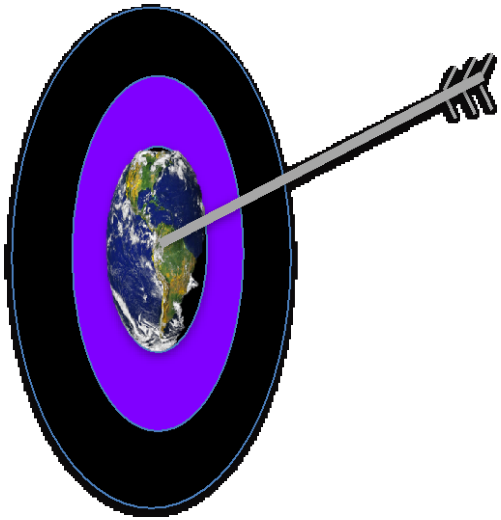
Satellite Continuity and Synergy: From MODIS to VIIRS and from LEO to GEO

Robert C. Levy (NASA-GSFC)



Global Climate Observing System

GCOS Aerosol CDR* Requirements

CDR = Climate Data Record

For Aerosol Optical Depth (AOD):

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

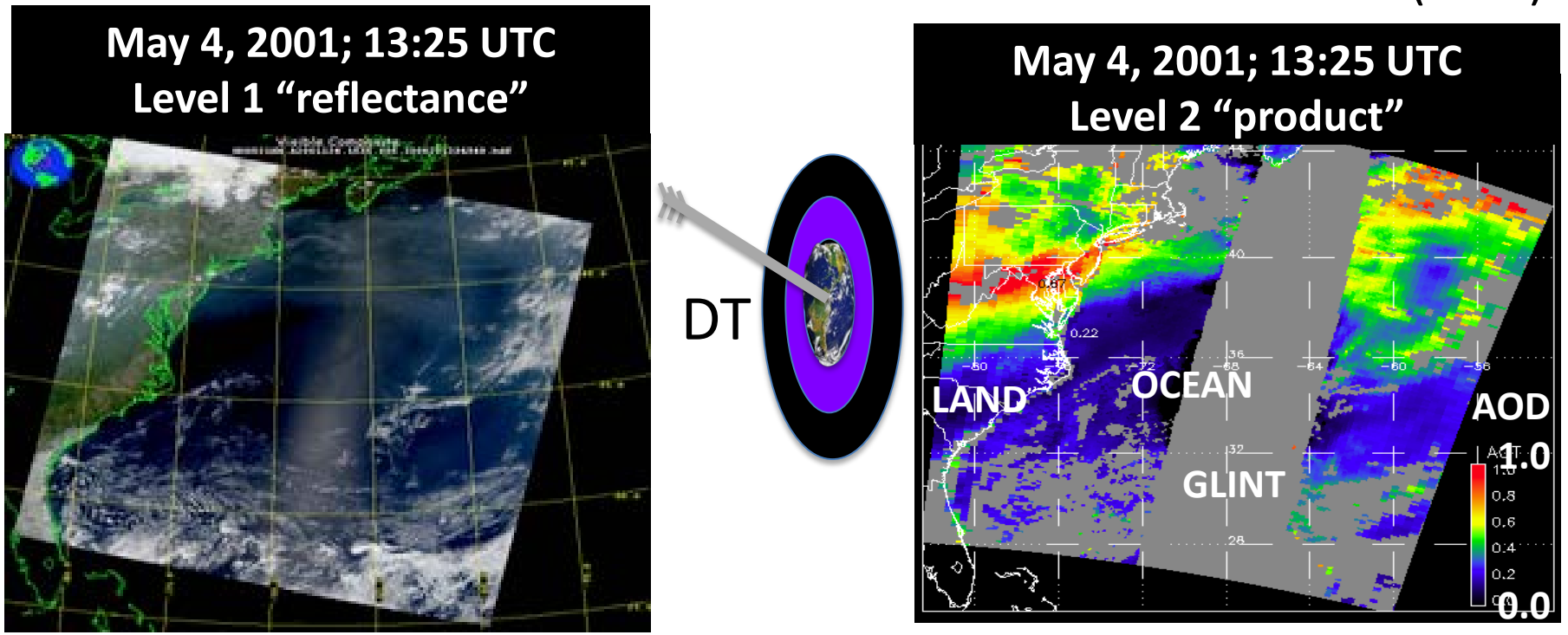
What is our status on meeting these requirements?

Note, all slides are related to “Dark-Target” algorithm

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

What a sensor observes

Attributed to aerosol (AOD)



"Established 1997" by Kaufman, Tanré, Remer, etc)

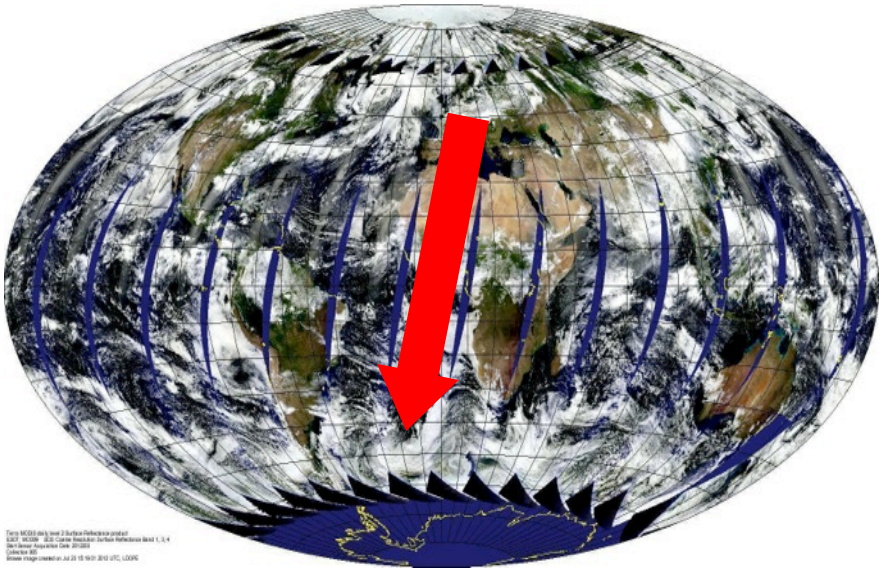
"Modified 2005, 2010, 2013, 2015" by Remer, Levy, Gupta, etc

Separate logic over land and ocean

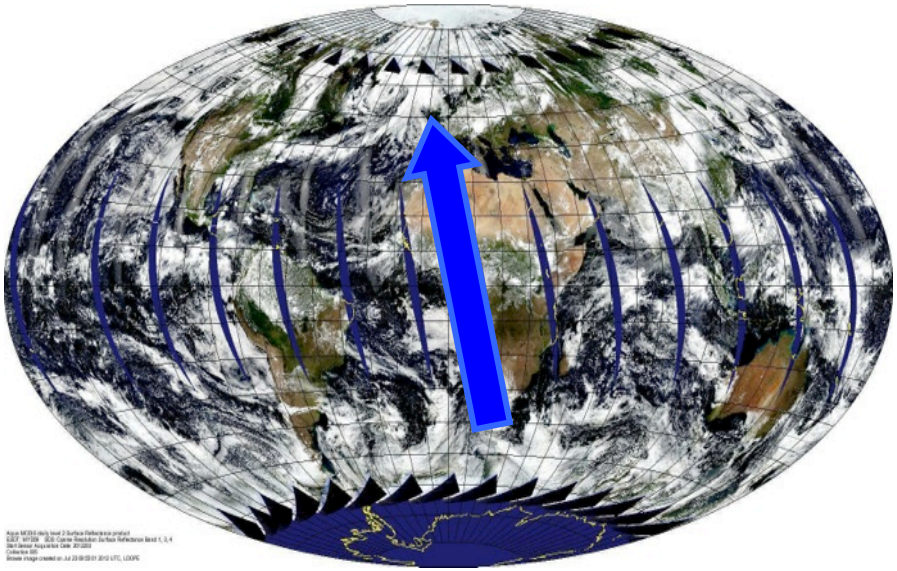
Retrieve: AOD at 0.55 μm, spectral AOD (AE), Cloud-cleared reflectances, diagnostics, quality assurance

