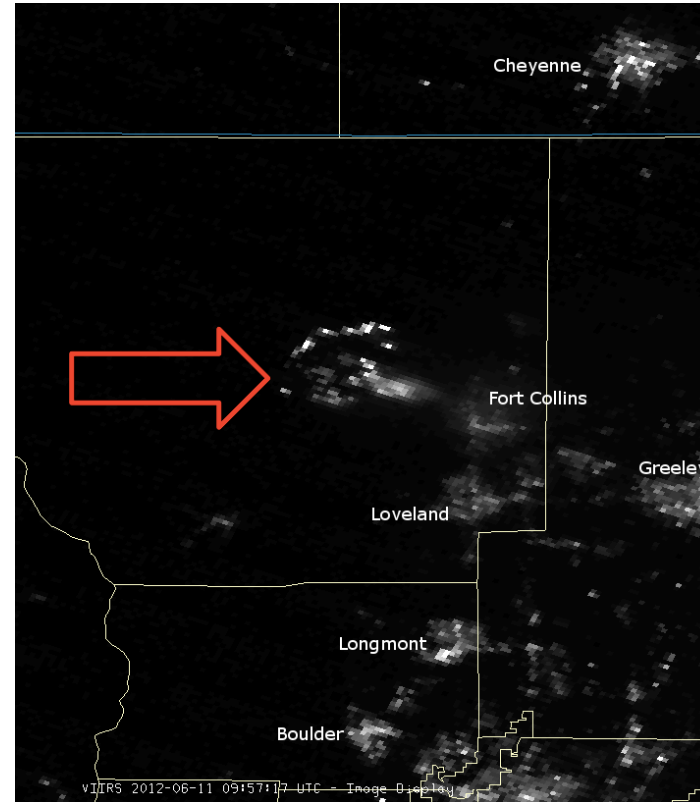


Fire Detection

Fire Detection From Satellites

Can be accomplished by detecting:

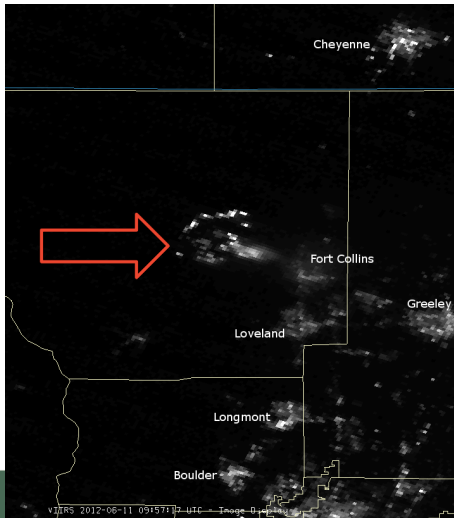
- Smoke
- Temperature Anomalies
- Light



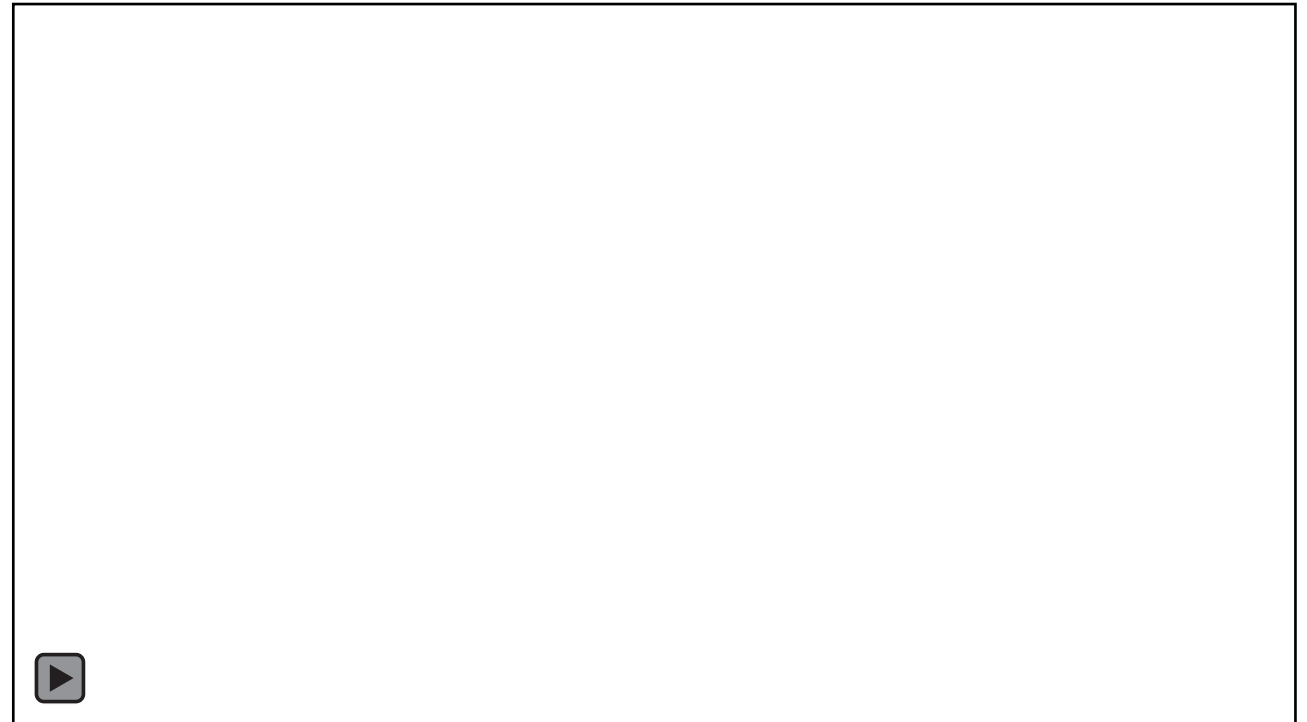
Fire Detection From Satellites

Can be accomplished by detecting:

- Temperature Anomalies
- Smoke
- Light



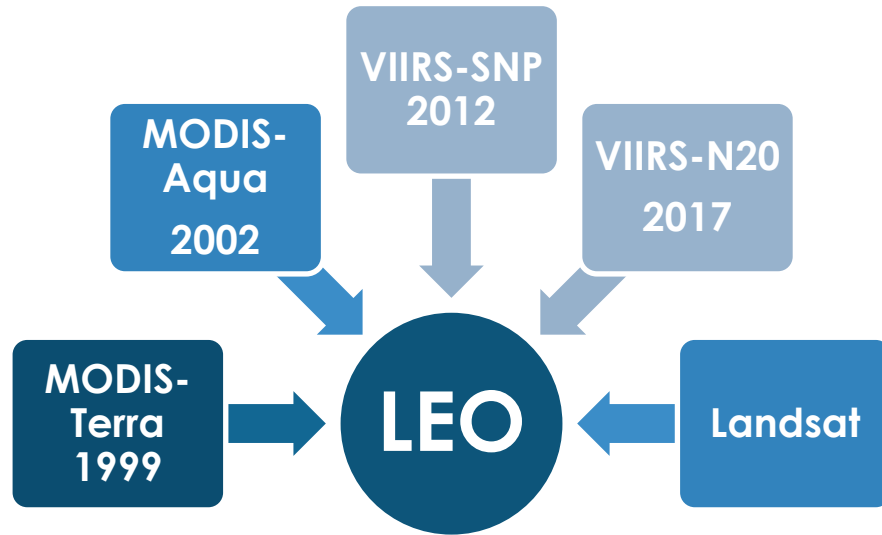
VIIRS-SNPP Fire Detections, January – September 2021



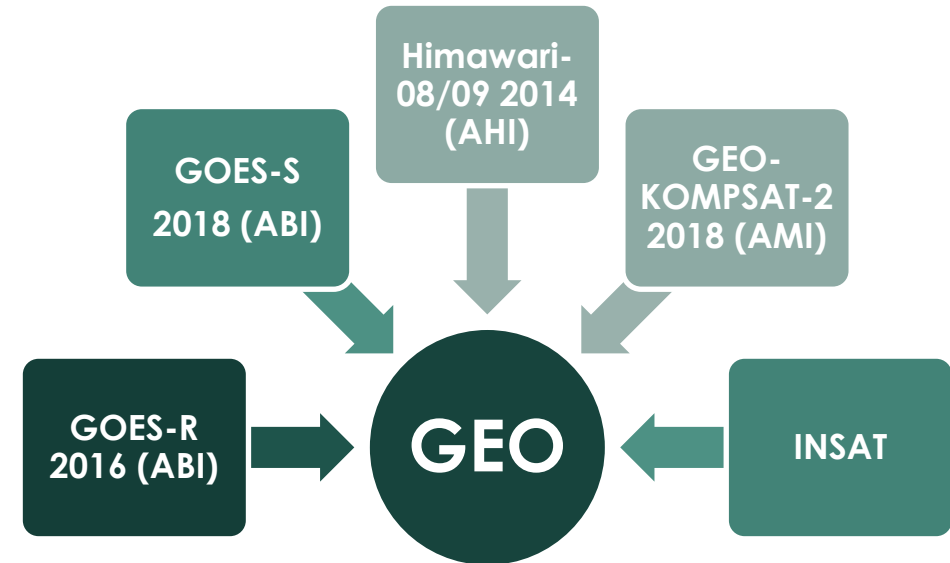
<https://svs.gsfc.nasa.gov/4945>



Satellites and Sensors for Fire and Smoke Detection



Global Coverage, typically twice per 24 hours



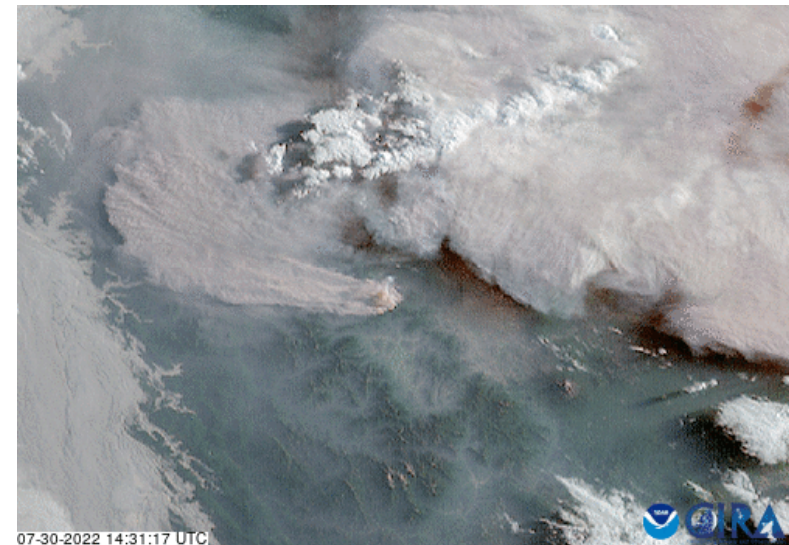
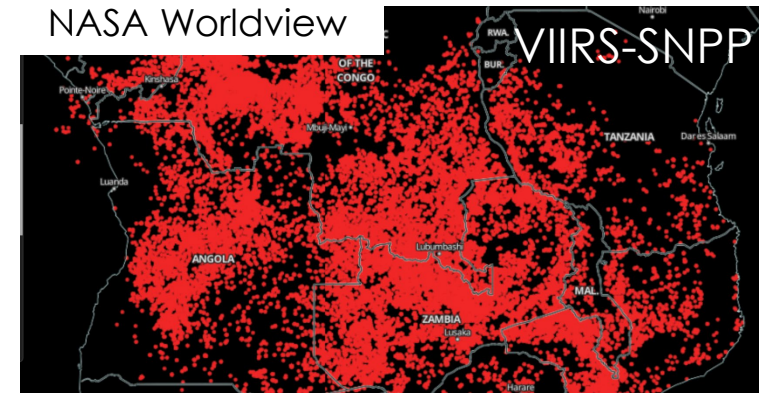
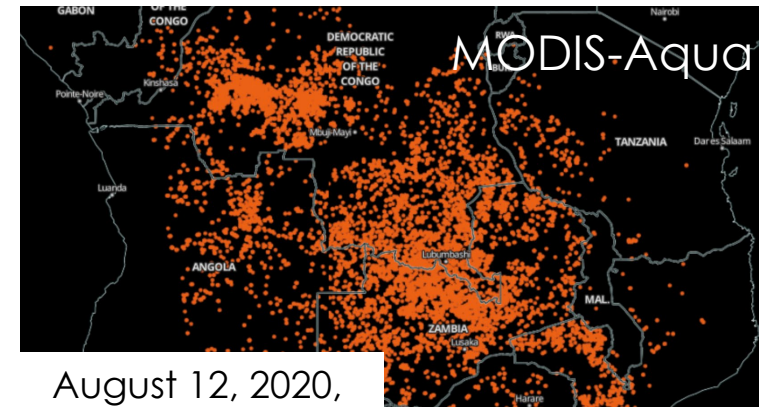
Regional Coverage, minutes to hours

LEO – Low Earth Orbit
GEO – Geostationary
ABI – Advanced Baseline Imager



Fire Detection

- Fire Detection:
 - Pixel flagged as containing one or more fires
 - MODIS: 1 km
 - VIIRS: 750 m and 375 m
 - ABI: 2 km
 - Can also detect volcanic signatures
 - VIIRS Detects 3-4x more fires than MODIS globally
 - ABI has coarser resolution, but much higher temporal resolution



