Infusing Aerosol Information from Satellite Observations into Air Quality Applications

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13th Meeting of the Atmospheric Composition Virtual Constellation
June 29, 2017

IDEA: Infusing satellite Data into Environmental Applications

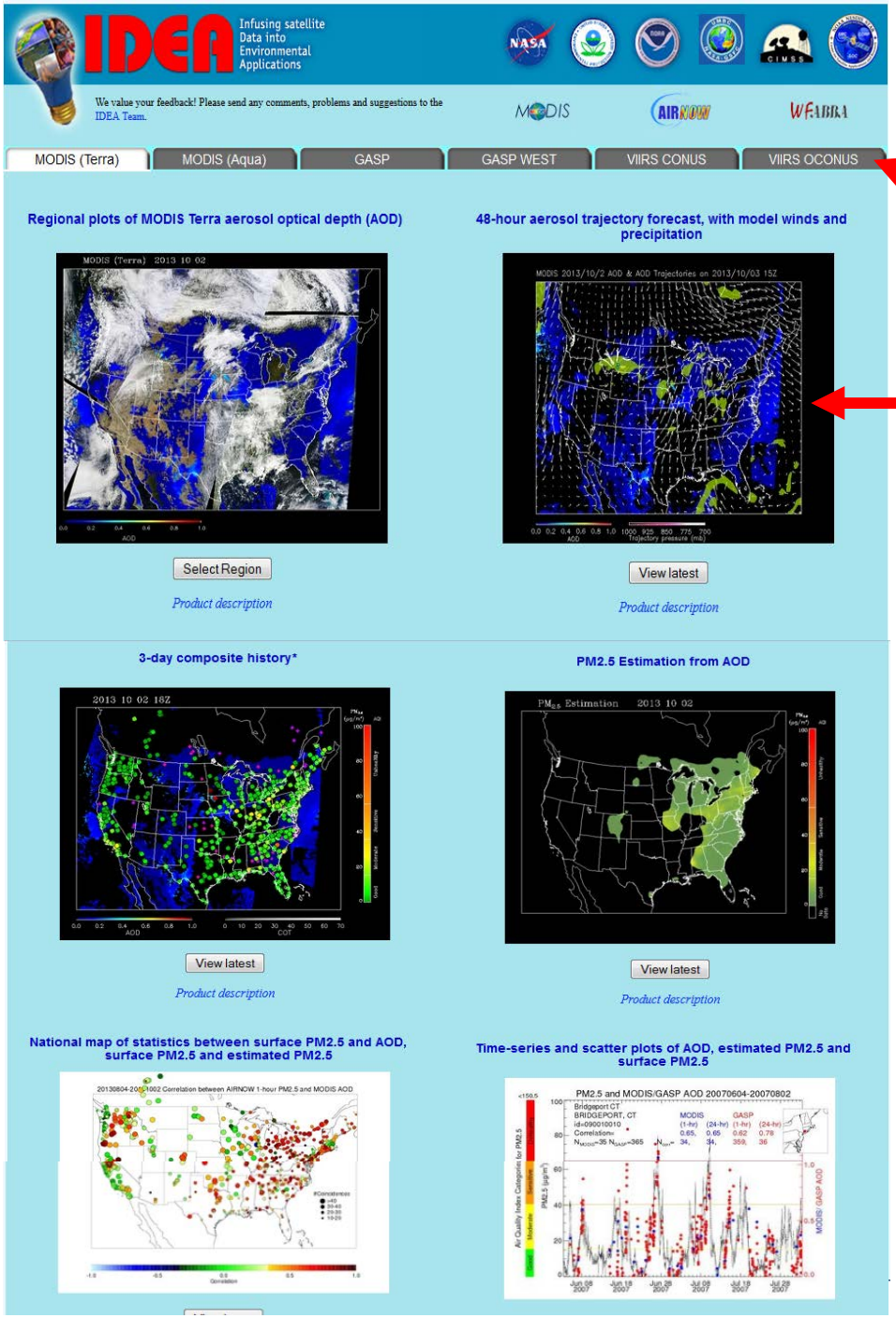
- Partnership between U.S. federal agencies to improve air quality assessment, management, and prediction
  - Developed by NASA and EPA in 2003
  - Transitioned to NOAA NESDIS in 2008
- Goal: provide access to satellite aerosol products for the operational air quality community
- Website with near real-time imagery
- Historical archive back to 2008
- Domain is flexible
  - Continental U.S. and Alaska on website
  - Anyone with access to NRT data through direct broadcast can set up with their own algorithms and products

Who are Operational Air Quality Data Users?

- Our users are primarily forecasters:
  - State/local air quality forecasters (O_3, $PM_{2.5}$, PM_{10})
  - Incident meteorologists (IMETs), National Weather Service forecasters (smoke, dust)
- They have unique limitations not shared by science data users:
  - Significant time constraints (no time to download data files and process)
  - Limited access to specialized software
- So operational users need satellite products available:
  - As prepared imagery
  - Via quick and easy access through a web browser

IDEA Web Page

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



Click tabs to select satellite

Click panels to select product

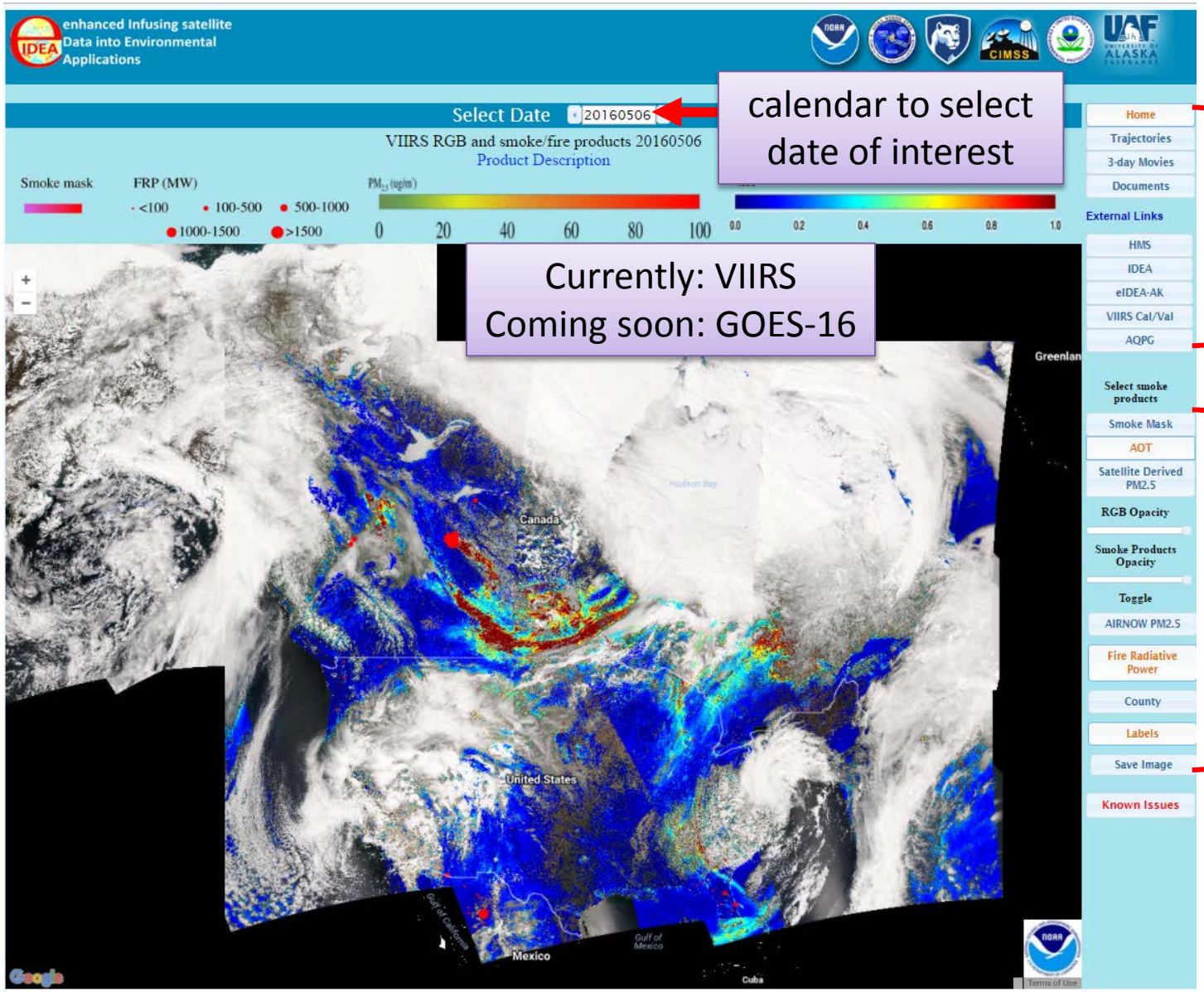
- Satellite imagery:
  - MODIS Terra and Aqua, VIIRS, GOES East and West
    - Aerosol optical depth (AOD)
    - True color imagery (RGB)
- Other data for analysis:
  - In situ $PM_{2.5}$ and satellite-estimated $PM_{2.5}$
  - 48-hour forward aerosol trajectories

