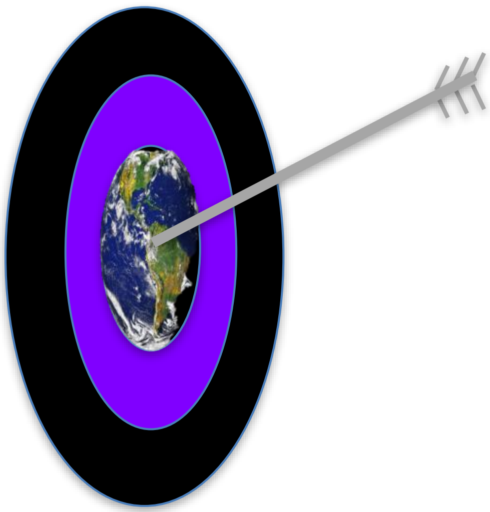
Satellite Continuity and Synergy: From MODIS to VIIRS and from LEO to GEO



Robert C. Levy (NASA-GSFC), robert.c.levy@nasa.gov

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[1]NASA Goddard Space Flight Center, [2]GESTAR/USRA, [3]SSEC/U.Wisconsin, [4]UMBC, [5]NOAA-STAR, [6]SSAI, [7]ADNET

One reason why we care

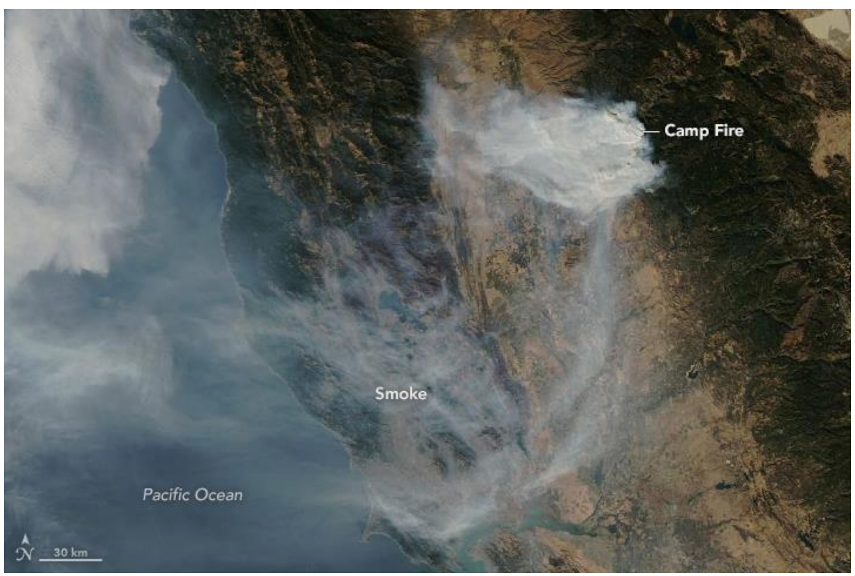
https://earthobservatory.nasa.gov/blogs/earthmatters/2018/11/14/satellites-and-ground-sensors-observe-smoke-blanketing-california

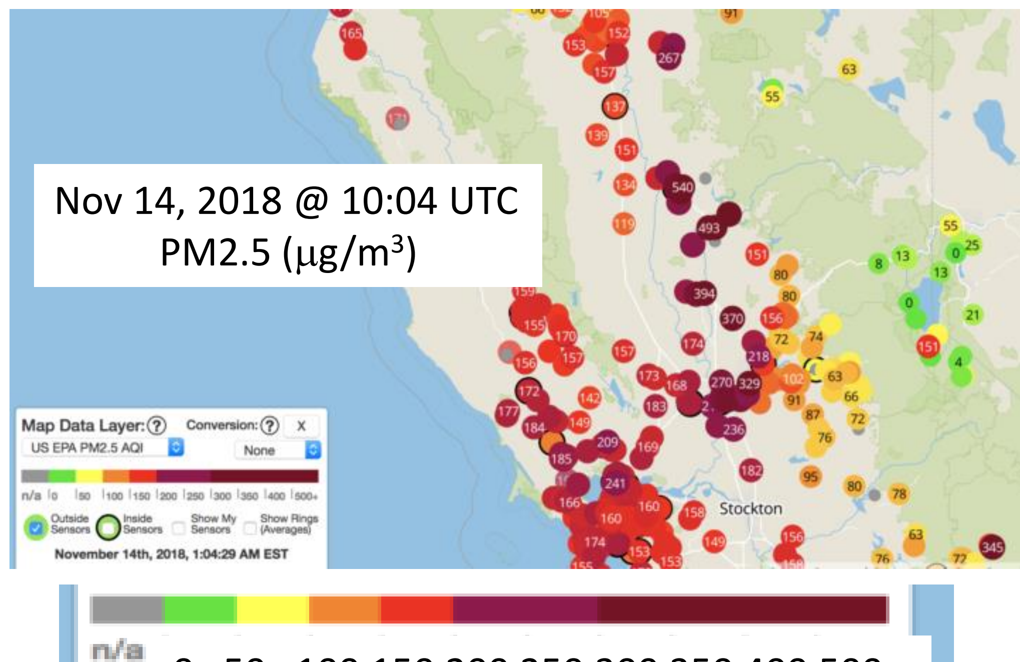
earth observatory

Earth Matters

Satellites and Ground Sensors Observe Smoke Blanketing California

November 14th, 2018 by Adam Voiland

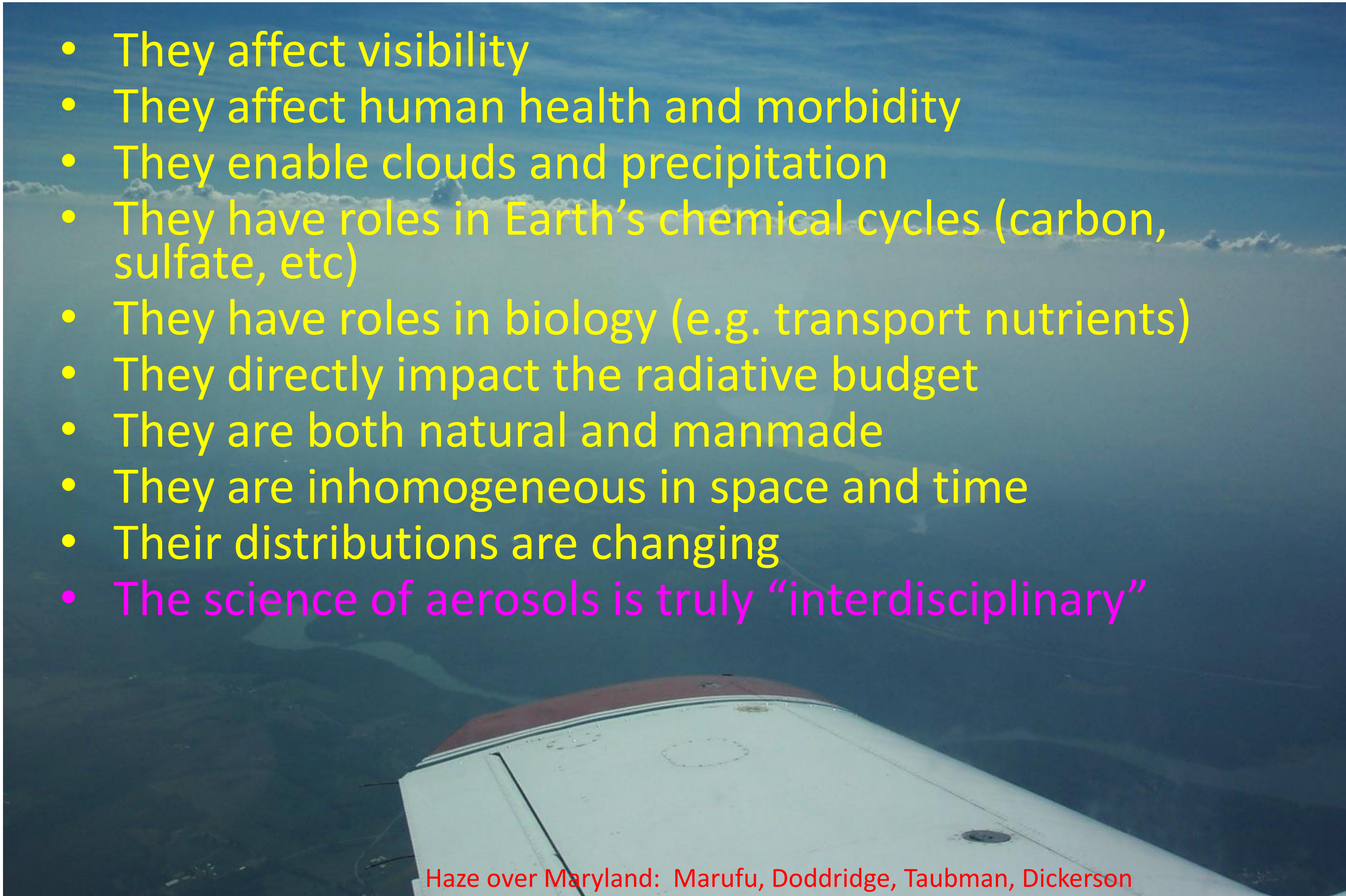




Pawan Gupta (USRA), Robert Levy (NASA),
Prakash Doraiswamy (RTI), Olga Pikelnaya (UCLA)

Aerosols (why do we care?)

- They affect visibility
- They affect human health and morbidity
- They enable clouds and precipitation
- They have roles in Earth's chemical cycles (carbon, sulfate, etc)
- They have roles in biology (e.g. transport nutrients)
- They directly impact the radiative budget
- They are both natural and manmade
- They are inhomogeneous in space and time
- Their distributions are changing
- The science of aerosols is truly "interdisciplinary"



Haze over Maryland: Marufu, Doddridge, Taubman, Dickerson

Global Climate Observing System (GCOS) requirements for **aerosol** climate data record (CDR)

Target Requirements

Variable/ Parameter	Horizontal Resolution	Vertical Resolution	Temporal Resolution	Accuracy	Stability
Aerosol optical depth	5-10km	N/A	4h	Max (0.03; 10%)	0.01
Single-scattering albedo	5-10km	N/A	4h	0.03	0.01
Aerosol-layer height	5-10km	N/A	4h	1km	0.5km
Aerosol-extinction coefficient profile	200-500km	<1km near tropopause, ~2km in middle stratosphere	weekly	10%	20 %

Stability means ”drift per decade less than X” .

Also requires: multi-decade (e.g. 30+ year data record)

Let us focus on Aerosol Optical Depth = AOD

Global Climate Observing System (GCOS) requirements for **Aerosol Optical Depth (AOD)** climate data record (CDR):

Target metric	Target
Horizontal Resolution	5-10 km, globally
Accuracy	MAX(0.03 or 10%)
Stability / bias	<0.01 / decade
Time Length	30+ years
Temporal Resolution	4 h

These are requirements for “climate” monitoring

Maybe different requirements for other applications

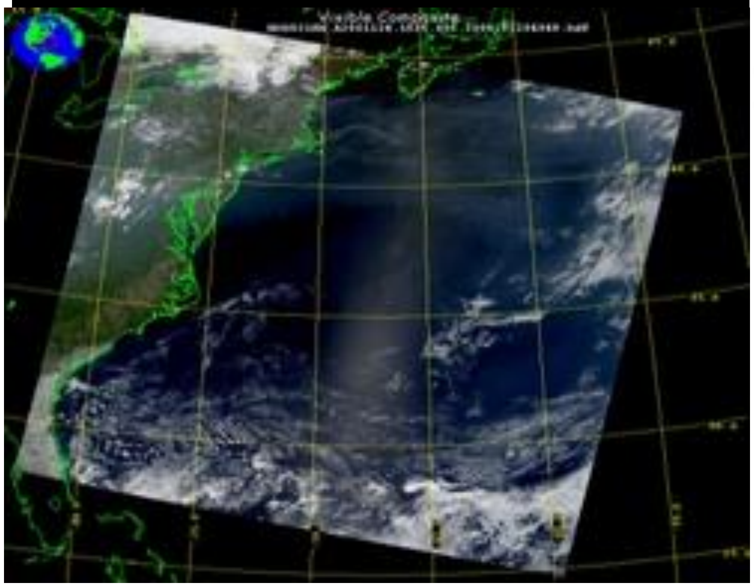
(air quality, ocean fertilization, weather forecasting...)

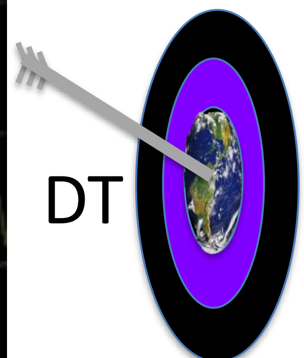
How are we get there?

