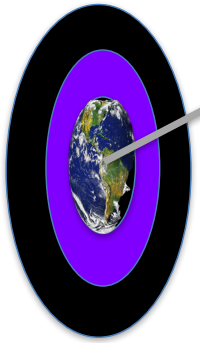


The Dark Target retrieval algorithm applied to a constellation of imagers: towards an integrated view of global aerosol.

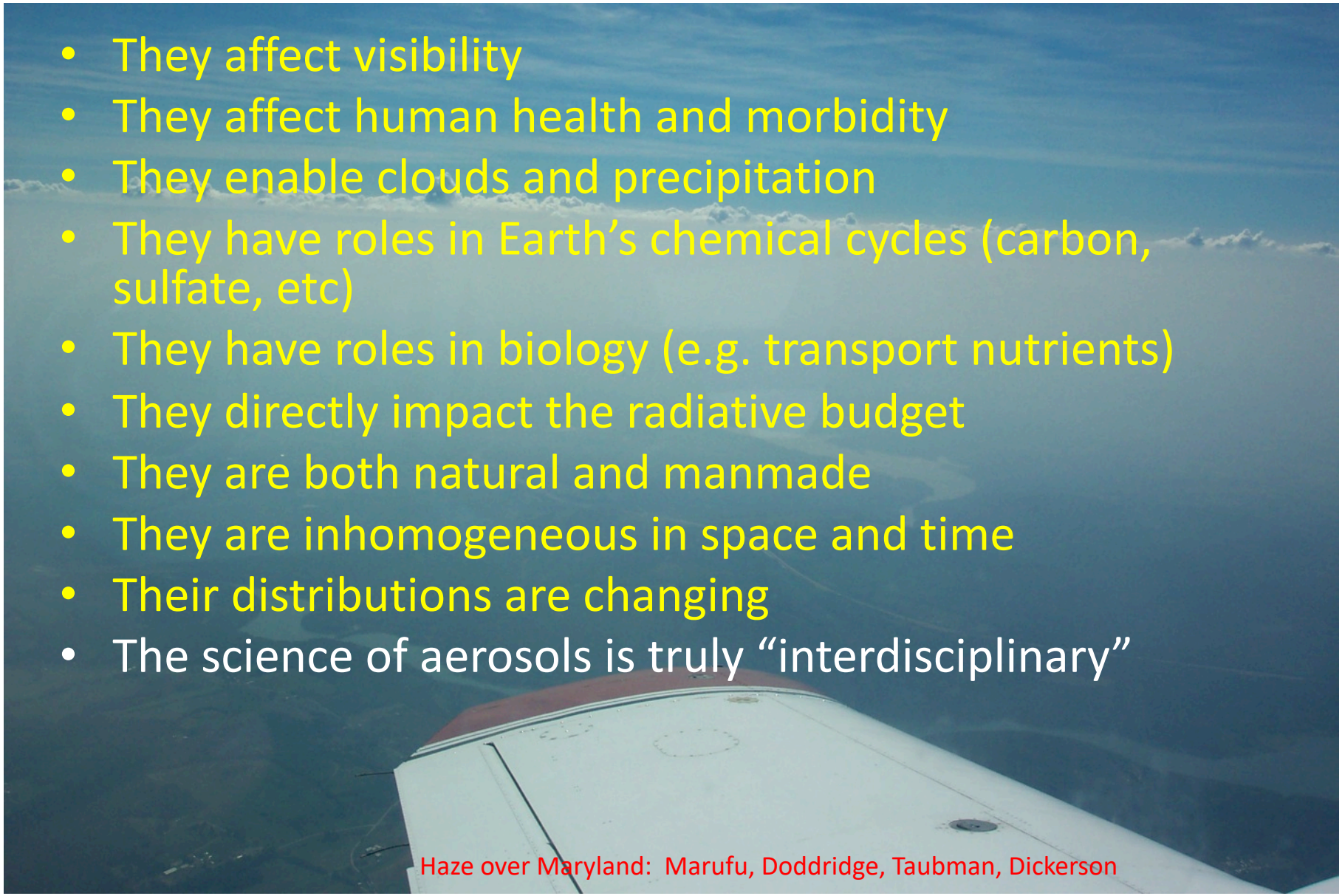
Robert C. Levy (NASA-GSFC), robert.c.levy@nasa.gov

Pawan Gupta[2,1], Shana Mattoo[6,1], Jennifer Wei[1], Min Oo[3], Lorraine Remer[4], Shobha Kontragunta[5], Zhaohui Zhang[7,1] Robert Holz[3] and Yingxi Shi[2,1]

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

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

Aerosols (why do we care?)

- **And we expect aerosol scientists to agree on A-CPP definitions and architecture ????????????**

In reference to APOLO-2019

- Here, we are learning about new and highly capable measurements (polarimeters with lots of angles, wavelengths, etc)
- And new missions including, A-CCP, PACE, 3MI, as well as other future sensors and missions
- Having a strong “Program of Record” is necessary for interpreting all of these new measurements.

What is the Program of Record? (in my mind)

- Stable and well-characterized datasets retrieved from well-characterized sensors
- Record begins before now, and will most likely be continued well into the future
- Includes parameters and variables indicated by the WMO as being integral to assessing climate
- Retrieved parameters from ‘current’ techniques (boring, yes)
- Could also include parameters from ‘in-development’ techniques

Our small contribution to PoR

- Developing a long (20 years +) and wide (nearly-global) data record using a consistent algorithm on multiple and diverse sensors.
- Moving (too slowly for Jeff) from simple ‘diagnostic’ error towards more useful ‘prognostic’ error estimates
- Primary is Aerosol optical depth (AOD) over land and ocean, along with size estimates over ocean.
- Now: Exploring methods of data fusion and new inversions that retrieve other aerosol parameters

Outline

- The Dark-Target aerosol retrieval algorithm
  - MODIS Terra versus MODIS Aqua
  - VIIRS-SNPP versus Terra-Aqua
  - Addition of Geostationary sensors (AHI and ABI)
- Relationship of AOD product versus GCOS climate requirements
- Data we hope are useful and easy
- Some new ideas for retrievals from LEO+GEO : Could these become PoR?

