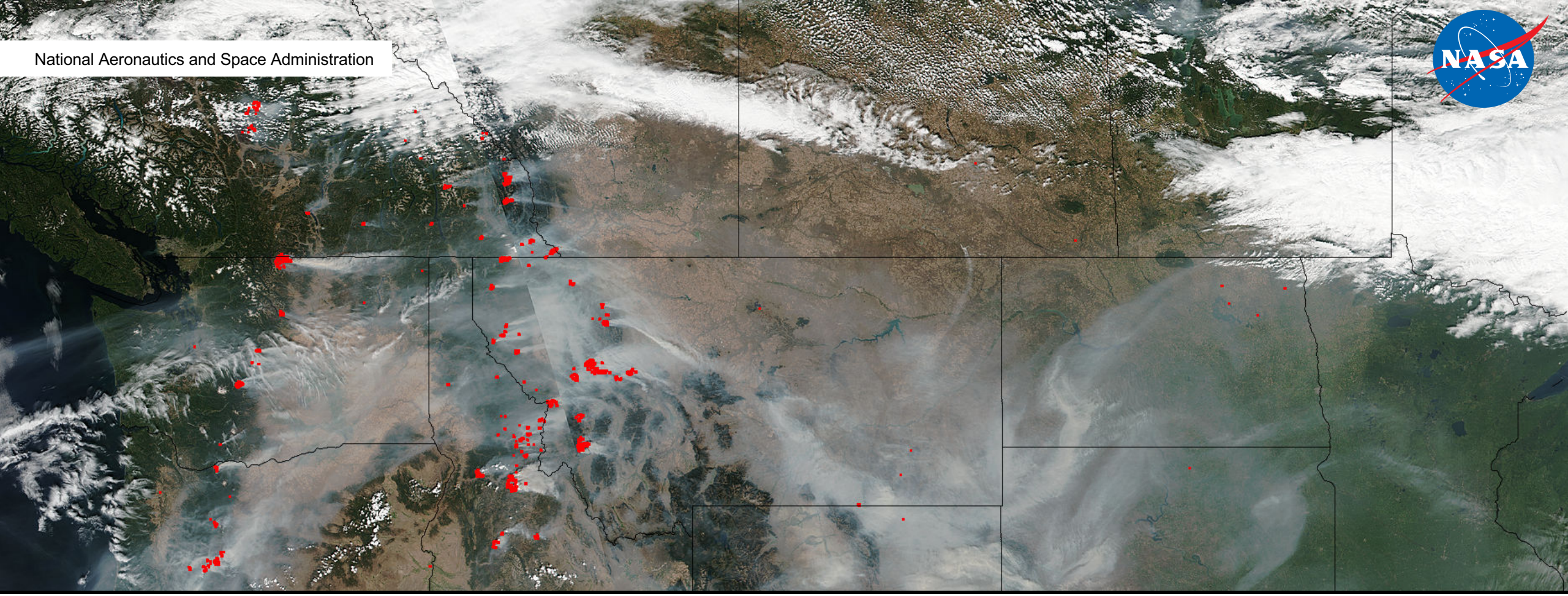
National Aeronautics and Space Administration



Aerosols from Geostationary Satellites

Pawan Gupta and Melanie Follette-Cook

Satellite Remote Sensing of Dust, Fires, Smoke, and Air Quality, July 10-12, 2018

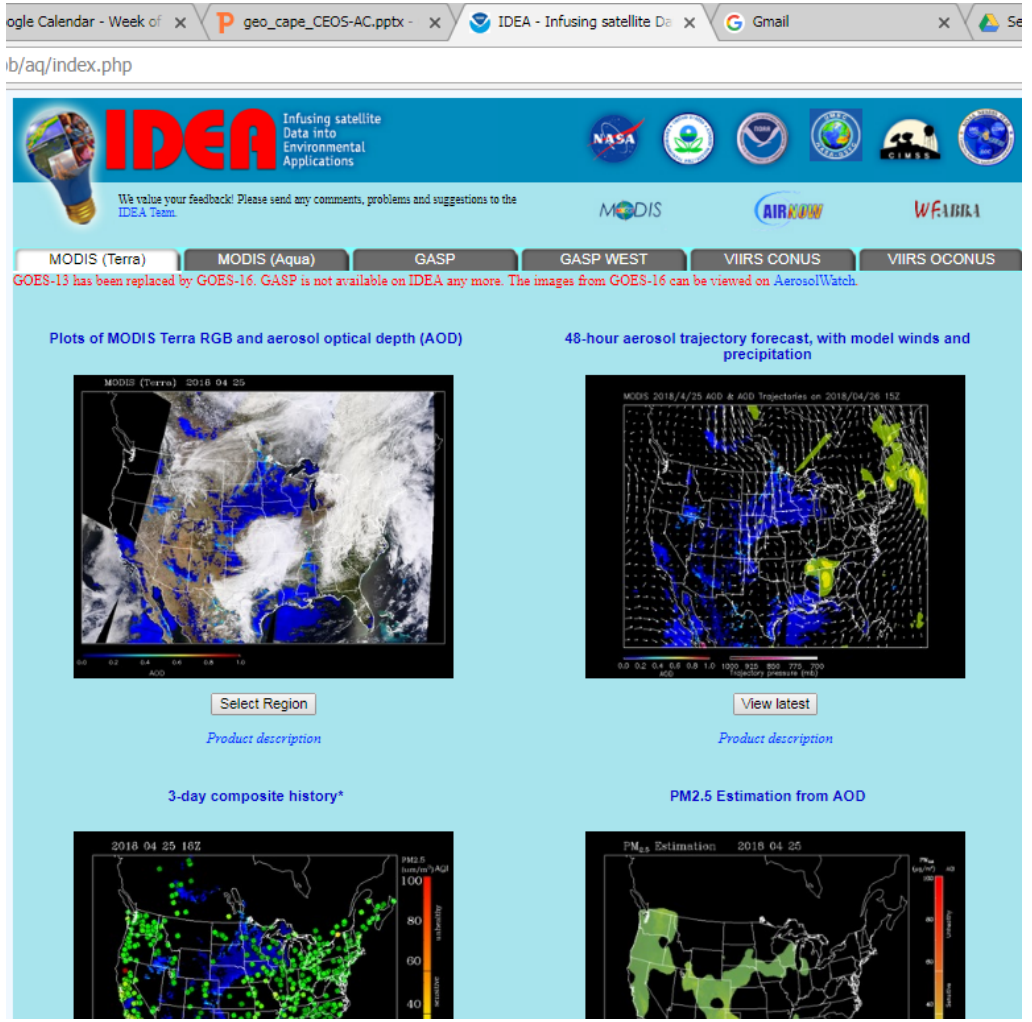
Legacy GOES Imager

- Five channel imager for meteorological applications
- GOES visible (520 – 720 nm) band used to retrieve aerosol optical depth (AOD). *Product name GASP*. Coverage of CONUS only.
- GASP for GOES-E from 2003-2017 and for GOES-W from 2003-present
- Archived data available from NOAA CLASS (class.noaa.gov)
- Resolution:
  - Spatial: 4 km nadir
  - Temporal: 30 min

Source: Shobha Kondragunta, NOAA

GASP Applications

- Air quality forecasting
- Numerical model verification
- Flight coordination during field campaigns
- Smoke exposure assessment
- Estimates of smoke plume areal extent and smoke concentration
- Diurnal variation etc.

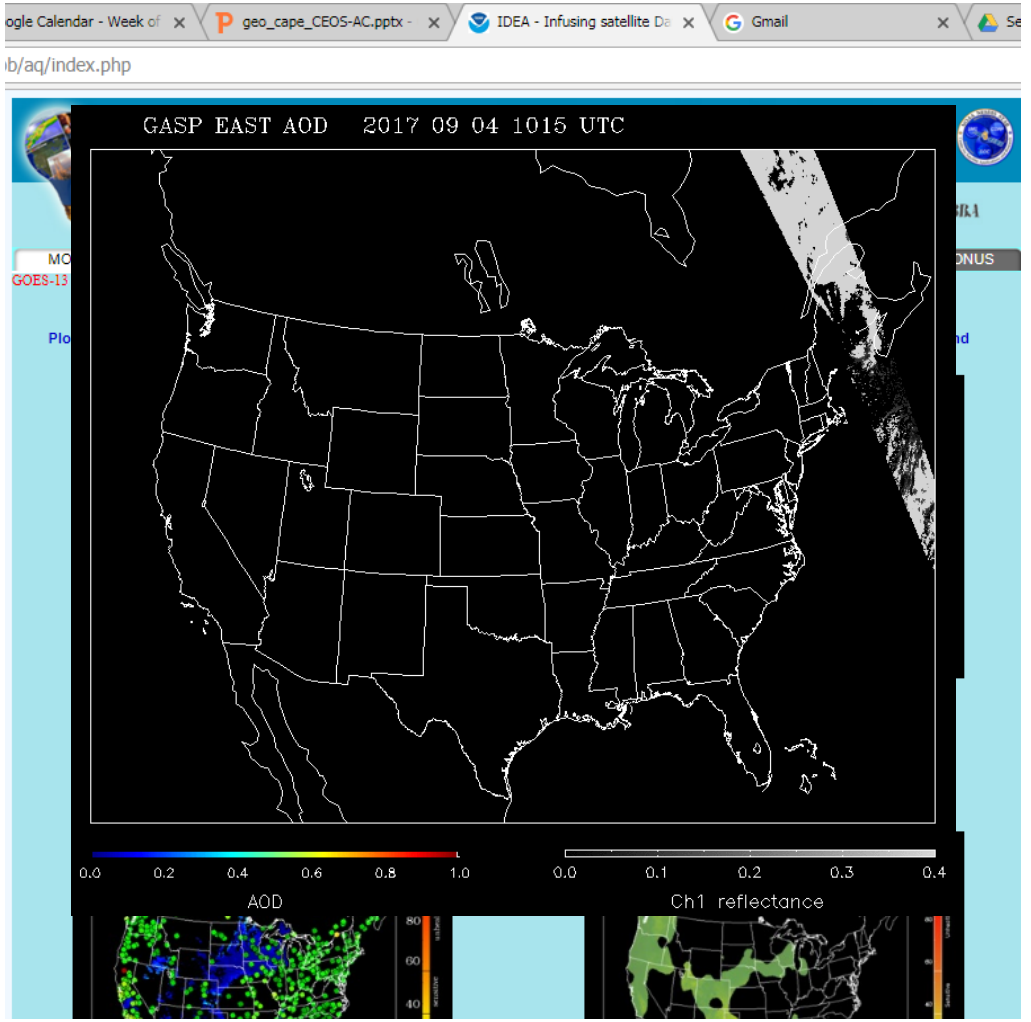


Source: Shobha Kondragunta, NOAA

GASP Applications

- Air quality forecasting
- Numerical model verification
- Flight coordination during field campaigns
- Smoke exposure assessment
- Estimates of smoke plume areal extent and smoke concentration
- Diurnal variation etc.

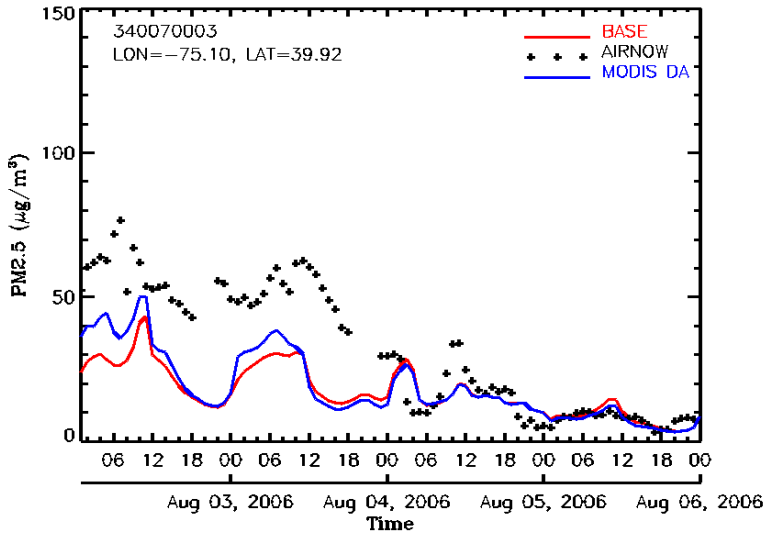
The main tools for air quality forecasters are yesterday's MODIS AOD and today's GOES AOD



Source: Shobha Kondragunta, NOAA

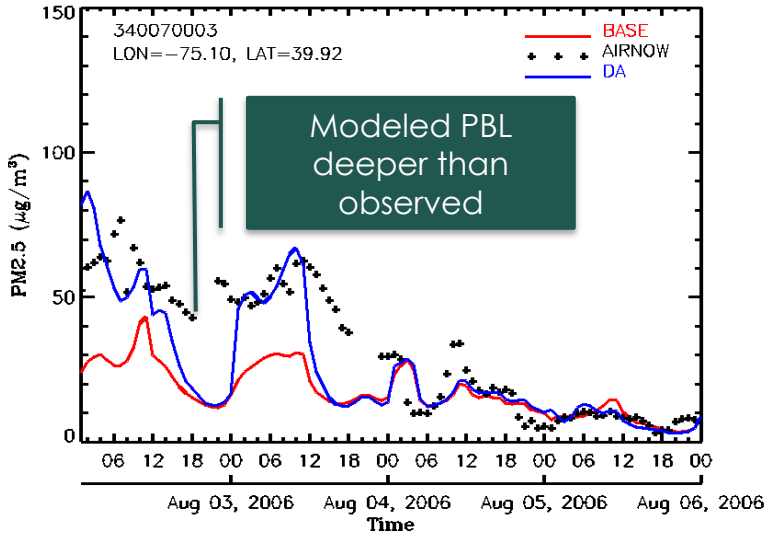
Data Assimilation Experiments

WRF-CMAQ run of an urban/industrial pollution event in the central/eastern US using Aqua and Terra MODIS AOD (two observations per day) assimilation



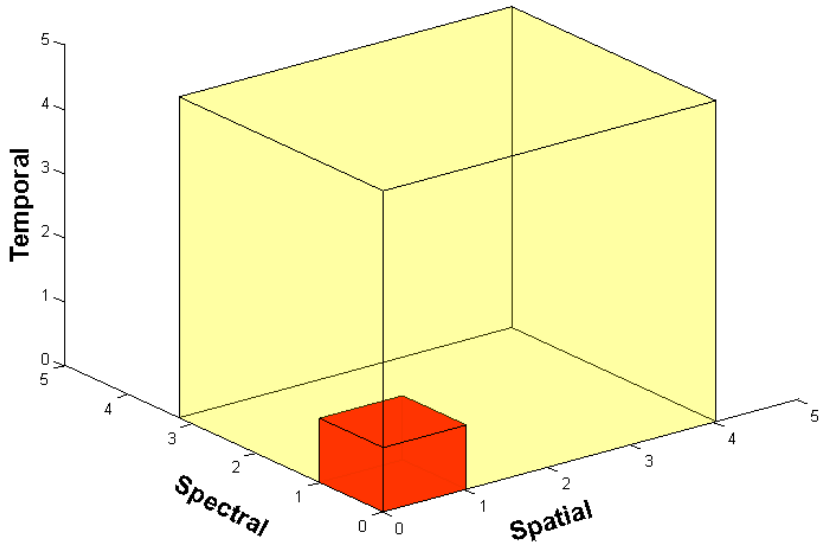
Breaking the temporal barrier in observation space is important

WRF-CMAQ run of an urban/industrial pollution event in the central/eastern US using legacy GOES AOD (twelve observations per day) assimilation



