Adding high temporal resolution to the global aerosol record: A synergy of LEO and GEO

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GCOS Aerosol CDR* Requirements

CDR = Climate Data Record

Target Requirements

For Aerosol Optical Depth

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 %

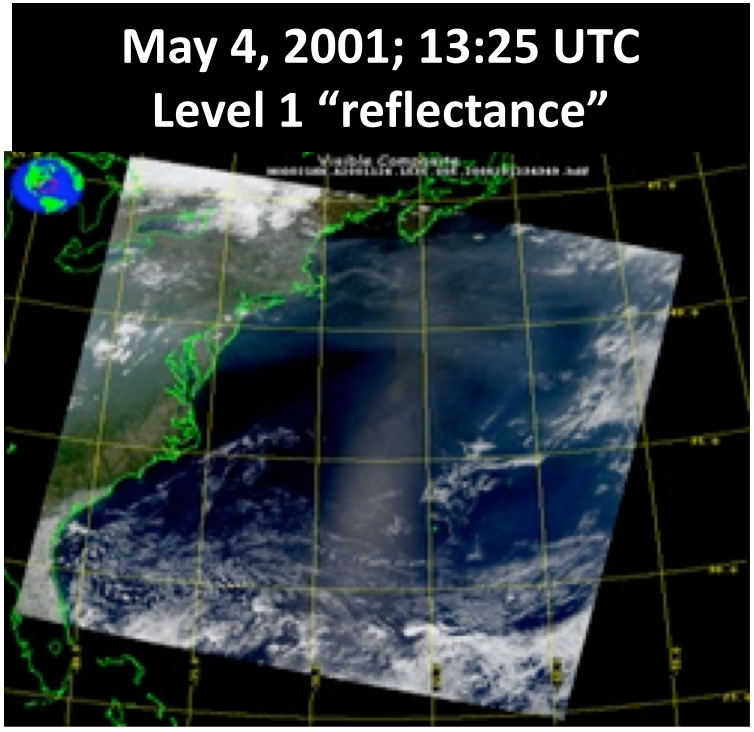
Stability means ”drift per decade less than X” .

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

Of course, not only AOD is relevant for air quality and climate.. But only discuss AOD here.

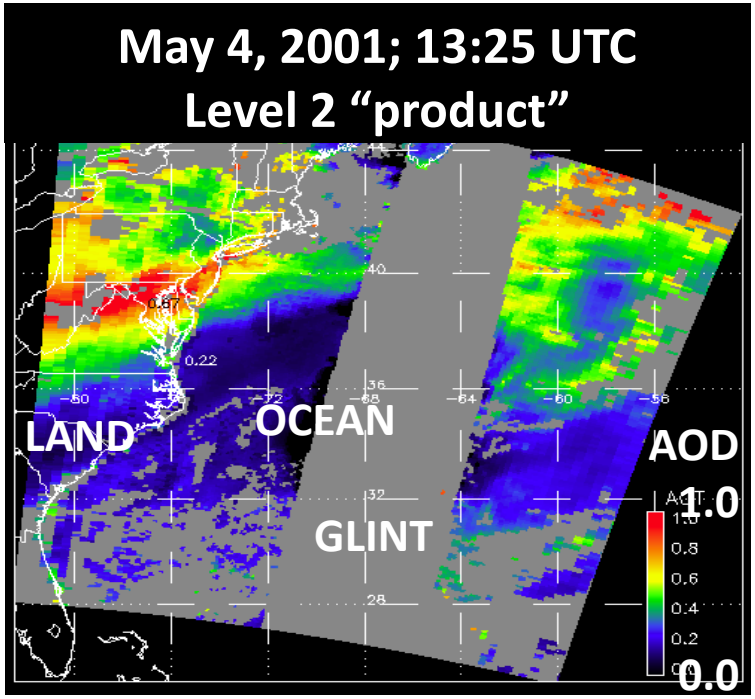
Dark-Target: A "Single View" aerosol algorithm

What a sensor observes



DT

Attributed to aerosol (AOD)

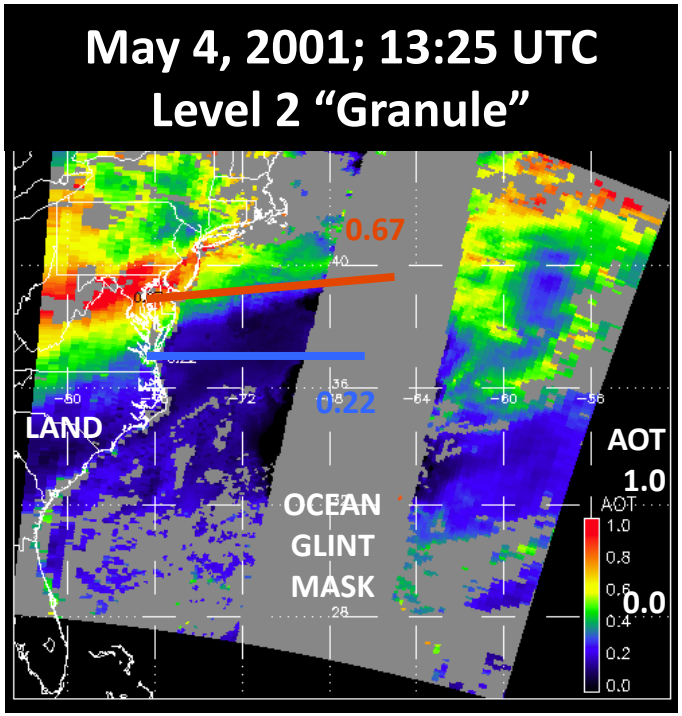


"Established 1997" by Kaufman, Tanré, Remer, etc)
"Modified 2005, 2010, 2013, 2015" by Remer, Levy, Gupta, etc

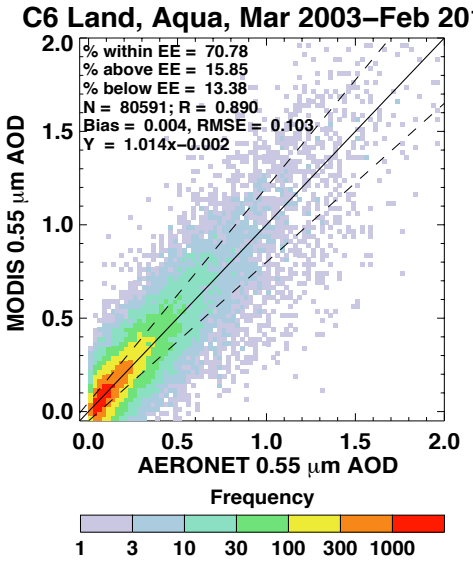
Separate logic over land and ocean
Retrieve: AOD at 0.55 μm, spectral AOD, etc
Can run in near-real-time (NRT; takes 2 minutes)

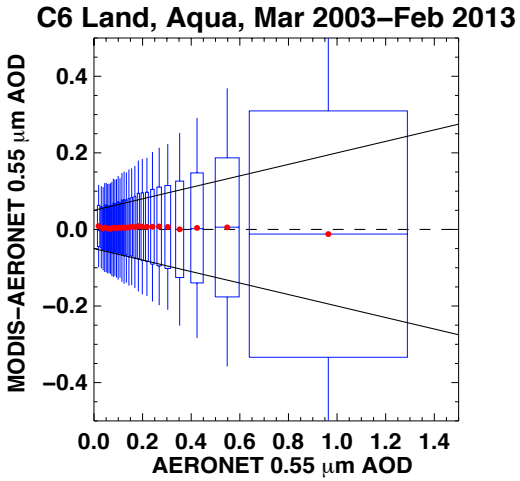
So where are we?

MODIS C6/C6.1 product



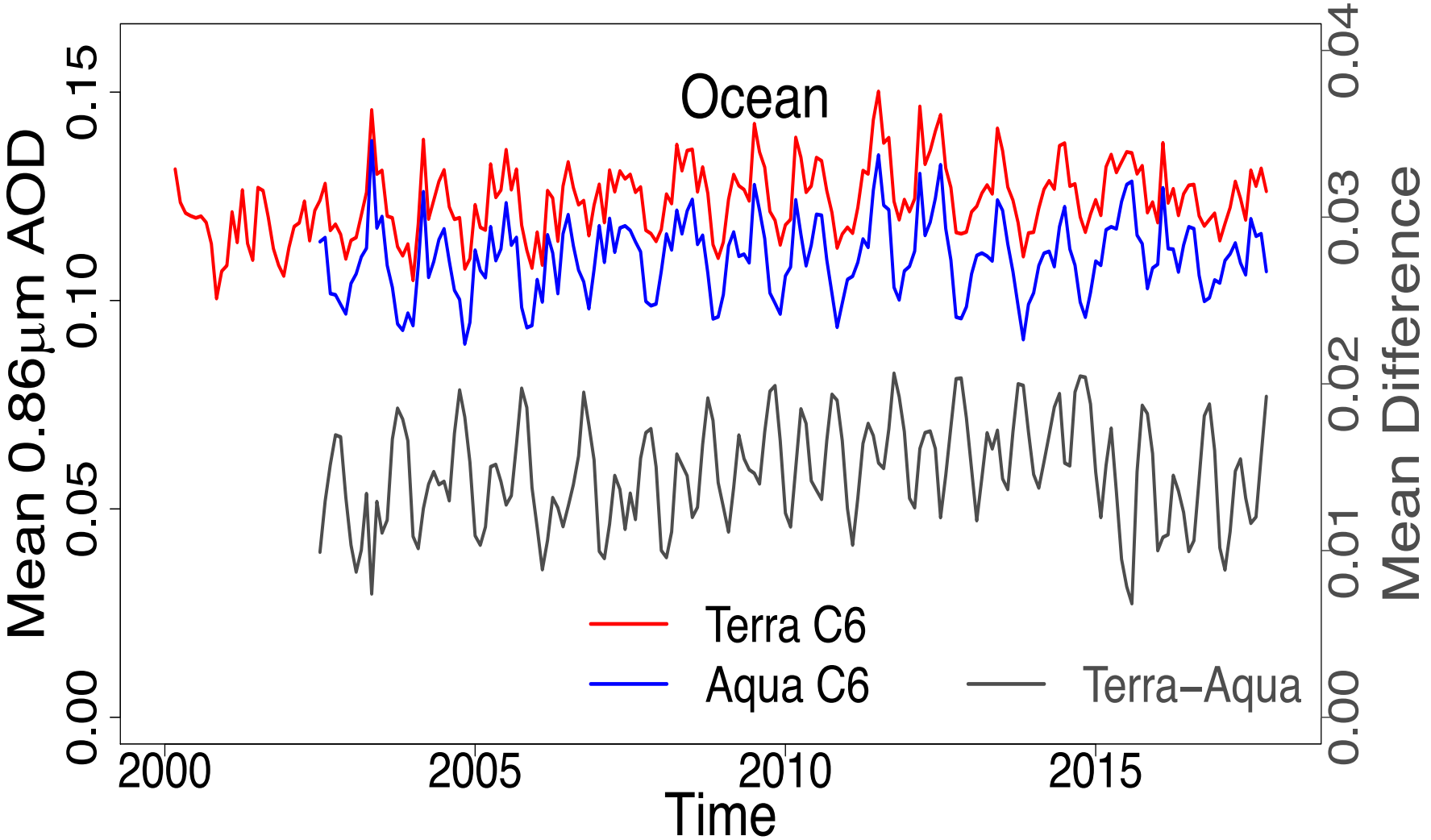
- Compare both land and ocean products to AERONET, separately
- Validation: 66% are within
  "Expected Error" (EE) defined as
  - Land: $\pm(0.15\tau + 0.05)$
  - Ocean: $\pm(0.10\tau + 0.04)$