IDEA Evolves into eIDEA

- NOAA launched Blended Fire and Smoke Initiative in May 2014; 4 objectives:
  1. Evaluate the current use of geostationary and polar-orbiting satellite capabilities in support of the Fire and Smoke mission
  2. Identify current SNPP/JPSS and new GOES-16 data and capabilities with the potential to improve support to this mission
  3. Establish methodologies and procedures for the operational demonstrations of these capabilities
  4. Identify the satellite capabilities whose operational impacts are sufficient to warrant transition from research to operations
- Key recommendation: develop tool for quick and easy access to NRT fire and smoke related satellite imagery
- In addition, our Advisory Group of operational users asked to have a separate section on IDEA to show only the most recent satellite info
- Result is evolution to eIDEA ("enhanced" IDEA)

eIDEA: 1-Stop Fire and Smoke Imagery

http://www.star.nesdis.noaa.gov/smcd/spb/aq/eidea/

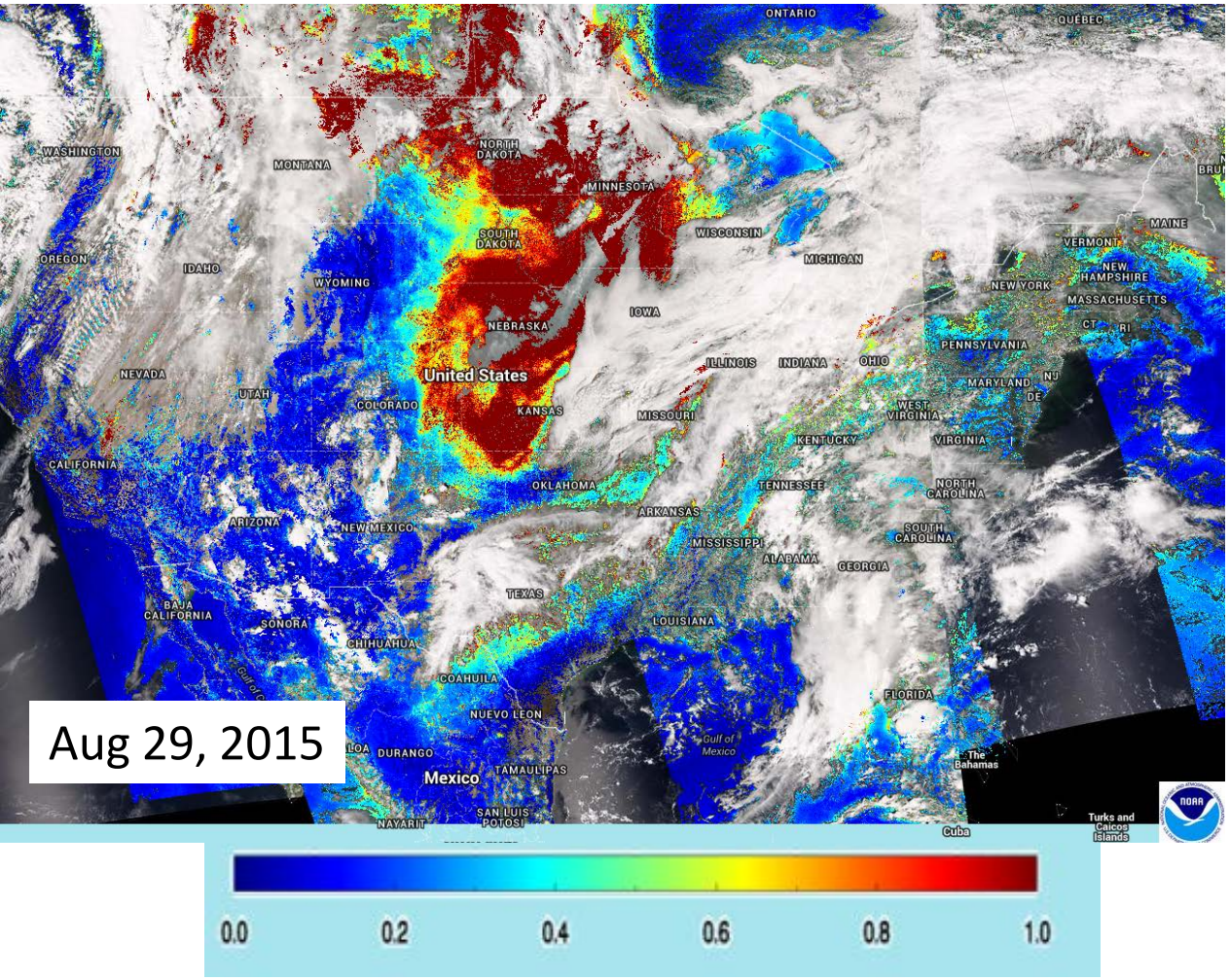


calendar to select date of interest

animations and external links

main product overlay buttons

eIDEA Products: Aerosol Optical Depth (AOD)



AOD has a rainbow color scale on eIDEA

- AOD: *quantitative* indicator of aerosols
- **Useful for identifying smoke, dust, or haze**
- AOD is unitless; values typically range from 0 to 1 in the U.S.
- Higher AOD values correspond to higher aerosol concentrations
- Clouds block the measurement of AOD, so there is no AOD in white cloud-covered areas

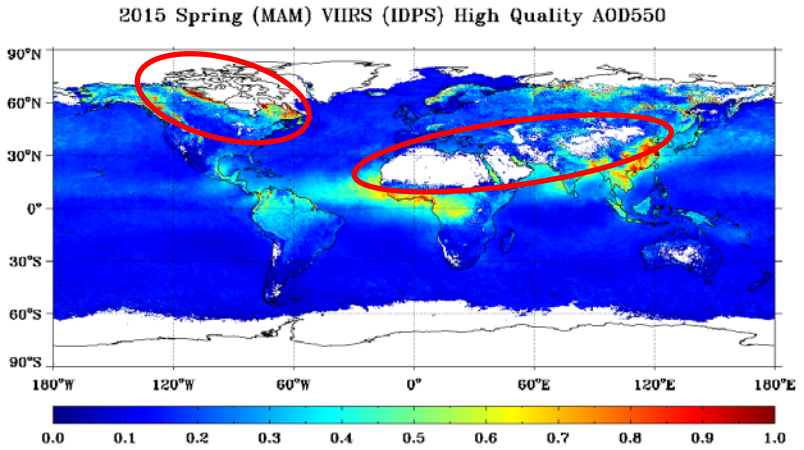
Zhang et al. (2016), An enhanced VIIRS aerosol optical thickness (AOT) retrieval algorithm over land using a global surface reflectance ratio database, *J. Geophys. Res. Atmos.*, 121, 10,717–10,738.

New Aerosol Optical Depth Algorithm

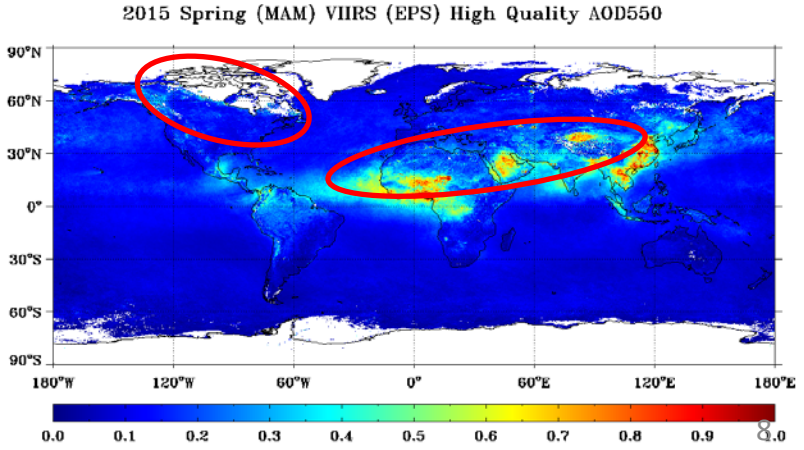
- **New** *Enterprise Processing System (EPS)* expected to become operational July 2017: replaces current *Interface Data Processing Segment (IDPS)* algorithm
  - Retrieval over bright land, extended reporting range [-0.05-5.0], extensive internal test
- Separate algorithms for land and water

Band	Central Wavelength (µm)	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	

