

# Aerosol Observations from GOES-R Series Geostationary Satellites

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# Satellites Identify Aerosols in the Atmosphere

- Satellites show the location and transport of **aerosols** in the atmosphere on continental and hemispheric scales:
  - Smoke plumes
  - Blowing dust
  - Haze
- Satellite aerosol products have many **applications**, such as:
  - Operational forecasting (e.g., air quality, aviation)
  - Numerical model validation/data assimilation
  - Public health/epidemiological studies
  - Outreach/media

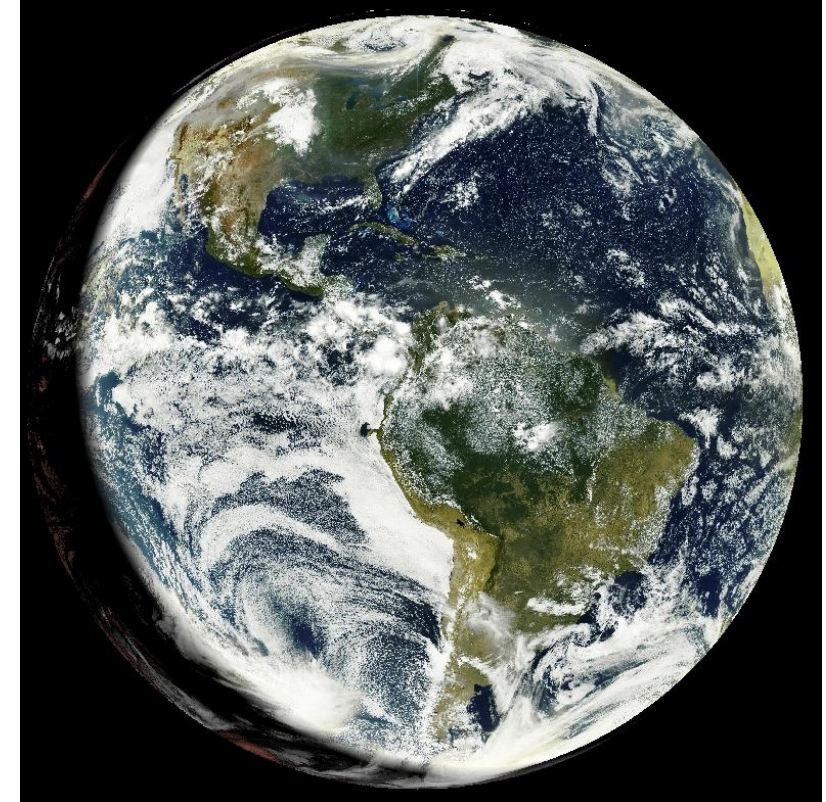
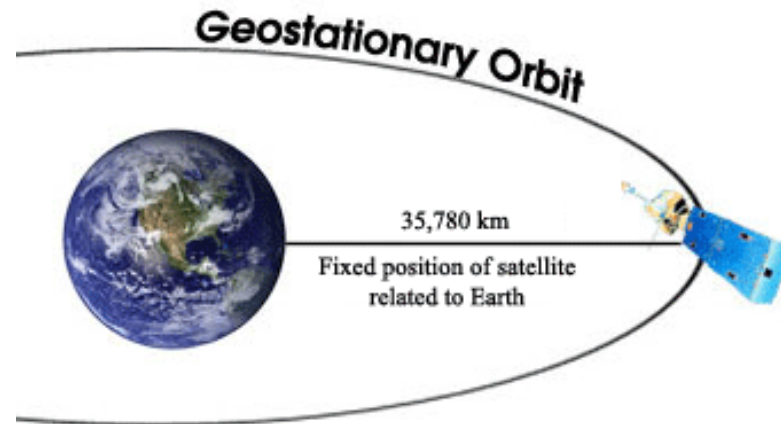


ABI GeoColor  
August 23, 2018

Smoke plumes across the continental U.S.

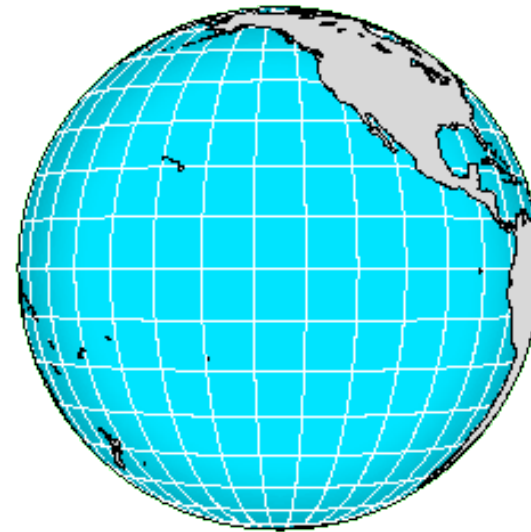
# Geostationary Satellites

- Meteorological satellites: used to monitor development of severe storms and natural hazards
- In a high-altitude orbit (~35,800 km)
  - Orbital speed of satellites match rotation speed of Earth
- Essentially continuous measurements (high temporal resolution)
- Hemispheric coverage, centered on the equator



# Geostationary Operational Environmental Satellites (GOES)

- U.S. geostationary weather satellites
- Administered by National Atmospheric and Oceanic Administration (NOAA)
- **Legacy GOES Imager** instrument:
  - 5 broad spectral bands:
    - Visible (0.55-0.75  $\mu\text{m}$ )
    - Shortwave IR (3.80-4.00  $\mu\text{m}$ )
    - Water Vapor (6.50-7.00  $\mu\text{m}$ )
    - IR 1 (10.20-11.20  $\mu\text{m}$ )
    - IR 2 (11.50-12.50  $\mu\text{m}$ )
  - Temporal resolution: 30 min to 3 hours
  - Spatial resolution: 1 km, 4 km, and 8 km



**GOES-West**  
(137 °W)



**GOES-East**  
(75 °W)



# Geostationary Operational Environmental Satellites R-Series (GOES-R)

- Revolutionary new generation of geostationary satellites
- “Like going from black and white TV to HD”
- Series of 4 satellites:
  - GOES-R launched **November 19, 2016**
    - Renamed GOES-16 after launch
    - Now it is **GOES-East**
  - GOES-S launched **March 1, 2018**
    - Renamed GOES-17 after launch
    - Will become **GOES-West** circa late 2018
  - GOES-T scheduled to launch in 2020
  - GOES-U scheduled to launch in 2024

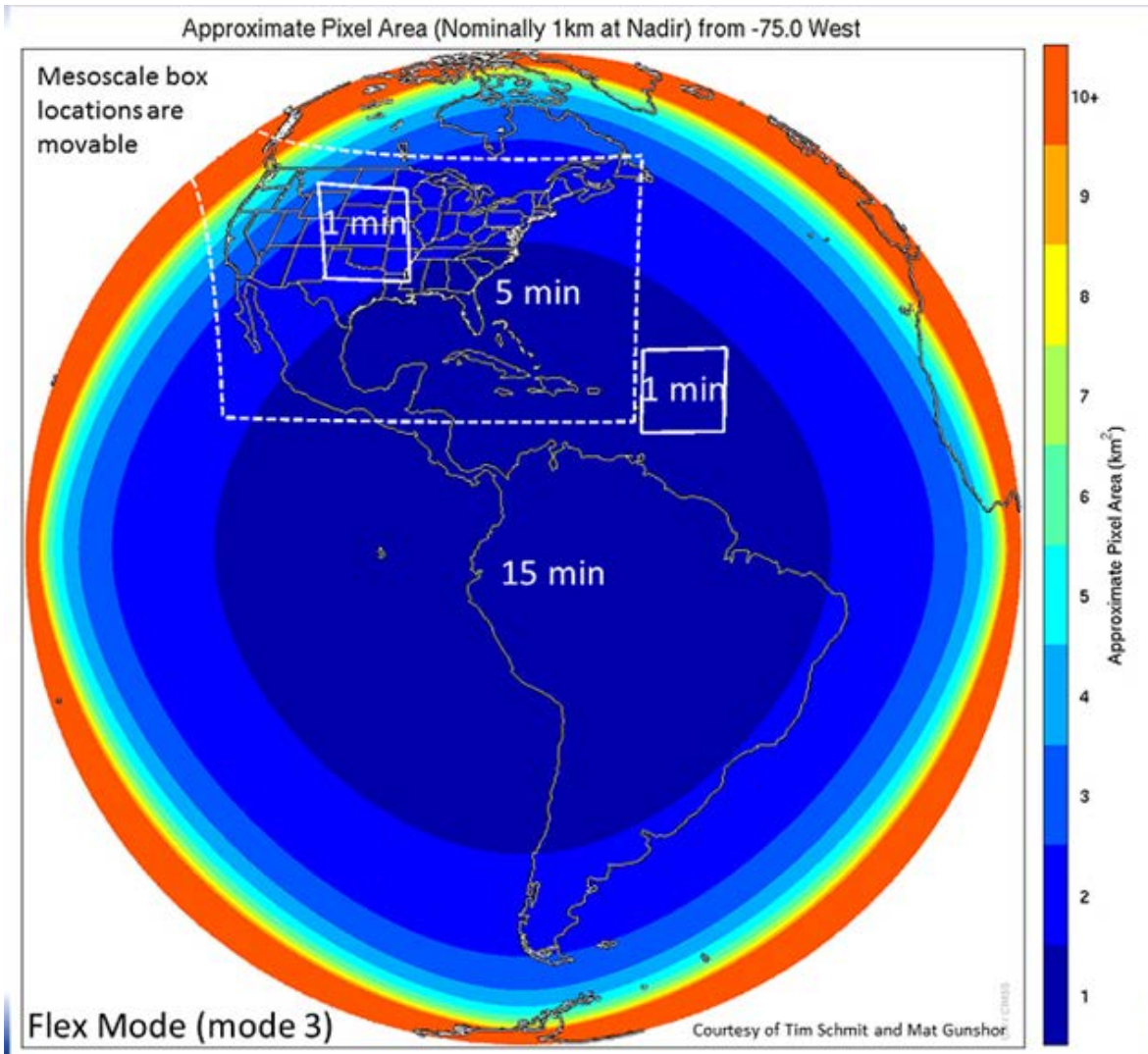


# ABI: New Generation GOES Imager

- **Advanced Baseline Imager (ABI)** is one of 6 instruments on the GOES-R series satellites
- Huge leap forward in geostationary satellite technology!
- ABI has **16 spectral bands** vs. 5 on the legacy GOES Imager
  - New products!
  - Higher accuracy!
  - Higher spatial resolution!
- Faster scan rate compared to the legacy GOES imager
  - More frequent observations! (higher temporal resolution)
  - Routine CONUS and full disk views!



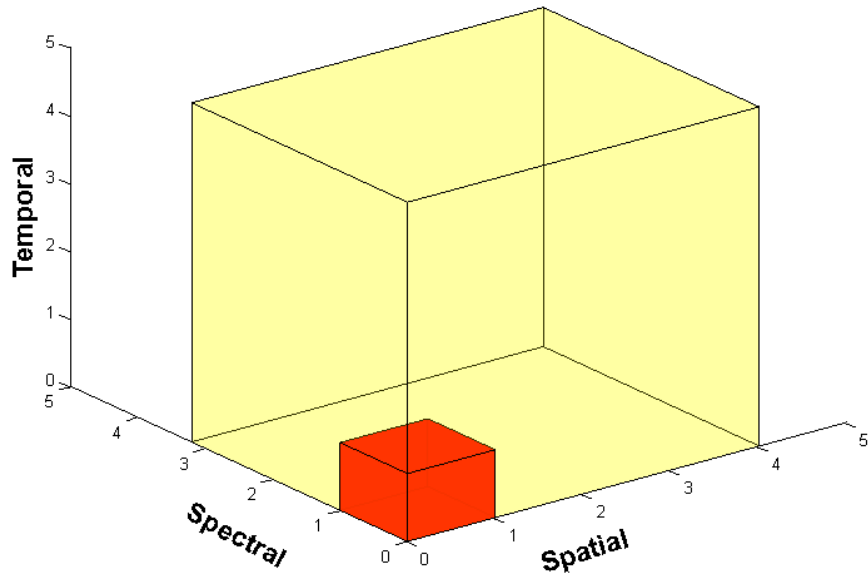
# ABI Scan Mode 3 ("Flex Mode")



- Scan mode 3 is the ABI default operational scan mode ("flex mode"):
  - Full disk every 15 min
    - Near hemispheric coverage
  - CONUS every 5 min
    - ~3000 km x 5000 km
  - 2 mesoscale scans every 1 min (adjustable based on current hazards)
    - 1000 km x 1000 km
- Compare to legacy GOES imager:
  - 26 min for full disk scan (every 3 hr)
  - 7 min for CONUS scan (every 30 min)
  - NO routine mesoscale scans



# GOES-16 Launched Nov 19, 2016



ABI Bands ( $\mu\text{m}$ )

0.47
0.64
0.86
1.6
1.38
2.2
3.9
6.2
6.7
7.3
8.5
9.7
10.3
11.2
12.3
13.3

Domain	Legacy GOES Imager			
	AOD	Geo Color	Dust RGB	Smoke/Dust Mask
CONUS	X			
Full Disk				
Meso-scale				

Domain	GOES-R Series ABI			
	AOD	Geo Color	Dust RGB	Smoke/Dust Mask
CONUS	X	X	X	X
Full Disk	X	X	X	X
Meso-scale		X	X	X

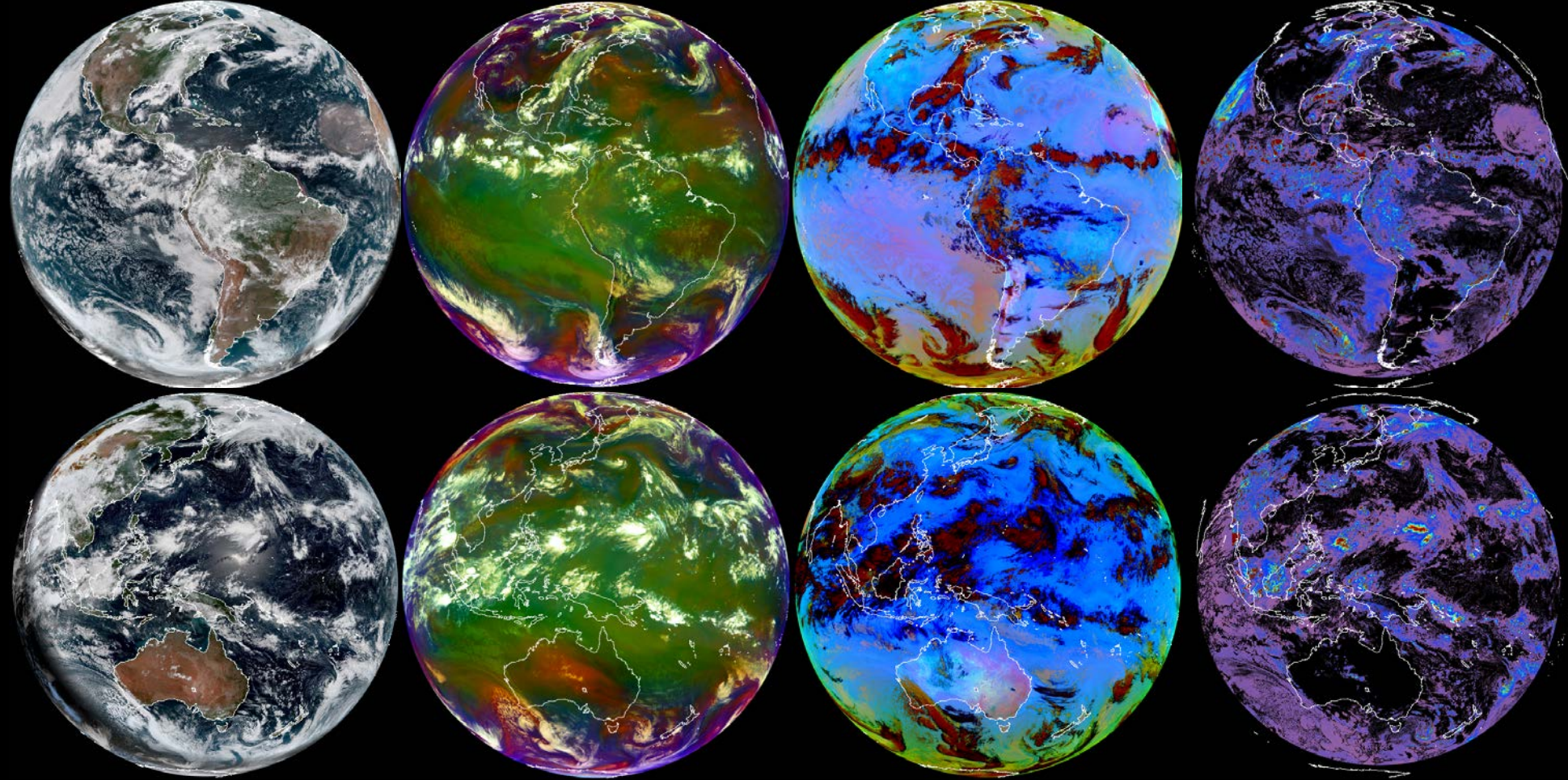
**5X** Faster coverage (5-minute full disk vs. 25-minute)