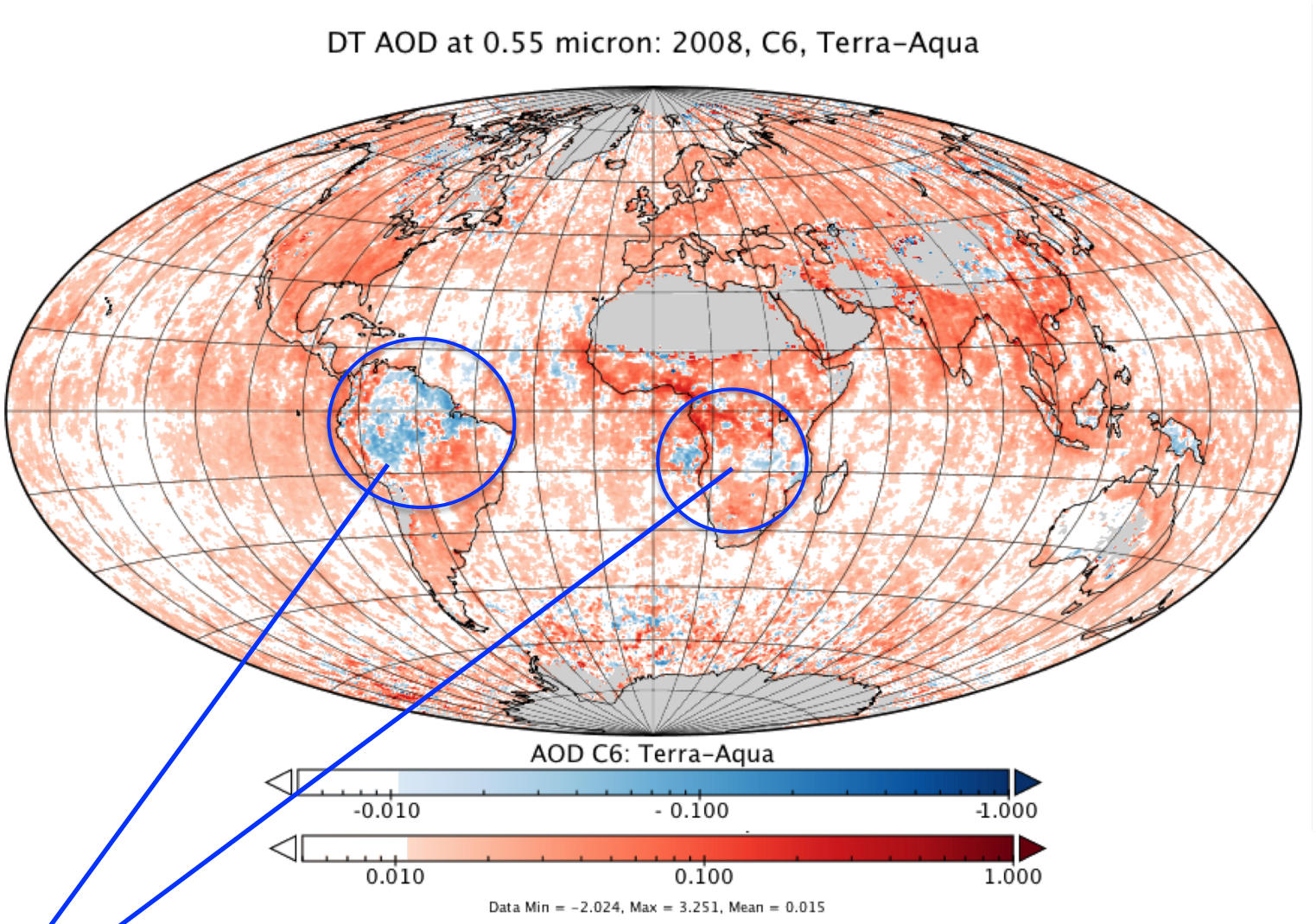


- We are getting close to CDR accuracy requirements!
- But….

Terra – Aqua: Near lockstep, but offset

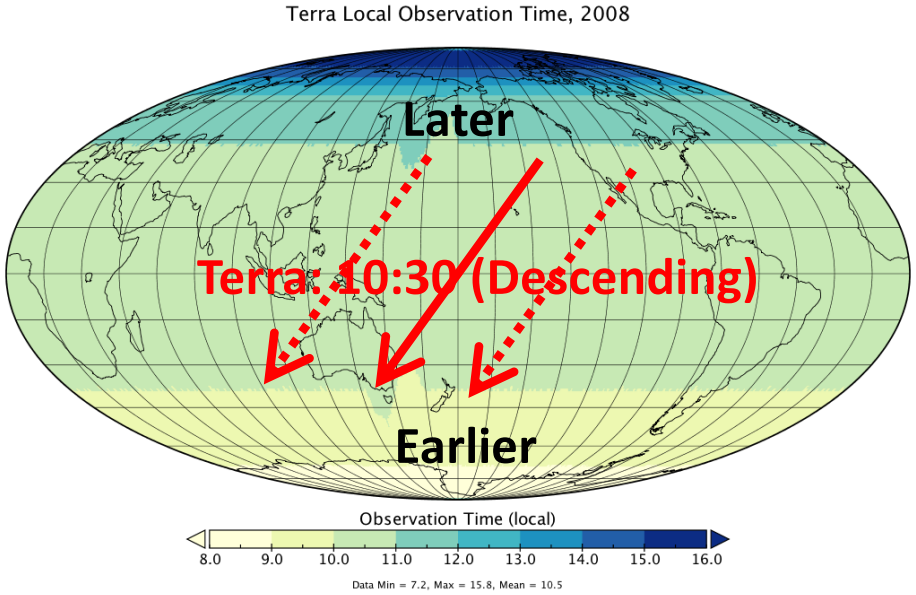


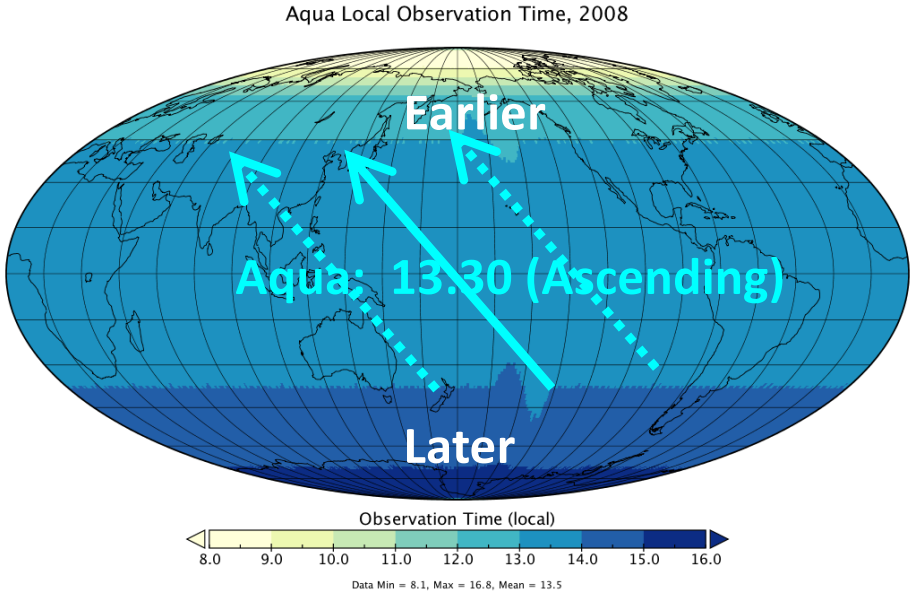
Offset of 0.015 is nearly everywhere!