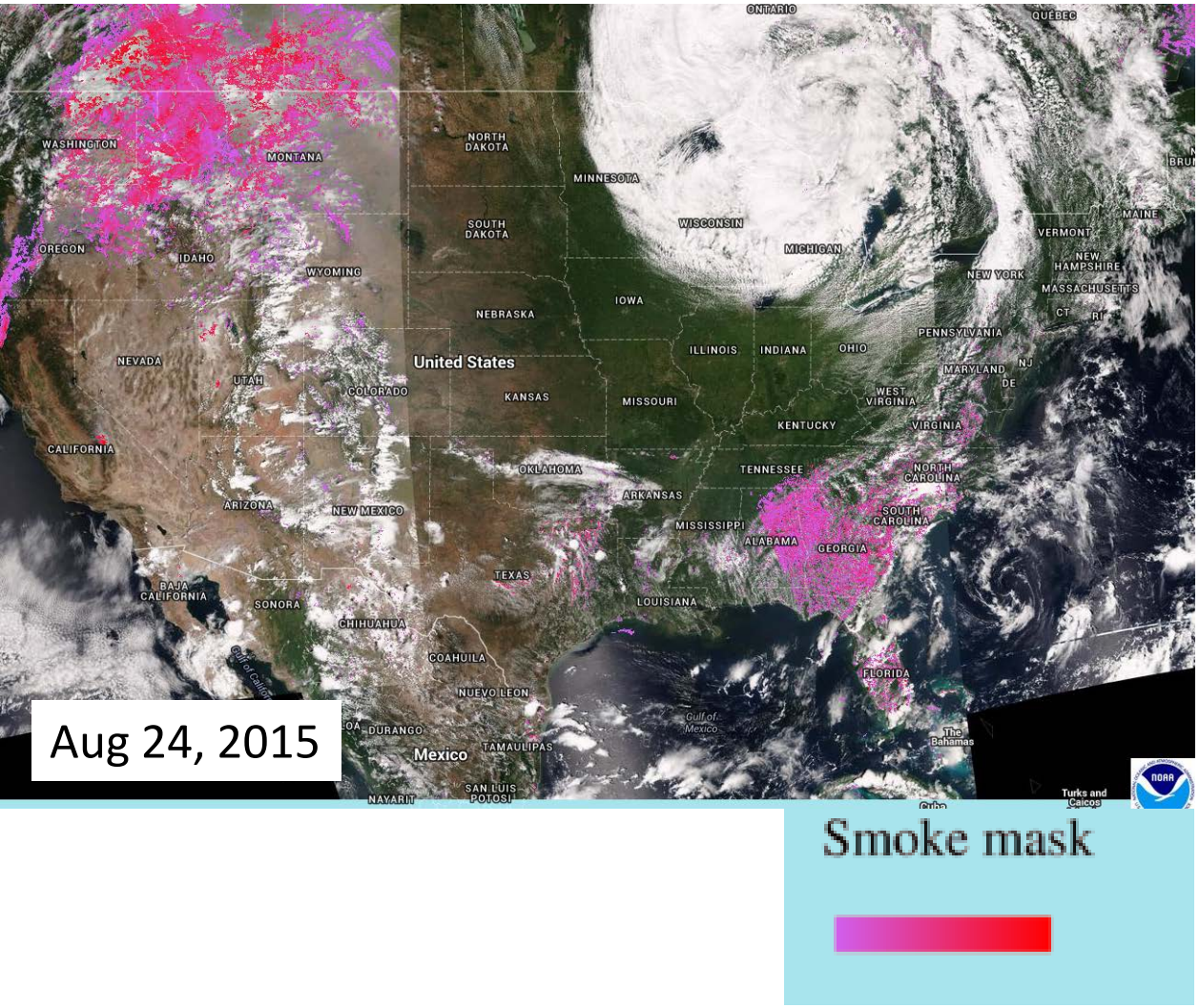
IDPS (current) seasonal mean AOD



EPS (new) seasonal mean AOD



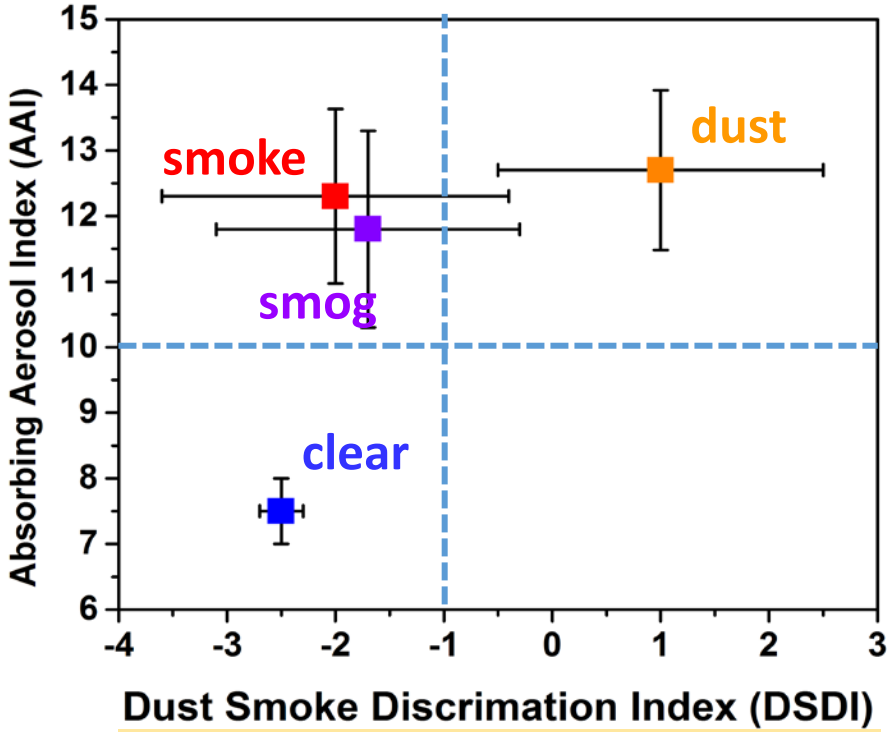
eIDEA Products: Smoke Mask (Aerosol Detection)



- Smoke mask: *qualitative* indicator of smoke
- Derived using spectral and spatial threshold tests based on VIIRS measurements in visible and IR
- **Useful for identifying local and transported smoke plumes**
- Colored shades of pink on eIDEA
  - Light pink: thin smoke
  - Dark pink/magenta: thick smoke

Overview of Aerosol Detection Algorithm (for the Smoke Mask Product)

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



$$DSDI = -10[1\log_{10}(R_{412}/R_{2250})$$

Input Reflectances

Dust: 412, 440, 2250 nm

Smoke: 412, 440, 2250 nm

Spatial Variability Test: 412 nm

Turbid Water Test: 488 nm, 1.24 µm, 1.61 µm, 2.25 µm

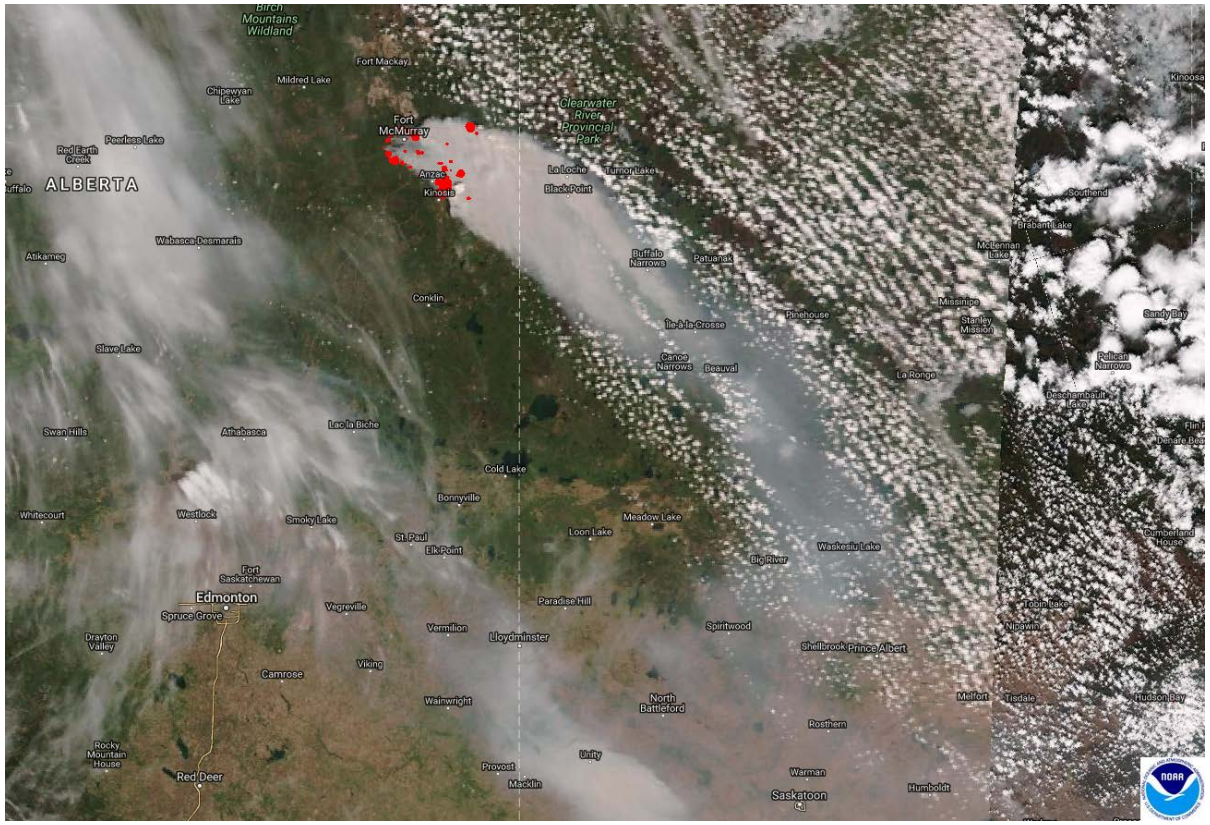
Bright Pixel Test:1.24 µm, 2.25 µm

NDVI Test: 640 nm, 865 nm

Snow Test: 865 nm, 1.24 µm

eIDEA in Action: Fort McMurray Fire, May 2016

- Fort McMurray fire, Alberta, Canada
  - Began May 1, 2016 and burned for more than 1 month
  - Consumed > 600,000 hectacres
  - Forced evacuation of > 88,000 residents from city in early May