Source: Shobha Kondragunta, NOAA

GOES-R ABI



- onboard calibration
- better navigation
- on-demand mesoscale

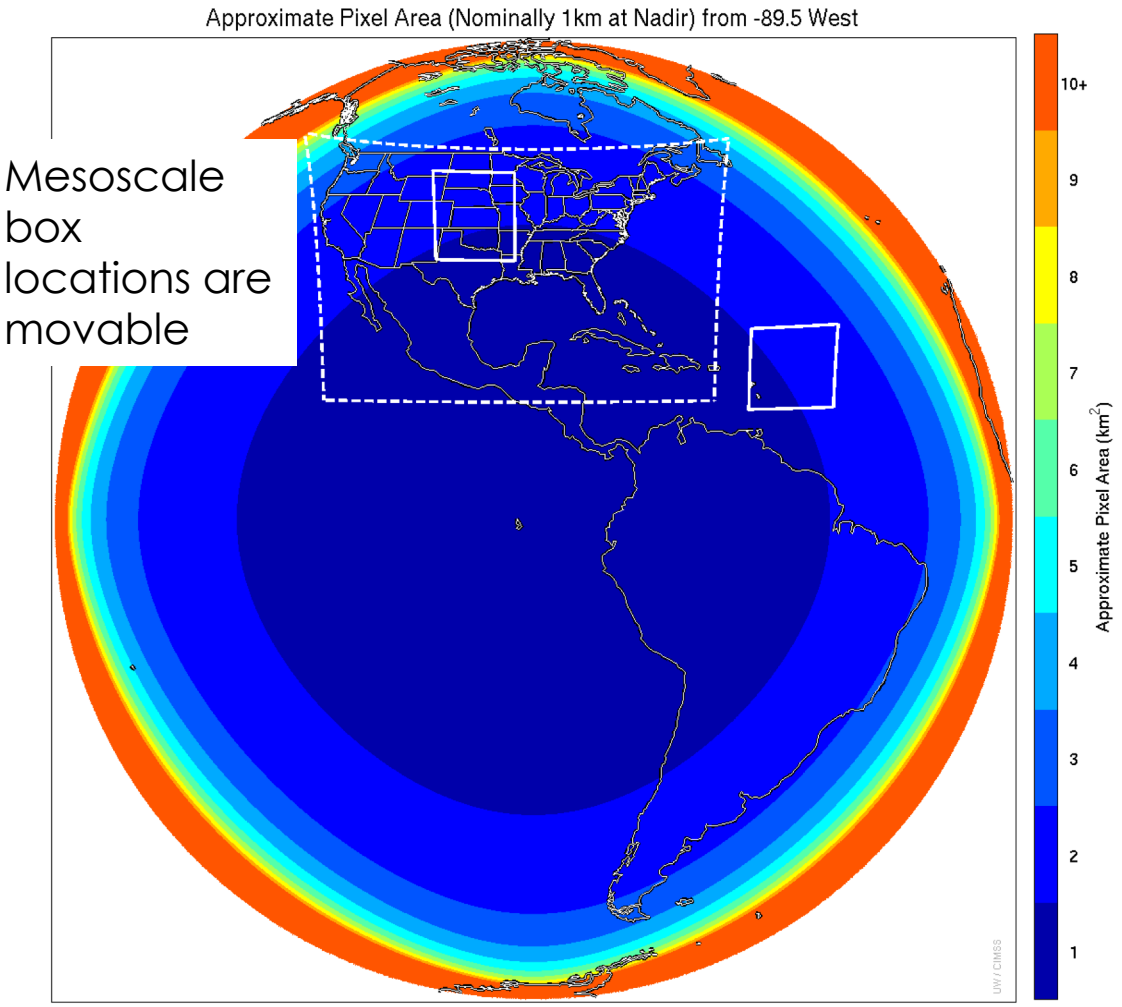
0.47
0.64
0.86
1.6
1.38
2.2
3.9
6.2
6.7
7.3
8.5
9.7
10.3
11.2
12.3
13.3

Domain	Legacy GOES			
	AOD	GeoCol or RGB	Dust RGB	Smoke/ Dust Mask
CONUS	X			
Full Disk				
Mesoscale				

Domain	GOES-R/S			
	AOD	GeoCol or RGB	Dust RGB	Smoke/ Dust Mask
CONUS	X	X	X	X
Full Disk	X	X	X	X
Mesoscale		X	X	X

Source: Tim Schmidt, NOAA

GOES-R ABI



Source: Tim Schmidt, NOAA

- Default Operational Mode:
  - Full Disk 15 min
  - CONUS 5 min
  - Mesoscale 1 min
- Proposed mode to be consistent with AHI:
  - Full Disk 10 min

A New Era for Aerosol Measurements

- First multi-channel AOD retrieval from a geostationary satellite covering the western hemisphere.
  - JAXA launched Himawari-8/9 ahead of GOES-R but instrument technology is the same as ABI
- First time on-board visible channel calibration for a GOES sensor
  - ABI 0.64 µm has a 7% positive bias

Retrievals generated with a specific target for requirements

AOD Over Land

AOD	Accuracy	Precision
<0.04	0.06	0.13
0.04 – 0.80	0.04	0.25
>0.8	0.12	0.35

AOD Over Water

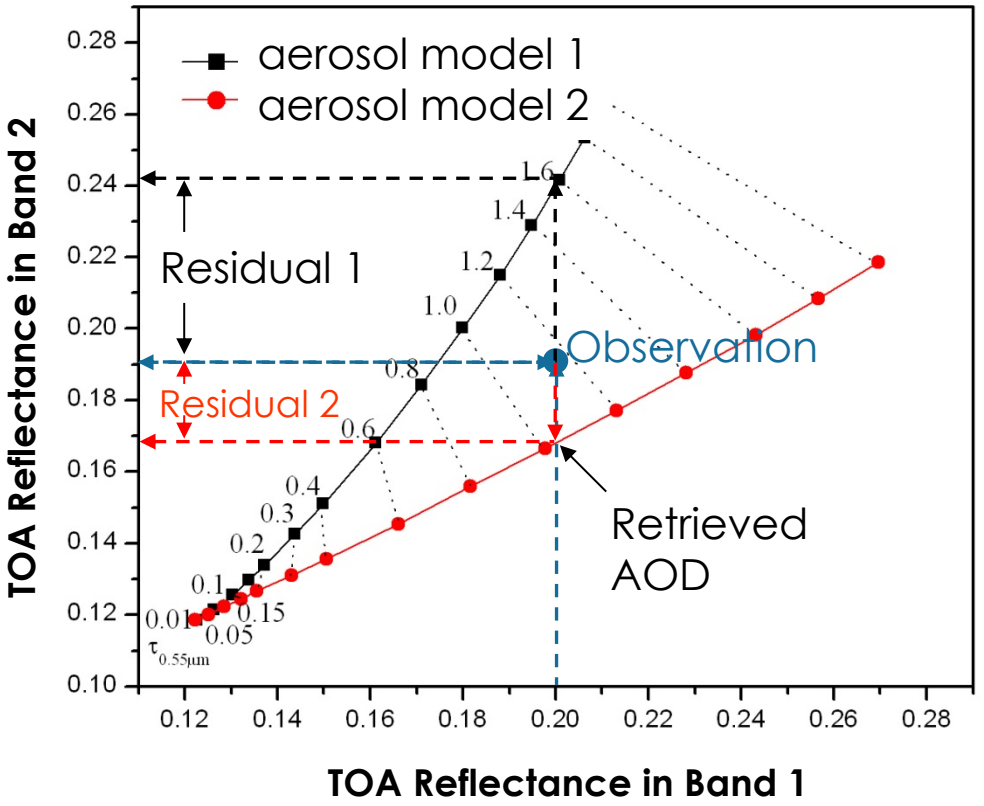
AOD	Accuracy	Precision
<0.4	0.02	0.15
>0.4	0.10	0.23

Source: Shobha Kondragunta, NOAA

GOES-R AOD Algorithm

AOD Retrieval

- Separate algorithms for 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.
- Water: 4 fine and 5 coarse mode models
- Land: generic, dust, smoke and urban models



Source: Shobha Kondragunta, NOAA

AOD Product

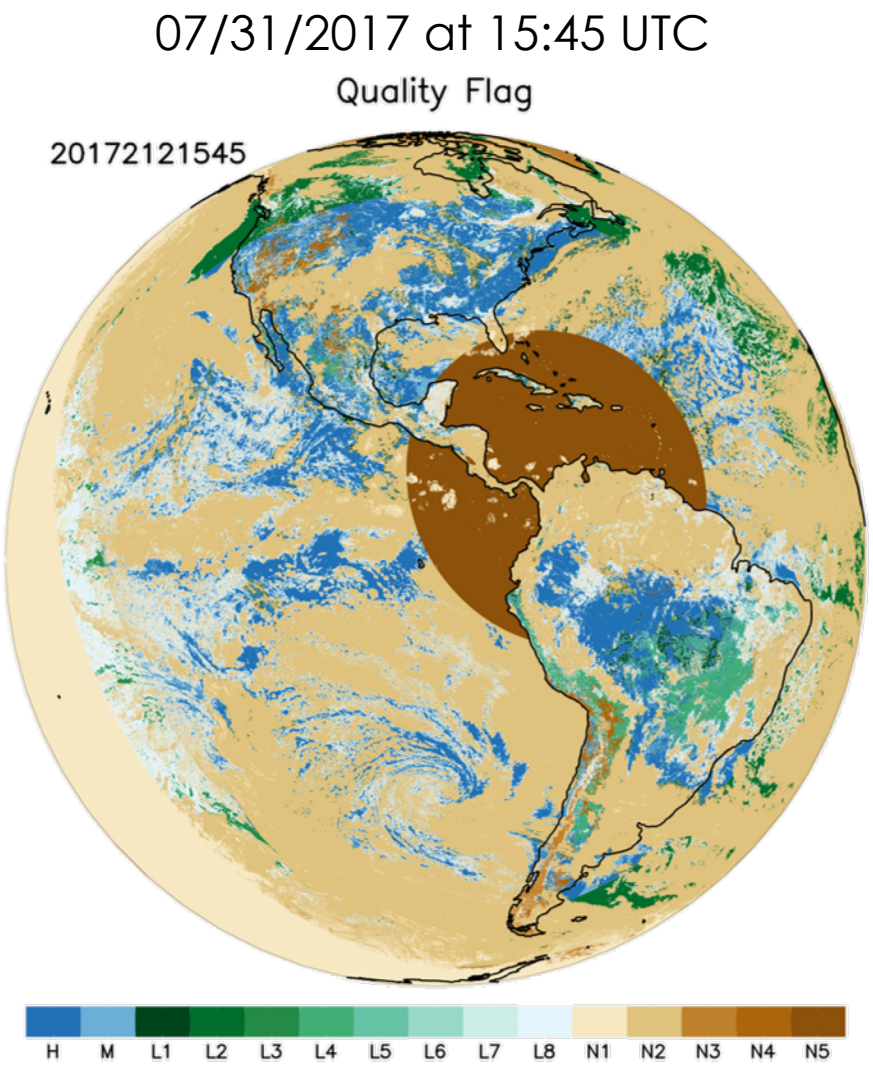
- Products in file:
  - 550-nm Aerosol Optical Depth for Full Disk and CONUS in range -0.05 to +5
  - Quality flag (0=good; 1=medium, 2=low, 3=not produced)
  - Mean, max, min and standard deviation of 550-nm AOD (and in bands used for AOD retrieval
- In Beta maturity status since May 24, 2017
  - Beta product is minimally validated and may still contain significant errors; not recommended for operational use

Disclaimer: The GOES-16 data are preliminary, non-operational data and are undergoing testing. Users bear all responsibility for inspecting the data prior to use and for the manner in which the data are utilized.

- Availability:
  - NOAA's Comprehensive Large Array-Data Stewardship System at https://www.class.ncdc.noaa.gov after product passed Provisional Review (review scheduled for June 2018)

Source: Shobha Kondragunta, NOAA

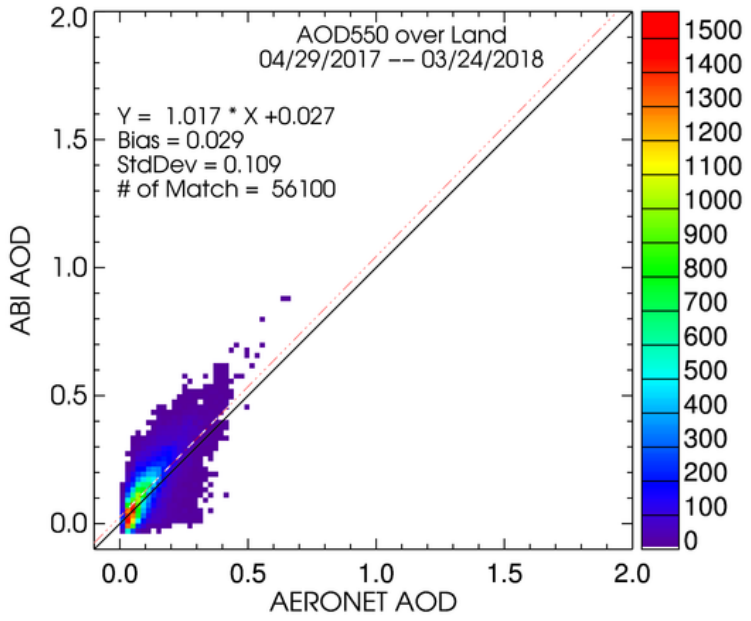
Quality Flags (Example)

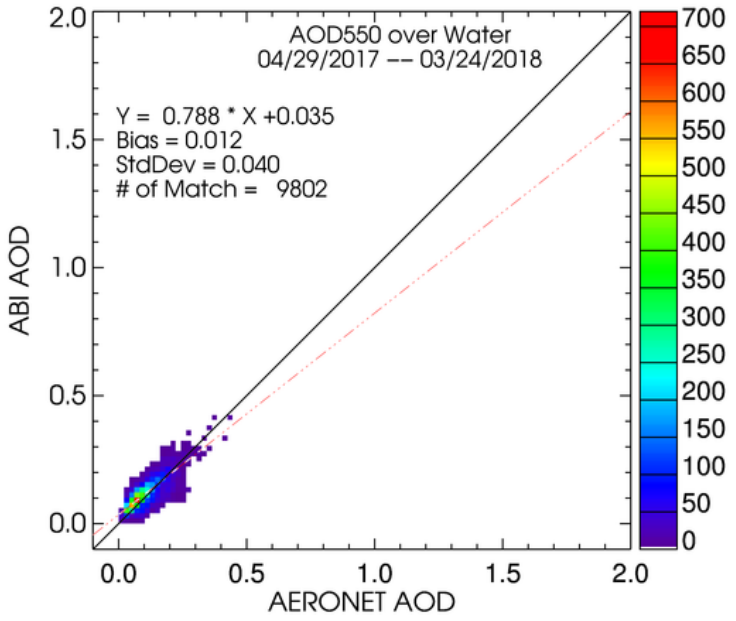


H	High
M	Medium
L	Low
L1	Contradicting Cloud Masks
L2	Low Satellite Angle
L3	Low Sun Angle
L4	Out of Spec Range
L5	Coastal Area
L6	Shallow Inland Water
L7	High Residual
L8	High Inhomogeneity
N	No Retrieval
N1	Invalid Input
N2	Cloud
N3	Snow
N4	Bright Land Surface
N5	Sun Glint

Source: Shobha Kondragunta, NOAA

Validation with AERONET





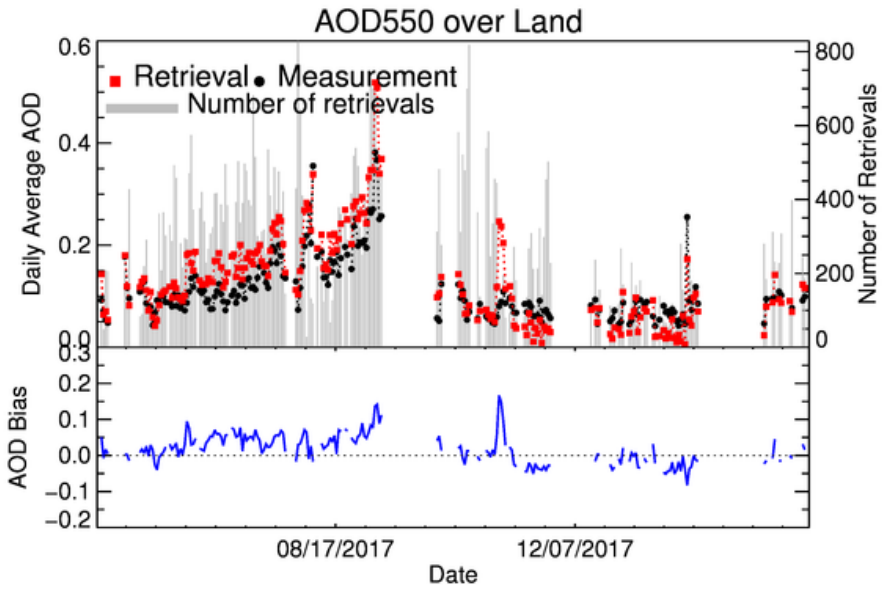
- Time period: 04/29/2017-03/24/2018
- **High Quality AOD**
- Bias and StDev: mean and standard deviation of ABI-AERONET differences

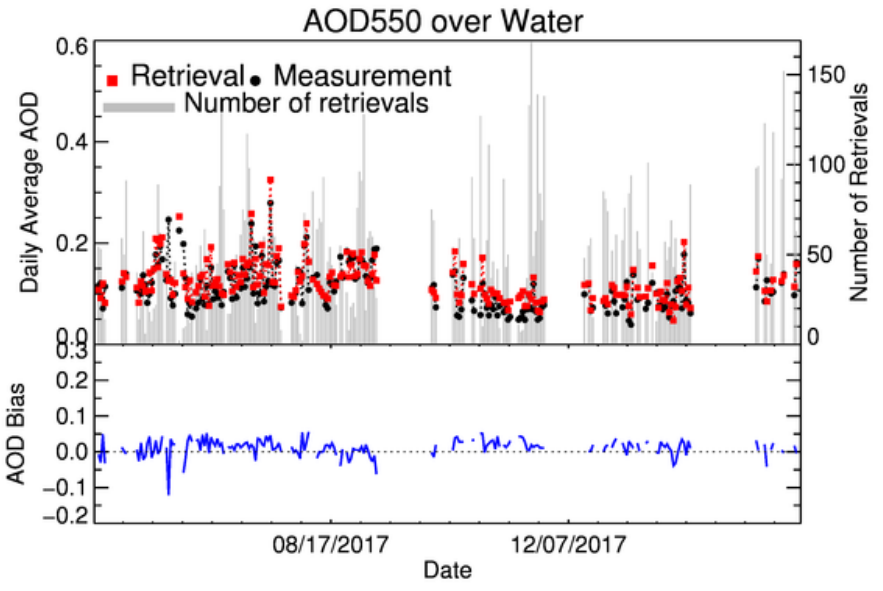
Disclaimer: GOES-16 data are preliminary, non-operational data and are undergoing testing. Users bear all responsibility for inspecting the data prior to use and for the manner in which the data are utilized.