**4X** Improved spatial resolution (2 km IR vs. 4 km)

**3X** More spectral bands (16 on ABI vs. 5 on legacy imager)

Slide Courtesy of Tim Schmit, NOAA

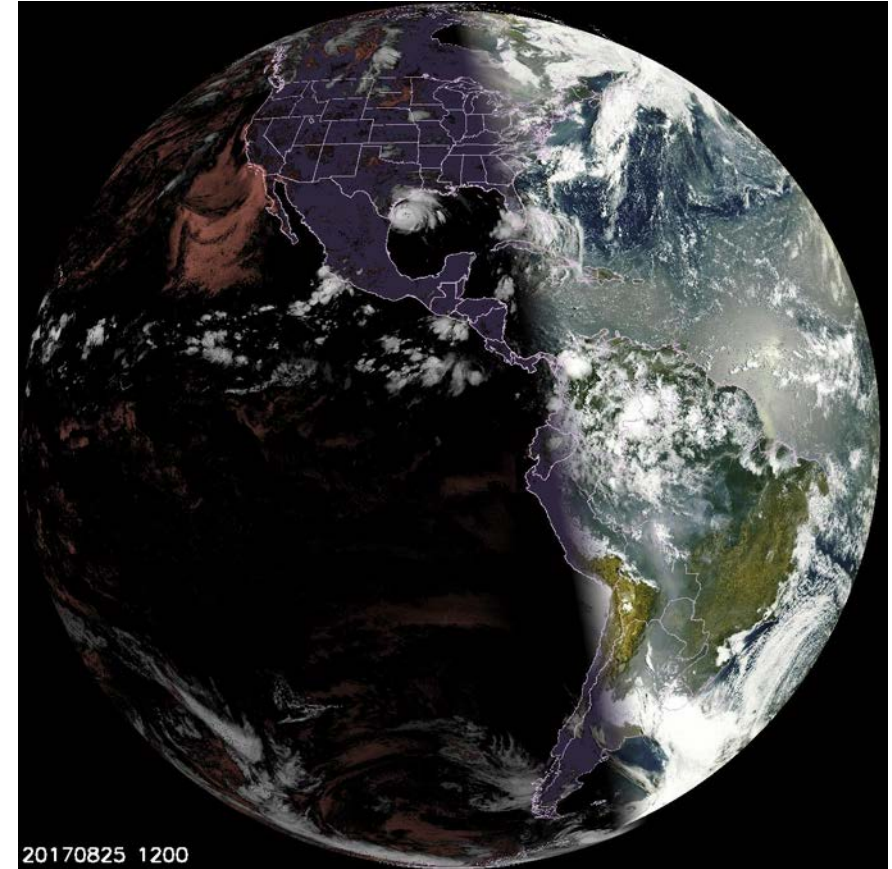




Overview of ABI Aerosol Products

# ABI Aerosol Products: GeoColor Imagery

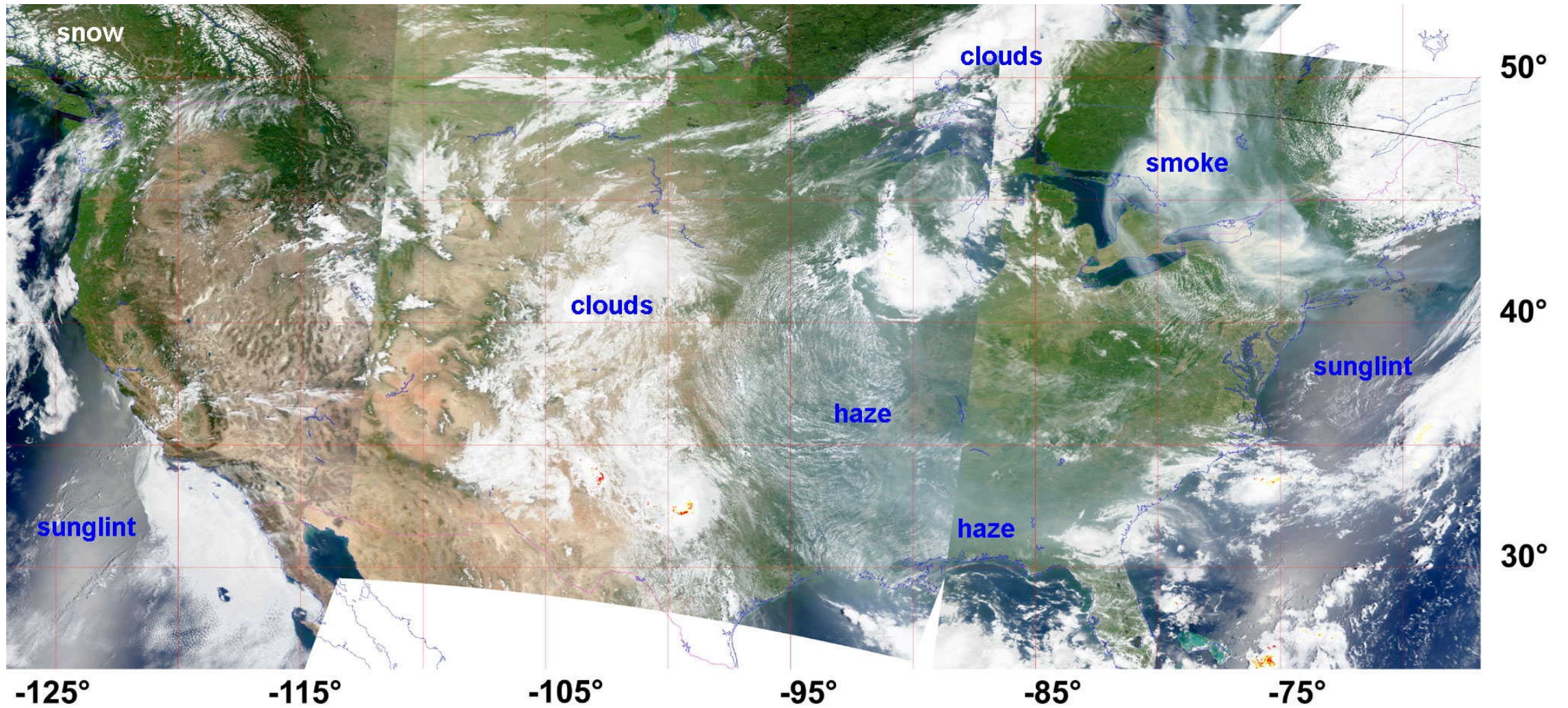
- During daytime, the closest approximation to true color imagery (combination of red, green, and blue spectral bands)
  - ABI doesn't have a green band, so it's simulated
  - GeoColor looks like what you see with your eyes
    - Smoke: grey
    - Blowing dust: brown
    - Clouds: bright white
- At night, multispectral IR imagery shows low-level liquid water clouds and higher-level ice clouds
- New product from ABI! Not available from legacy GOES Imager!



- GOES-16 ABI GeoColor imagery, full disk:
- 4 km spatial resolution
  - 15 min temporal resolution

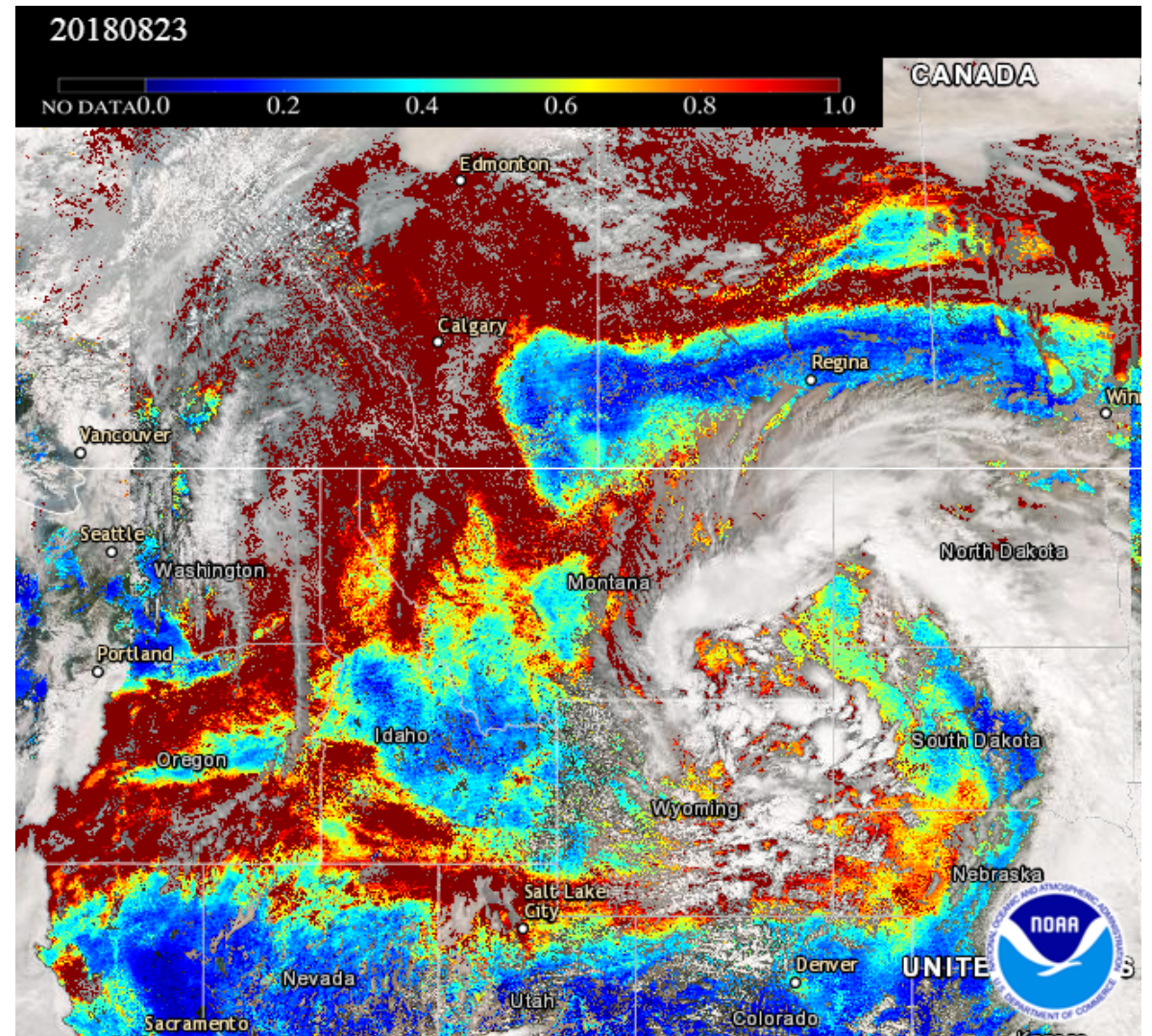


# Examples of Features in GeoColor/True Color (RGB) Imagery



# ABI Products: Aerosol Optical Depth (AOD)

- AOD is a **quantitative** measure of aerosols in the atmosphere
- Measure of scattering/absorption of visible light by aerosols
- AOD is unitless; values typically range from 0 to 1 in the U.S.
  - High AOD (red, orange, yellow): smoke, blowing dust, haze
- No AOD retrieval in regions with clouds or bright surfaces
  - No AOD in white cloud-covered areas