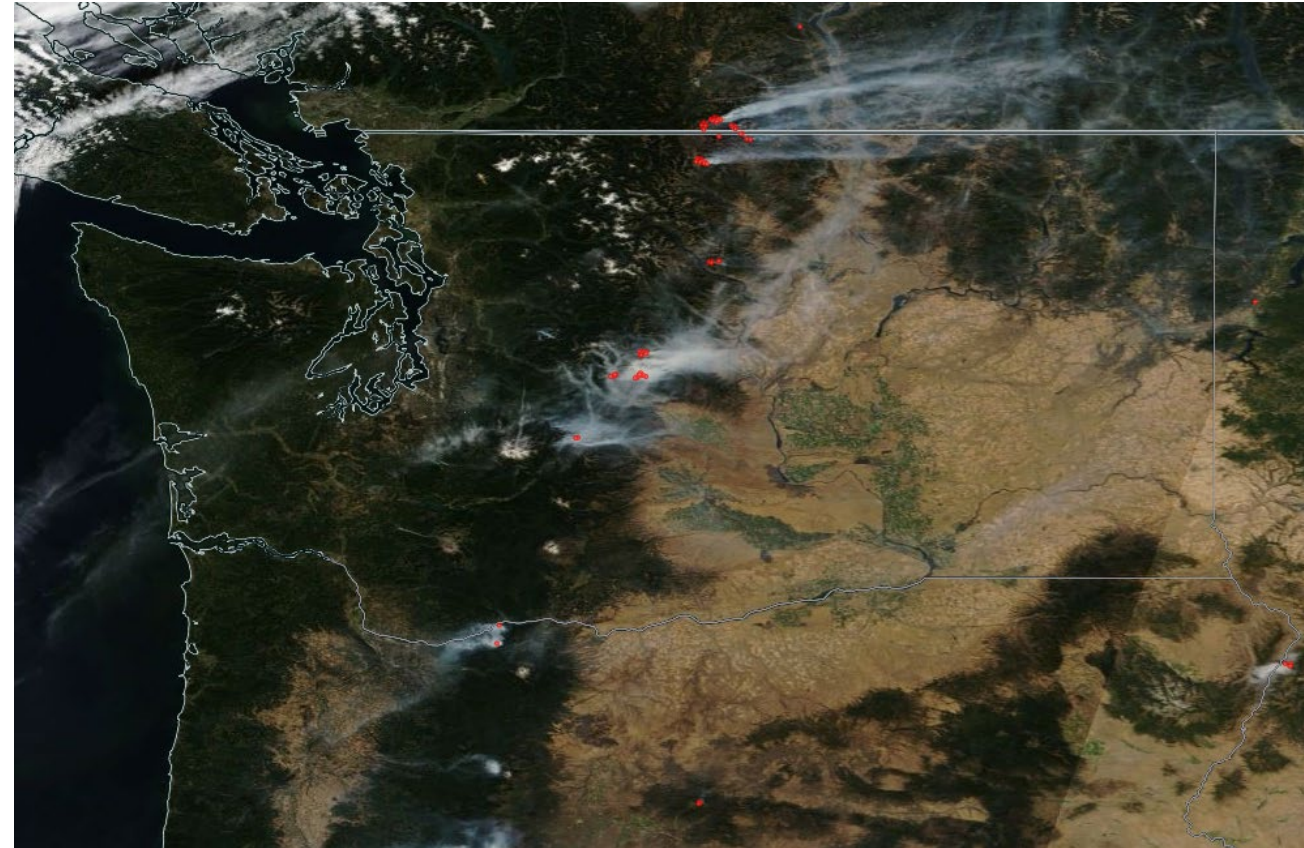
Several Satellite Instruments Observe Fire Detections

	MODIS	VIIRS	ABI
Platform	Terra , Aqua	Suomi NPP, NOAA-20	GOES 16, GOES 17
Launched	Dec 1999, May 2002	Oct 2011, Nov 2017	Nov 2016, Mar 2018
Swath	2,330 km	3,040 km	---
Equator Crossing Time	10:30 am (des), 1:30 pm (asc)	1:30 pm (asc), 1:30 pm (asc)	Geostationary
Spatial Resolution	250 m, 500 m, 1 km	375 m, 750 m	500 m, 1km, 2km
Temporal Resolution	Global Coverage: 1-2 days	Global Coverage: Daily	Full Disk: 15 min CONUS: 5 min
Spectral Coverage	36 bands (VIS, IR, NIR, MIR) Band 1-2: 250 m Band 3-7: 500 m Band 8-36: 1 km	22 bands (VIS, IR, NIR, MIR) I-Bands (1-4): 375 m M-Bands (1-16): 750 m Day/Night Band: 750 m	16 bands (VIS, IR, NIR, MIR) 500 m – 2 km



Thermal Anomalies Algorithms

- Limitations:
 - False Positives: Small forest clearings (bare soil)
 - Large fire omissions due to thick smoke
 - Larger pixel size of MODIS and ABI can miss small fires
- MODIS Collection 6 (most recent) improves upon these errors.
 - Global commission error of 1.2%
 - Similar error for VIIRS

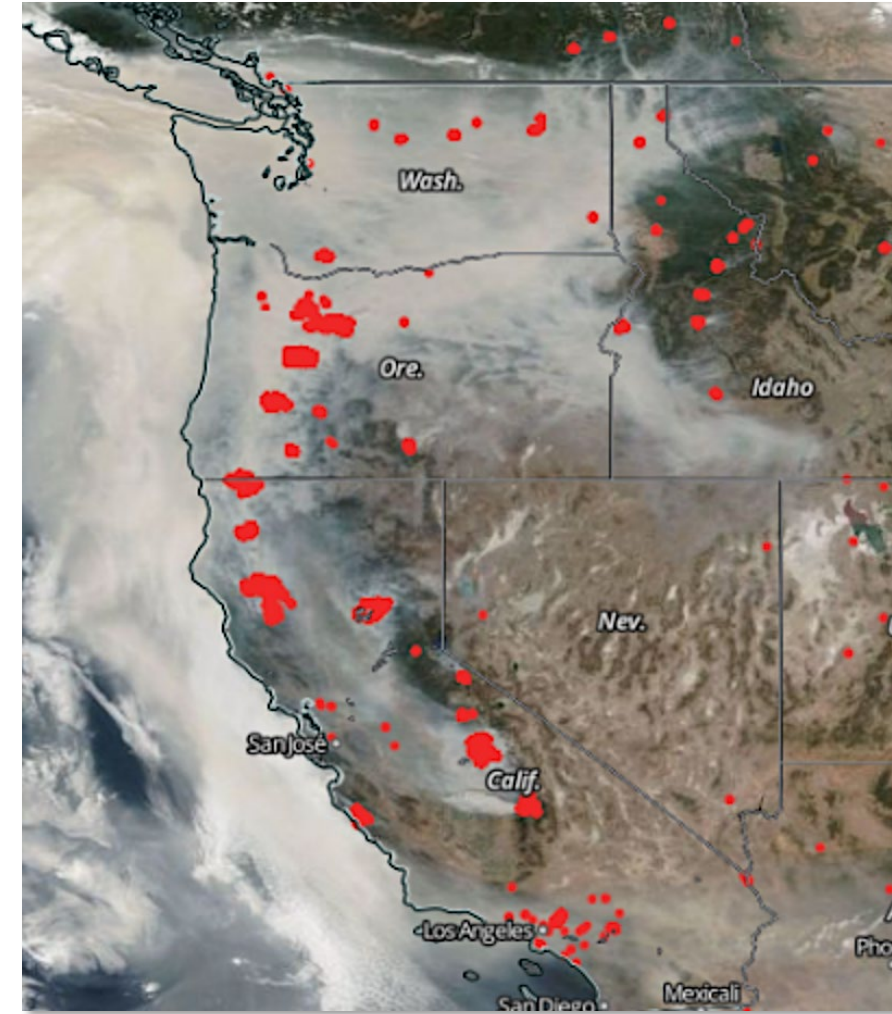


MODIS Fire Detections, NASA Worldview



What is a fire count?

- Number of hotspots (or pixels) detected by a satellite/sensor in a certain region of interest over a fixed period is called fire count.
- The region of interest can be a regular or irregular polygon defined by boundaries in terms of latitude and longitude. For example:
 - Rectangular box
 - A city boundary
 - A county/province/district
 - State/country/continent
- The fixed period can be 1 hour, 24 hours, 3 days, 7 days, 1 year, and so on.



Download Fire Data – Fire Information for Resource Management System (FIRMS)

<https://earthdata.nasa.gov/earth-observation-data/near-real-time/firms>

- Near real-time (NRT) active fire data within 3 hours of satellite overpass
- Global MODIS and VIIRS fire locations
- Historical data available
- Available In:
 - Email Alerts
 - Download Shapefile, WMS, KML, or txt
 - Visualization in **Web Fire Mapper** or **Worldview**
- FIRMS Webinar:
 - <https://www.youtube.com/watch?v=0fPVmnY6pBs&feature=youtu.be>

The screenshot shows the NASA Earth Data website interface for the Fire Information for Resource Management System (FIRMS). The page title is "Fire Information for Resource Management System (FIRMS)". The main content area includes a description: "FIRMS distributes Near Real-Time (NRT) active fire data within 3 hours of satellite overpass from both MODIS and VIIRS." Below this, there are two buttons: "MODIS Active Fire Products" and "VIIRS Active Fire Products". A sidebar on the left contains "Related Content" with links to "EOIS Data News - 4/28/2017", "Mount Ruapehu, New Zealand", "EOIS Data News - 4/21/2017", "Celebrate Earth Day with NASA at Union Station on Thursday, April 20th", and "Tropical Storm Maartut". A "More Resource:" section is also visible. A dropdown menu is open, showing options: "Get hotspot/fire locations", "Fire Email Alerts", "Download Active Fire Data", "Web Fire Mapper", "Global Fire Maps", and "Web Services".

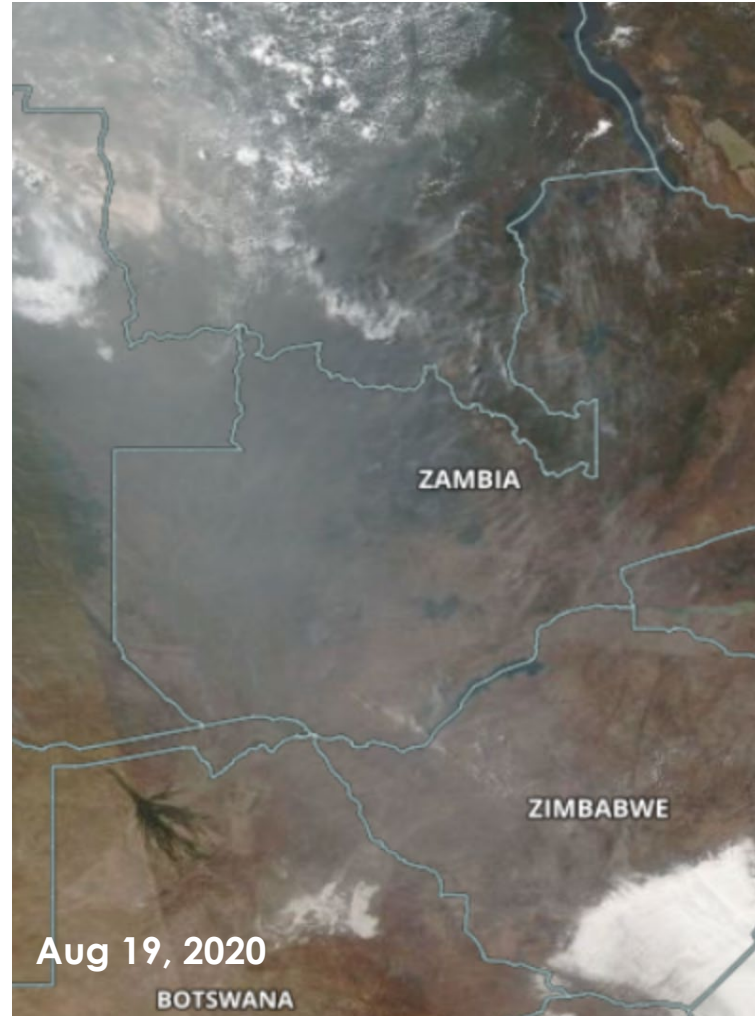




Aerosols and Smoke

Visible Smoke from Fires

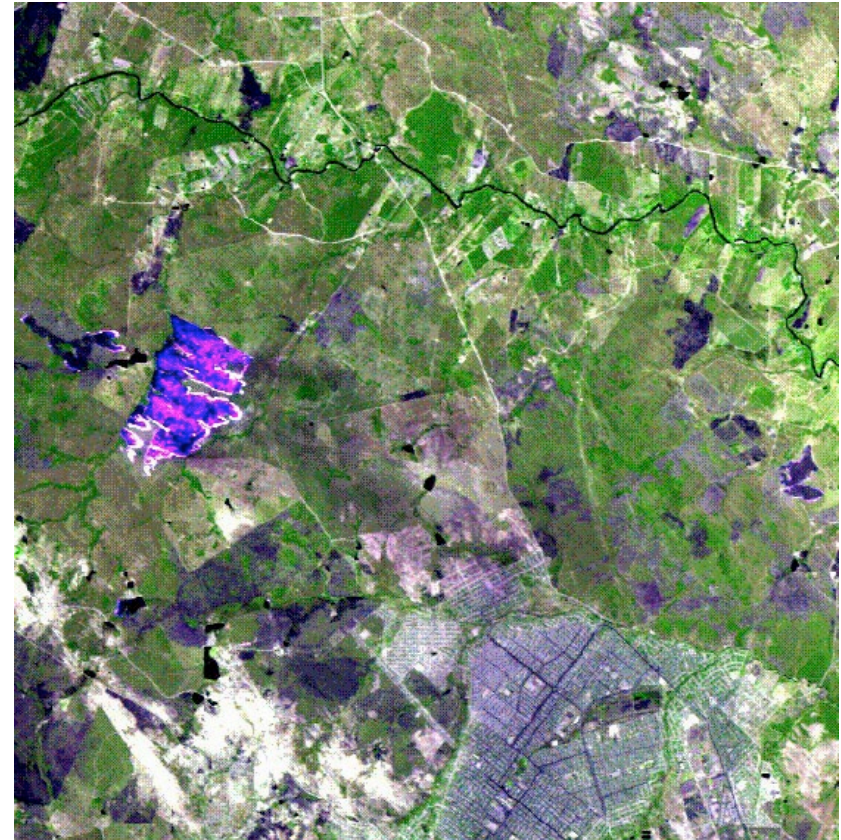
<https://worldview.earthdata.nasa.gov/>



Selection of Spectral Bands for Smoke Detection



R = 0.66 μm
G = 0.55 μm
B = 0.47 μm



R = 1.6 μm
G = 1.2 μm
B = 2.1 μm



NOAA's Aerosol Detection Product (ADP)

