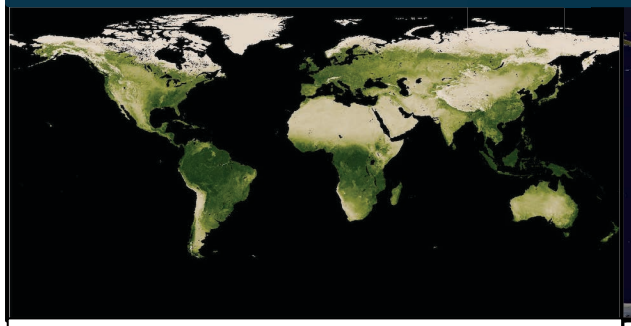
Fire, Smoke, and Aerosol Monitoring from Space

Pawan Gupta (USRA/MSFC), Melanie Follette-Cook (MSU/GSFC), and Ana Prados (UMBC/GSFC)

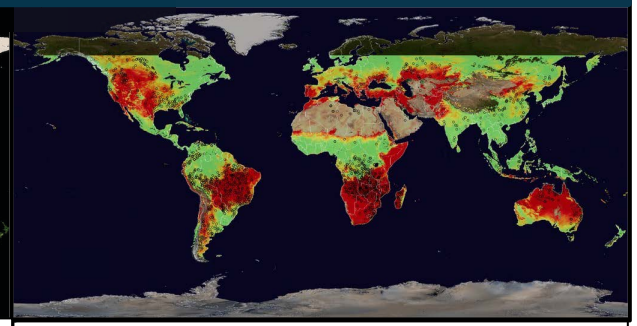
May 18, 2021

Webinar Agenda

Pre-Fire

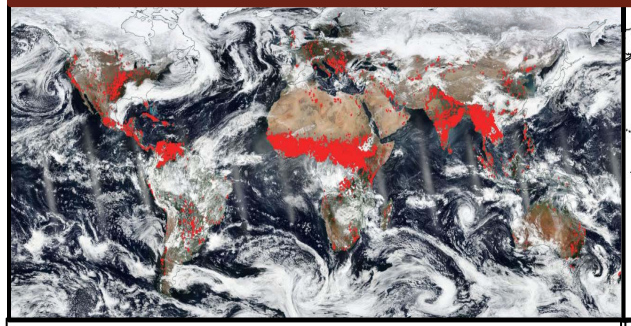


Session 1:
Climate and Hydrology

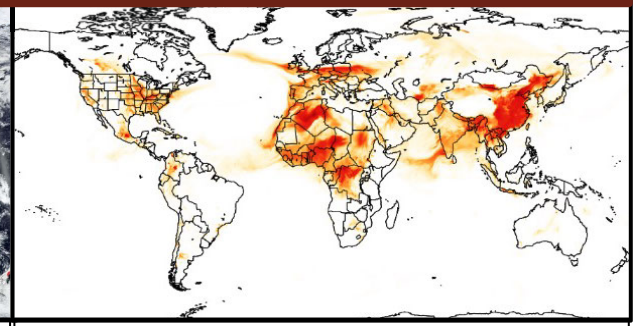


Session 2:
Vegetation

During Fire

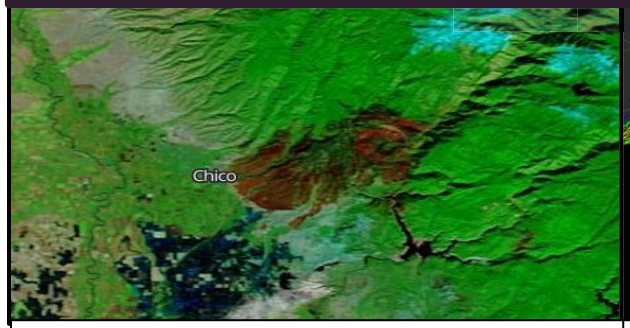


Session 3:
Active Fires and Smoke

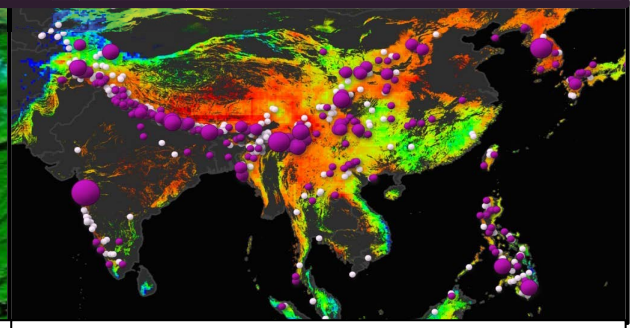


Session 4:
Smoke Forecasting

Post-Fire



Session 5:
Climate & Hydrology

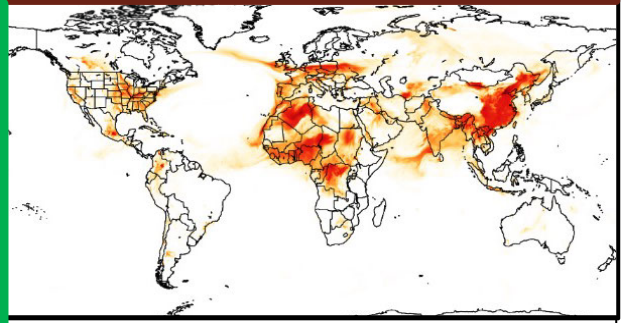


Session 6:
Vegetation

Webinar Agenda

During Fire

Session 3:
Active Fires and Smoke



Session 4:
Smoke Forecasting

Pawan Gupta

Melanie Follette-Cook

Ana Prados

Webinar Case Studies

Western US Wildfires Aug-Sep 2020

Agricultural Fires – Sub-Saharan Africa Aug-Sep 2020

Wildfires in Southern Mexico May 2019

Learning Objectives

- Understand the different ways fire is detected using satellite observations
- Identify and download satellite-detected fire datasets
- Understand available smoke and aerosol datasets from satellites and how to use them for air quality monitoring during fire events

Fire and Smoke Detection

Fires in Pictures – Google Image Search

Forest Fires in Pictures - Google Image Search

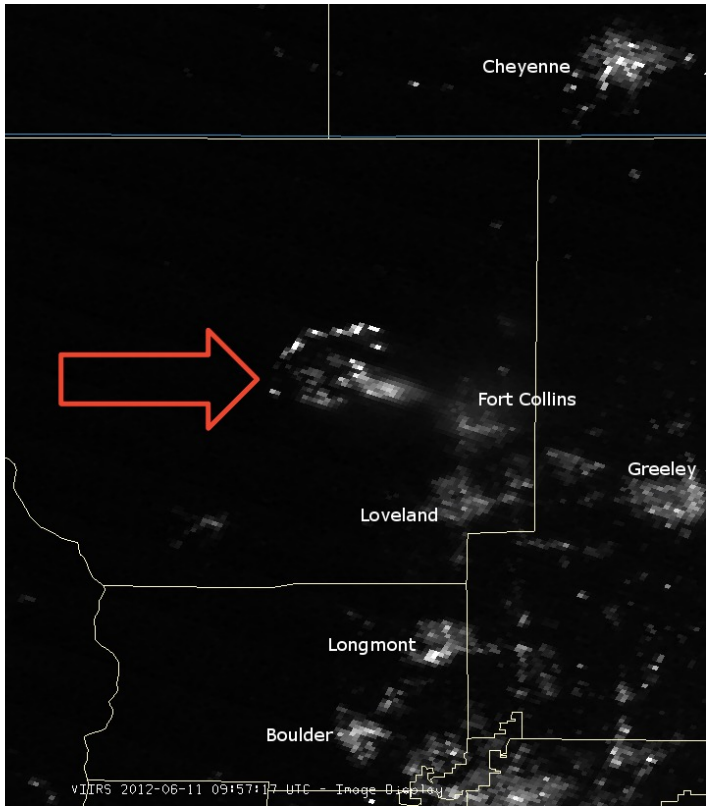
Agricultural Fires in Pictures - Google Image Search

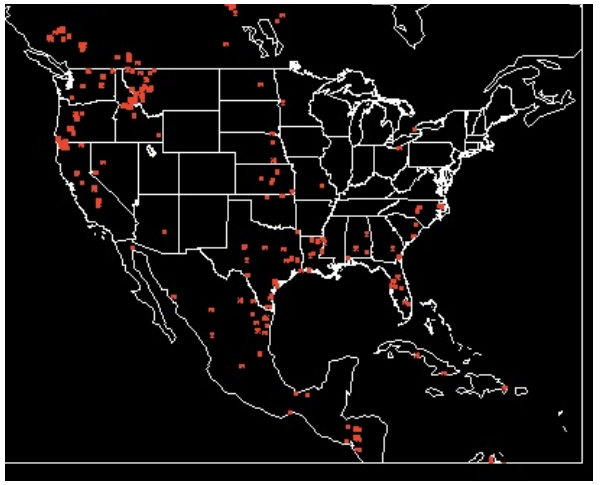
Waste Burning in Pictures - Google Image Search

Fire Detection From Satellites

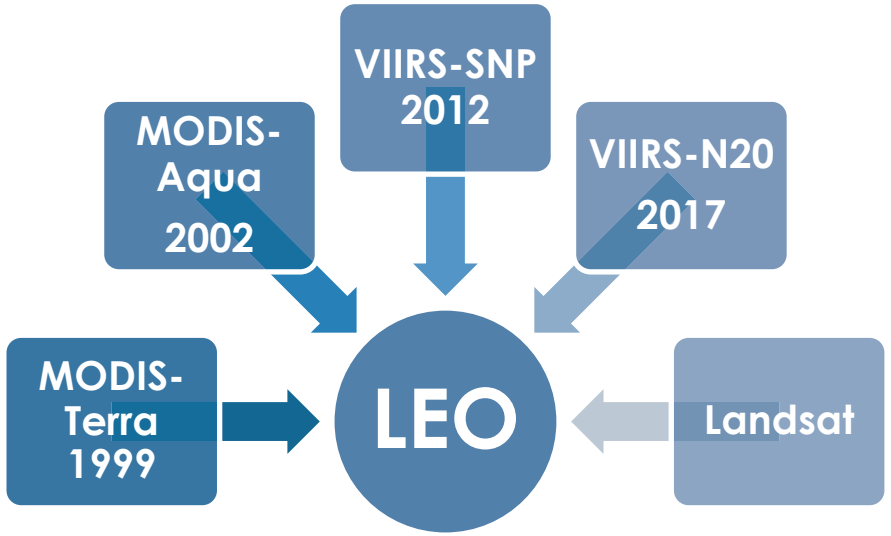
Can be accomplished by detecting:

- Smoke
- Temperature Anomalies
- Light

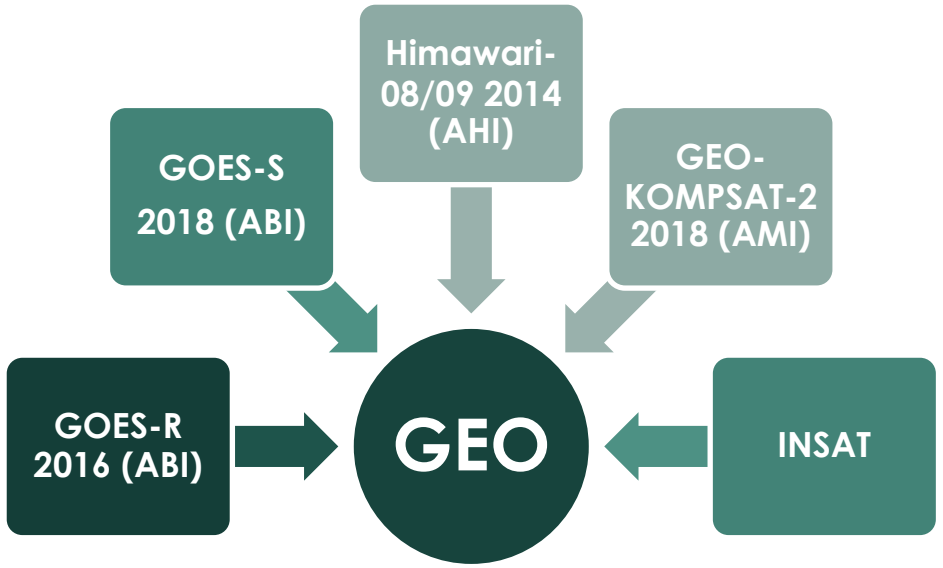




Satellites and Sensors for Fire Detection



Global Coverage, typically twice per 24 hours



Regional Coverage, minutes to hours

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

True Color Image (or RGB) for Visible Smoke

A MODIS "true color image" uses visible wavelength bands 1, 4, & 3.

R = 0.66 µm

G = 0.55 µm

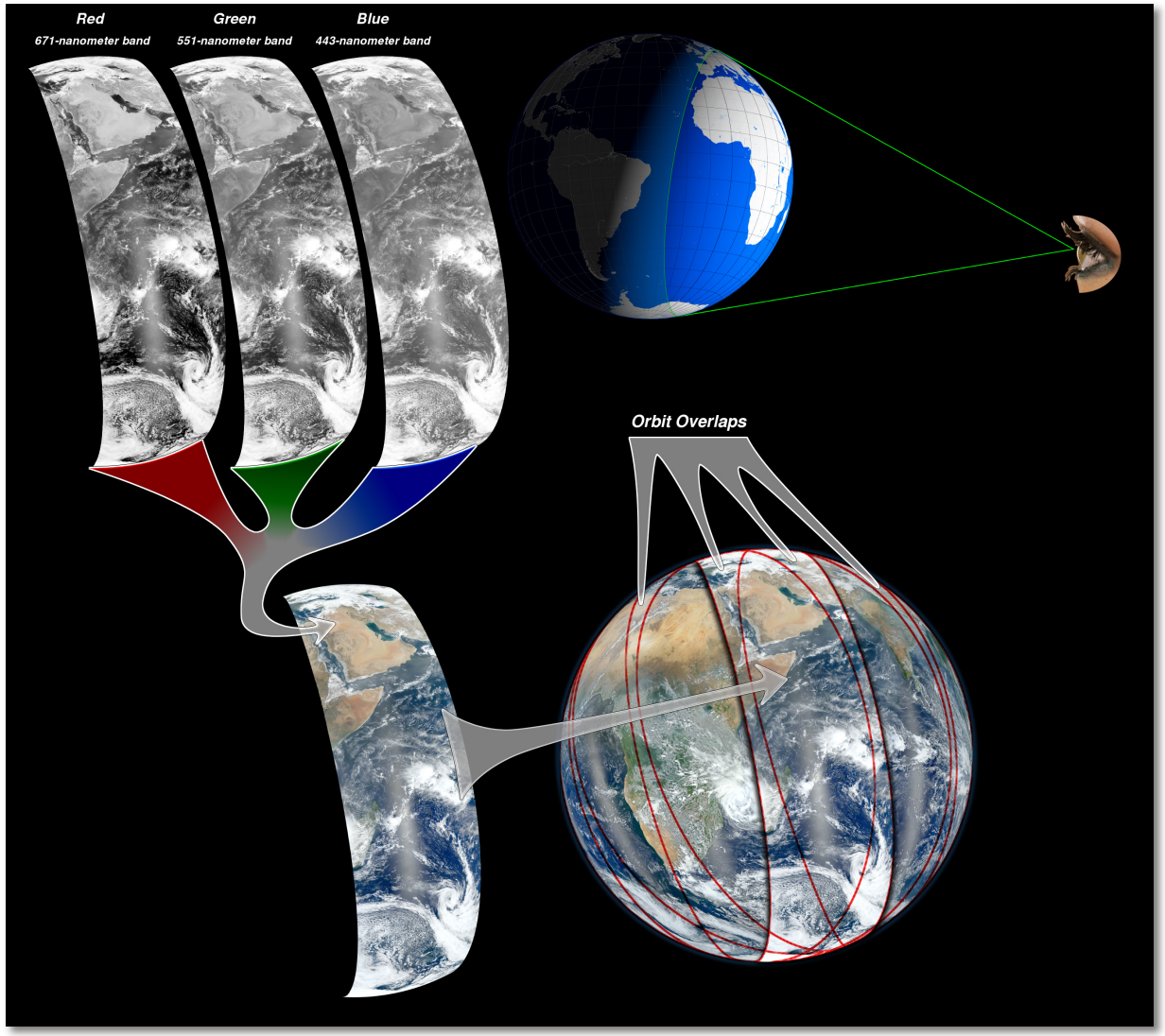
B = 0.47 µm

A VIIRS "true color image" uses visible wavelength bands I1, M4, & M3.