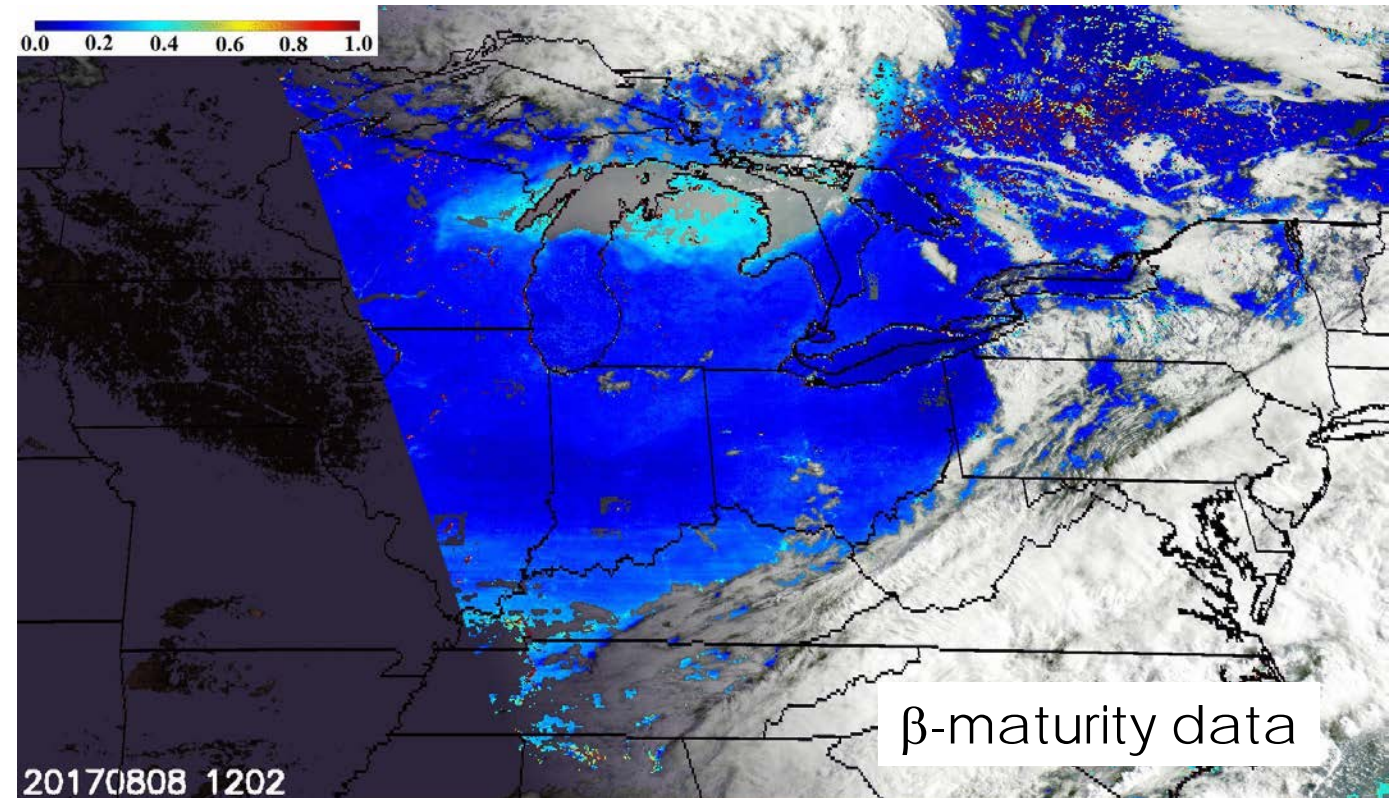
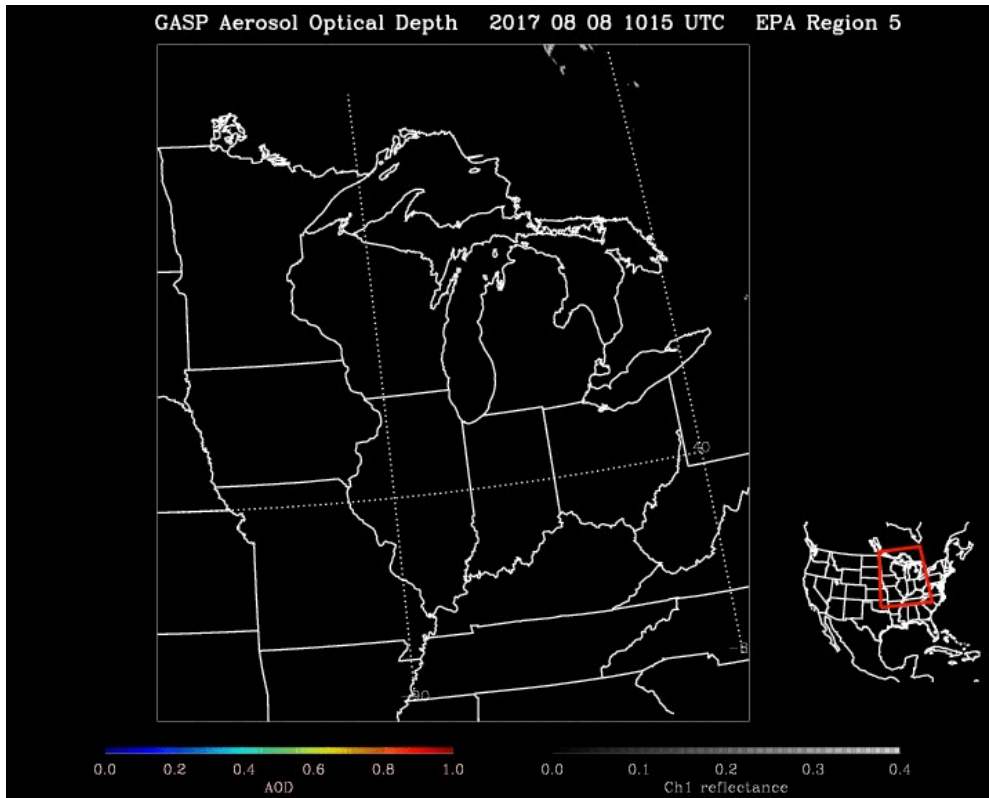


# ABI AOD Has High Accuracy and High Resolution

from a multi-channel algorithm (similar to VIIRS & MODIS)

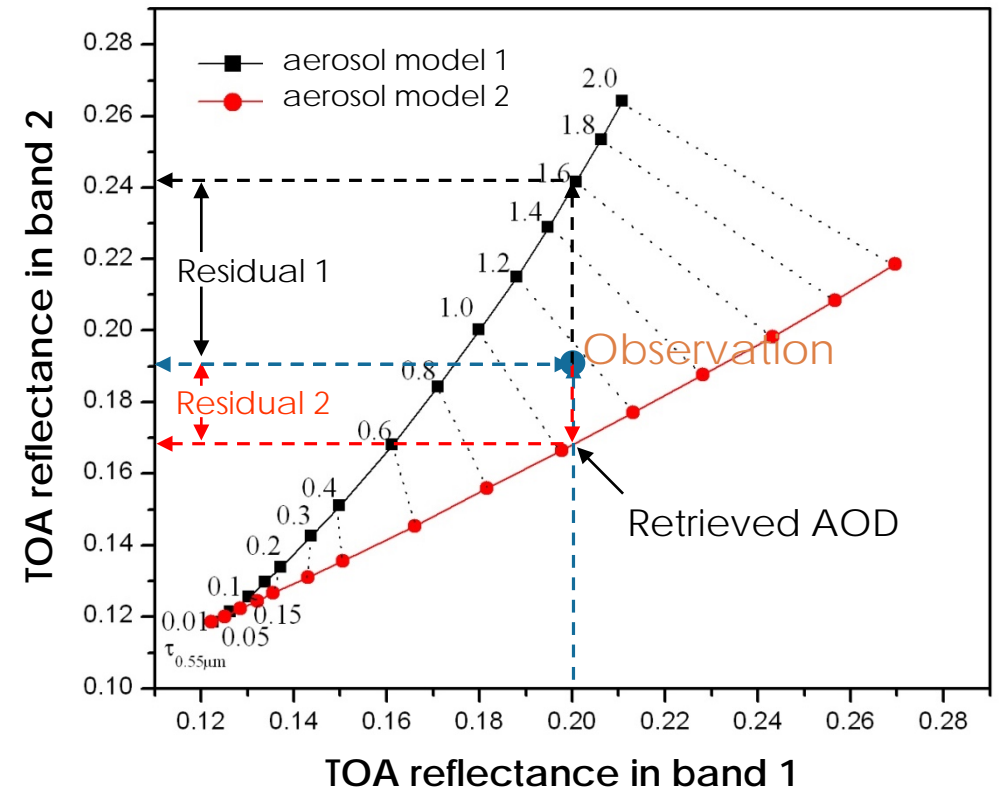
Previous GOES Imager:  
4 km, 30 min, lower accuracy

GOES-16 ABI:  
2 km, 15 min, high accuracy



# GOES-R Series AOD Algorithm (Multi-Channel AOD Retrieval)

- Separate ABI AOD algorithms for over land and water
- MODIS and early VIIRS heritage (Tanre et al., 1997; Remer et al., 2005; Levy et al., 2007, Vermote et al., 2007)
- **Simultaneous retrieval of AOD and aerosol type by comparing calculated and observed reflectances at multiple wavelengths**
- A simplified version of the multi-channel AOD retrieval is shown in the figure on the right
  - Example is for 2 aerosol models and 2 ABI spectral channels (bands)



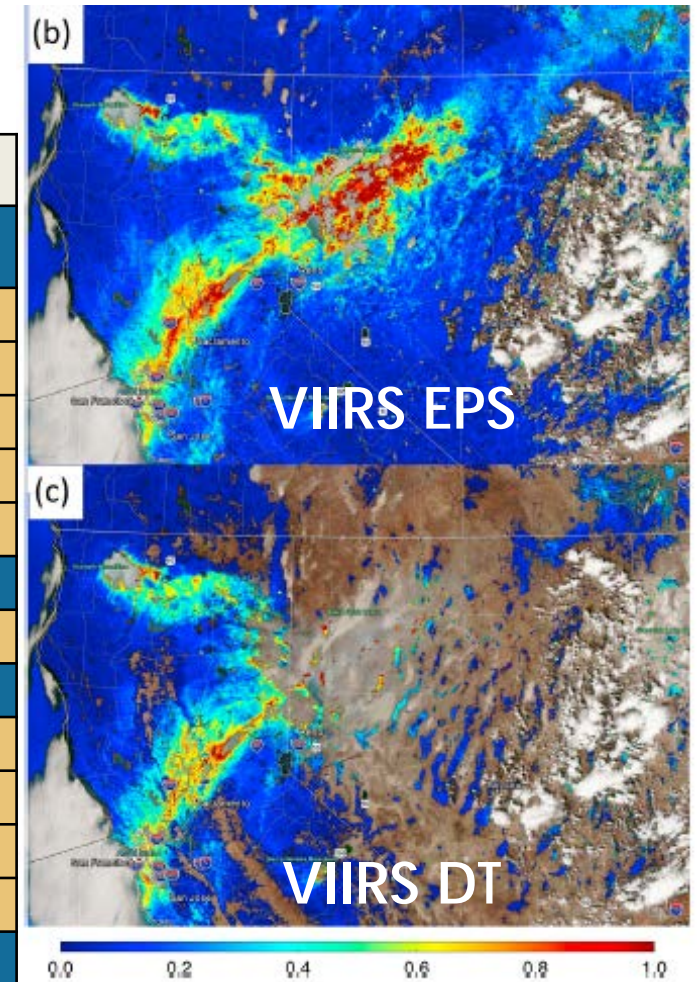
**Water:** 4 fine, 5 coarse mode aerosol models  
**Land:** generic, dust, smoke and urban aerosol models



# Enterprise (EPS) AOD Algorithm

- **ABI AOD algorithm** will be updated next year with EPS algorithm currently running on SNPP VIIRS
- EPS algorithm capable of retrieving AOD over bright land surfaces
- With similar AOD algorithm, VIIRS and ABI AOD can be used synergistically in various applications

VIIRS Band	Central Wavelength ( $\mu\text{m}$ )	Retrieval		Internal Test	
		Land	Water	Land	Water
M1	0.412	X		X	X
M2	0.445	X		X	X
M3	0.488	X		X	X
M4	0.555		X	X	X
M5	0.672	X	X	X	X
M6	0.746		X		
M7	0.865		X	X	X
M8	1.240		X	X	
M9	1.378			X	X
M10	1.610		X		X
M11	2.250	X	X	X	X
M15	10.763			X	X
M16	12.013			X	

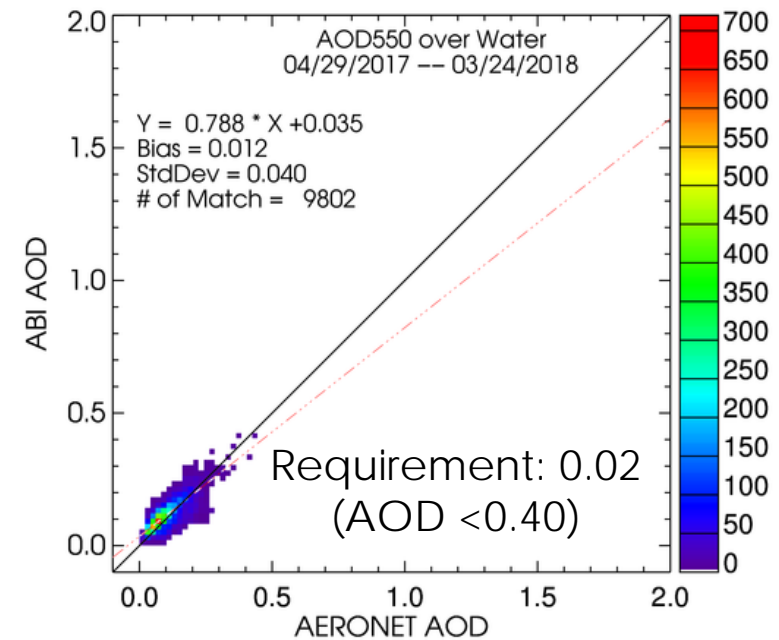
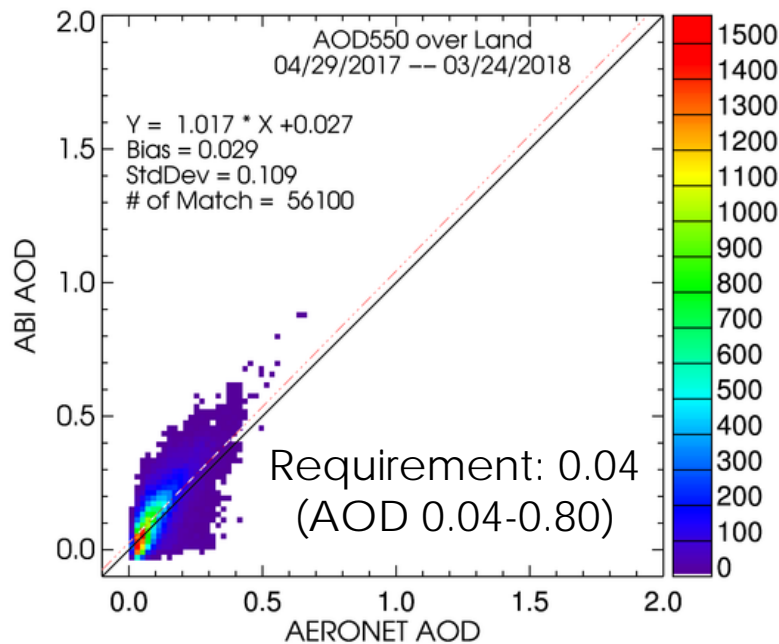


Zhang et al., JGR, 2016



# ABI AOD Validation with AERONET

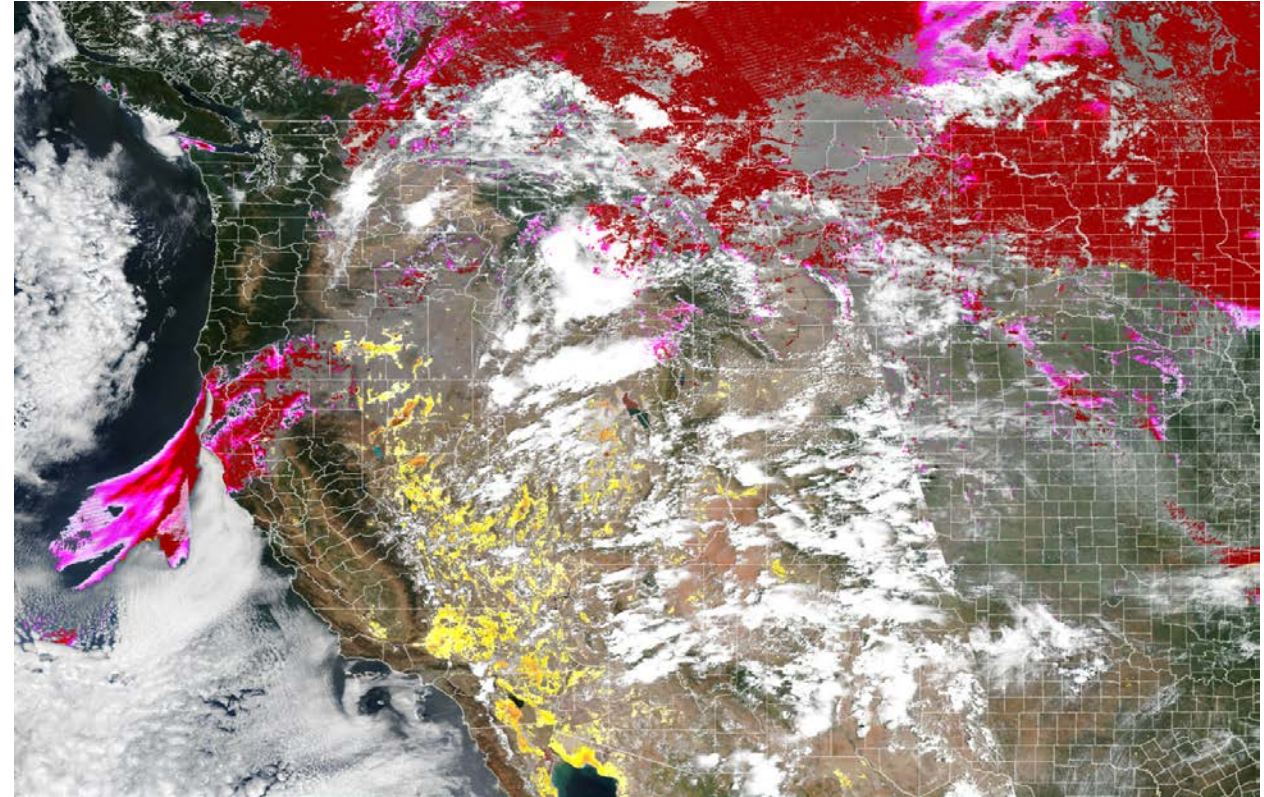
- ABI AOD algorithms (land and water) must meet specific requirements
- Validated with AERONET AOD
- Time period: 04/29/2017 – 03/24/2018
- **High quality AOD** (preliminary maturity)
- Bias and StDev: mean and standard deviation of ABI-AERONET differences