- Absorption Aerosols Index
- Dust, Smoke Discrimination Index
- 6 Type Flags: (1-presence; 0-absence)
 1. Volcanic Ash Flag
 2. Dust Flag
 3. Smoke Flag
 4. None/Unknown/Clear
 5. Cloud Flag
 6. Snow/Ice Flag
- Quality Flags

Low, medium, and high confidence for each type

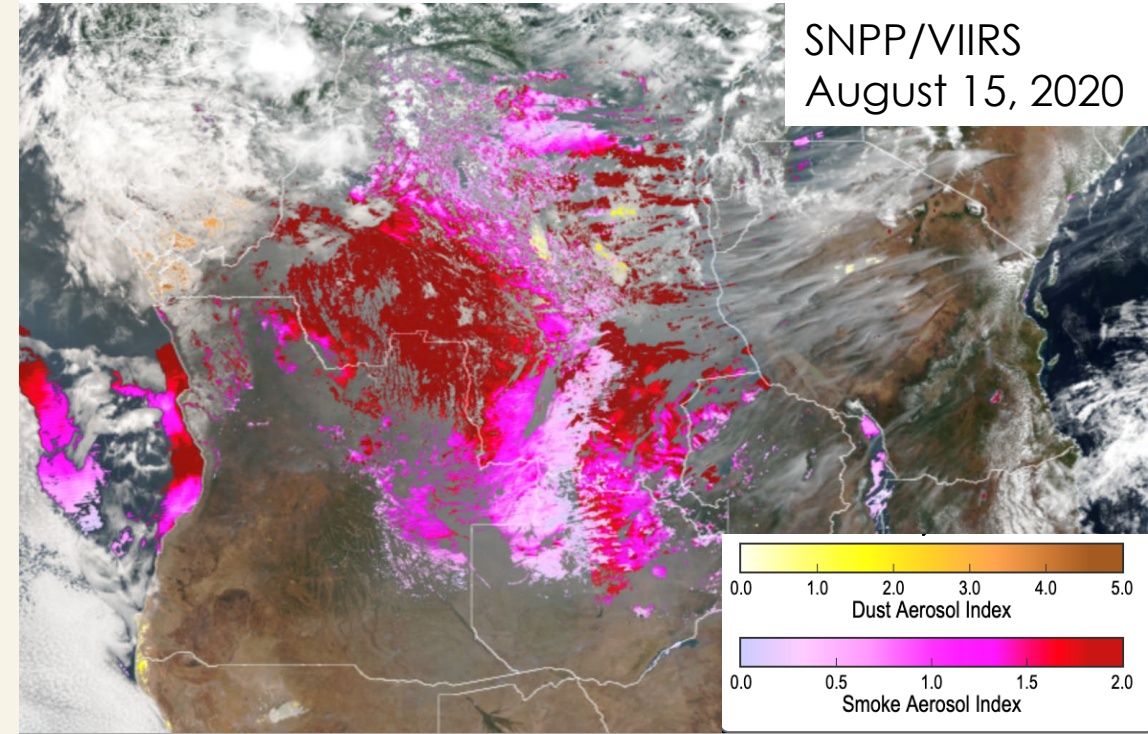


Image: <https://www.star.nesdis.noaa.gov/jpss/mapper>

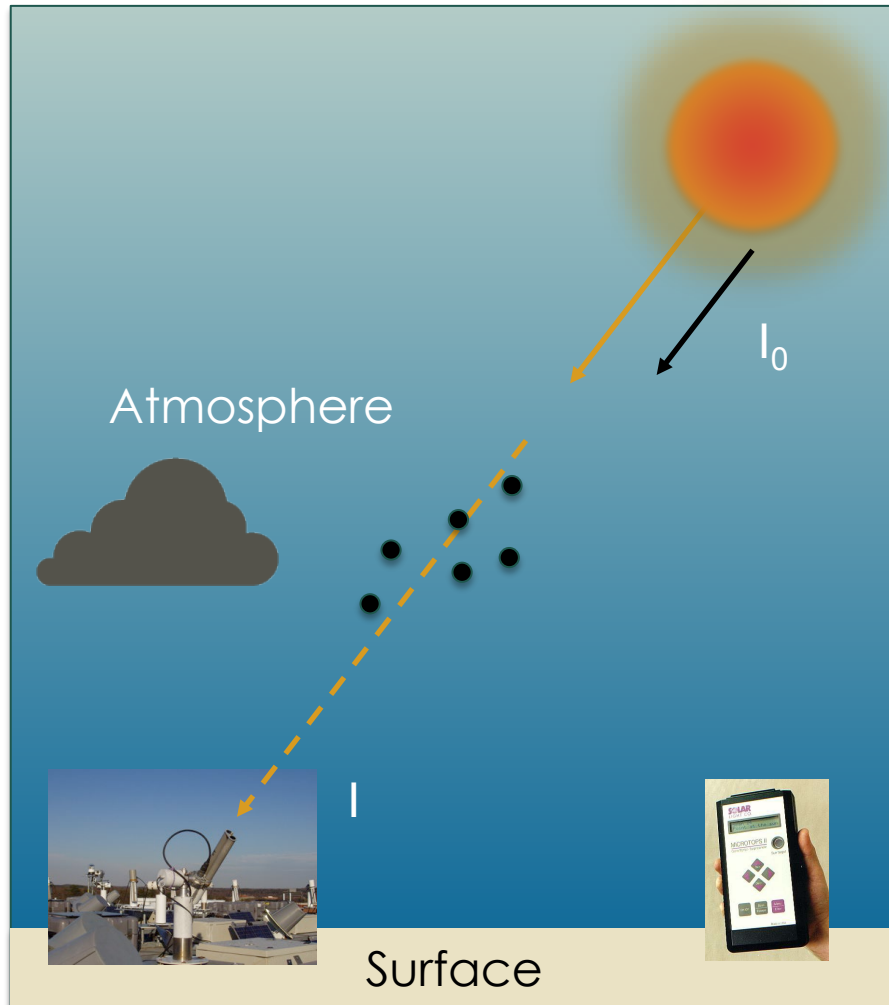
Reference:

1. Algorithm Theoretical Basis Document

[https://www.star.nesdis.noaa.gov/jpss/documents/ATBD/ATBD_EPS_Aerosol ADp v1.1.pdf](https://www.star.nesdis.noaa.gov/jpss/documents/ATBD/ATBD_EPS_Aerosol_ADp_v1.1.pdf)

2. Hai et al., Evaluation of VIIRS dust detection algorithms over land, *J. of Applied Remote Sensing*, 12(4), 042609 (2018).

Aerosol Optical Depth



Aerosol optical depth expresses the quantity of light at a certain wavelength removed by aerosols from a beam by **scattering** and/or **absorption** during its path through a medium.

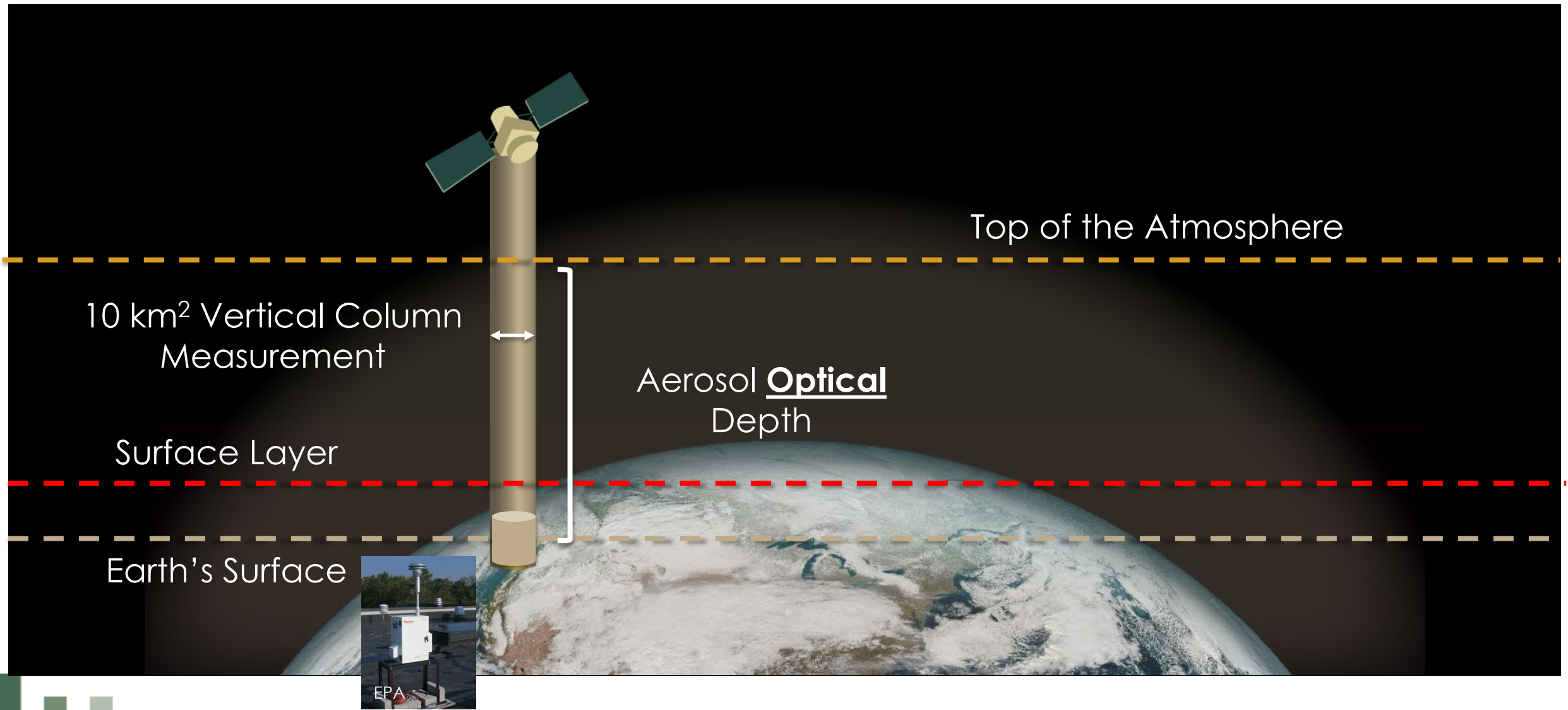
Aerosol optical depth τ as:

$$I = I_0 e^{-m\tau}$$
$$m = \sec \theta_0$$

- AOD or AOT
- Typically reported at 550 nm
- unitless

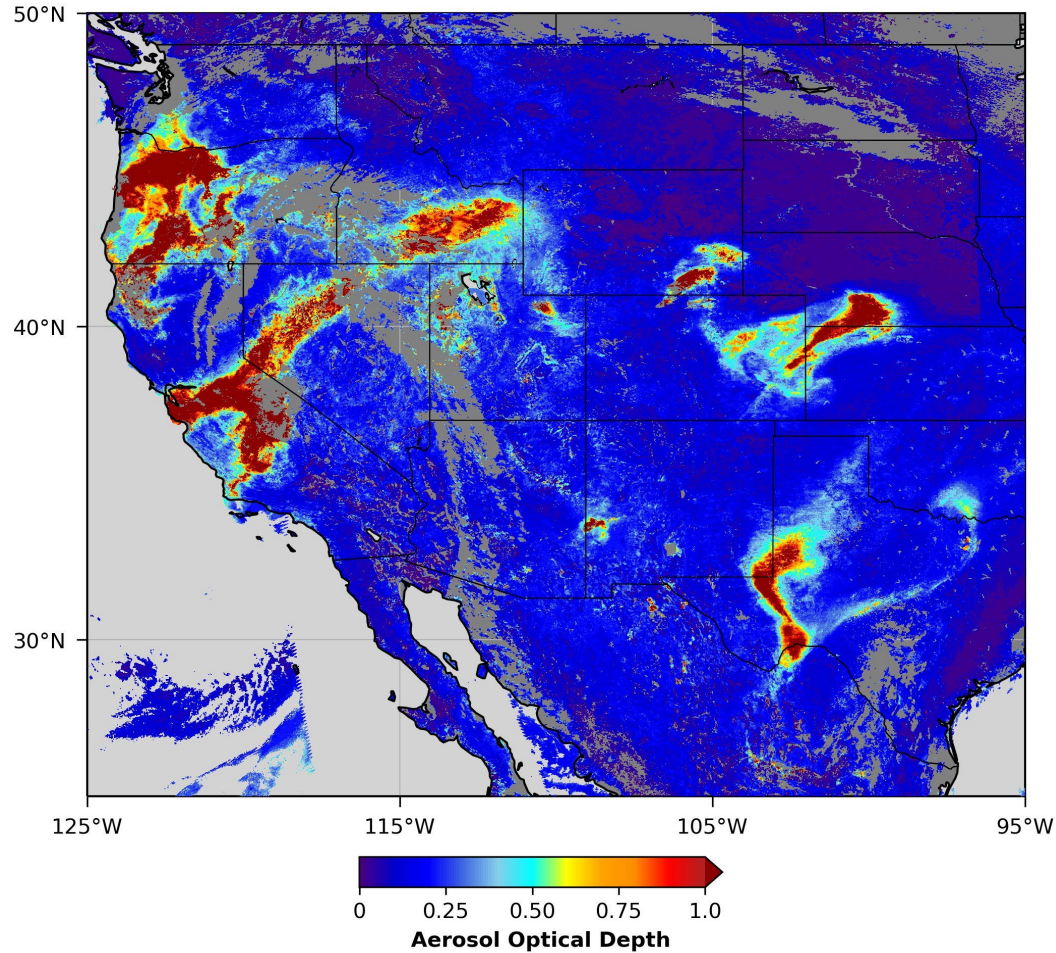


Aerosol Optical Depth

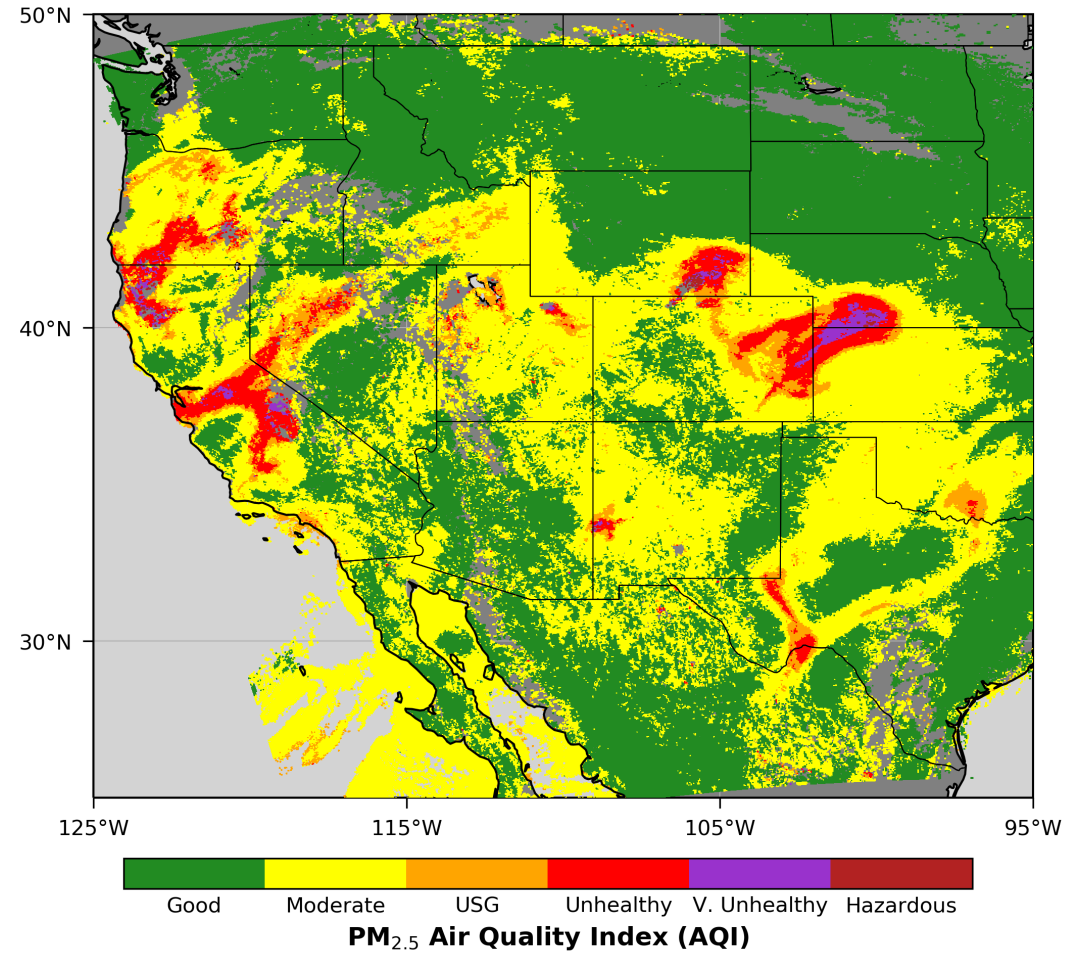


Aerosol Optical Depth to PM2.5

NOAA-20/VIIRS
Aerosol Optical Depth
07 Oct 2020



Daily (24-Hour Average) Fine Particles
Estimated from VIIRS Aerosol Optical Depth
07 Oct 2020



<https://twitter.com/AerosolWatch/status/1314208278222569472>

Hai and Kondragunta, 2021 - <https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2020EA001599>



Smoke Monitoring Tools – JSTAR Mapper

<https://www.star.nesdis.noaa.gov/jpss/mapper/>

Aerosol Watch

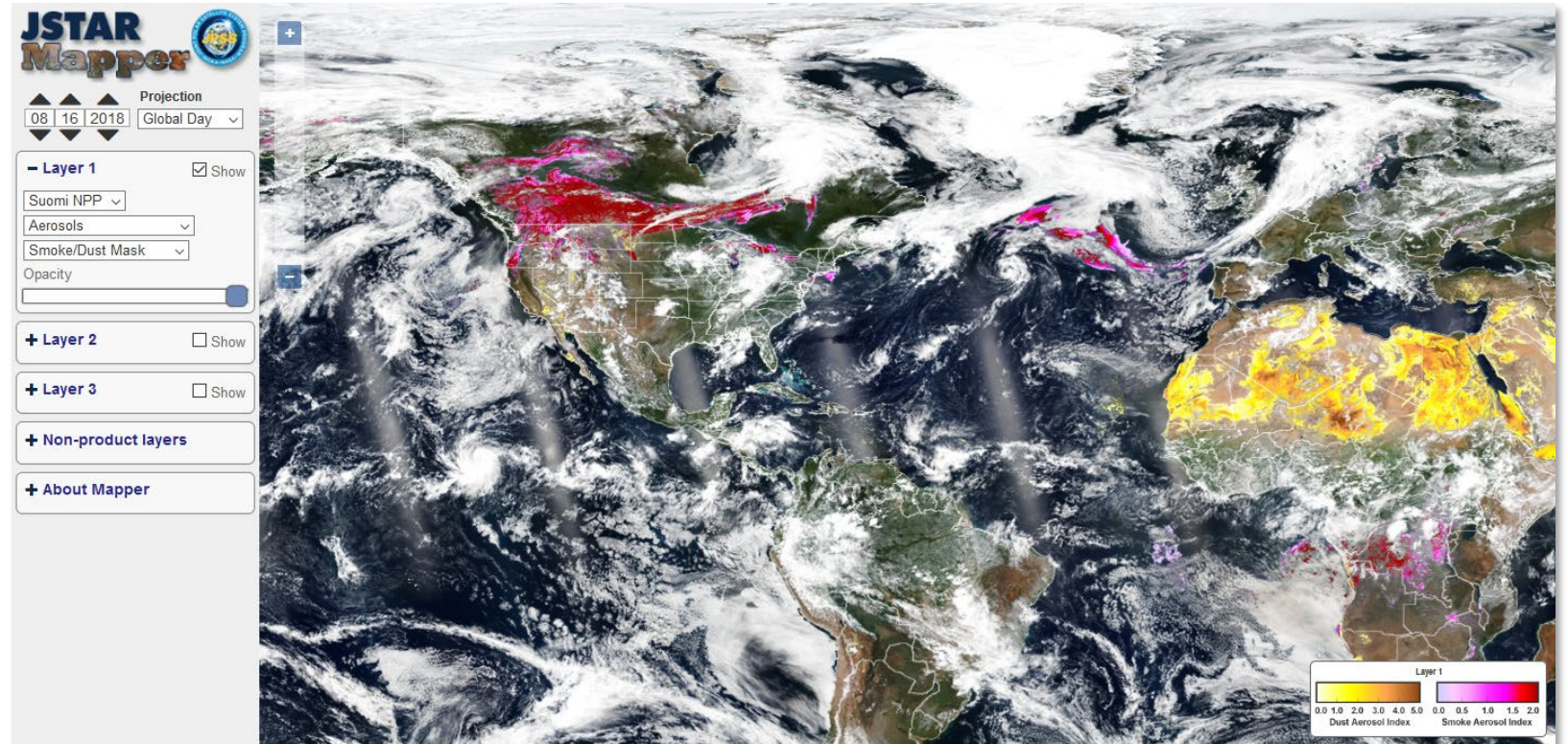
<https://www.star.nesdis.noaa.gov/smcd/spb/aq/AerosolWatch/>

**Data Access: NOAA CLASS
(The Comprehensive Large
Array-data Stewardship
System)**

<https://www.class.ngdc.noaa.gov/saa/products/welcome>

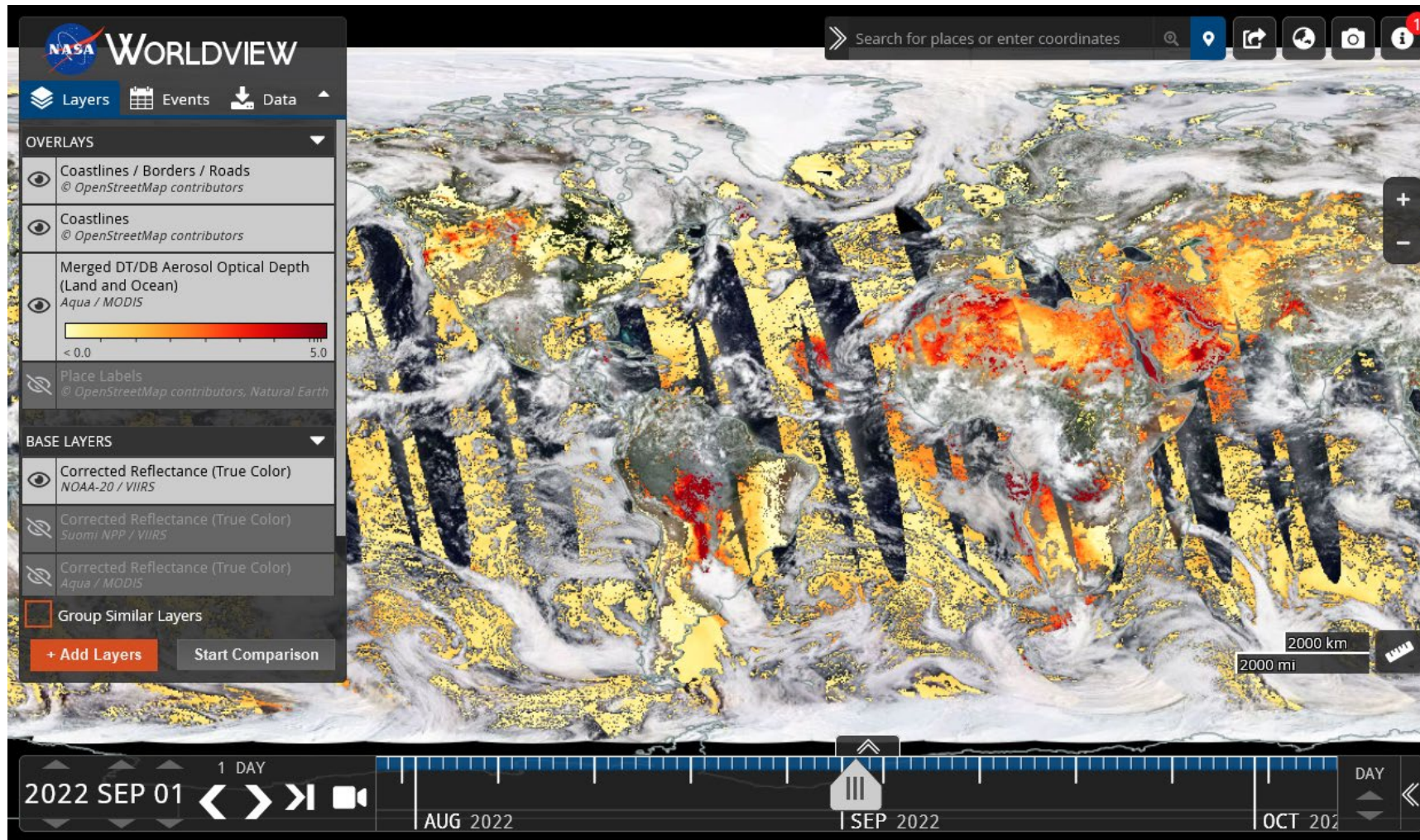
ARSET Training material and recording provide more details on the tool and data