Source: Shobha Kondragunta, NOAA

High-Quality AOD Time Series

All Sites





- Co-located ABI-AERONET matchup data for 04/29/2017-03/24/2018
- Retrieval generally follows AERONET
- Apparent seasonal bias over land: slight positive bias, but no apparent trend

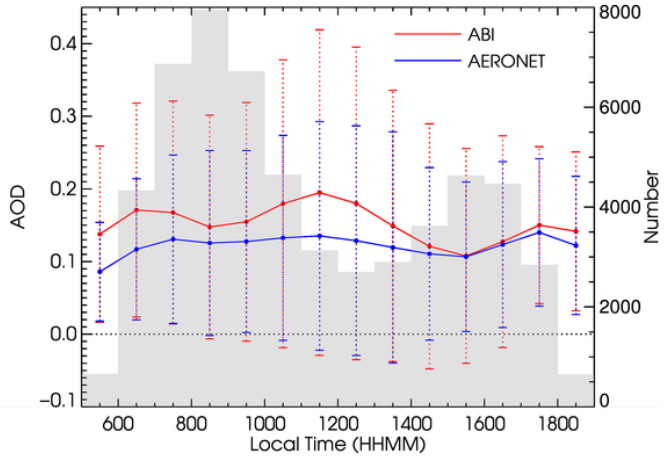
Disclaimer: GOES-16 data are preliminary, non-operational data and are undergoing testing. Users bear all responsibility for inspecting the data prior to use and for the manner in which the data are utilized.

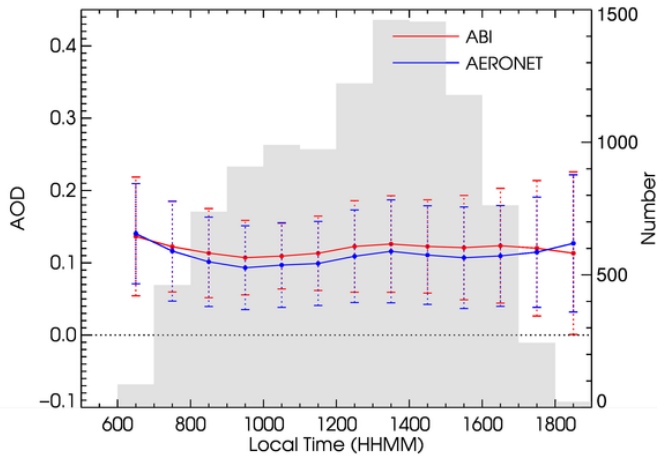
Source: Shobha Kondragunta, NOAA

Diurnal Changes

Matchup Data for 04/29/2017-03/24/2018

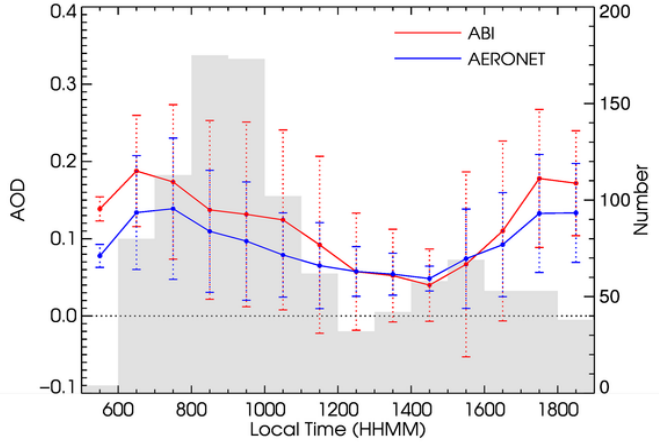
Land

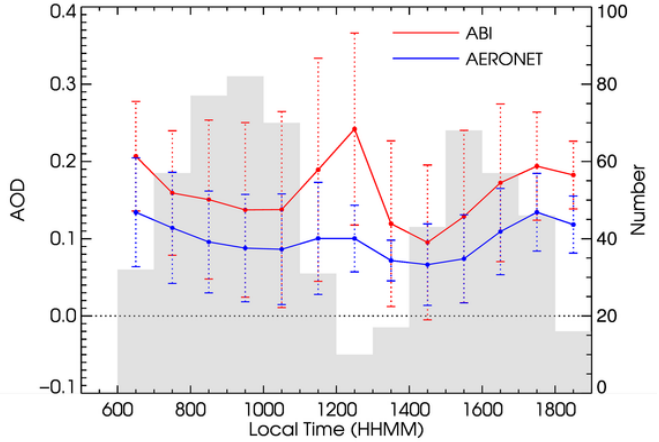




Water

GSFC





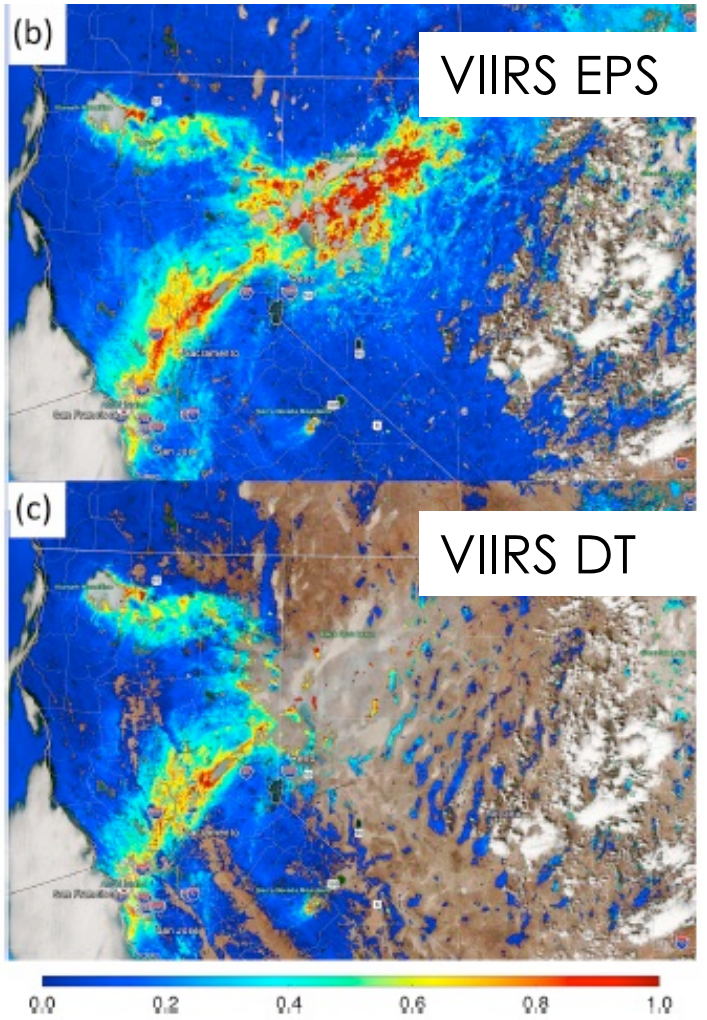
Wallops-Land

Disclaimer: GOES-16 data are preliminary, non-operational data and are undergoing testing. Users bear all responsibility for inspecting the data prior to use and for the manner in which the data are utilized.

Source: Shobha Kondragunta, NOAA

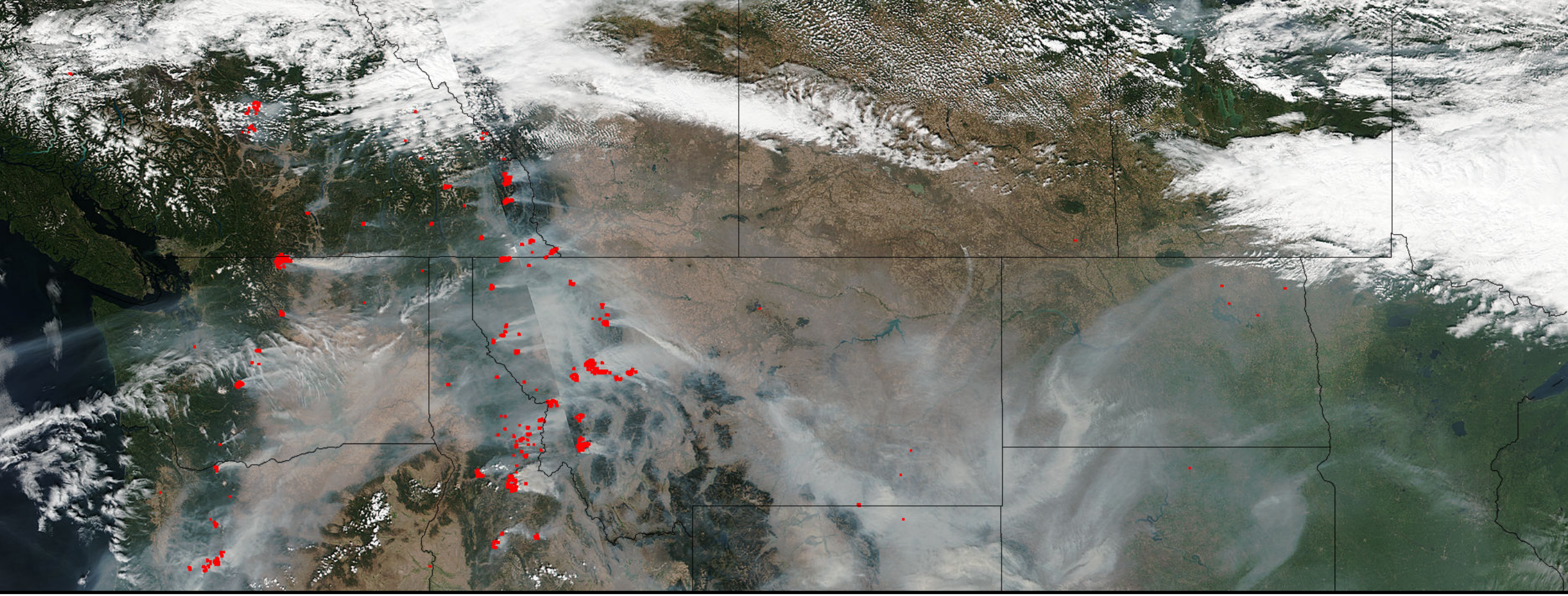
Enterprise (EPS) Algorithm

- ABI AOD algorithm will be updated with EPS algorithm running on SNPP VIIRS
- With similar algorithm the data can be used synergistically in various applications
- EPA algorithm capable of retrieving over bright land surface