# ABI Products: Aerosol Detection

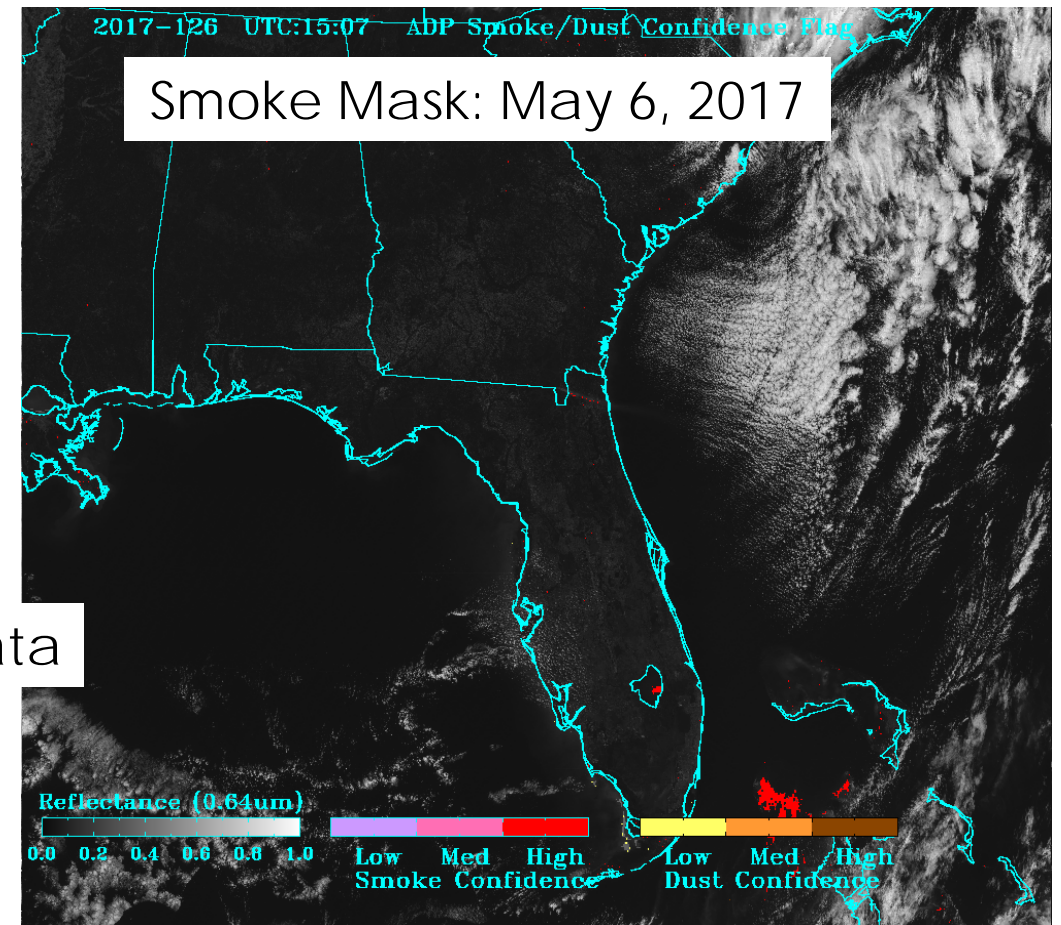
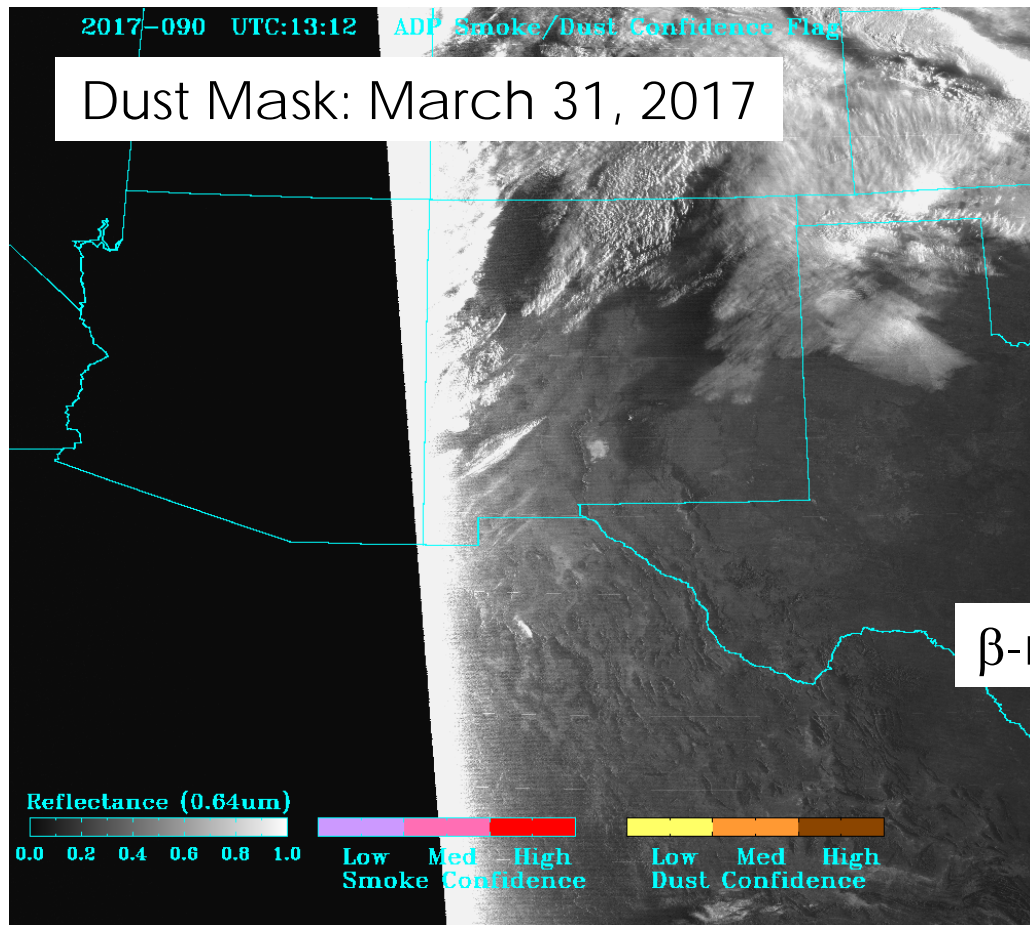
- Aerosol detection is a **qualitative** measure of aerosols
- Derived using spectral and spatial threshold tests based on ABI measurements in visible and IR
- Smoke mask: indicates **smoke plumes**
  - Colored in shades of **pink/magenta**
- Dust mask: indicates **blowing dust**
  - Colored in shades of **yellow/brown**
- New product from ABI! Not available from legacy GOES Imager!



August 17, 2018



# Example of ABI Smoke Mask and Dust Mask Imagery



ABI smoke/dust mask imagery:

- 2 km spatial resolution
- 15 min temporal resolution

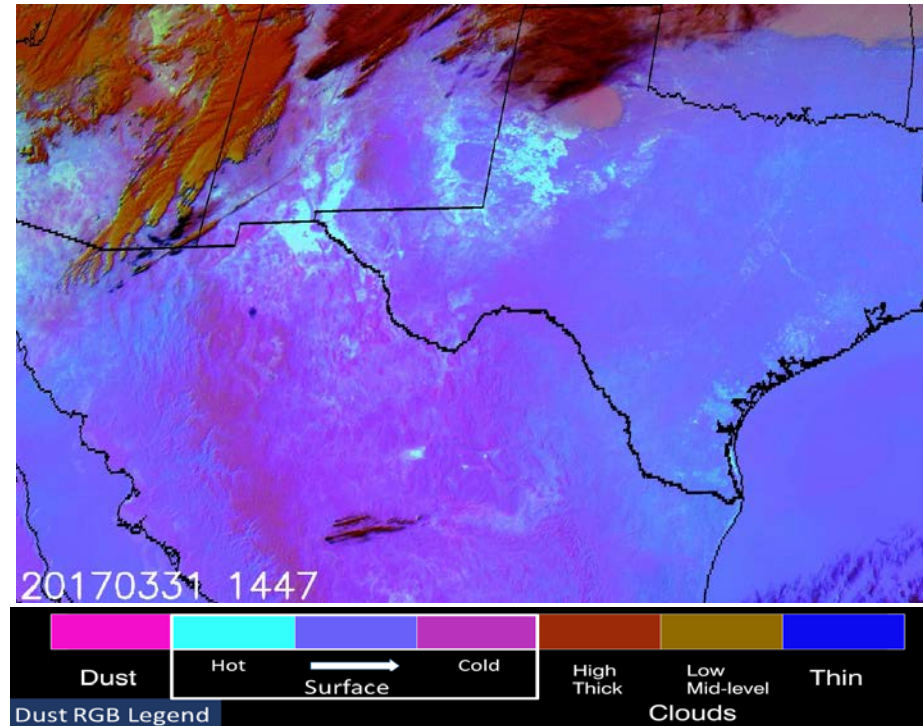


# ABI Products: Dust RGB

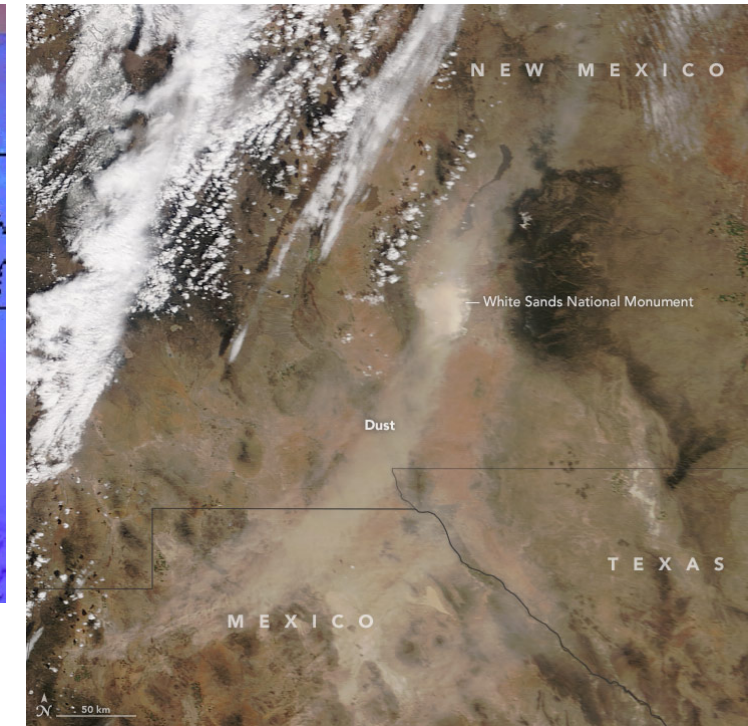
- Made from a combination of three of the ABI's IR spectral bands (brightness temperature at 8.4  $\mu\text{m}$ , 11.2  $\mu\text{m}$ , 12.3  $\mu\text{m}$ )
- Indicates areas of **blowing dust** in the atmosphere: appears as a **magenta** feature
- New product from ABI! Not available from legacy GOES imager!

ABI dust RGB imagery:

- 2 km spatial resolution
- 15 min temporal resolution



Dust RGB: March 31, 2017



MODIS RGB

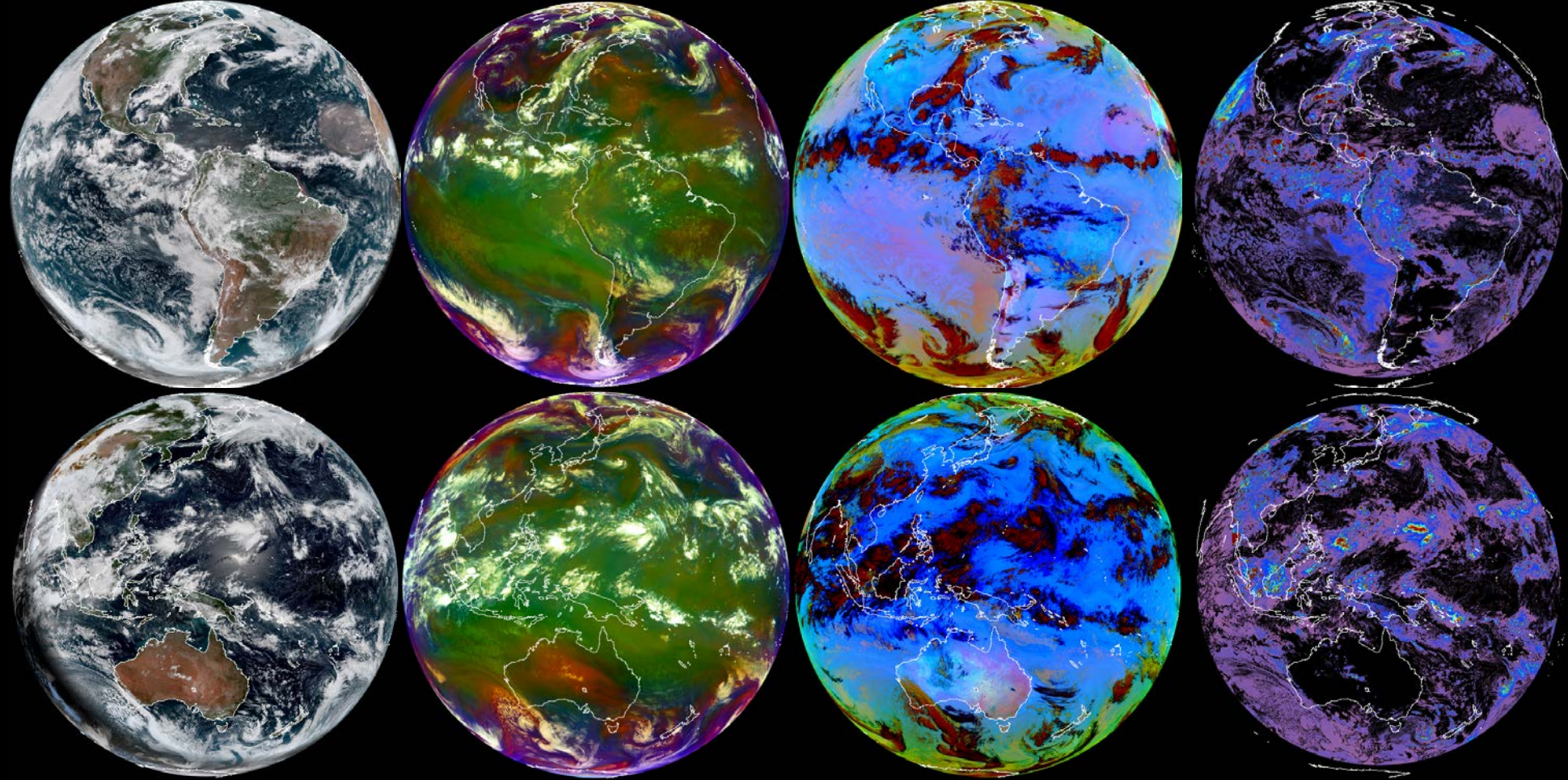


# Summary of ABI Aerosol Product Specifications

ABI Aerosol Product	Spatial Resolution (km)		Temporal Resolution (min)		Data Maturity
	Full Disk	CONUS	Full Disk (Scan Mode 3)	CONUS (Scan Mode 3)	
GeoColor	4	1	15	5*	Provisional
AOD	4	2	15	5*	Provisional
Smoke/Dust Mask	4	2	15	5*	Provisional
Dust RGB	4	2	15	5*	Provisional