<https://appliedsciences.nasa.gov/join-mission/training/english/arset-modis-viirs-transition-air-quality-applications>



NASA Worldview

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

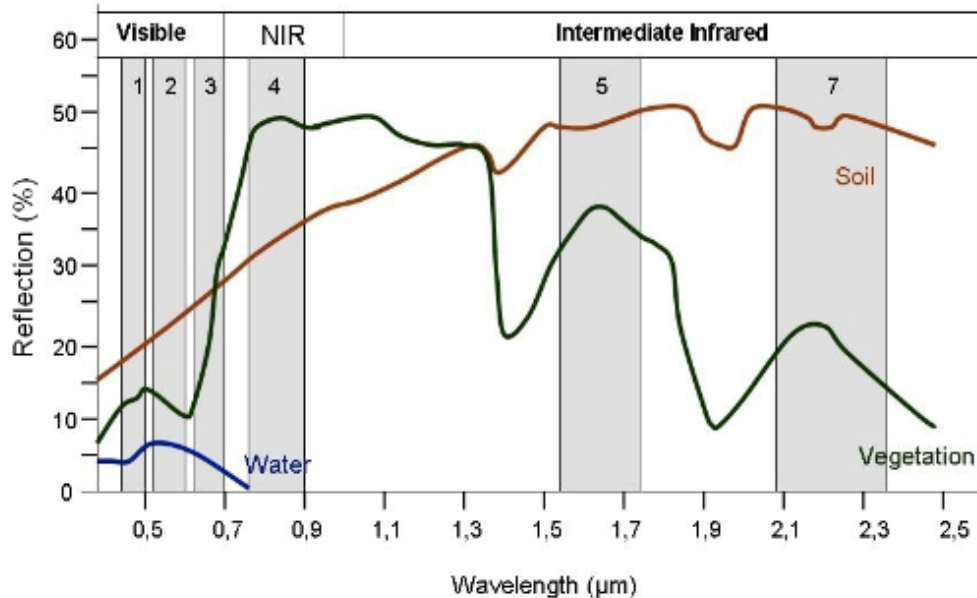




Appendix

Land Cover Monitoring for Flood Detection

Optical Radiation: Reflected by the surface and depends on the surface type



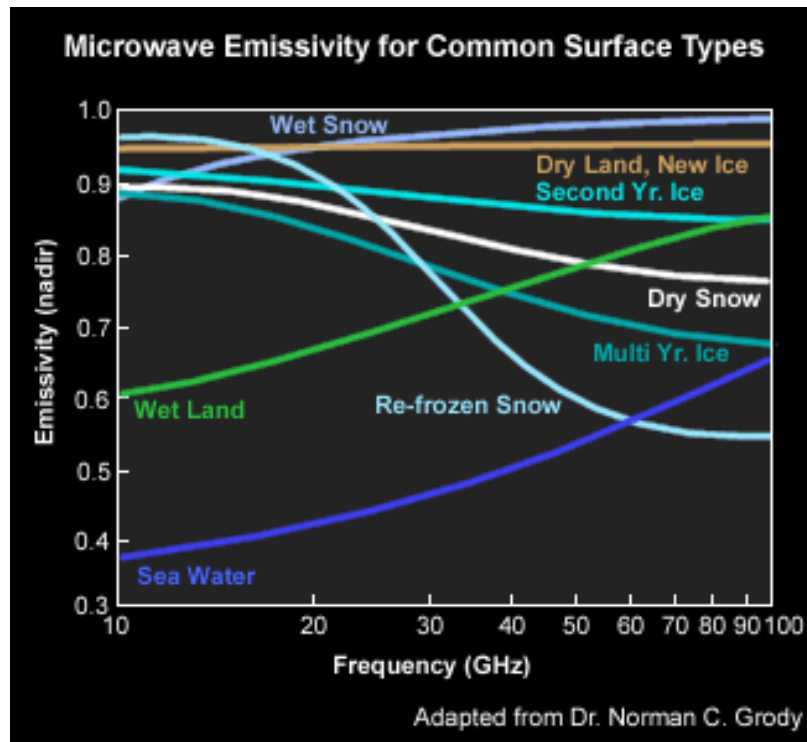
Optical Radiation

- Used for flood detection:
 - Terra/Aqua MODerate Resolution Imaging Spectroradiometer (MODIS) reflectance changes
- Used by:
 - MODIS NRT Flood Mapping
 - Dartmouth Flood Observatory (DFO)
- Used to observe land cover changes:
 - Reflectance from Landsat
- Used by: DFO



Land Cover Monitoring for Flood Detection

Passive Microwave Radiation: Emitted by the surface and influenced by the presence of water



Passive Microwave Radiation

- Sources:
 - Microwave (37 GHz) brightness temperatures from TRMM Microwave Imager (TMI)
 - GPM Microwave Imager (GMI)
 - GCOM-W based Advanced Microwave Scanning Radiometer 2 (AMSR2)
- Tools:
 - GFDS2 (GDACS)
 - DFO River Watch



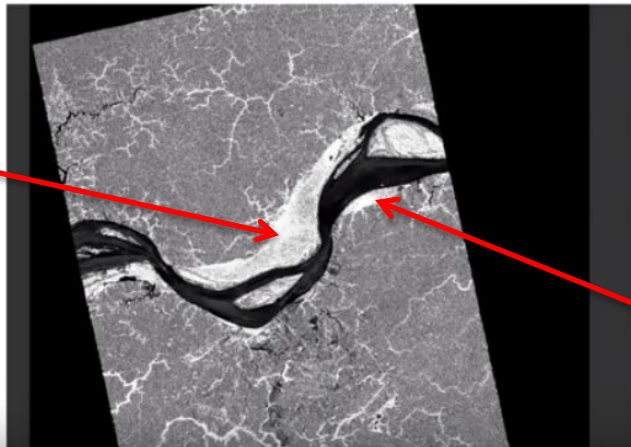
Land Cover Monitoring For Flood detection

- Active Microwave Radar (Synthetic Aperture Radar): The backscattered signal is primarily sensitive to surface structure

SAR Signal Scattering Over Inundated Regions

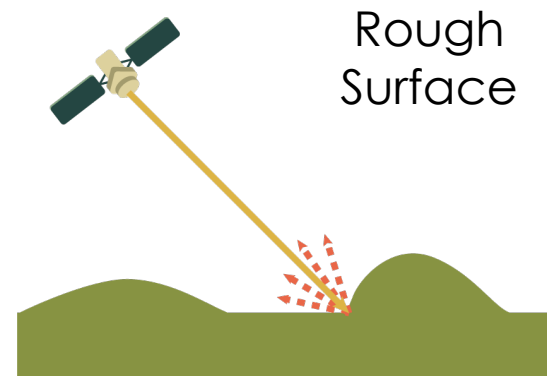
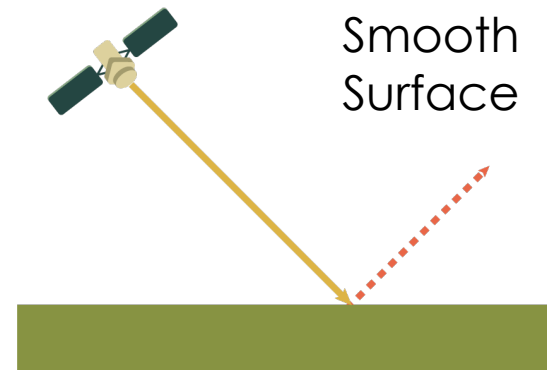
Palsar Image (L-band) near Manaus, Brazil

Inundated
Vegetation



Smooth
River Water
Surface

Backscattering Mechanisms



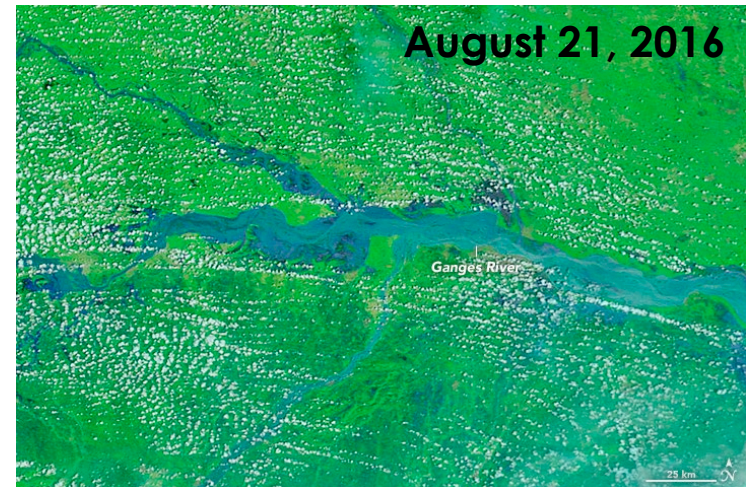
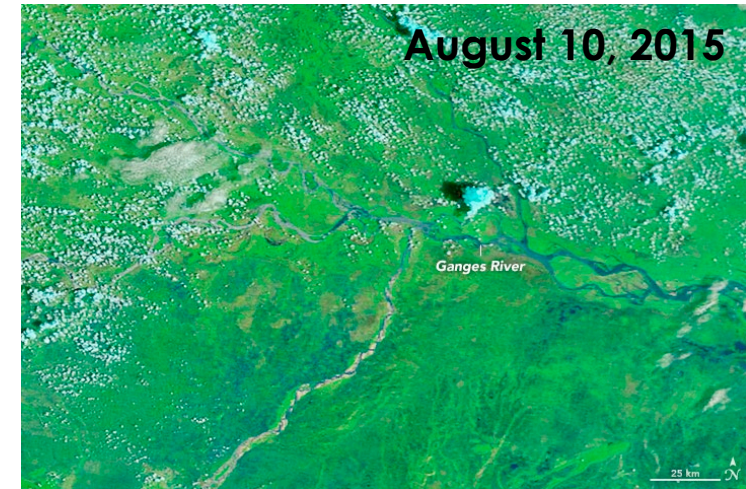
Details in next presentation



MODIS-Based Inundation Mapping [Optical Radiation]

- 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.

Flooding in the Ganges-- Aug 2016



<https://earthobservatory.nasa.gov/images/88624/flooding-on-the-ganges-river>

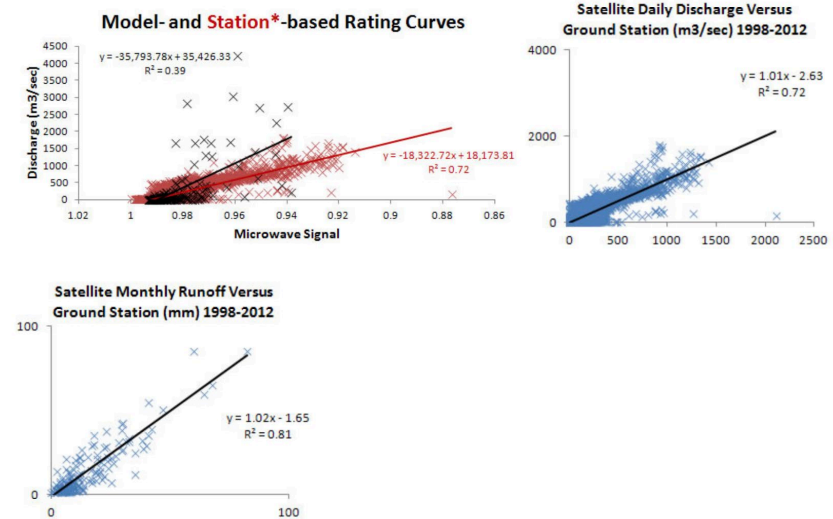


Flood Detection and River Discharge Based on Passive Microwave Radiation

<https://floodobservatory.colorado.edu/Measuring%20Discharge.pdf>

Based on:

- Station discharge data
- Microwave (37 GHz) brightness temperatures from TRMM Microwave Imager (TMI)
- GPM Microwave Imager (GMI)
- GCOM-W-based Advanced Microwave Scanning Radiometer 2 (AMSR2)



SGR 446, Trinity River, Texas, USA: Top Left shows two scatter plots and associated model- and ground-based rating equations and simple linear regression Rsquared values. Top right shows the independent daily discharge output of River Watch remote sensing at this site, as compared with the ground gauging station. Bottom shows the independent monthly runoff output, again as compared to that of the ground station.