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

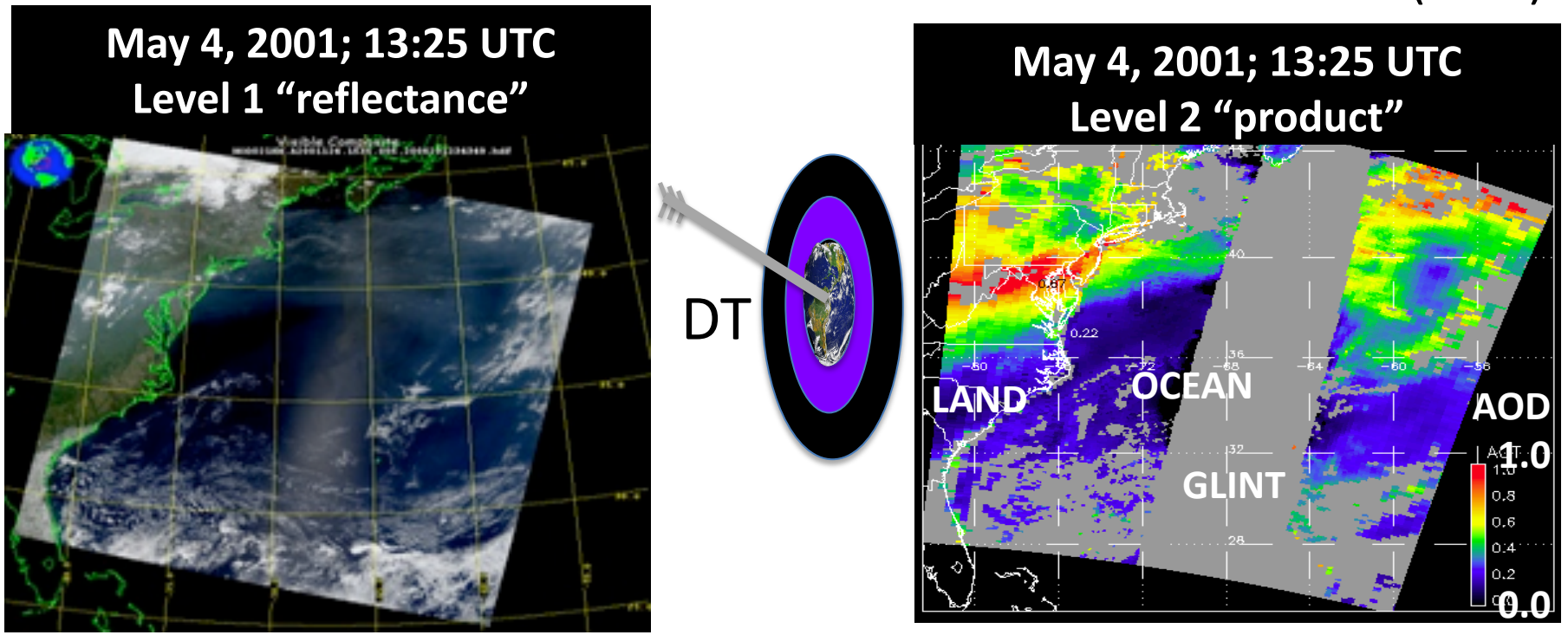
(air quality, ocean fertilization, weather forecasting...)

How are we get there?

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

What a sensor observes

Attributed to aerosol (AOD)



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

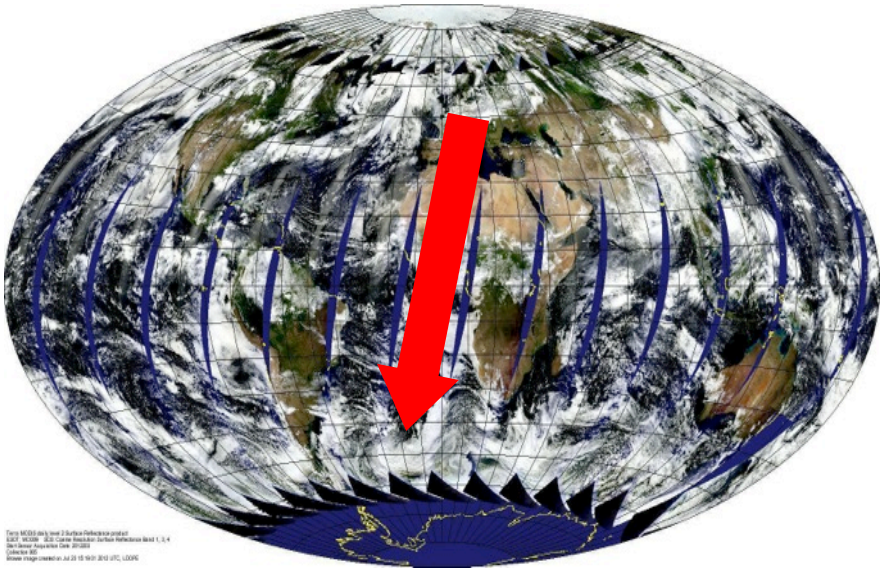
"Modified 2005, 2010, 2013, 2015" by Remer, Levy, Mattoo, Gupta, etc