Dark-Target (DT): A "Single View" aerosol algorithm developed for MODIS (Terra and Aqua)

What a sensor observes

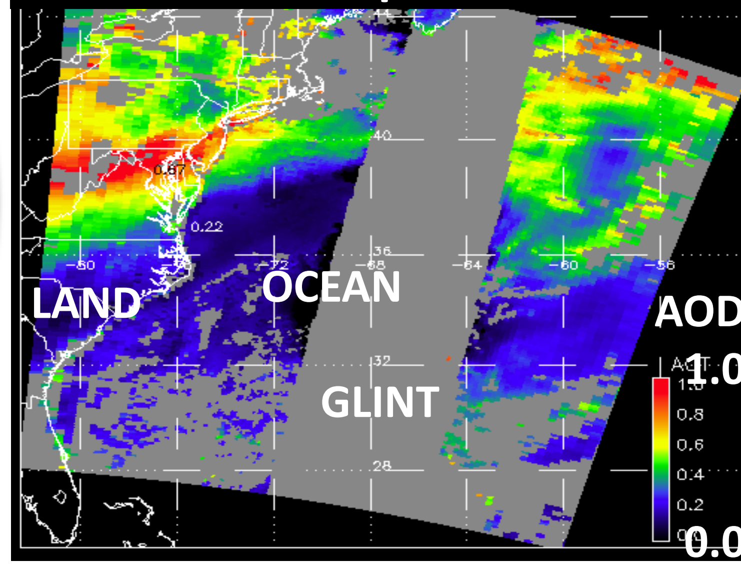
May 4, 2001; 13:25 UTC
Level 1 "reflectance"





Attributed to aerosol (AOD)

May 4, 2001; 13:25 UTC
Level 2 "product"

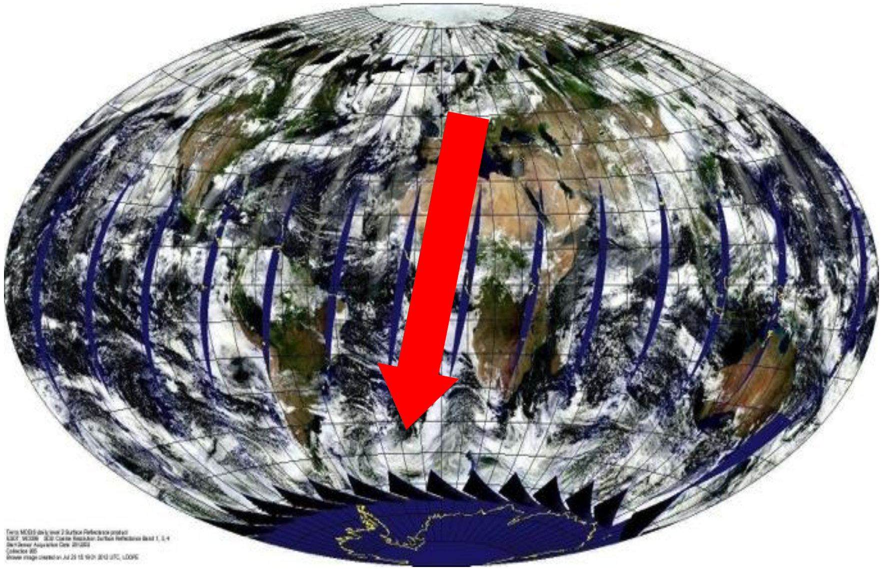


"Established 1997" by Kaufman, Tanré, Remer, etc)
"Modified 2005, 2010, 2013, 2015" by Remer, Levy, Gupta, etc

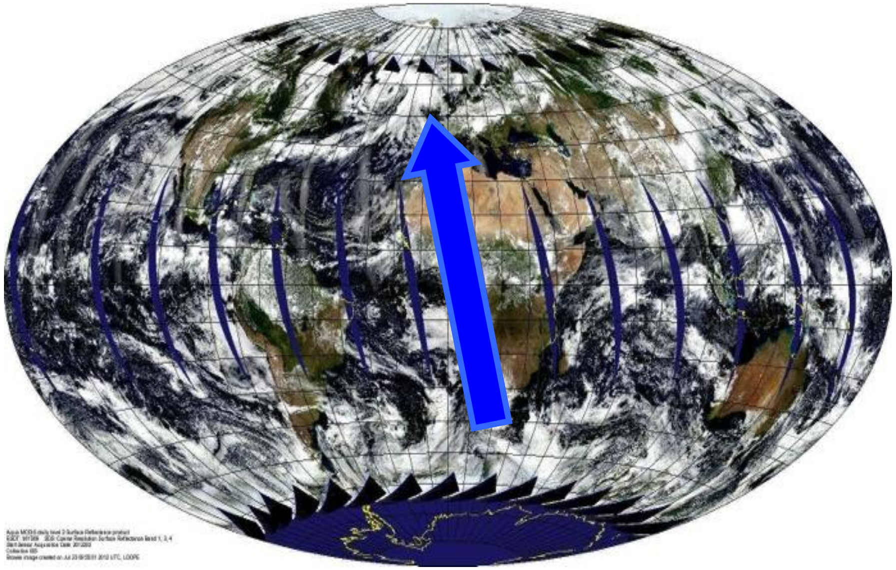
Separate logic over land and ocean
Retrieve: AOD at 0.55 μm, spectral AOD (AE), Cloud-cleared reflectances, diagnostics, quality assurance

MODIS-Terra vs MODIS-Aqua

Terra (10:30, Descending)



Aqua (13:30, Ascending)



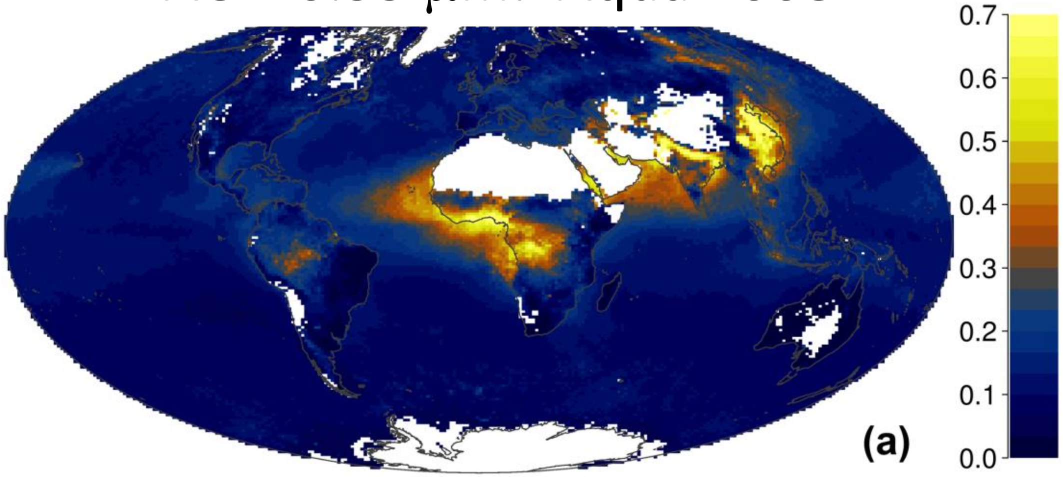
The two MODIS instruments are **TWINS!**

Do they observe the world in the same way?

Levy, R. C., et al.: Exploring systematic offsets between aerosol products from the two MODIS sensors, Atmos. Meas. Tech., 11, 4073-4092, https://doi.org/10.5194/amt-11-4073-2018, 2018.

Aggregations of 2008 AOD shows offsets

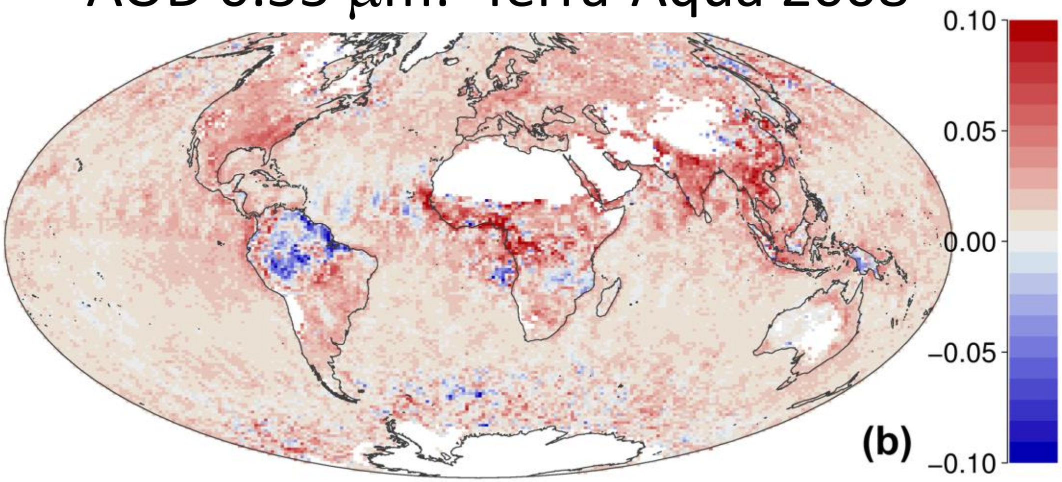
AOD 0.55 μm: Aqua 2008



Higher AODs; Dust, pollution

Lower AODs; open ocean, remote land

AOD 0.55 μm: Terra-Aqua 2008



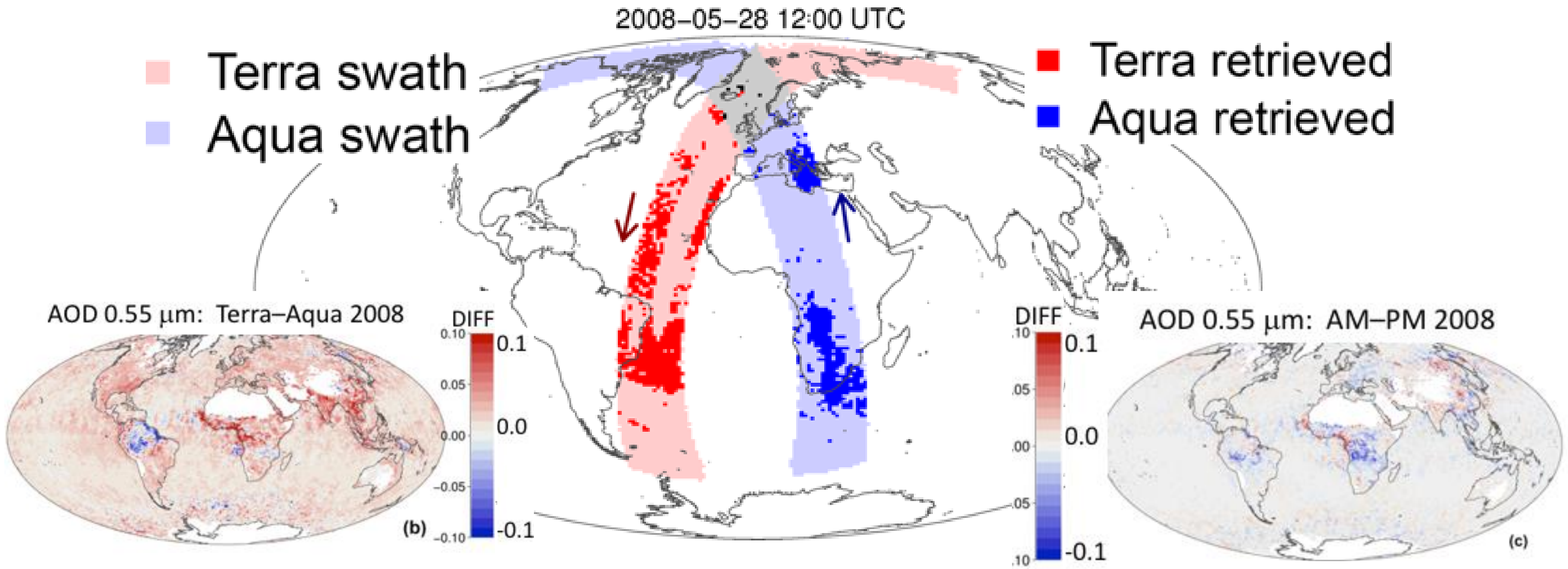
Positive offset nearly everywhere!

Terra also larger offset compared to AERONET

Angstrom Exponent (AE) also shows offsets

Using "model" to explore difference in AOD?

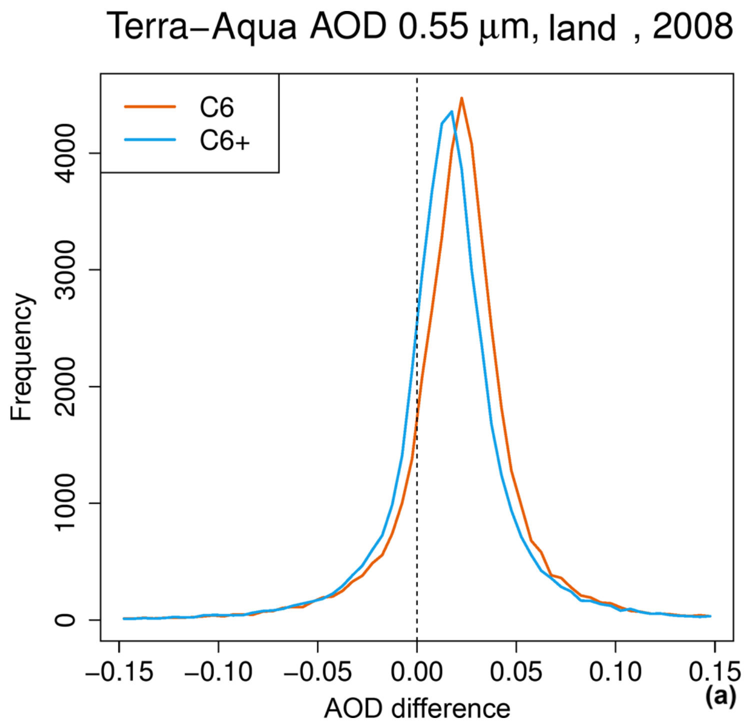
MERRA-2 (replay) sampled at 12:00 UTC on May 25, 2008
Overpasses within ±30 minutes

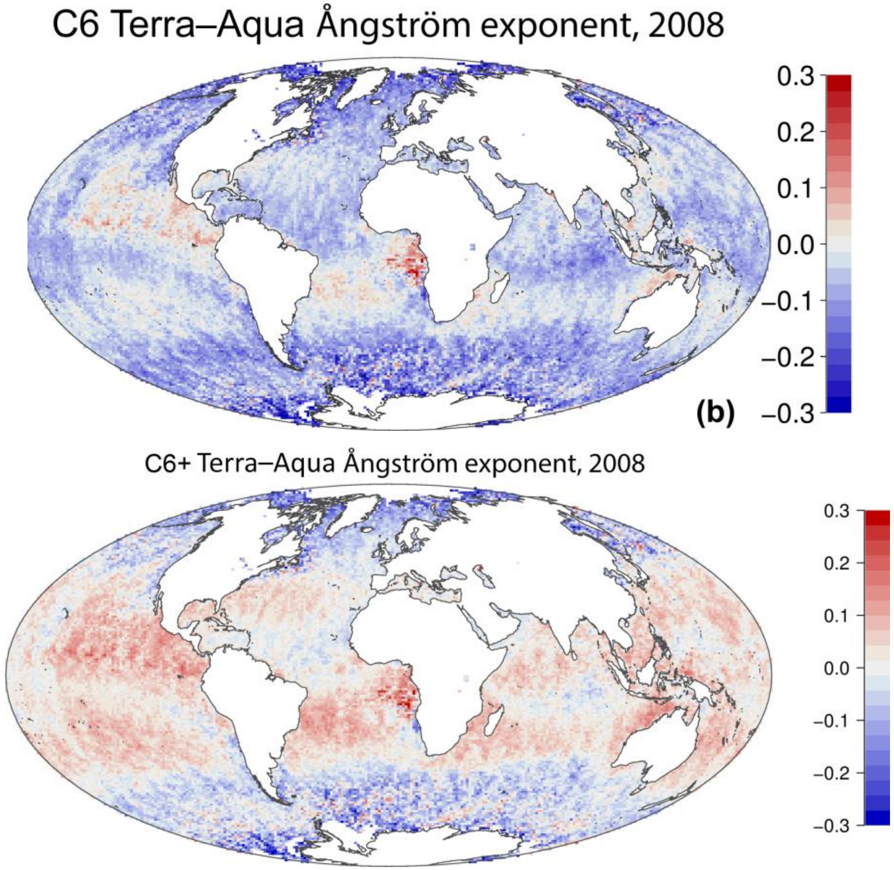


- MERRA-2 "replay" (meteorological assimilation – no Terra/Aqua)
- Sample at time of Terra and Aqua overpass (swath)
- Sample only where DT algorithm provided retrieval (retrieved)
- Aggregate to monthly and global means
- Look at AM–PM differences (Terra–Aqua) for AOD and AE
  - → **Some similarity in "smoke" regions, but overall much less difference for MODEL then SATELLITE**