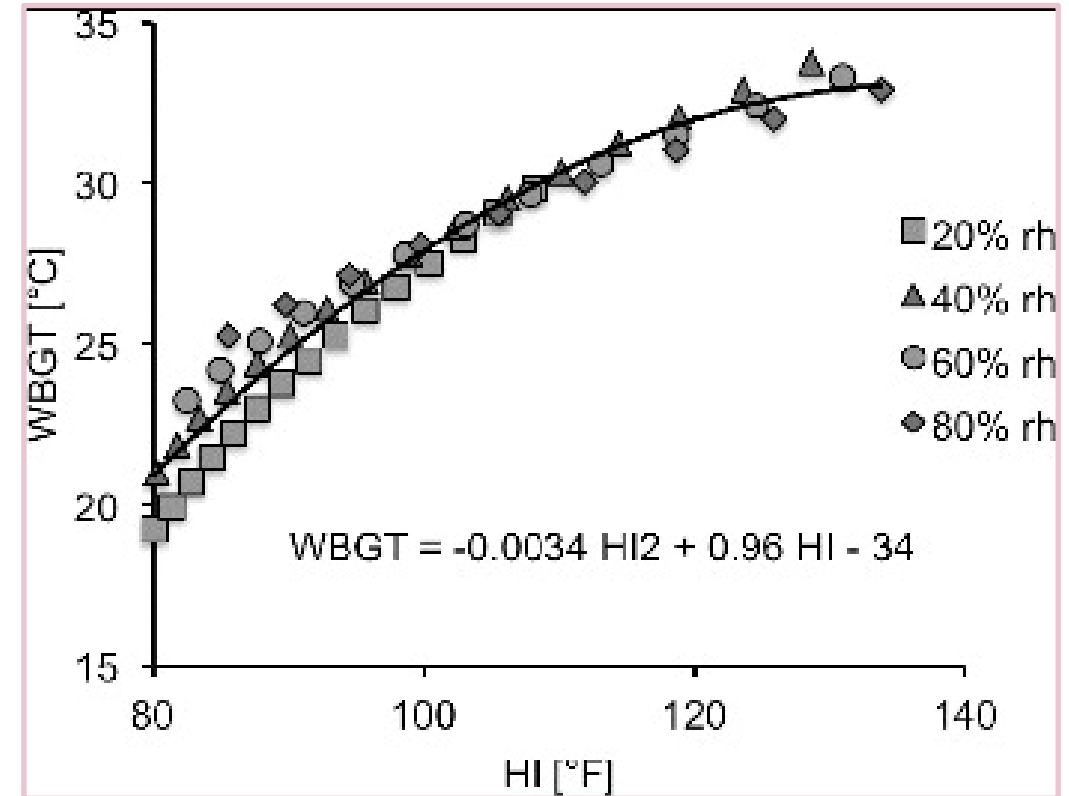




Extreme Heat

Global High-Resolution Daily Extreme Urban Heat Exposure (UHE-Daily), v1 (1983–2016)

- Use CHIRTS-daily to calculate daily maximum heat index, following the US National Weather Service procedure.
 - Daily maximum air temperature
 - Daily minimum relative humidity
- Then convert Hlmax to WBGTmax, following Bernard & Iheanacho 2015.
- Assumes a fixed wind speed and radiation.

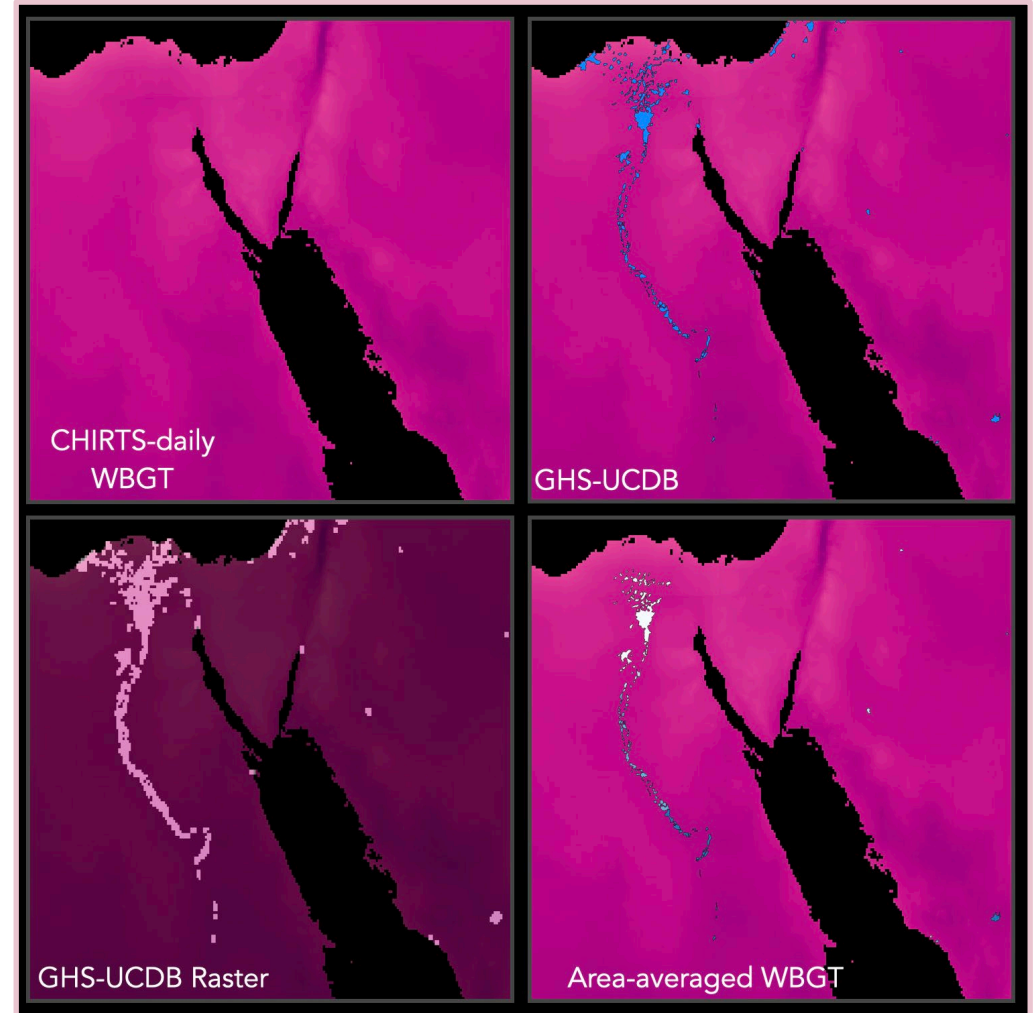


Bernard & Iheanacho 2015.



Global High-Resolution Daily Extreme Urban Heat Exposure (UHE-Daily), v1 (1983–2016)

- Combine CHIRTS-daily WBGTmax record with the Global Human Settlement Layer Urban Centre Data Base (Florczyk et al. 2019)
- Create a record of WBGTmax for every urban settlement on the planet from 1983 – 2016 (150 million observations).
- Apply ISO threshold to identify dangerous hot-humid days (e.g., WBGTmax > 30°C) for each city on the planet, from 1983 – 2016 **to produce a record of all urban hot-humid heat waves.**

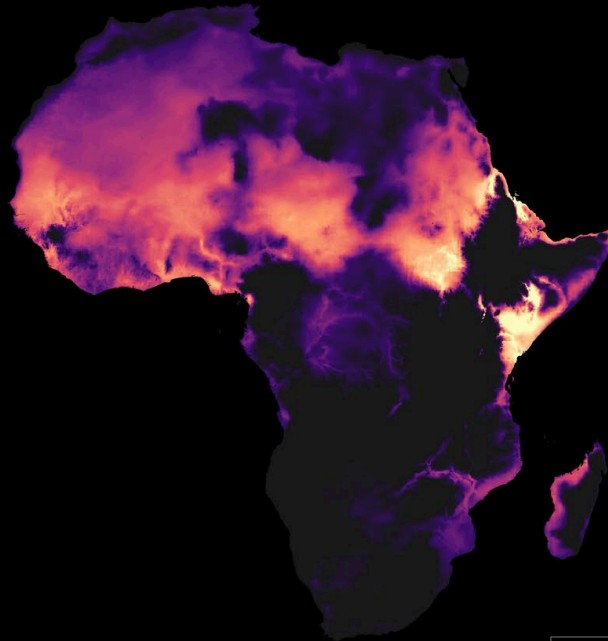


Global High-Resolution Daily Extreme Urban Heat Exposure (UHE-Daily), v1 (1983–2016)

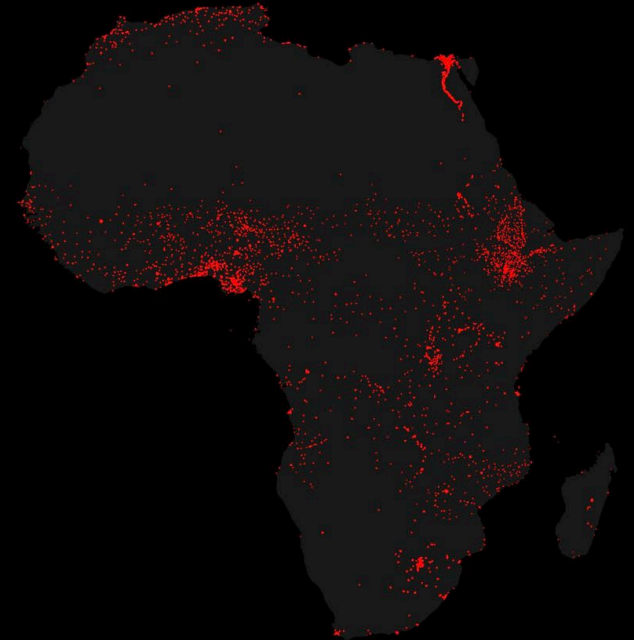


Exposure
(Person-days) =

=



X



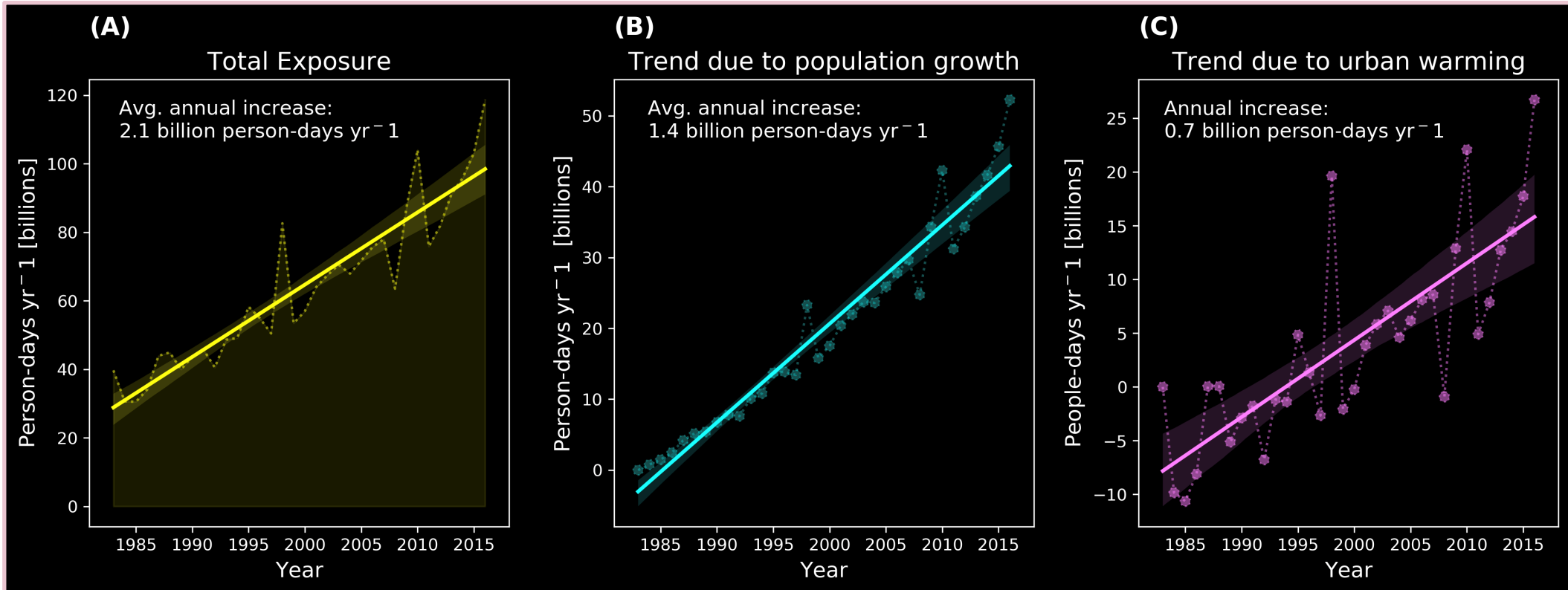
Hot Days = # Days $WBGT_{max} > 30^{\circ} C$

Exp = Hot Days X Population

$Exp\ yr^{-1} = \beta_0 + \beta\ Exp + \epsilon$



Global High-Resolution Daily Extreme Urban Heat Exposure (UHE-Daily), v1 (1983–2016)