Separate logic over land and ocean

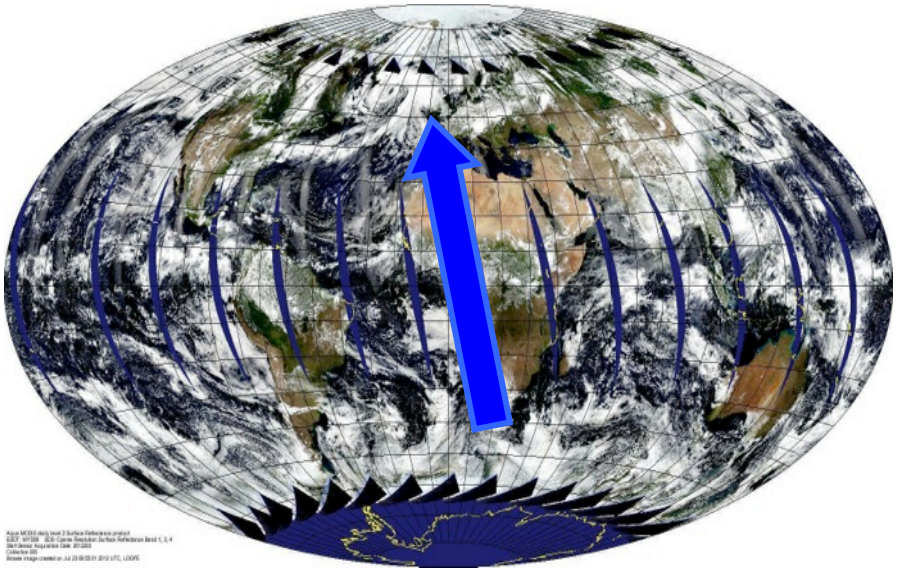
Retrieve: AOD at 0.55 μm, spectral AOD (AE), Cloud-cleared reflectances, diagnostics, quality assurance

MODIS-Terra vs MODIS-Aqua

Terra (10:30, Descending)



Aqua (13:30, Ascending)



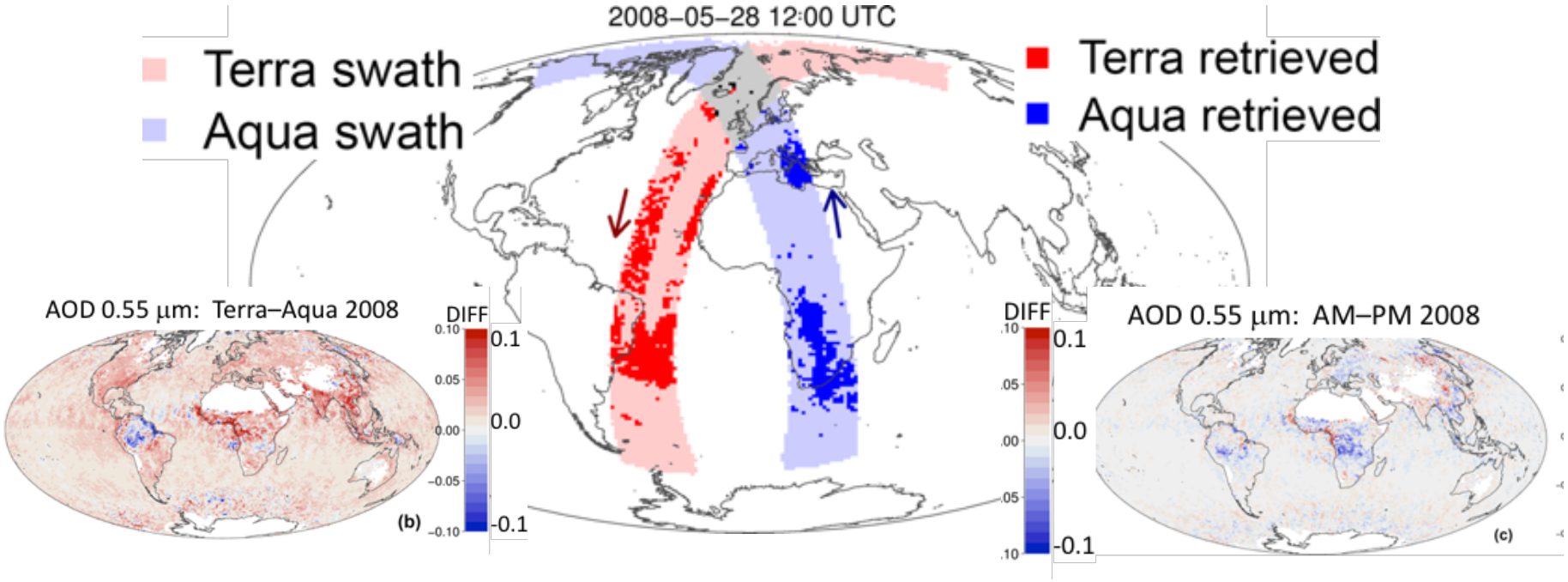
The two MODIS instruments are **TWINS!**

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.

Both datasets are in spec
But offsets of 10-15% (0.01-0.02).

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

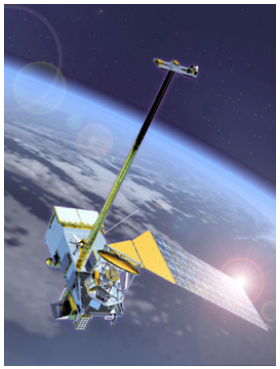


- MERRA-2 “replay” (meteorological assimilation – no Terra/Aqua)
- Sample at time of Terra and Aqua overpass (swath)
- Sample only where DT algorithm provided retrieval (retrieved)
- Aggregate to monthly and global means
- Look at AM–PM differences (Terra–Aqua) for AOD and AE
  - → **Some similarity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