VIIRS RGB and fire radiative power May 6, 2016

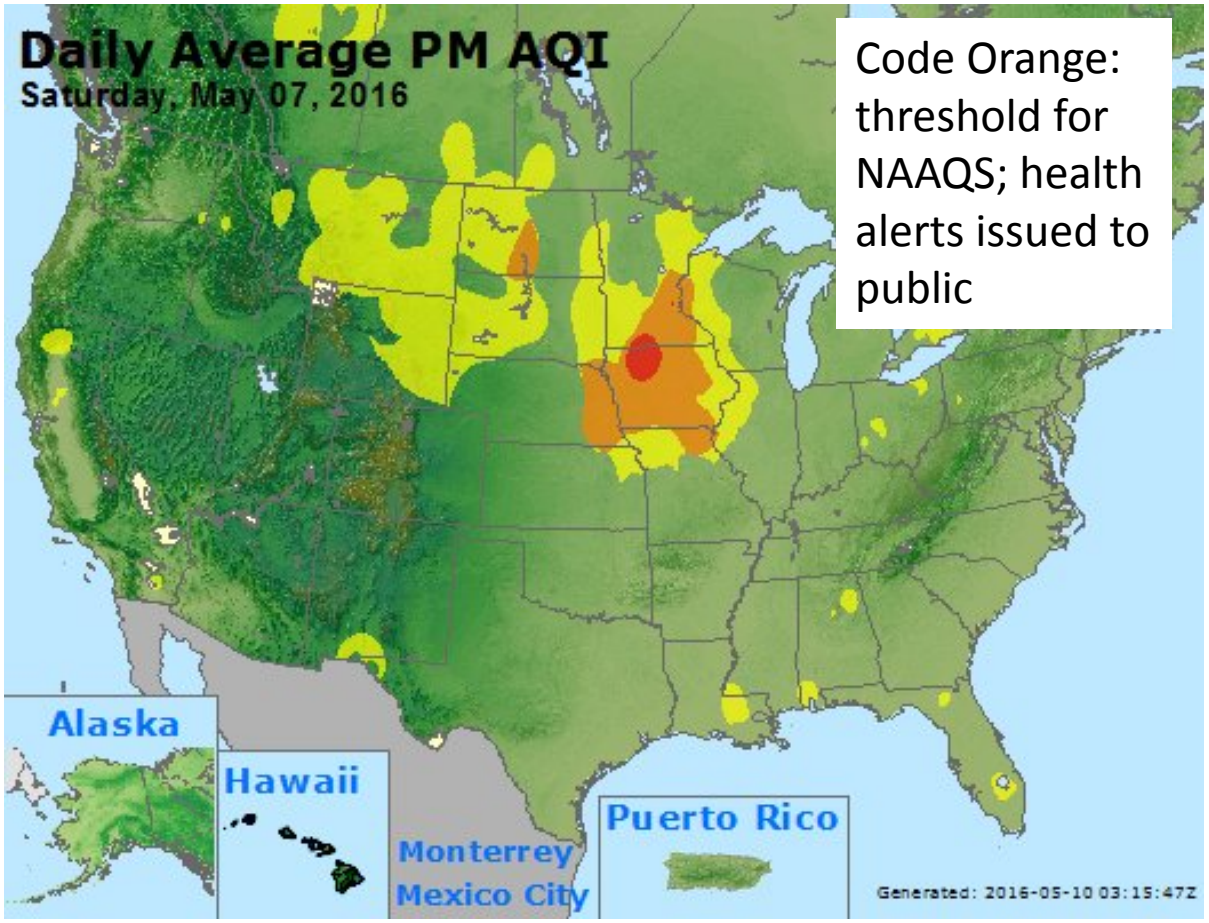
Often Difficult to Forecast Impacts of Smoke

- Smoke is an issue for air quality because plumes contain precursors for O_3 and $PM_{2.5}$ production (NO_x and hydrocarbons) and primary $PM_{2.5}$
- Smoke from major wildfires can be transported long distances, sometimes 100s of km downwind, at varying altitudes
- If smoke mixes to the surface, it can cause exceedances of the daily U.S. health standards for O_3 and $PM_{2.5}$
  - National Ambient Air Quality Standard (NAAQS)
- Most of our forecast tools in the U.S. are not skillful for predicting impacts of transported smoky air masses
  - National numerical O_3 and $PM_{2.5}$ models: currently don't include transported smoke in lateral boundary conditions
- Satellite aerosol products help to track transport of smoke plumes and to predict whether smoke will mix to surface

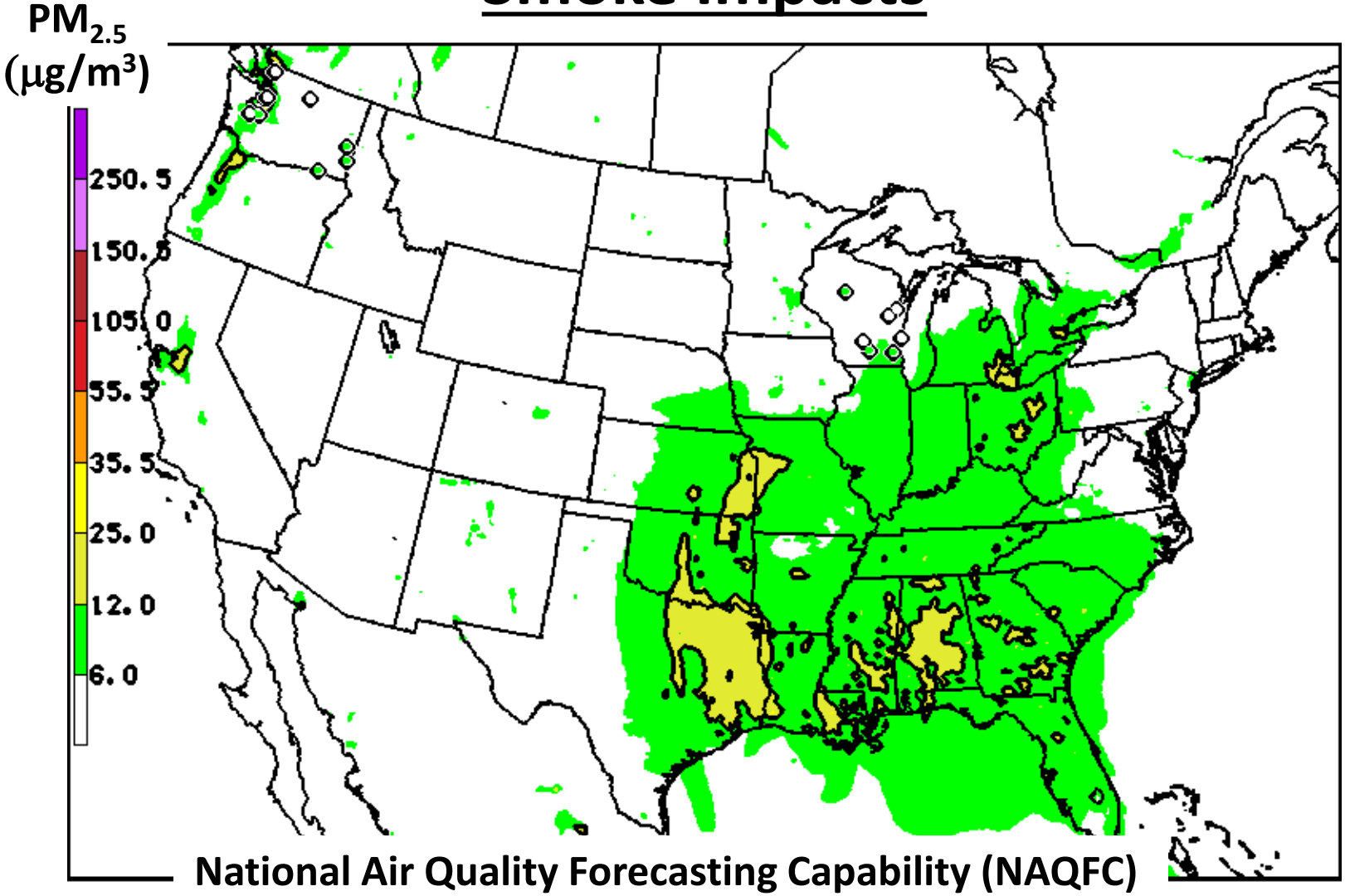
Smoke Transported to U.S. on May 7, 2016