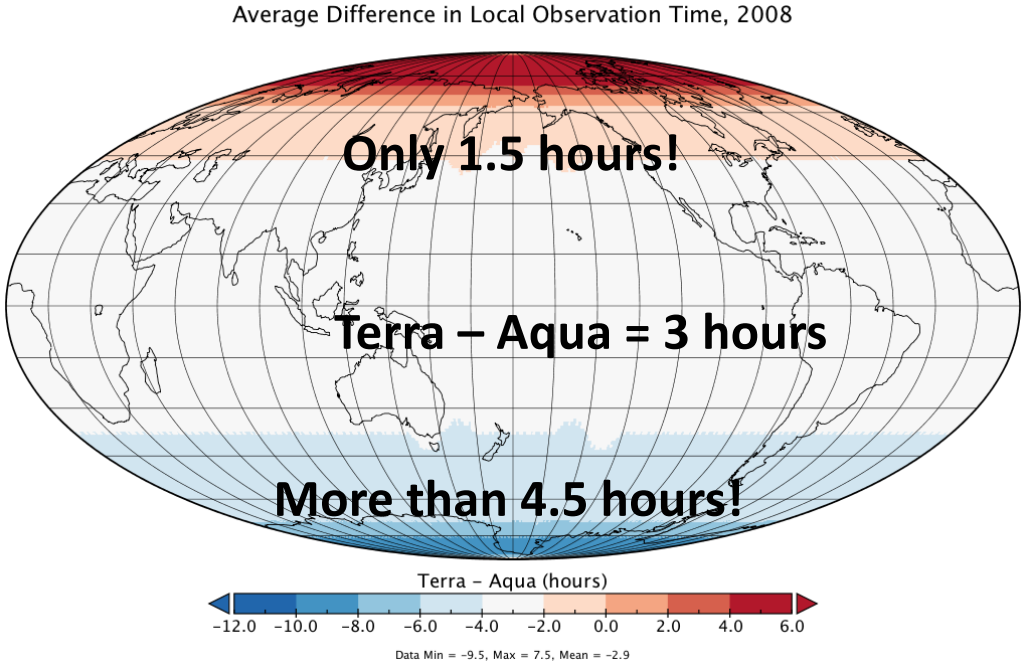


except for “smoke” regions where known maximum in afternoon!

Overpass time differences?



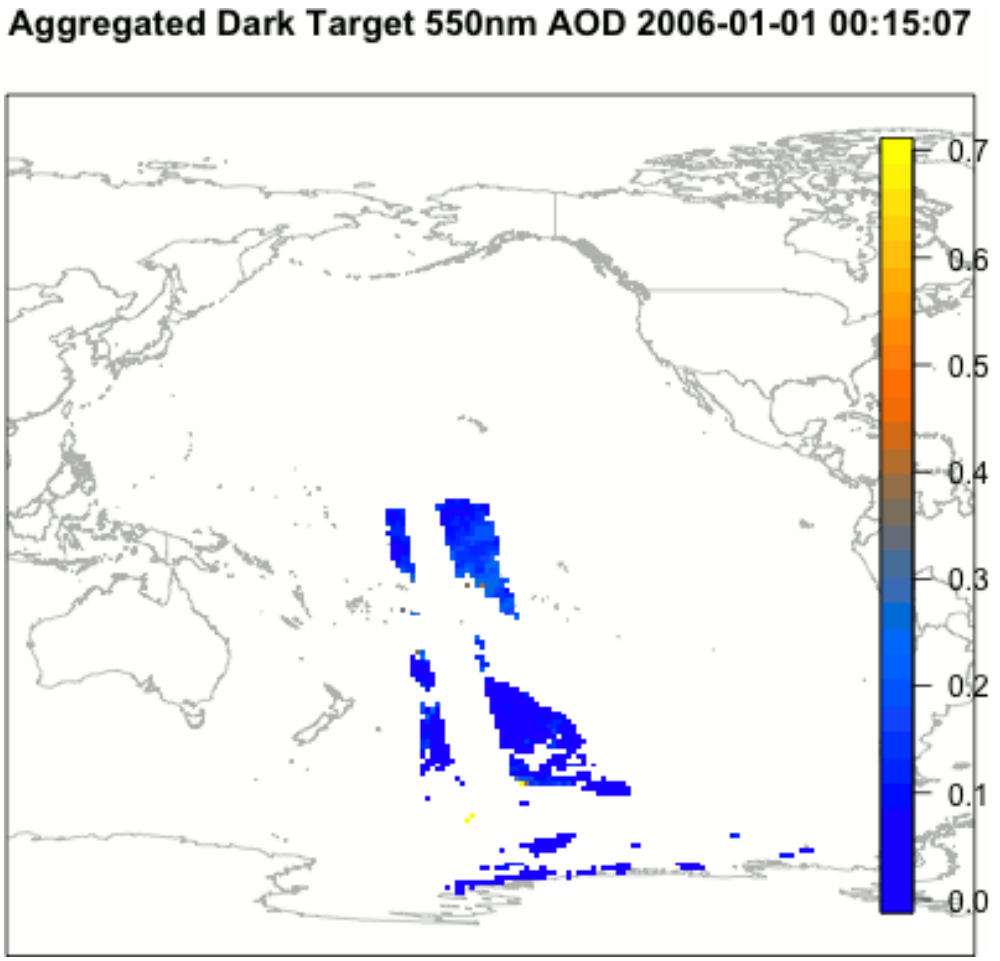




“Expected” offset due to AM/PM? What can model tell us?

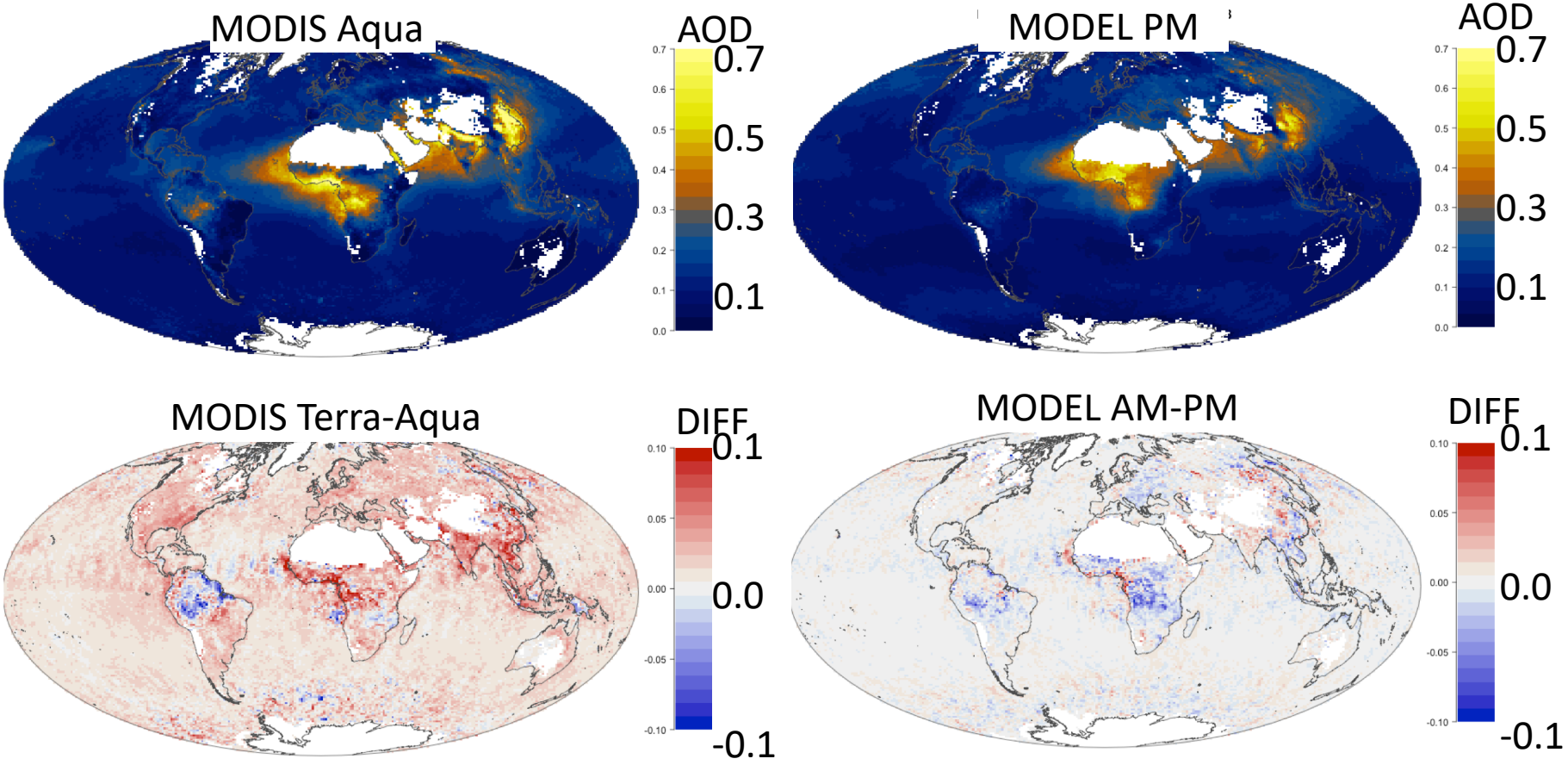
- For Terra and Aqua separately,
  - Create two “empty” grids (hourly and 0.5° x 0.625°)
  - Perform hourly aggregations of MODIS AOD
  - If valid MODIS pixels, populate one grid with MODIS data, and the other with GEOS-5 AOD.

- Model version includes assimilation of meteorological variables and infrared /Microwave radiances, but not MODIS (nor Terra or Aqua radiances)



Pete Colarco and Virginia Sawyer

offset from the MERRA model outputs?



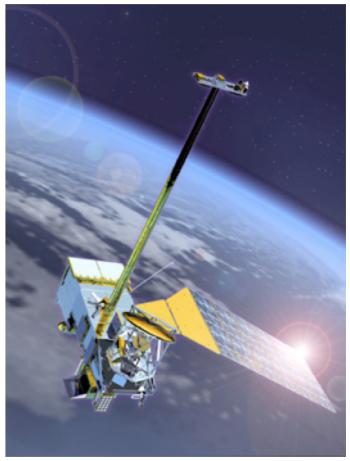
AM-PM for MODIS is greater than AM-PM expected by MODEL

→ We probably can't interpret Terra-Aqua as diurnal differences.