Calibration is important: "C6+"

- Over land, AOD offset is reduced (by 0.005)
- Over ocean, negligible change in AOD offset

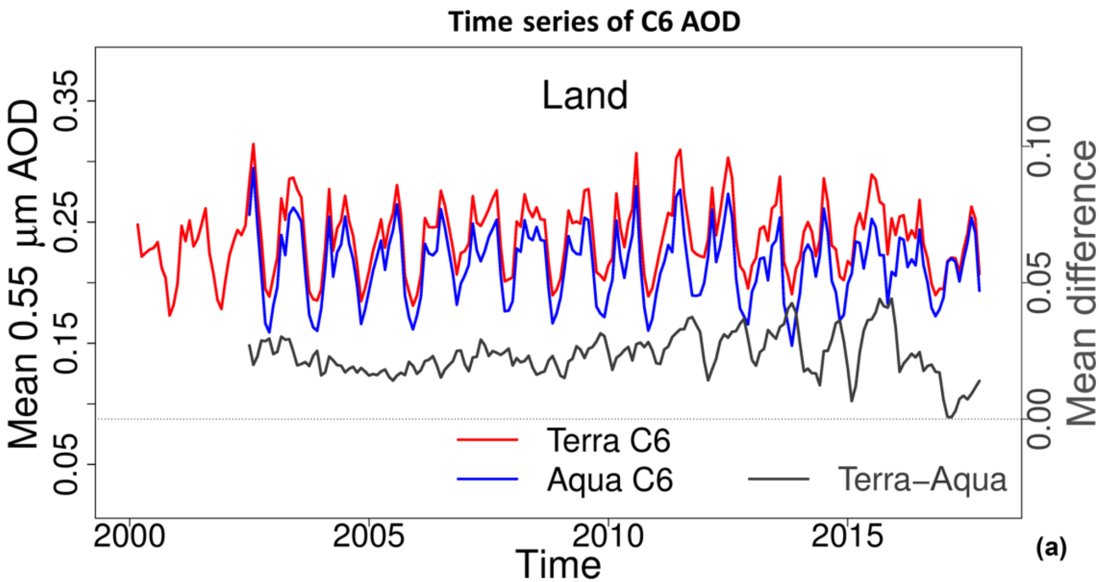




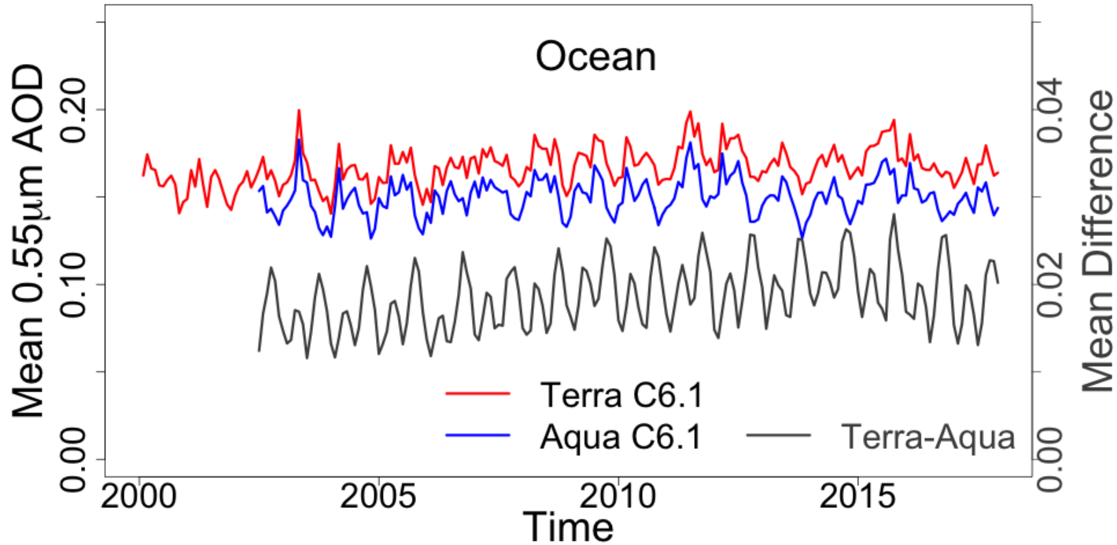
A. Lyapustin et al

- For AE, C6+ reduces negative offset

Time series of AOD Collection 6.1

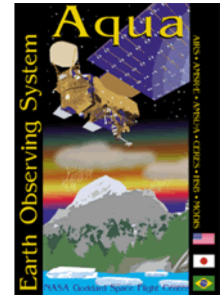


Global **offset** of ~0.015 or about ~13%

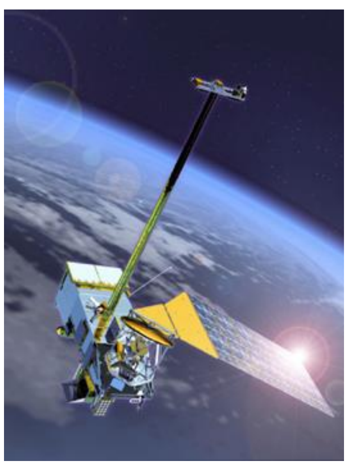


"trend" of offset reduced in 6.1. Maybe can use for trend studies?

Beyond **MODIS**



- Terra (19+) and Aqua (17) have both have well-exceeded their planned mission lifetimes.
- With luck, they will last until 2022.
- But for climate, we need to continue the MODIS record, with no "jumps"



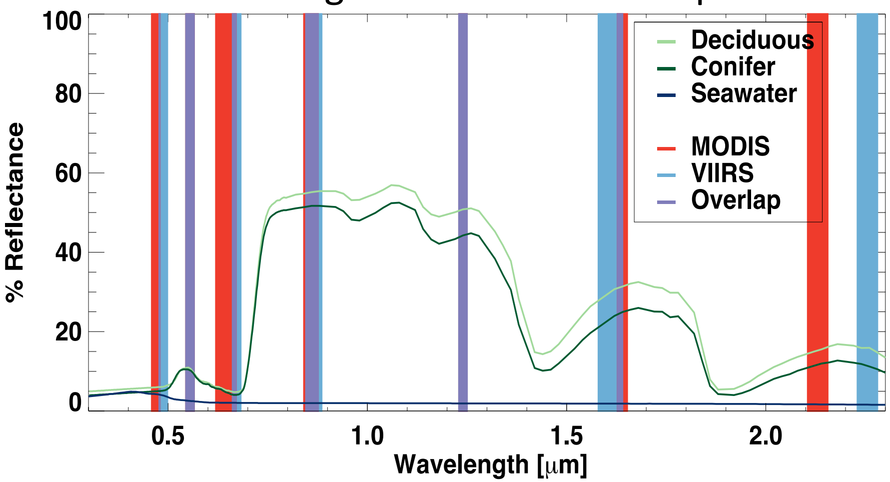
VIIRS!

Visible-Infrared Imager Radiometer Suite
aboard Suomi-NPP, NOAA-20 and beyond

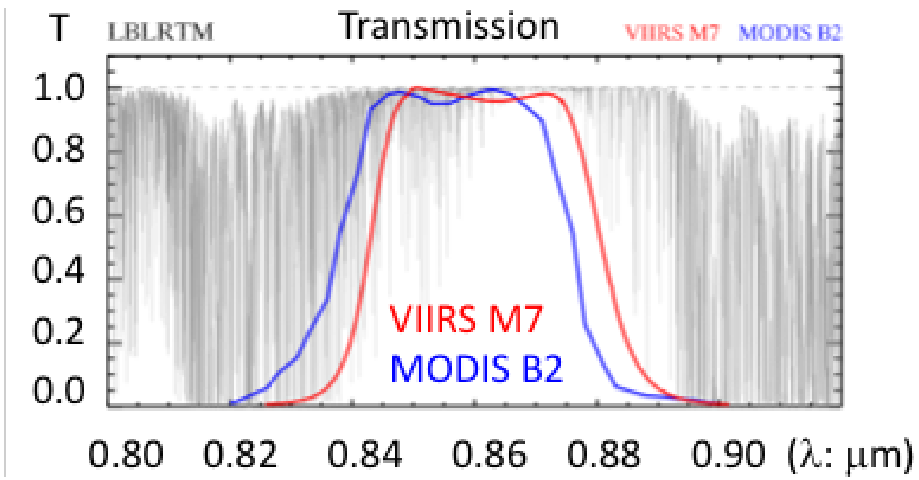
For “continuity” we can port the algorithms (Example: DT from MODIS→VIIRS)

- Deal with differences in wavelengths (gas corrections/Rayleigh, etc)

Wavelength bands & surface spectra



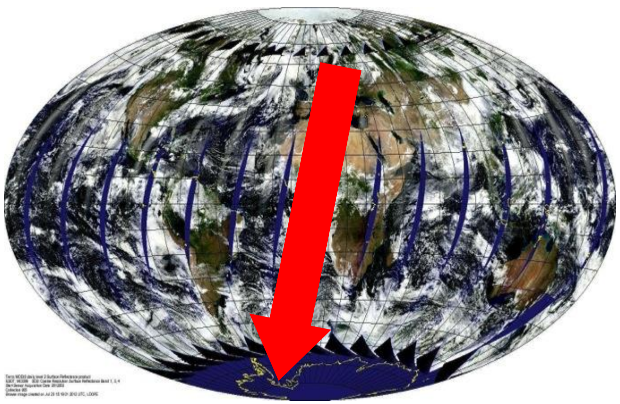
Example: 0.86 µm channel over “clear” sky



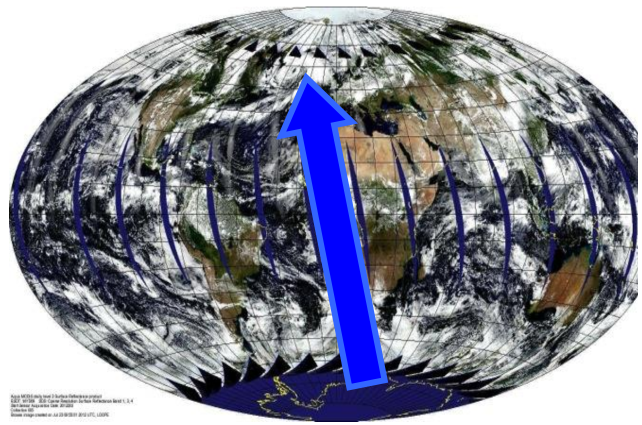
- Deal with differences in resolution, etc.
- Retrieve on new sensors (compared with retrieval on MODIS):

MODIS-Terra vs MODIS-Aqua vs SNPP-VIIRS

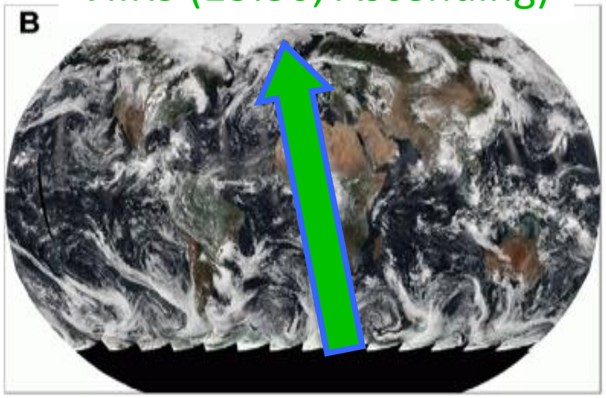
Terra (10:30, Descending)

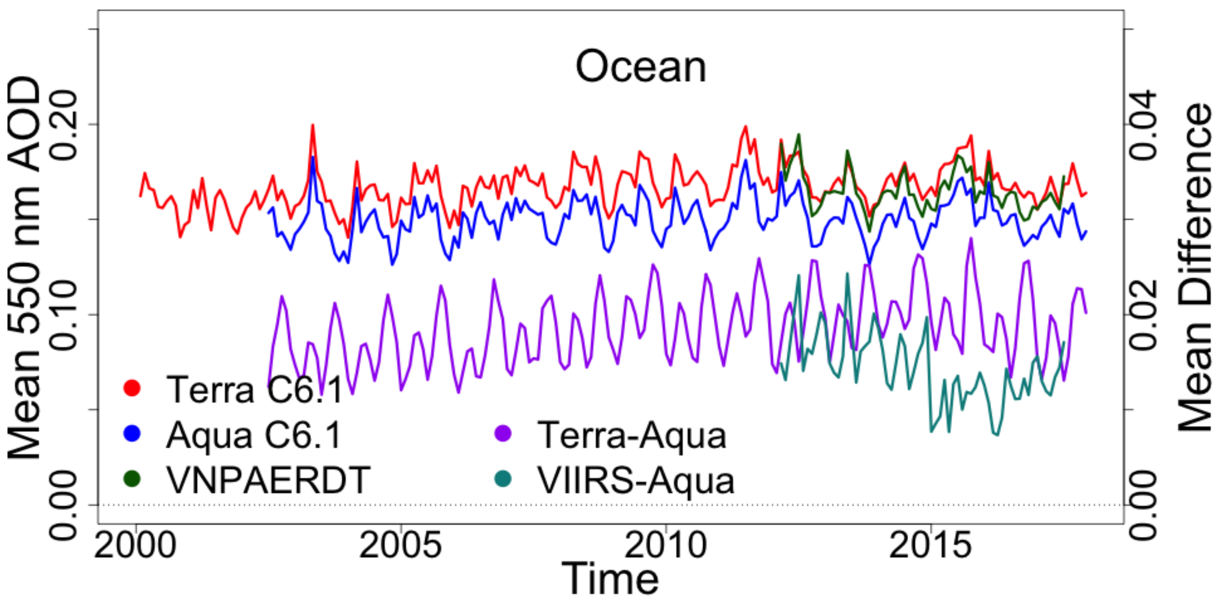


Aqua (13:30, Ascending)