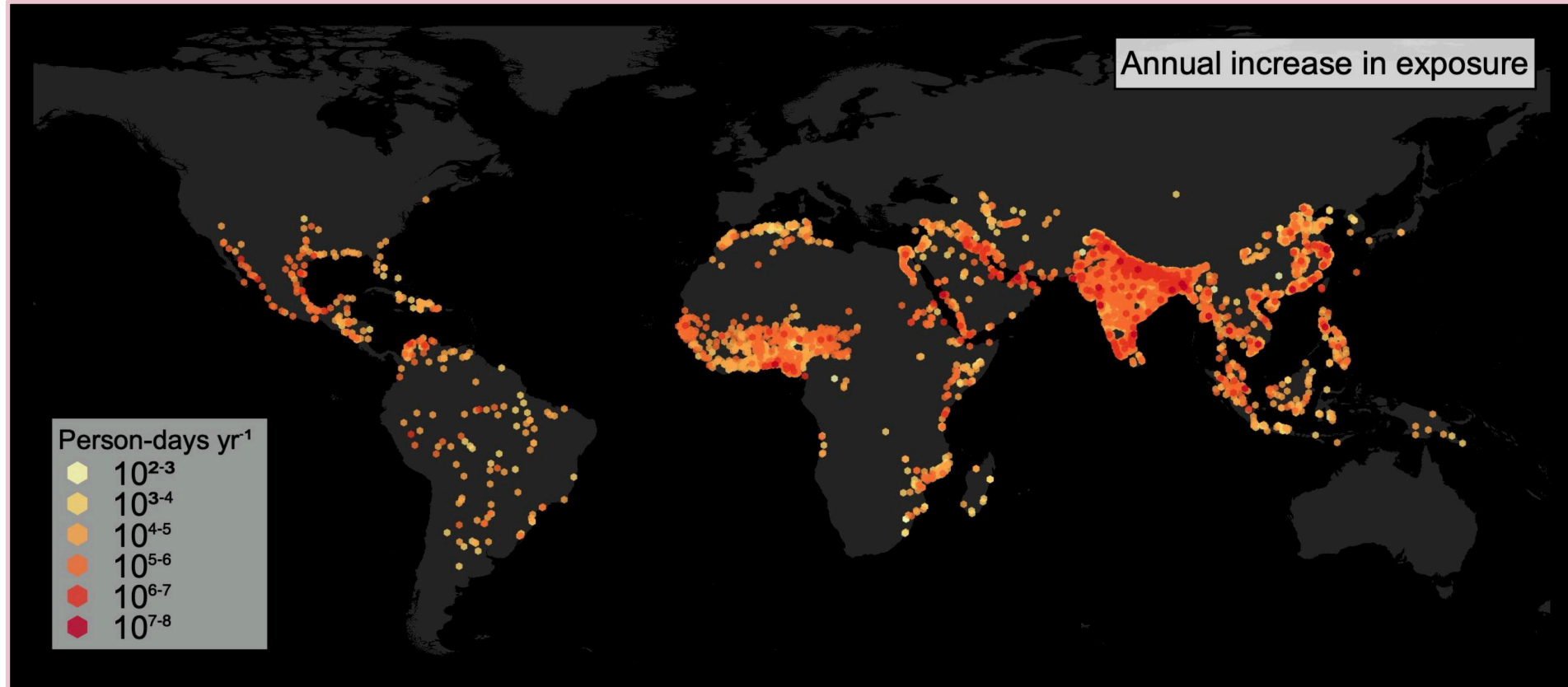


Tuholske et al. 2021

Global exposure increased 200% from 1983 – 2016. Total urban warming contributed a **third** of the annual increase in exposure.



Global High-Resolution Daily Extreme Urban Heat Exposure (UHE-Daily), v1 (1983–2016)

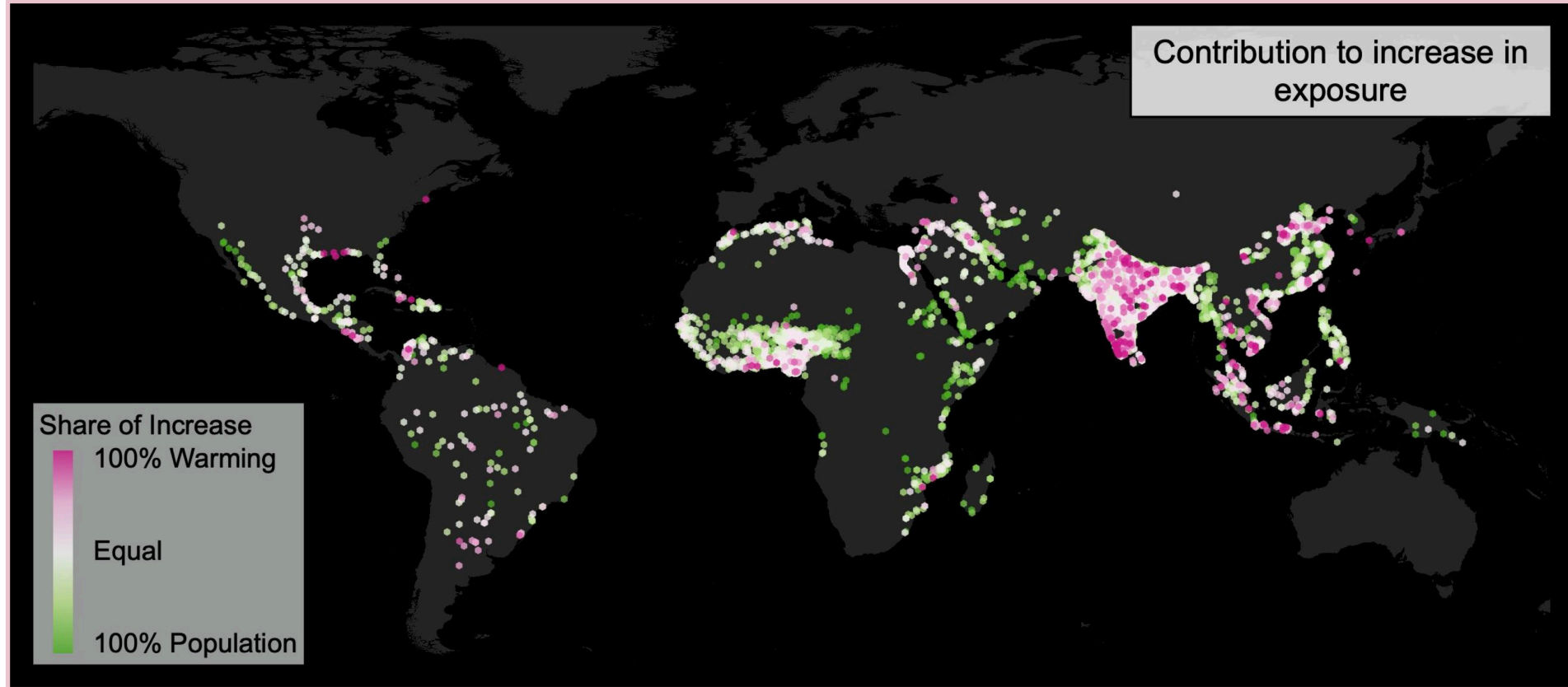


Tuholske et al. 2021

Nearly 6,000 urban settlements had an increase in exposure, which housed 1.7 billion people in 2016.



Global High-Resolution Daily Extreme Urban Heat Exposure (UHE-Daily), v1 (1983–2016)

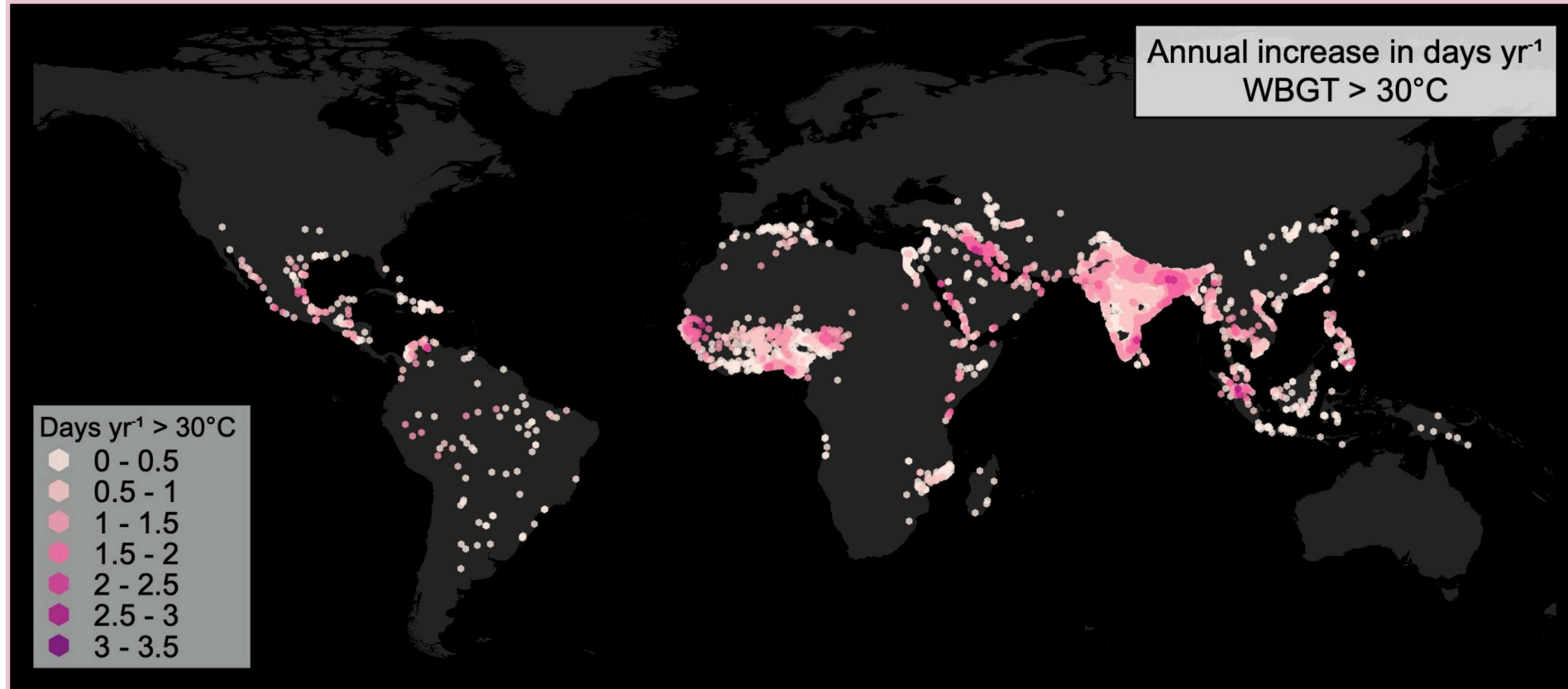


Tuholske et al. 2021

Heterogenous contribution of population growth vs. total urban warming.



Global High-Resolution Daily Extreme Urban Heat Exposure (UHE-Daily), v1 (1983–2016)

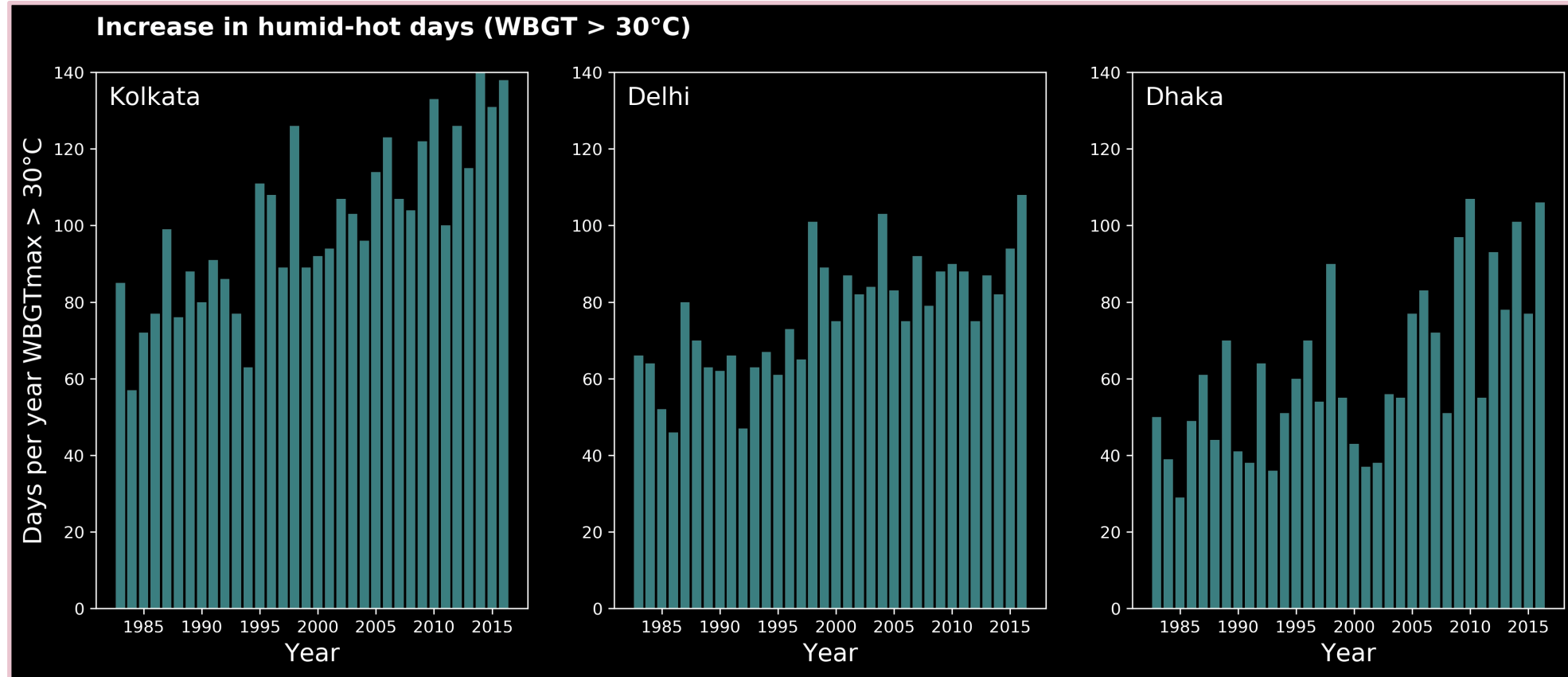


Tuholske et al. 2021

Important Note: Urban warming is both climate change and the urban heat island effect.