→ But we still are not SURE..

Beyond **MODIS**

- Terra (18) and Aqua (almost 16) have both have well-exceeded their planned mission lifetimes.
- How to get to long-term 30+ record?

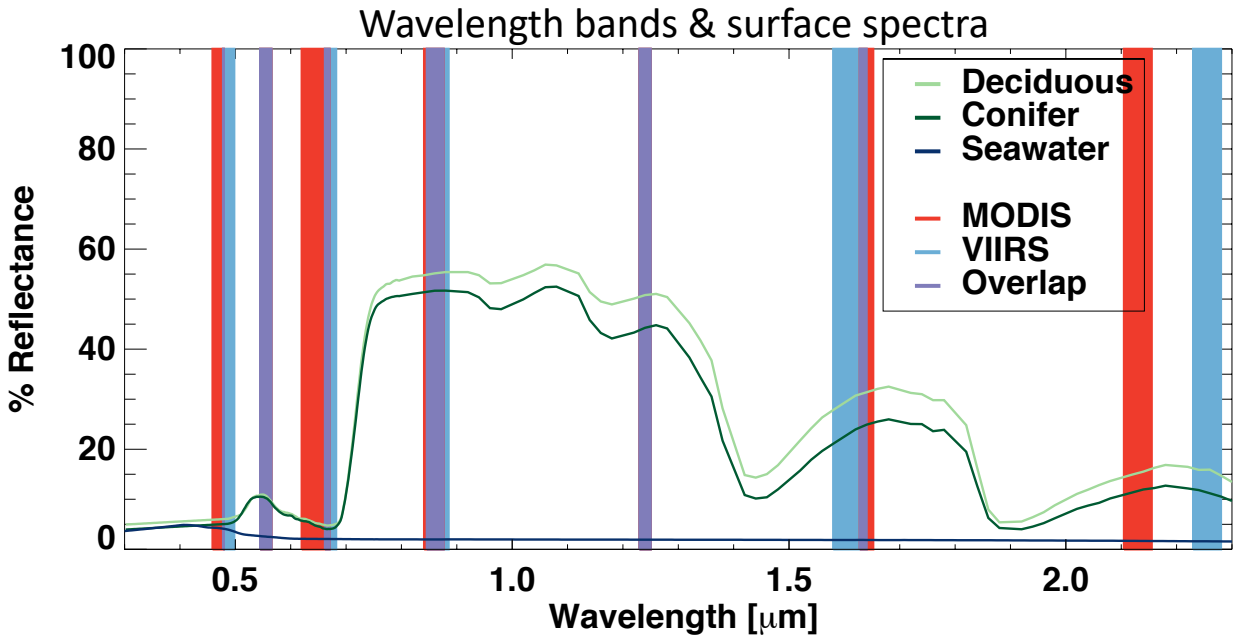


VIIRS!

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

To develop "continuity" we port algorithms! (Example: DT from MODIS→VIIRS)

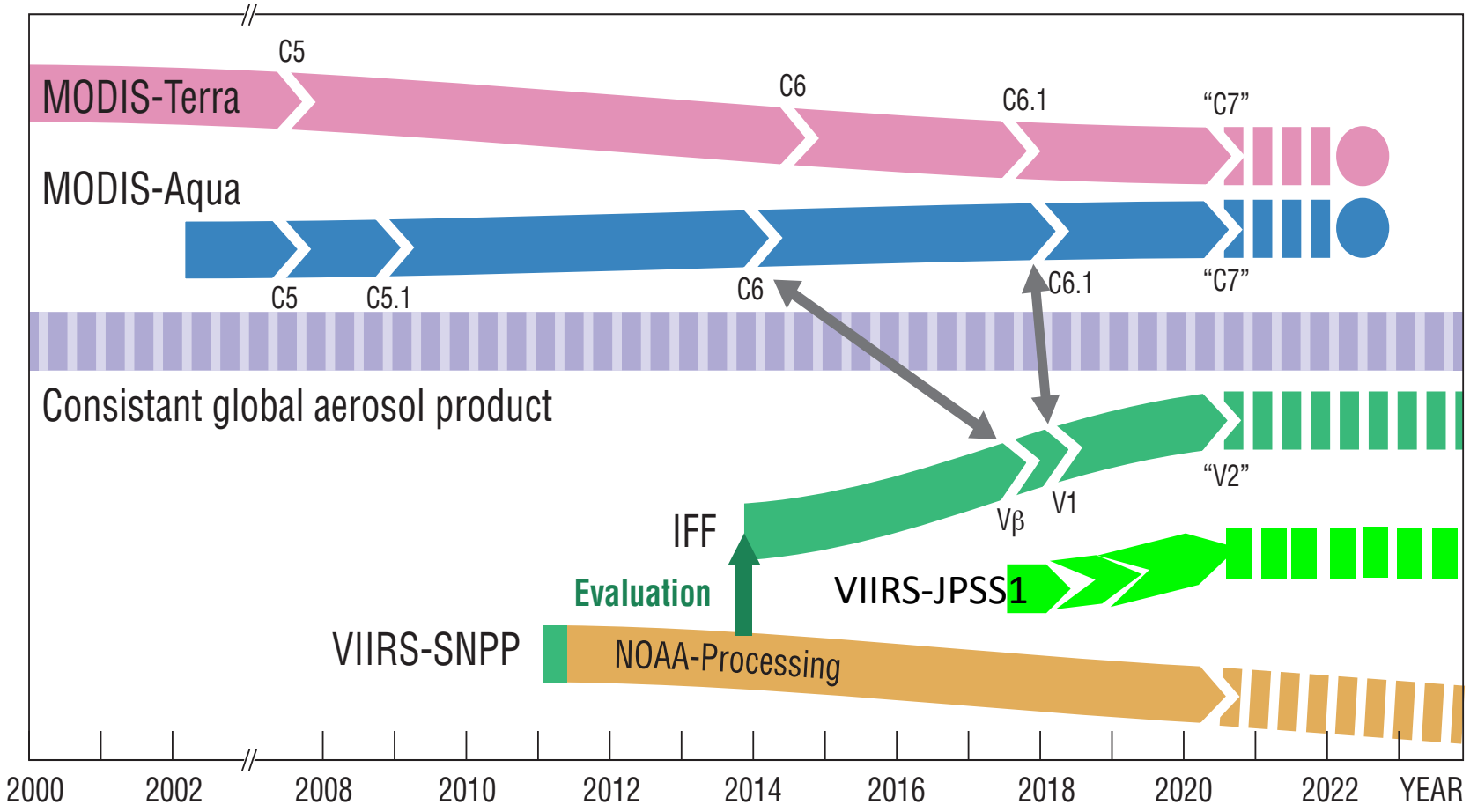
- Deal with differences in wavelengths (gas corrections/Rayleigh, etc)



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

Levy et al., 2015

Towards consistent global aerosol using DT on LEO!



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

Plan for re-processing of entire mission

Schedule is TBD, but hopefully soon!

Note, our recent proposal was NOT SELECTED for funding, so….

Compared to GCOS requirements

For Aerosol Optical Depth

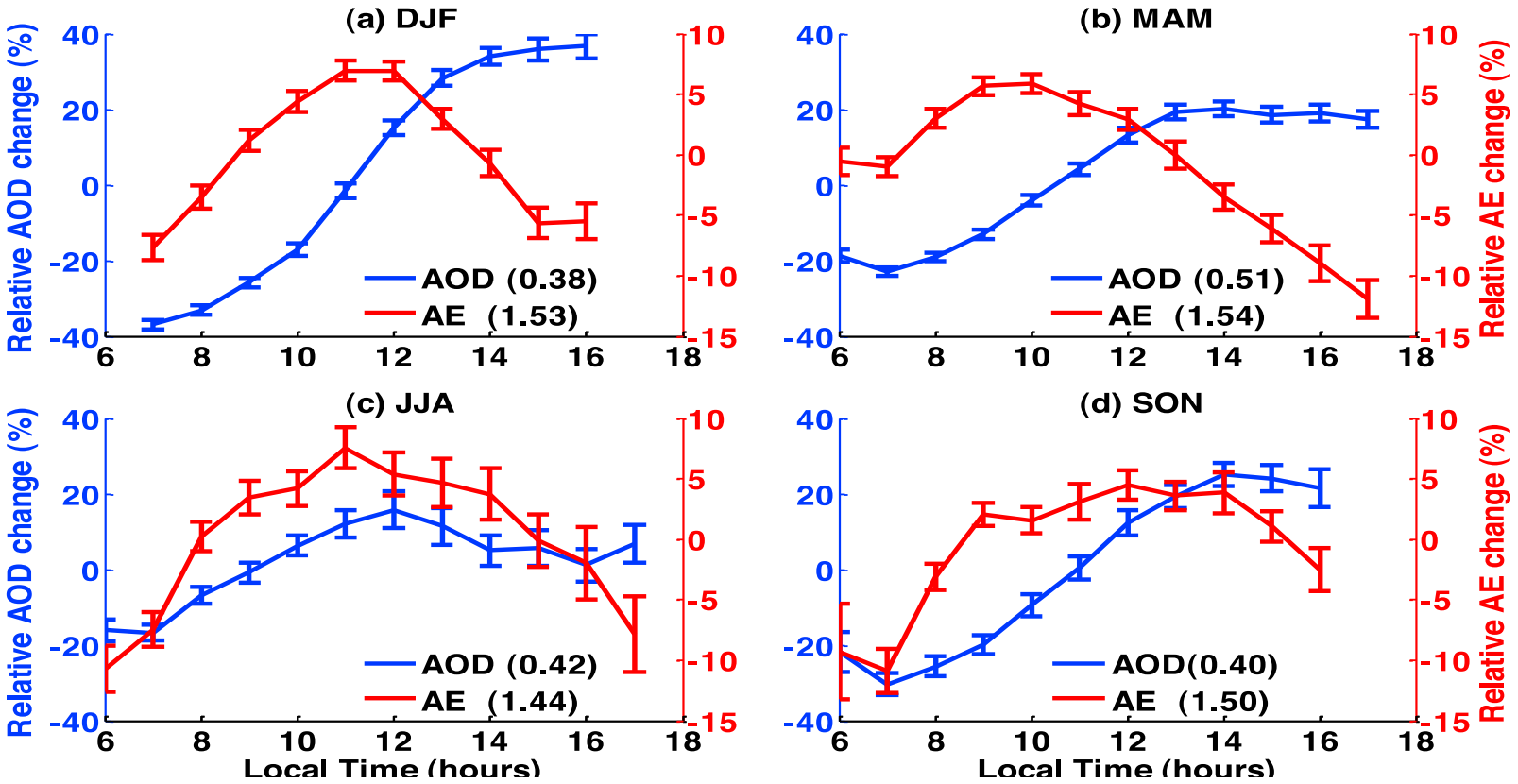
Target metric	Target	Current with MODIS or VIIRS-DT
Horizontal Resolution	5-10 km, globally	10 km MODIS and 6 km VIIRS, over ice-free and cloud-free scenes
Temporal Resolution	4 h	2+ / day (Terra + Aqua/VIIRS)
Accuracy	MAX(0.03 or 10%)	±(0.04+10%): Ocean ±(0.05+15%): Land
Time Length	30+ years	30+ years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