Source: Zhang et al., JGR, 2016

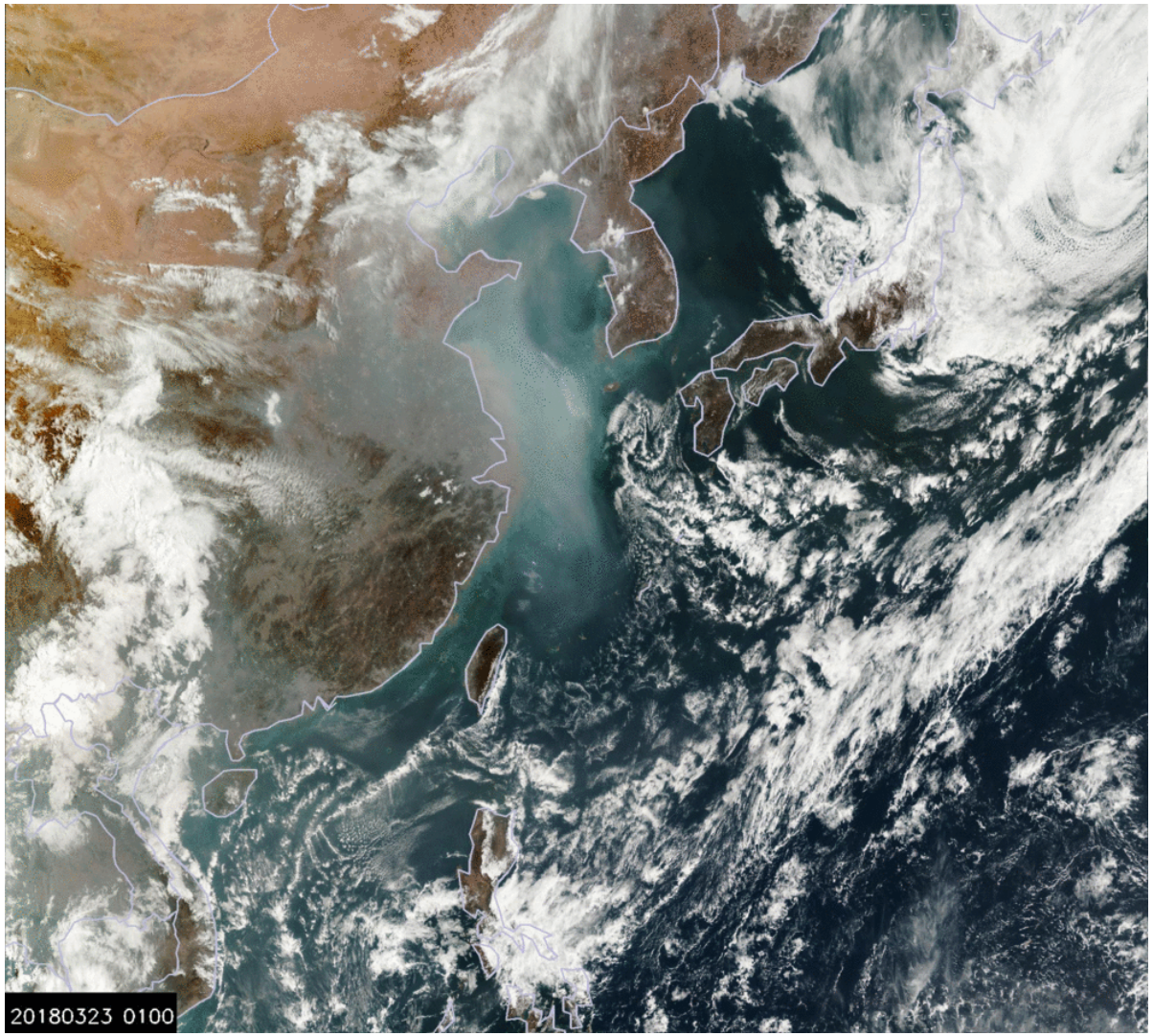
Source: Shobha Kondragunta, NOAA



GOES-R ABI Aerosol Algorithms Applied to Himawari AHI

Widespread Smog

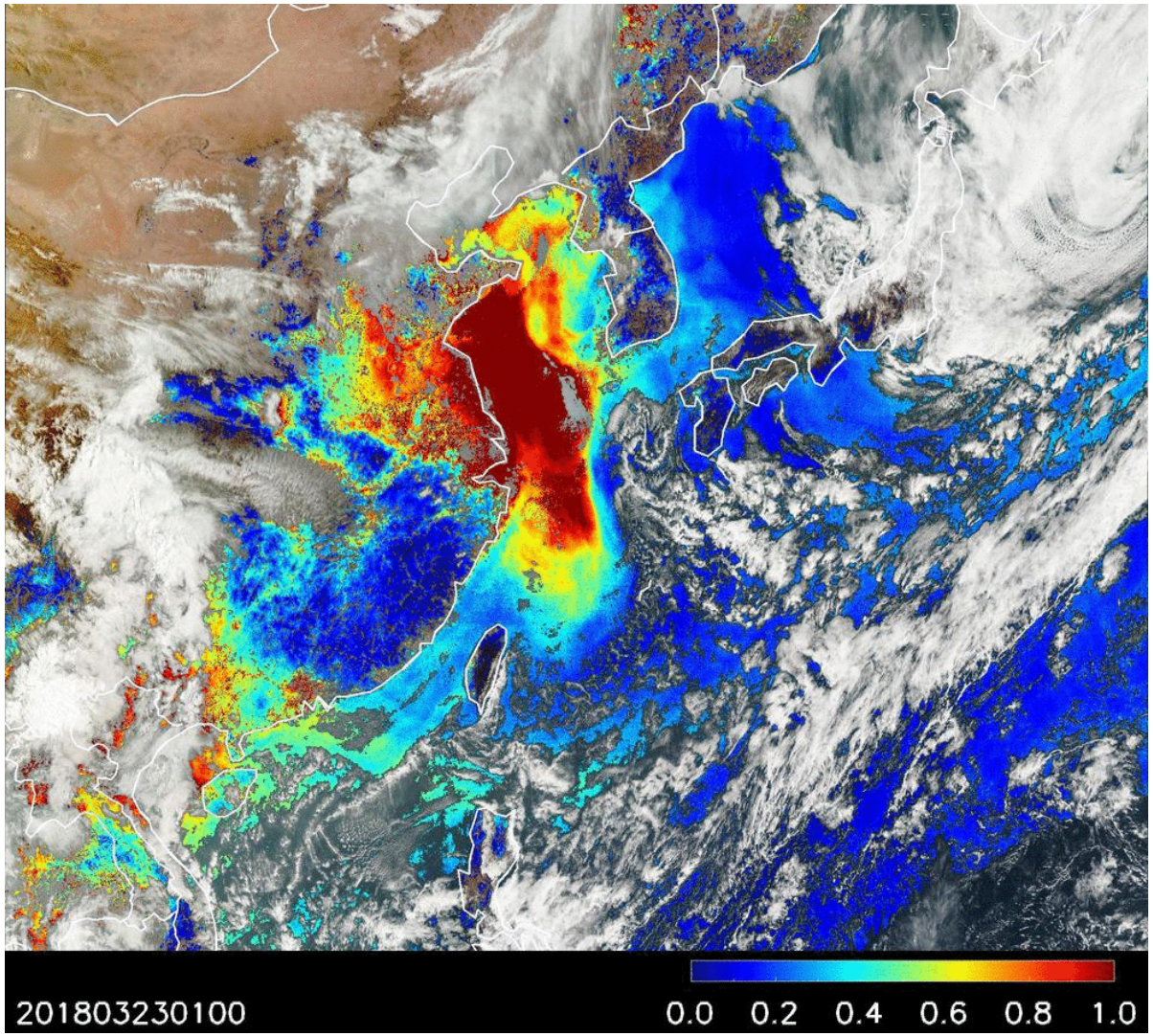
AHI True Color RGB



Source: Shobha Kondragunta, NOAA

AHI Aerosol Optical Depth

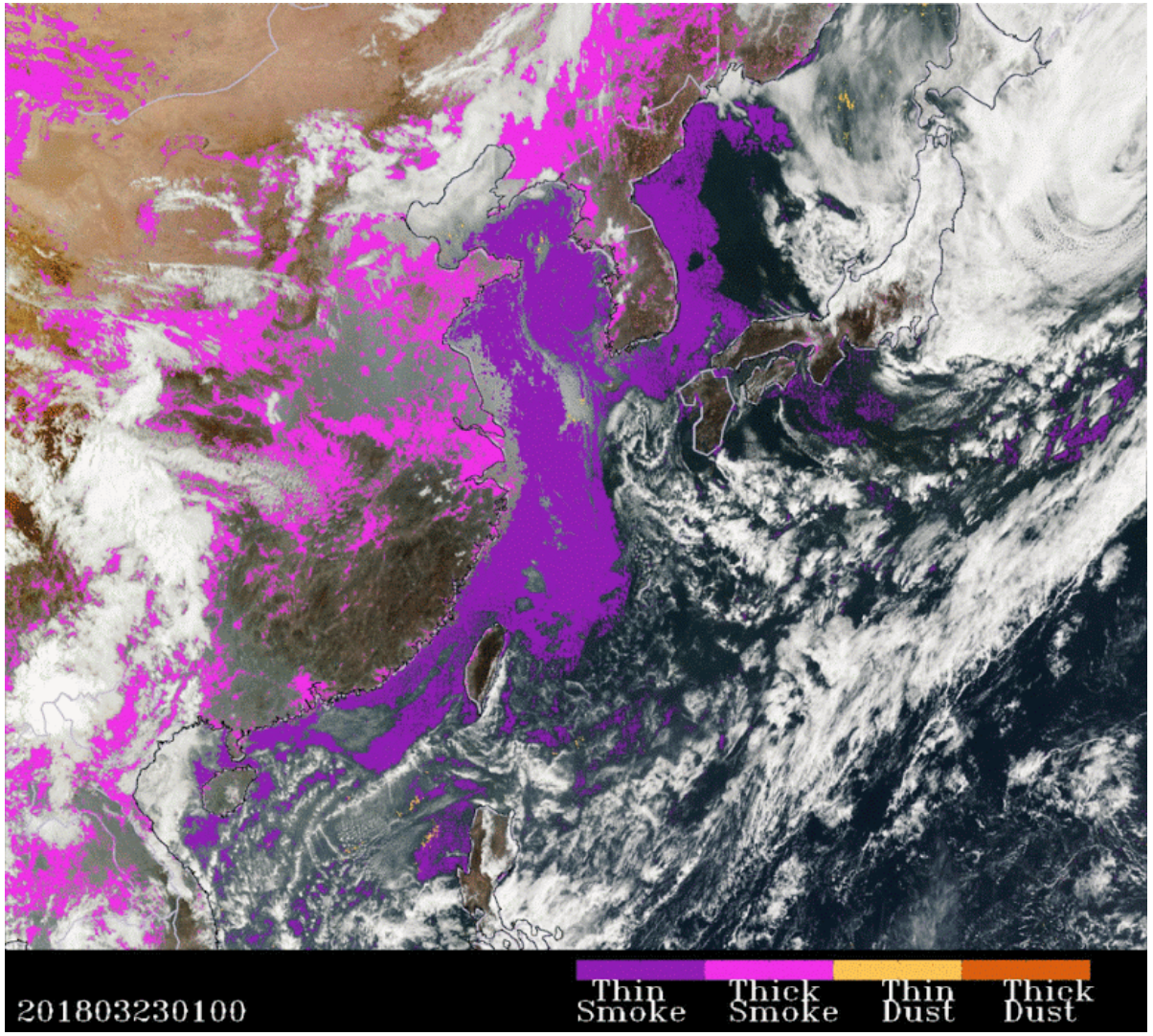
AOD Algorithm able to capture what is likely urban or industrial pollution



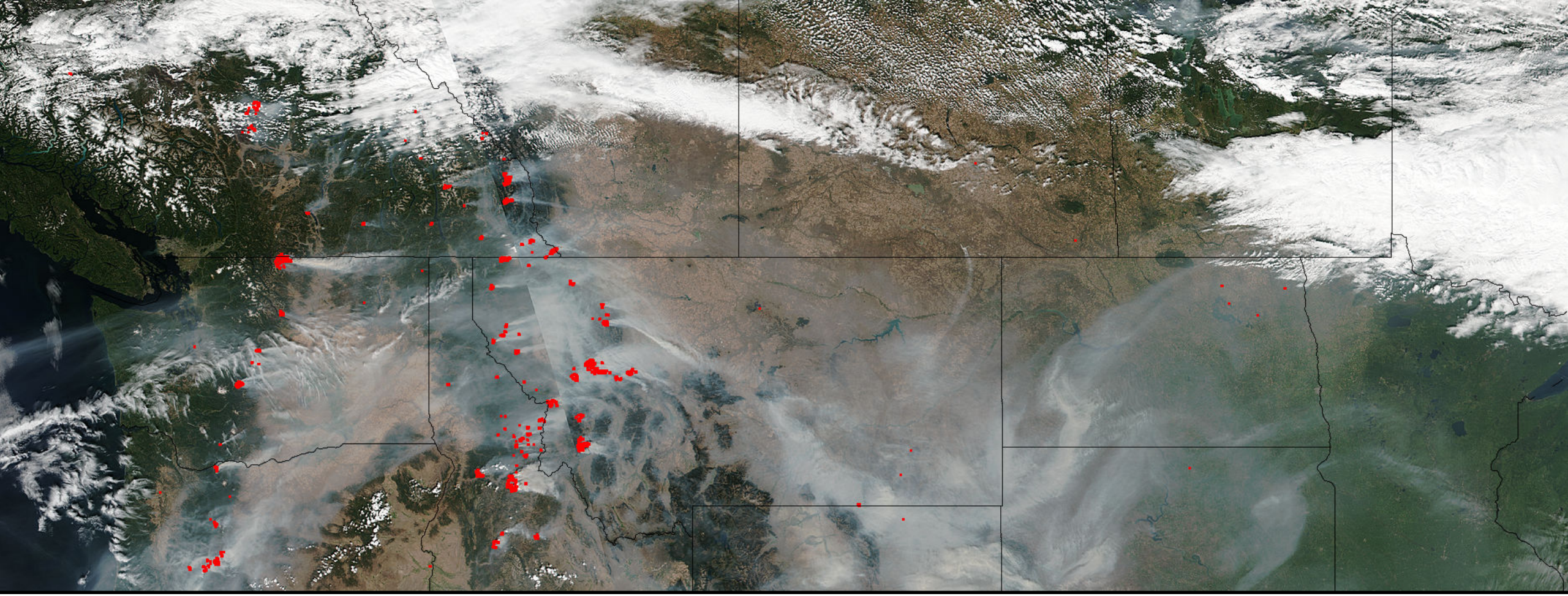
Source: Shobha Kondragunta, NOAA

AHI Smoke or Dust Flag

The aerosol detection algorithm is retrieving the pollution as smoke. This is likely because pollution in China is highly absorbent (brown or black carbon) and has optical properties similar to biomass burning smoke

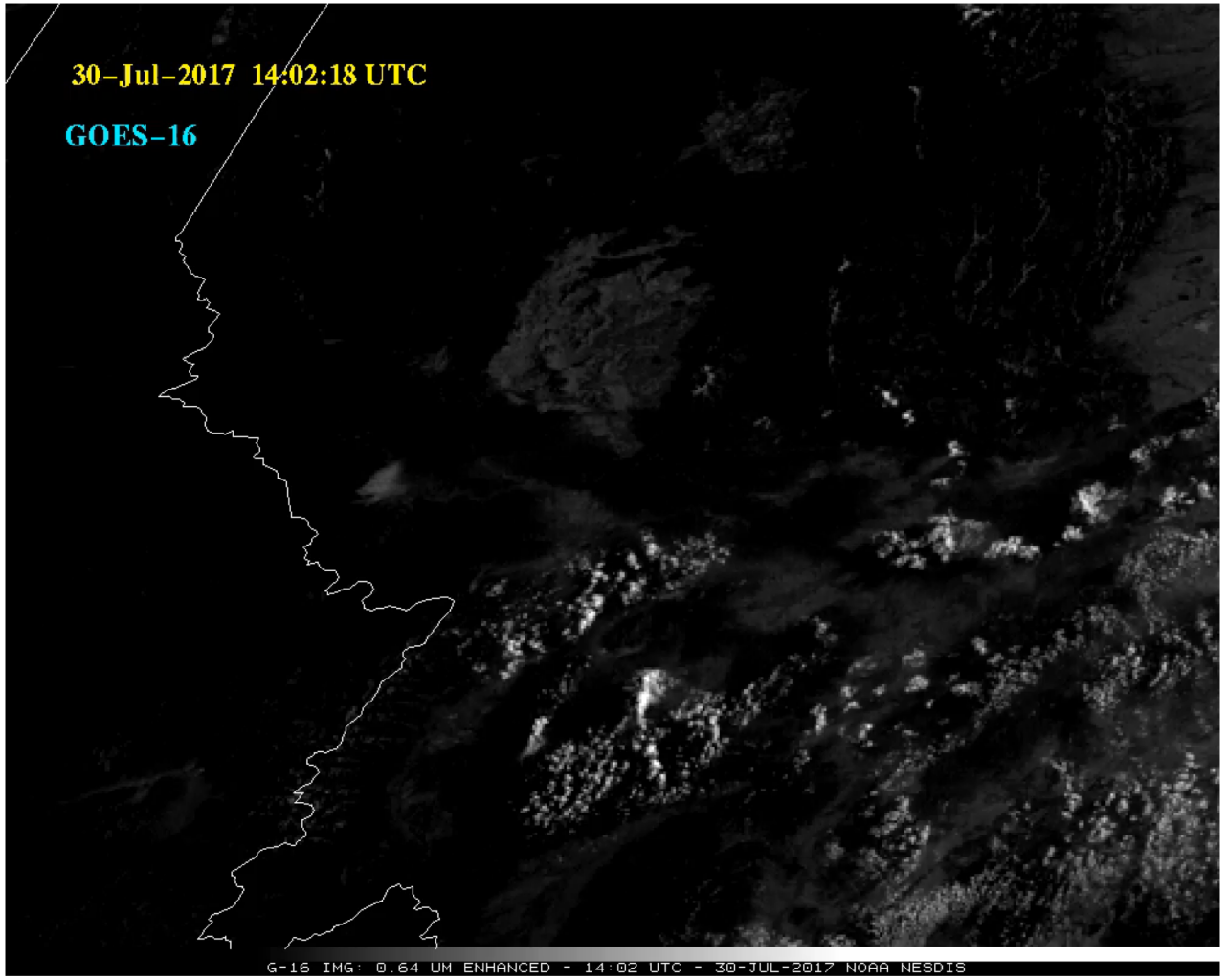


Source: Shobha Kondragunta, NOAA



GOES-R ABI New Capabilities

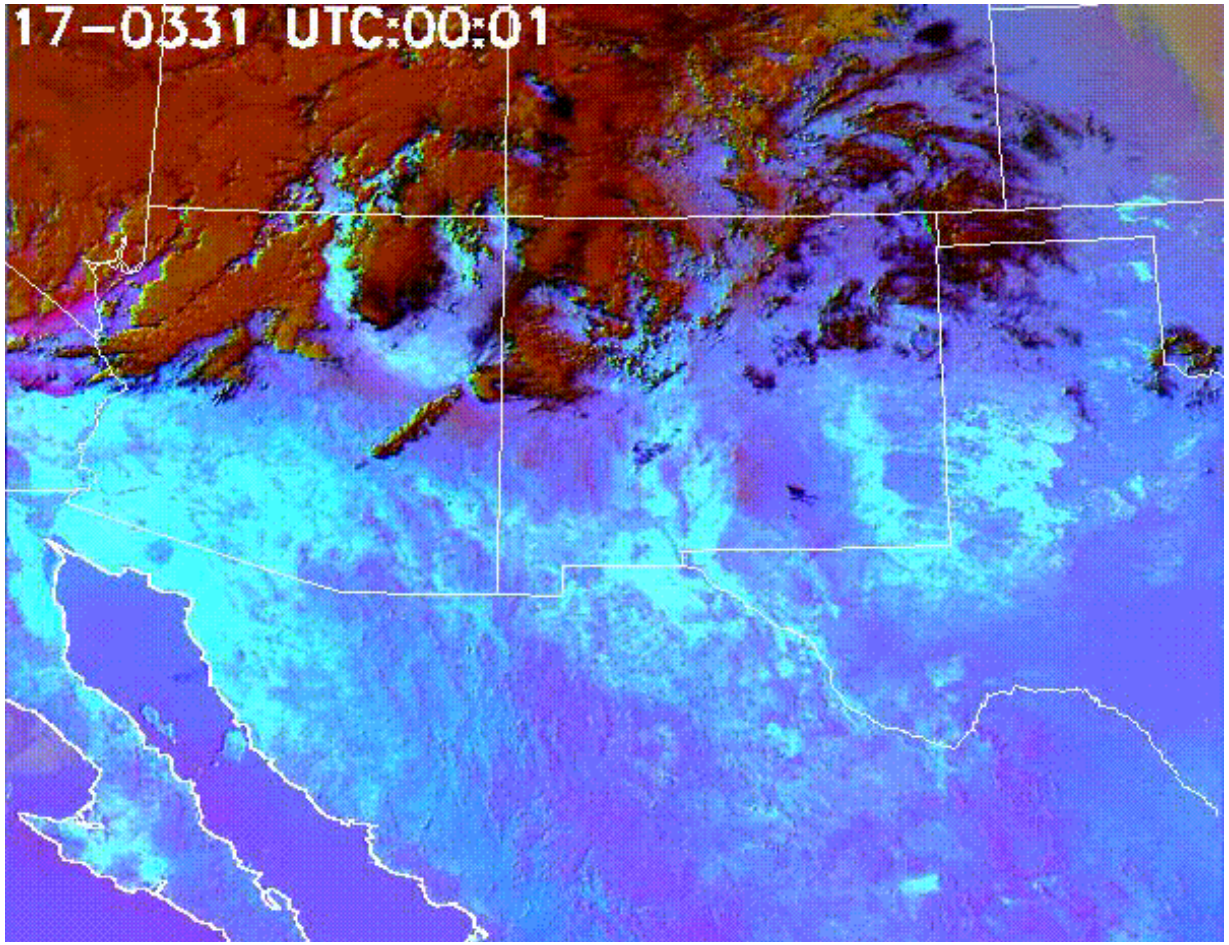
GOES-R ABI New Capabilities: 0.5 m Visible Band Every 5 Minutes