R = 0.640 µm

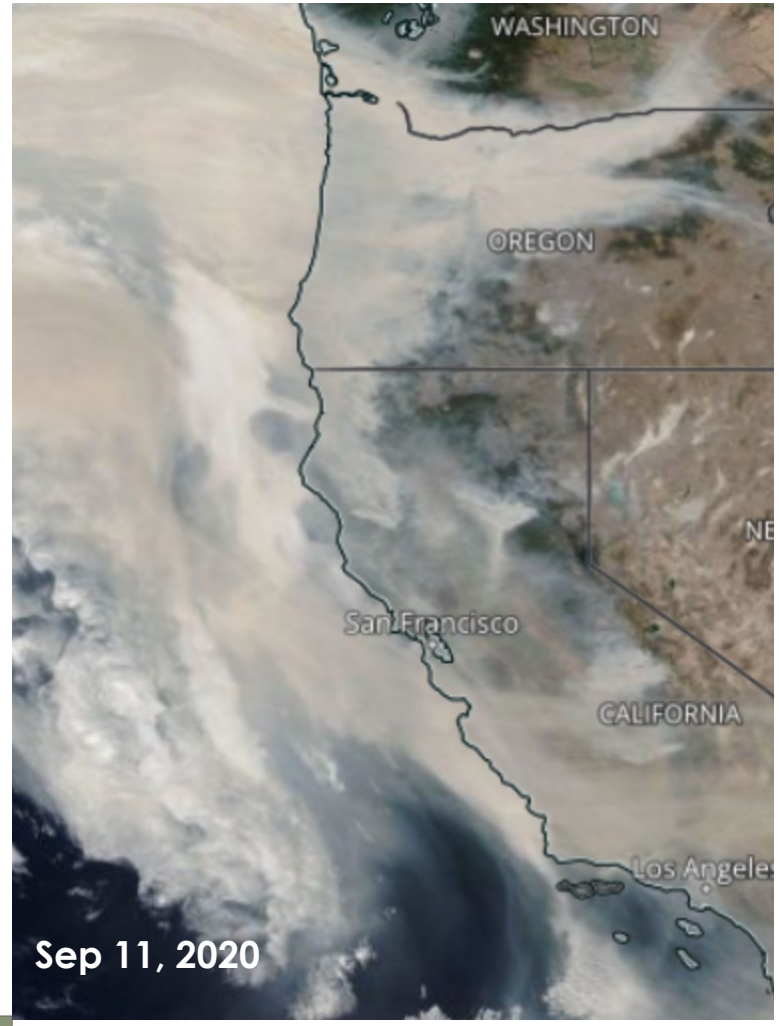
G = 0.555 µm

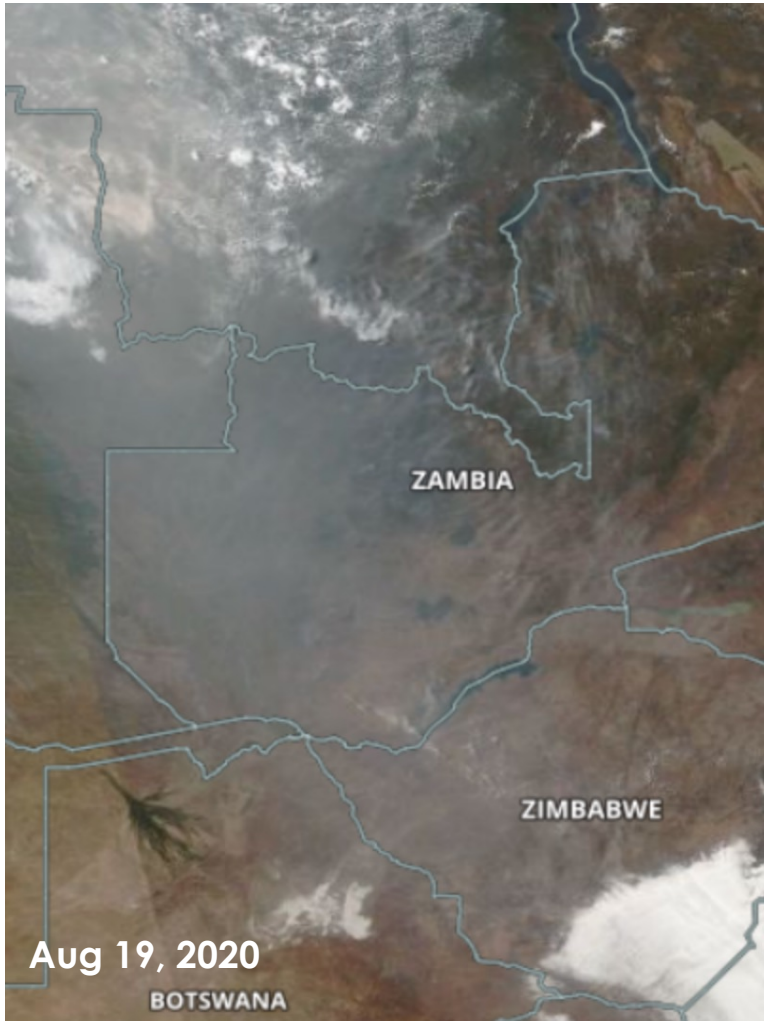
B = 0.488 µm



Visible Smoke from Fires - VIIRS

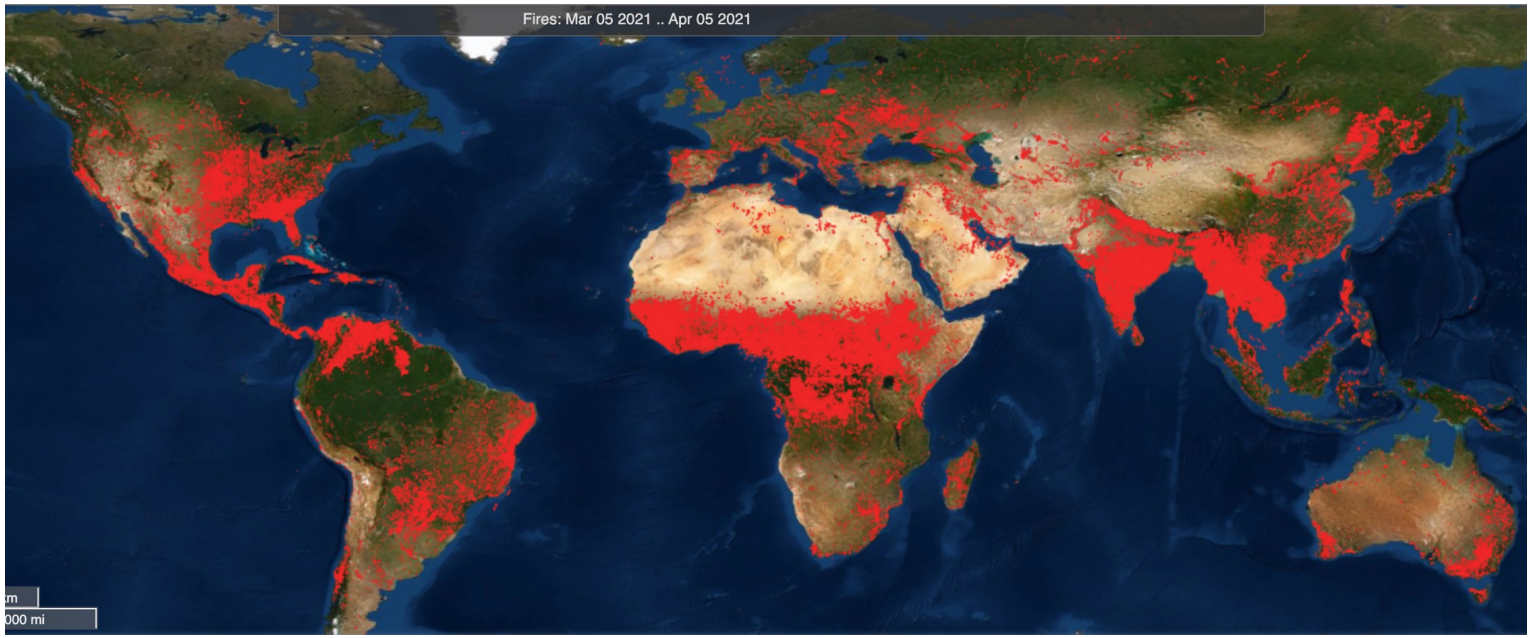
https://worldview.earthdata.nasa.gov/





Active Fire Products (Dataset)

- MODIS (MOD04A1/MYD04A1), VIIRS (VNP14IMGTDL_NRT), and ABI (FDC)
- Near Real-Time (NRT) thermal anomalies
- Provides snapshots of active burning fires

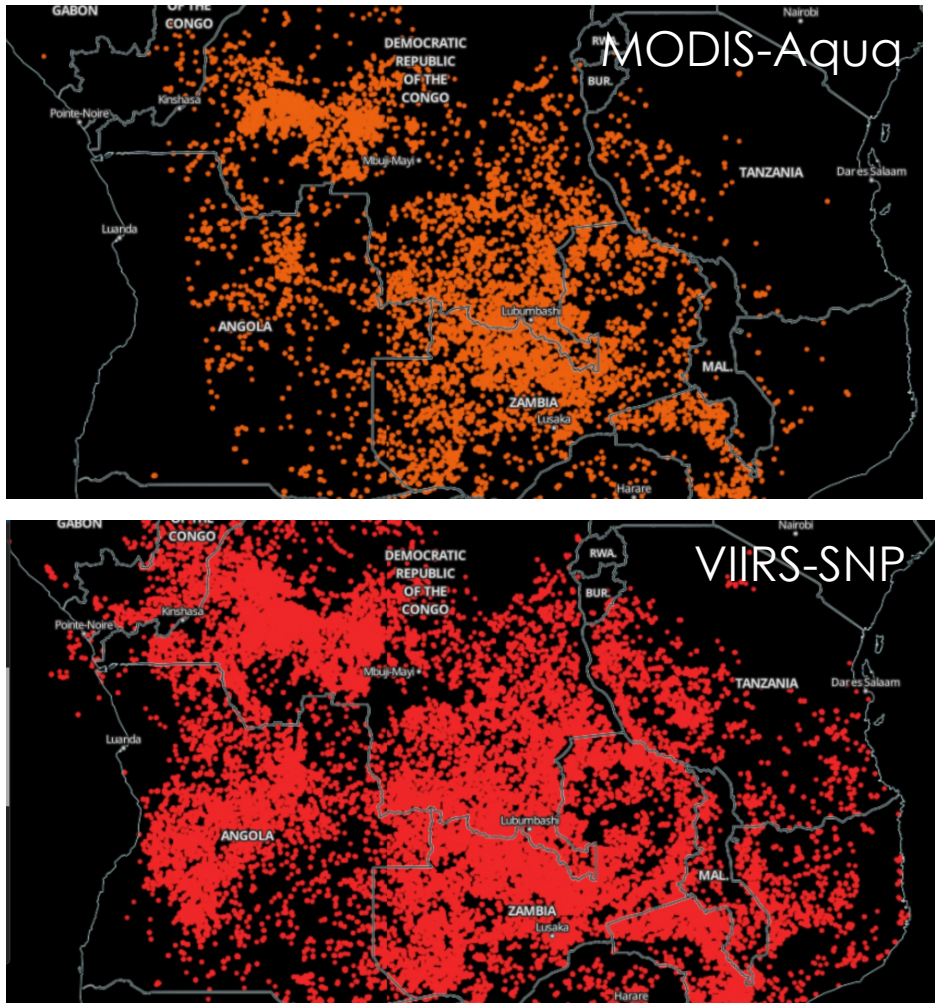


Global Fire Map showing all the fires detected by VIIRS (March 5 – April 05, 2020)

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

Fire Detection

- Fire Detection:
  - Pixel flagged as containing one or more fires
  - MODIS: 1 km
  - VIIRS: 750 m and 375 m
  - ABI (GOES-R/S): 2 km
  - Can also detect volcanic signatures
  - VIIRS Detects 3-4x more fires than MODIS globally.



August 12, 2020, NASA Worldview

Thermal Anomalies (or Active Fire, or Fire Hotspot) Algorithms

Mask Water and Cloud Pixels

Brightness temperature and reflectance thresholds	Different thresholds for day and night

Fire Detection

Use fixed thresholds on Brightness Temperature (BT) of fire band to identify potential fire pixels	Use complementary data from other channels

Are you sure it's a fire?

Characterize background	Check for bright fire-free targets (glint, coastal regions, deserts, cleared forests)

MODIS C6 Fire Detection Algorithm

http://modis-fire.umd.edu/pages/manuals.php

Table 2: MODIS channels used for active-fire detection and characterization.

Channel	Central wavelength (μm)	Purpose
1	0.65	Sun glint and coastal false alarm rejection; cloud masking.
2	0.86	Bright surface, sun glint, and coastal false alarm rejection; cloud masking.
7	2.1	Sun glint and coastal false alarm rejection.
21	3.96	High-range channel for fire detection and characterization.
22	3.96	Low-range channel for fire detection and characterization.
31	11.0	Fire detection, cloud masking.
32	12.0	Cloud masking.

- Potential fire pixel identified
  - 0.86 reflectance < 0.35
  - BT4 > BT4* (where 300 K ≤ BT4* ≤ 330 K)
  - BT4 – BT11 > ΔBT* (where 10 K ≤ ΔBT* ≤ 35 K)
- Otherwise flagged as a non-fire pixel

VIIRS Fire Detection Algorithm

https://viirsland.gsfc.nasa.gov/PDF/VIIRS_activefire_375m_ATBD.pdf

Channel	Spatial Resolution (m)	Spectral resolution (µm)	Primary Use
I1	375	0.60 – 0.68	Cloud & water classification
I2	375	0.846 – 0.885	Cloud & water classification
I3	375	1.58 – 1.64	Water classification
I4	375	3.55 – 3.93	Fire detection
I5	375	10.5 – 12.4	Fire detection & cloud classification
M13*	750	3.973 – 4.128	FRP retrieval, fire detection over water and across the South Atlantic magnetic anomaly region

Thermal Anomalies Algorithms

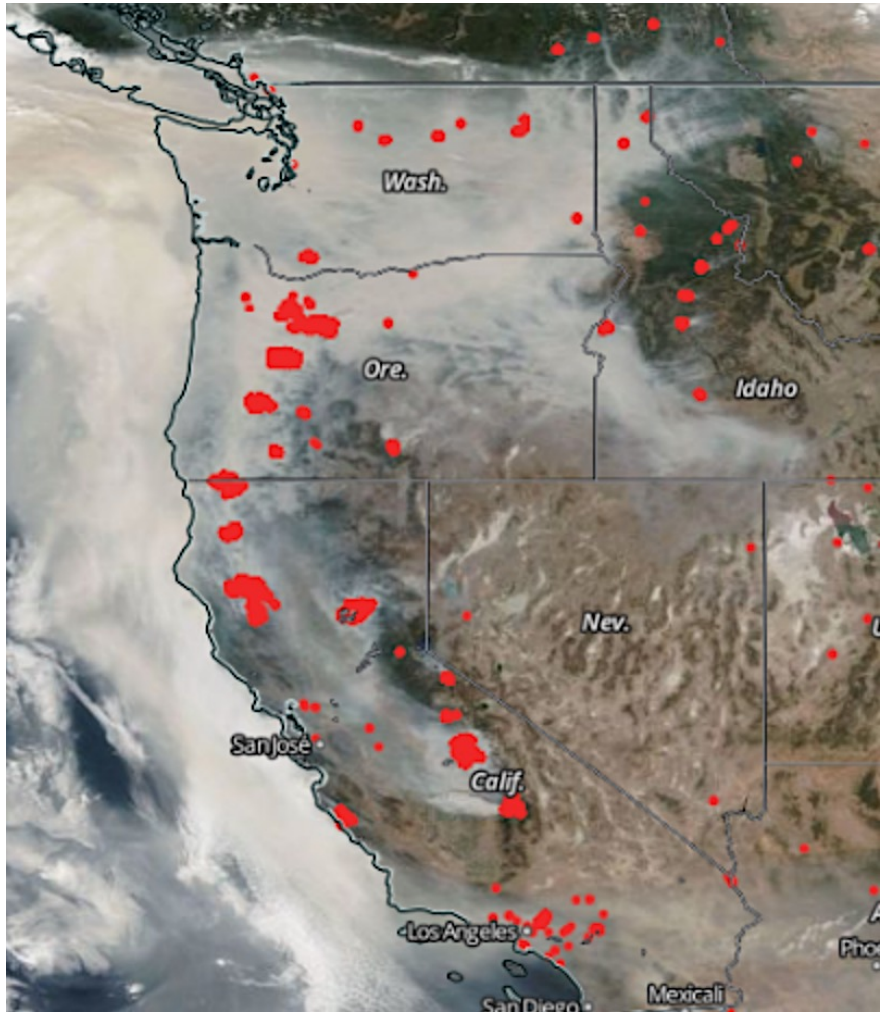
- Limitations:
  - False Positives: Small forest clearings (bare soil)
  - Large fire omissions due to thick smoke
  - Larger pixel size of MODIS and ABI can miss small fires
- MODIS Collection 6 (most recent) improves upon these errors
  - Global commission error (false alarm rate) of 1.2%
  - Similar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

MODIS Fire Detections, NASA Worldview

More details on MODIS data - https://cdn.earthdata.nasa.gov/conduit/upload/10575/MODIS_C6_Fire_User_Guide_B.pdf
More details on VIIRS data - https://viirsland.gsfc.nasa.gov/PDF/VIIRS_activefire_User_Guide.pdf

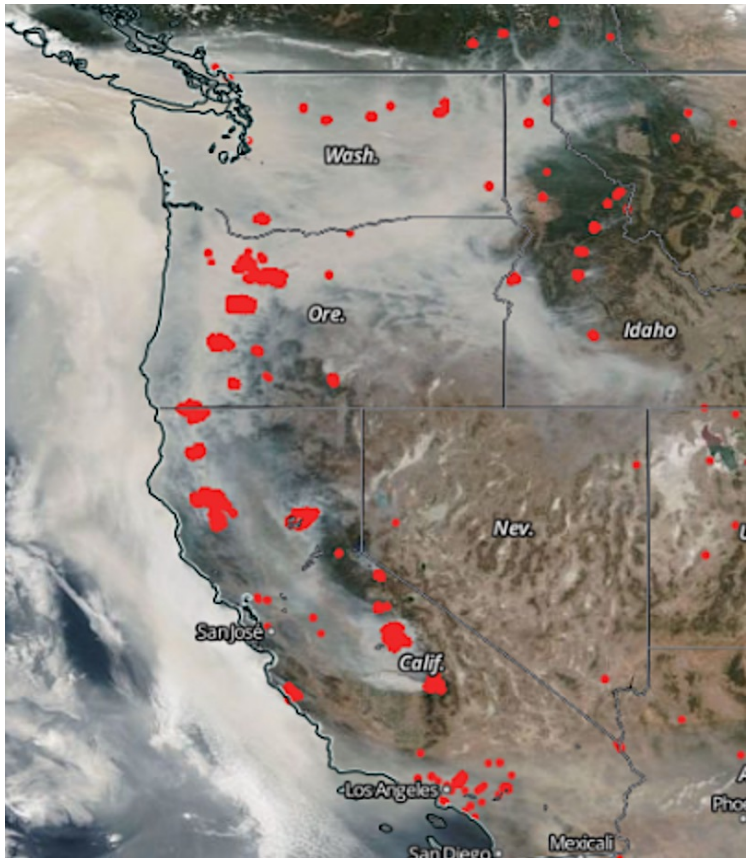
What are fire counts?