JPSS-1 has been launched (November 2017), and will be in SAME ORBIT as S-NPP!

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

But what's missing? Multi-x/day!

% deviation in hourly AOD at 0.44 μm (left y axis) and Ångström exponent (AE: 0.44/0.87 μm ; right y axis) relative to the daily mean in four seasons 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*.

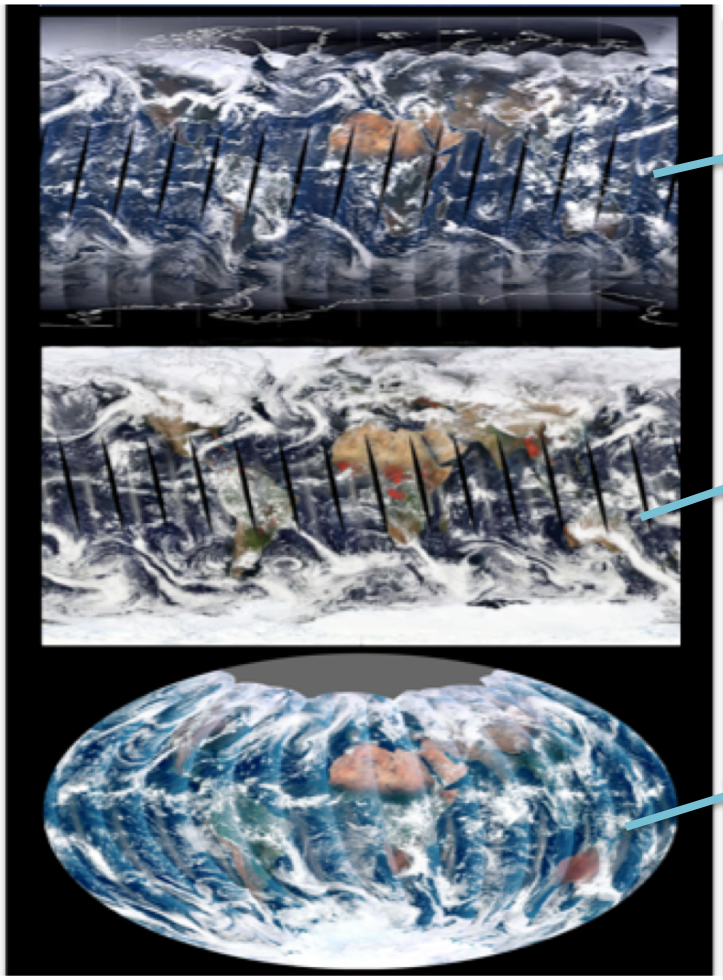
Potential sensors for DT algorithm?

Polar Orbiting Sensors

MODIS-Terra

MODIS-Aqua

VIIRS-SNPP



17+ Years (2000)

15+ Years (2002)

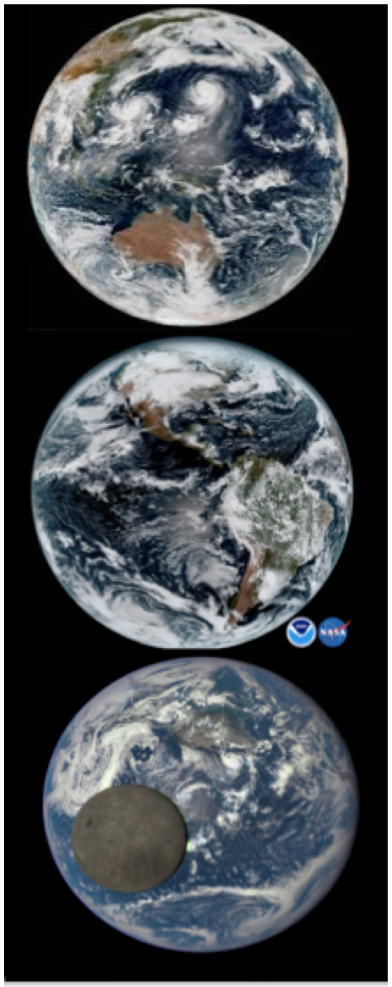
6+ Years (2011)

Geo & Beyond

AHI 8 & 9

GOES 16 & 17

EPIC



3+ Years (2014)

1+ Years (2016)

2+ Years (2015)

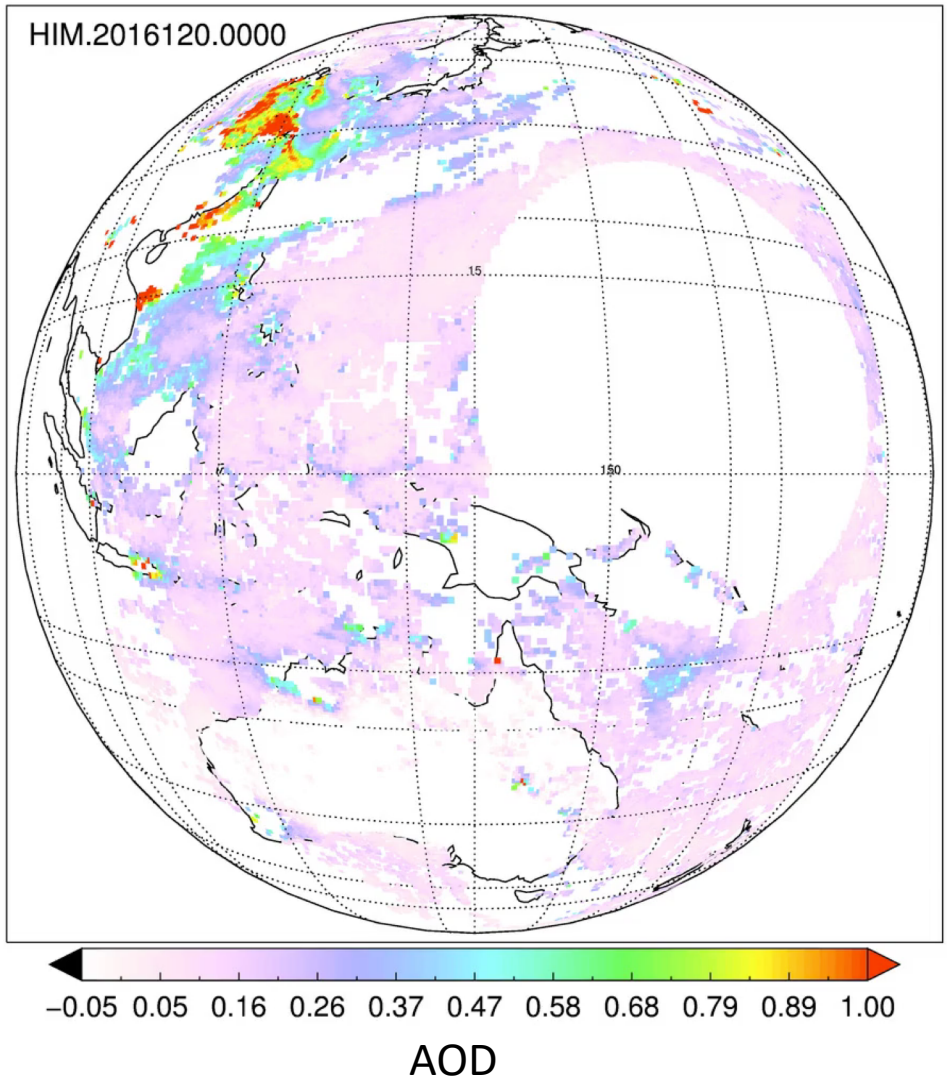
Port DT algorithm to GEO!