- Provisional maturity data products can be used now for scientific applications
- Final maturity products expected late 2018/early 2019
- CONUS view products (\*) have native 5 min resolution, but near real-time imagery available on the *AerosolWatch* website is limited to 15 min to make data loading manageable





ABI Aerosol Products in Action

# Smoke, Blowing Dust, and Haze Affect Air Quality

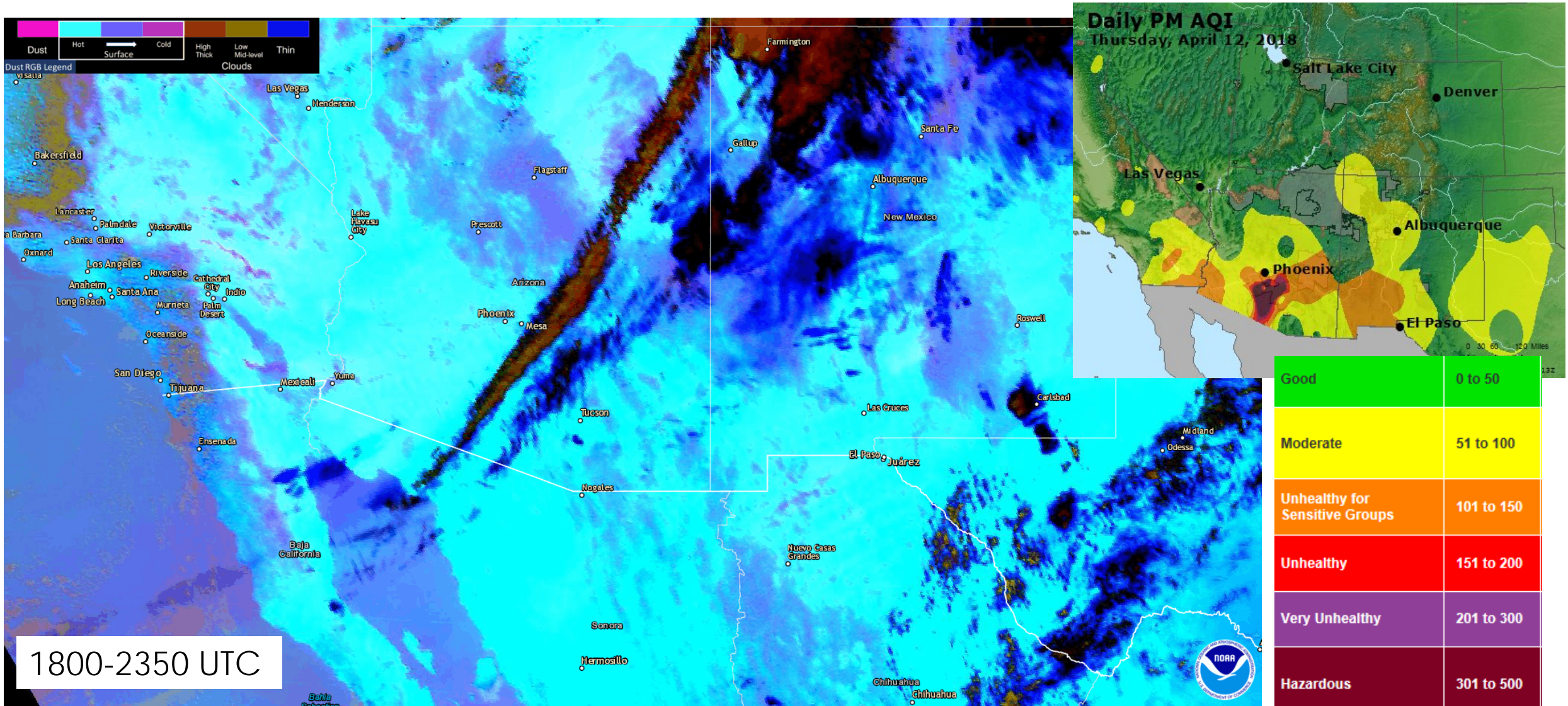
- Aerosols in the atmosphere are made up of **particulate matter**:
  - Solid, liquid, and mixed phase particles
  - Can be primary (directly emitted) or secondary (formed by chemical reactions in the atmosphere)
- Two sizes of particles considered **criteria pollutants** in the U.S.:
  - Fine particulate matter (PM<sub>2.5</sub>)
  - Coarse particulate matter (PM<sub>10</sub>)
  - Ambient concentrations communicated using the **Air Quality Index (AQI)**
- **Smoke** plumes from wildfires and biomass burning contain:
  - Primary PM<sub>2.5</sub> and PM<sub>10</sub> (smoke aerosols)
- Blowing **dust** affects PM<sub>10</sub> and PM<sub>2.5</sub> air quality (dust aerosols)
  - Primarily in arid regions, like the Southwestern U.S. (local sources)
  - Transported Saharan dust periodically affects the Caribbean and the U.S. Atlantic/Gulf coasts
- **Haze** becoming less of an issue in U.S. in recent years
  - Mostly contains secondary PM<sub>2.5</sub> (nitrate, sulfate, and organic carbon particles)

## Air Quality Index (AQI)

Good	0 to 50
Moderate	51 to 100
Unhealthy for Sensitive Groups	101 to 150
Unhealthy	151 to 200
Very Unhealthy	201 to 300
Hazardous	301 to 500



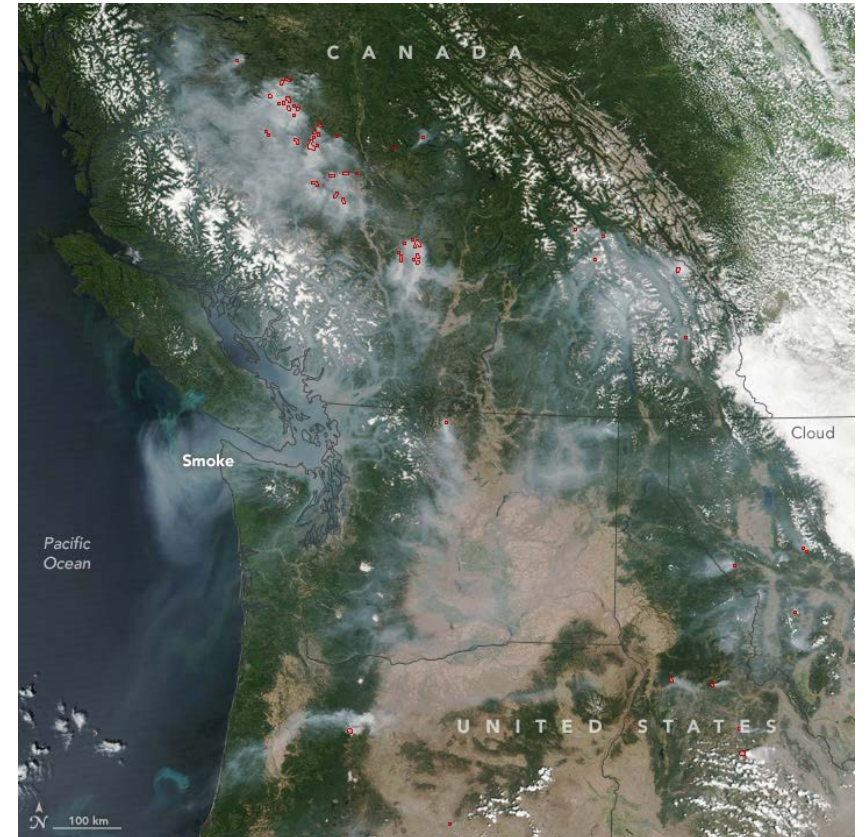
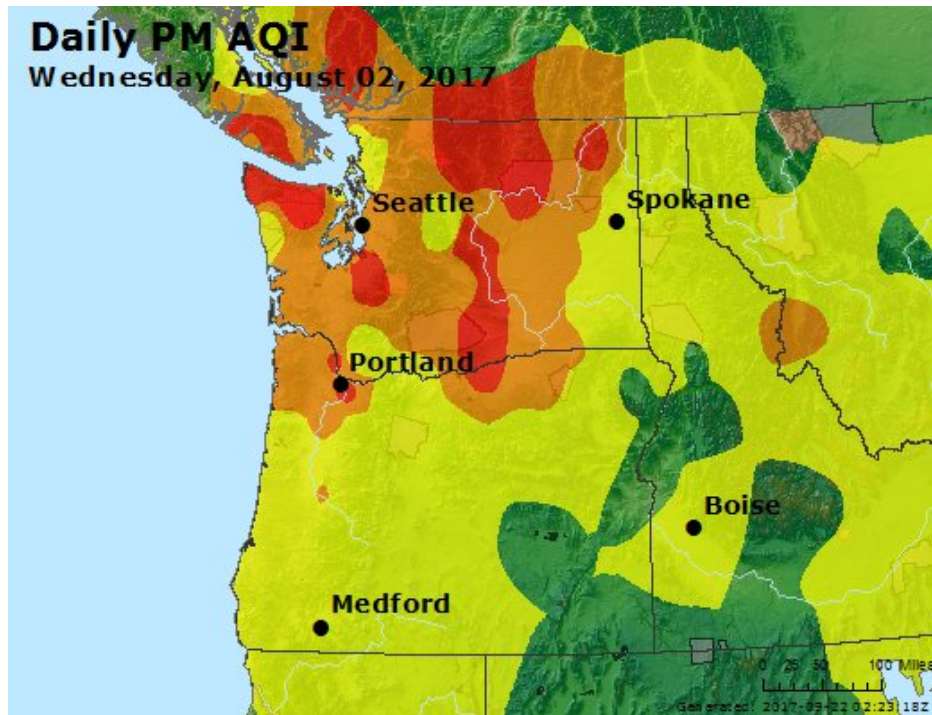
# ABI Dust RGB: Dust Storm in Southwest U.S., April 12, 2018



# August/September 2017 Wildfires

- Wildfires raged last summer in western U.S. and British Columbia
  - Huge ridge of high pressure over western US; record-breaking heat wave in Pacific NW
- Seattle, WA and Portland, OR hit particularly hard; days of Code Orange/Red PM<sub>2.5</sub> air quality

Good	0 to 50
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VIIRS RGB, Aug 2, 2017

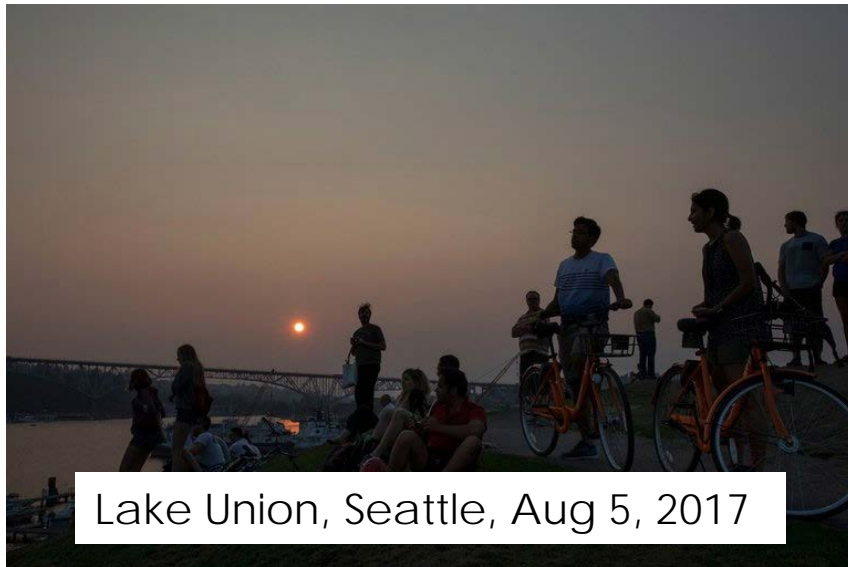




# Lots of Media Coverage of Smoke from 2017 Wildfires



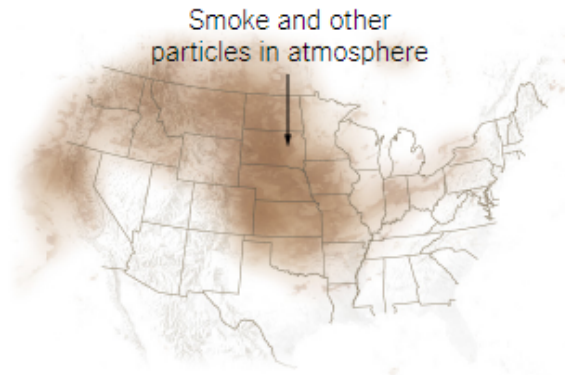
Photos courtesy of the New York Times



# ABI GeoColor Animation of Smoke (Aug 29 – Sep 5, 2017)

<https://www.nytimes.com/interactive/2017/09/16/us/wildfires-smoke-pacific-northwest.html>