Smoke from several small plumes blend together and become one large plume

Source: Tim Schmidt, NOAA

GOES-R ABI New Capabilities: Dust RGB



R: $BT_{12.3\mu m} - BT_{11.2\mu m}$ G: $BT_{12.8\mu m} - BT_{8.5\mu m}$ B: $BT_{8.5\mu m}$

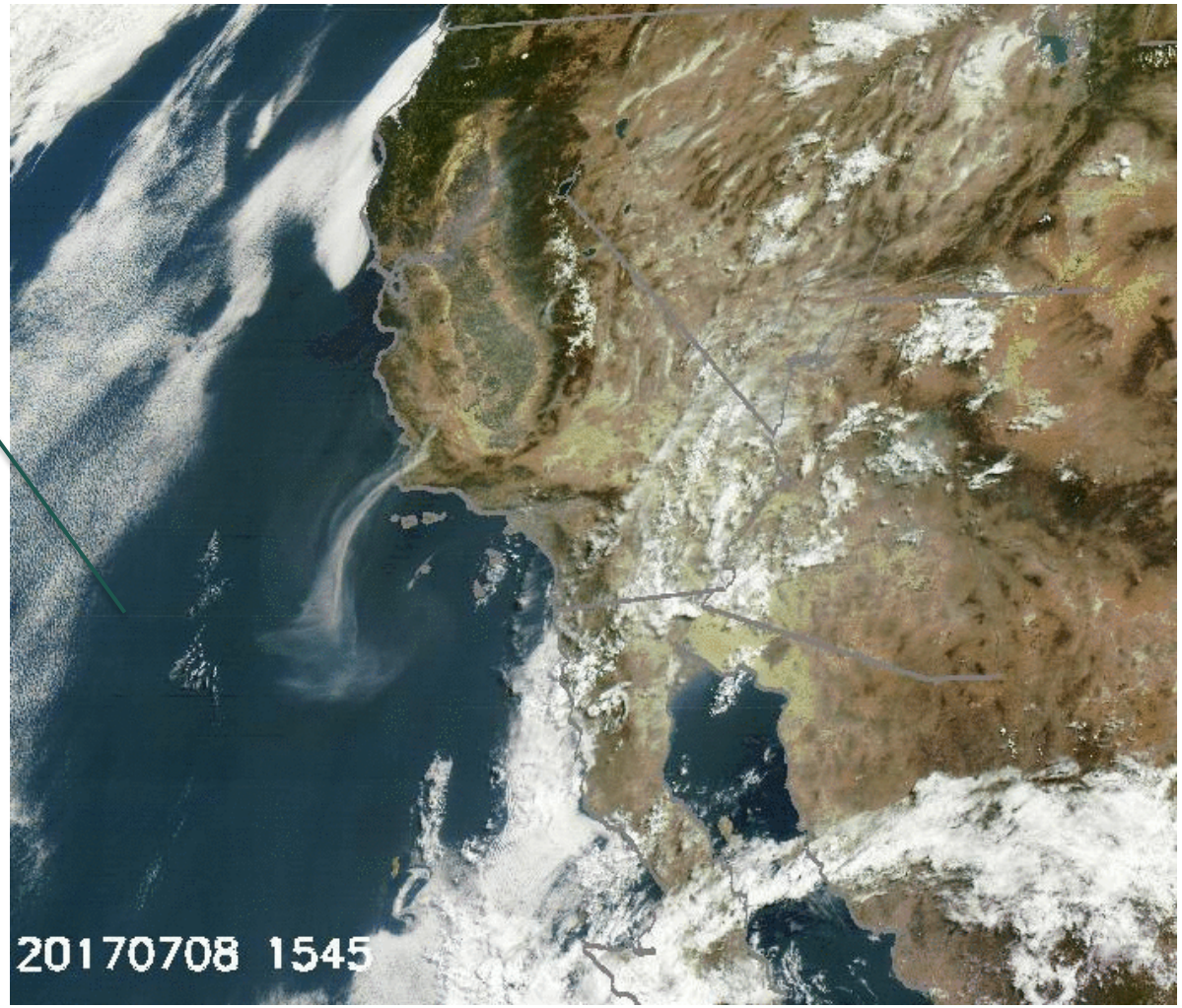
Source: Kondragunta et al., Tracking dust storms using latest satellite technology, EM, 2018

- Dust storms in the southeast form in late evenings and last into the night
- Polar-orbiting satellites miss them due to mid-afternoon overpass time
- ABI imagery captures the events

GOES-R New Capabilities: GeoColor RGB

Alamo Fire:
July 6-19, 2017

Some image striping is present. Calibration fixes have been implemented to remote striping

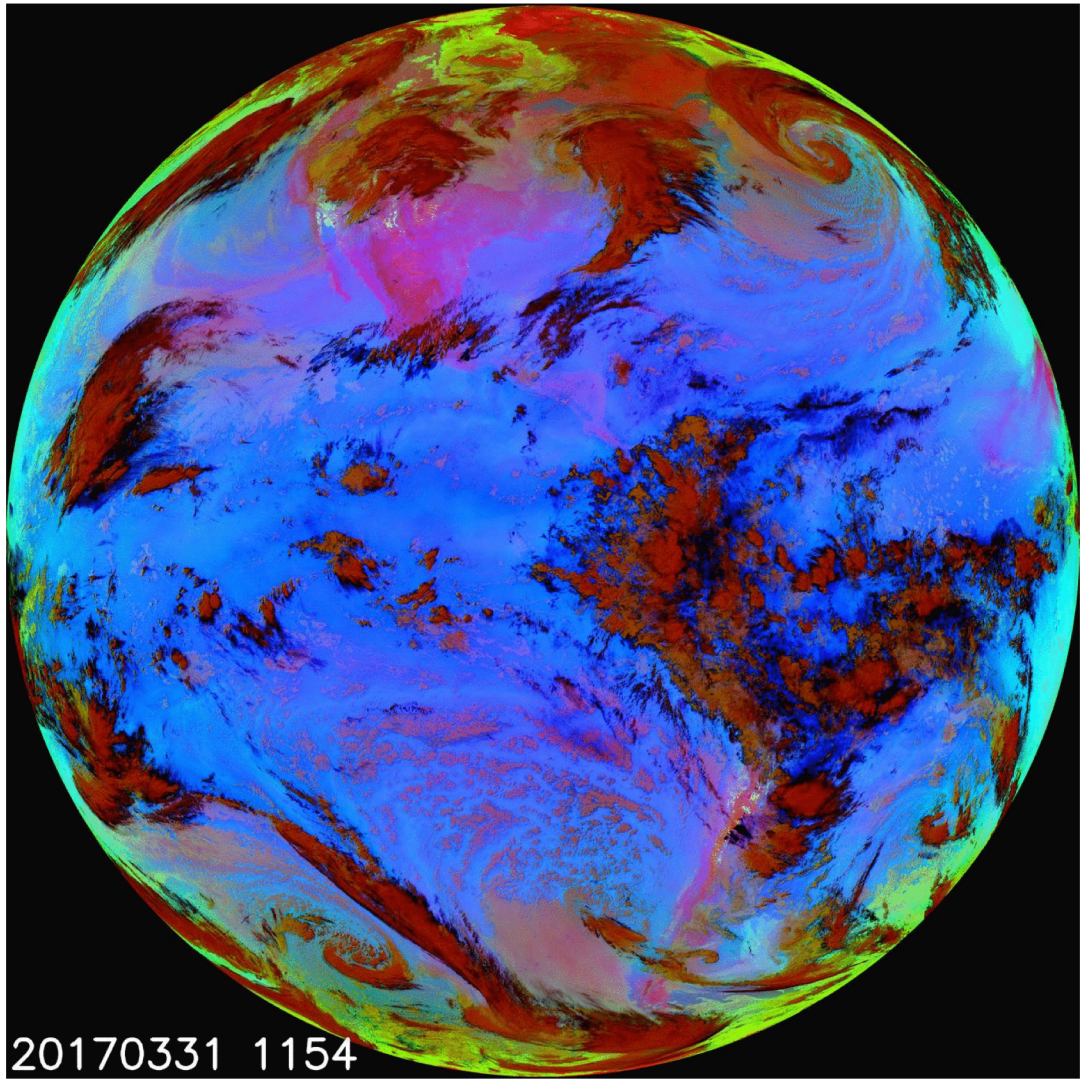


Source: Shobha Kondragunta, NOAA

GOES-R ABI New Capabilities: Full Disk Imaging Every 15 Minutes

Dust RGB show as an example

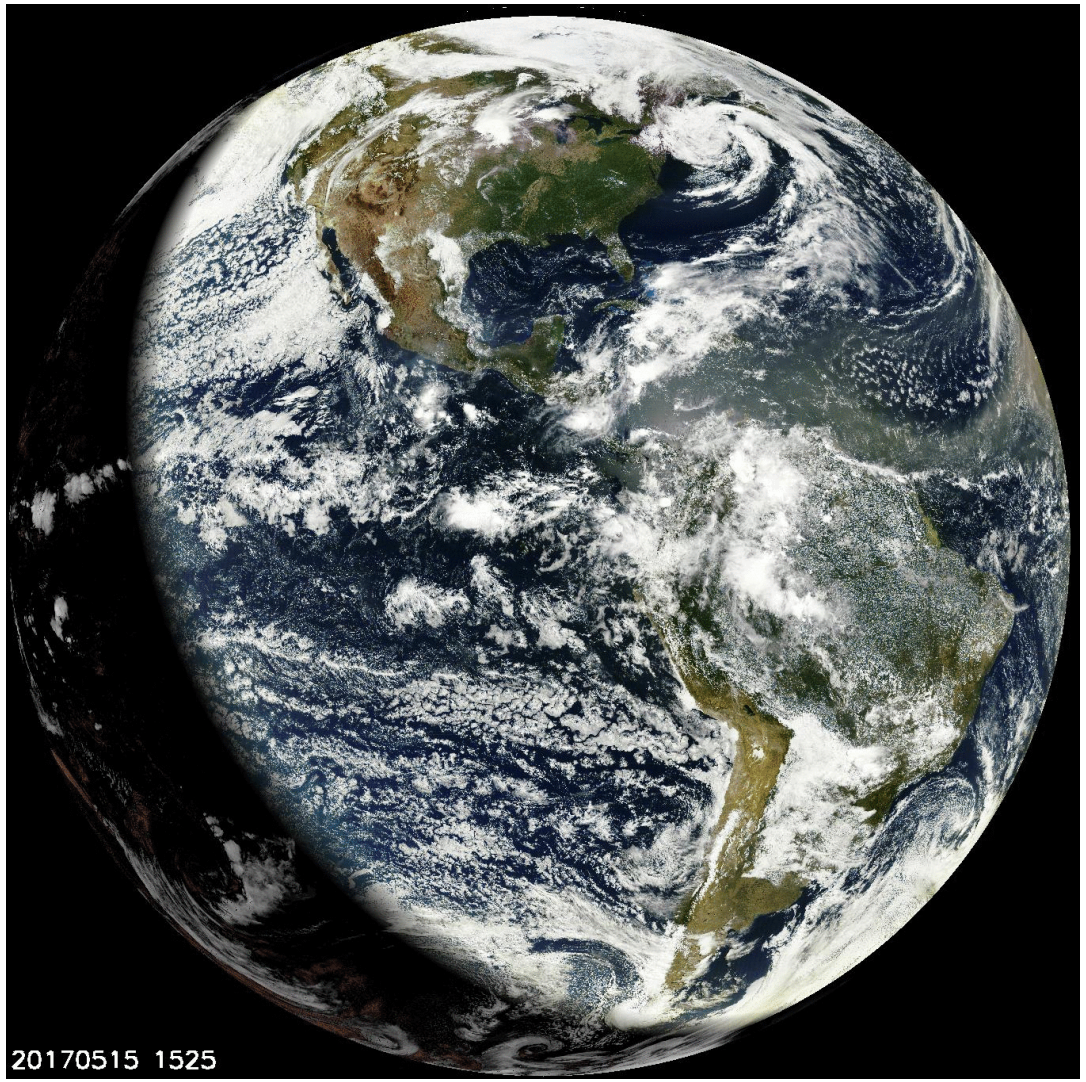
R: $BT_{12.3\mu m} - BT_{11.2\mu m}$
G: $BT_{12.8\mu m} - BT_{8.5\mu m}$
B: $BT_{8.5\mu m}$



Source: Shobha Kondragunta, NOAA

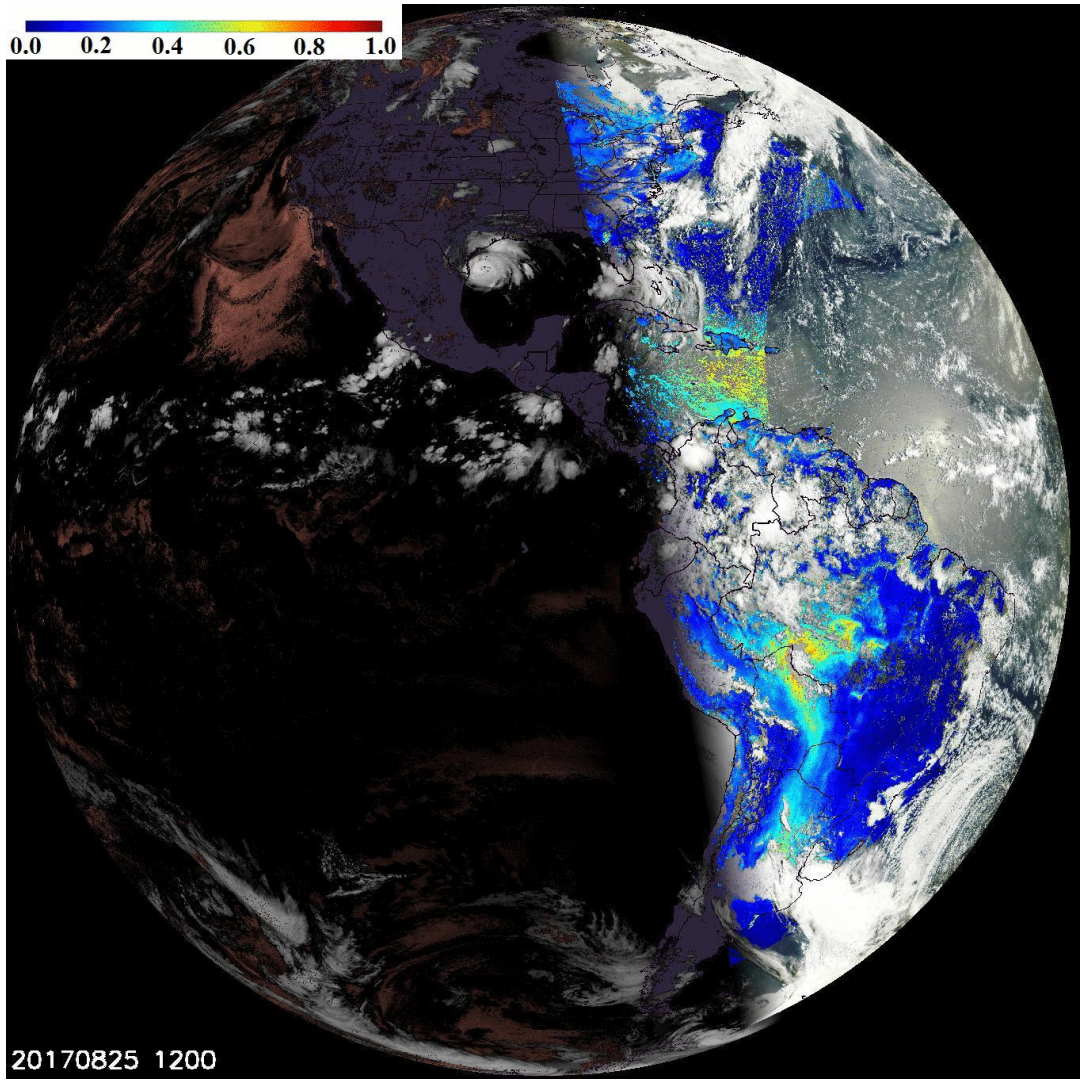
GOES-R ABI New Capabilities: Full Disk Imaging Every 5 Minutes