Spectral/Spatial: AHI / ABI ≈ MODIS / VIIRS

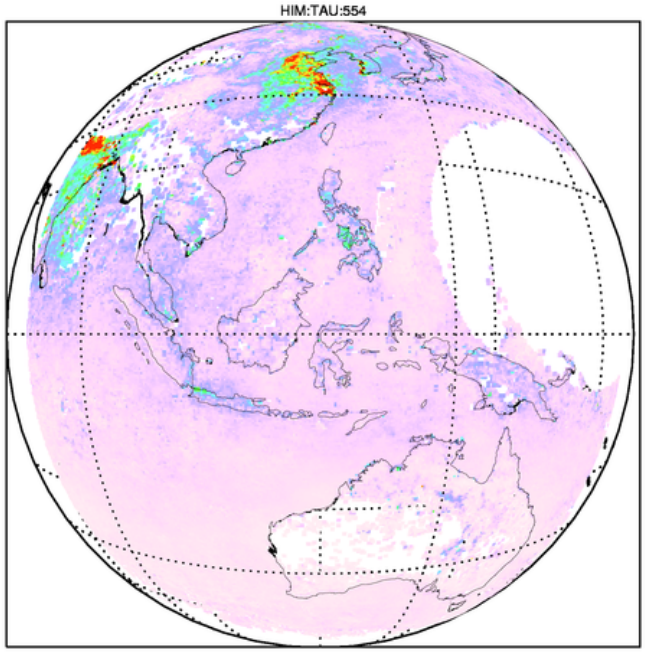
	MODIS	VIIRS	AHI	ABI
Blue	0.47/0.5	0.49/0.75	0.47/1.0	0.47/1.0
Green	0.55/0.5	0.55/0.75	0.51/1.0	
Red	0.66/0.25	0.67/0.75	0.64/0.5	0.64/0.5
NIR	0.86/0.25	0.86/0.75	0.86/1.0	0.86/1.0
NIR	1.24/0.5	1.24/0.75		
Cirrus	1.38/0.5	1.38/0.75		1.38/2.0
SWIR	1.61/0.5	1.61/0.75	1.61/2.0	1.61/1.0
SWIR	2.11/0.5	2.25/0.75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

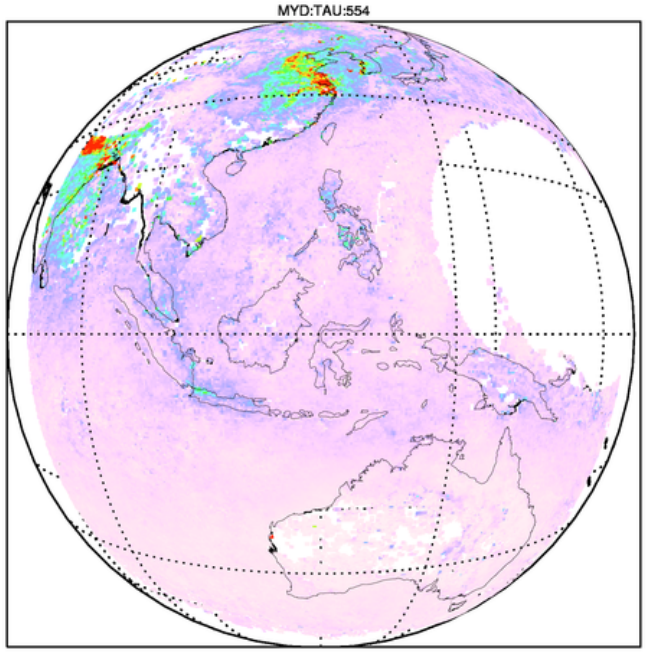
Some details need to be worked out (e.g. lack of “cirrus” band on AHI);

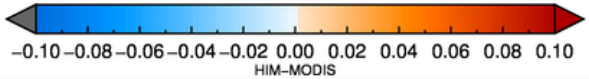
Breaking the Temporal Barrier: 15-Day DT retrieval on AHI (May, 2016)