→ **Can we Evaluate, who is correct? Can we cross-calibrate one to the other?**

Beyond **MODIS**

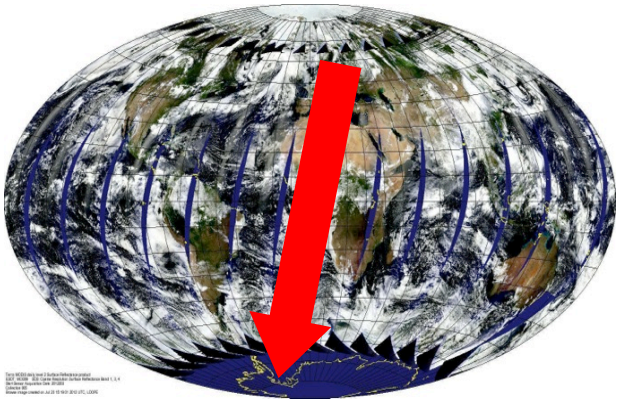
- Terra (19+) and Aqua (17) have well-exceeded their planned lifetimes.
- With luck, they will last through 2022.
- For climate, we need to continue the MODIS record, with no “jumps”



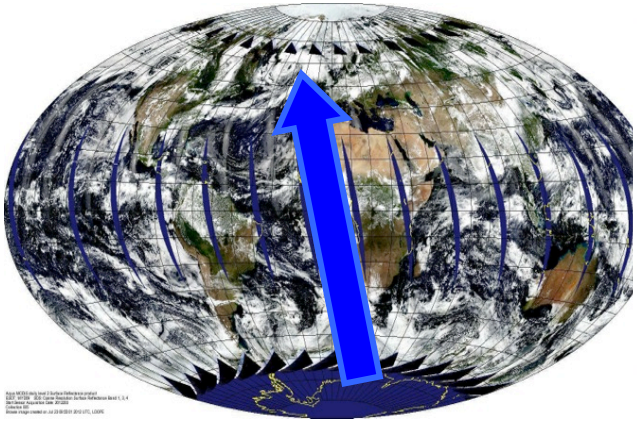
VIIRS!

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

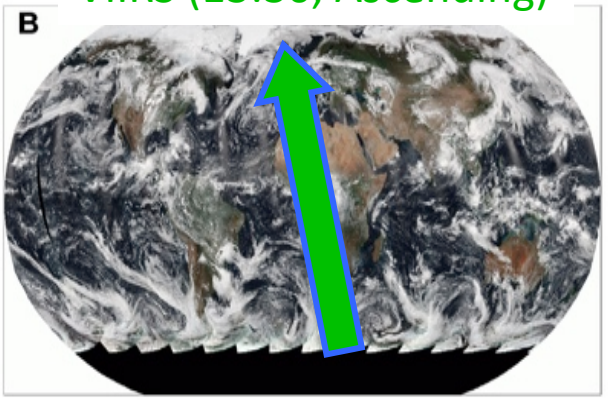
Terra (10:30, Descending)



Aqua (13:30, Ascending)

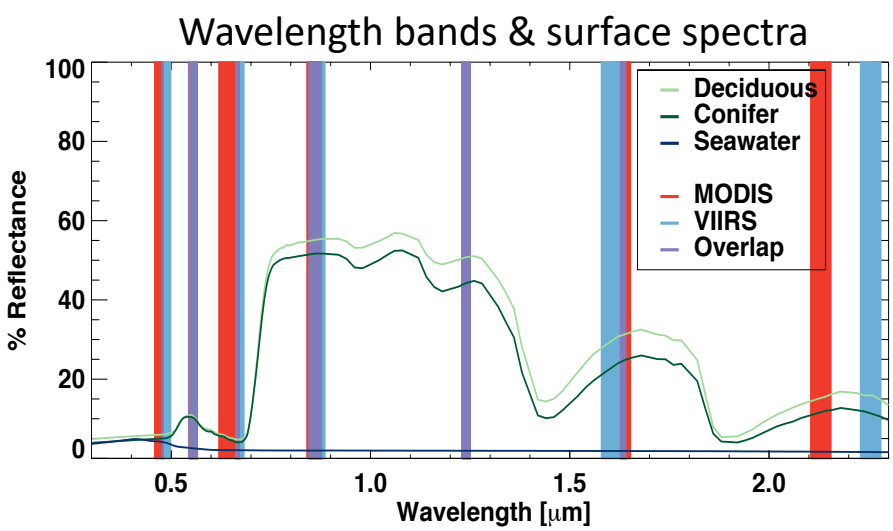


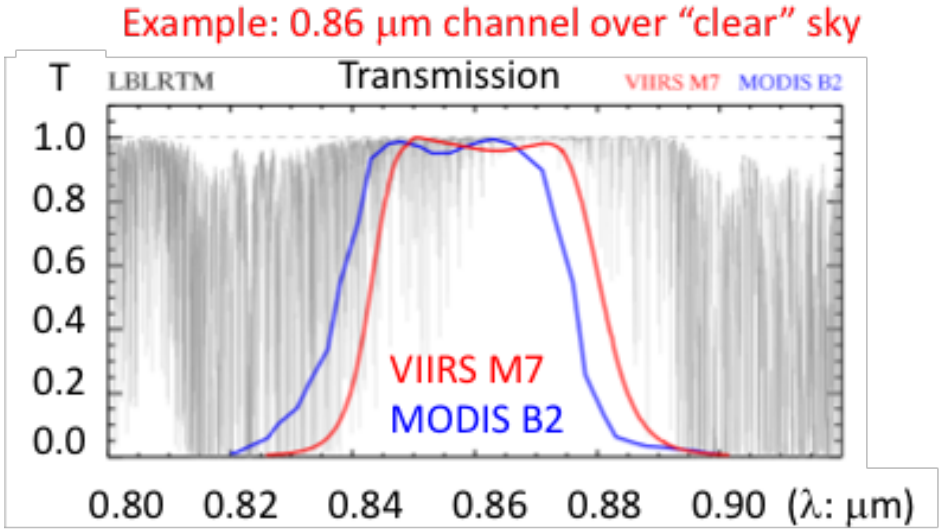
VIIRS (13:30, Ascending)