VIIRS (13:30, Ascending)

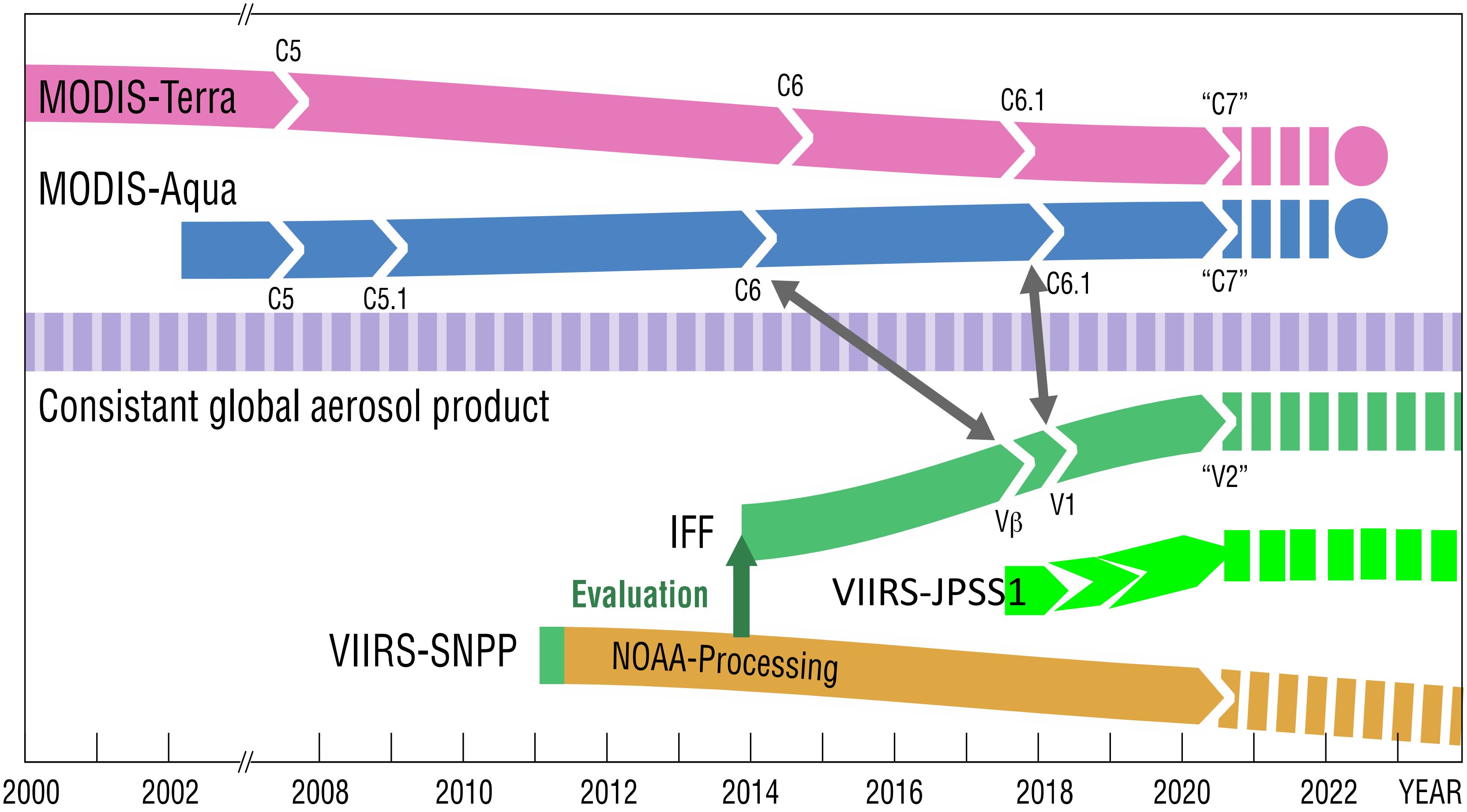




- Offsets remain.
- Why different seasonal cycles of differences?

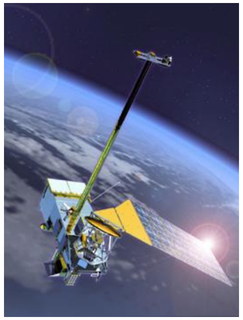
- Calibration?
- Sampling?
- Cloud detection?
- Cloud diurnal cycle?

Towards consistent global aerosol on LEO



VIIRS on SNPP (and beyond) should include all updates (e.g. 6.1) for MODIS.

LEO versus GCOS (for AOD)



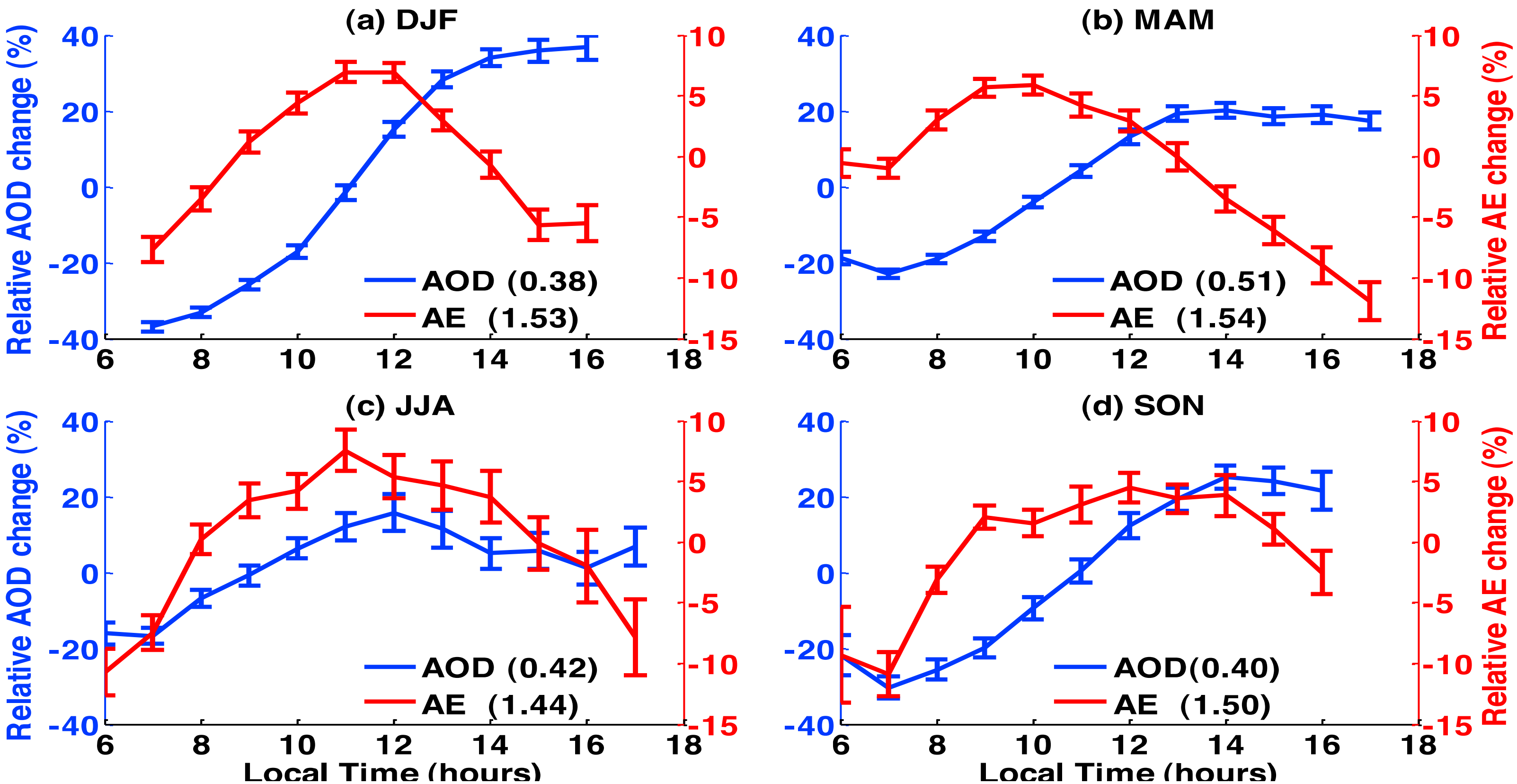
Target metric	Target	Current with MODIS
Horizontal Resolution	5-10 km, globally	≤10 km over ice-free and cloud-free scenes
Accuracy	MAX(0.03 or 10%)	±(0.04+10%): Ocean ±(0.05+15%): Land
Stability / bias	<0.01 / decade	Nearly stable trends, but offsets still
Time Length	30+ years	Can do with MODIS + VIIRS
Temporal Resolution	4 h	2+ / day (Terra + Aqua/VIIRS)

What's still missing?

Temporal variability!

Break the Temporal Barrier!

% deviation in hourly AOD and AE relative to the daily means in Mexico City.

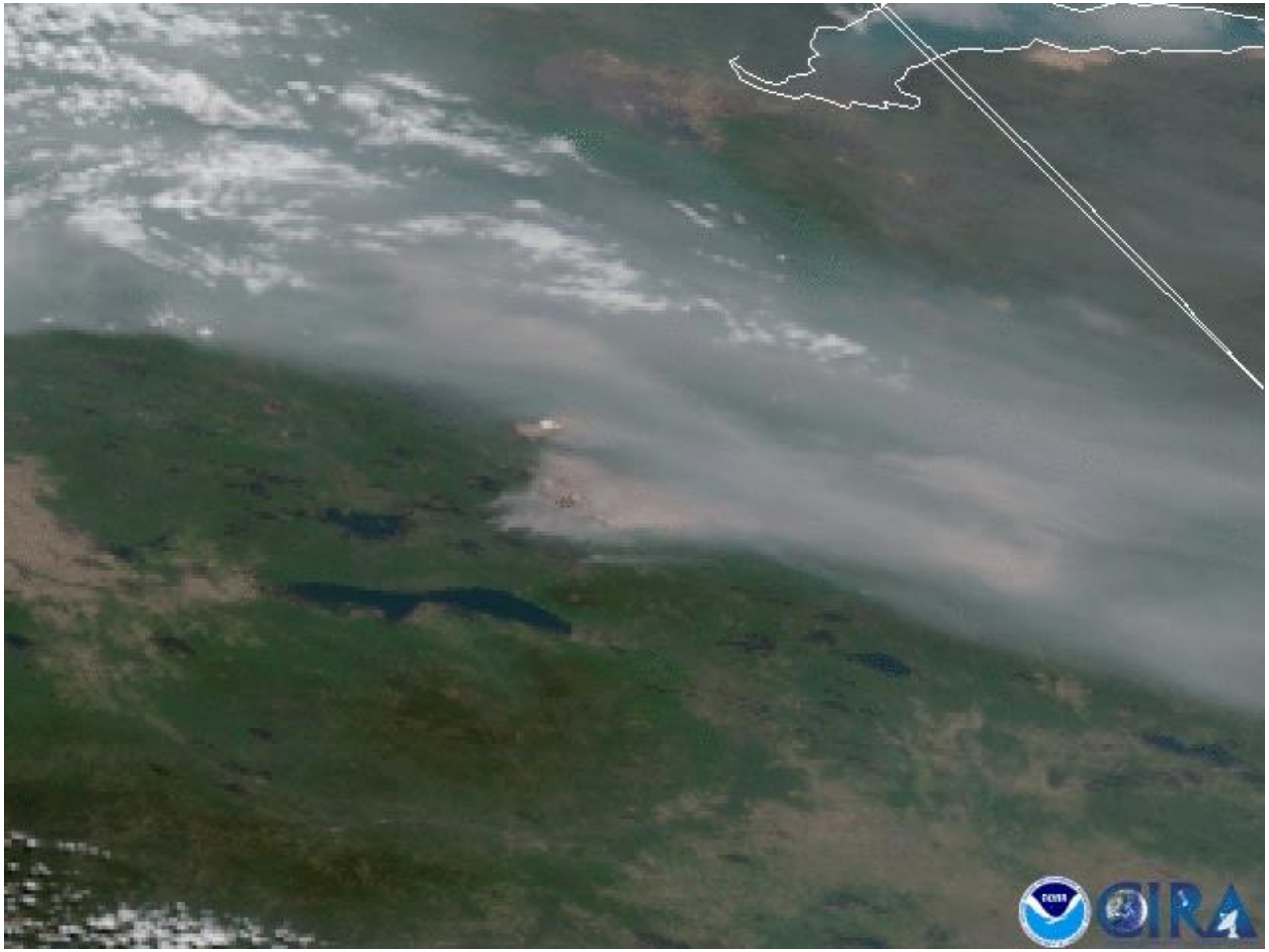


From: Zhang, Y., Yu, H., Eck, T. F., et al, (2012). Aerosol daytime variations over North and South America derived from multiyear AERONET measurements, *J. Geophysical Research*.

ABI = Advanced Baseline Imager on GOES-16 (East) and GOES-17 (West)

Also, AHI = Advanced Himawari Imager on Himawari-8 (Japan), and
AMI = Advanced Meteorological Imager on KOMPSAT-2A (Korea)

Alberta Fires from GOES – 29 May 2019



Port DT algorithm to GEO!