MODIS-Terra vs MODIS-Aqua

Terra (10:30, Descending)



Aqua (13:30, Ascending)



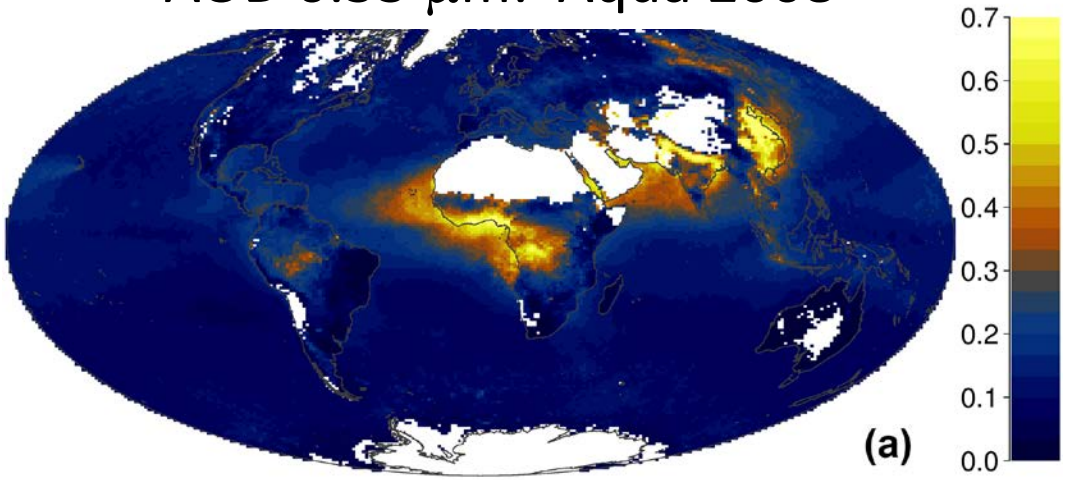
The two MODIS instruments are **TWINS!**

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

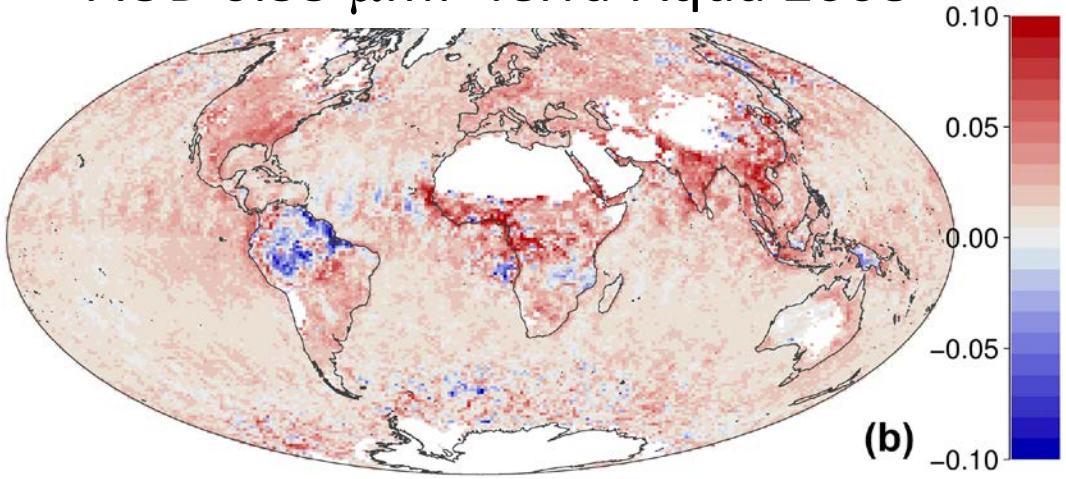
AOD 0.55 μm: Aqua 2008



Higher AODs; Dust, pollution

Lower AODs; open ocean, remote land

AOD 0.55 μm: Terra-Aqua 2008



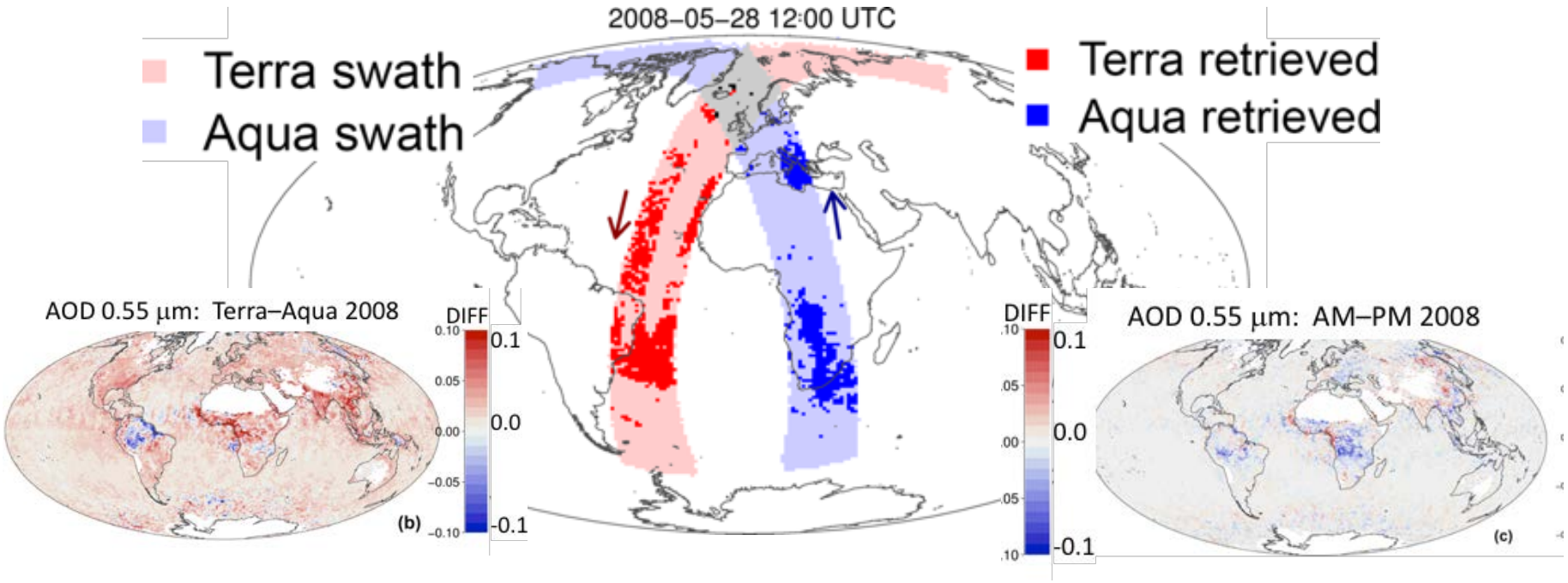
Positive offset nearly everywhere!

Terra also larger offset compared to AERONET

Angstrom Exponent (AE) also shows offsets

Using “model” to explore difference in AOD?