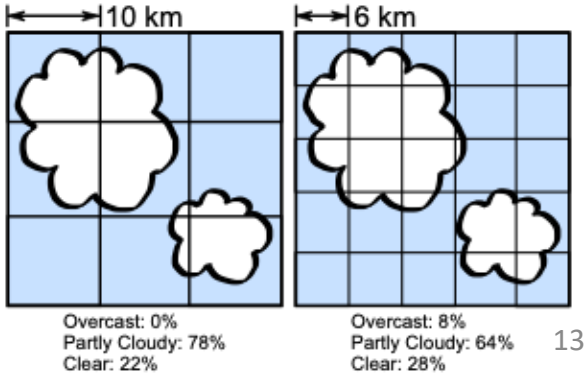
For “continuity” we can port the algorithms (Example: DT from MODIS→VIIRS)

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

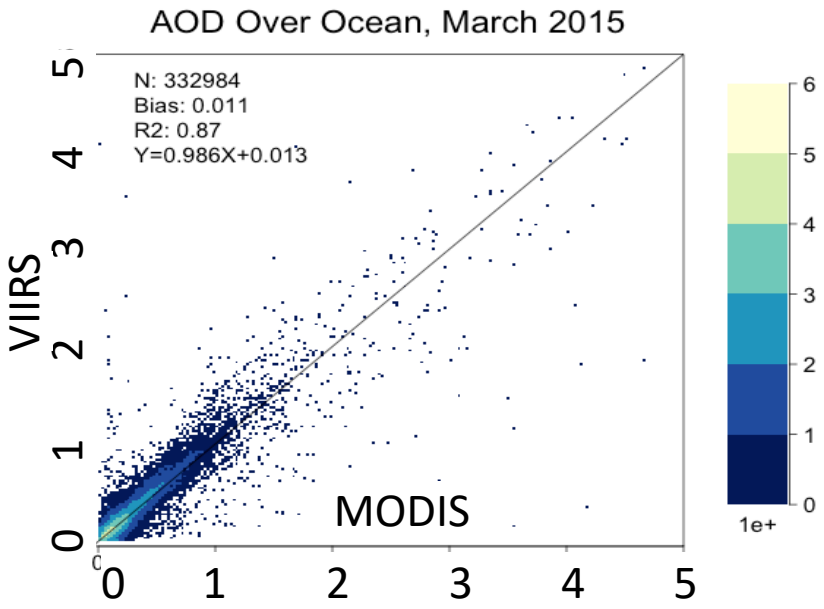


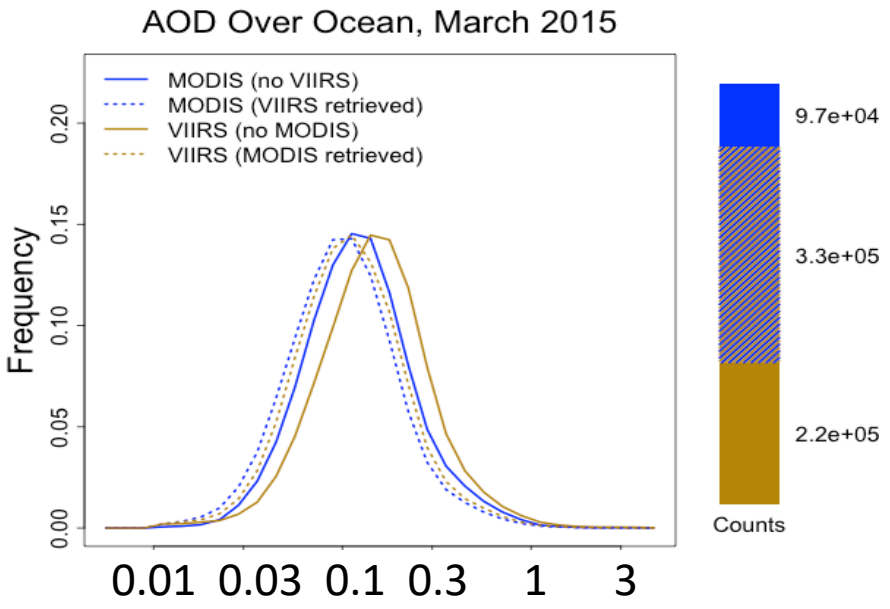


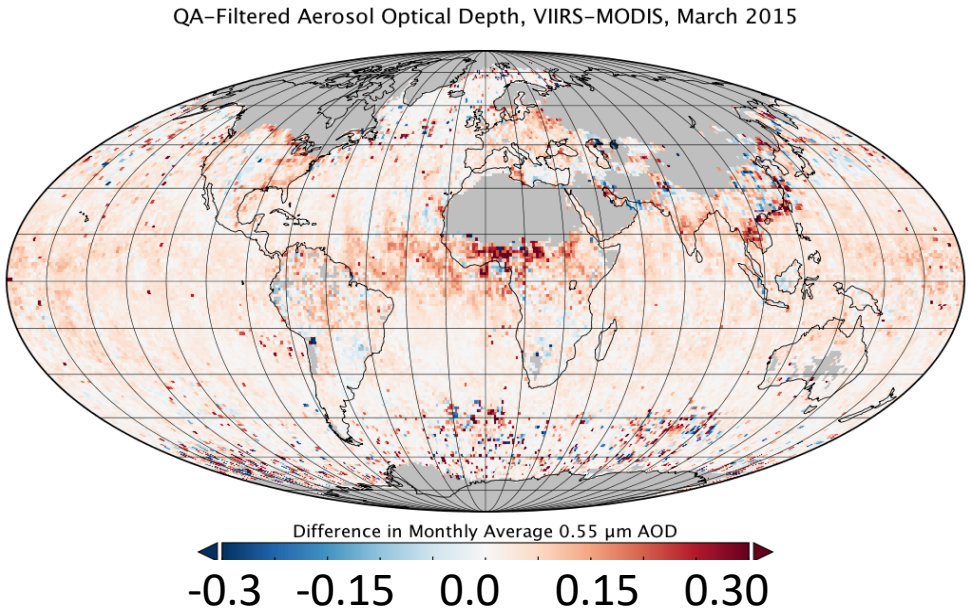
- Deal with differences in resolution, etc.
  - MODIS standard is 10x10 of 1 km pixels
  - VIIRS standard is 8x8 of 0.75 km pixels