Spectral/Spatial: AHI / ABI ≈ MODIS / VIIRS

	MODIS	VIIRS	AHI	ABI
Blue	0.47/0.5	0.49/0.75	0.47/1.0	0.47/1.0
Green	0.55/0.5	0.55/0.75	0.51/1.0	
Red	0.66/0.25	0.67/0.75	0.64/0.5	0.64/0.5
NIR	0.86/0.25	0.86/0.75	0.86/1.0	0.86/1.0
NIR	1.24/0.5	1.24/0.75		
Cirrus	1.38/0.5	1.38/0.75		1.38/2.0
SWIR	1.61/0.5	1.61/0.75	1.61/2.0	1.61/1.0
SWIR	2.11/0.5	2.25/0.75	2.25/2.0	2.25/2.0

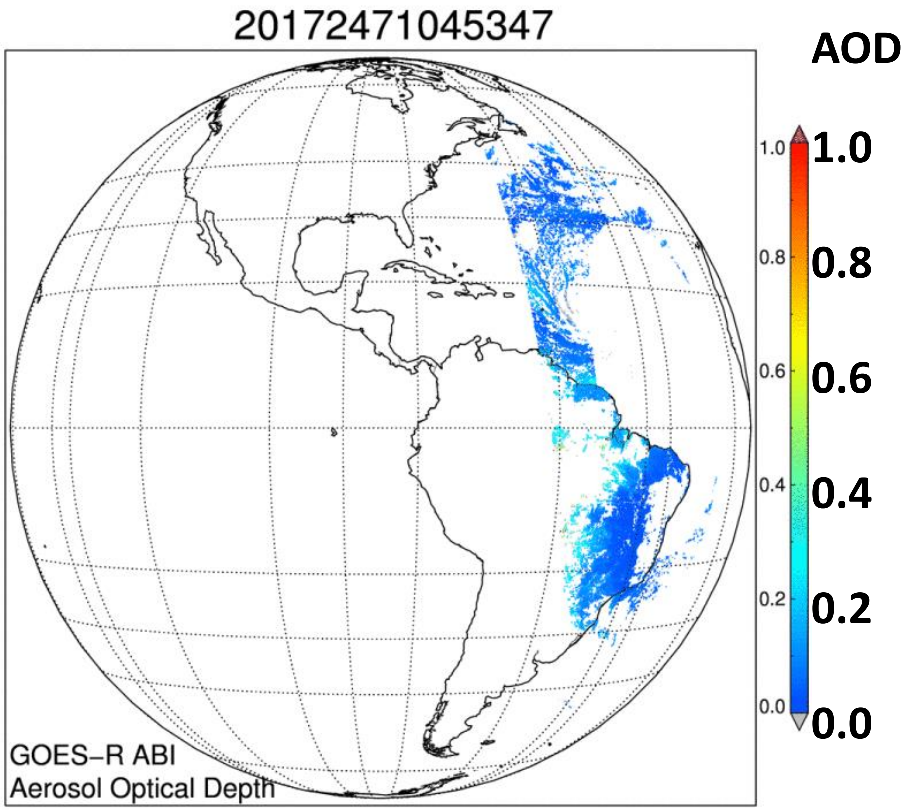
Some details need to be worked out (e.g. lack of "cirrus" band on AHI);

Green band: MODIS/VIIRS @ 0.55 μm, AHI @ 0.51 μm, ABI @ none

In the end, we will report AOD at 0.55 μm for everyone!

Same products as MODIS, including spectral AOD, cloud-cleared reflectance, etc

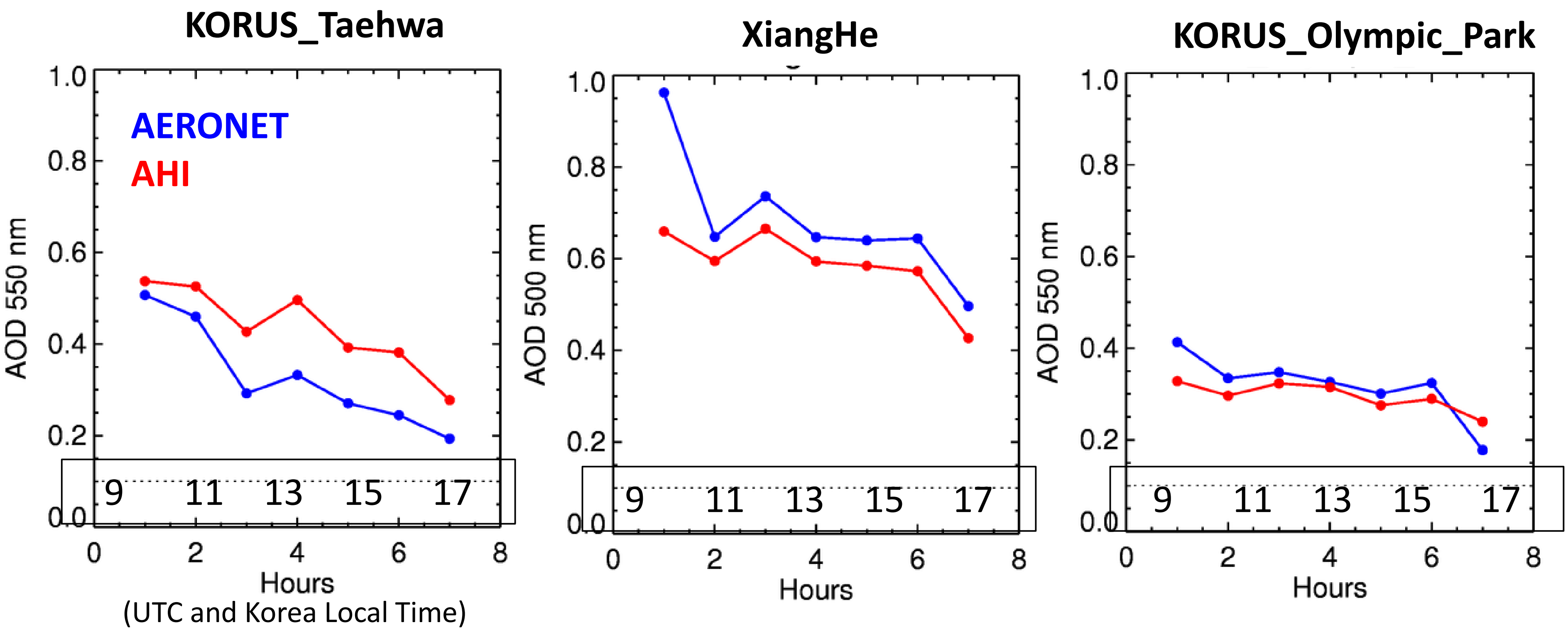
RGB and AOD from ABI for Sep 4, 2017
Canada/Washington fires and smoke mega-event



ABI = Advanced Baseline Imager

Diurnal Cycle of AODs from AHI (from KORUS-AQ, 2016)

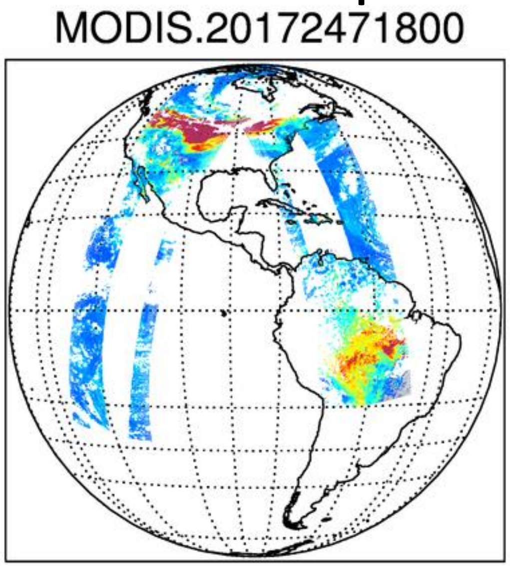
-→ GEO does have sensitivity to Diurnal Cycle!!



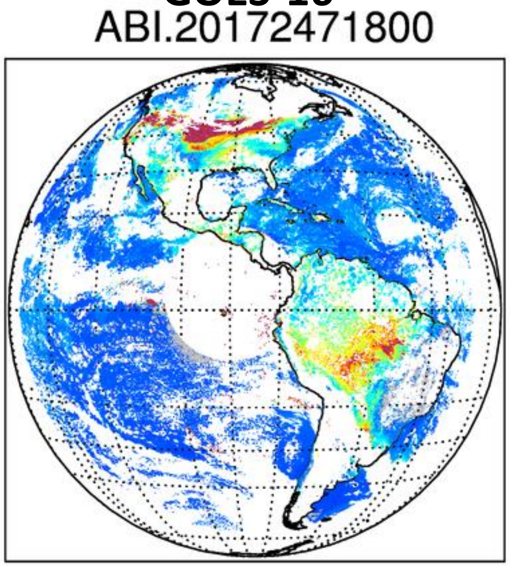
Pawan Gupta

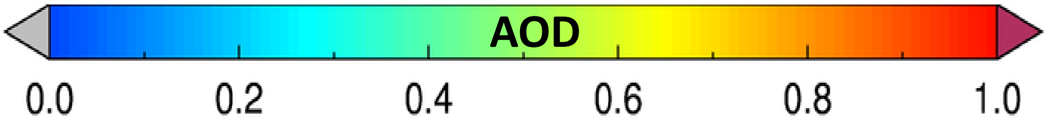
GEO vs LEO : Sep 7, 2017 (±30 minutes of MODIS orbits)

Terra and Aqua

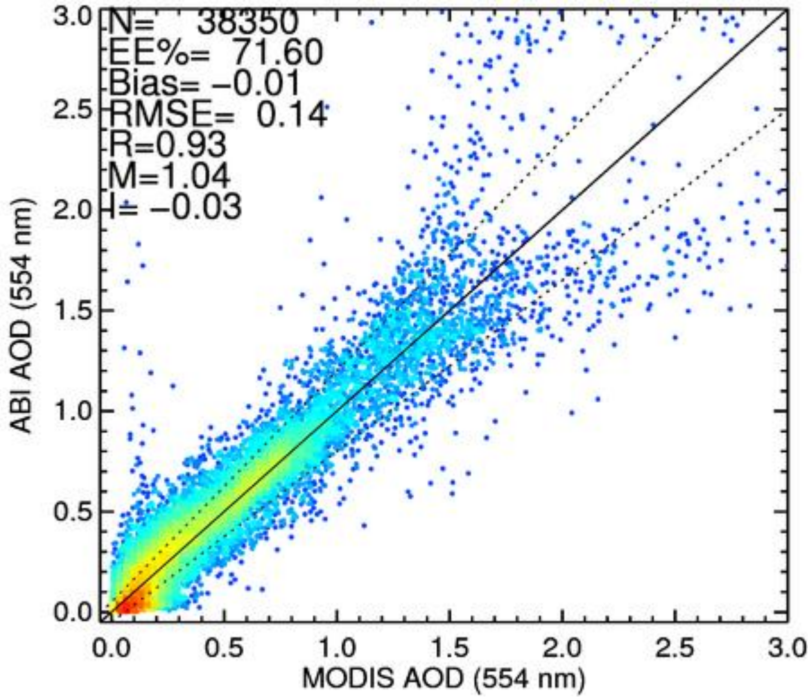


GOES-16



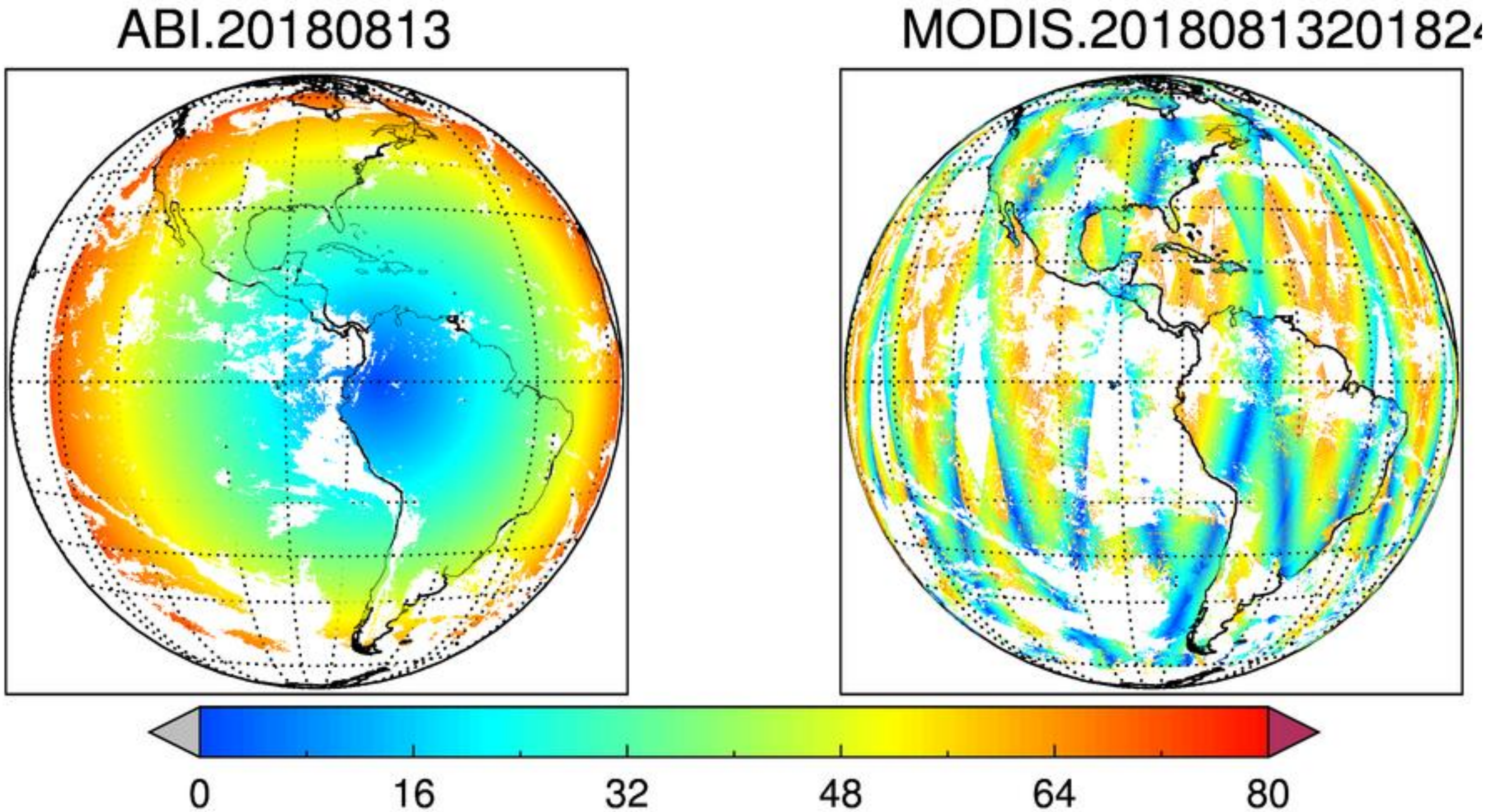


ABI versus MODIS



Overall, not too bad
But are there systematic biases?