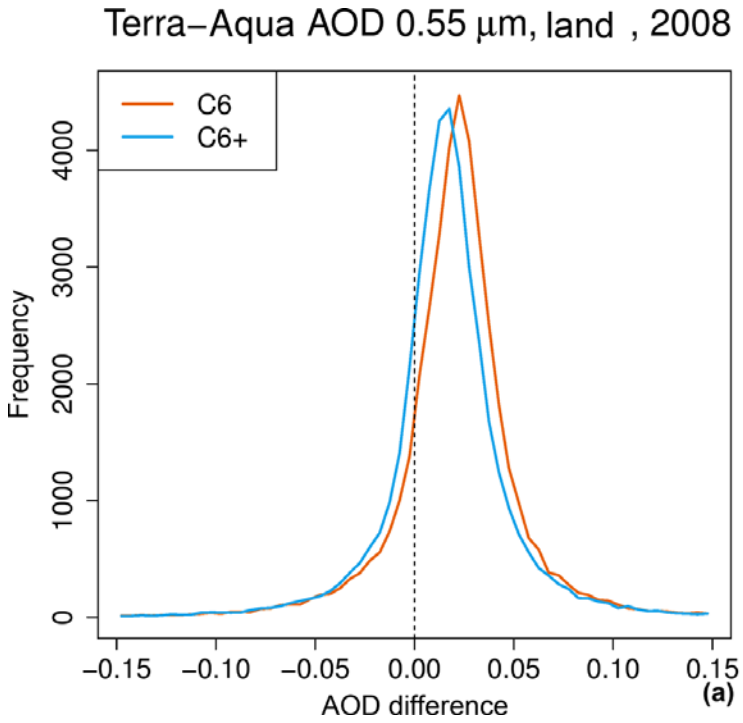
MERRA-2 (replay) sampled at 12:00 UTC on May 25, 2008
Overpasses within ±30 minutes

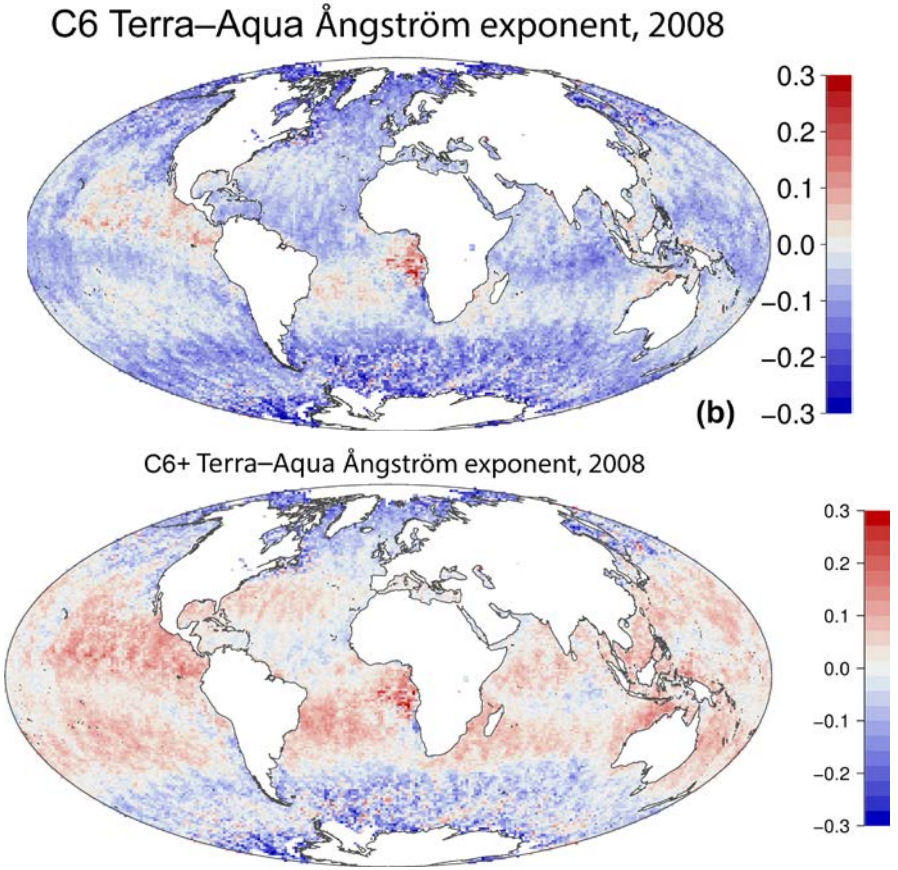


- MERRA-2 “replay” (meteorological assimilation – no Terra/Aqua)
- Sample at time of Terra and Aqua overpass (swath)
- Sample only where DT algorithm provided retrieval (retrieved)
- Aggregate to monthly and global means
- Look at AM–PM differences (Terra–Aqua) for AOD and AE
  → **Some similarity in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

Exploring additional calibration: "C6+"

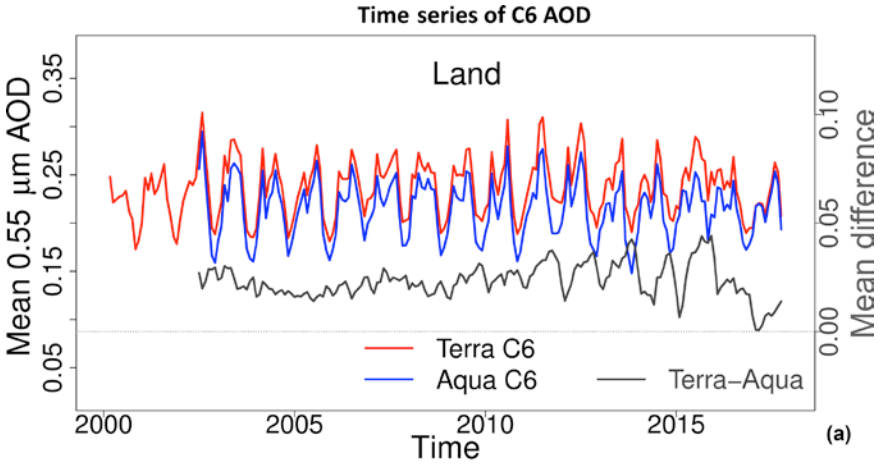
- Over land, AOD offset is reduced (by 0.005)
- Over ocean, negligible change in AOD offset

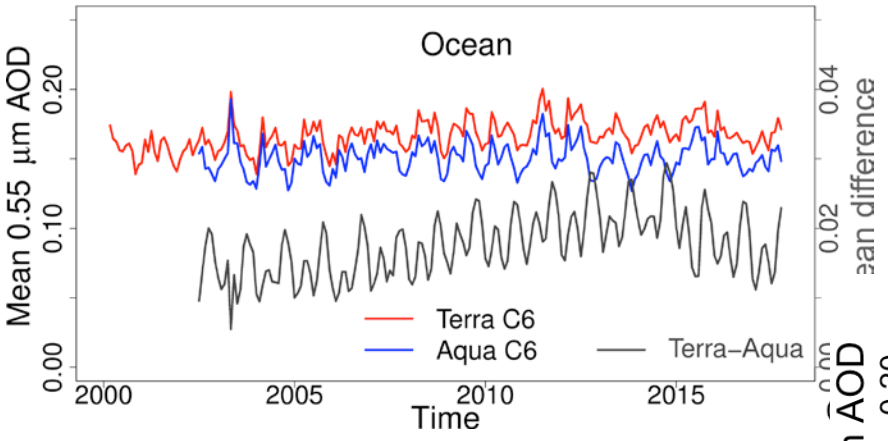




- For AE, C6+ reduces negative offset

Time series of AOD Collection 6/6.1

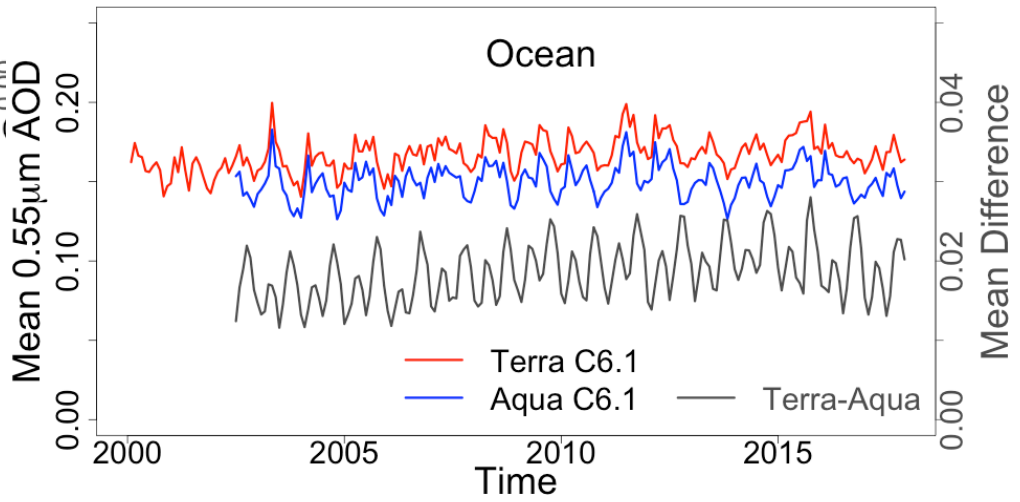




Collection 6 of the aerosol products

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

Collection 6 also shows a bit of trending in the offset



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

Global Climate Observing System

GCOS Aerosol CDR* Requirements

CDR = Climate Data Record

Aerosol Optical Depth (AOD) from MODIS 6.1:

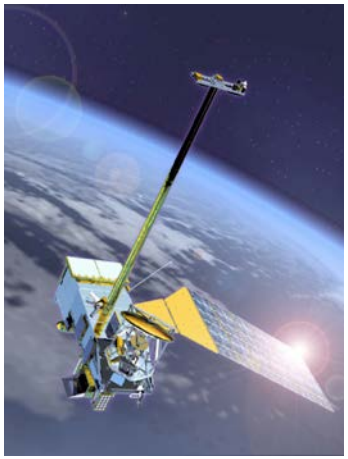
Target metric	Target	Current with MODIS
Horizontal Resolution	5-10 km, globally	10 km over ice-free and cloud-free scenes (No desert for DT)
Temporal Resolution	4 h	2+ / day (Terra + Aqua)
Accuracy	MAX(0.03 or 10%)	±(0.04+10%): Ocean ±(0.05+15%): Land
Time Length	30+ years	20 years and counting
Stability / bias	<0.01 / decade	Nearly stable trends, but offsets still

Key: Black = almost there, Blue = on the way, Red = not close or unknown

How do we get closer?

Beyond **MODIS**

- Terra (18) and Aqua (16) 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”



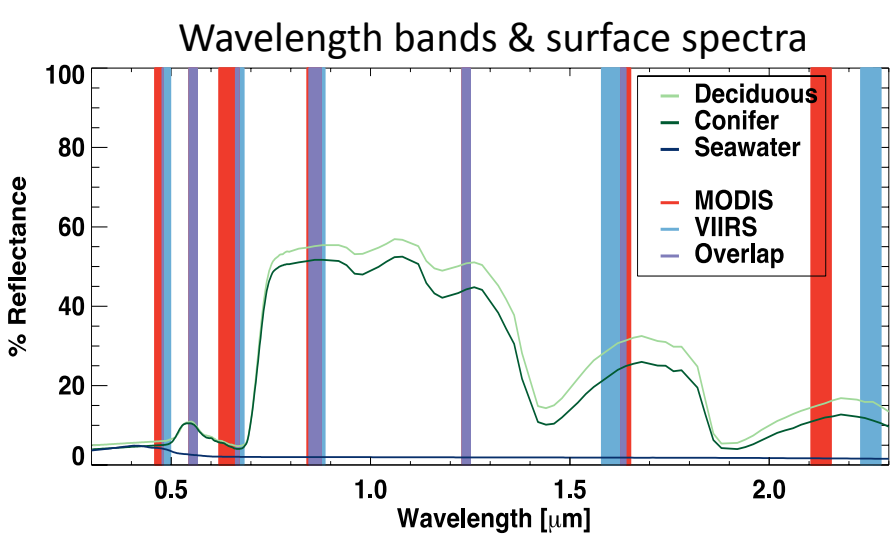
VIIRS!

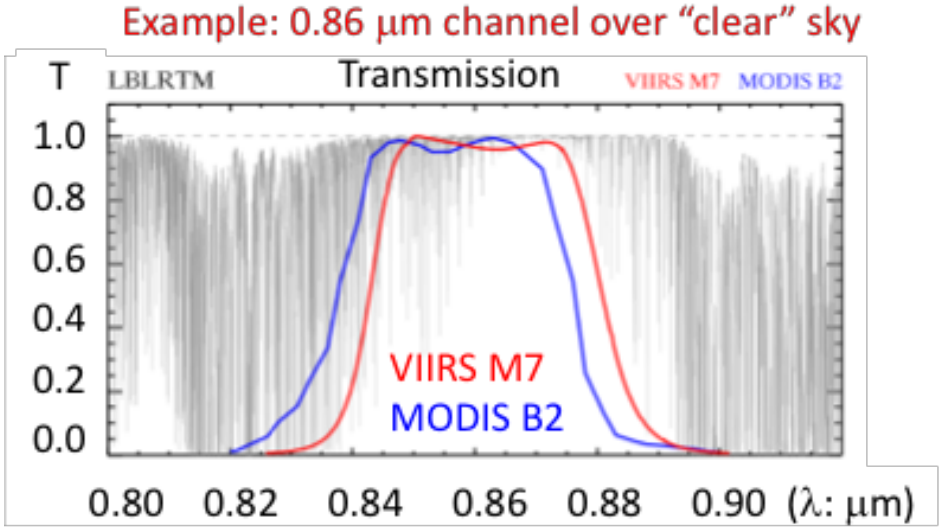
Visible-Infrared Imager Radiometer Suite aboard Suomi-NPP (and future JPSS)

- Both DT and DB algorithms are ported

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

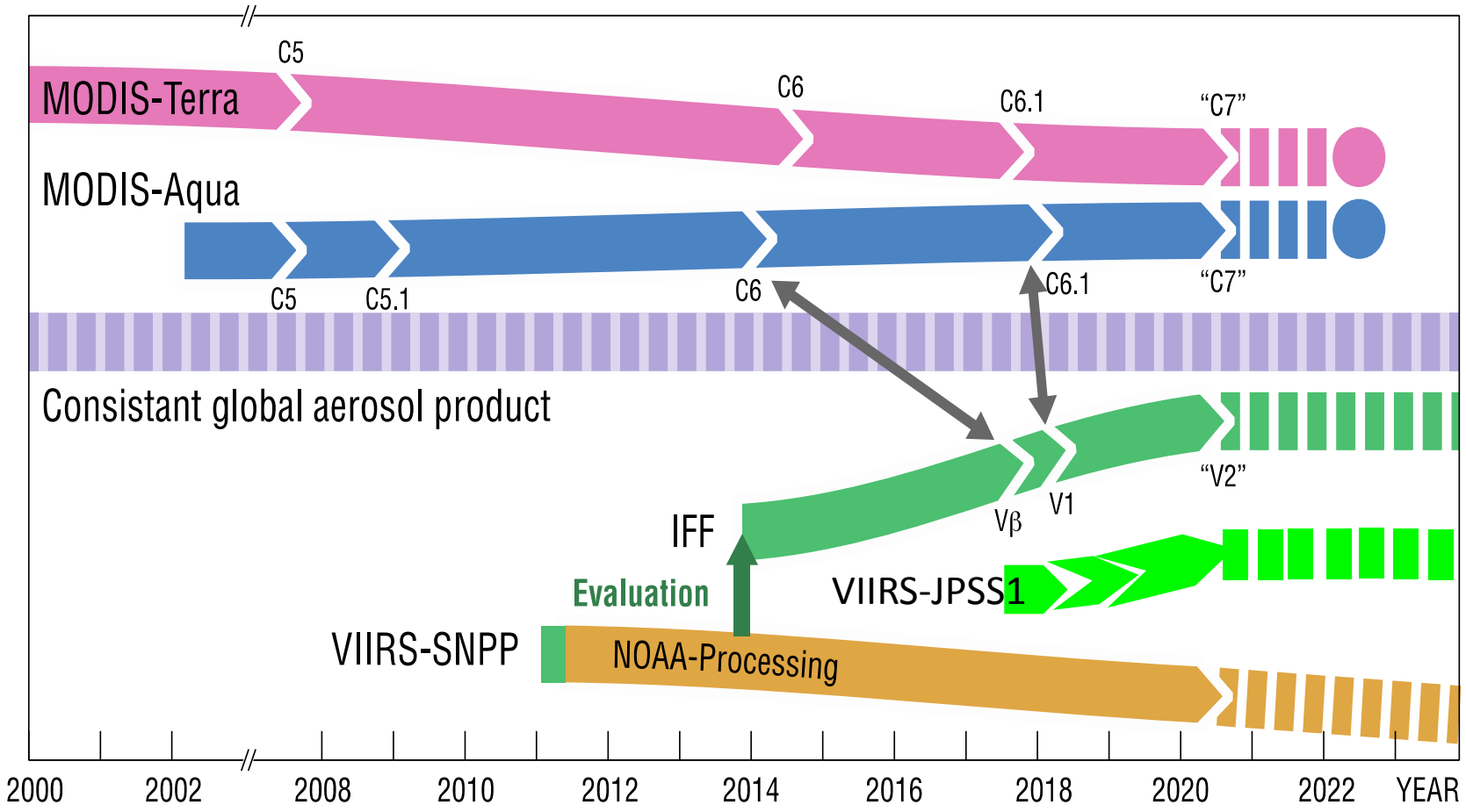
- Deal with differences in wavelengths (gas corrections/Rayleigh, etc)