Statistics of VIIRS vs MODIS

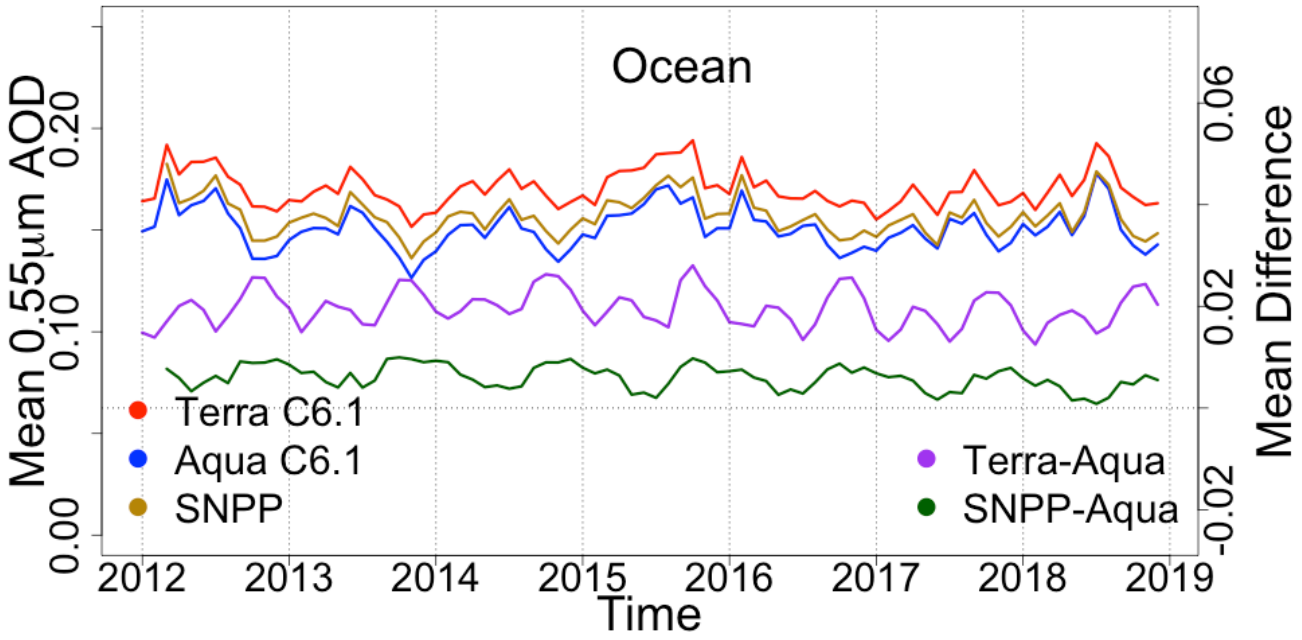






- Common grids
- For March 2015:
  - Over ocean, overall: VIIRS-MODIS = 0.01
  - Bigger story is that VIIRS-only is much larger than MODIS-only

MODIS-Terra vs MODIS-Aqua vs SNPP-VIIRS



- Close over ocean, but offsets remain.
- Why different seasonal cycles of offsets?

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

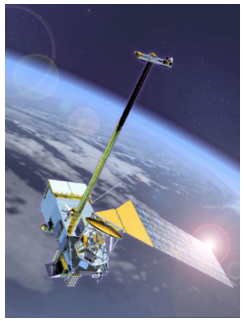
Status of MODIS and VIIRS

- MODIS Collection 6.1 (MxD04) available from 2017
  - All data reprocessed (2000 – 2017) use 'detrended' calibration for L1B,
  - >2017 data use 'step-forward' calibration for L1B
  - Data available in HDF4 format, scripts to convert to NetCDF4.
  - Provides 'reflectance' information for data assimilation
  - Includes Dark-Target / Deep Blue (DT/DB) merge product

- VIIRS Version 1.0 Dark-Target ('AERDT_VIIRS_SNPP') available any day now.
  - All data reprocessed (2011-present) use 'step-forward' calibration (no de-trending applied)
  - DT Data (will be) available in NetCDF4. All output parameters same as MODIS
  - Deep Blue already ('AERDB') available since early 2019.
  - Currently, no DT/DB merge, but Christina and I are willing to develop.
  - Testing on NOAA-20.

- Joint 'Collection 7' (TBD)? Hopefully will include
  - Prognostic error analysis: Jacobians as well as Ensemble calculations
  - Consideration of 'distance to nearest cloud' in retrieval
  - Retrievals (qualitative) in high loading (e.g. smoke/dust/pollution) conditions (not flagged as cloud, inland water, or snow).
  - Coastal retrievals
  - Continued integration with NASA-tools (e.g. Giovanni, Worldview, Panoply, etc).