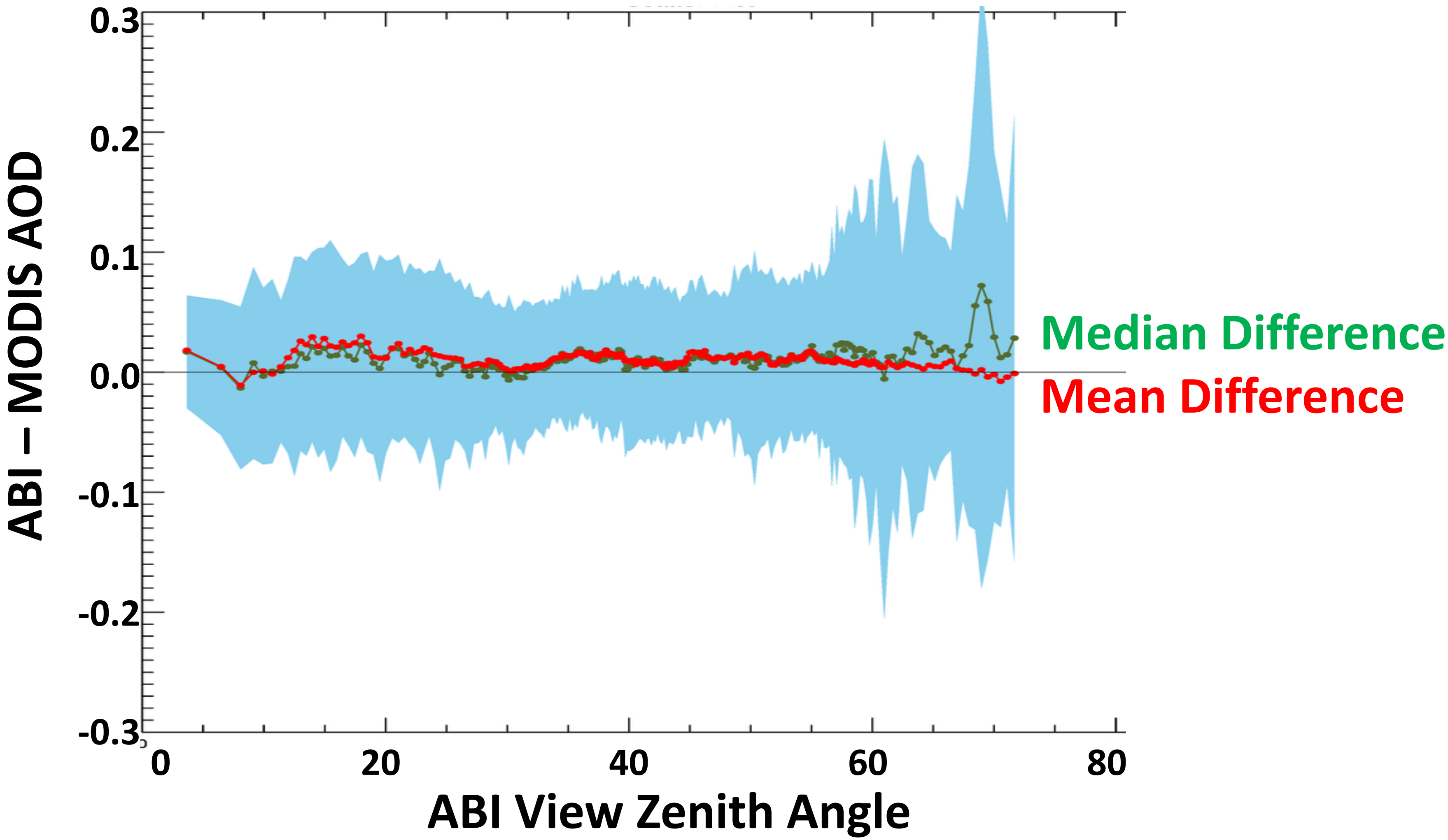
GEO vs LEO: Aug 13, 2018
Sensor View Zenith angle



- GEO Sensor view distribution for all disk images
- LEO sensor view distribution varies along orbit

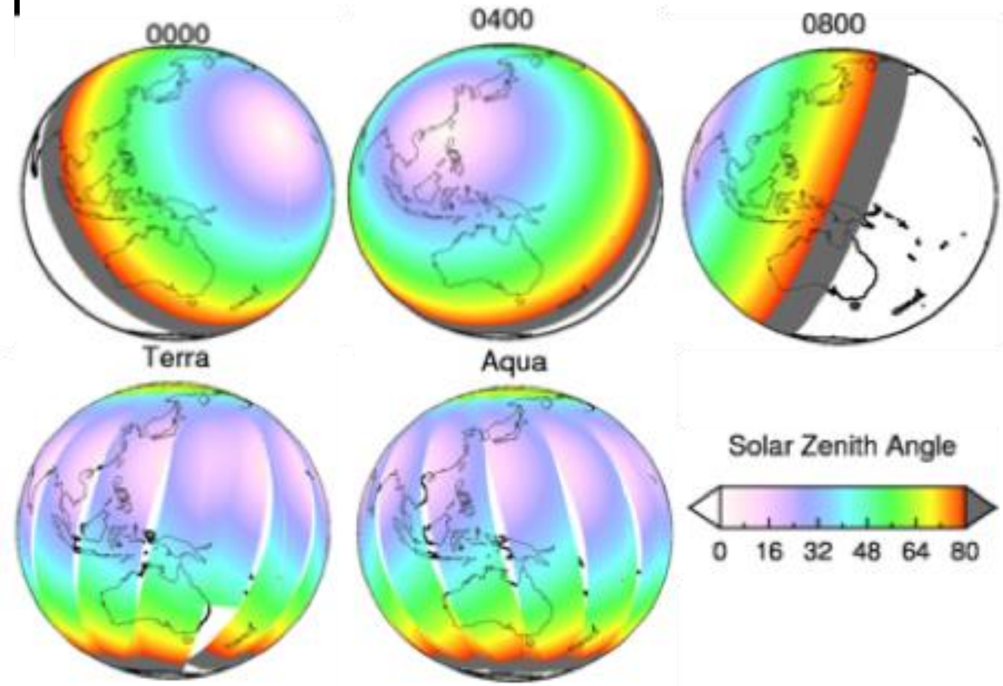
- **We hope to not see consistent biases.**

GEO vs LEO: Aug 13, 2018   Sensor View Angle

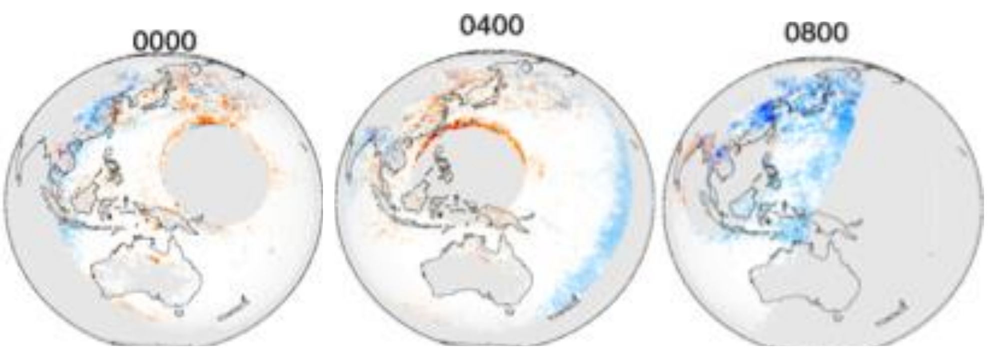


- Overall, not too bad, except for when ABI view angle > 65°
- We will have to work on this.

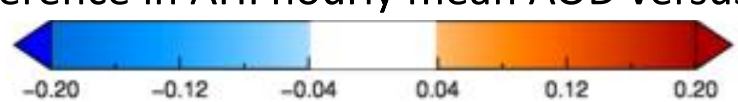
Also some solar angle issues



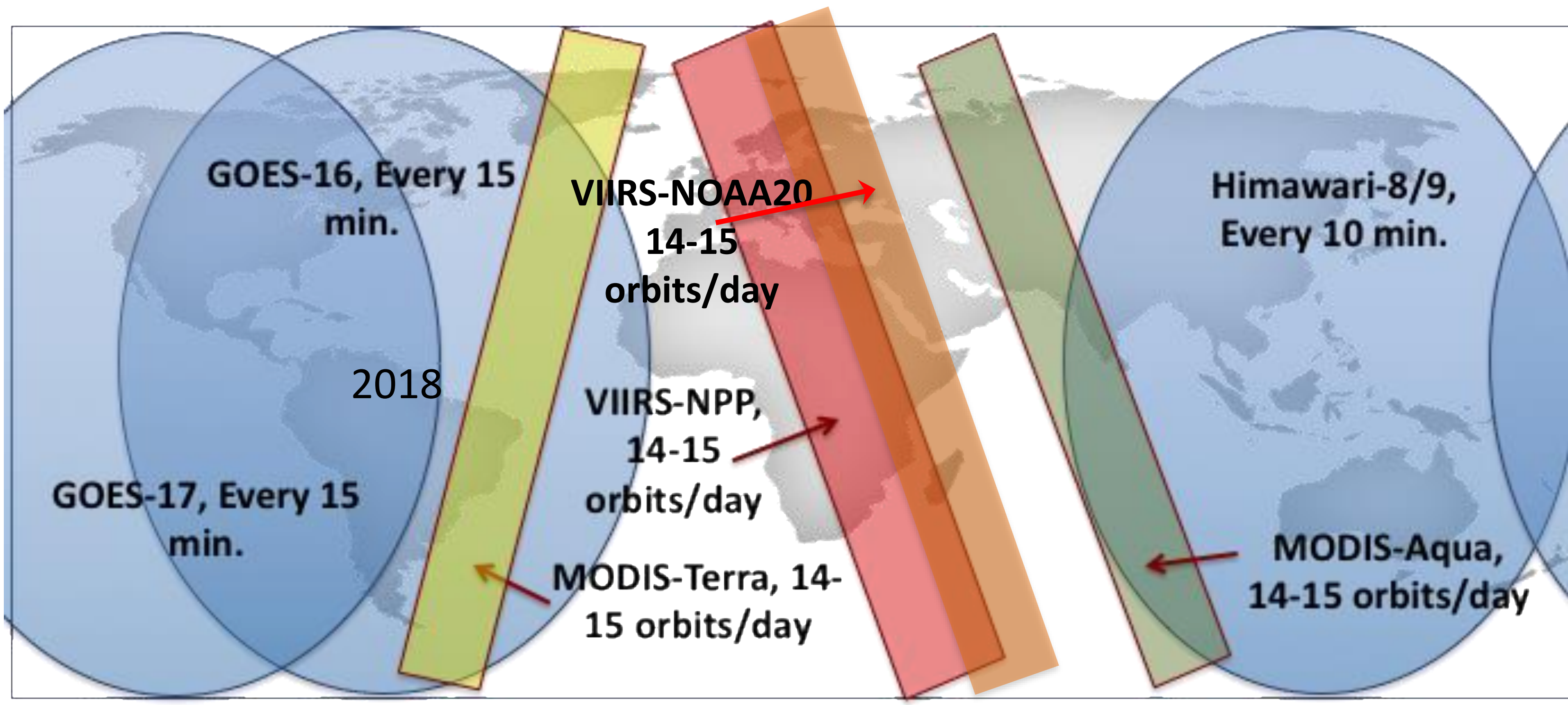
- Solar/Viewing (Zenith & Azimuth Angles) geometry is new to us.
- Constant VZA at fixed grids
- High SZA near sunrise/sunset never observed by MODIS/VIIRS
- Distribution of glint/scattering angle patterns / phase function?
- Radiative Transfer challenge for very large angles?
- “Spherical” earth has a big impact?
- How to correct for gas absorption approaching “limb”?
- Calibration?