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

Towards consistent global aerosol on LEO



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

Global Climate Observing System

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For Aerosol Optical Depth (AOD) from LEO

Target metric	Target	Current with MODIS + VIIRS
Horizontal Resolution	5-10 km, globally	10 km MODIS and 6 km VIIRS, over ice-free and cloud-free scenes
Temporal Resolution	4 h	2+ / day (Terra + Aqua/VIIRS)
Accuracy	MAX(0.03 or 10%)	±(0.04+10%): Ocean ±(0.05+15%): Land
Time Length	30+ years	**30+ years (MODIS + VIIRS on JPSSx)**
Stability / bias	<0.01 / decade	Not there yet, but possible?

Key: Black = almost there, Blue = on the way, Red = not close or unknown

JPSS-1 launched (November 2017), and in same orbit as S-NPP, continue with JPSS-X!

Nearly accurate enough, and will have long term, and presumably we can reduce drift.

What's missing?
Breaking 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*.

4 Sept 2017: Alberta/BC, Canada fires observed by ABI (GOES-R before moving to GOES-16/East)

1st loop: RGB
2nd loop: RGB + AOD

But also look at fires in South America!

(NOAA beta products)

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

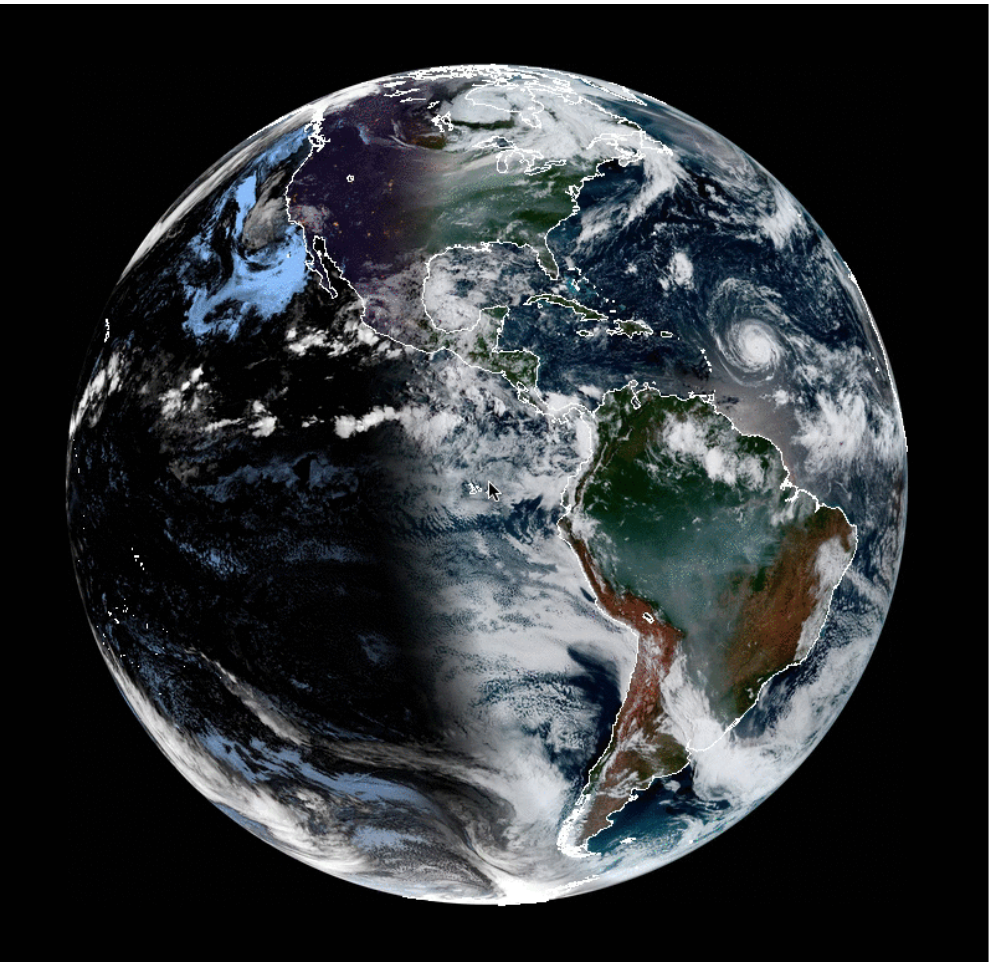
Some details need to be worked out (e.g. lack of "cirrus" band on AHI);

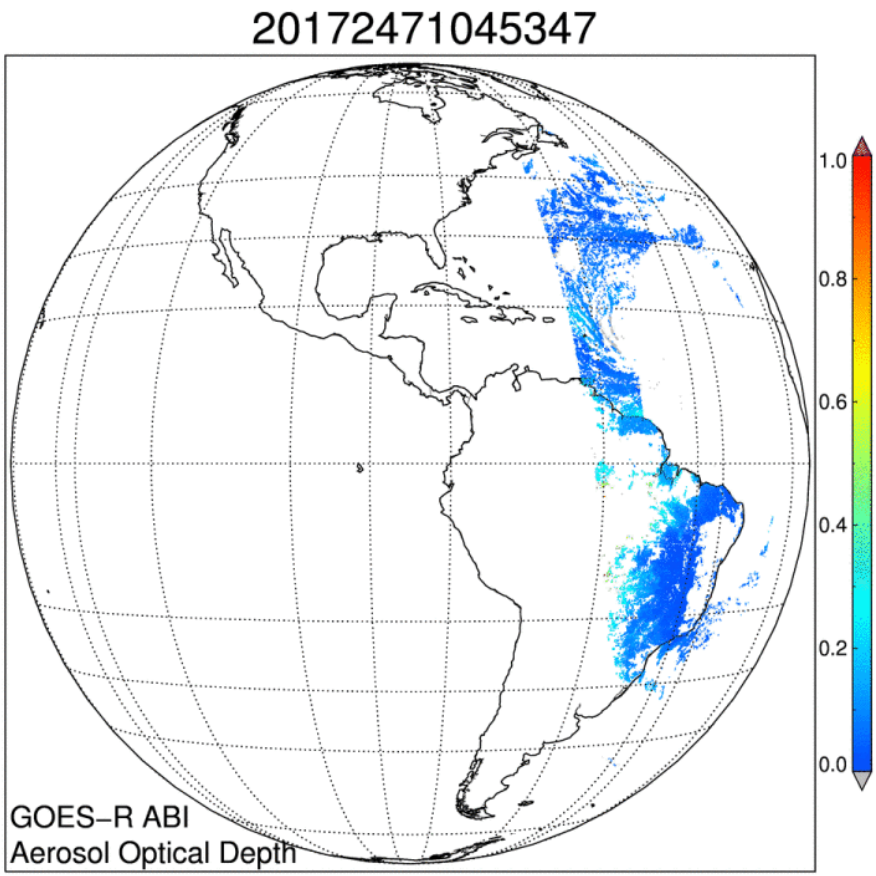
Green band: MODIS/VIIRS @ 0.55 μm, AHI @ 0.51 μm, ABI @ none