- Number of hotspots (or pixels) detected by a satellite/sensor in a certain region of interest over a fixed period is called a 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.
- Users calculate their own fire count

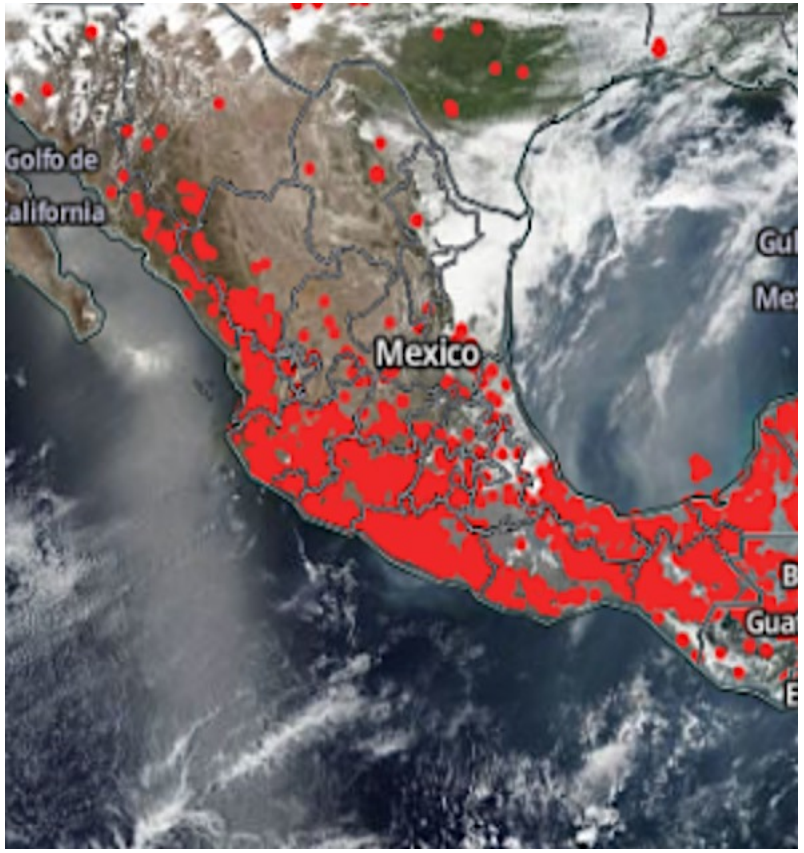


Worldview Tour - Display Fire Hotspots and Smoke

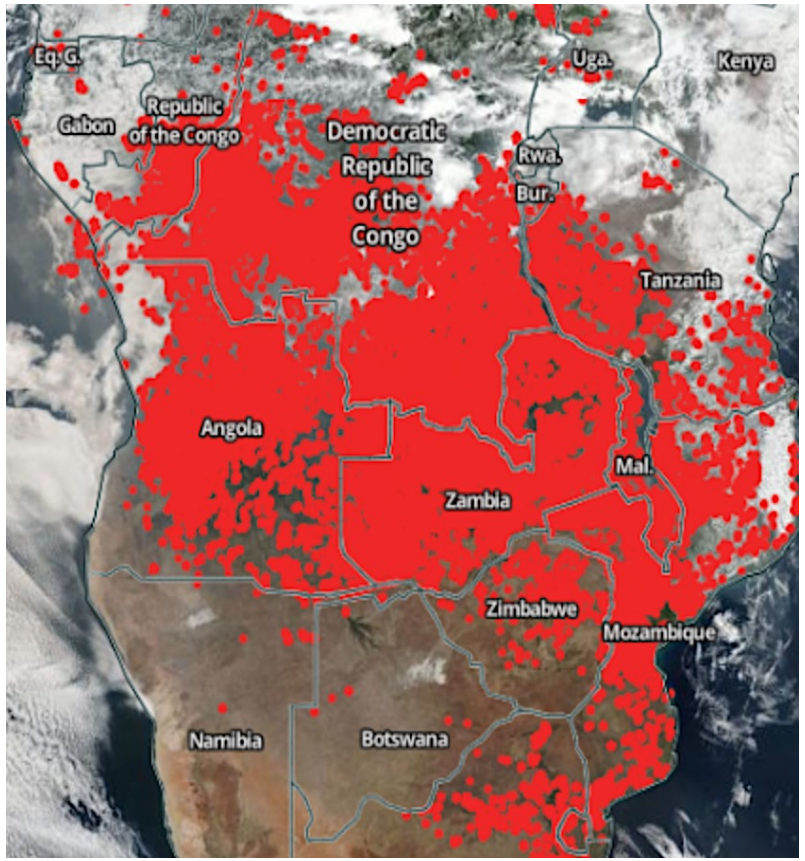
- California Fires



- Mexico Fires



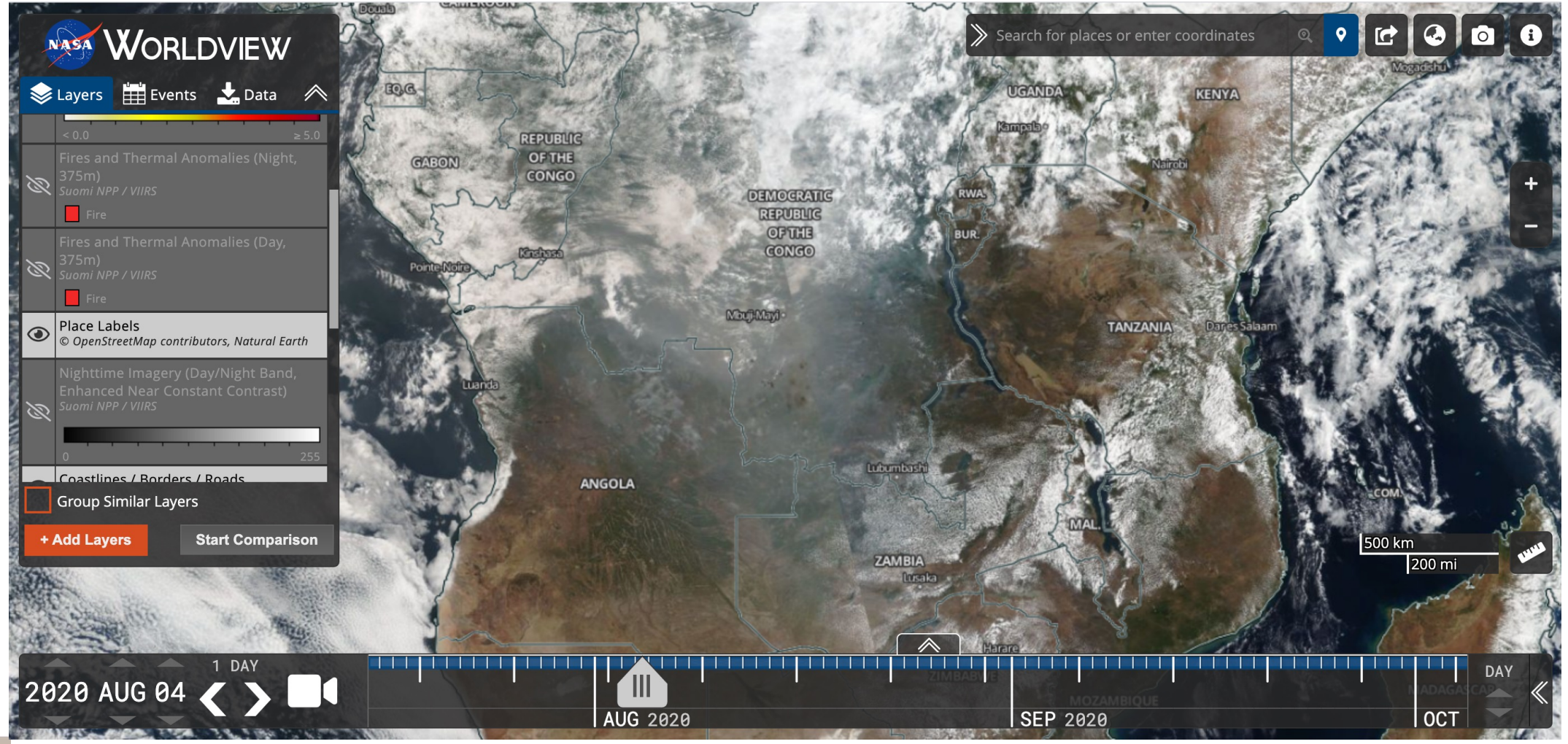
- African Fires



VIIRS Fire Detections, NASA Worldview

Worldview - NASA Near Real Time Data Visualization

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

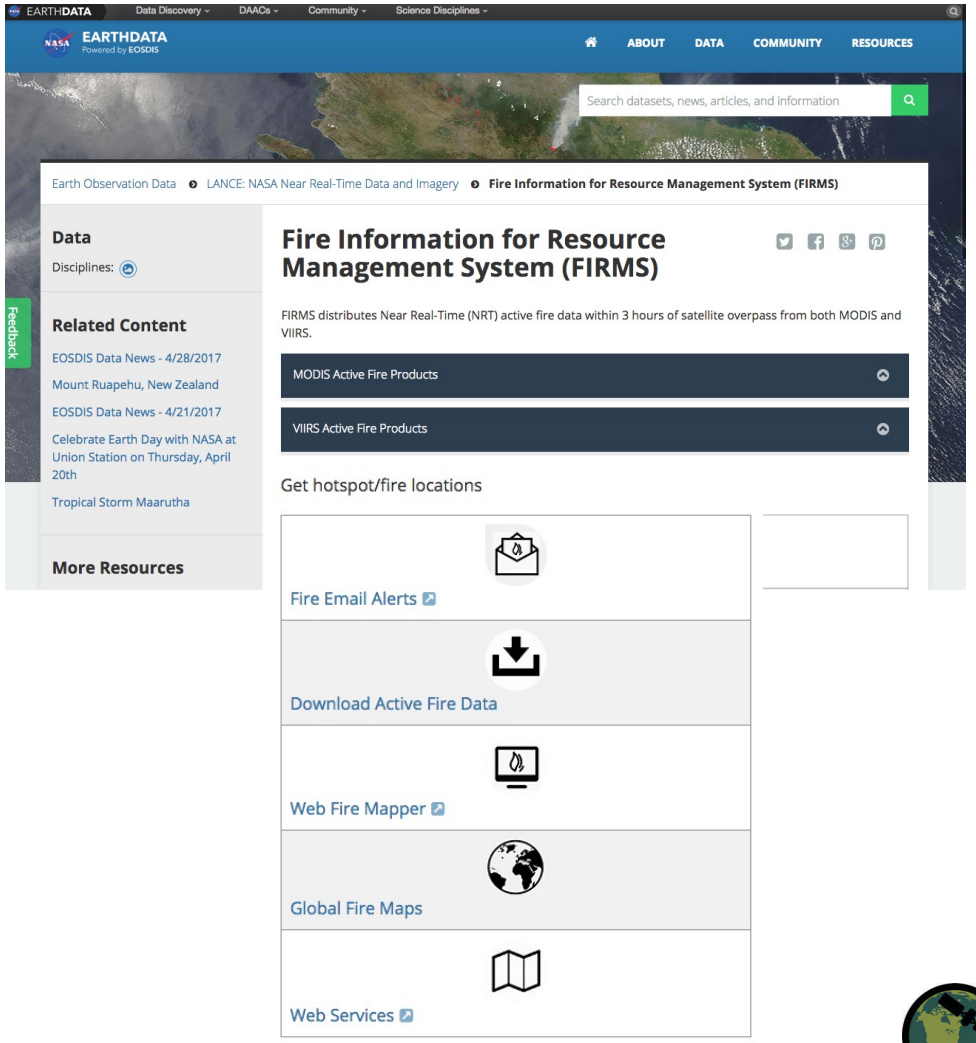


Worldview Tour and Exercise

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



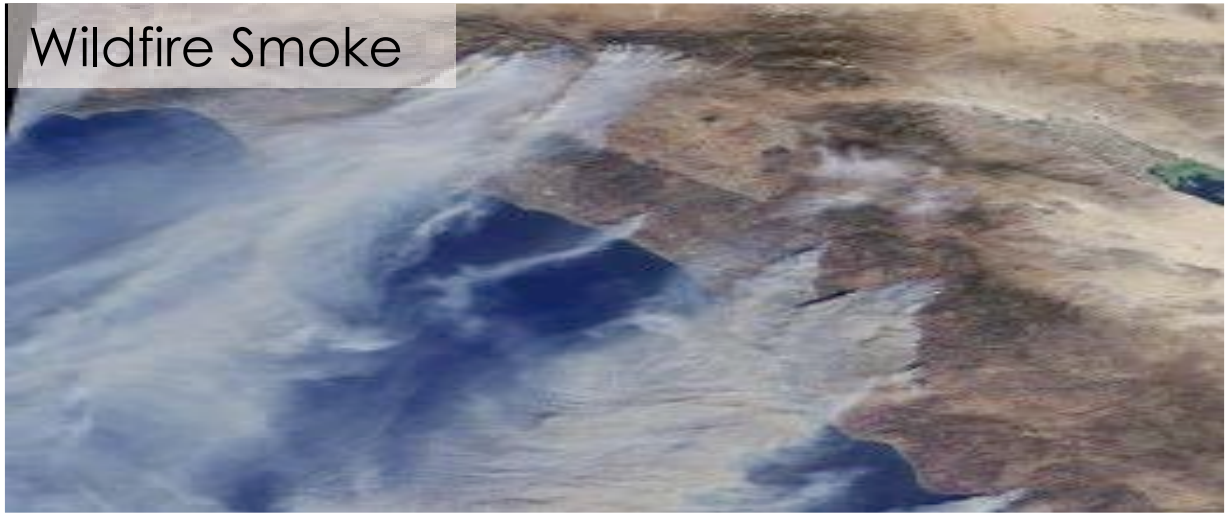
FIRMS Tour and Exercise

Smoke Detection

Smoke Color and Texture in Satellite Images

Smoke from Small Fires

Wildfire Smoke

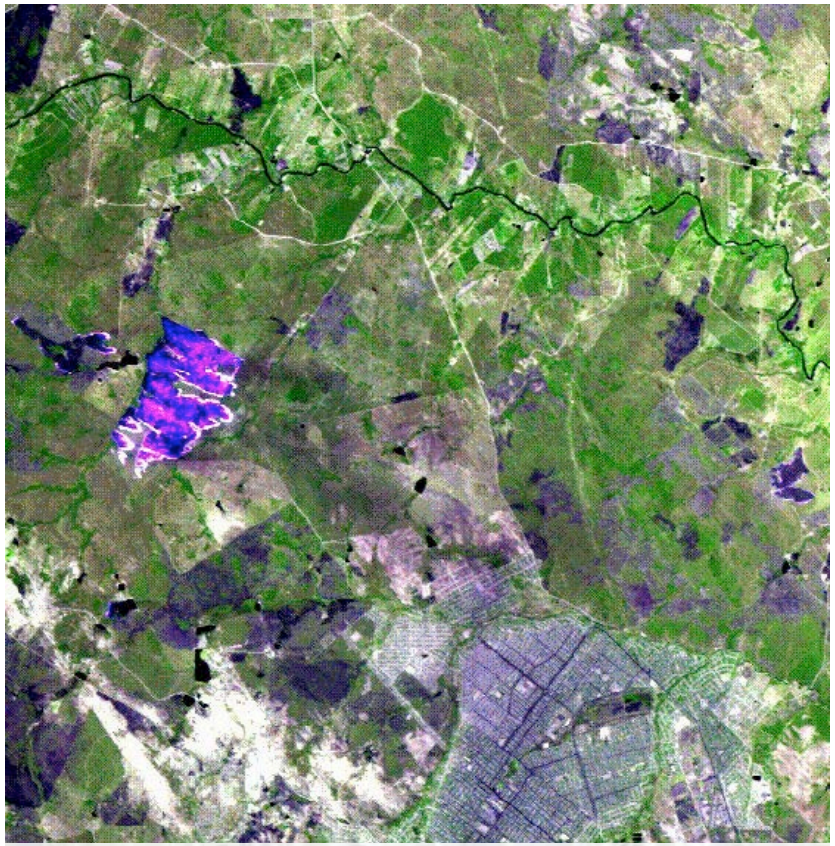


Oil Fires in Iraq

Urban-Industrial/Smoke Pollution

Selection of Spectral Bands for Smoke Detection

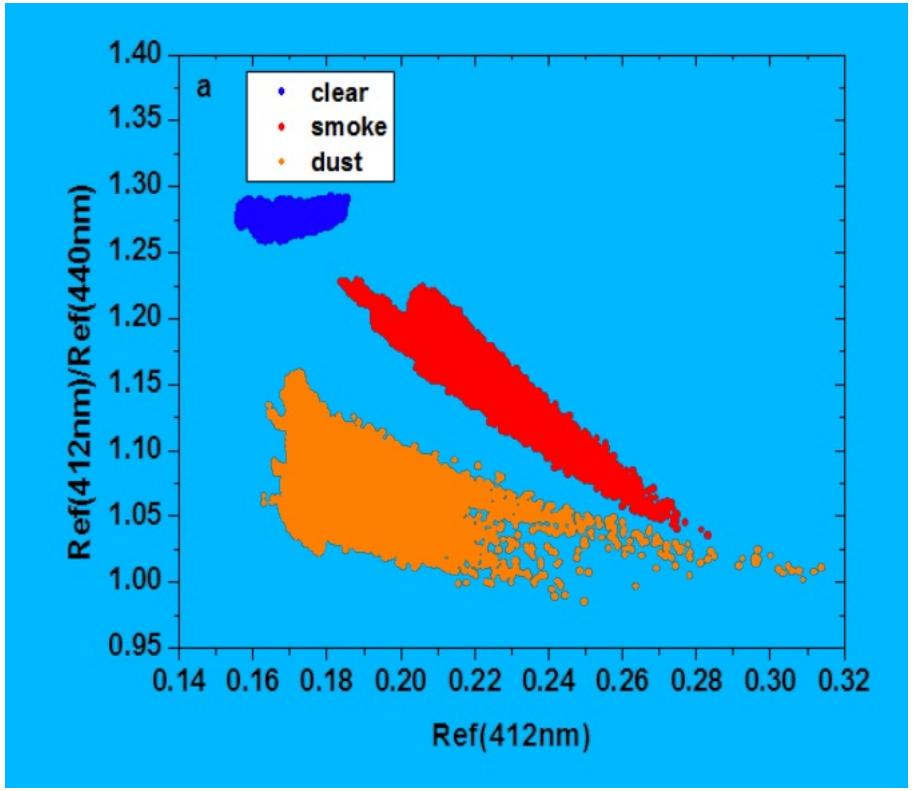
R = 0.66 µm
G = 0.55 µm
B = 0.47 µm

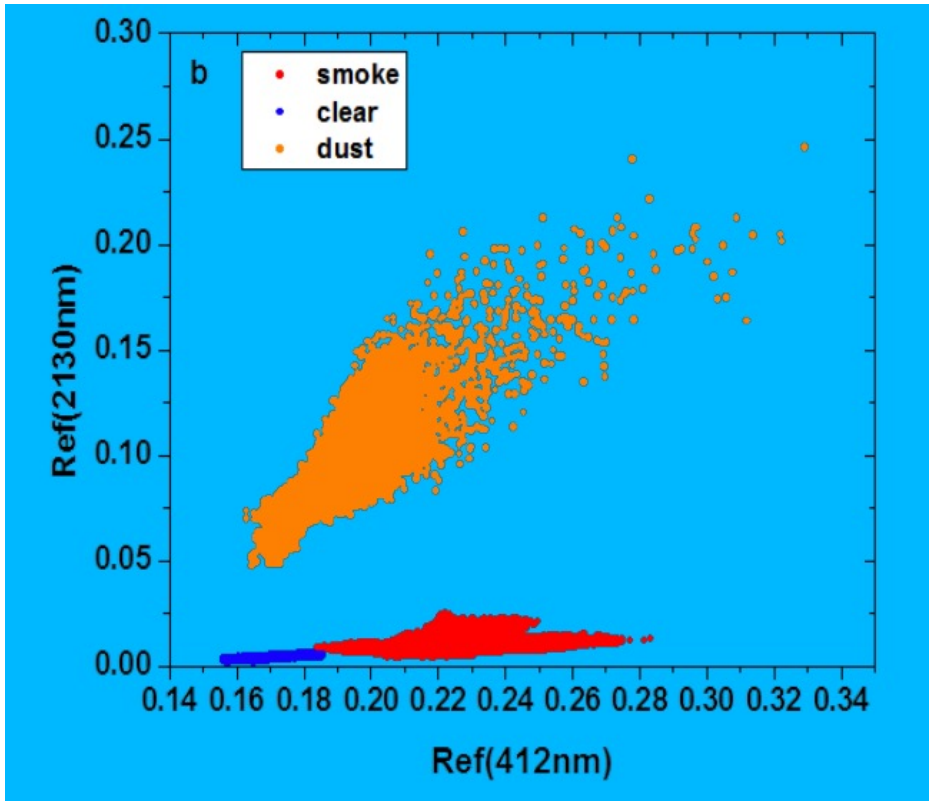


R = 1.6 µm
G = 1.2 µm
B = 2.1 µm