Difference in AHI hourly mean AOD versus daily mean

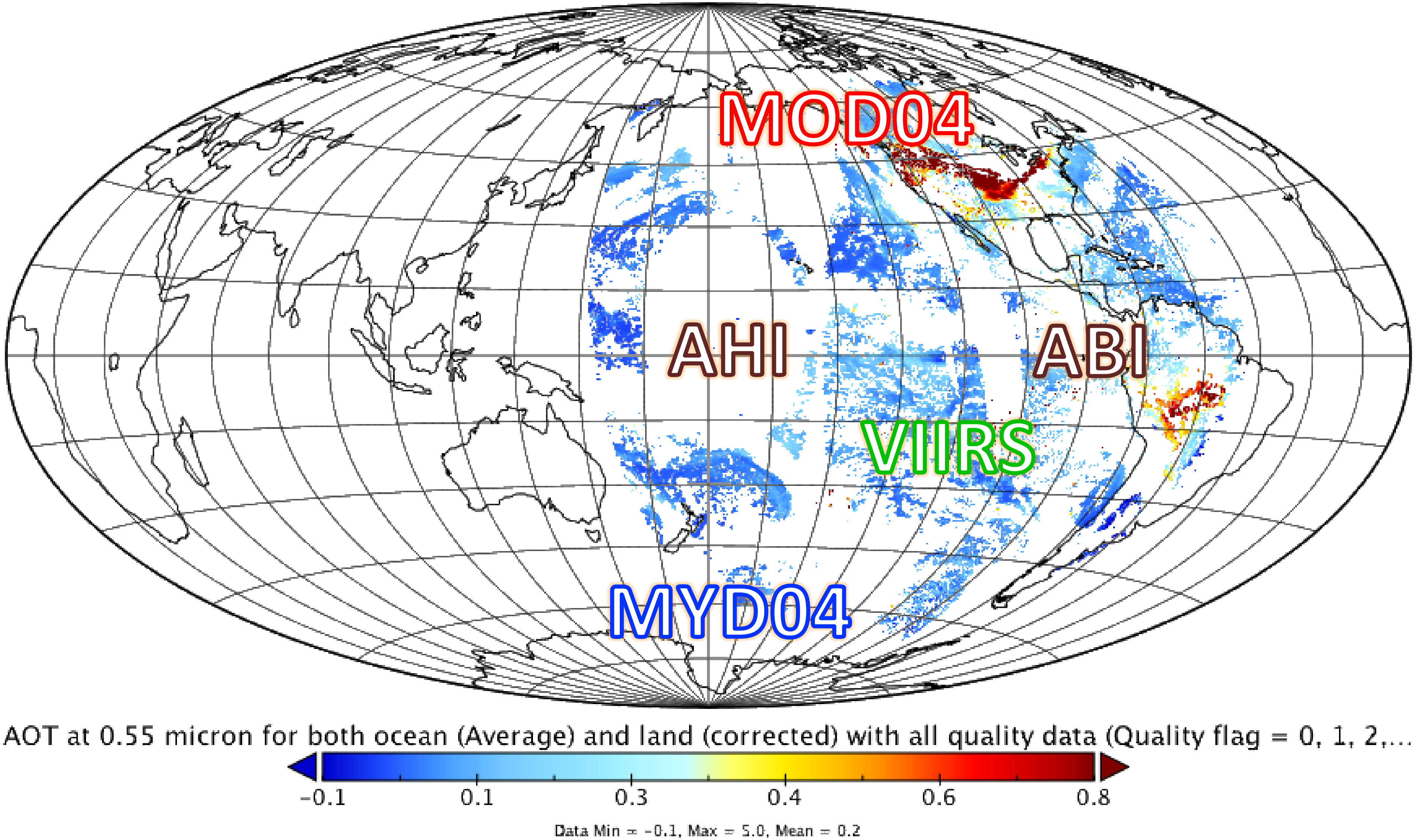


But once we fix:
Statistics of UTC (compare with model)
Statistics of LST (understand local diurnal cycle)



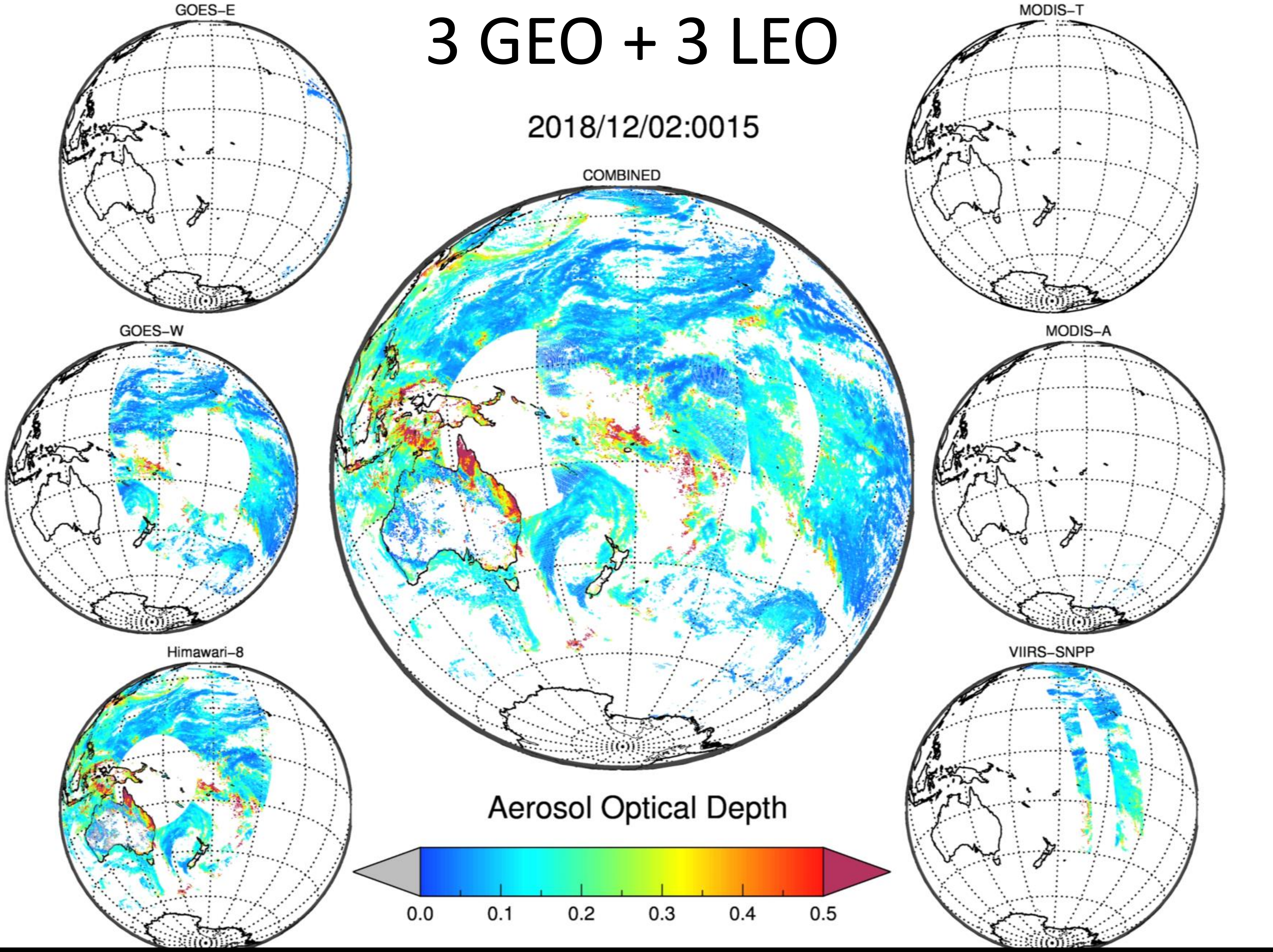
- How many additional sensors do we need to observe climatology (and diurnal cycle and transport) of global aerosol?

AOD from LEO + GEO within ±30 mins
Sept 7, 2017 @ 2030 UTC

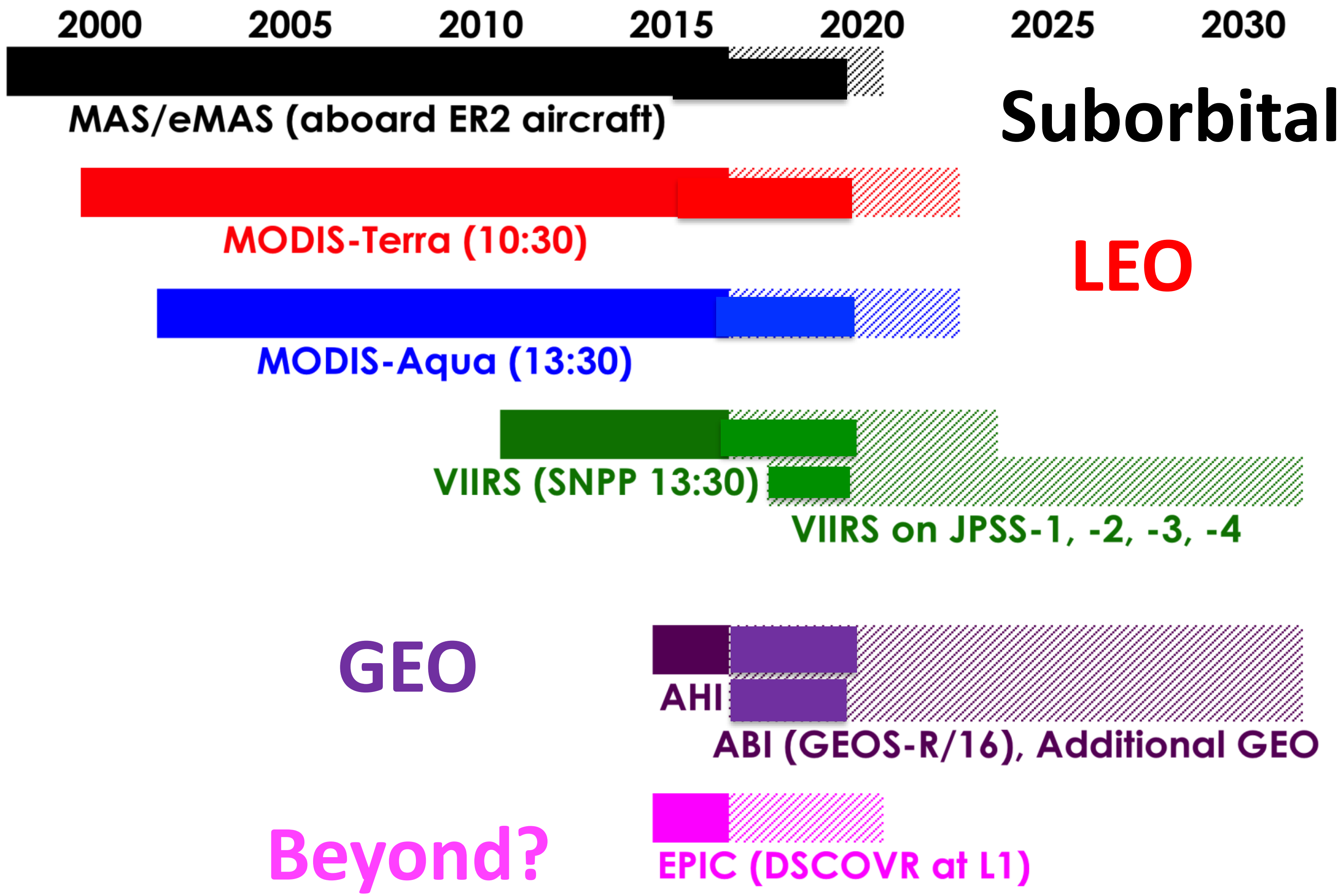


And now for a movie…

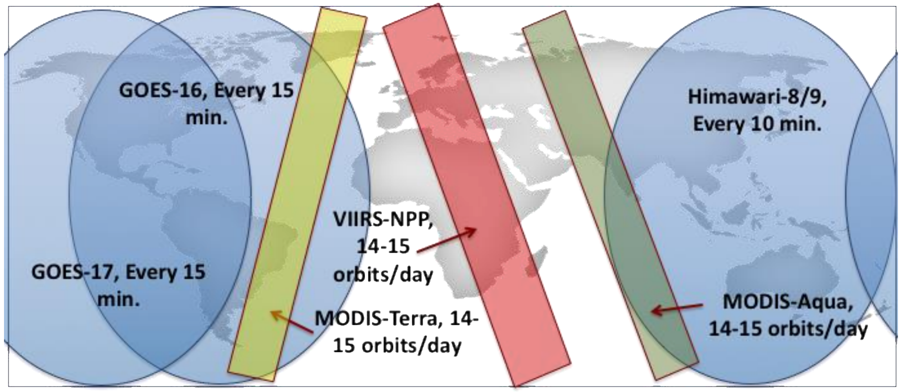
3 GEO + 3 LEO


2018/12/02:0015
GOES–E
GOES–W
Himawari–8
COMBINED
MODIS–T
MODIS–A
VIIRS–SNPP
Aerosol Optical Depth
0.0
0.1
0.2
0.3
0.4
0.5

Towards synergy of aerosol observations



LEO+GEO versus GCOS (for AOD)



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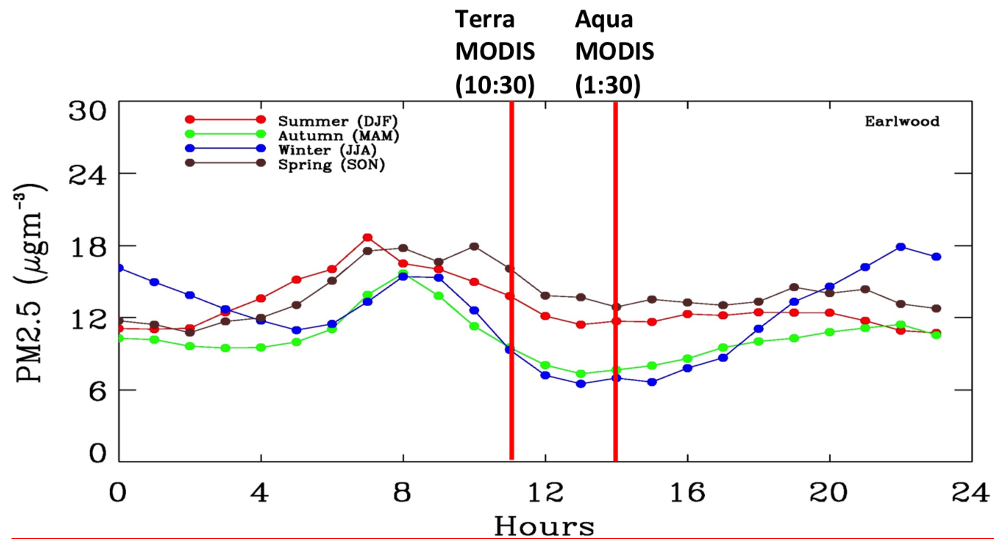
Accuracy	MAX(0.03 or 10%)	±(0.04+10%): Ocean ±(0.05+15%): Land
Stability / bias	<0.01 / decade	Nearly stable trends, but offsets still
Time Length	30+ years	Can do with MODIS + VIIRS
Temporal Resolution	4 h	Where GEOs:

What's still missing? GEO 3G over Europe, Africa, Middle-East
Desert retrievals, Ice/Snow retrievals

But we are getting there!