*New York Times* article, Sep 16, 2017

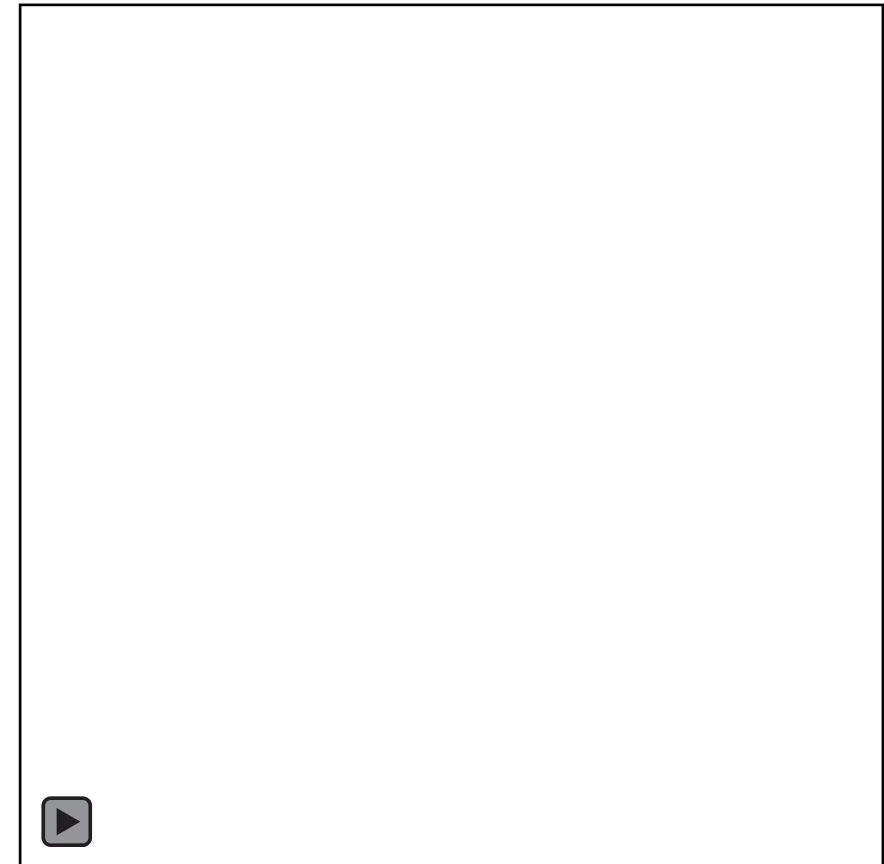


## As Wildfires Burn in West, Ash Rides Wind High Across U.S.

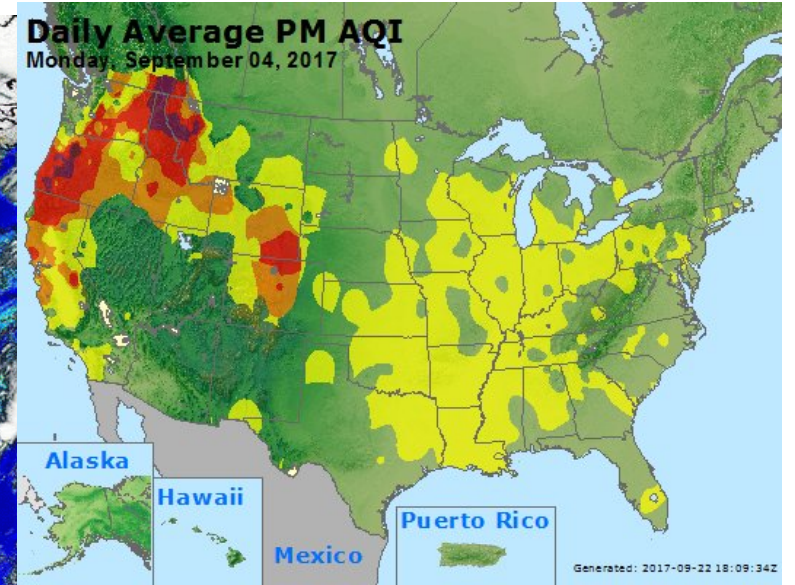
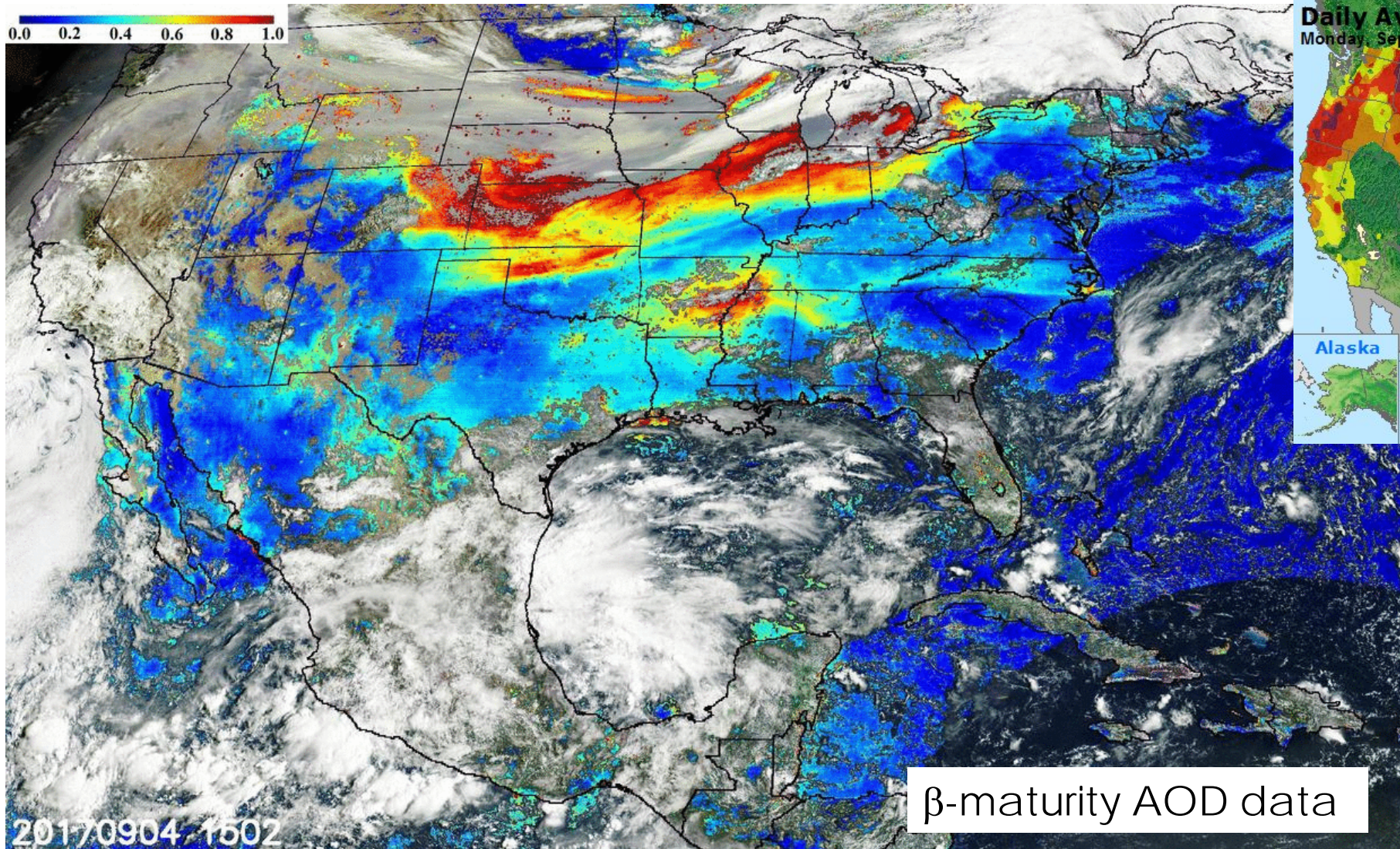
By TROY GRIGGS, K.K. REBECCA LAI, JEREMY ASHKENAS and JUGAL K. PATEL SEPT. 16, 2017

Wildfires in the Pacific Northwest this summer gave rise to dangerous air quality throughout the region, and generated plumes of smoke that spread across vast swaths of North America.

15 min loop of ABI GeoColor and fire hotspots, Aug 29 – Sep 5, 2017



# ABI AOD/GeoColor Smoke Animation (Sep 4, 2017)

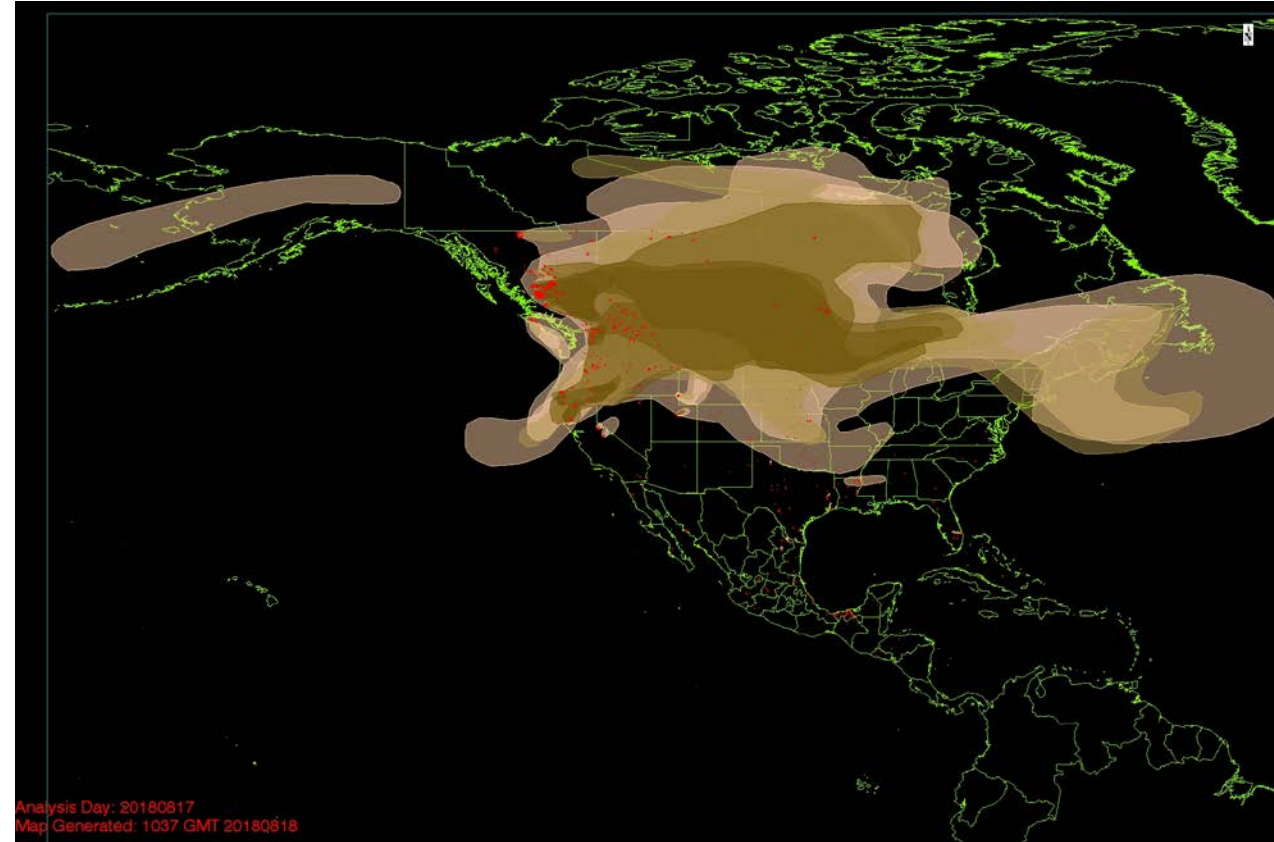


Good	0 to 50
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# July/August 2018 Wildfires

- Another round of wildfires raged this summer in the western U.S. and British Columbia, Canada
- > 500 fires were burning in British Columbia
- Mendocino Complex fire is largest wildfire in California history
- Hundreds of flights cancelled due to low visibility in Seattle and Vancouver
- Days of Code Red, Purple, and Maroon PM<sub>2.5</sub> air quality
- On August 20, 2018, air quality rankings in the world:
  - Vancouver, BC: #1 worst
  - Seattle, WA: #4 worst



NOAA Hazard Mapping System Fire and Smoke Product Analysis for August 17, 2018



# Smoke Transport News in the *Washington Post*

Capital Weather Gang

## Smoke from California's wildfires is reaching Washington and Baltimore

By **Jason Samenow**, Weather editor  
August 16



Lest anyone living in the D.C. area think Western wildfires are a problem 3,000 miles away, they might take a whiff of the air in their own backyard. Yes, high-altitude winds have carried the smoke across the country into the Mid-Atlantic region.

“I walked outside earlier and definitely smelled wildfire smoke,” [tweeted @annikaep](#) from downtown Washington on Wednesday.

Capital Weather Gang readers queried on Twitter reported smelling smoke [all over the region](#).

Capital Weather Gang

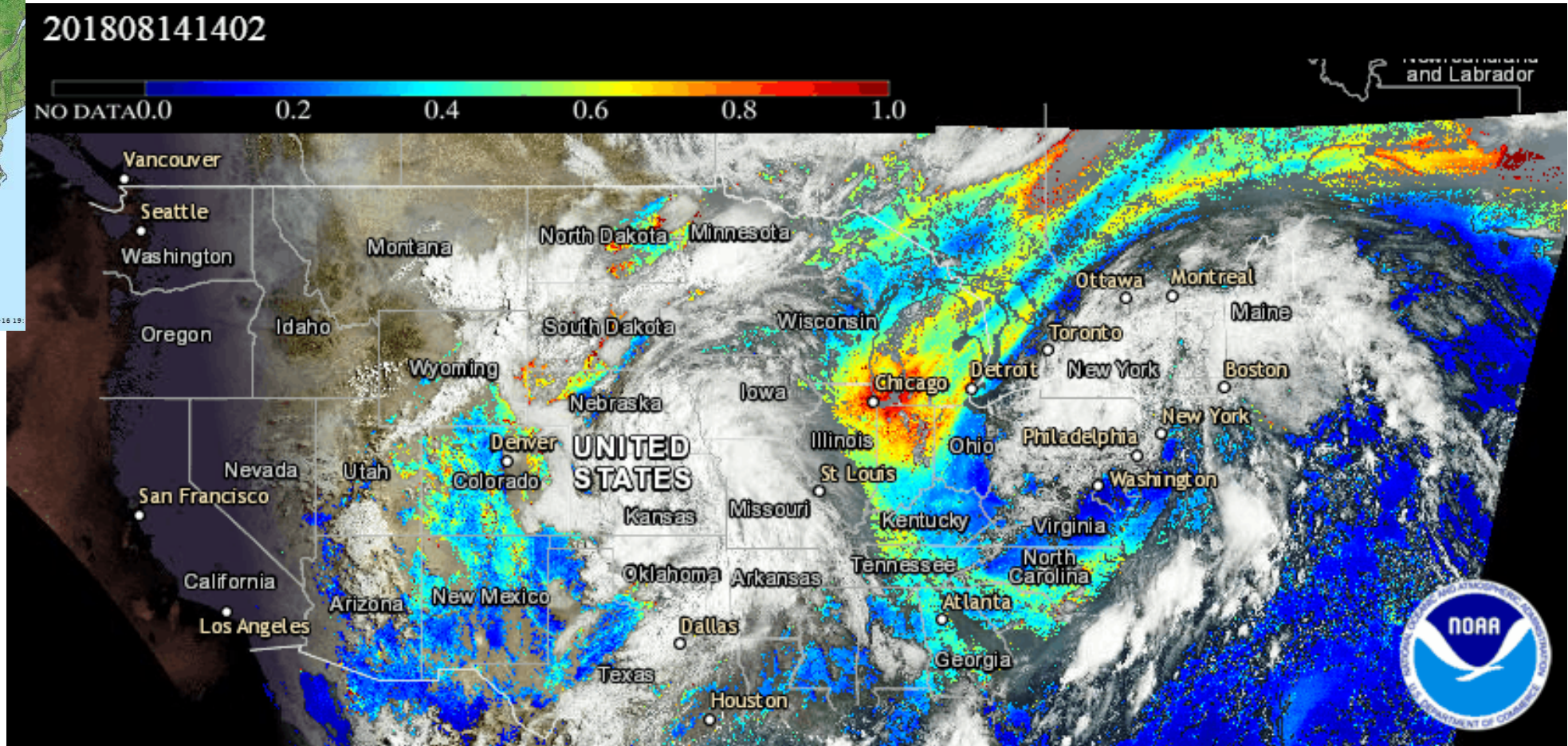
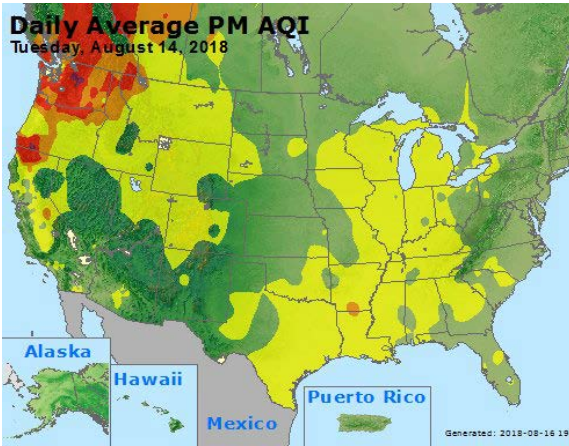
## Mount Rainier looked like an iceberg floating in a sea of smoke earlier this week