Smoke Detection – Spectral Signature

https://www.star.nesdis.noaa.gov/jpss/documents/ATBD/ATBD_EPS_Aerosol_ADP_v1.1.pdf





Specific spectral responses of dust, smoke, clear, and cloudy parts of the atmosphere allow us to separate and classify different features in a satellite image .

How is smoke/dust detected?

- Smoke/dust reduces the contrast between 412 nm and 440 nm as the absorption increases with the decreasing wavelength.

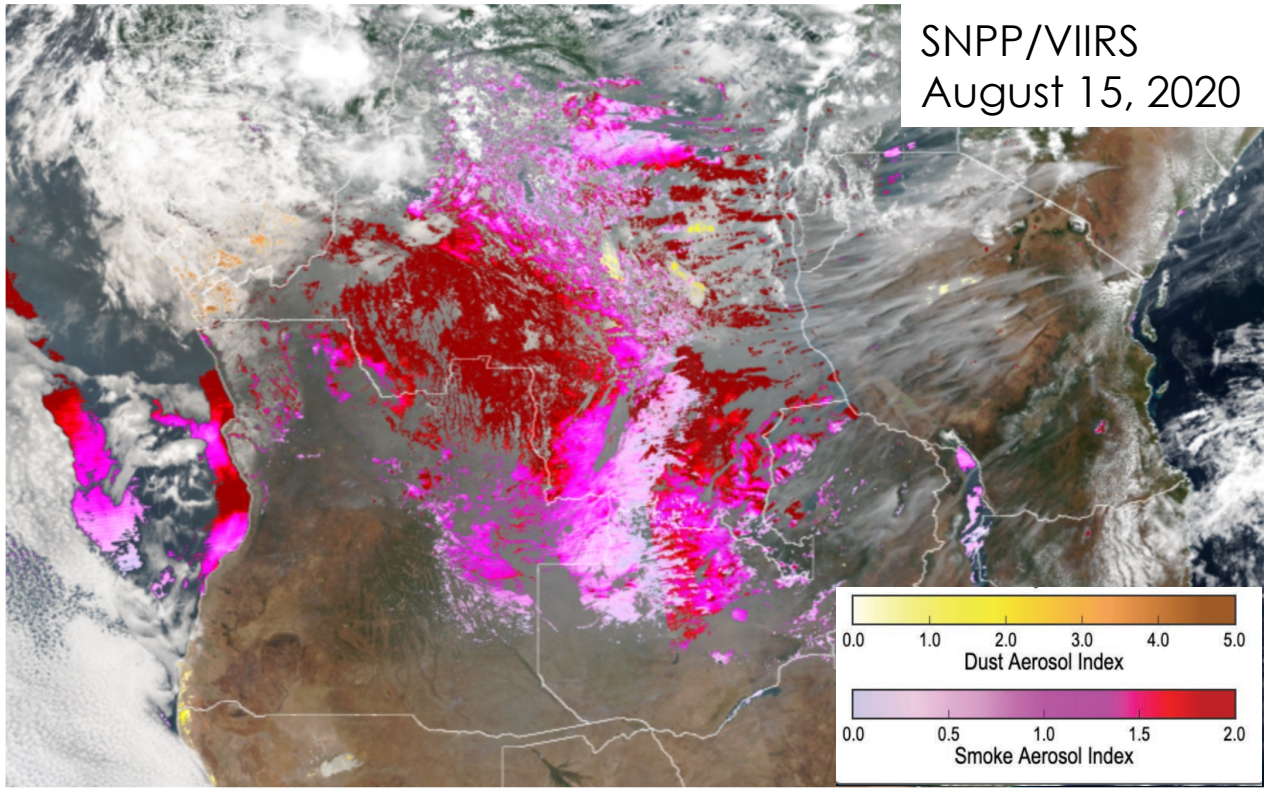
Absorbing Aerosol Index

$$AAI = -100[1og_{10}(R_{412}/R_{440}) - log_{10}(R'_{412}/R'_{440})]$$

- Difference in particle size enables us to pick-out the smoke by introducing the short-wave IR channel (2.25 μm).

Dust, Smoke Discrimination Index

$$DSDI = -10[1og_{10}(R_{412}/R_{2250})]$$



Reference:

1. Algorithm Theoretical Basis Document
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).

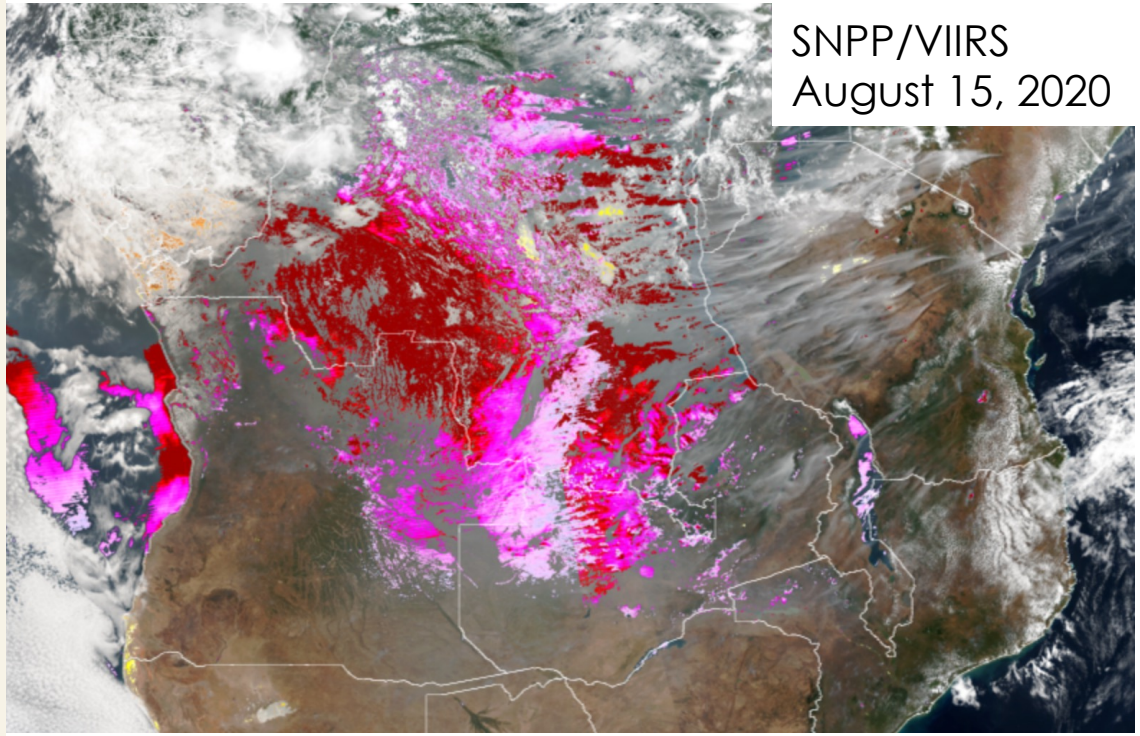
Side Courtesy of Pubu Seren and Shobha Kondragunta

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



SNPP/VIIRS
August 15, 2020

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

File Example - **JRR-ADP_v2r1_npp_s201911010742162_e201911010743404_c201911010834210.nc**