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

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

DT: AOD and RGB from ABI for Sep 4, 2017

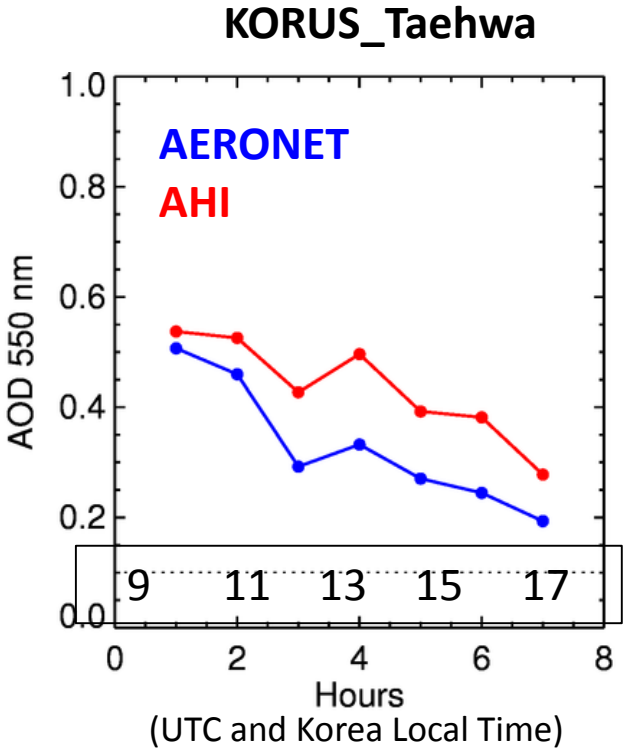


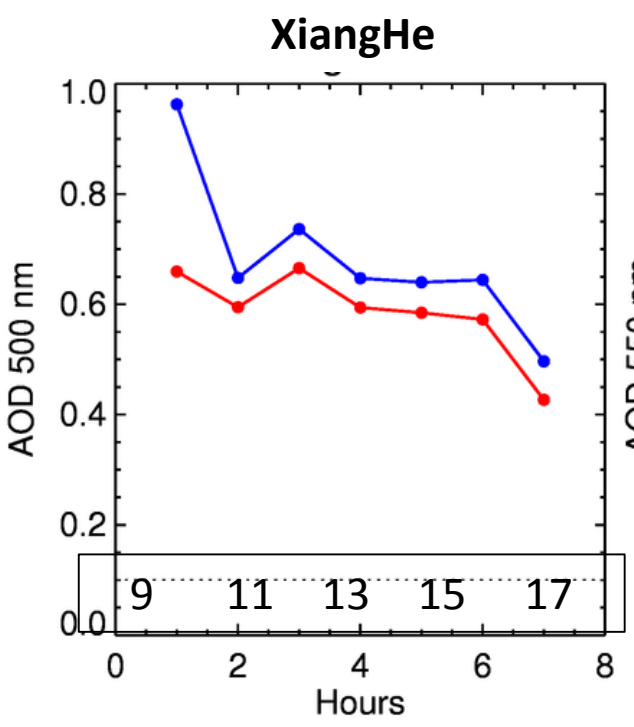


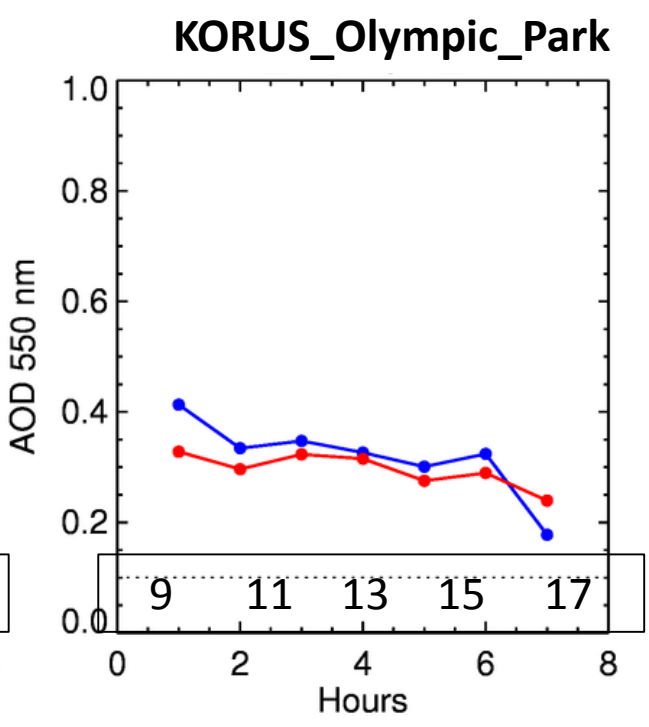
Special thanks to Andy Heidinger (NOAA) for special data processing

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

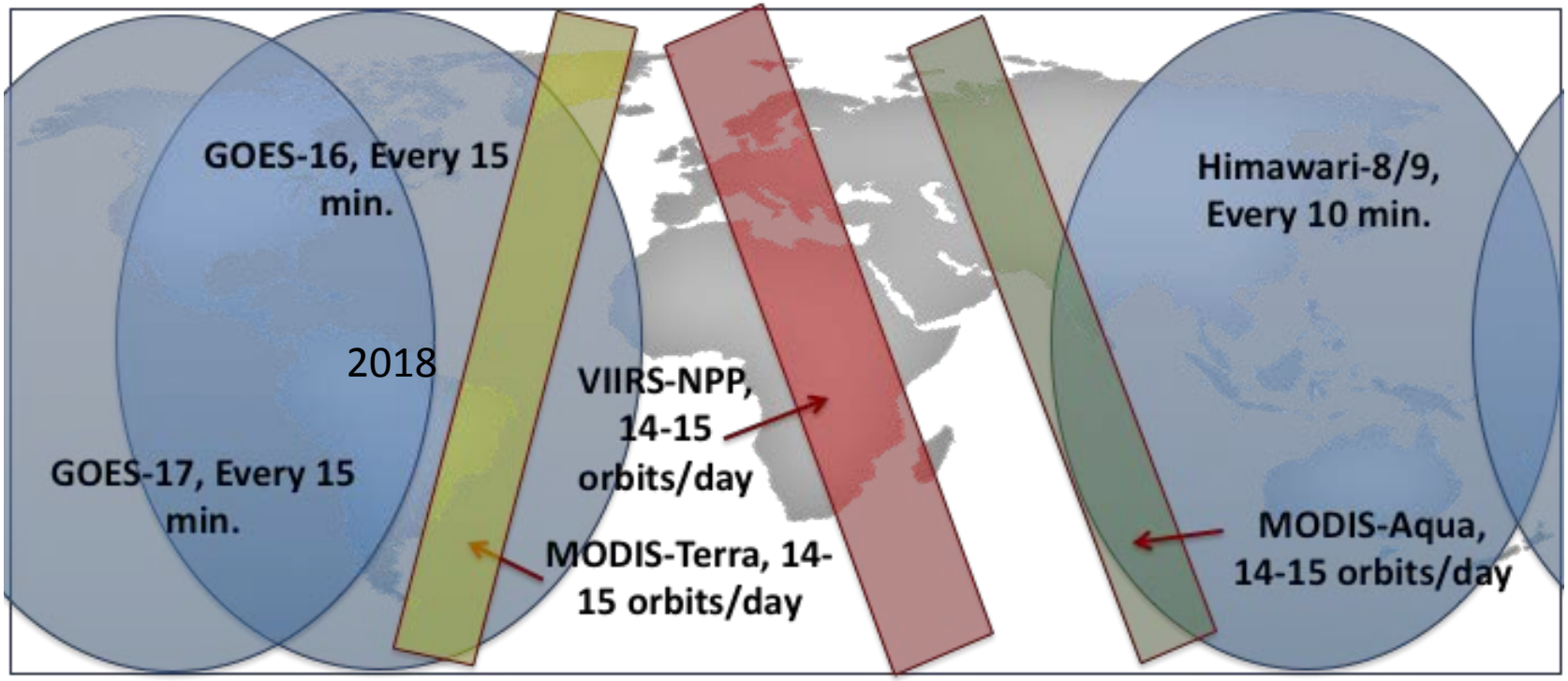
-→ GEO does have sensitivity to Diurnal Cycle!!