- Smoke from the Ft McMurray fire traveled to the north/central U.S. and caused widespread exceedances of $PM_{2.5}$ NAAQS on May 7
- Event only lasted one day – $PM_{2.5}$ dropped to Code Yellow on May 8

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

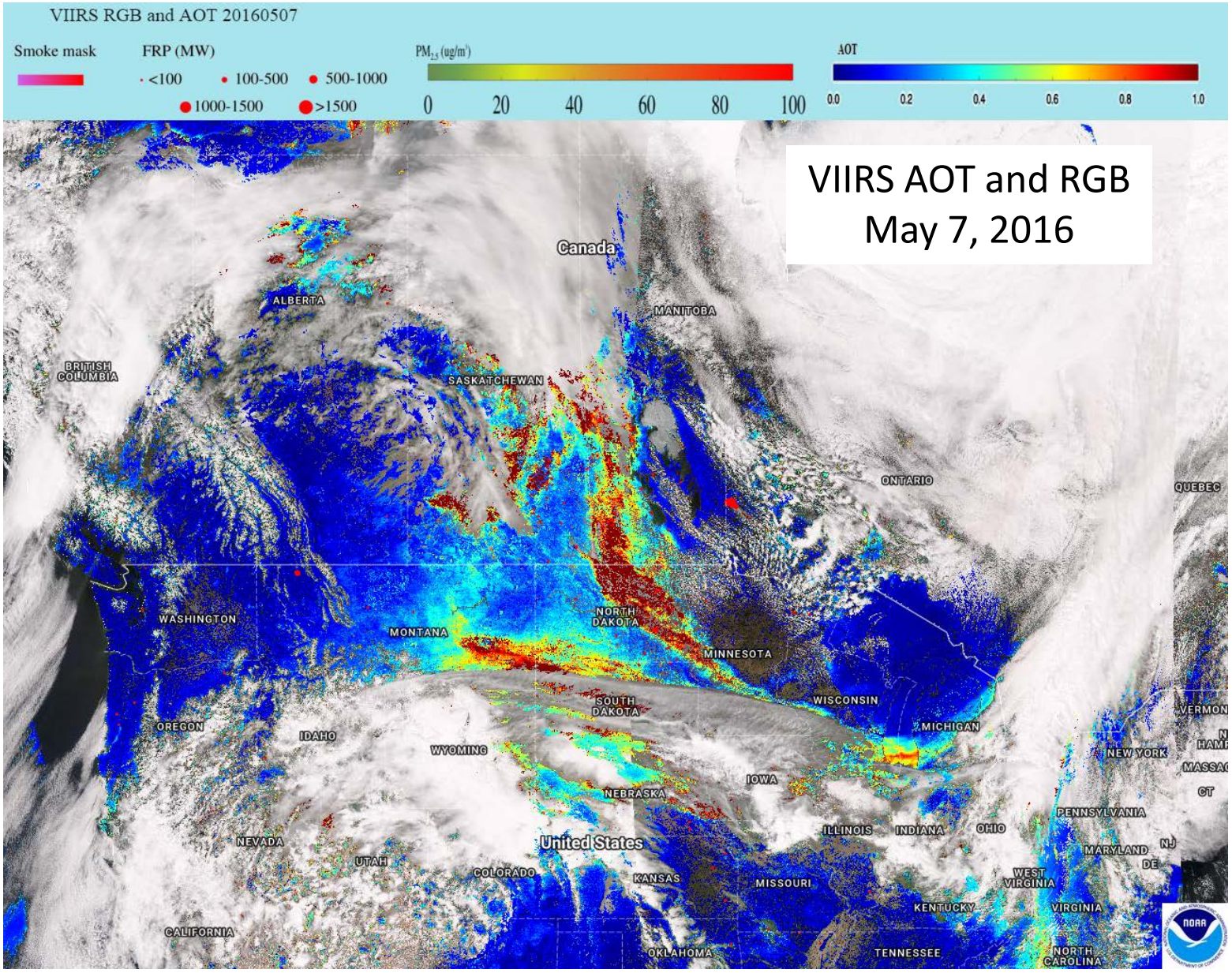


U.S. National $PM_{2.5}$ Model Did Not Predict Smoke Impacts



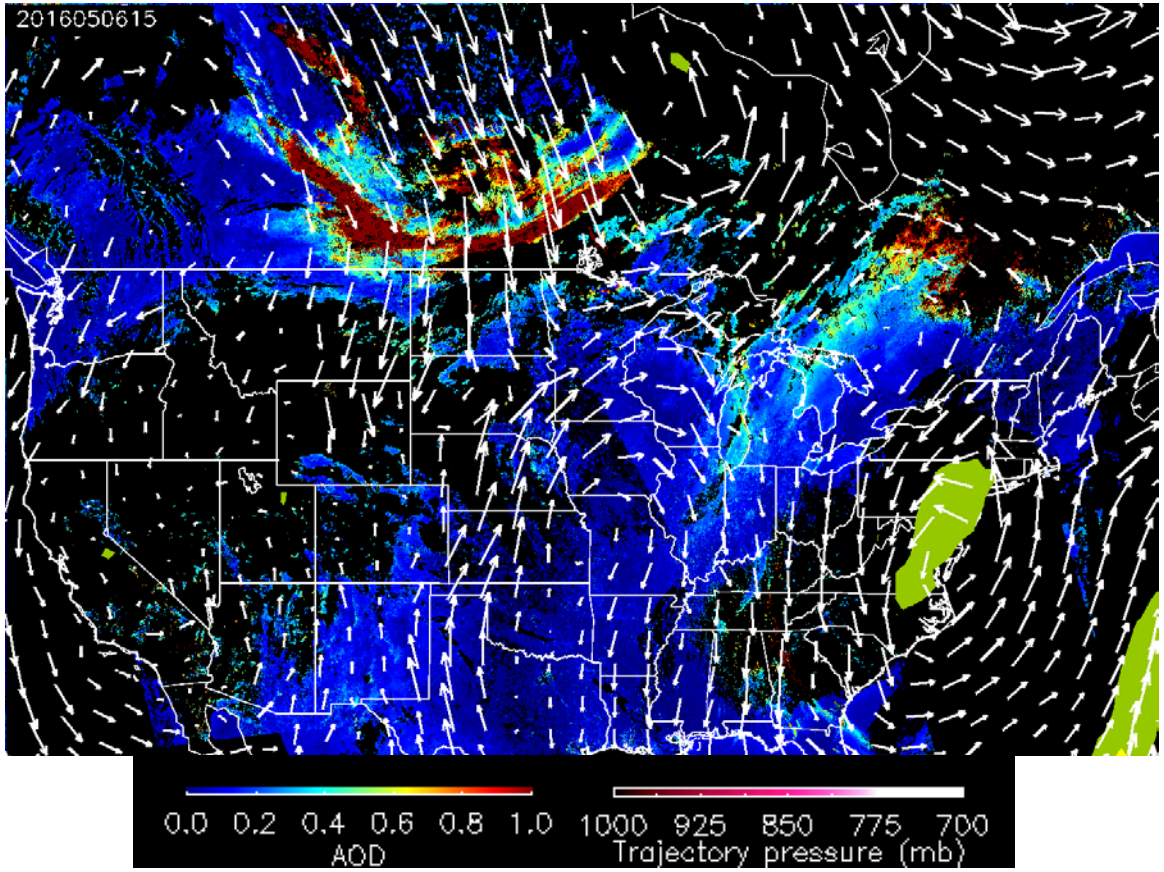
National Air Quality Forecasting Capability (NAQFC)
24-hour average $PM_{2.5}$ Predictions valid May 7, 2016

VIIRS AOT Shows Smoke Transport



VIIRS Trajectories Predicted Transport to Surface

VIIRS Aerosol Trajectories
Initiated 12 UTC, May 6, 2016



Magenta/pink lines indicate transport of smoke south into U.S., remaining near surface

- Trajectories: transport of smoke plumes in next 48 hours
- Areas of high AOT (>0.4) used as starting locations
- Trajectories initialized at 50, 100, 150, and 200 mb above surface
- Trajectories run using NAM 12Z run output:
  - Pink: near surface
  - White: away from surface
- 850 mb wind vectors (white)
- 3-hr accumulated precipitation (yellow)