GOES-16 scan mode is flexible and on demand can do full disk imaging every 5 minutes
GeoColor image show as an example



Source: Shobha Kondragunta, NOAA

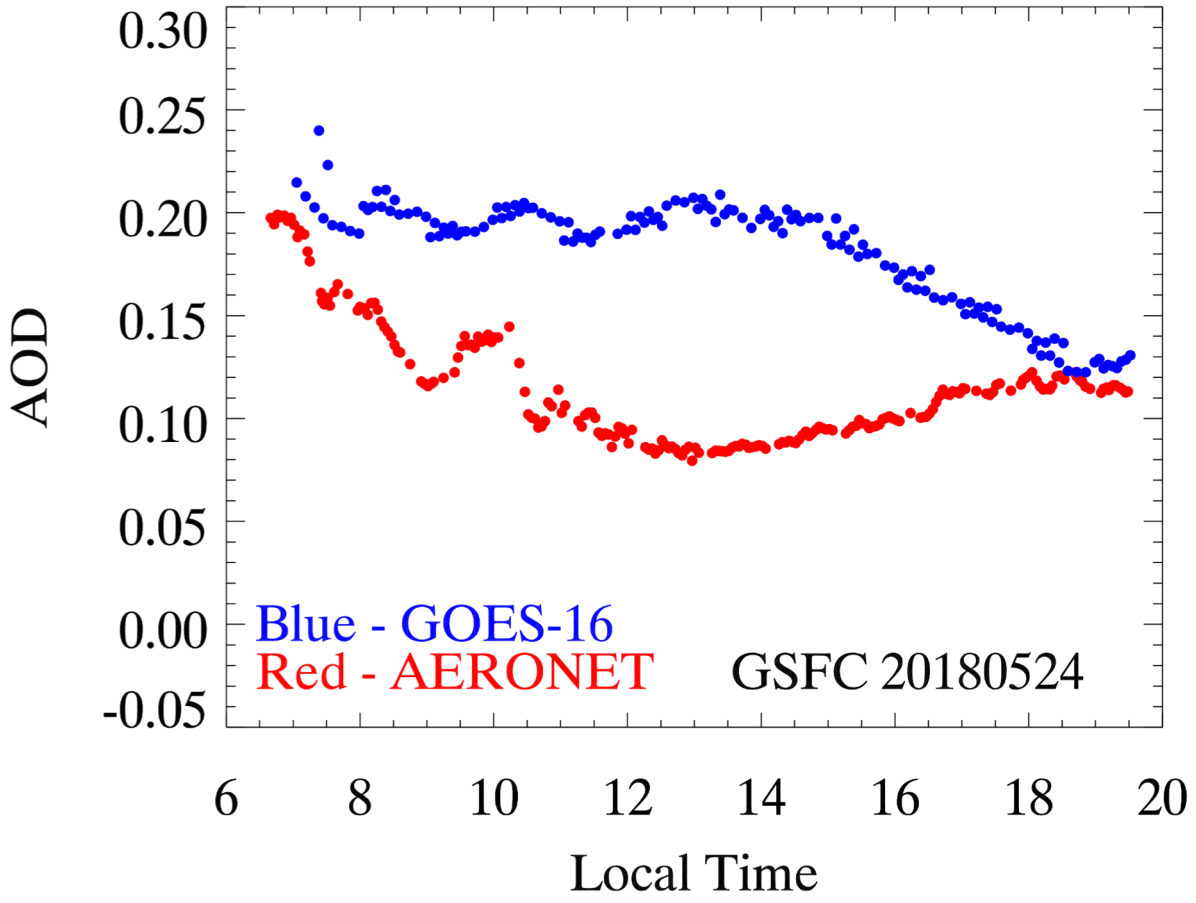
GOES-R ABI New Capabilities: Full Disk AOD Every 15 Minutes



Source: Shobha Kondragunta, NOAA

Breaking The Temporal Barrier

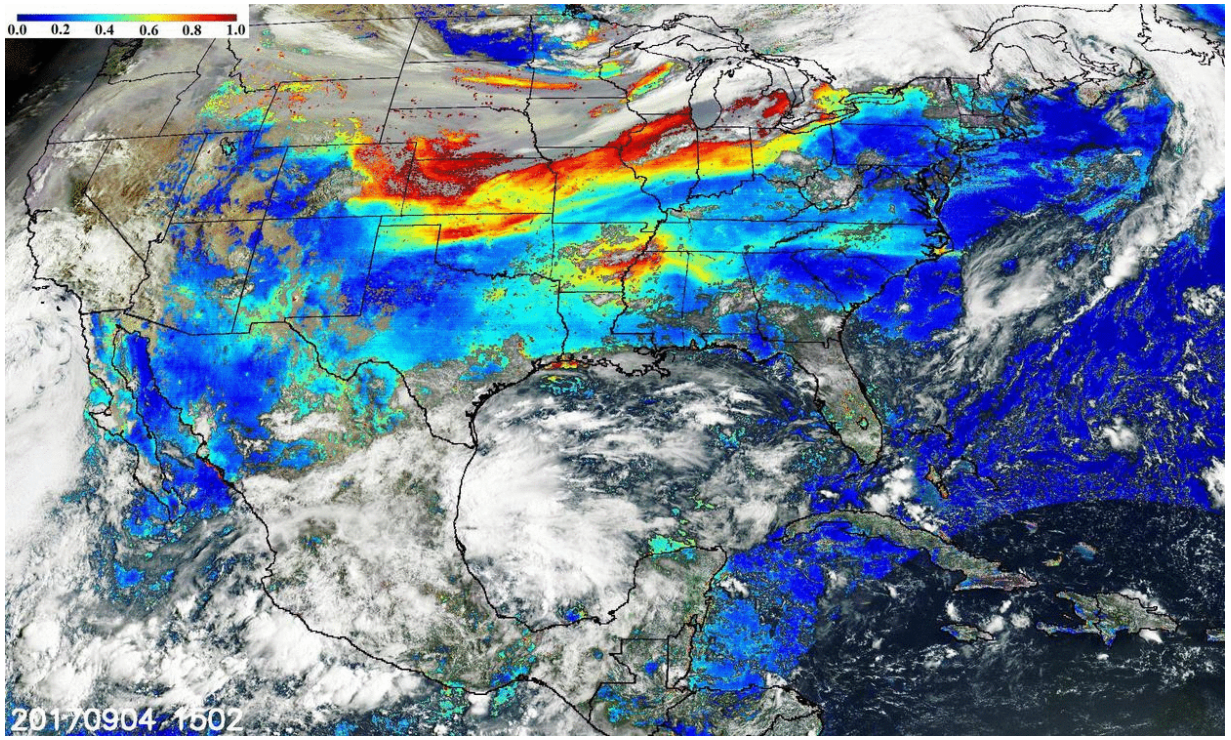
Satellite observations can now compete with high resolution temporal ground observations with the added benefit of observing large geographic regions that are cloud and snow free

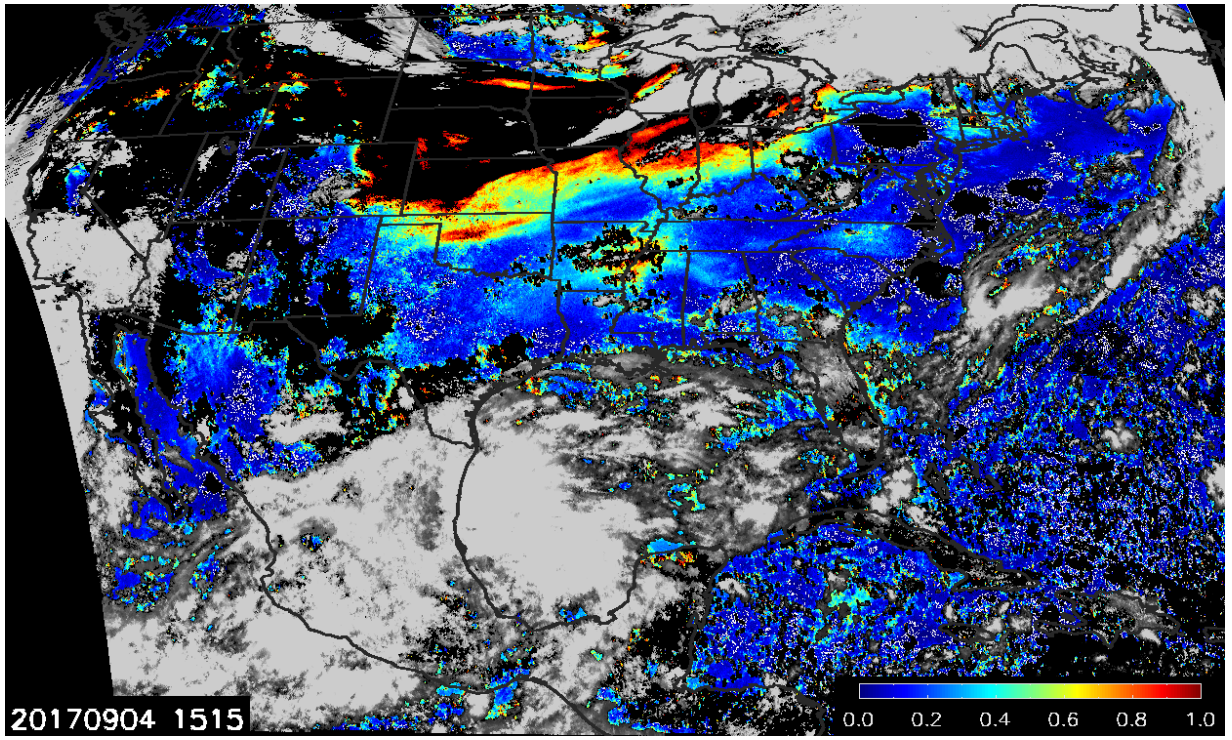


Disclaimer: GOES-16 data are preliminary, non-operational data and are undergoing testing. Users bear all responsibility for inspecting the data prior to use and for the manner in which the data are utilized.

Source: Shobha Kondragunta, NOAA

AOD: GOES-R ABI vs. GOES-13





Disclaimer: GOES-16 data are preliminary, non-operational data and are undergoing testing. Users bear all responsibility for inspecting the data prior to use and for the manner in which the data are utilized.

Source: Shobha Kondragunta, NOAA

Concluding Remarks: Breaking the Temporal Barrier

- **Get excited for 5-minute aerosol products**
- Satellites can finally compete with AERONET in temporal space
  - Viewing geometries different from polar-orbiting satellites
  - Need to gain experience working in this space (e.g., spectral surface reflectance ratios)
- Requirements are to be met for a statistically large sample
  - Uncertain how performance metrics will be as a function of time of the day ---> important for air quality
- Data volume is enormous
  - Users need to be ready for the "fire hose of information"
  - Product tailoring is required

Source: Shobha Kondragunta, NOAA

Acknowledgements

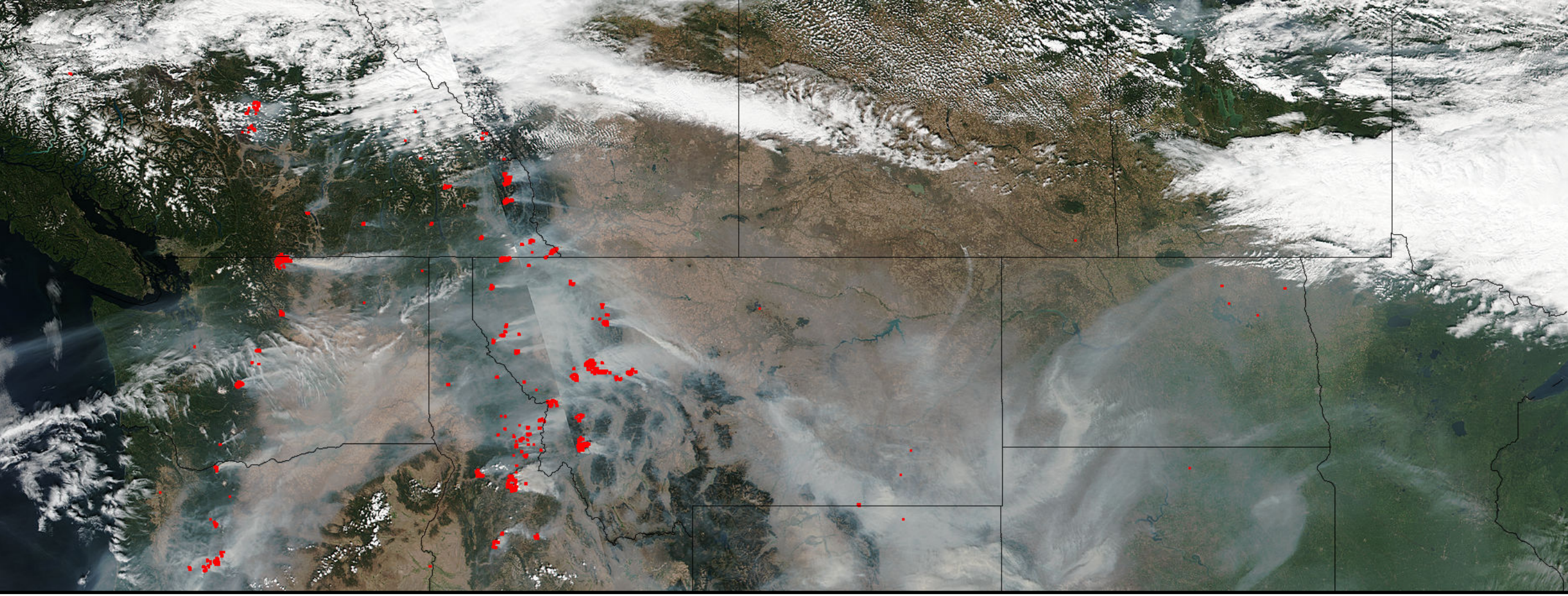
- GOES-R program for funding

- Hai Zhang (IMSG at NOAA) for software tool development

- Mi Zhou (IMSG at NOAA) for running the AOD algorithm

- Pubu Ciren (IMSG at NOAA) for running the aerosol detection algorithm

Source: Shobha Kondragunta, NOAA



Potential Geo Product from NASA

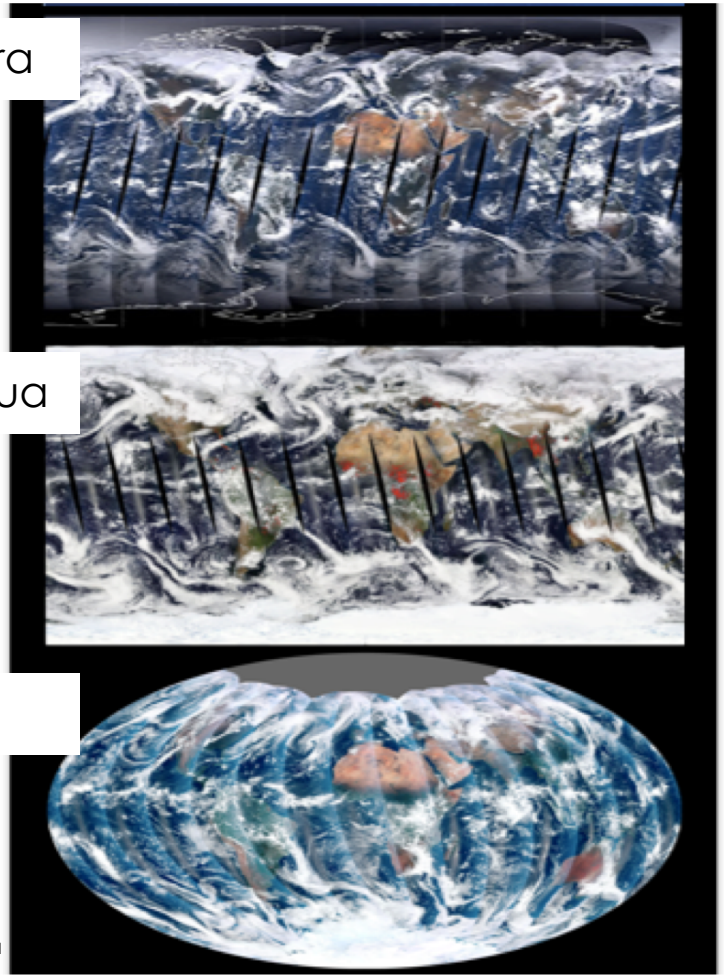
Dark Target Aerosol Retrieval Algorithm

Polar Orbiting Sensors

MODIS-Terra

MODIS-Aqua

VIIRS-SNPP



Credit: Pawan Gupta

18+ years (1999)

15+ years (2003)