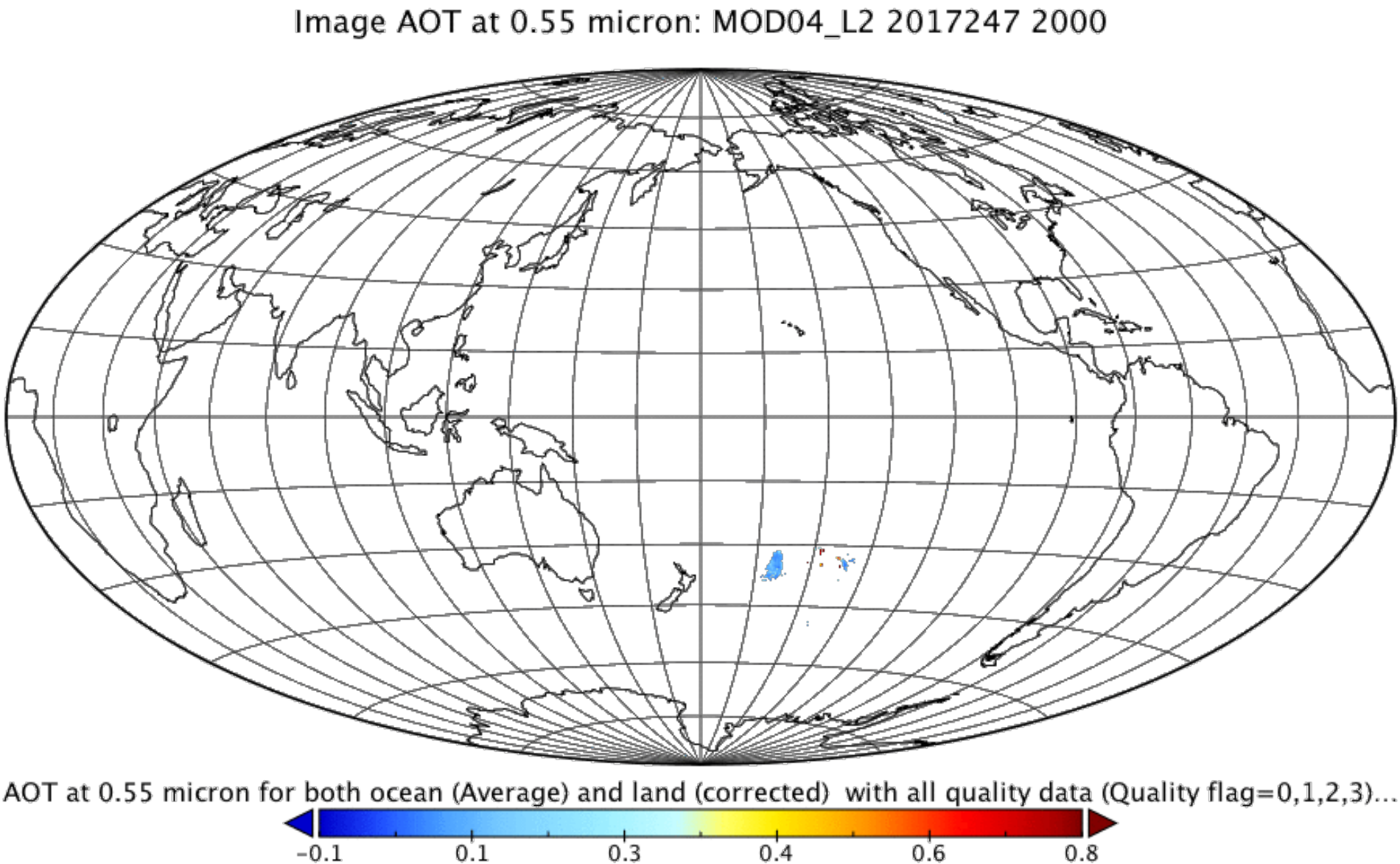


Global/Regional/Temporal synergy with
A consistent DT algorithm!
Statistics of UTC (compare with model)
Statistics of LST (understand local diurnal cycle)

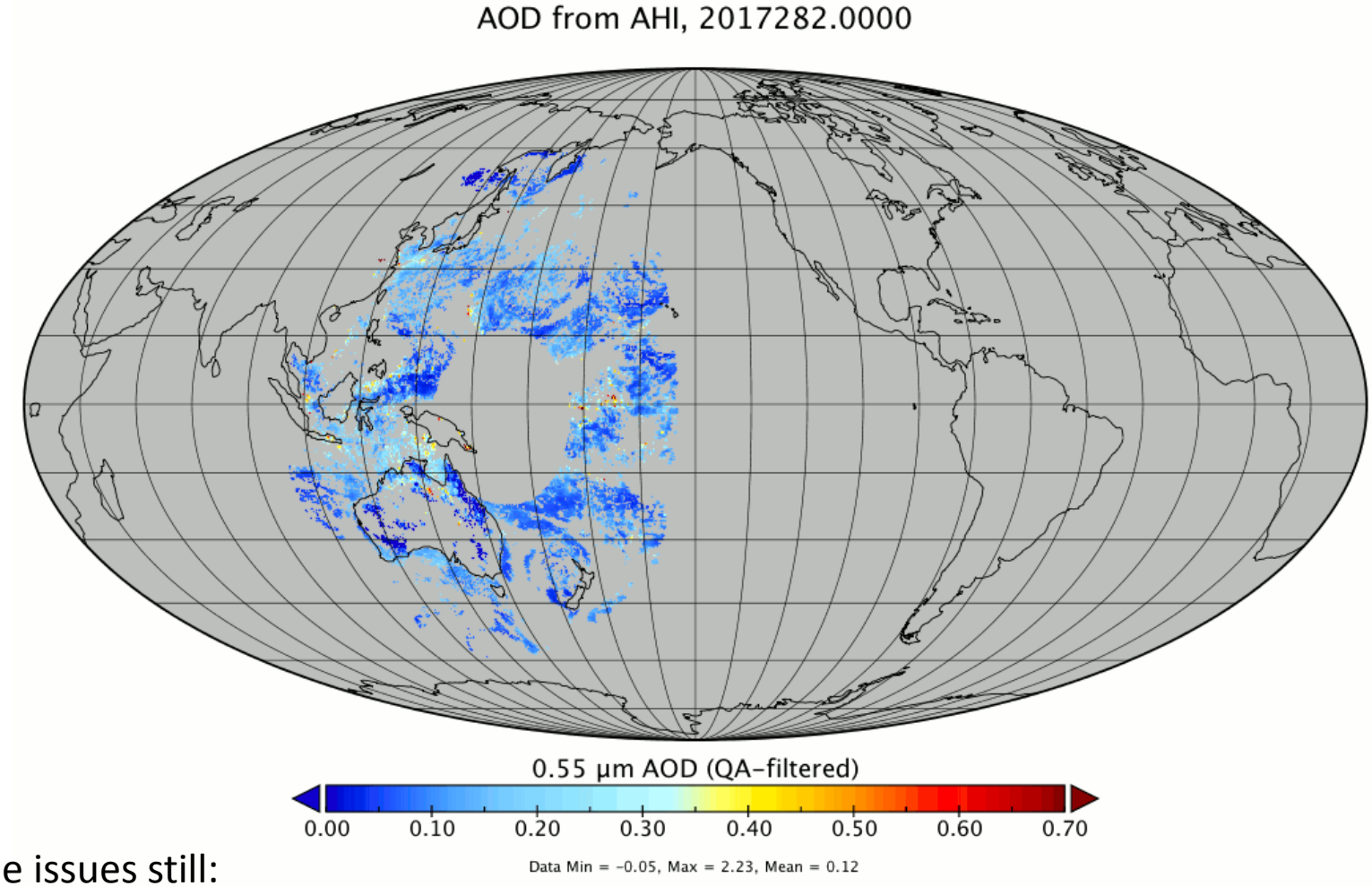


- How many additional sensors do we need to observe climatology (and diurnal cycle and transport) of global aerosol?