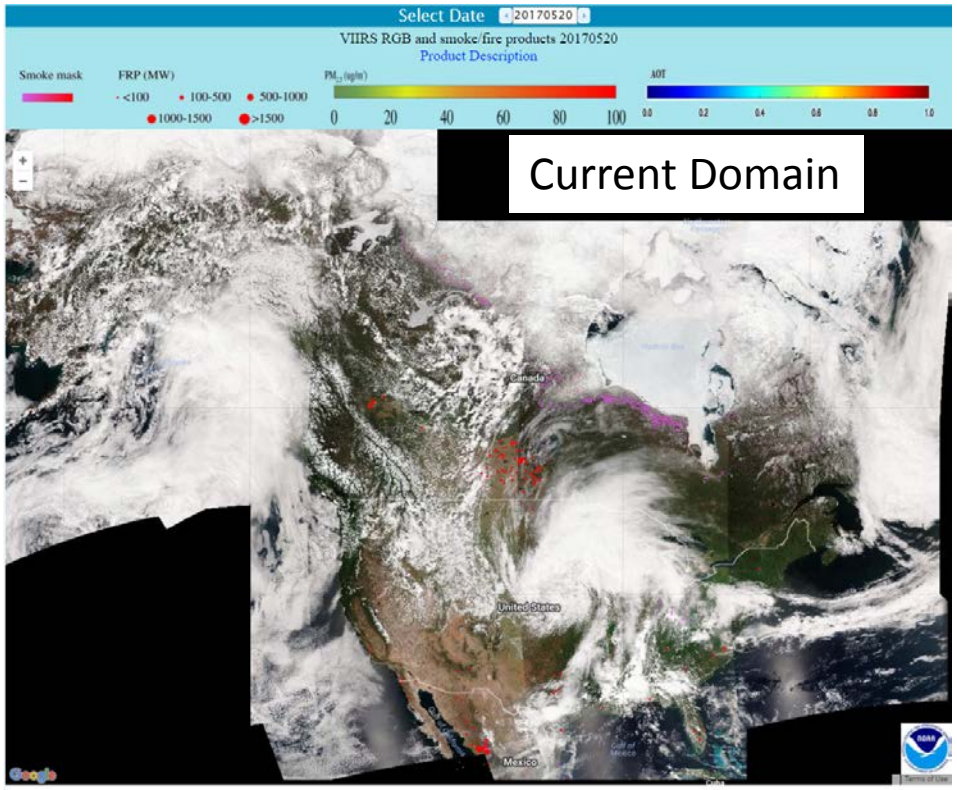
Products on eIDEA Critical for Operational Air Quality Users

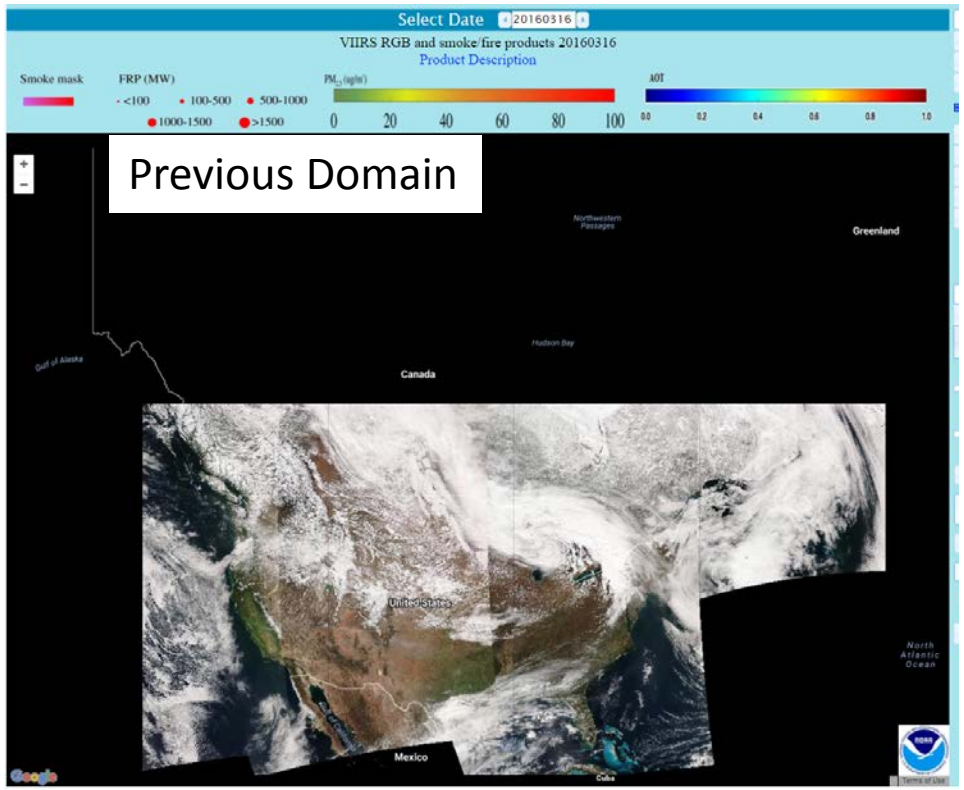
- Satellite AOD, RGB, and smoke mask
  - Identify location and transport of smoke plumes
  - Give forecasters a heads-up when smoke may be heading toward forecast area
- 48-hour aerosol trajectories
  - Identify when smoke will reach surface in forecast area
  - No other current forecast tools in the U.S. can predict when smoke-laden air mass will move into forecast area and mix to surface
- New eIDEA website designed for operational users
  - Quick, easy, 1-stop for access to aerosol satellite imagery

eIDEA is Improving: Feedback from Users

- eIDEA demonstrated to operational users in the U.S.:
  - IMET CEE Training Workshops, March 2016
  - NOAA Satellite Aerosol Product Workshop for Science and Operational Users, September 2016
- Examples of feedback/requests from users:
  - Love eIDEA, will be very useful for forecasting and retrospective event analysis
  - Expand domain to see:
    - Dust transport from Asia (west) and Africa (south, east) COMPLETED
    - Smoke across Alaska and Canada COMPLETED
  - Add zoom capability to aerosol trajectories COMPLETED
  - Add GOES-16 data as soon as possible IN PROGRESS

eIDEA Domain Recently Expanded





eIDEA domain now includes CONUS, Alaska, Canada, Mexico, western Atlantic, and eastern Pacific

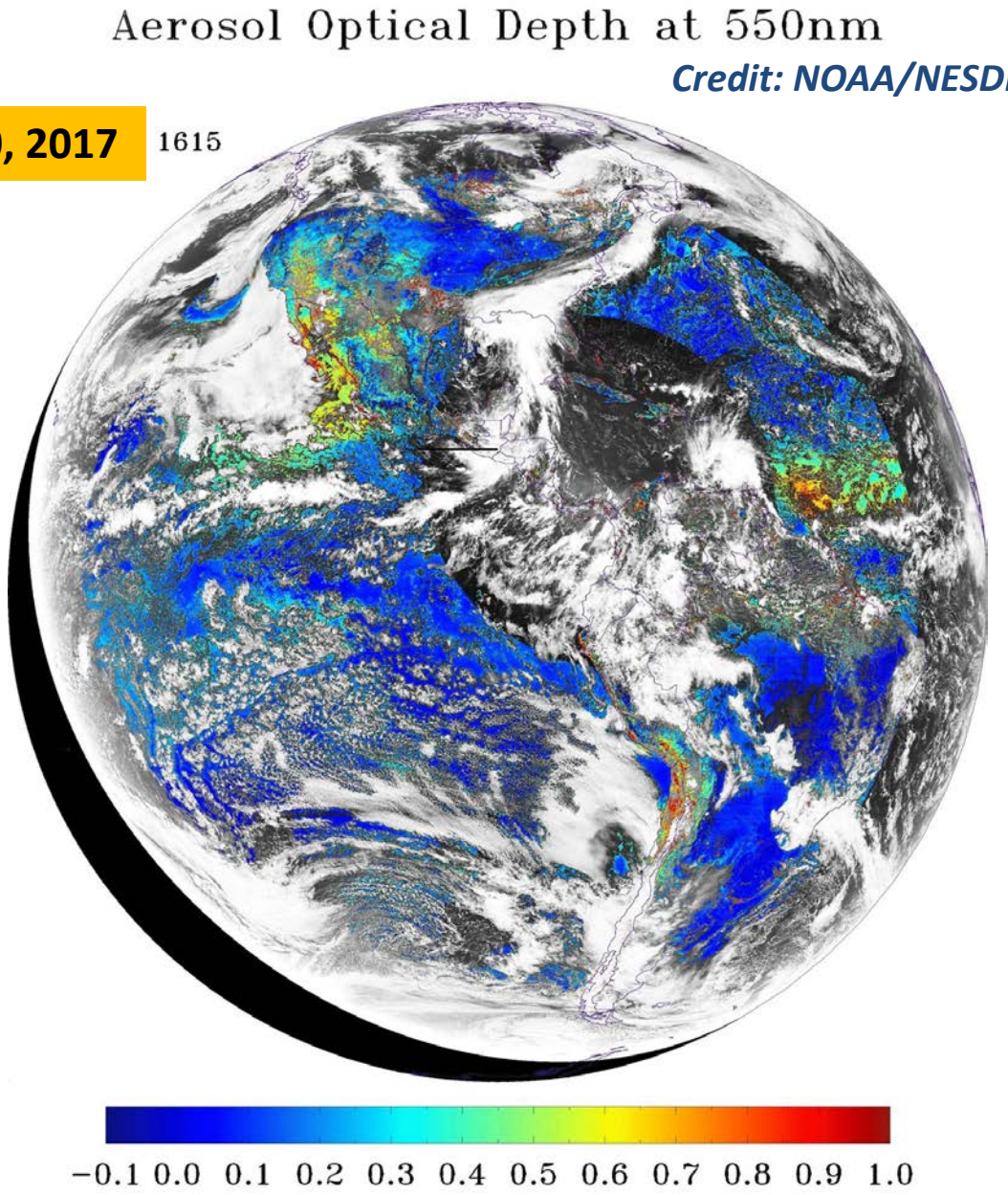
Coming Soon to eIDEA: GOES-16 Aerosol Imagery