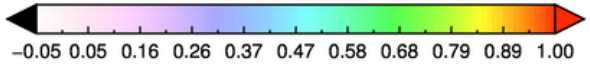


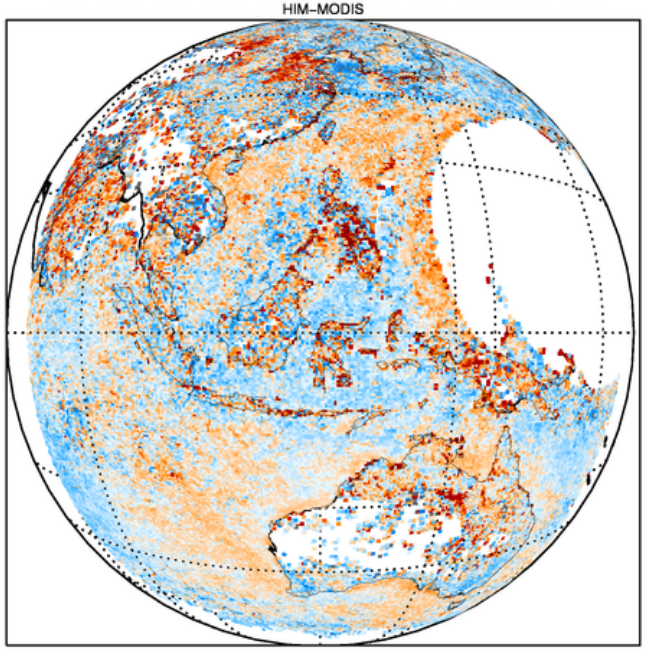
June 2016, All Hours

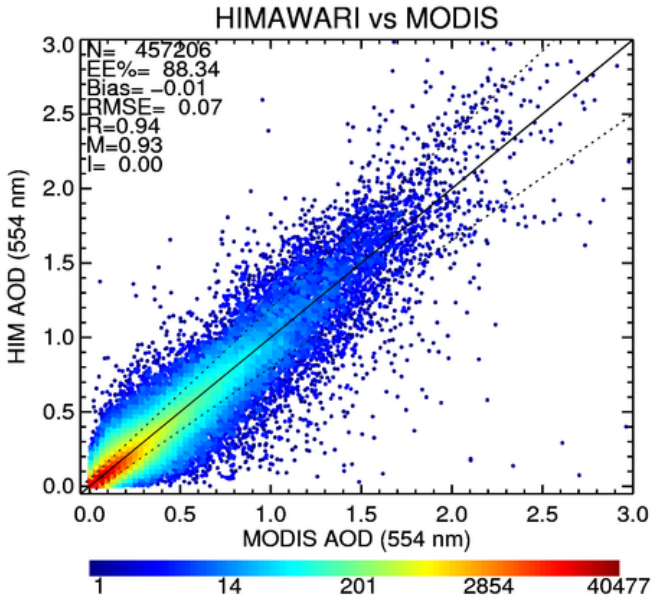




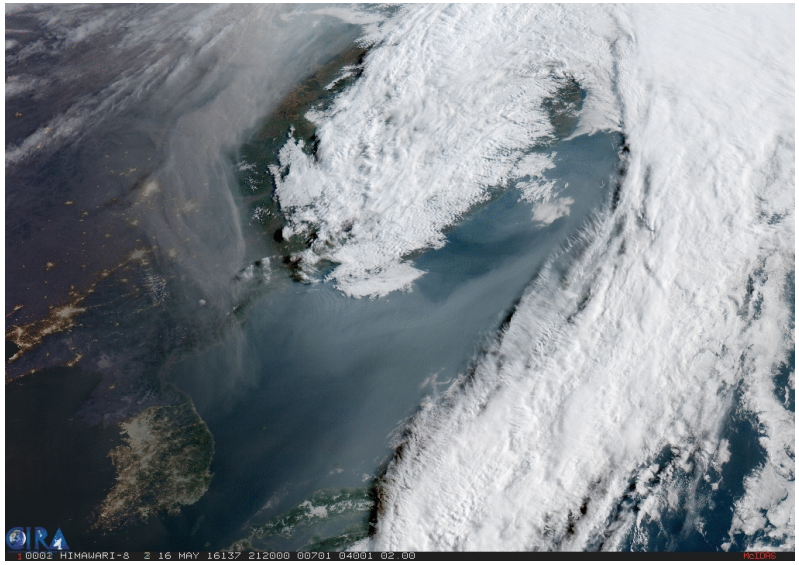


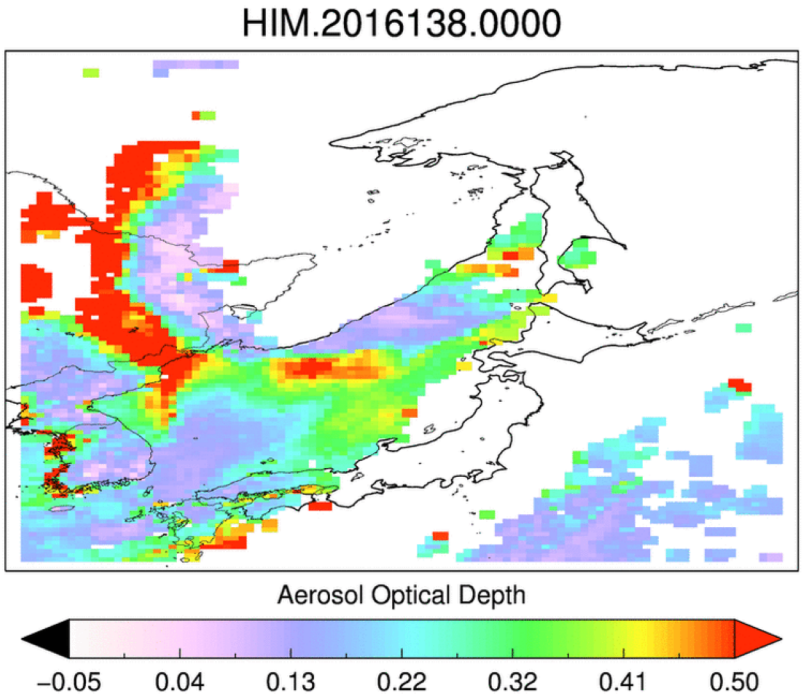






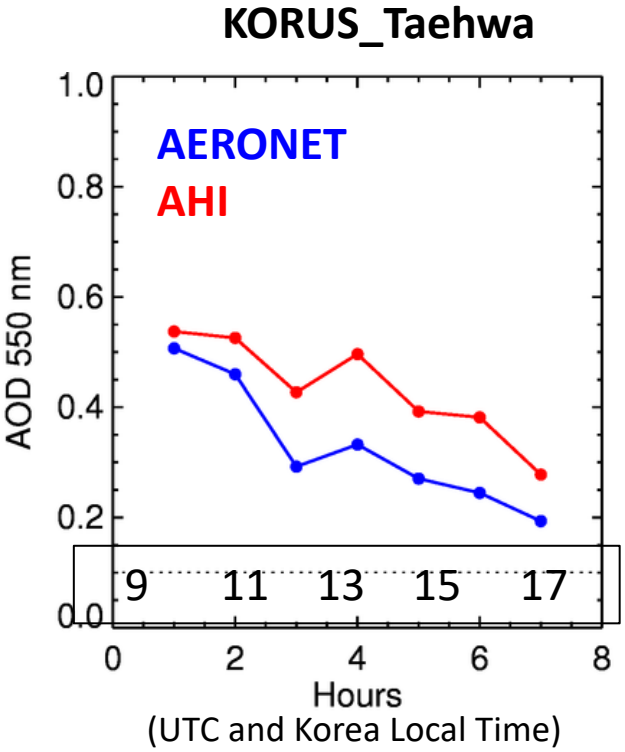
Tracking events

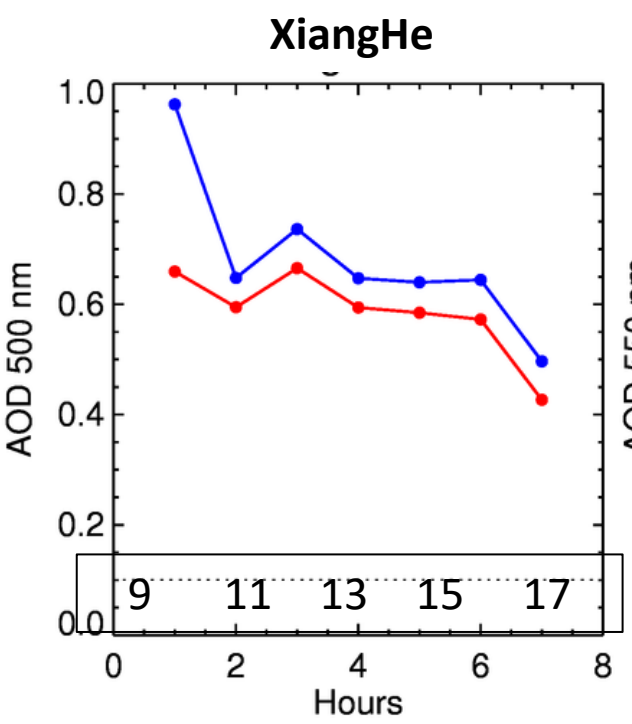


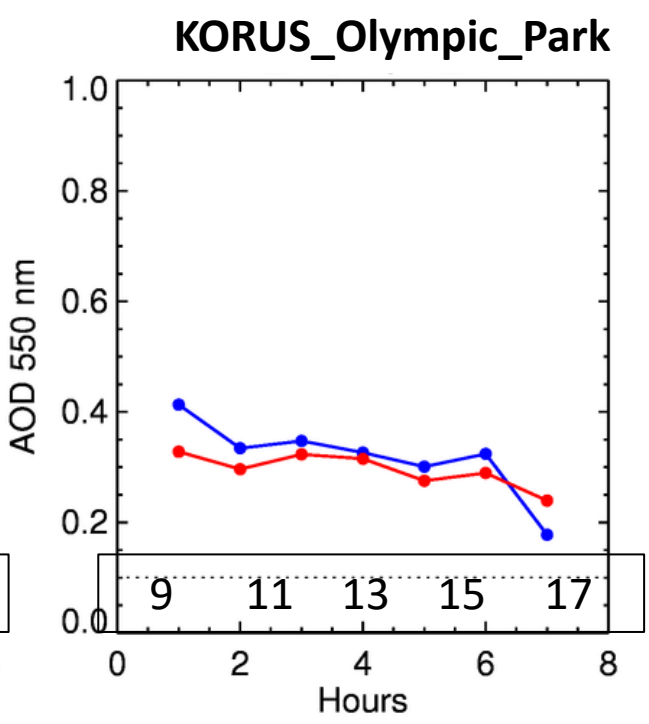


Diurnal Cycle of AODs (from KORUS-AQ, 2016)

-→ GEO does have sensitivity to Diurnal Cycle!!



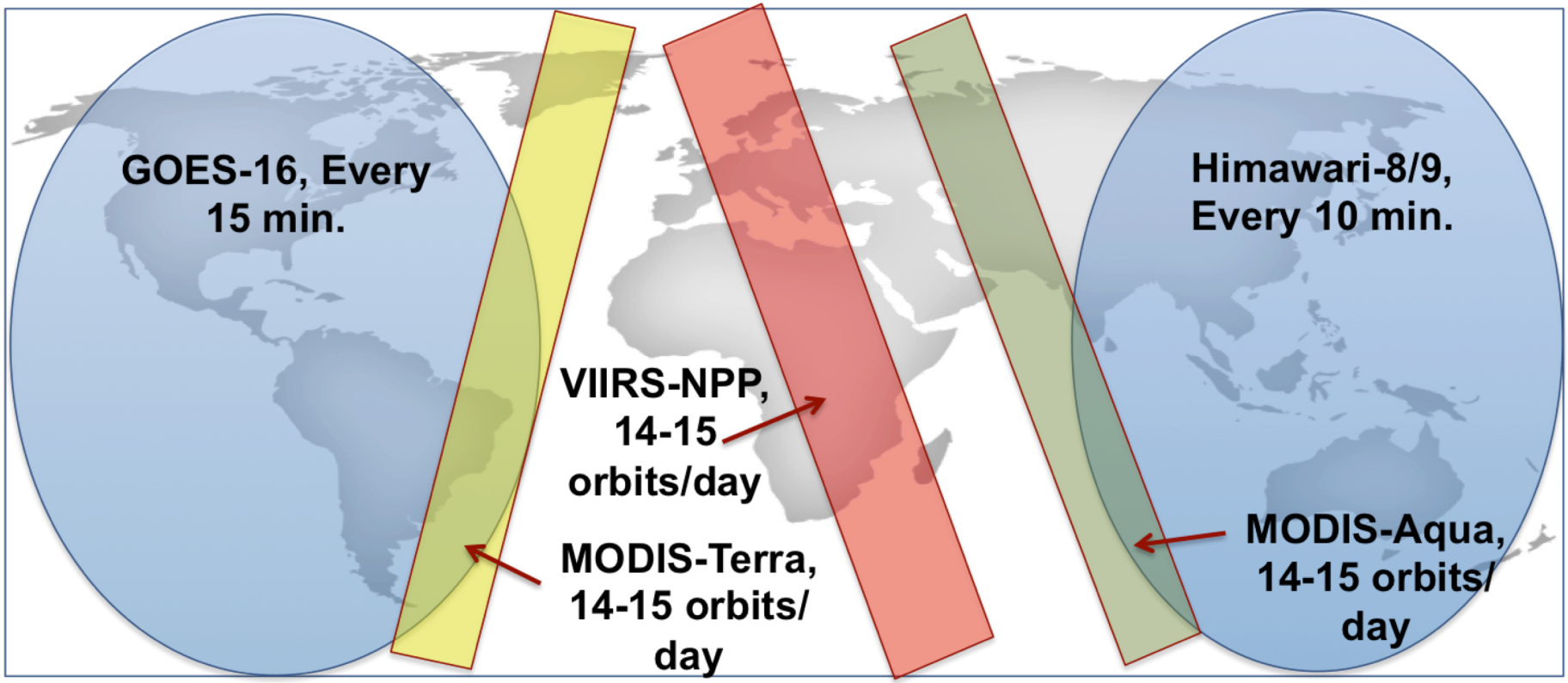




BIG PROBLEM!
How to re-process 5+ years of GEO?

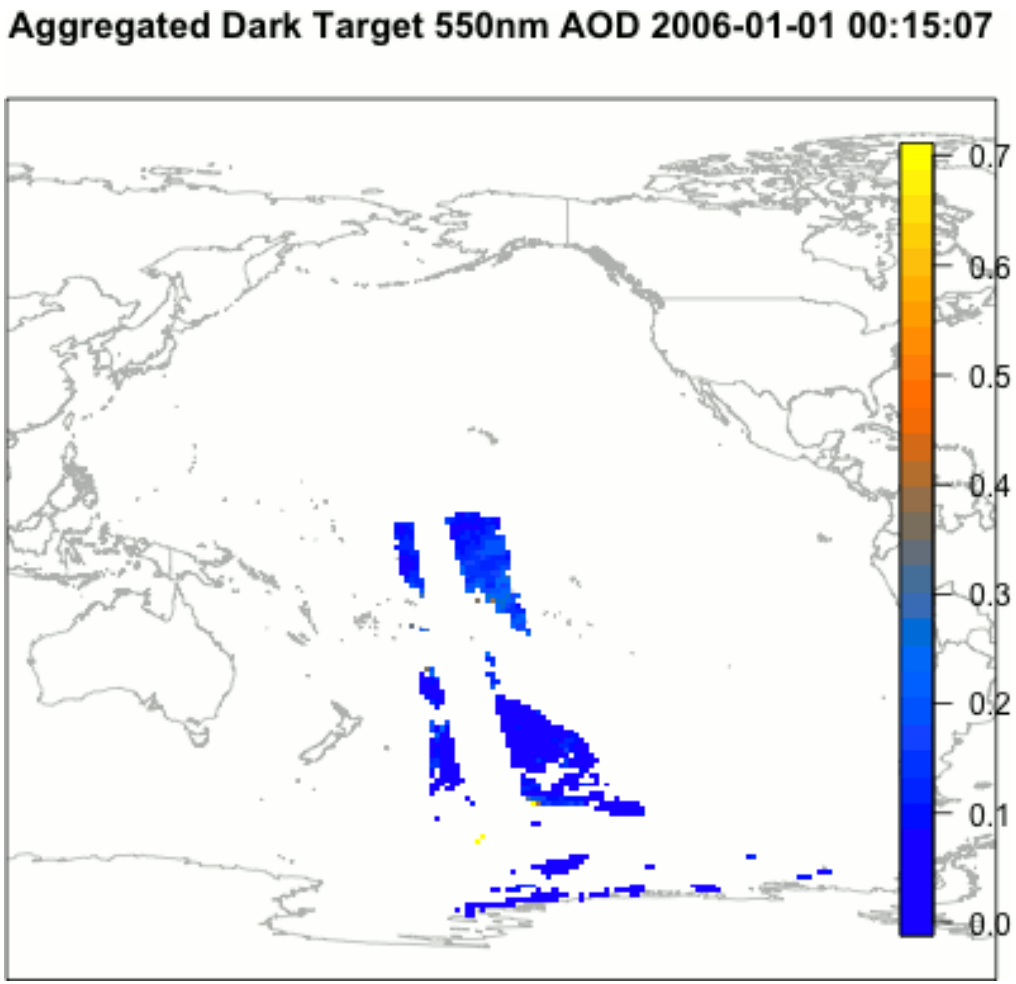
- GEO data are huge! Native-resolution full disc is 2.75 GB. We want to reprocess entire time series at 30 min resolution.
- Need to modernize DT algorithm, parallelize, access to data, “the Cloud”, etc.
- Outputs must be small, usable, archived and searchable.
- Subject of a recently selected NASA-MEaSUREs project.