LEO-GEO within ±30 mins



AOD from GEO (ABI+AHI): Oct 9-11 2017

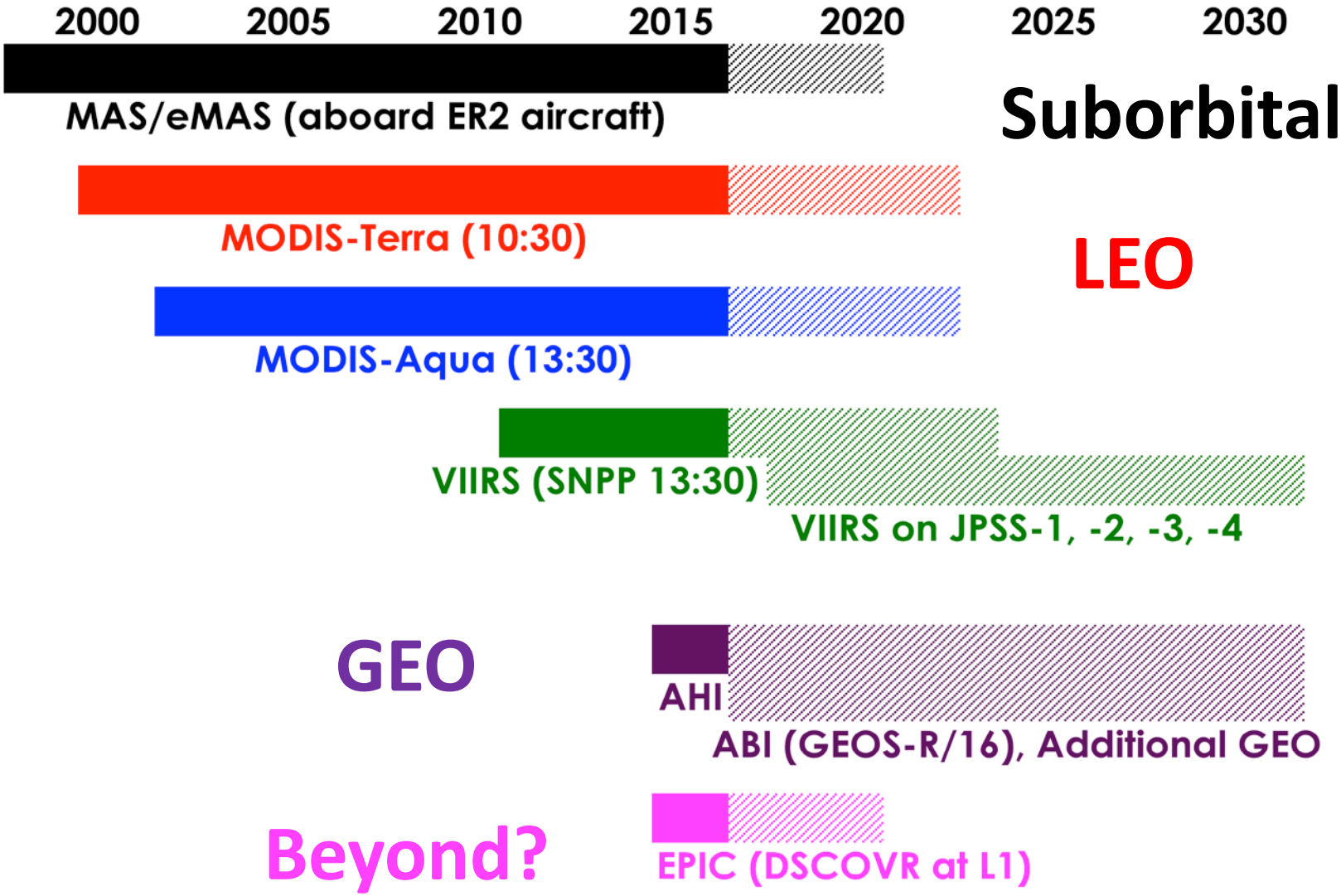


Some issues still:

- High solar and view zenith angles show lower AOD (better spherical corrections?).
- Cloud contamination indicated by “red monsters”
- Not sure why some time stamps are not being processed.
- Calibration uncertainties are still large (maybe as much as 5%!)

But really, really interesting! Potential to learn about Terra vs Aqua (AM vs PM)?

Towards synergy of aerosol observations



Global Climate Observing System

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Temporal Resolution	4 h	**20+ / day (daylight only)**
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Time Length	30+ years	30+ years (MODIS + VIIRS on JPSSx)
Stability / bias	<0.01 / decade	Not there yet, but possible?

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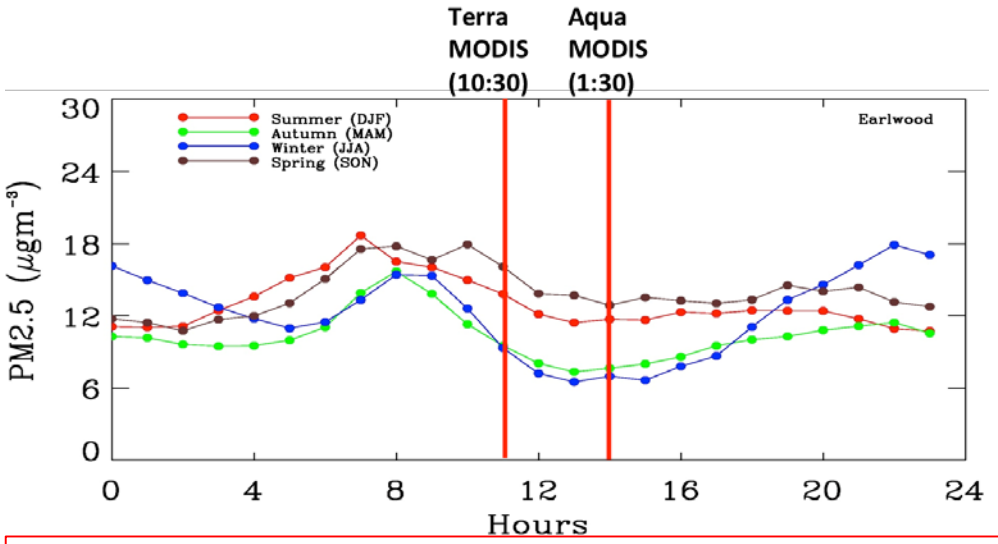
By 2021 there will be more GEO sensors (Europe, China, etc)

Now we need to work on improving algorithm, coverage to ice surfaces.

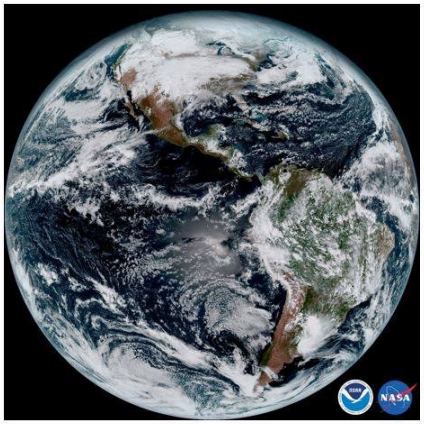
Summary

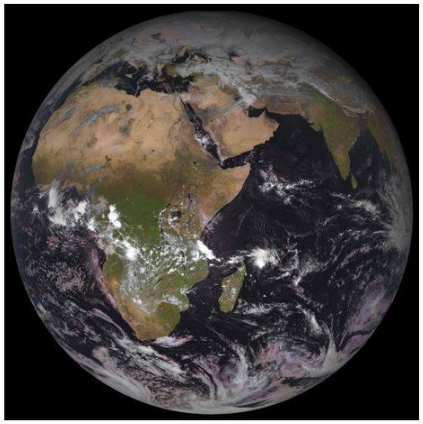
- ✓ Aerosol measurements for LEO have long history , validation and use for AQ and climate applications.
- ✓ Aerosol measurements from GEO orbit is a step forward in breaking the temporal barrier.
- ✓ GEO constrains multiple LEO sensors, .and LEO constrains multiple GEO. Synergy!
- ✓ For the global climate 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

a new era in satellite remote sensing of aerosol SYNERGY!

Caveats: But we still got work to do!

- Calibration
- 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
- How to make data useful? (archive, searchable)
- I expect that assimilation may be key.
- New algorithms, that make use of time-dependence and multi-observation synergy