Smoke Monitoring Tools – JSTAR Mapper

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

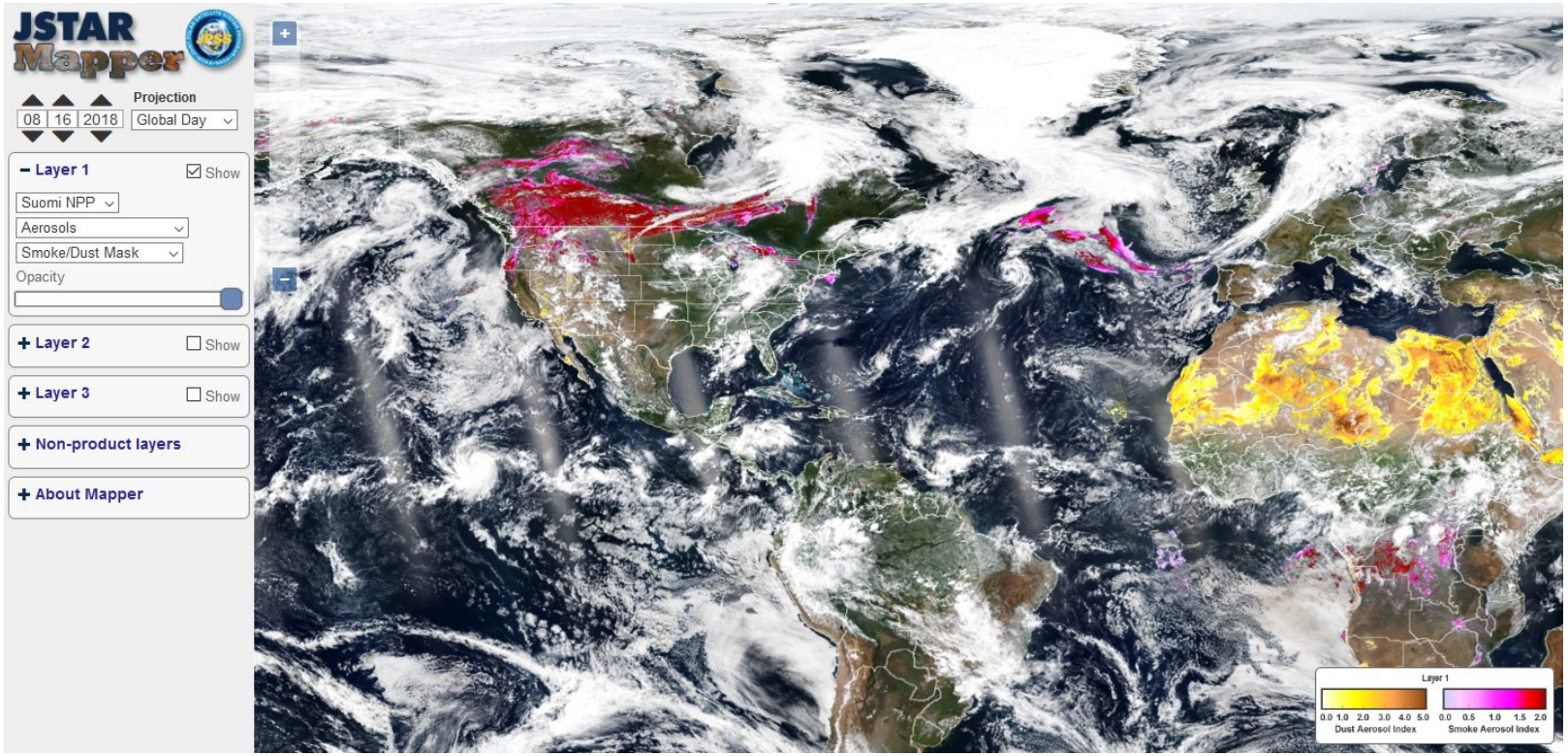
Aerosol Watch

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

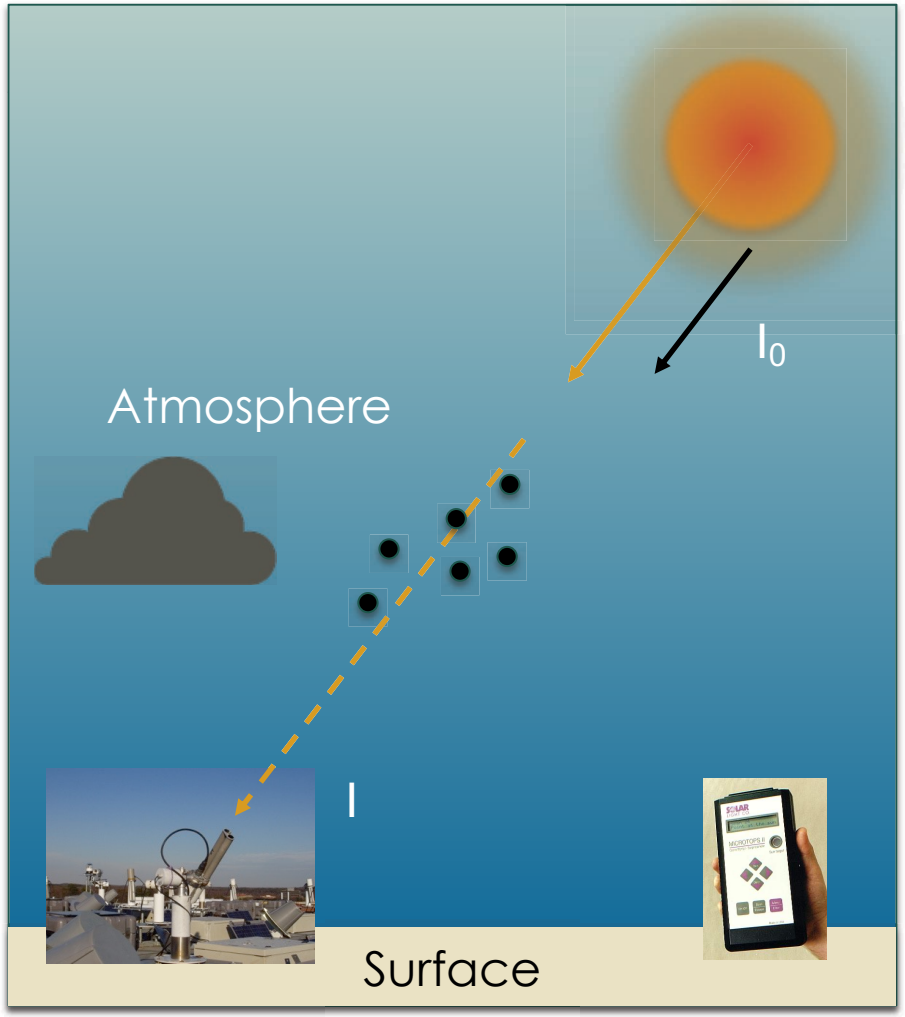
ARSET Training material and recording provide more details on the tool and data



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

Aerosol Data

Aerosol Optical Depth



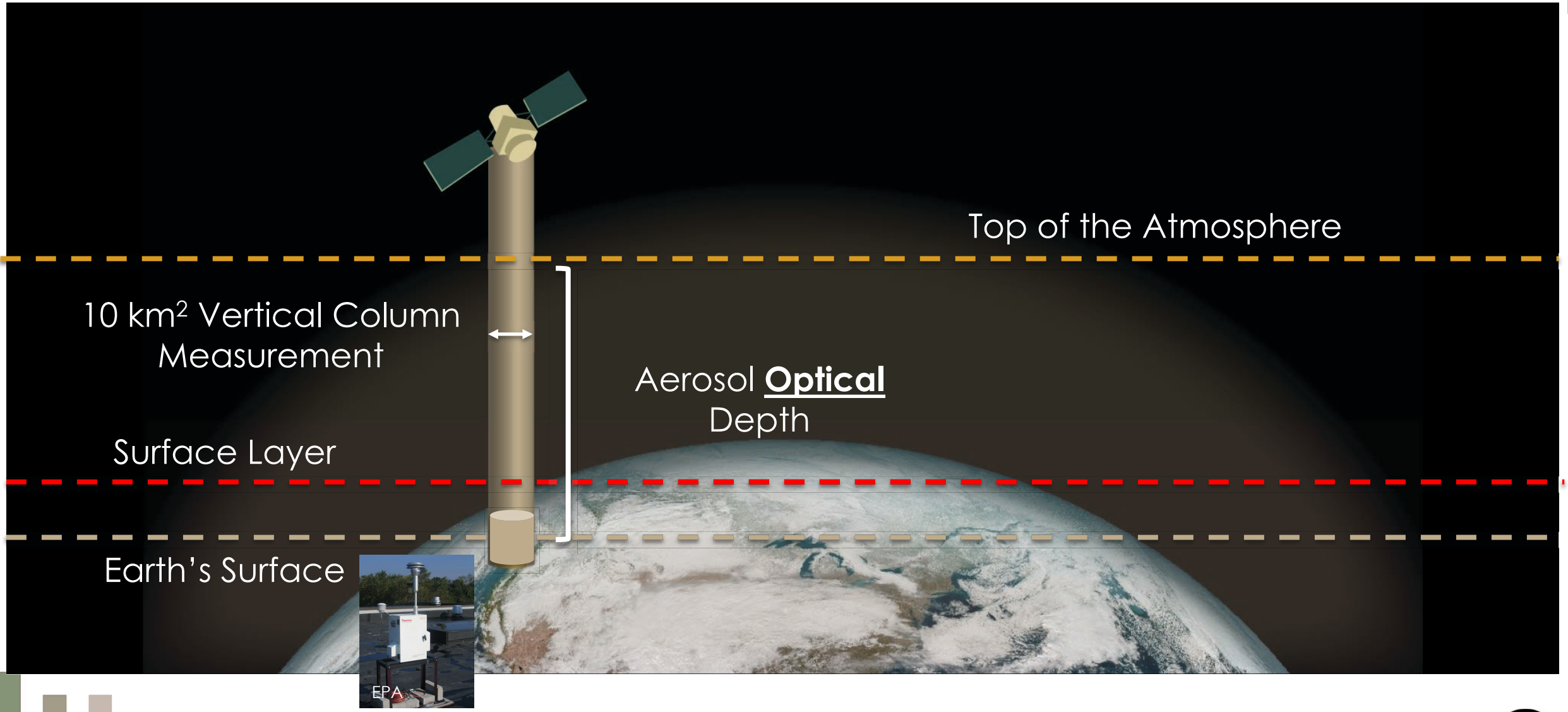
Aerosol optical depth expresses the quantity of light at a certain wavelength removed by aerosols from a beam by **scattering** and/or **absorption** during its path through a medium.

Aerosol optical depth τ as:

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

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

Aerosol Optical Depth



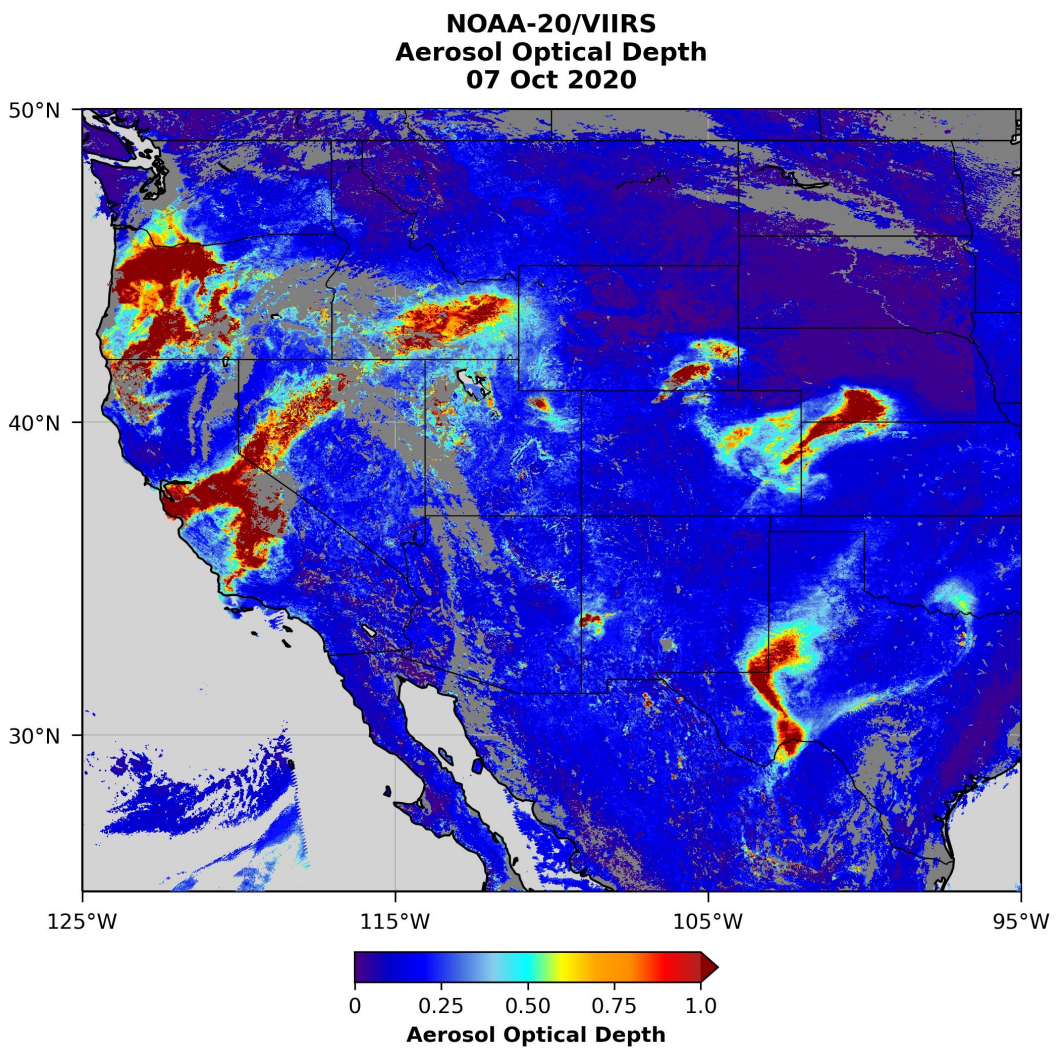
Satellites for Air Quality Data

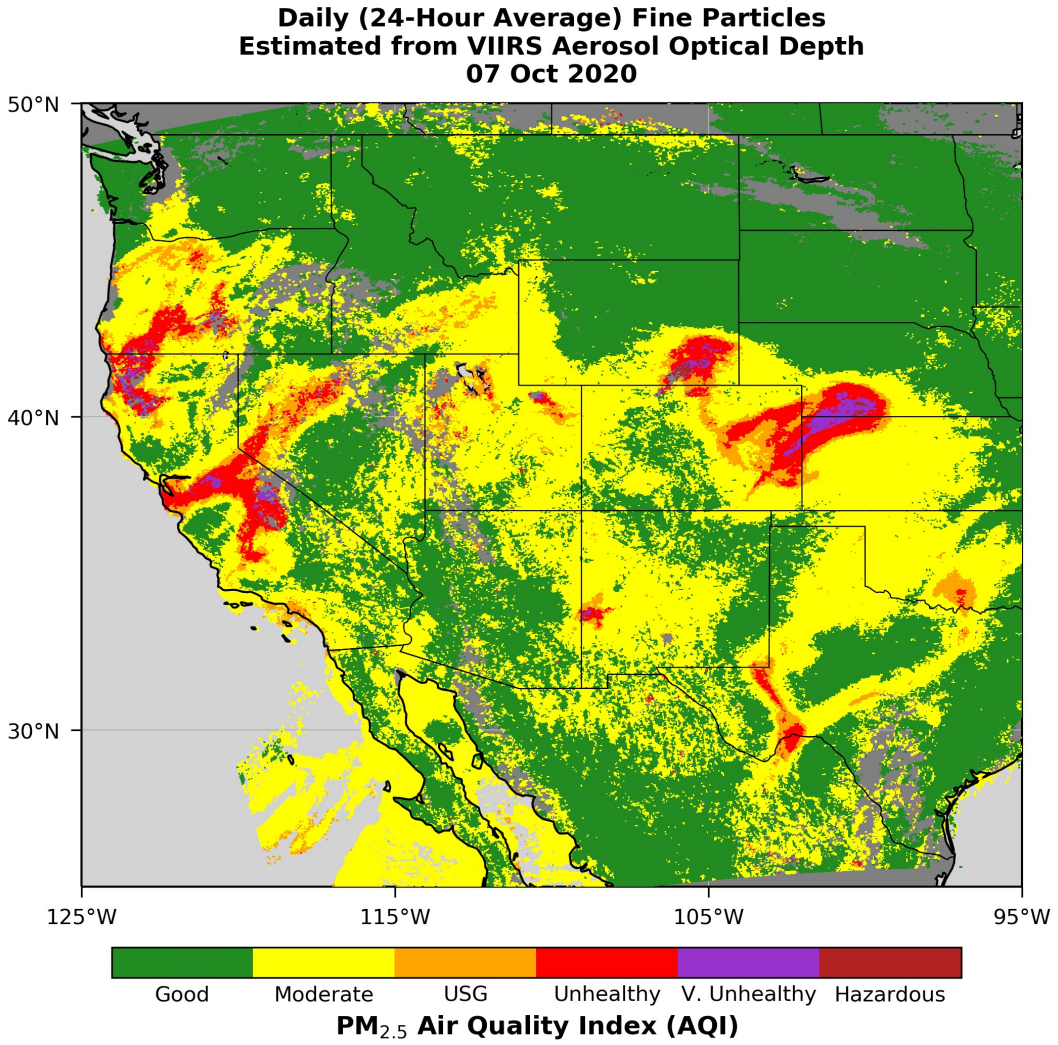
- MODIS (Terra and Aqua)
  - AOD: Columnar Aerosol Loading – Can be used to estimate $PM_{2.5}$ or PM_{10}
- MISR (Terra)
  - Columnar Aerosol Loading in different particle size bins
  - In some cases, Aerosol Heights
- OMI (Aura), OMPS, TROPOMI
  - Absorbing Aerosols, Total Aerosols
  - Trace Gases
  - Aerosol Height
- VIIRS (NPP, JPSS)
  - Aerosol Optical Depth
  - Aerosol Type
- Geostationary Sensors (GOES-R, S, Himawari, KOMPSAT-2, GEMS, GOCI, INSAT)
  - Aerosol Optical Depth
  - Smoke Mask
  - Regional PM2.5 (Research)

CALIPSO, POLDER, etc. and more coming (i.e., MAIA, TEMPO, Sentinel-4)

In this presentation, we will focus on VIIRS, GOES-R, and TROPOMI aerosol data.