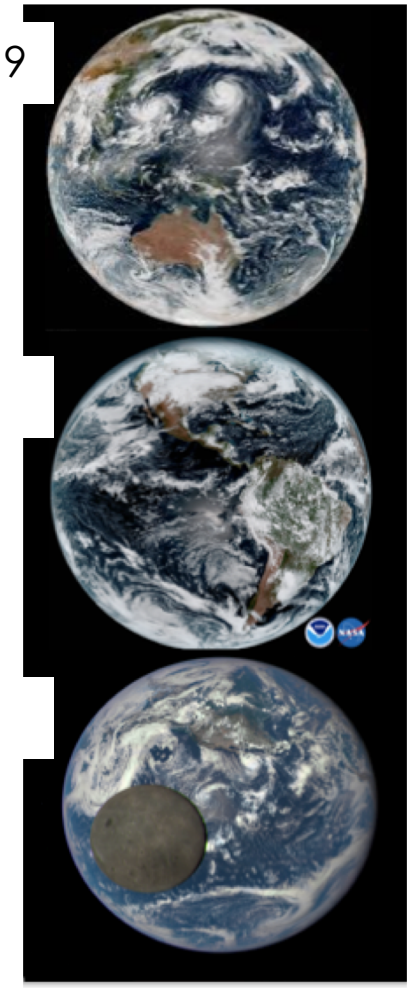
7+ years (2011)

Geostationary & Beyond

AHI 8 & 9

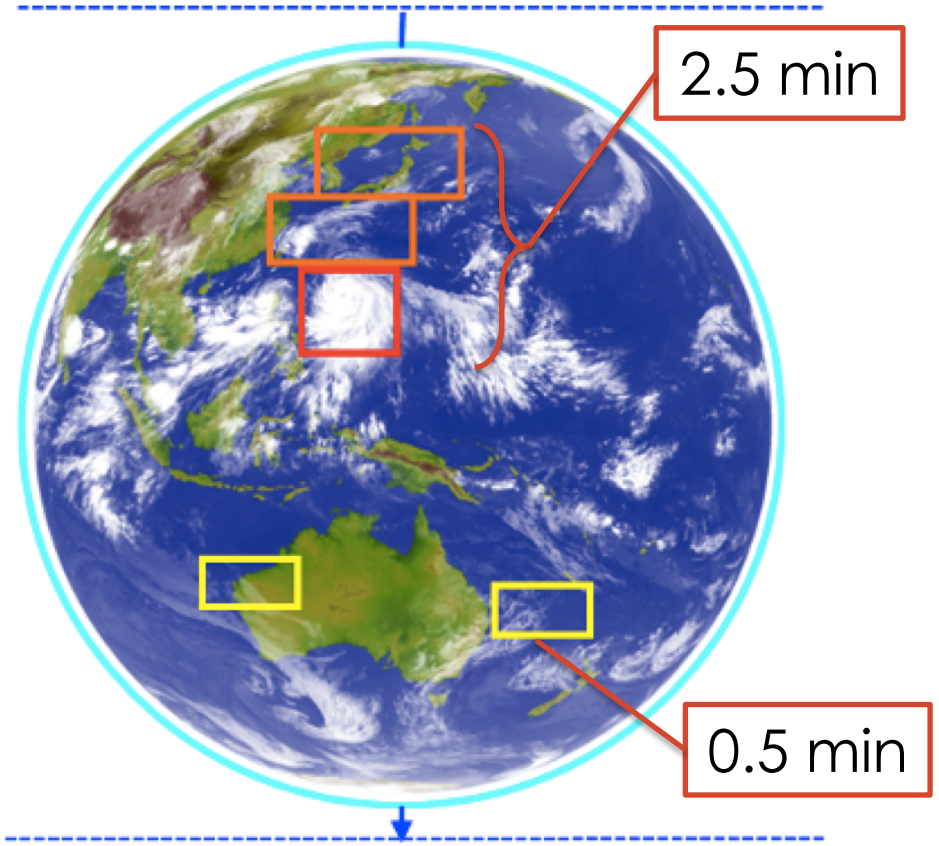
GOES-R

EPIC

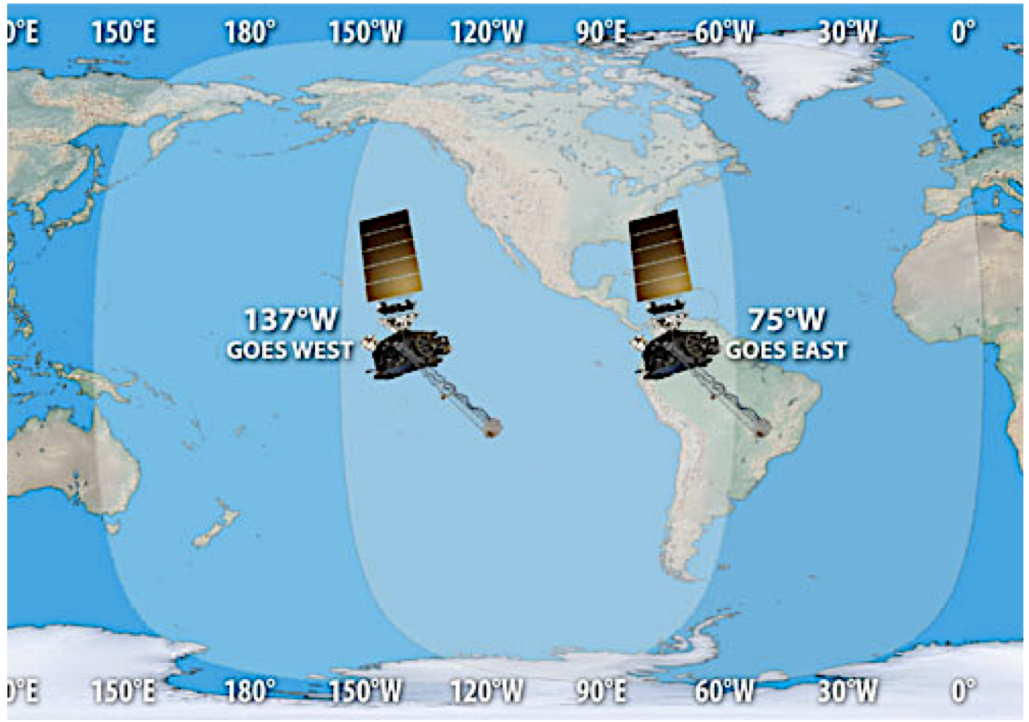


VIIRS- JPSS1, GOES-S, TROPOMI, LANDSAT

AHI & ABI: Spatial Coverage and Temporal Resolution



Full disk: every 10 min



Full disk: every 15 min
CONUS: every 5 min
Mesoscale: every 0.5 min

Image Sources: JAXA, NOAA

AHI & ABI: Spectral Coverage

AHI

Band	Wavelength (μm)	Spatial Resolution (km)
1	0.46	1
2	0.51	1
3	0.64	0.5
4	0.86	0.5
5	1.6	2
6	2.3	2
7	3.9	2
8	6.2	2
9	7.0	2
10	7.3	2
11	8.6	2
12	9.6	2
13	10.4	2
14	11.2	2
15	12.3	2
16	13.3	2

Source: http://www.data.jma.go.jp/

ABI

Future GOES Imager (ABI) band	Central Wavelength (μm)	Nominal Subsatellite IGFOV (km)
1	0.47	1
2	0.64	0.5
3	0.865	1
4	1.378	2
5	1.61	1
6	2.25	2
7	3.90	2
8	6.19	2
9	6.95	2
10	7.34	2
11	8.5	2
12	9.61	2
13	10.35	2
14	11.2	2
15	12.3	2
16	13.3	2

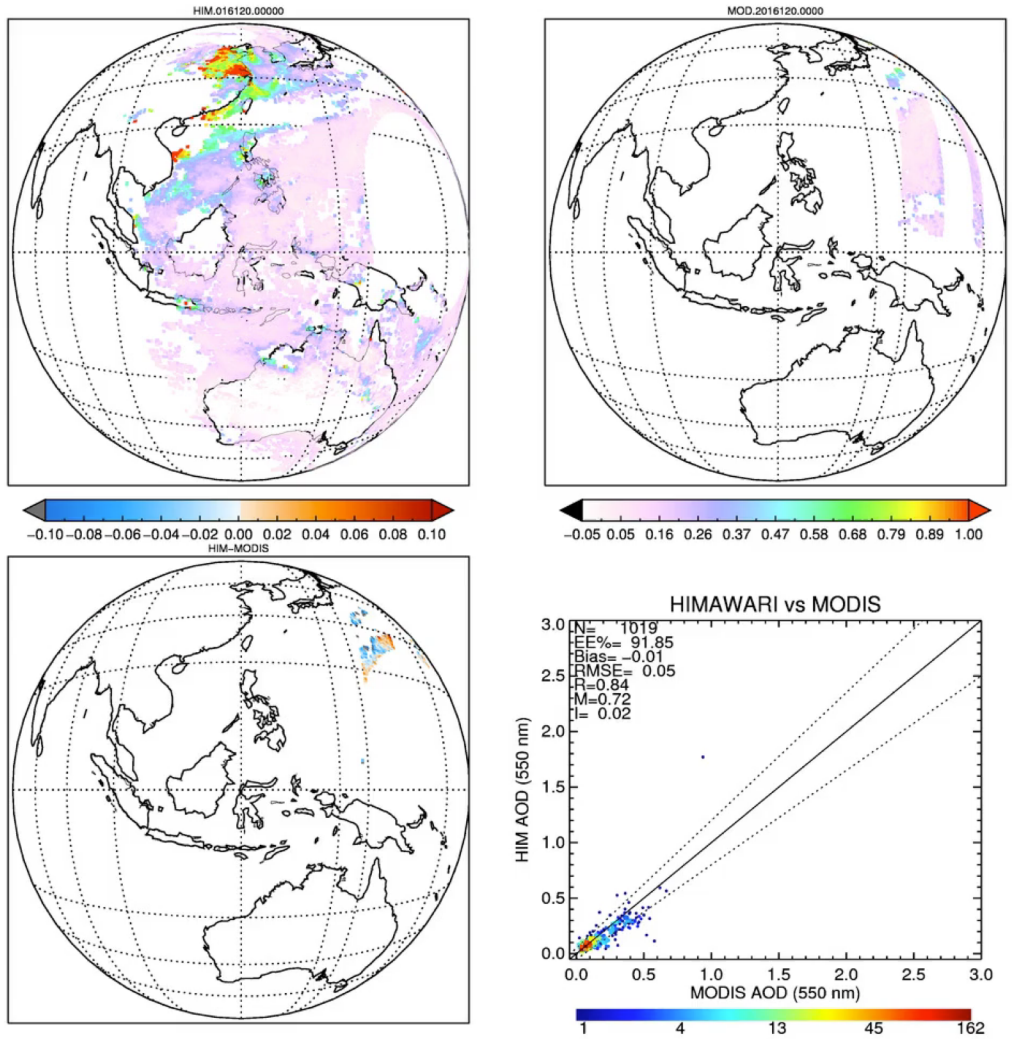
1.24 μm - Missing

Importing MDT Algorithm to AHI & ABI

- ABI does not have green channel – ocean retrieval
- SWIR NDVI are revised and estimated using pair of 0.86 & 2.3 micron channels as compared to 1.24 and 2.1 in MODIS
- Surface characterization need revision to account for the change in wavelength
- Pixel selection, cloud masking (no cirrus band in AHI), and aerosol model selection remain same as MODIS DT algorithm
- Revised algorithm is applied on AHI data during KORUS-AQ (May-June, 2016) and on one day (Sep 4th 2017) of ABI

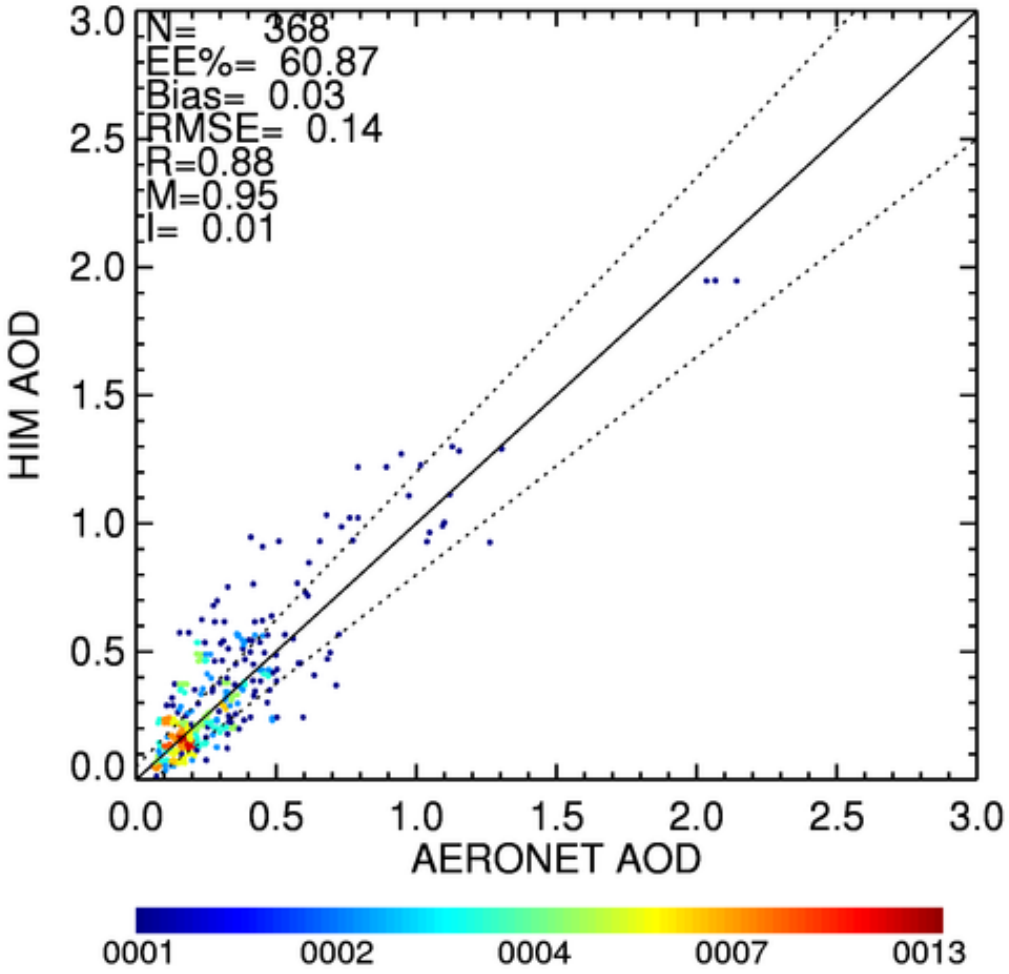
AHI & MODIS for the Nearest Hour Measurement