- Very high temporal resolution!
- e.g., scan mode 3 (”flex mode”):
  - 15 min, full disk (North and South America)
  - 5 min, continental U.S.
  - 1 min, 2 mesoscale regions (selectable based on current hazards)
- **Data latency is 2 minutes!**
- New and exciting products:
  - AOD
  - Smoke and dust masks (aerosol detection)
  - Dust RGB
  - Synthetic RGB
  - Natural color RGB
- GOES-16 ABI aerosol products passed β-maturity in late May 2017

Synthetic RGB Full Disk 5-minute Animation

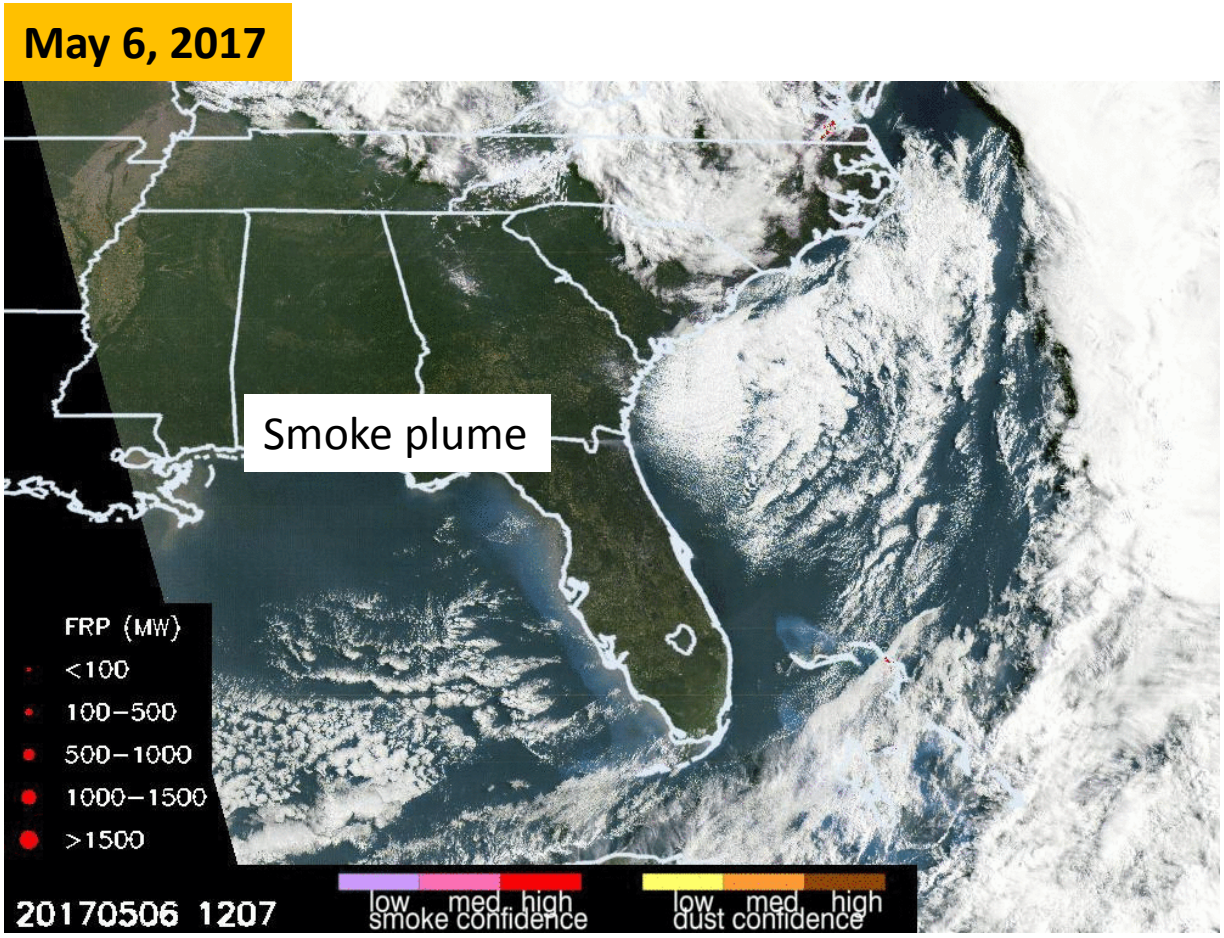
Credit: NOAA/NESDIS/STAR aerosol team

AOD Full Disk 15-minute Animation



Disclaimer: Product preliminary at β-maturity. ***Not to be used in any science studies.*** *Satellite and instruments still in checkout phase. Parked at 89°W. Will be moved to 75°W in November to its permanent East location and will replace GOES-13.*

Smoke Mask/Synthetic RGB: West Mims Fire, Florida

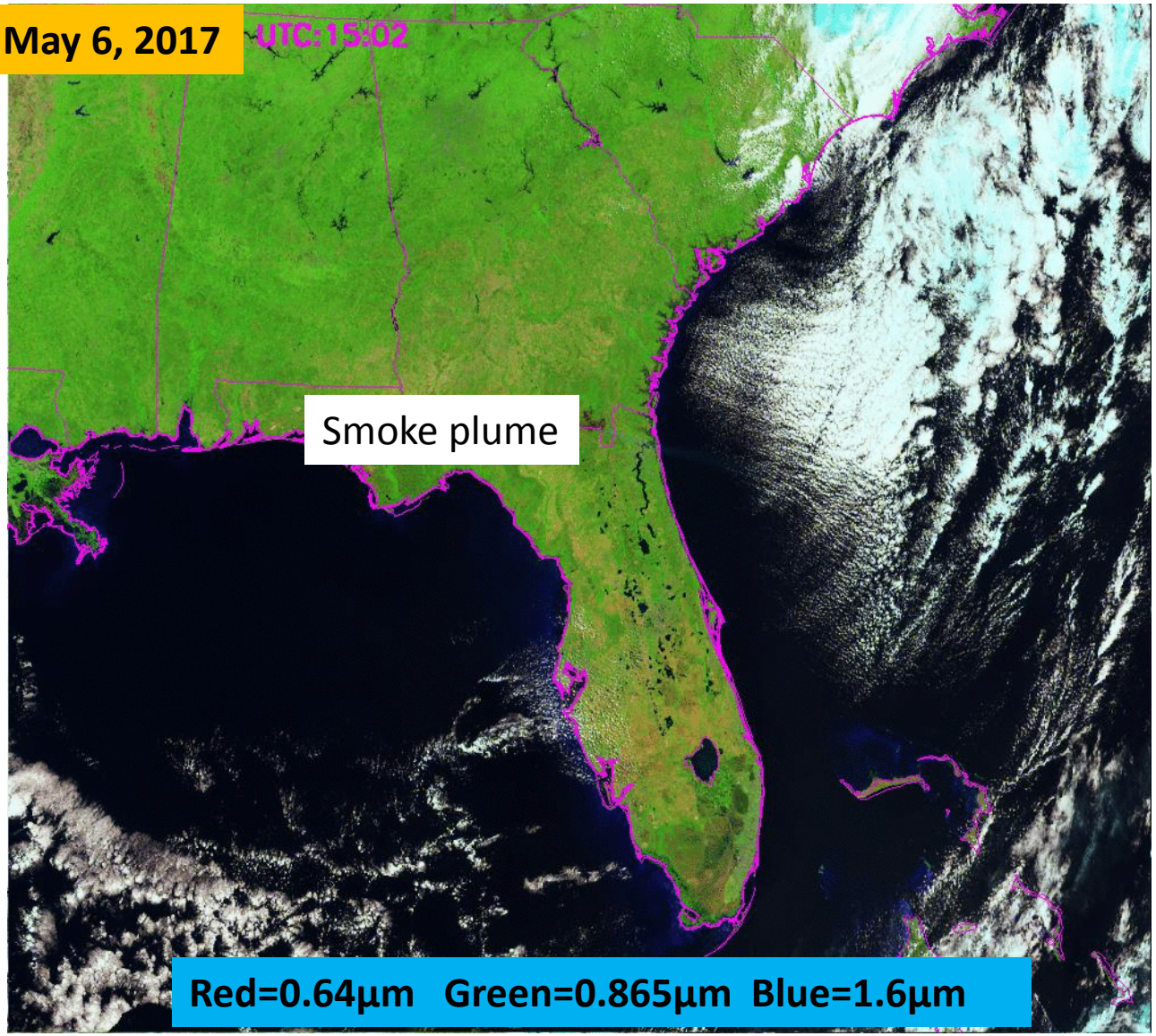


15-min animation

- Smoke mask from fires in FL/GA overlaid on synthetic RGB image
- First implementation of smoke detection for a geostationary satellite sensor!
- Parts of smoke plume detected
- Algorithm upgrades to tune spectral threshold tests pending
- False smoke over shallow water regions; Shallow water test to screen pixels pending
- Angle dependencies of various spectral tests still being investigated