Global High-Resolution Daily Extreme Urban Heat Exposure (UHE-Daily), v1 (1983–2016)



Tuholske et al. 2021

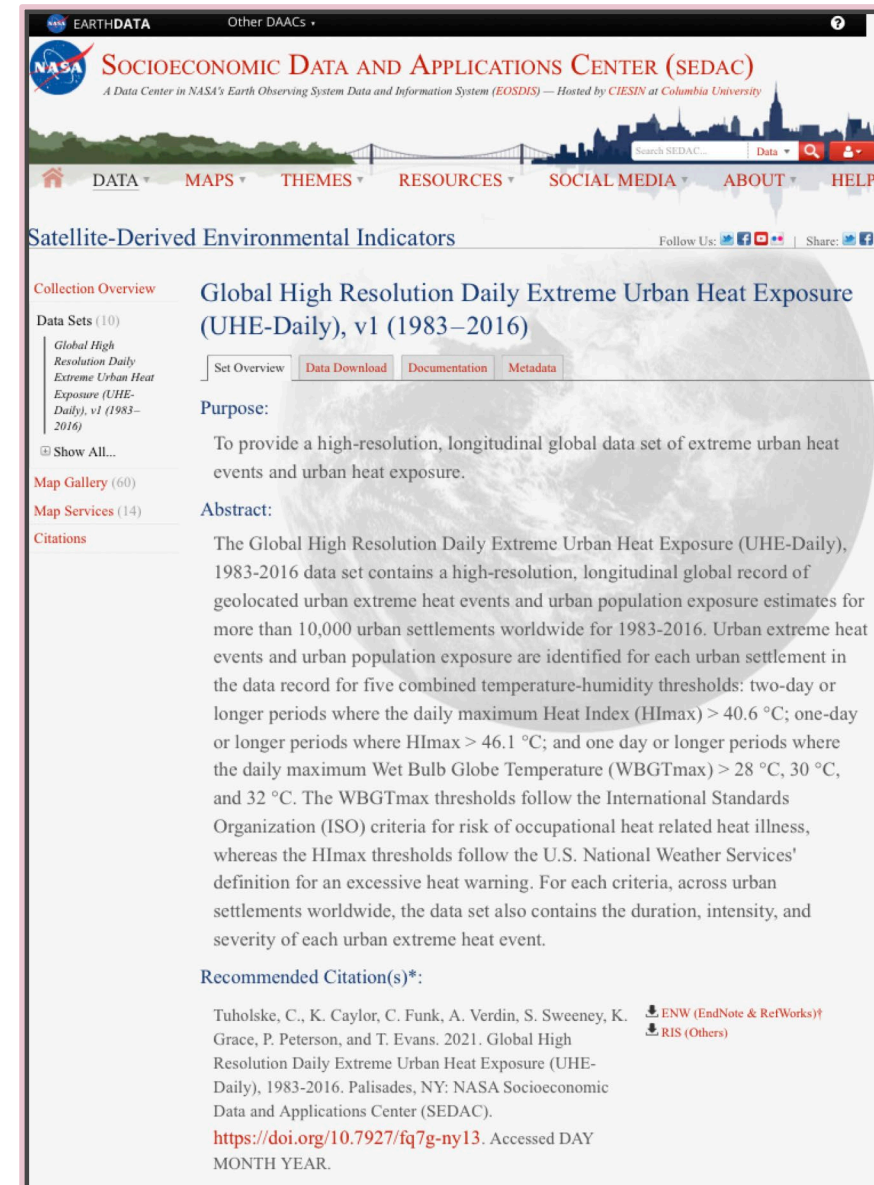
“Proximate” urban settlements of similar size populations and levels of economic development have much different increase in the number of dangerous hot-humid days per year.



Global High-Resolution Daily Extreme Urban Heat Exposure (UHE-Daily), v1 (1983–2016)

<https://sedac.ciesin.columbia.edu/data/set/sdei-high-res-daily-uhe-1983-2016>

- UHE-Daily, v1 dataset is available from the NASA Socioeconomic Data and Applications Center (SEDAC).
- Record Includes:
 - Every hot-humid urban heat wave, including dates and WBGTmax estimates, from 1983 – 2016 for three ISO thresholds (WBGTmax 28°C, 30°C, & 32°C)



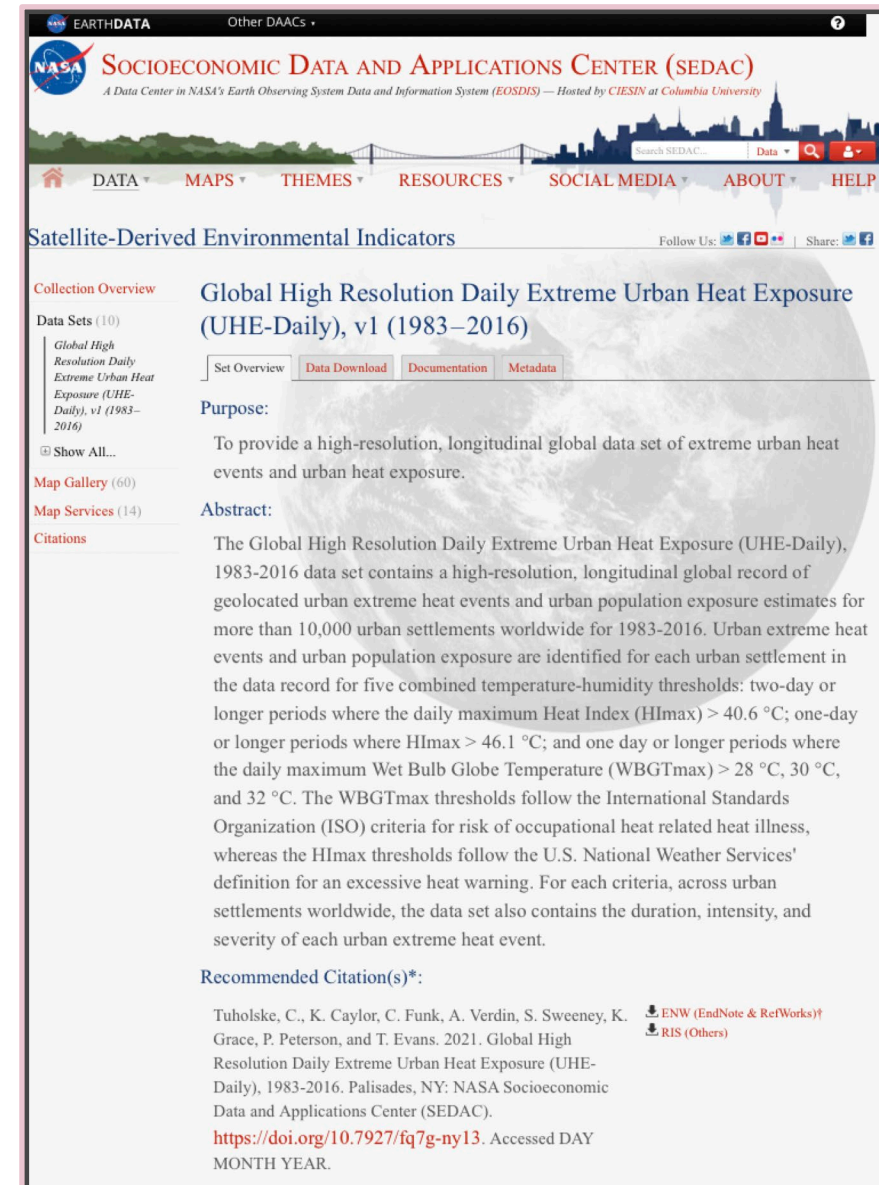
The screenshot shows the NASA Socioeconomic Data and Applications Center (SEDAC) website. The main heading is "Global High Resolution Daily Extreme Urban Heat Exposure (UHE-Daily), v1 (1983–2016)". The page includes a "Purpose" section stating: "To provide a high-resolution, longitudinal global data set of extreme urban heat events and urban heat exposure." The "Abstract" section describes the data set: "The Global High Resolution Daily Extreme Urban Heat Exposure (UHE-Daily), 1983-2016 data set contains a high-resolution, longitudinal global record of geolocated urban extreme heat events and urban population exposure estimates for more than 10,000 urban settlements worldwide for 1983-2016. Urban extreme heat events and urban population exposure are identified for each urban settlement in the data record for five combined temperature-humidity thresholds: two-day or longer periods where the daily maximum Heat Index (HI_{max}) > 40.6 °C; one-day or longer periods where HI_{max} > 46.1 °C; and one day or longer periods where the daily maximum Wet Bulb Globe Temperature (WBGT_{max}) > 28 °C, 30 °C, and 32 °C. The WBGT_{max} thresholds follow the International Standards Organization (ISO) criteria for risk of occupational heat related heat illness, whereas the HI_{max} thresholds follow the U.S. National Weather Services' definition for an excessive heat warning. For each criteria, across urban settlements worldwide, the data set also contains the duration, intensity, and severity of each urban extreme heat event." The "Recommended Citation(s)*" section provides the following information: "Tuholske, C., K. Caylor, C. Funk, A. Verdin, S. Sweeney, K. Grace, P. Peterson, and T. Evans. 2021. Global High Resolution Daily Extreme Urban Heat Exposure (UHE-Daily), 1983-2016. Palisades, NY: NASA Socioeconomic Data and Applications Center (SEDAC). <https://doi.org/10.7927/fq7g-ny13>. Accessed DAY MONTH YEAR." There are also links for "ENW (EndNote & RefWorks)" and "RIS (Others)".



Global High-Resolution Daily Extreme Urban Heat Exposure (UHE-Daily), v1 (1983–2016)

<https://sedac.ciesin.columbia.edu/data/set/sdei-high-res-daily-uhe-1983-2016>

- Annual person-day estimates for each urban settlement.
- Exposure + warming trends for each urban settlement.
- Dataset available in .json, .csv. & .shp file formats.
- DOI: <https://doi.org/10.7927/fq7g-ny13>



The screenshot shows the SEDAC website interface. At the top, there is a navigation bar with 'DATA', 'MAPS', 'THEMES', 'RESOURCES', 'SOCIAL MEDIA', 'ABOUT', and 'HELP'. The main content area is titled 'Satellite-Derived Environmental Indicators' and features a search bar. Below this, the 'Collection Overview' section displays the title 'Global High Resolution Daily Extreme Urban Heat Exposure (UHE-Daily), v1 (1983–2016)' and provides buttons for 'Set Overview', 'Data Download', 'Documentation', and 'Metadata'. The 'Purpose' section states: 'To provide a high-resolution, longitudinal global data set of extreme urban heat events and urban heat exposure.' The 'Abstract' section describes the data set: 'The Global High Resolution Daily Extreme Urban Heat Exposure (UHE-Daily), 1983-2016 data set contains a high-resolution, longitudinal global record of geolocated urban extreme heat events and urban population exposure estimates for more than 10,000 urban settlements worldwide for 1983-2016. Urban extreme heat events and urban population exposure are identified for each urban settlement in the data record for five combined temperature-humidity thresholds: two-day or longer periods where the daily maximum Heat Index (HI_{max}) > 40.6 °C; one-day or longer periods where HI_{max} > 46.1 °C; and one day or longer periods where the daily maximum Wet Bulb Globe Temperature (WBGT_{max}) > 28 °C, 30 °C, and 32 °C. The WBGT_{max} thresholds follow the International Standards Organization (ISO) criteria for risk of occupational heat related heat illness, whereas the HI_{max} thresholds follow the U.S. National Weather Services' definition for an excessive heat warning. For each criteria, across urban settlements worldwide, the data set also contains the duration, intensity, and severity of each urban extreme heat event.' The 'Recommended Citation(s)*' section provides the citation: 'Tuholske, C., K. Caylor, C. Funk, A. Verdin, S. Sweeney, K. Grace, P. Peterson, and T. Evans. 2021. Global High Resolution Daily Extreme Urban Heat Exposure (UHE-Daily), 1983-2016. Palisades, NY: NASA Socioeconomic Data and Applications Center (SEDAC). <https://doi.org/10.7927/fq7g-ny13>. Accessed DAY MONTH YEAR.'