Global/Regional/Temporal synergy Statistics of UTC (compare with model)



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

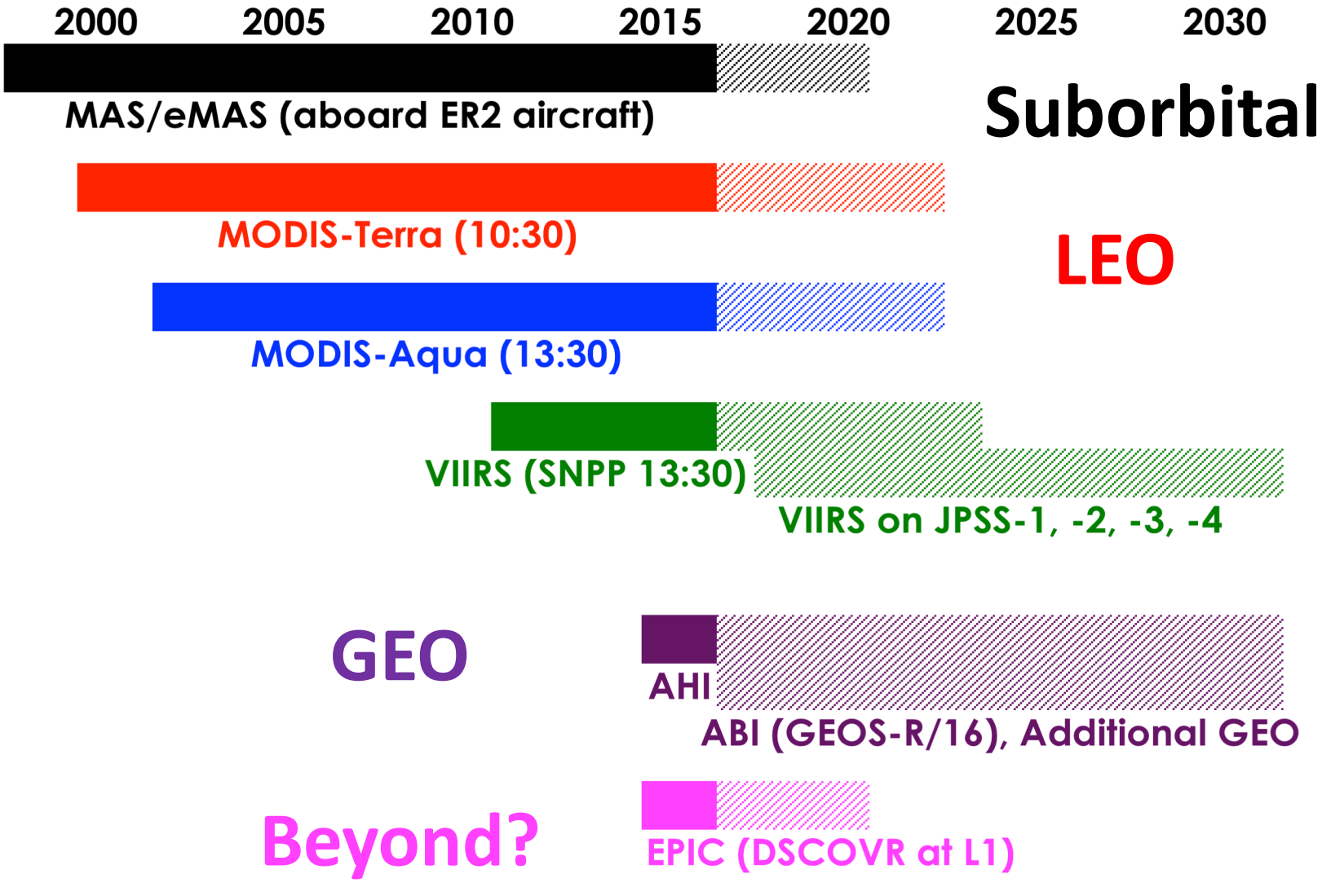
Idea of temporal “snapshots”
Proposal is for every hour at least



+ LEO Terra - MODIS
+ LEO SNPP – VIIRS
+ GEO Himawari - AHI
+ GEO GOES - ABI
+ ….

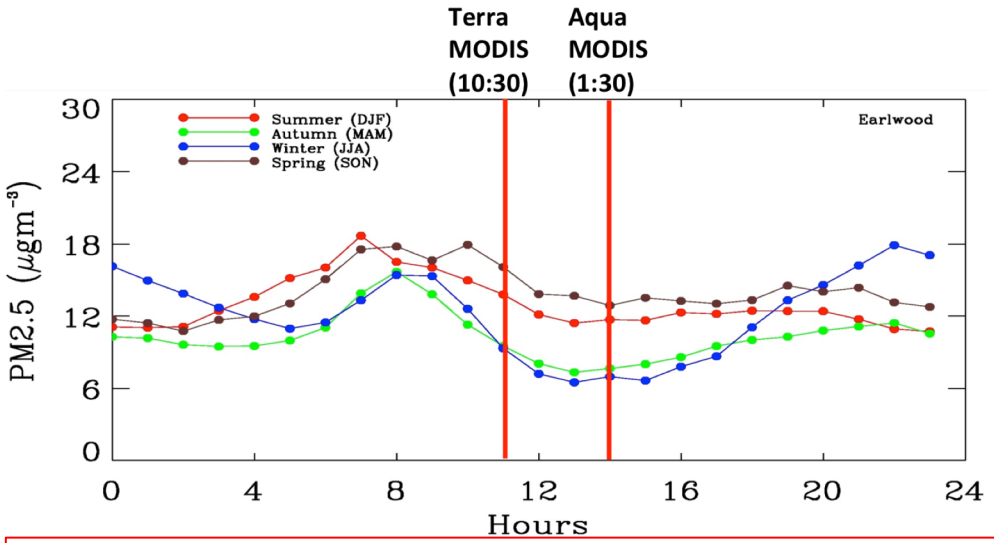
= L2 and L3 statistics

The DT family



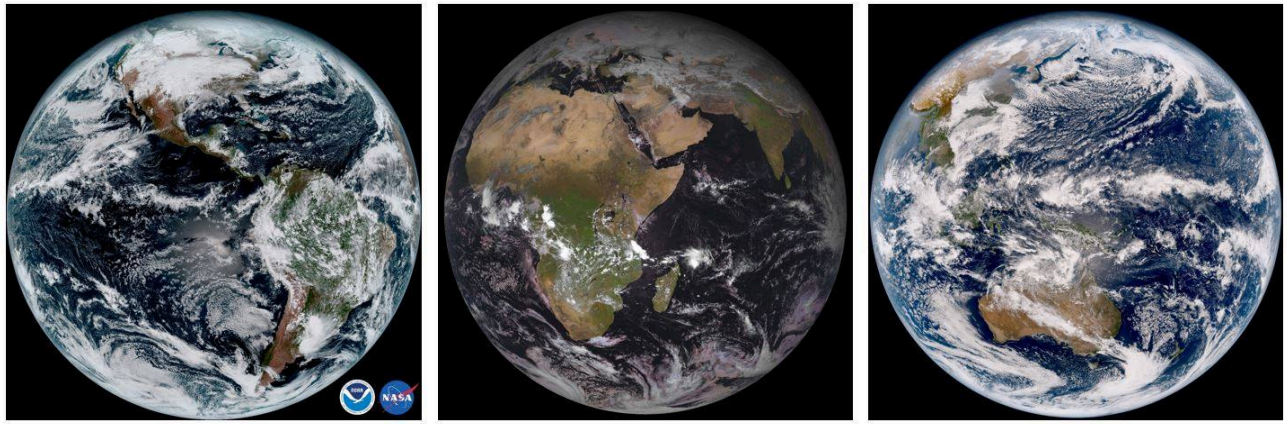
Summary

- ✓ 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 historical record



Polar orbiting satellites only provides 1-2 observations per day, which limits the application for continuous air quality monitoring.

GEO: Breaking the Temporal Barrier



GOES-16 METEOSAT-8 HIMAWARI-9

The beginning of a new era in satellite remote sensing of aerosol