LEO versus GCOS (for AOD)



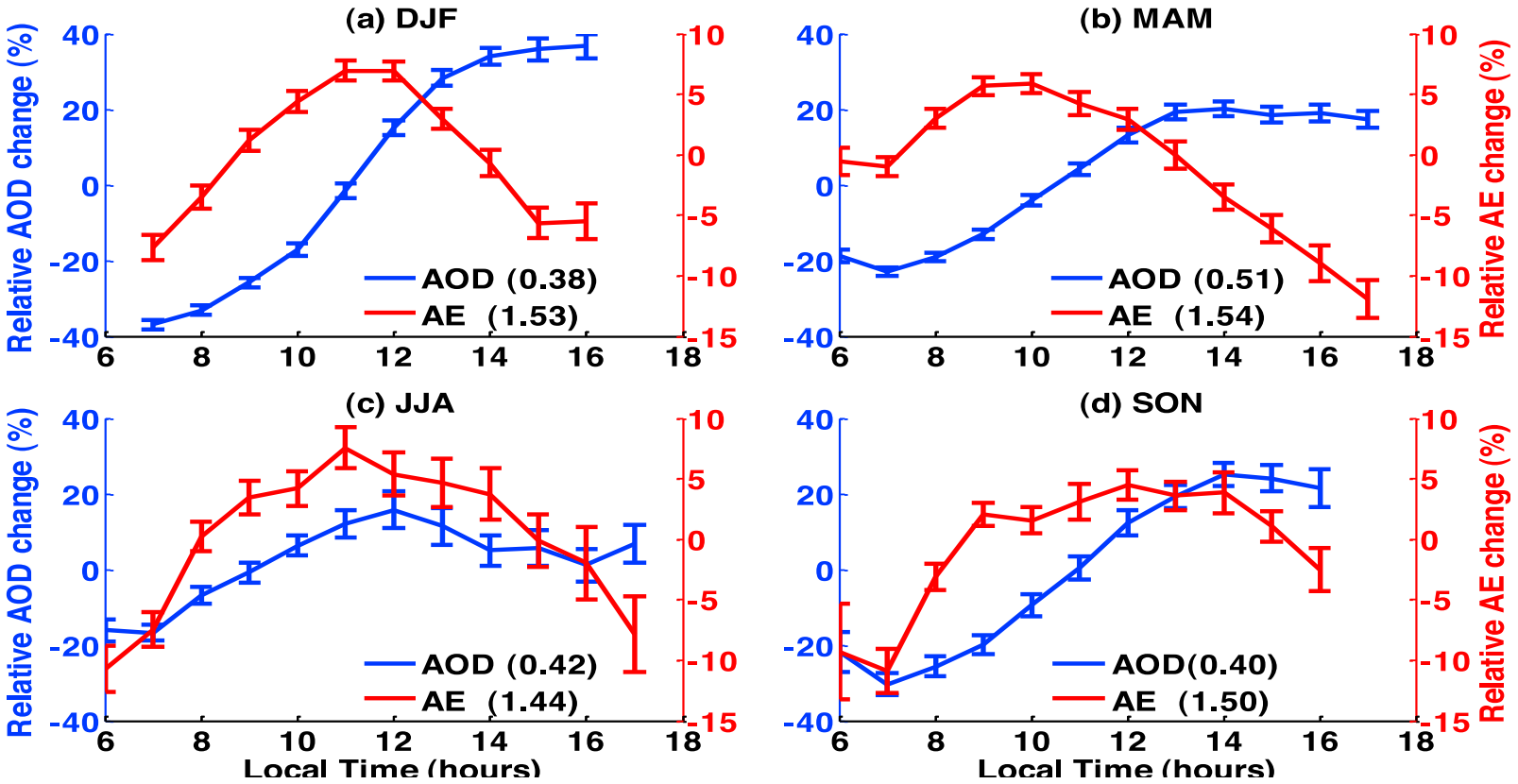
Target metric	Target	Current with MODIS
Horizontal Resolution	5-10 km, globally	≤10 km over ice-free and cloud-free scenes
Accuracy	MAX(0.03 or 10%)	±(0.04+10%): Ocean ±(0.05+15%): Land
Stability / bias	<0.01 / decade	Nearly stable trends, but offsets still
Time Length	30+ years	Can do with MODIS + VIIRS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

What's still missing?

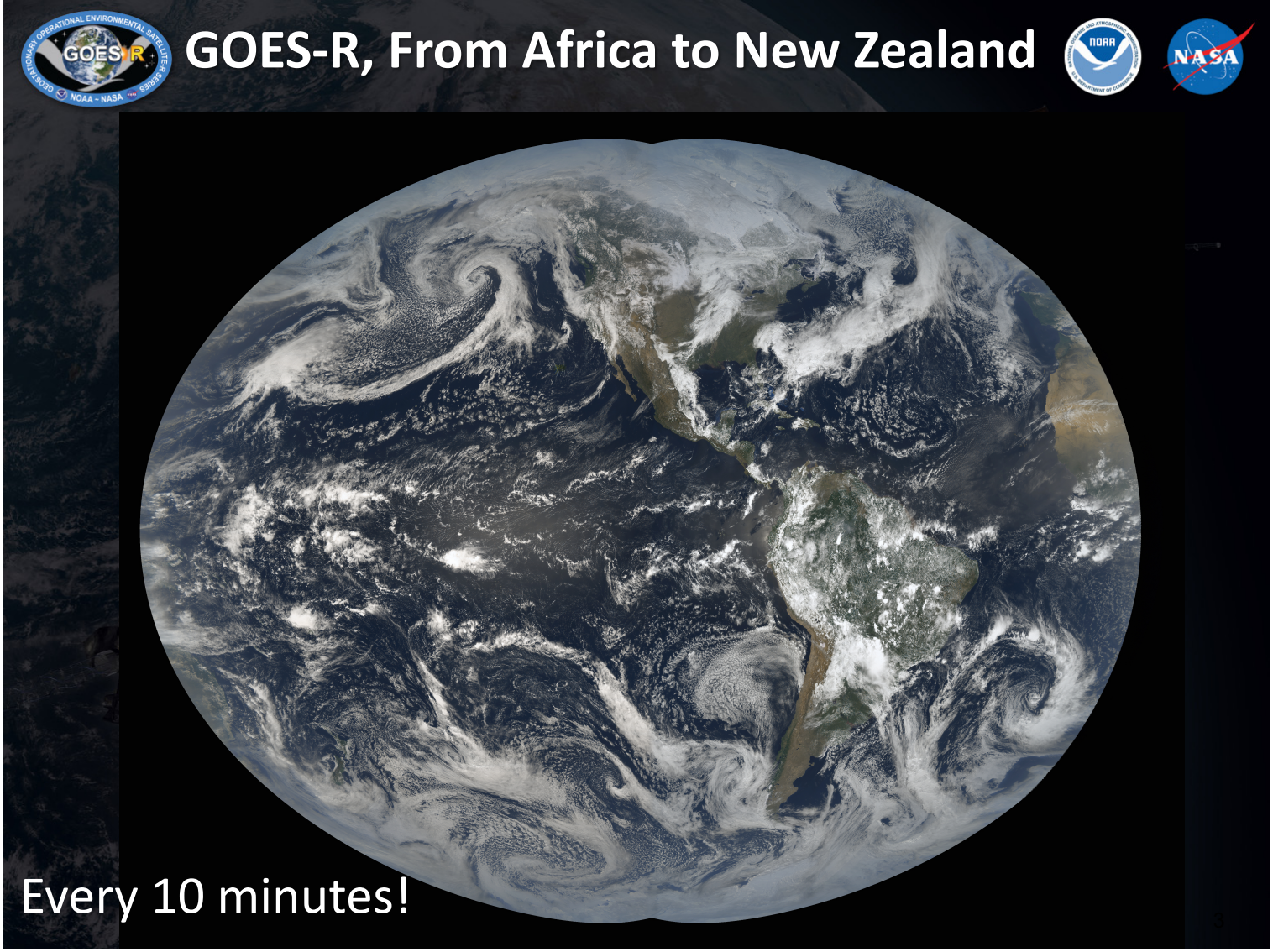
Temporal variability!