Aerosol Optical Depth to PM2.5

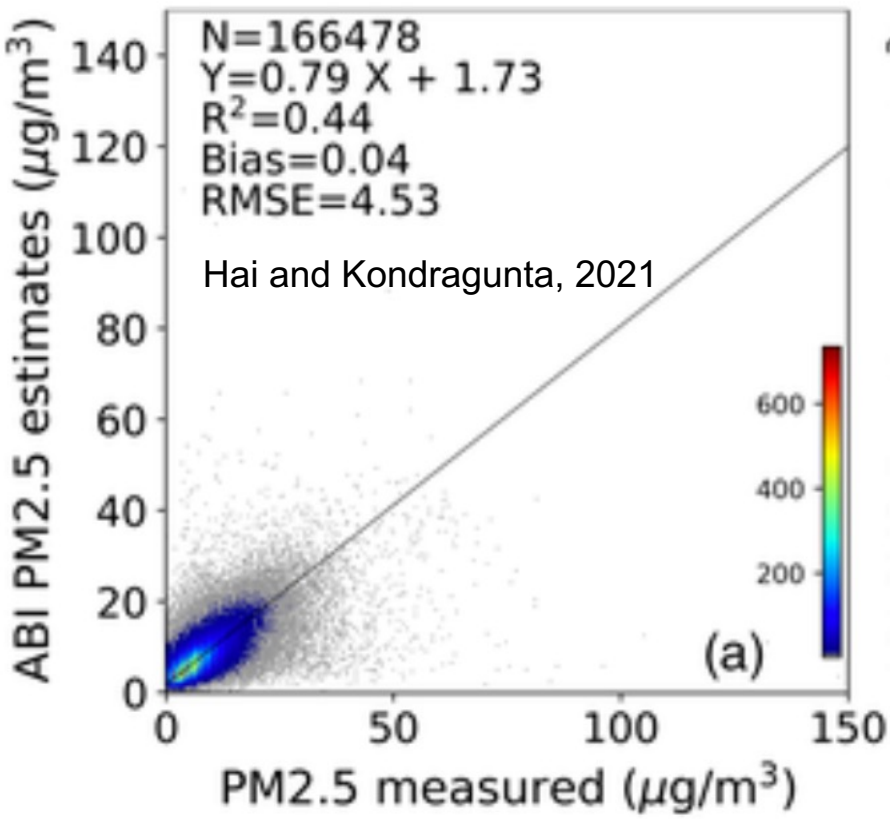


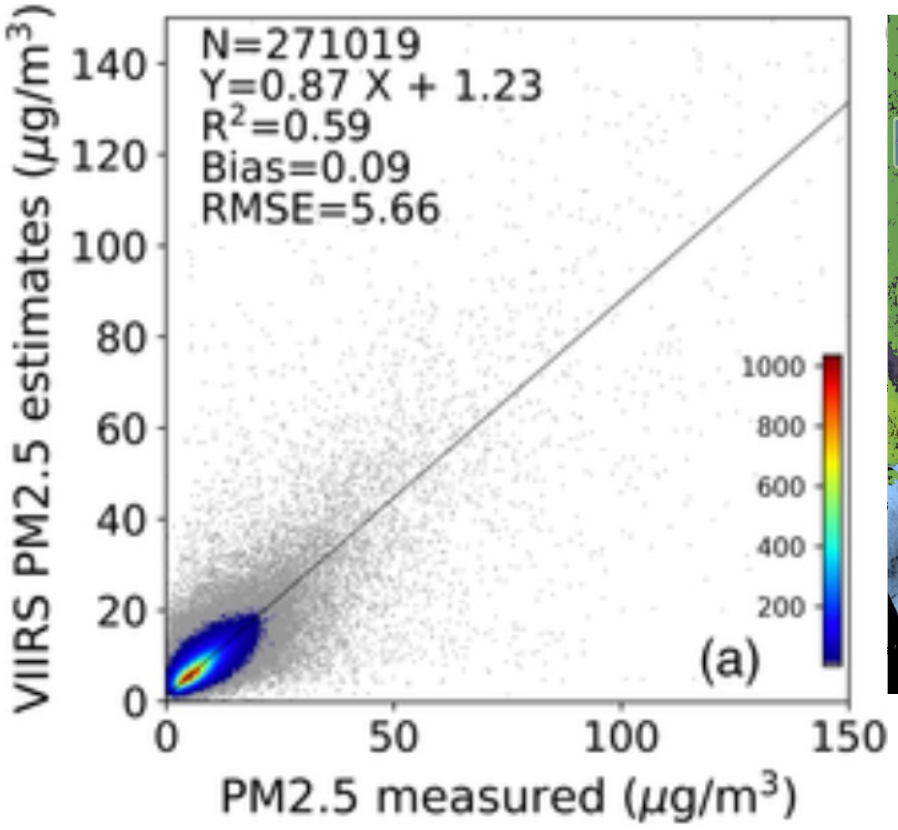


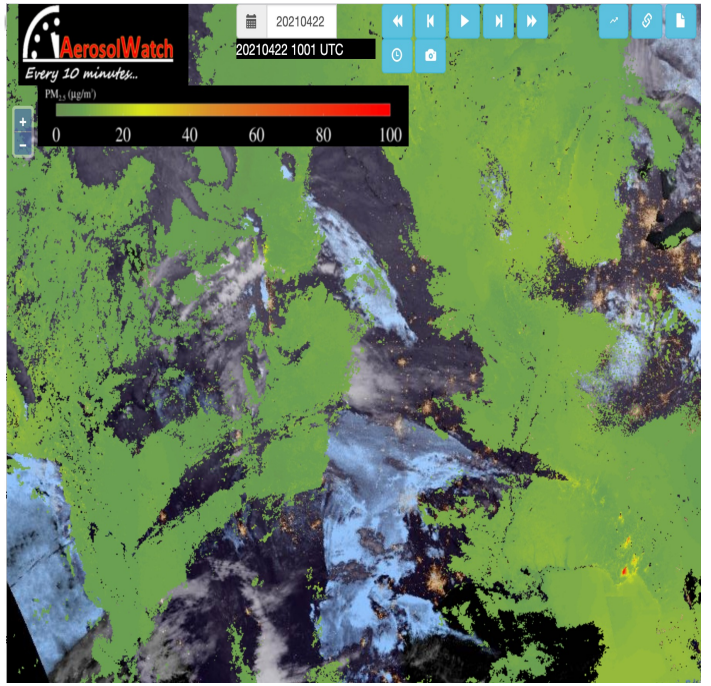
https://twitter.com/AerosolWatch/status/1314208278222569472

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

PM2.5 Data & Access





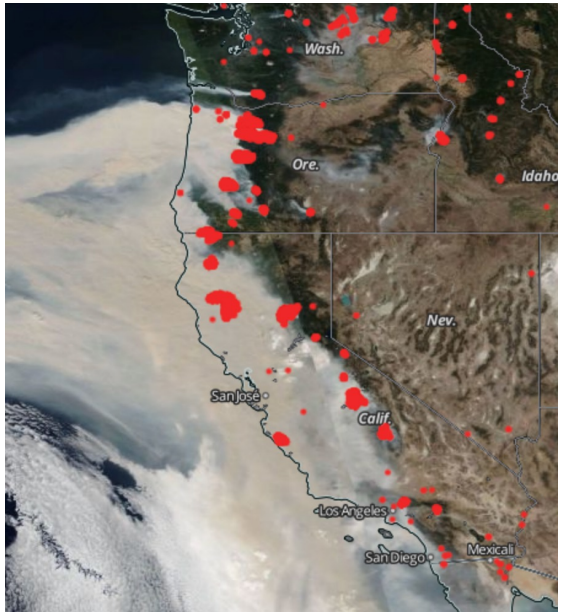


https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2020EA001599

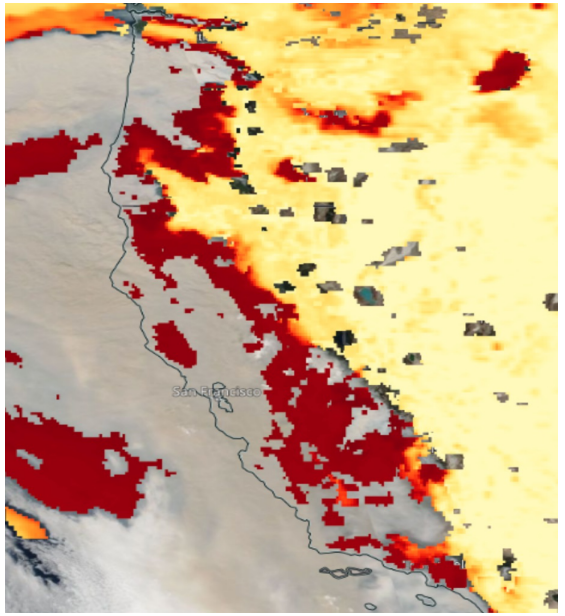
https://www.star.nesdis.noaa.gov/smcd/spb/aq/AerosolWatch/

Putting Everything together – Air Quality Case Study

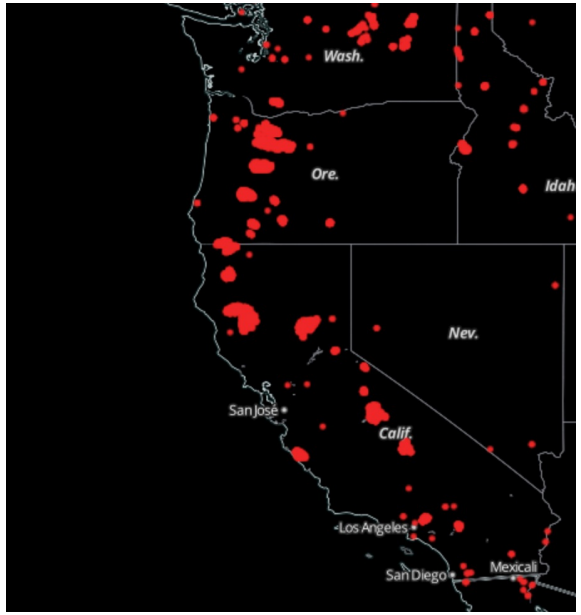
Western US Fires - September 9, 2020 – NASA Worldview



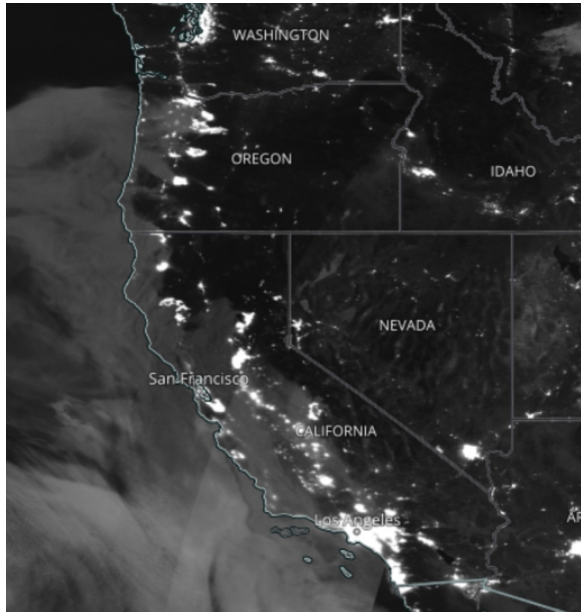
VIIRS - True Color Image



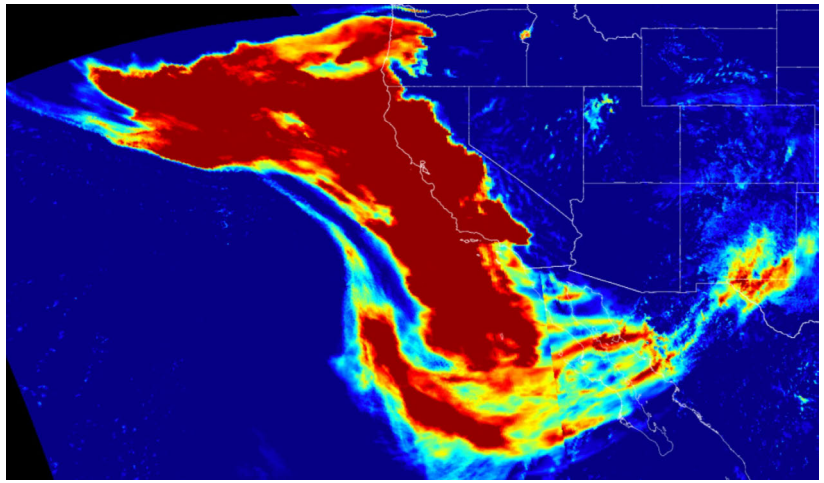
Aerosol Optical Depth



VIIRS – Fire Hot Spots

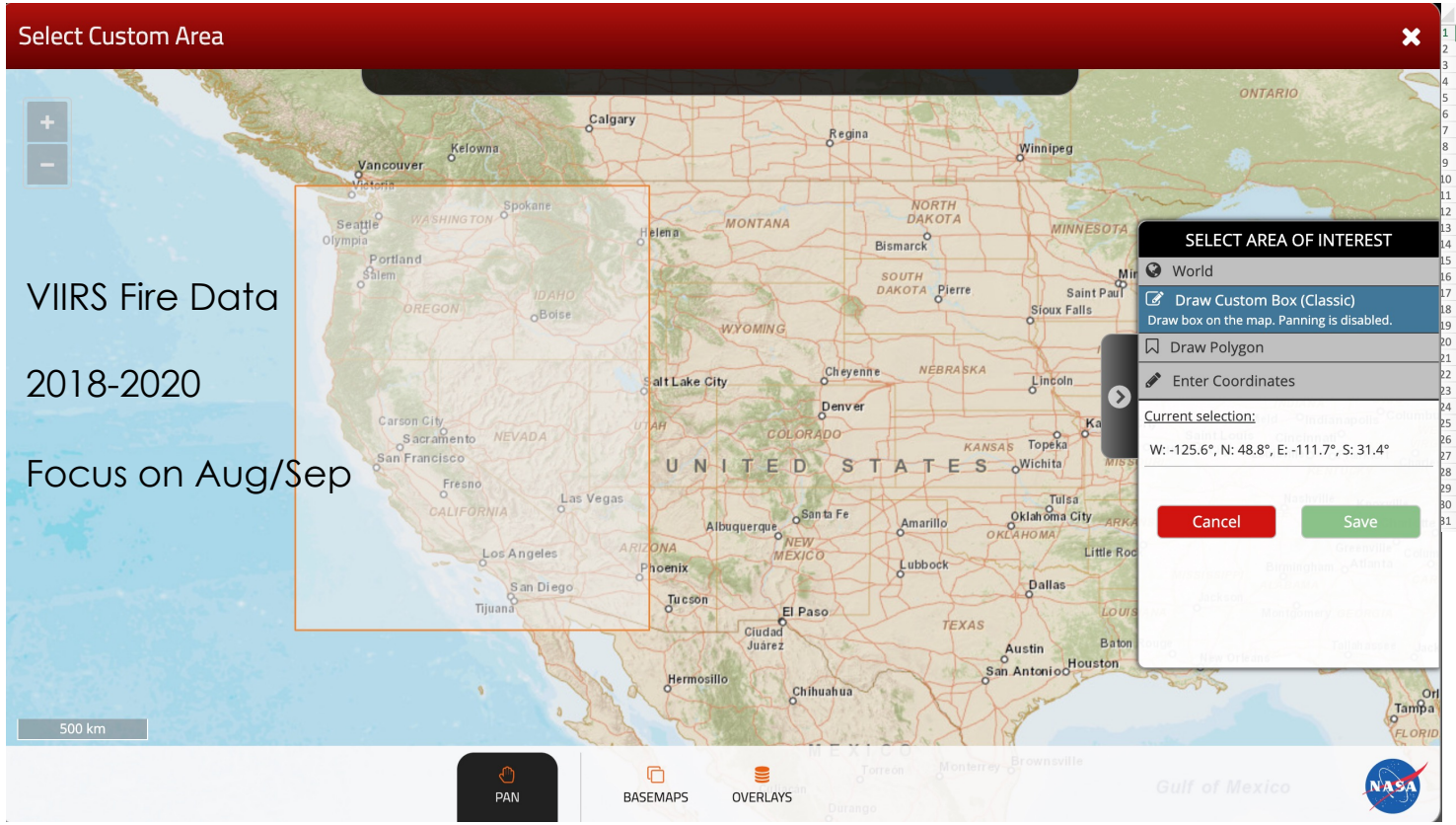


VIIRS – Night Lights



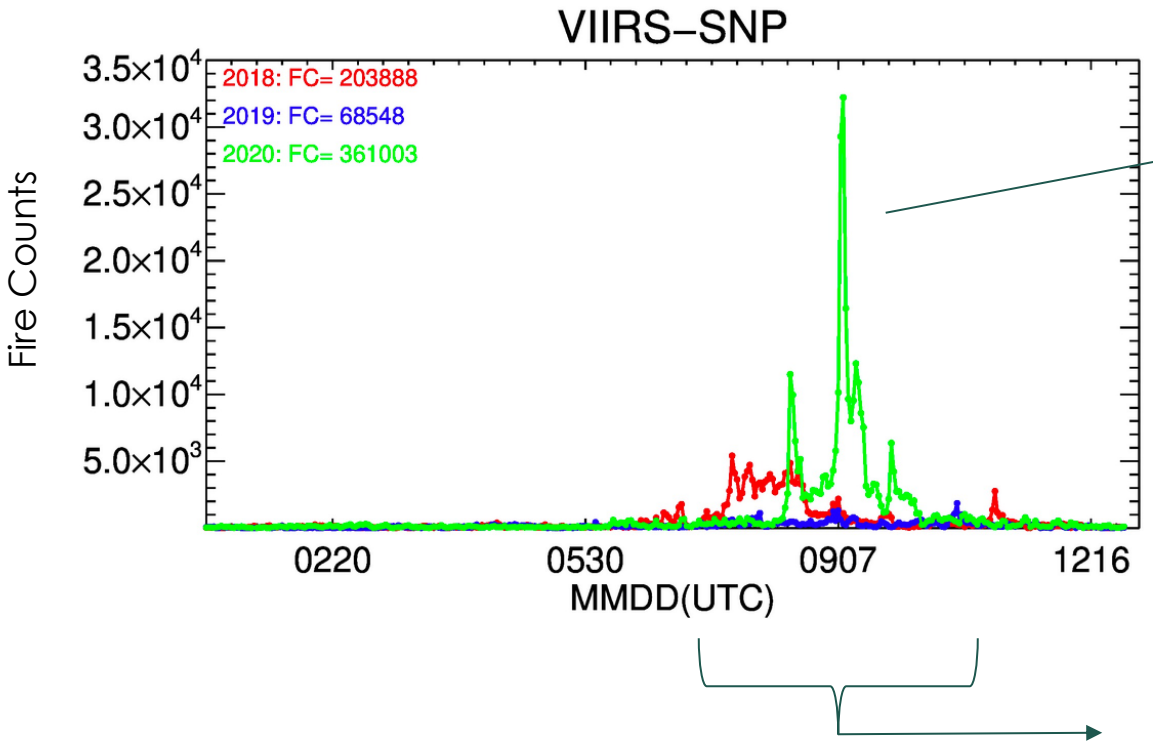
https://www.star.nesdis.noaa.gov/jpss/mapper/