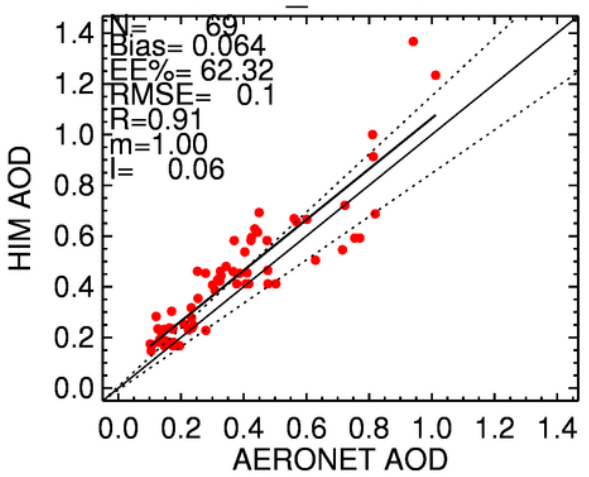
April-May 2016



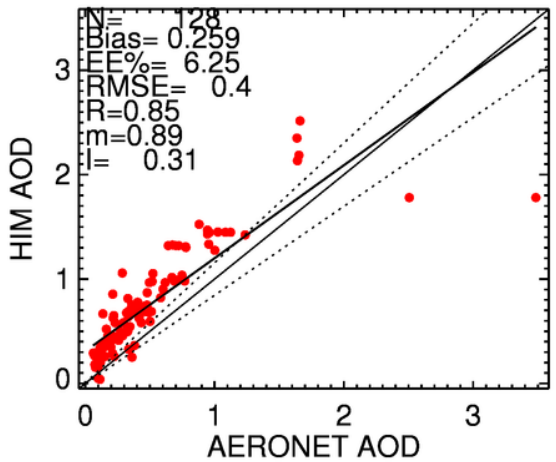
Credit: Pawan Gupta

AERONET vs. AHI

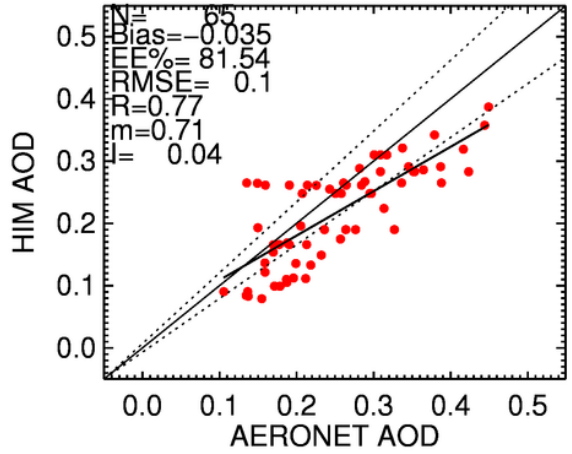




KORUS_Baeksa



Beijing-CAMS

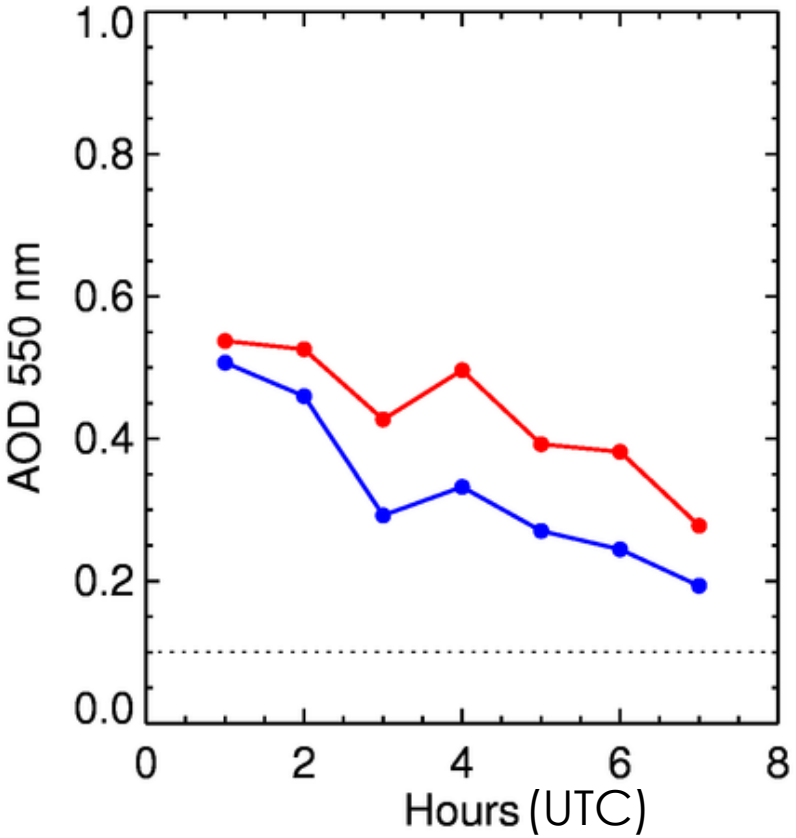


KORUS_UNIST

Credit: Pawan Gupta

Diurnal Cycle of AODs

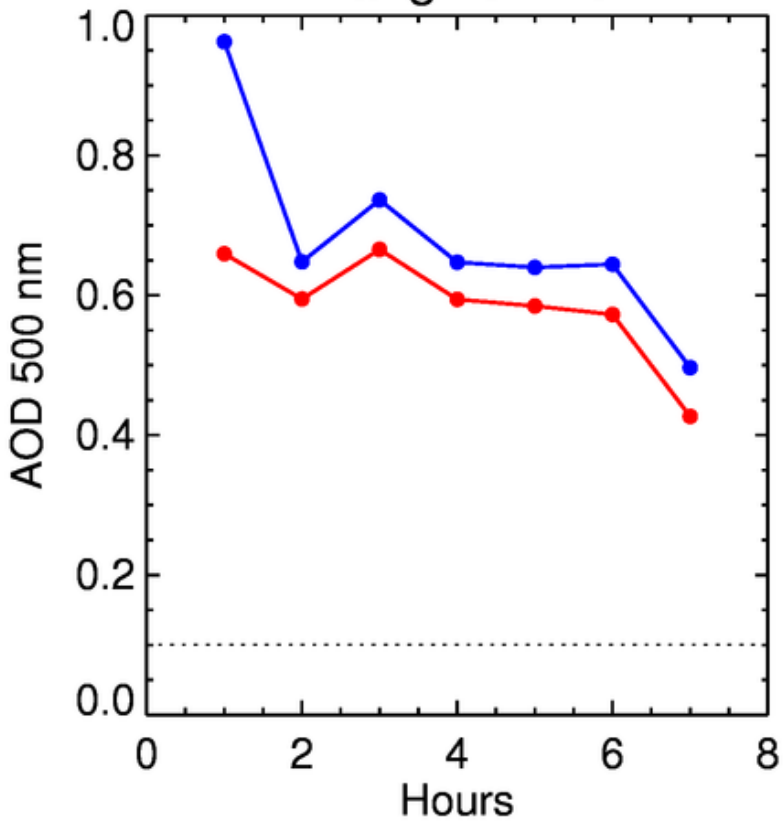
KORUS_Taehwa



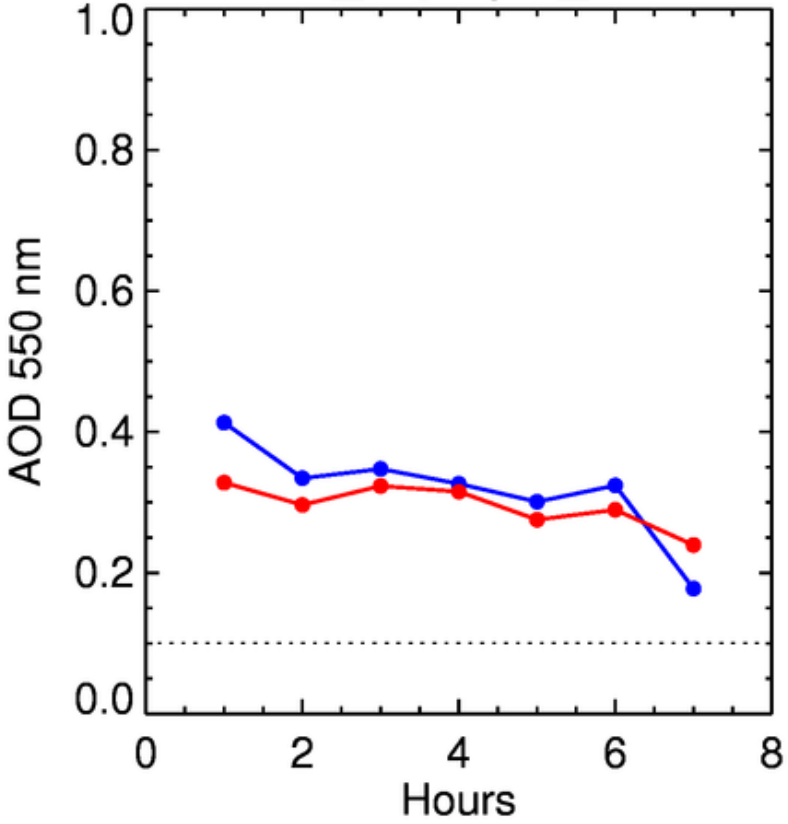
9 11 13 15 17

(Local Time, Korea)

XiangHe



KORUS_Olympic_Park

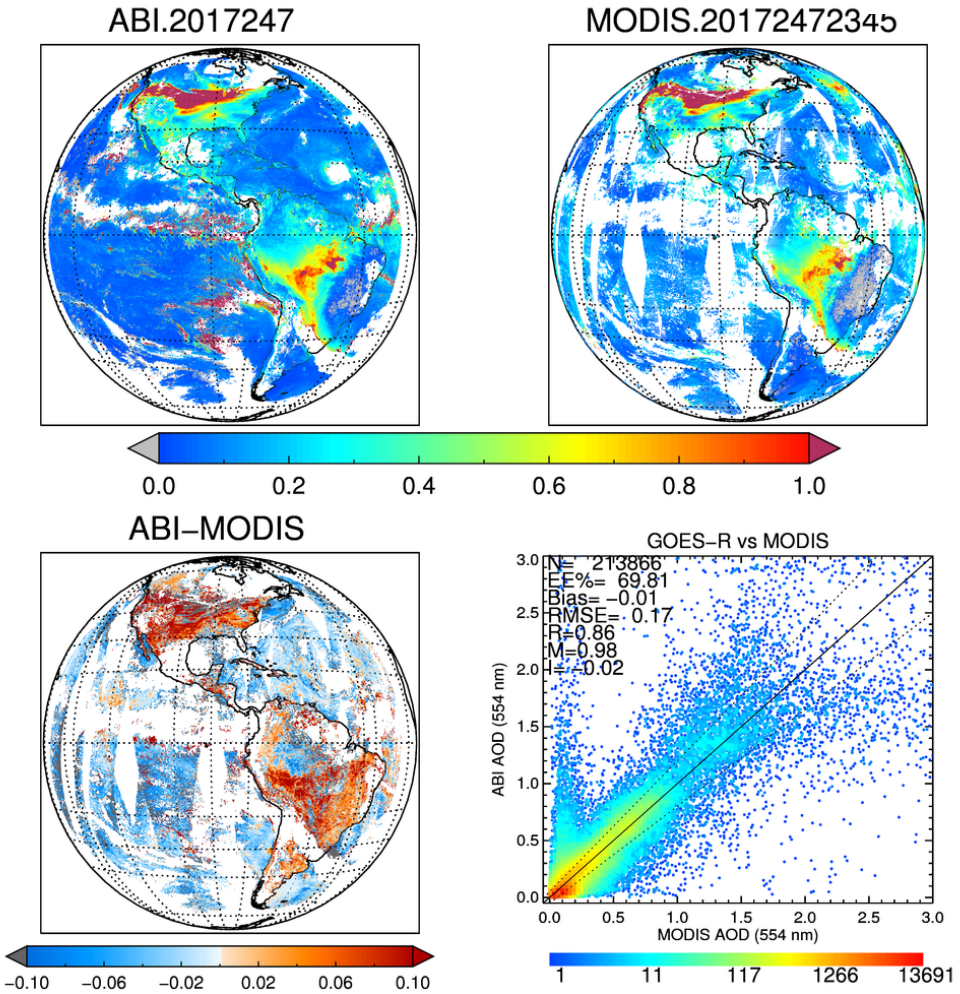


Credit: Pawan Gupta

ABI Retrievals - preliminary

- Play AOD Movie Here

ABI vs MODIS – preliminary



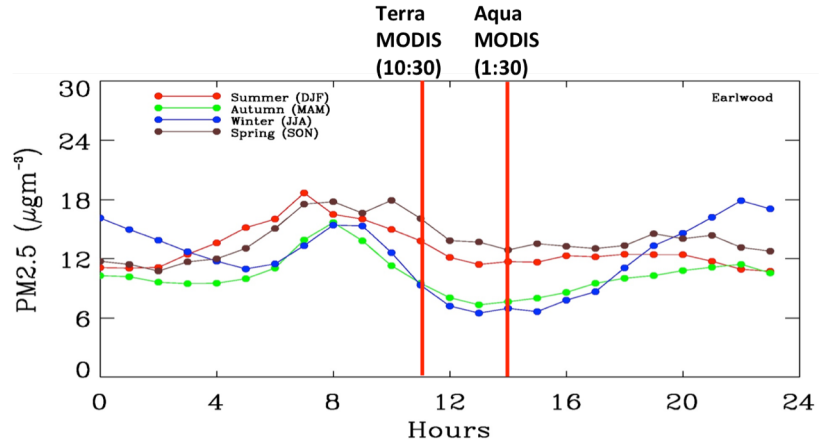
Credit: Pawan Gupta

ABI Retrievals - preliminary

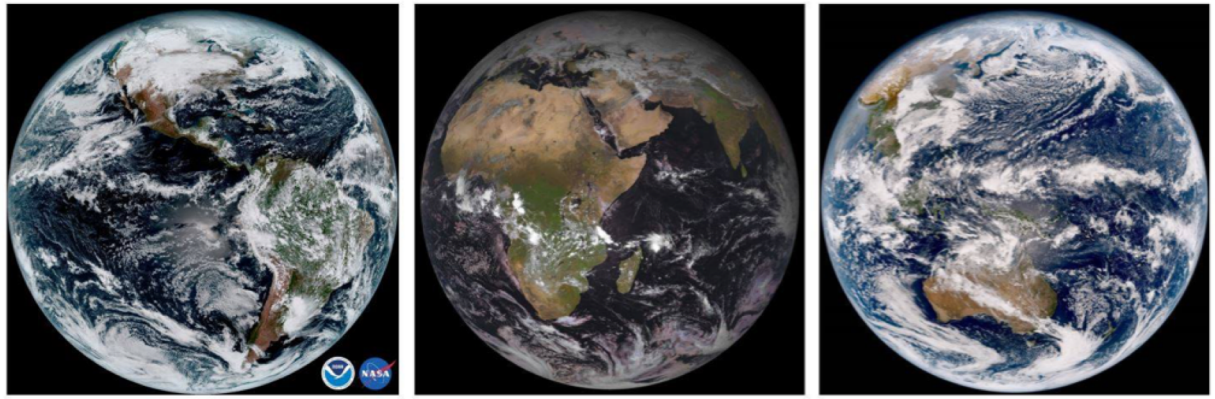
- Play PM2.5 movie here

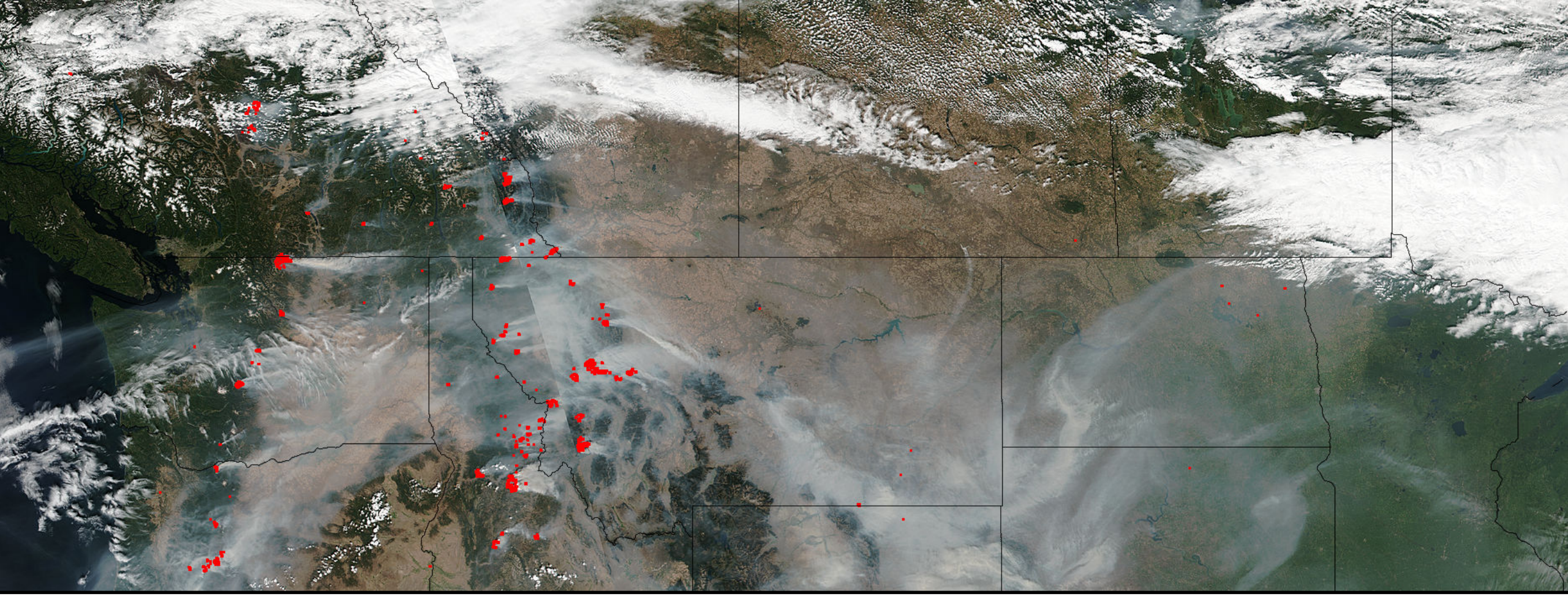
Summary

- Aerosol measurements from Geo orbit is a step forward in breaking the temporal barrier
- Challenges associated with global aerosol retrievals can be addressed more effectively with regional retrievals
- For the global climate record, consistent and long-term aerosol retrieval is a key challenge
- The beginning of a new era in satellite remote sensing of air quality



Polar orbiting satellites only provide 1-2 observations per day, which limits their application for continuous air quality monitoring





Thanks