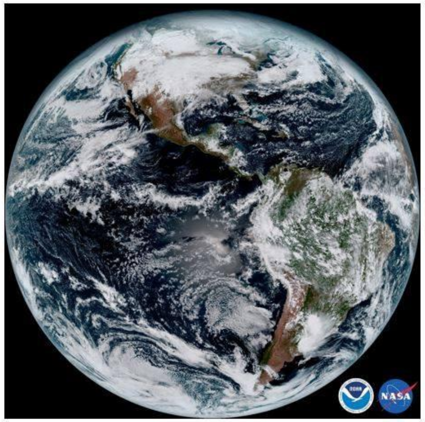
Summary

- ✓ Aerosol measurements for LEO have long history , validation and use for AQ and climate applications.
- ✓ Aerosol measurements from GEO orbit is a step forward in breaking the temporal barrier.
- ✓ GEO constrains multiple LEO sensors, .and LEO constrains multiple GEO. Synergy!
- ✓ For the global climate record, consistent and long-term aerosol retrieval is a key challenge.
- ✓ GEO can tell us about AM versus PM in LEO historical record

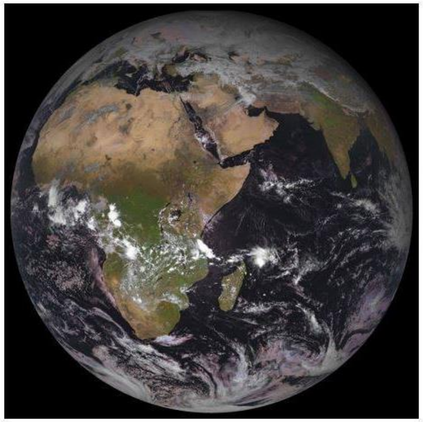


Polar orbiting satellites only provides 1-2 observations per day

GEO: Breaking the Temporal Barrier



GOES-16



METEOSAT-8

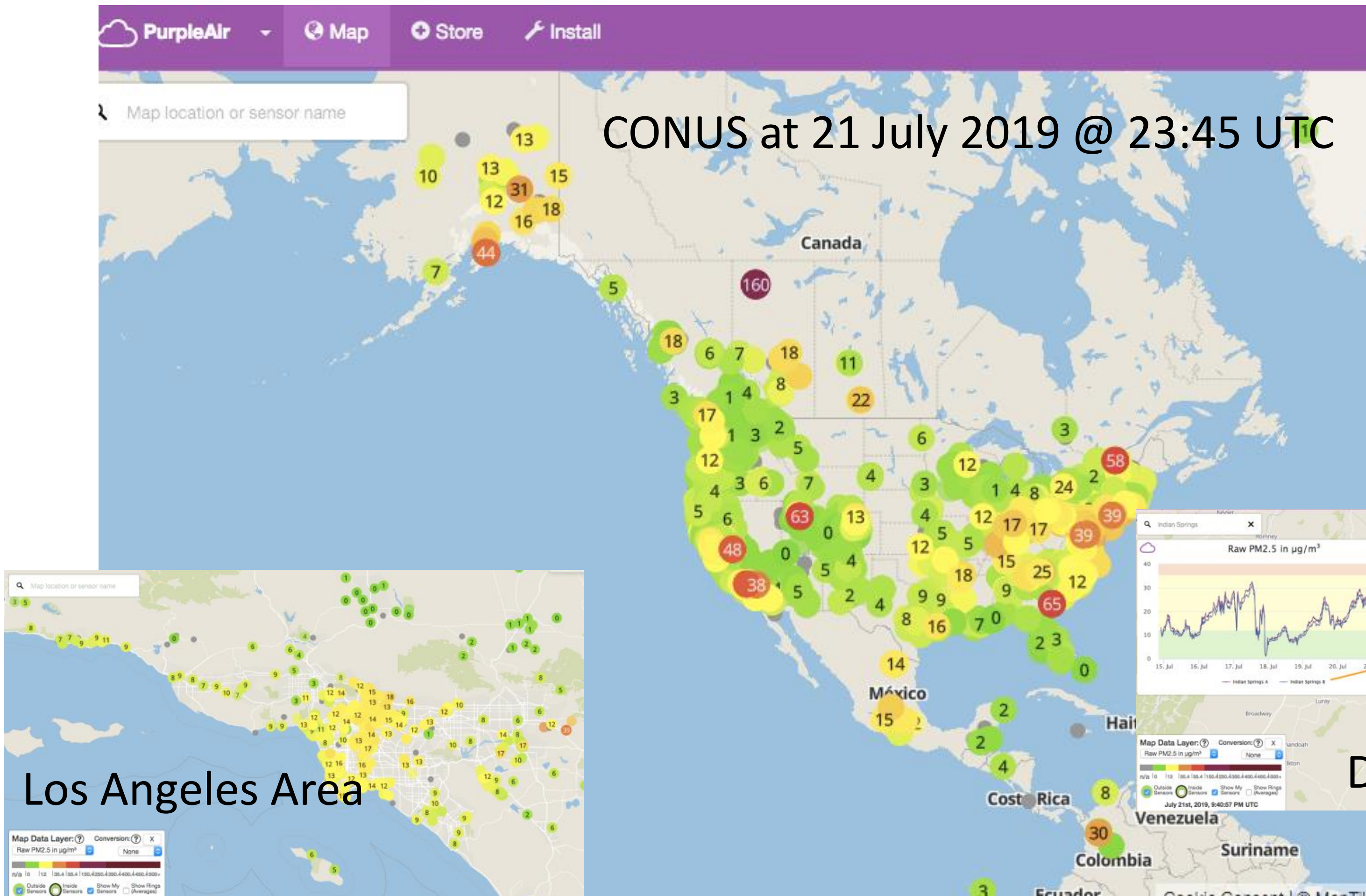
HIMAWARI-9

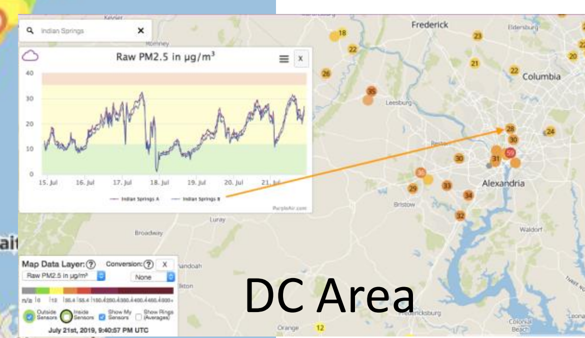
Caveats: But we still got work to do!

- Calibration (e.g. GOES-R red channel changed by 6% in May 2019)
- Funky geometry (GEO different than LEO)
- Canceling biases in LEO may not occur in GEO (scattering phase functions versus observing geometry)
- GEO data are huge! (2.75 GB native disk imagery), so reprocessing with consistent algorithms needs thought, CPUs and storage (thank you Bob Holz at Wisconsin)
- How to make data useful? (archive, searchable, DAAC)
- New algorithms, that make use of time-dependence and multi-observation synergy

And Air Quality

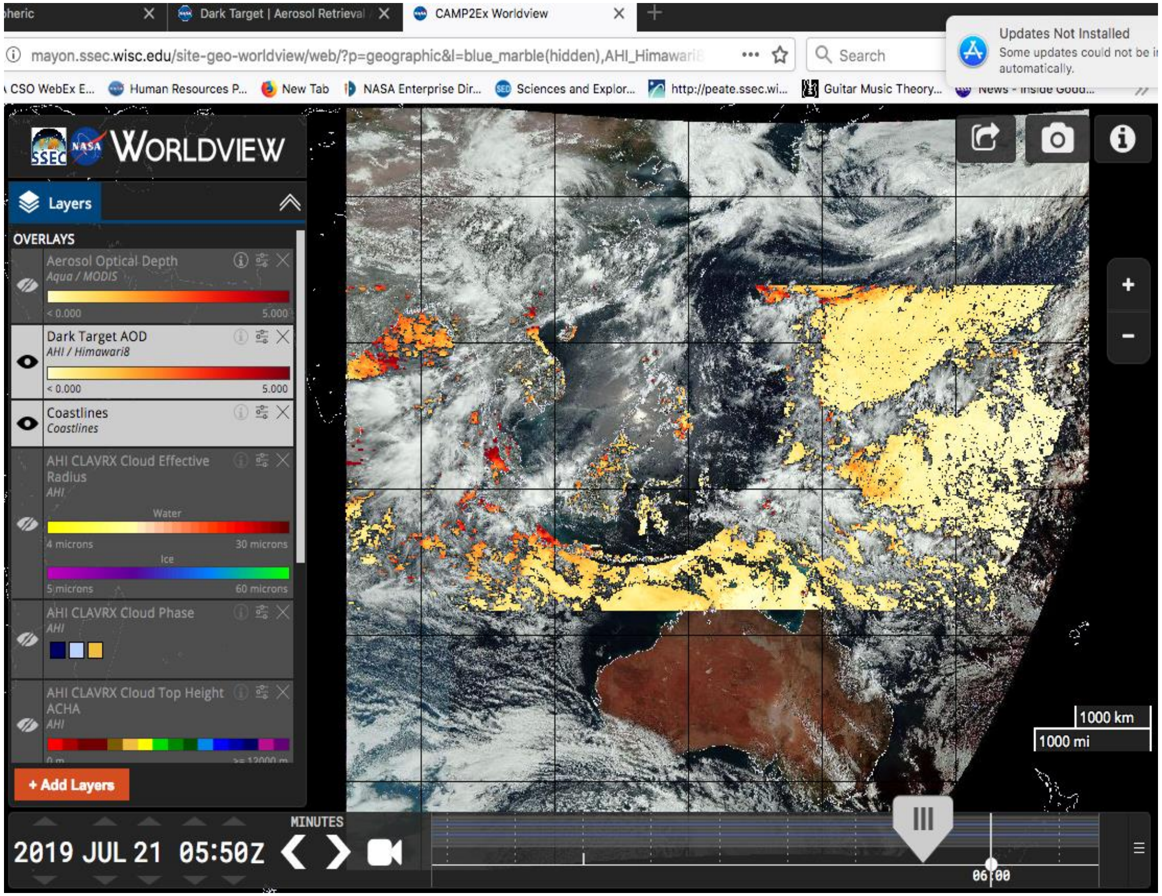
- While not the most accurate, there is a rapidly increasing ground network of PM sensors





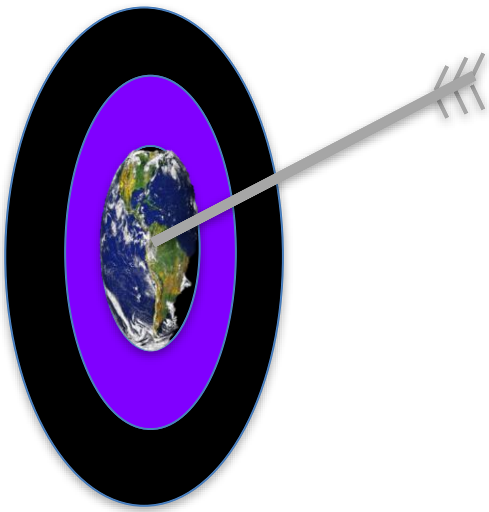
AHI during CAMP2EX

- Wisconsin running Dark Target in NRT for AHI.
- Using GFS “forecast” as ancillary for H_2O, O_3, wind speed.
- Follows NOAA CLAVR-X in production – 2 km resolution pixels (10 km at 137°E).
- Domain centered over Philippines
- imagery within instance of Worldview

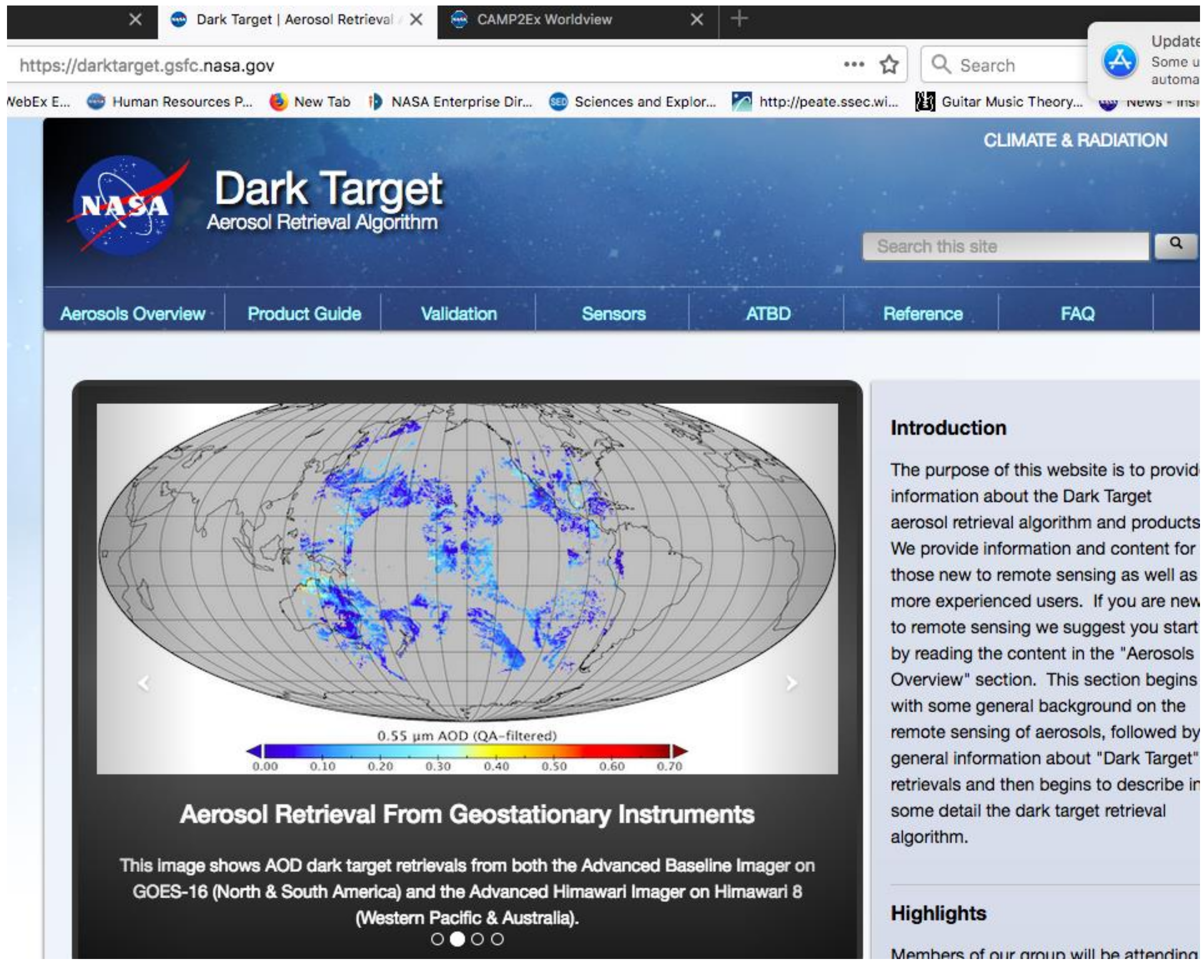


Bob Holz, U Wisconsin

Dark Target website being updated



Thank you!



https://darktarget.gsfc.nasa.gov