Download Fire Data from FIRMS

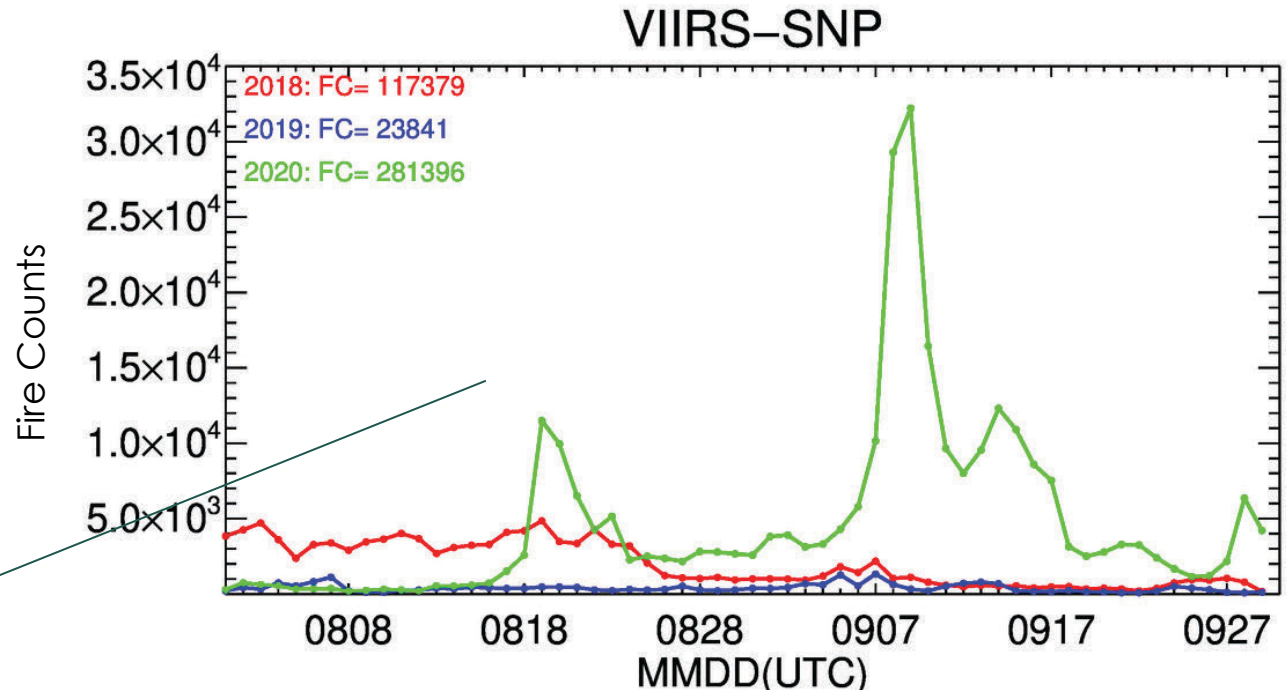


	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	latitude	longitude	bright_ti4	scan	track	acq_date	acq_time	satellite	instrument	confidence	version	bright_ti5	frp	daynight	type
2	28.597708	83.409172	367	0.6	0.71	1/1/18	826	N	VIIRS	l	1	289.67	25.02	D	0
3	28.599108	83.409851	349.68	0.6	0.71	1/1/18	826	N	VIIRS	n	1	283.67	26.76	D	0
4	28.598953	83.407013	367	0.6	0.71	1/1/18	826	N	VIIRS	l	1	283.03	22.98	D	0
5	28.597561	83.406303	354.47	0.6	0.71	1/1/18	826	N	VIIRS	n	1	284.27	25.02	D	0
6	28.592434	83.408409	352.83	0.6	0.71	1/1/18	826	N	VIIRS	n	1	288.61	12.07	D	0
7	29.031992	82.568085	351.45	0.54	0.68	1/1/18	827	N	VIIRS	n	1	296.73	11.9	D	0
8	29.034752	82.568535	335.64	0.54	0.68	1/1/18	827	N	VIIRS	n	1	288.54	5.45	D	0
9	29.964676	80.66275	295.88	0.47	0.48	1/1/18	2051	N	VIIRS	n	1	275.2	0.85	N	0
10	26.917847	87.643944	329.95	0.5	0.66	1/2/18	627	N	VIIRS	n	1	290.32	5.91	D	0
11	27.471279	86.950508	341.9	0.54	0.67	1/2/18	627	N	VIIRS	n	1	283.19	23.14	D	0
12	27.470766	86.948517	367	0.54	0.68	1/2/18	627	N	VIIRS	l	1	285.47	23.14	D	0
13	27.469418	86.943298	325.56	0.54	0.68	1/2/18	627	N	VIIRS	n	1	276.23	9.6	D	0
14	27.47016	86.946167	352.06	0.54	0.68	1/2/18	627	N	VIIRS	n	1	281.07	9.6	D	0
15	27.463888	86.947243	325.2	0.54	0.68	1/2/18	627	N	VIIRS	n	1	278.5	9.6	D	0
16	27.44512	83.89608	326.6	0.32	0.55	1/2/18	807	N	VIIRS	n	1	291.01	1.56	D	0
17	27.7243	84.719139	333.66	0.36	0.58	1/2/18	807	N	VIIRS	n	1	296.44	4.77	D	0
18	27.723976	84.715088	344.7	0.36	0.58	1/2/18	807	N	VIIRS	n	1	298.11	4.77	D	0
19	29.695415	81.850616	367	0.51	0.49	1/2/18	808	N	VIIRS	h	1	303.79	26.41	D	0
20	28.98444	82.515671	342.6	0.55	0.51	1/2/18	808	N	VIIRS	n	1	299.67	9.71	D	0
21	28.7292	80.25531	335.39	0.4	0.44	1/2/18	808	N	VIIRS	n	1	289.85	3.21	D	0
22	28.98402	82.519661	347.22	0.55	0.51	1/2/18	808	N	VIIRS	n	1	299.29	11.06	D	0
23	29.895834	81.859917	297.66	0.47	0.4	1/2/18	2032	N	VIIRS	n	1	270.82	0.87	N	0
24	27.105923	87.105301	295.51	0.34	0.56	1/2/18	2033	N	VIIRS	n	1	281.77	1.18	N	0
25	27.992563	84.423912	326.64	0.55	0.43	1/3/18	748	N	VIIRS	n	1	295.71	2.47	D	0
26	27.953709	84.910782	339.22	0.39	0.44	1/3/18	748	N	VIIRS	n	1	296.35	3.35	D	0
27	27.091135	87.672165	326.28	0.55	0.51	1/3/18	748	N	VIIRS	n	1	296.06	3.72	D	0
28	29.957298	80.658821	329.45	0.41	0.37	1/3/18	749	N	VIIRS	n	1	297.95	3.02	D	0
29	29.081125	82.236092	326.07	0.45	0.39	1/3/18	749	N	VIIRS	n	1	298.07	2.3	D	0
30	29.973759	81.977081	336.57	0.45	0.39	1/3/18	749	N	VIIRS	n	1	291.55	8.13	D	0
31	28.48118	84.995369	332.35	0.4	0.44	1/3/18	749	N	VIIRS	n	1	301.51	4.95	D	0

Fire Counts – VIIRS SNP

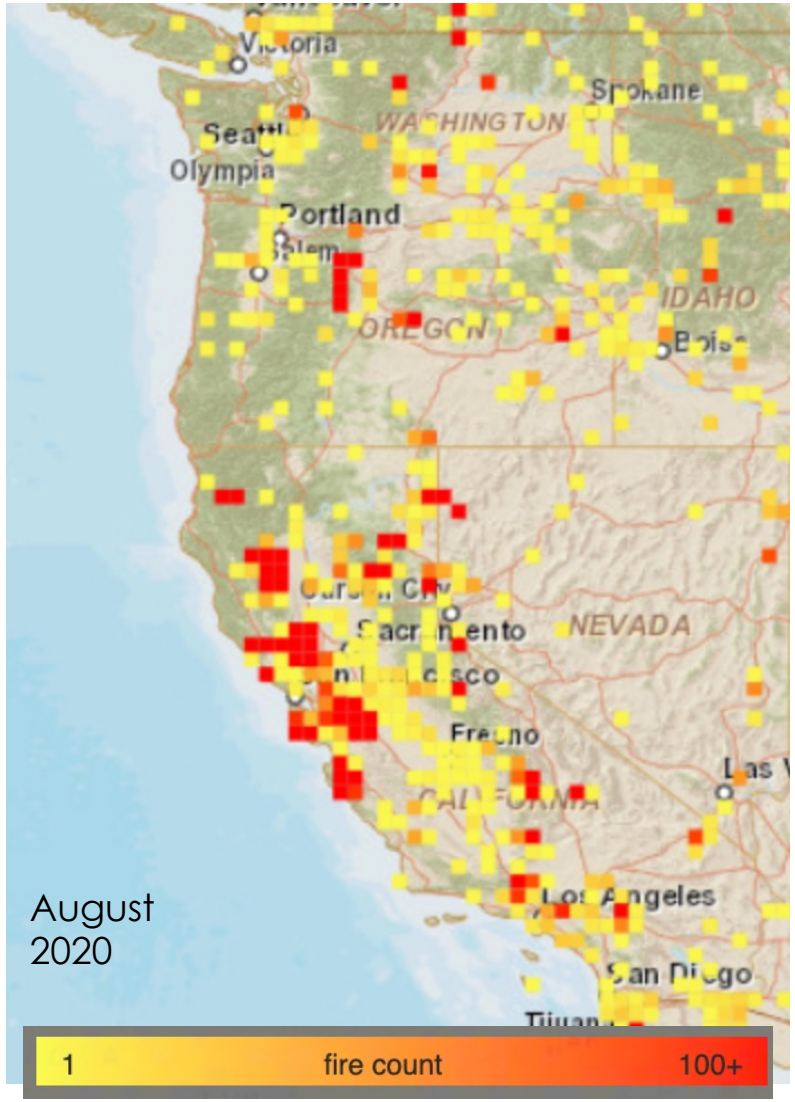


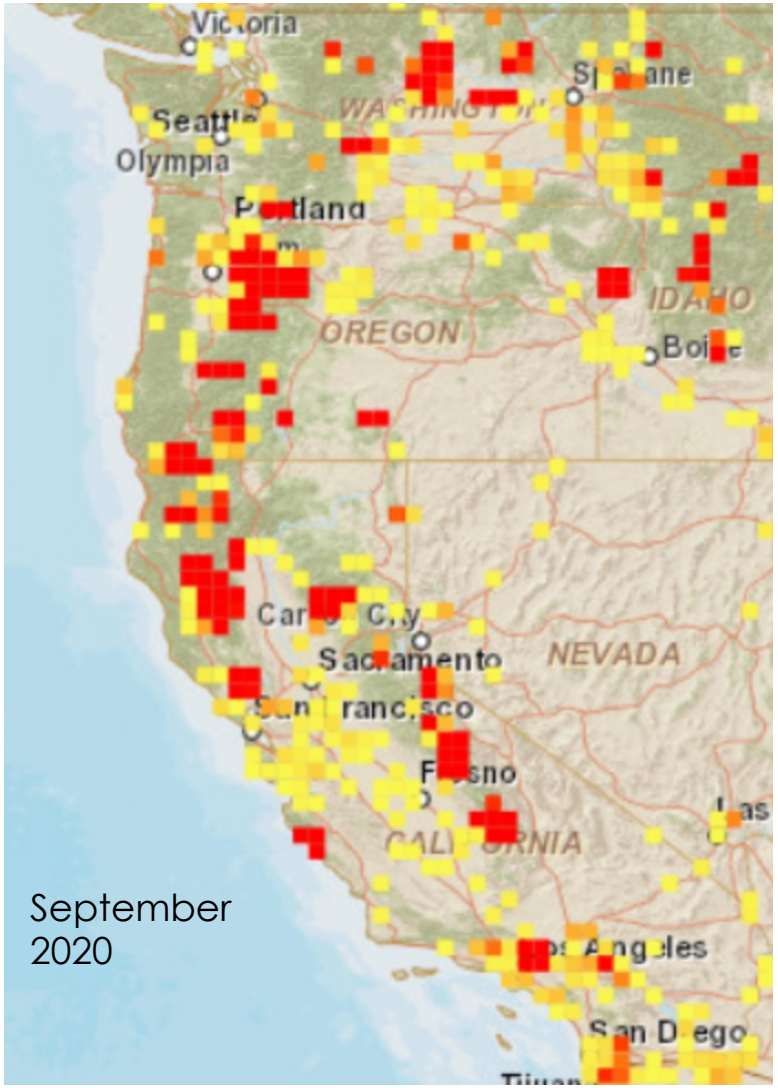
2020 shows a lot more fires compared to the previous two years and peaks in early September.



VIIRS detected the highest number of fires around mid-August and in early September.