Capital Weather Gang

## Wildfire smoke is choking Seattle, obscuring the view and blocking out the sun



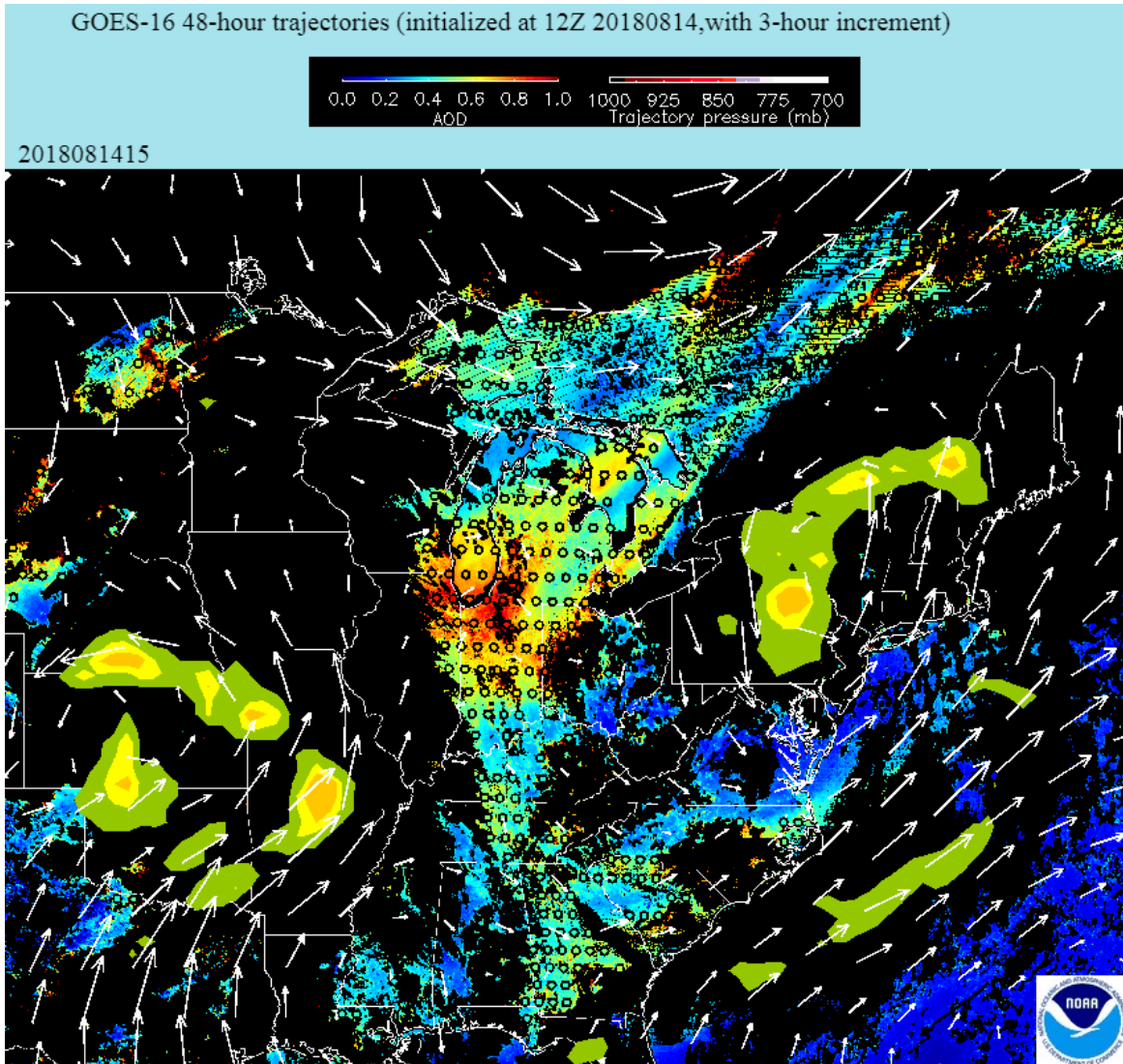
# ABI AOD/GeoColor Smoke Animation (Aug 14, 2018)



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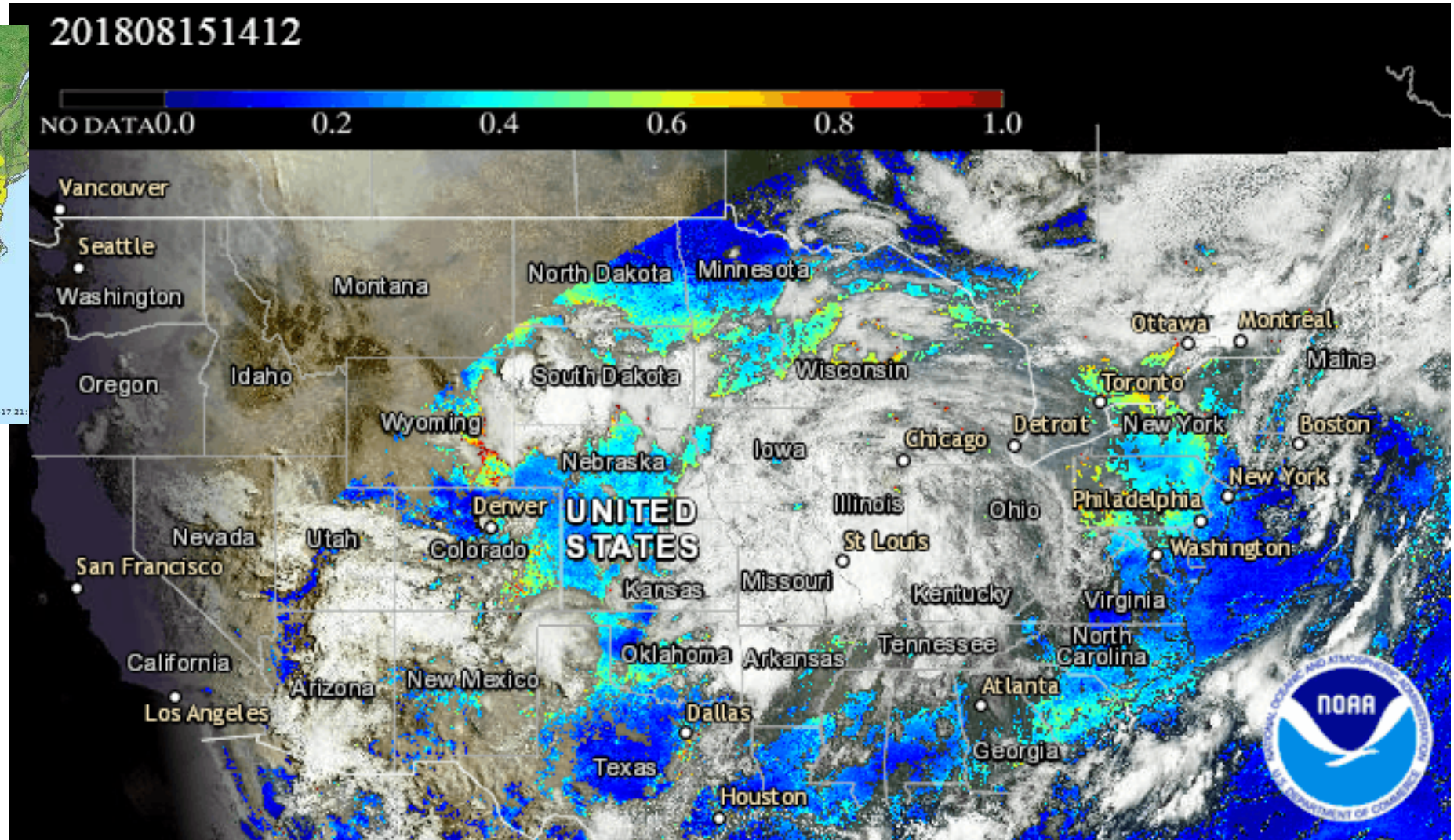
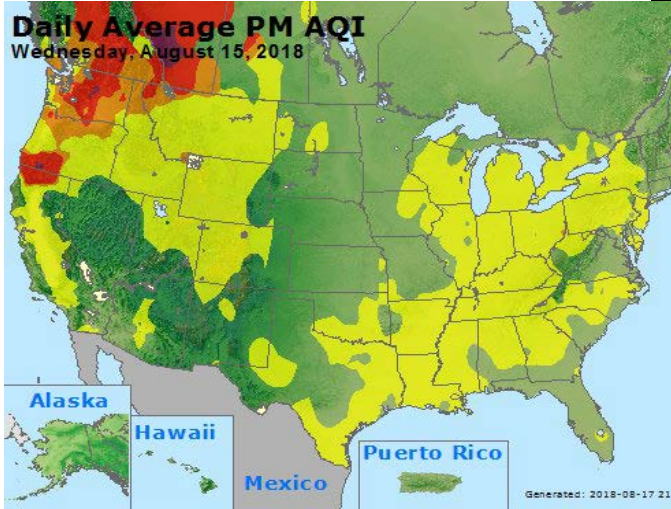
# Where is the Smoke in the Great Lakes on Aug 14 Going to be on Aug 15? 48-hr aerosol trajectories based on ABI AOD



- Trajectories indicate 48-hr forward motion of aerosol plumes, vertically and horizontally
- Areas of high ABI AOD ( $>0.4$ ) used as starting locations
- Trajectories initialized at 50, 100, 150, and 200 mb above surface
  - Trajectories initialized with NAM 12Z run, plotted in 3-hr increments:
    - Pink: near surface
    - White: away from surface
  - 850 mb wind vectors (white)
  - 3-hr accumulated precipitation (yellow)



# Smoke Moves Eastward: ABI AOD/GeoColor (Aug 15, 2018)

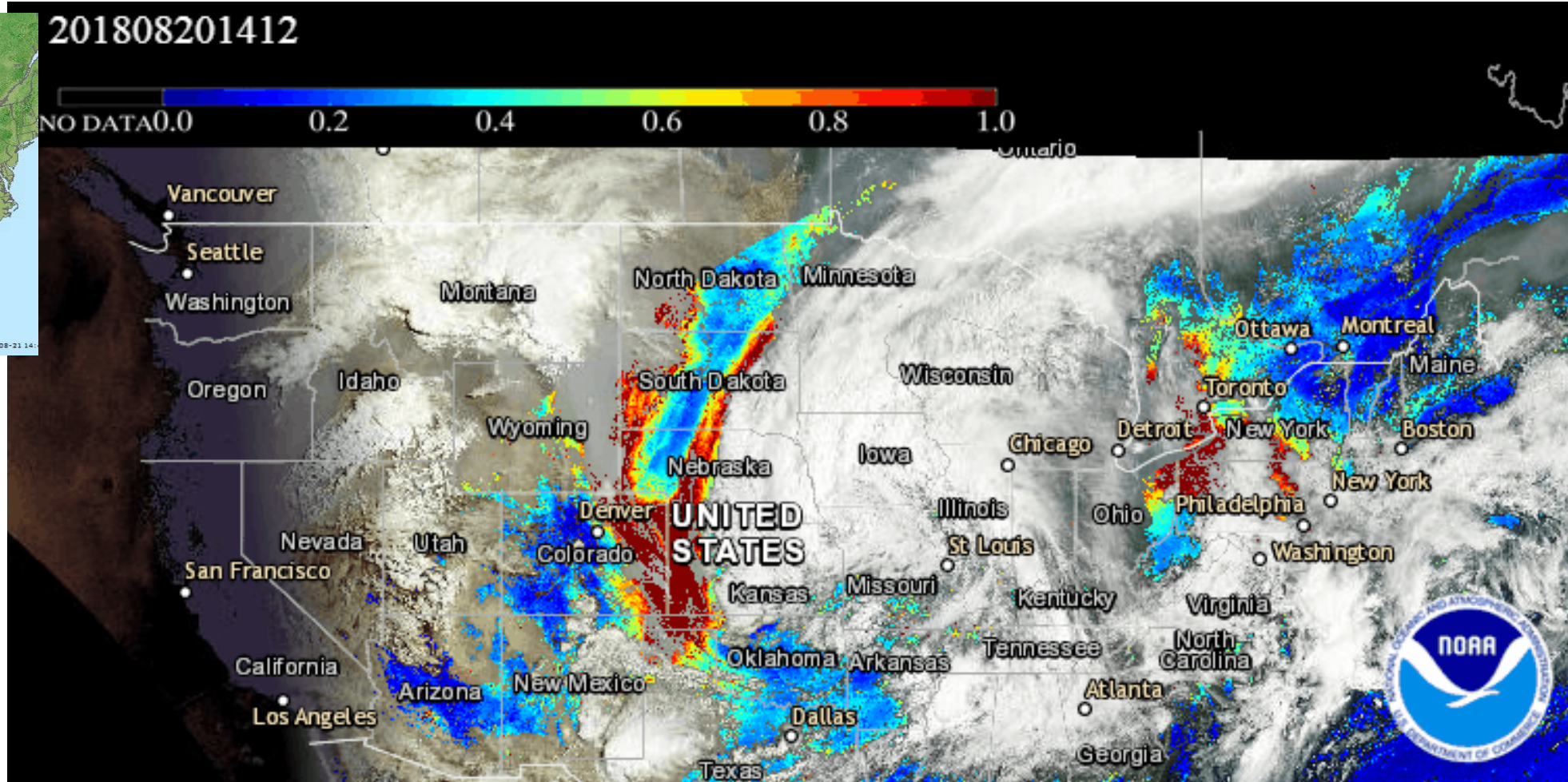
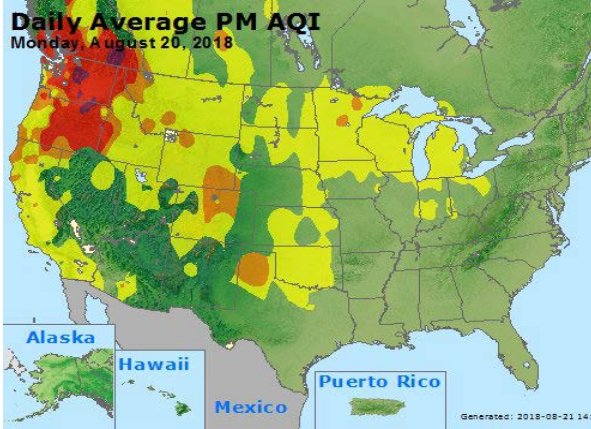