Credit: NOAA/NESDIS/STAR aerosol team

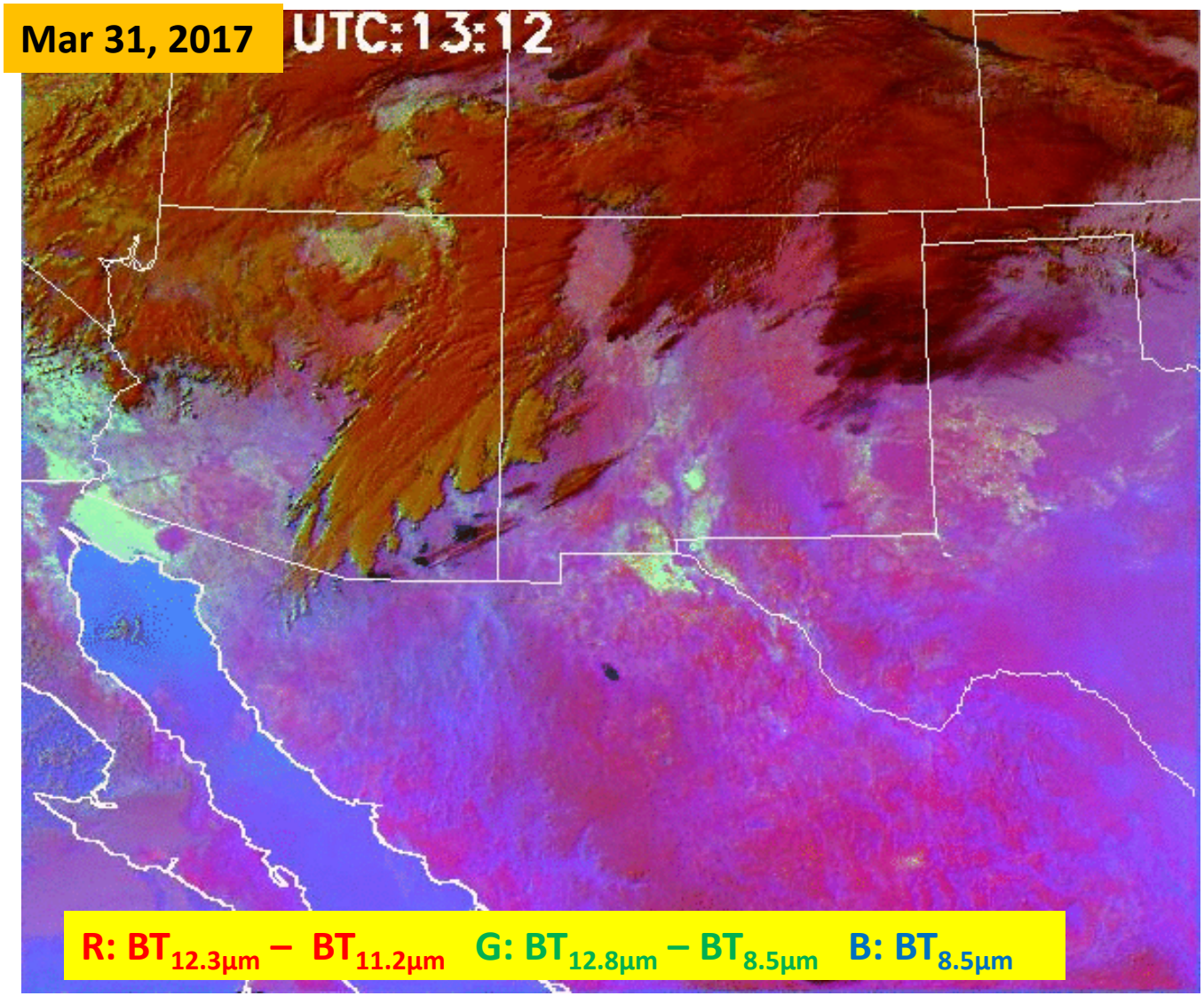
Natural Color RGB: West Mims Fire, Florida



15-min animation

Credit: NOAA/NESDIS/STAR aerosol team

Dust RGB: Dust Storm in Texas

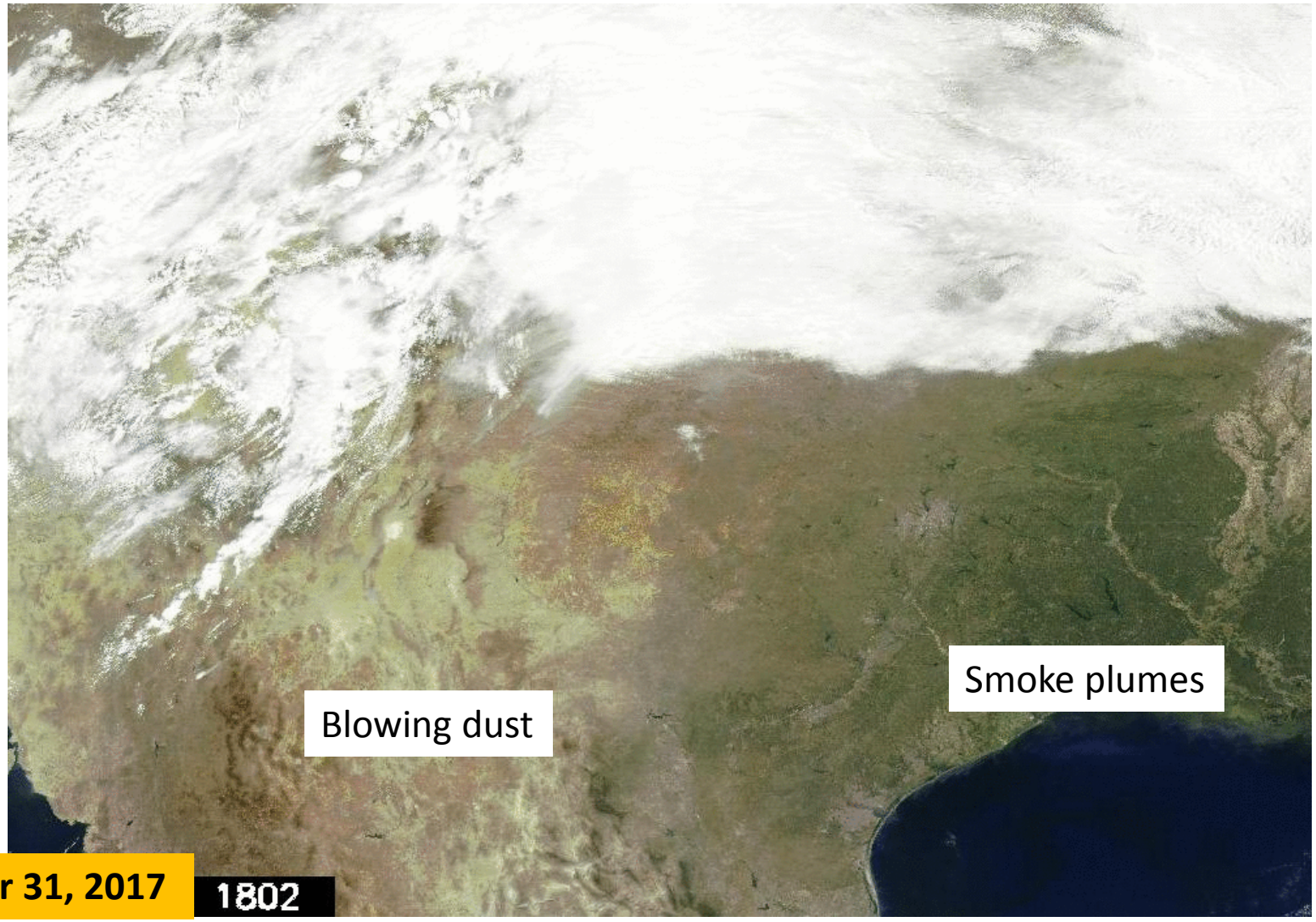


- Dust in bright pink color
- Thin cirrus in deep blue
- Thick cirrus in red/orange
- Water cloud in brown/orange
- Surface in cyan/blue

15-min animation

Credit: NOAA/NESDIS/STAR aerosol team

Synthetic RGB: Dust in Texas, Fires in Louisiana



15-min animation

Credit: NOAA/NESDIS/STAR aerosol team

NOAA Sentinel-5P Validation Team Activities: Contribution to Sentinel-5P TROPOMI Mission

- Add smoke and dust detected by S-5P TROPOMI using UVAI and AAI to the eIDEA website for a select period of time during which there are known smoke and dust events over the U.S.
- Consult our Advisory Group of > 30 forecasters to provide feedback specifically on the value added information from TROPOMI
- Areas of benefit are expected to be a decrease in artifacts over bright surfaces and coverage in cloudy regions
- The focus group will be asked to report on:
  - Usefulness of TROPOMI aerosol index and aerosol type information compared to VIIRS and OMPS in documenting smoke/dust events
  - Forecaster ability to use the information of where the smoke is present and where it is being transported
  - Decrease in data gaps in cloudy regions