VIIRS-SNP – Fire Density

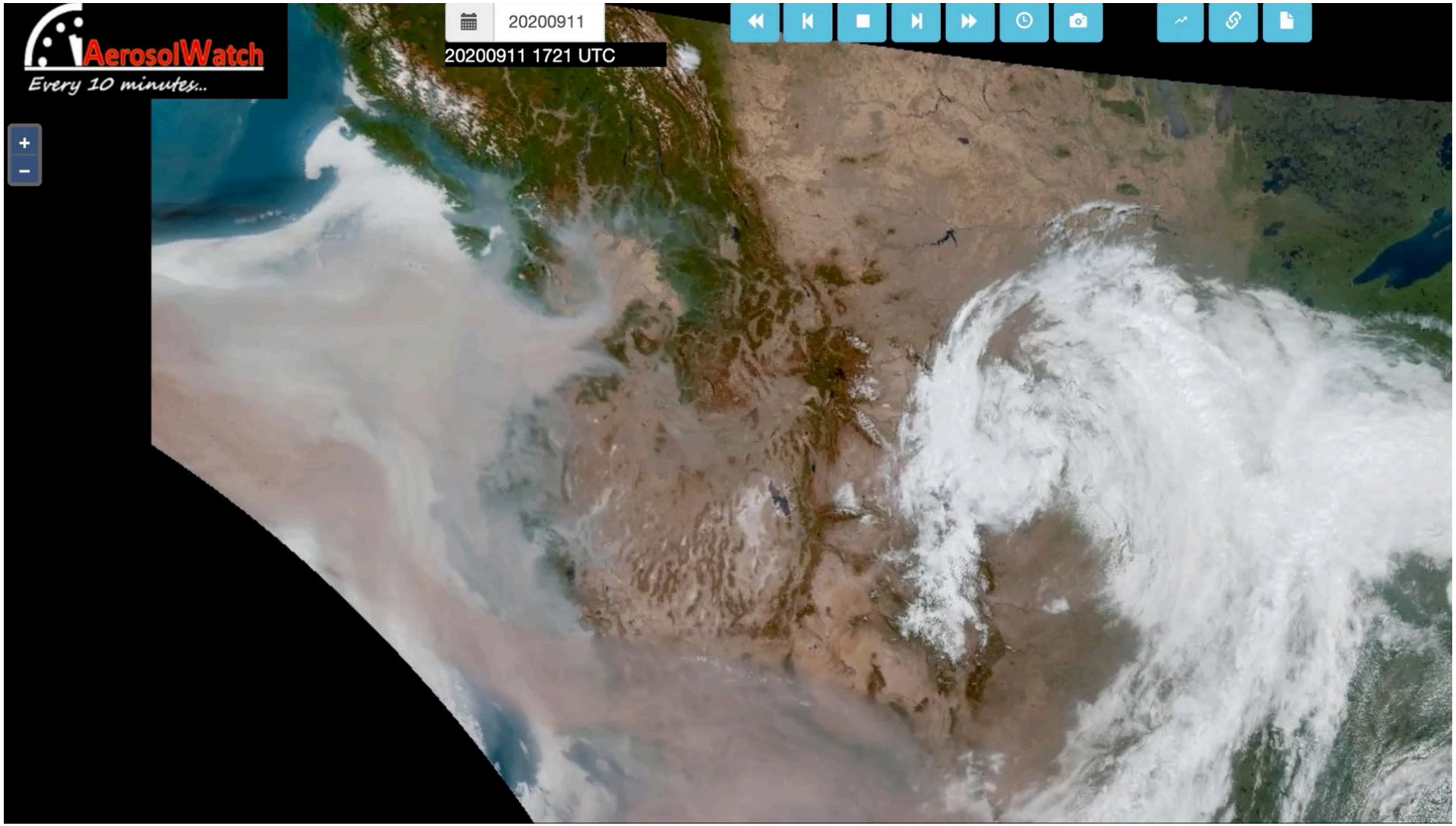




https://earthdata.nasa.gov/earth-observation-data/near-real-time/firms

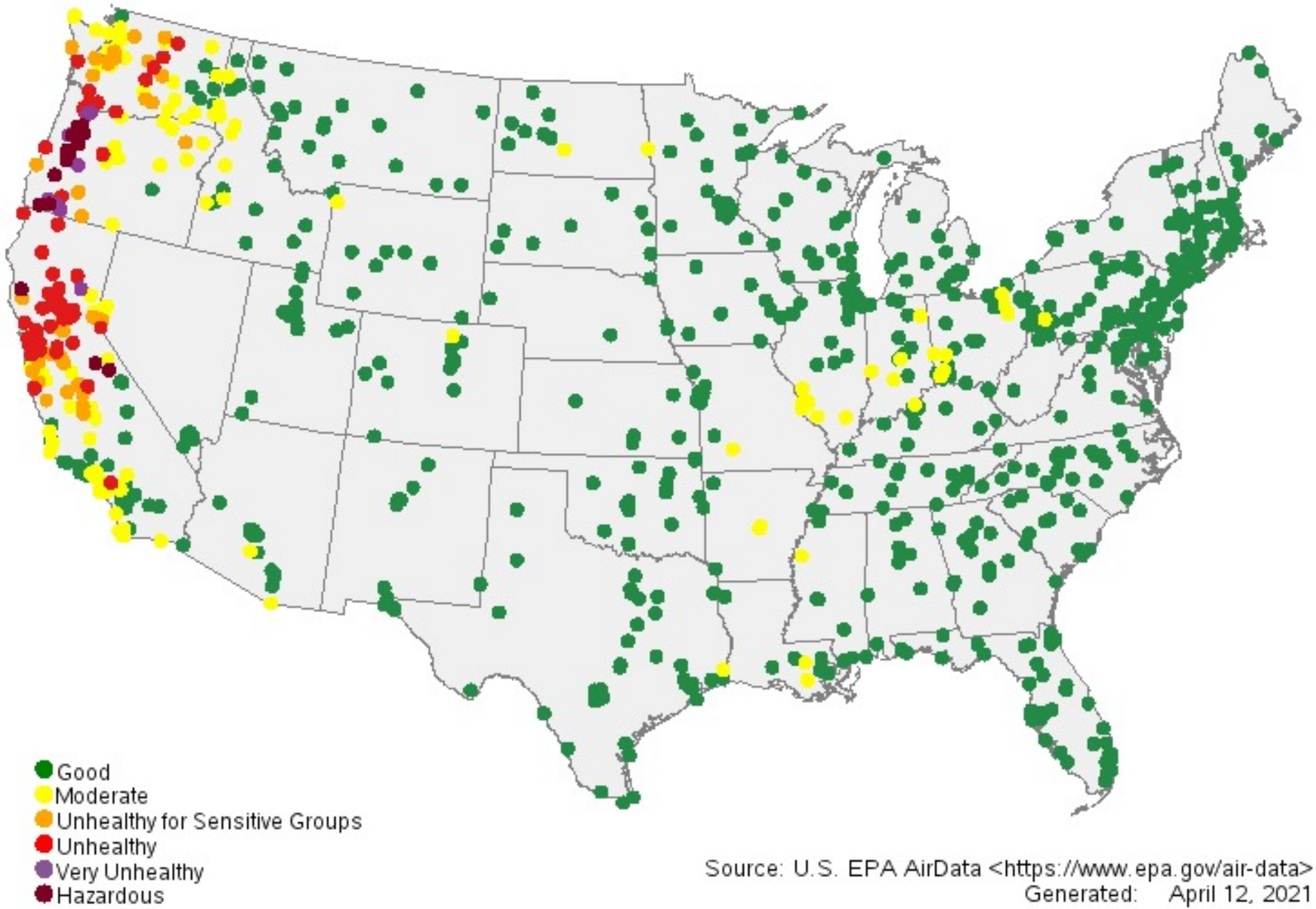
Transport of Smoke – TROPOMI Loop (Sep 3-11, 2020)

High Frequency Measurements – A Geostationary View



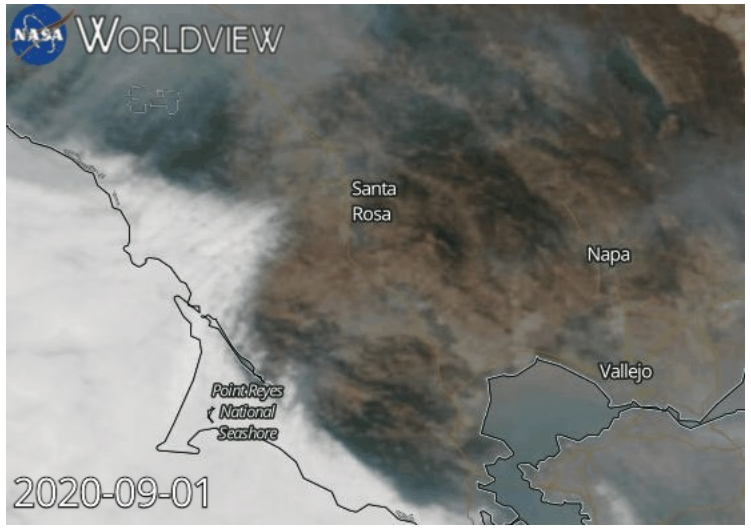
https://www.star.nesdis.noaa.gov/smcd/spb/aq/AerosolWatch/

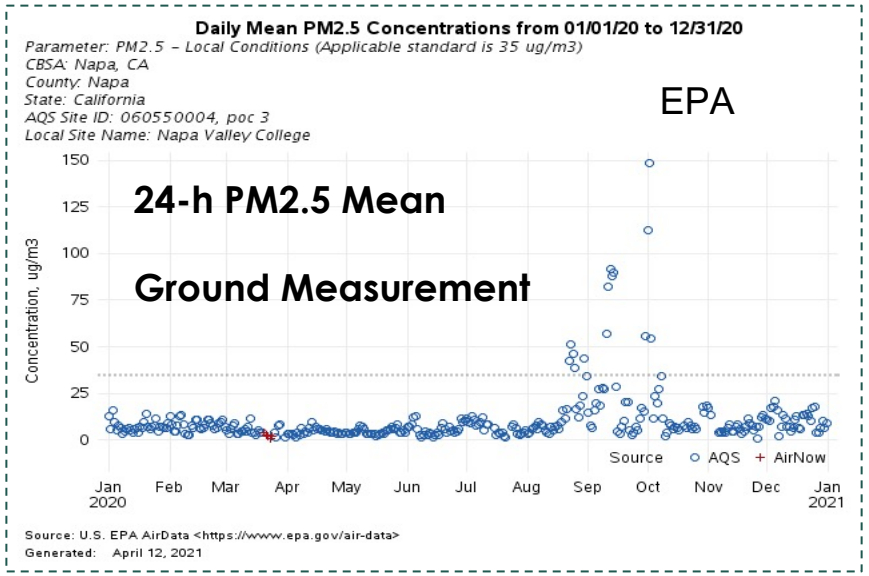
PM2.5 AQI Values by site on 09/10/2020

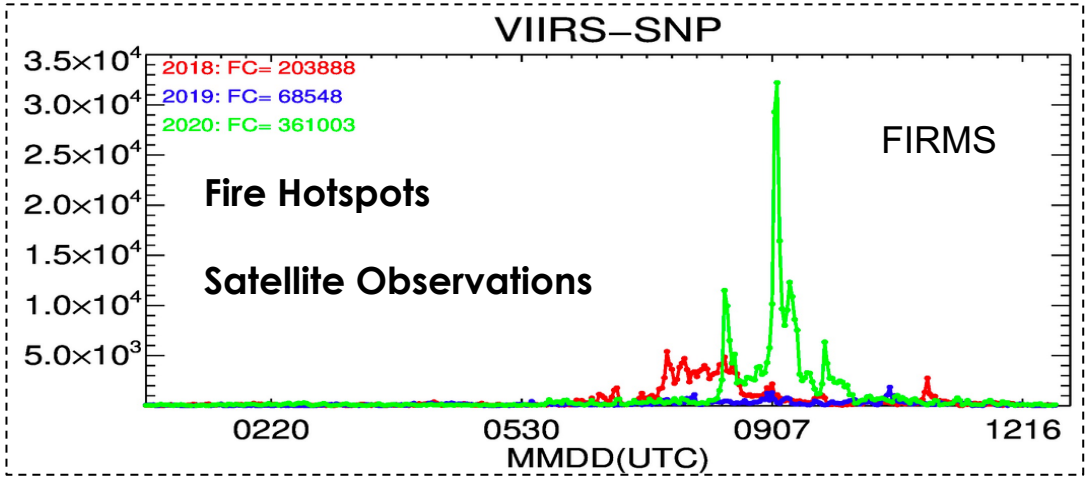


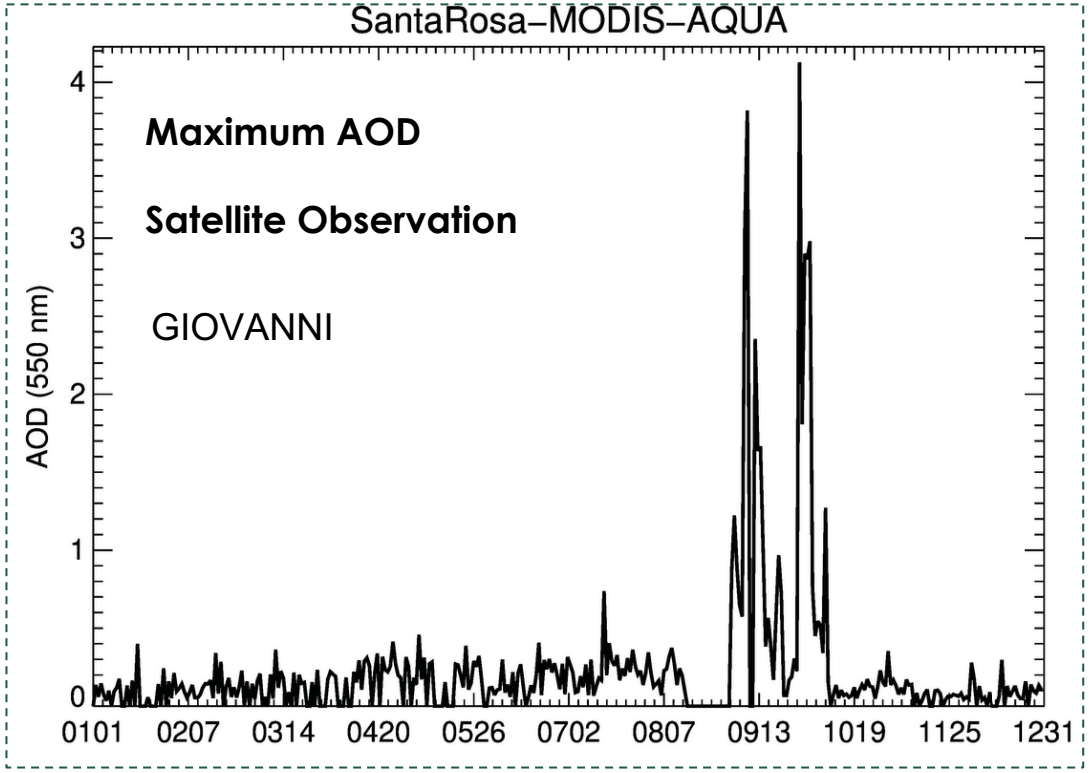
Source: U.S. EPA AirData <https://www.epa.gov/air-data>
Generated: April 12, 2021

Fires, Smoke/Aerosols, and PM2.5









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- Training Webpage:
  - https://appliedsciences.nasa.gov/join-mission/training/english/arset-satellite-observations-and-tools-fire-risk-detection-and
- ARSET Website:
  - https://appliedsciences.nasa.gov/what-we-do/capacity-building/arset

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Thank You!

Reference Slides

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

Aerosol Data Products

	MODIS (T & A)	VIIRS-SNPP	VIIRS-NOAA20	Geostationary
Data	AOD	AOD, Smoke/Dust Mask	AOD, Smoke/Dust Mask	AOD, Smoke/Dust Mask
Spatial Resolution	1, 3, 10 km	6 km, 0.75 km	0.75 km	2 km, 10km
Global Coverage	1-2 days	Daily	Daily	Regional Coverage - Hourly, Daily
Algorithm	DT, DB, MAIAC	DB, DT, NOAA	NOAA	NOAA, DT
Data Availability	2000 (2003) -current	2012- current	2017-current	2017-current
Data Format	HDF	NetCDF	NetCDF	NetCDF

DT = Dark Target DB = Deep Blue MAIAC = Multi-Angle Implementation of Atmospheric Correction

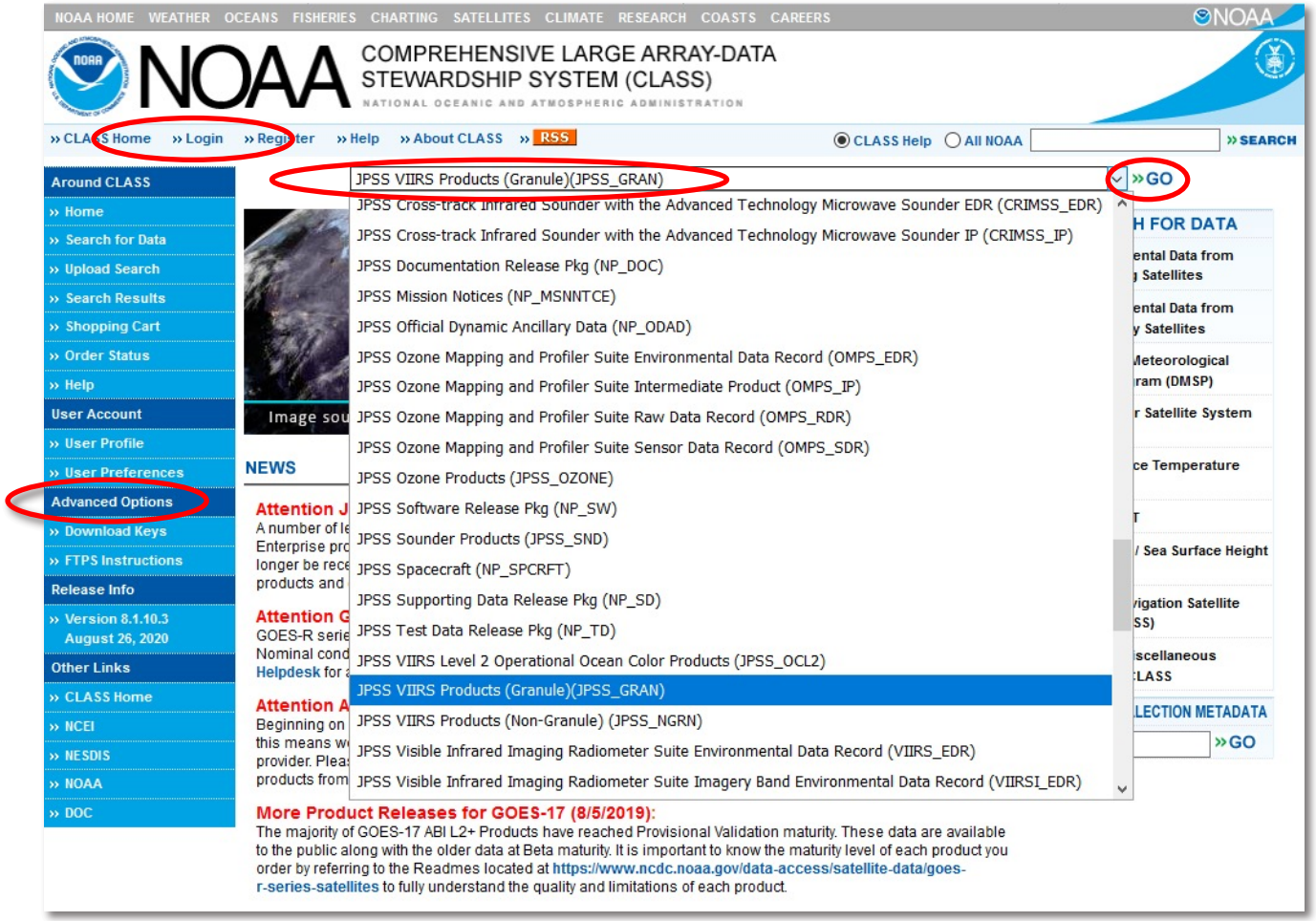
Geostationary = ABIs, AHIs

Aerosol Data Access and Tools

- NOAA Aerosol Data – https://youtu.be/mu6K4KopEyA
- LAADS – NASA Aerosol Data Download - https://ladsweb.modaps.eosdis.nasa.gov/
- GIOVANNI – Level 3 data analysis Tool - https://giovanni.gsfc.nasa.gov/giovanni/
- Dark Target Aerosol Algorithm – http://darktarget.gsfc.nasa.gov/
- Deep Blue Aerosol Algorithm - https://deepblue.gsfc.nasa.gov/
- NASA AERONET network - https://aeronet.gsfc.nasa.gov/
- NOAA Aerosol Watch - https://www.star.nesdis.noaa.gov/smcd/spb/aq/AerosolWatch/

NOAA Data Download

- NOAA CLASS
  - https://www.avl.class.noaa.gov/saa/products/welcome
- Register; Login; User Preference
- Select JPSS VIIRS Products (Granule)(JPSS_GRAN) from the drop-down list at the top of the CLASS page and click GO



More details – click here

Data Products Relevant to Fires and Air Quality – Polar

	MODIS (T & A)	VIIRS-SNPP	VIIRS-N20
Aerosol Optical Depth	✓	✓	✓
Smoke Detection	✗	✓	✓
Fire Detection	✓	✓	✓
True Color Image	✓	✓	✓

Data Products Relevant to Fires and Air Quality – GEO

	GOES (East & West)	Himawari-08	AMI & others
Aerosol Optical Depth	✓	✓	–
Smoke Detection	✓	✗	–
Fire Detection	✓	✓	–
True Color Image	✓	✓	–