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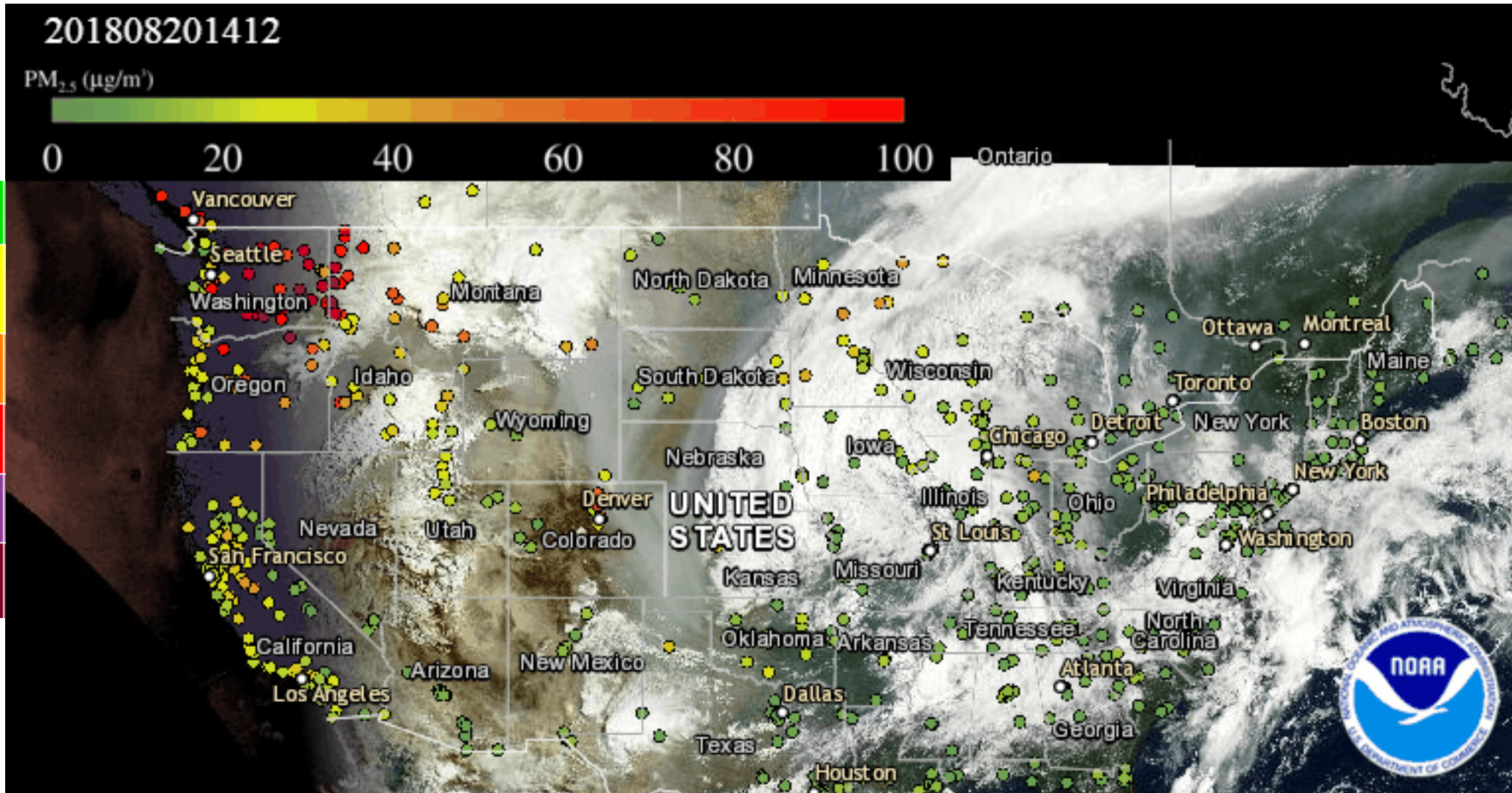
# Smoke Threat Continues: ABI AOD/GeoColor (Aug 20, 2018)

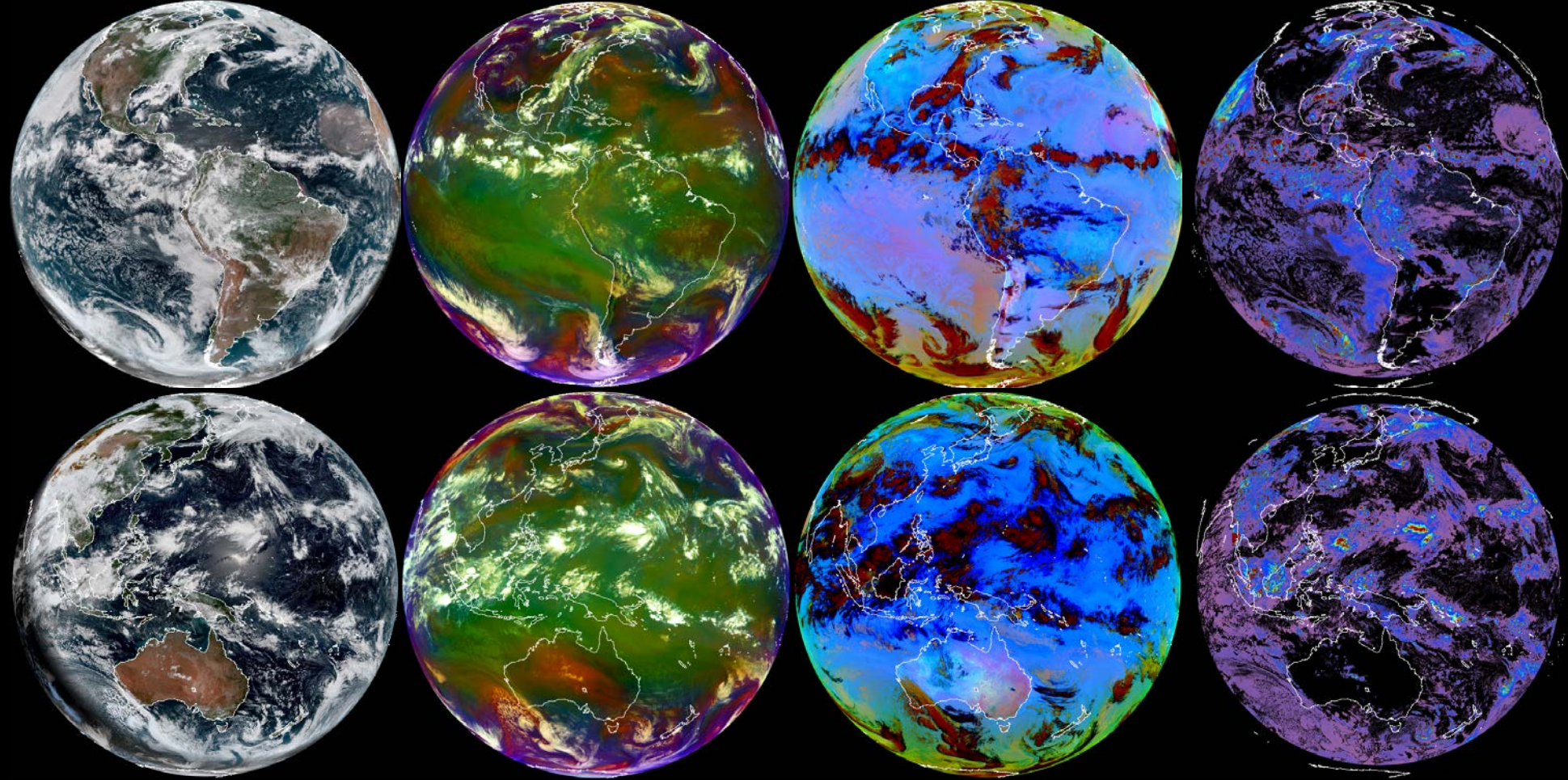


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# ABI GeoColor with Hourly PM<sub>2.5</sub> Observations (Aug 20, 2018)





How to Access ABI Aerosol Data and Imagery

# NOAA AerosolWatch Website: NRT ABI & VIIRS Aerosol Imagery

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

The screenshot shows the NOAA AerosolWatch website interface. The main display is a satellite image of Earth with aerosol data overlaid. The interface includes a top navigation bar with the AerosolWatch logo and the text "Every 15 minutes...". A date and time stamp "20180824 2042 UTC" is displayed. A set of animation controls (back, play, forward, stop) is visible. A layer selection menu on the right lists "GOES-16 Layers", "VIIRS Layers (SNPP)", "VIIRS Layers (NOAA-20)", "PM2.5 Layers", and "Labels Layer". A "CONUS Full Disk" button is also present. A callout box on the right indicates "CONUS or Full Disk View". A white banner at the bottom of the image reads "For best results, use AerosolWatch in Google Chrome".

Zoom in/out

Archive (past days); time stamp for current day

Animation controls

Select animation; save image

Click to select ABI and/or VIIRS Products

Aerosol trajectories (opens in new window)

Click to overlay observed PM<sub>2.5</sub>, state, national levels

CONUS or Full Disk View

GOES-16 Layers

VIIRS Layers (SNPP)

VIIRS Layers (NOAA-20)

PM2.5 Layers

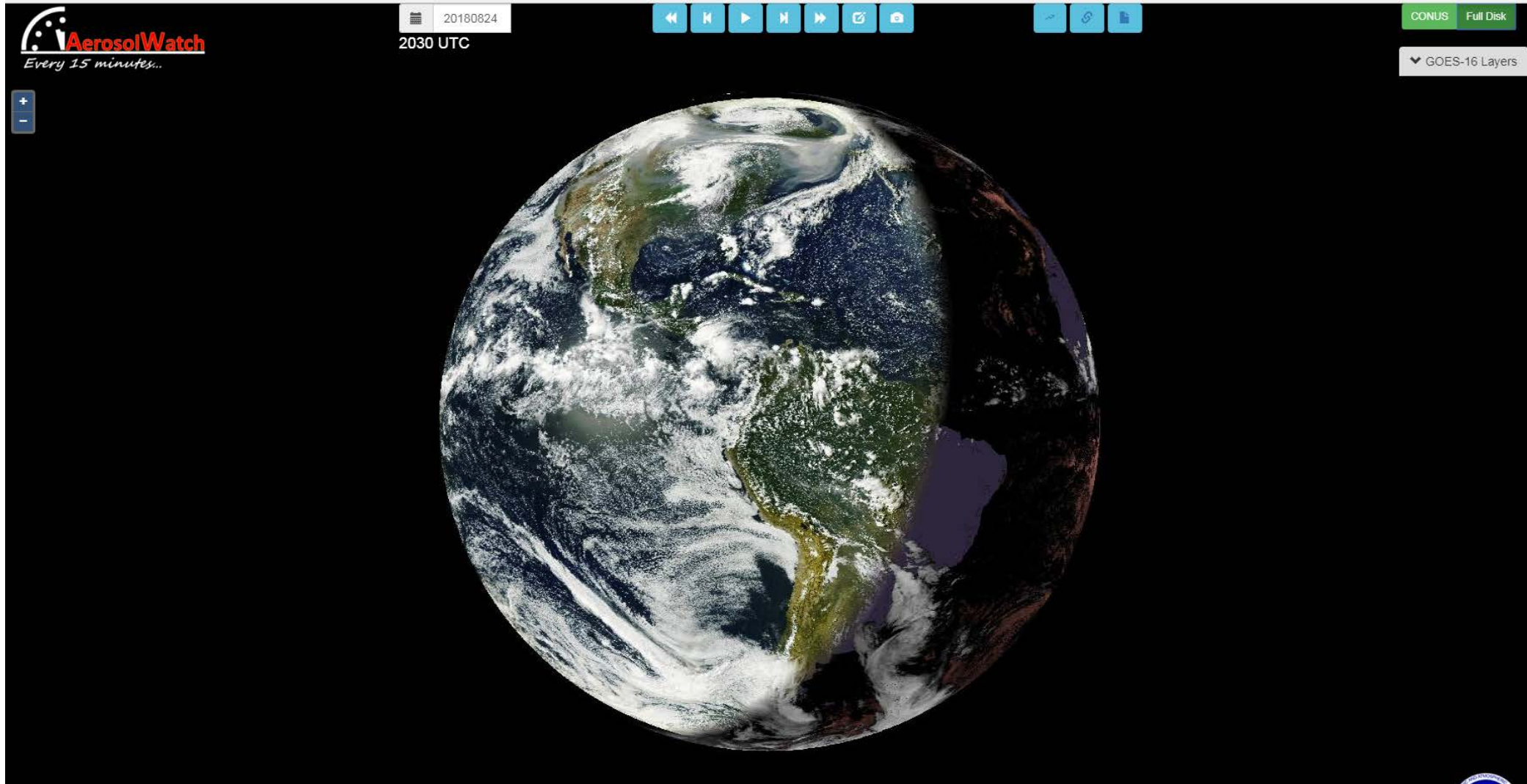
Labels Layer

CONUS Full Disk

For best results, use *AerosolWatch* in Google Chrome



# AerosolWatch ABI Full Disk View



# GOES-R Series ABI AOD Product Data Files

- All NOAA data are available from NOAA's Comprehensive Large Array-Data Stewardship System (<https://www.class.ncdc.noaa.gov>)
- However, AOD data are not available yet, since they only recently achieved provisional maturity status (as of July 2018)
- They should be available in late 2018
- AOD products in file:
  - 550-nm Aerosol Optical Depth for Full Disk and CONUS in range -0.05 to +5
  - Quality flag (0=good; 1=medium, 2=low, 3=not produced)
  - Mean, max, min and standard deviation of 550-nm AOD (and in bands used for AOD retrieval)



# Status of GOES-17

- Cooling system problem with ABI on GOES-17
  - Loop heat pipe subsystem, which transfers heat from the ABI electronics to the radiator, not operating properly
  - ABI's IR channel detectors are not being cooled properly during parts of the night
  - Once the IR detectors heat up, the channels saturate, and ABI can't accurately measure IR wavelengths
- Seems likely that ABI will not make all the measurements it was designed to (will be missing ~10%)
- Should NOT affect ABI aerosol products from GOES-17!
- NOAA plans to move GOES-17 into operations as GOES-West in late 2018



# Summary

- GOES-R series geostationary satellites provide revolutionary new, high accuracy and high resolution aerosol products!
  - **Aerosol optical depth (AOD)**: *quantitative* measure of aerosols
    - High accuracy, multi-channel aerosol retrieval
  - **Aerosol detection (smoke/dust mask)**: *qualitative* indicator of aerosols
    - New product! Not available from legacy GOES Imager!
  - **Dust RGB imagery**: indicates blowing dust
    - New product! Not available from legacy GOES Imager!
  - **GeoColor imagery**: visual indicator of smoke, blowing dust, and haze
    - New product! Not available from legacy GOES Imager!
- GOES-16 (GOES-East): routine full disk, CONUS and mesoscale views
- ABI aerosol imagery available from **AerosolWatch** website in NRT!