Breaking the Temporal Barrier!

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



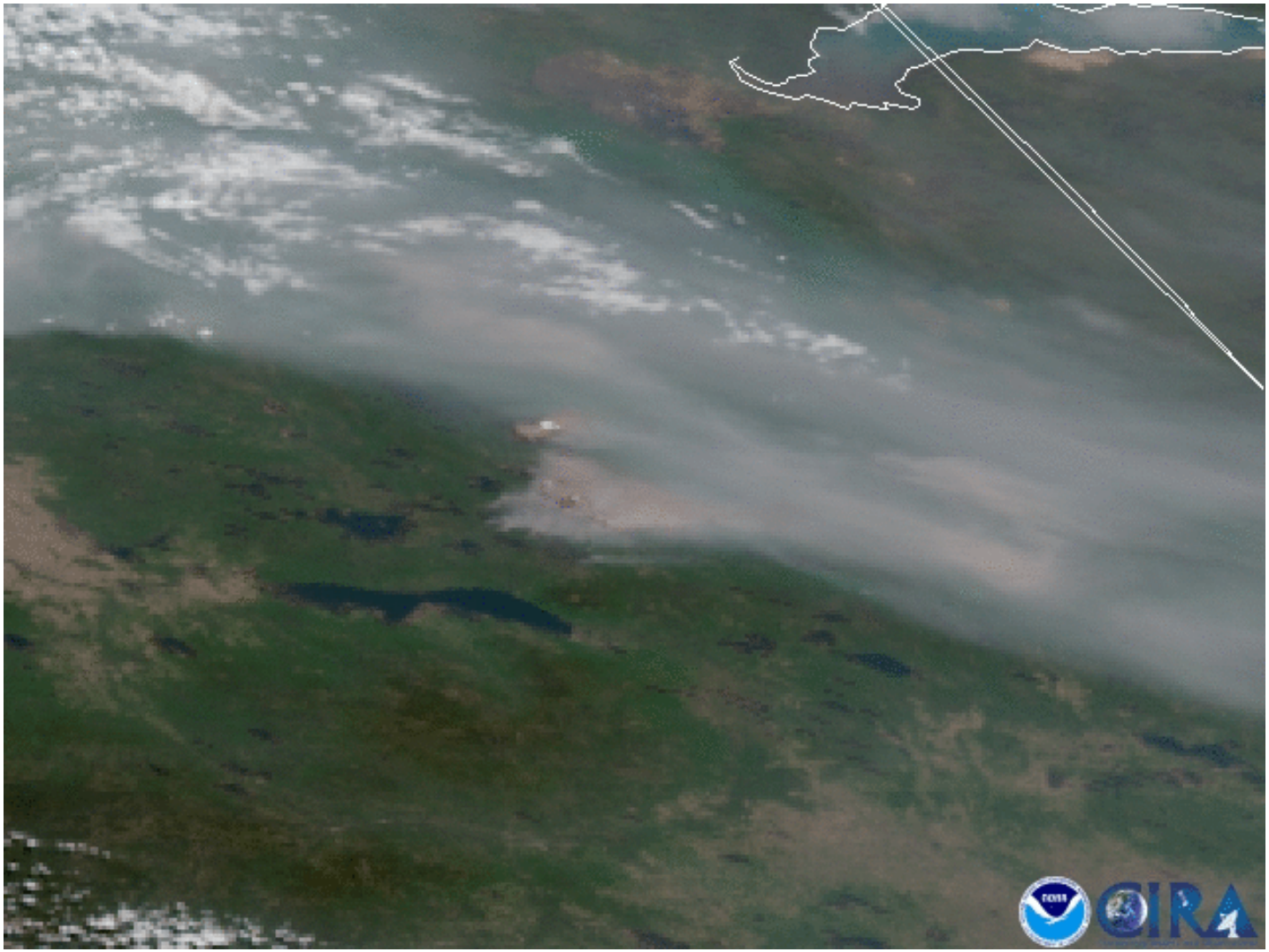
From: Zhang, Y., Yu, H., Eck, T. F., et al, (2012). Aerosol daytime variations over North and South America derived from multiyear AERONET measurements, *J. Geophysical Research*.



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

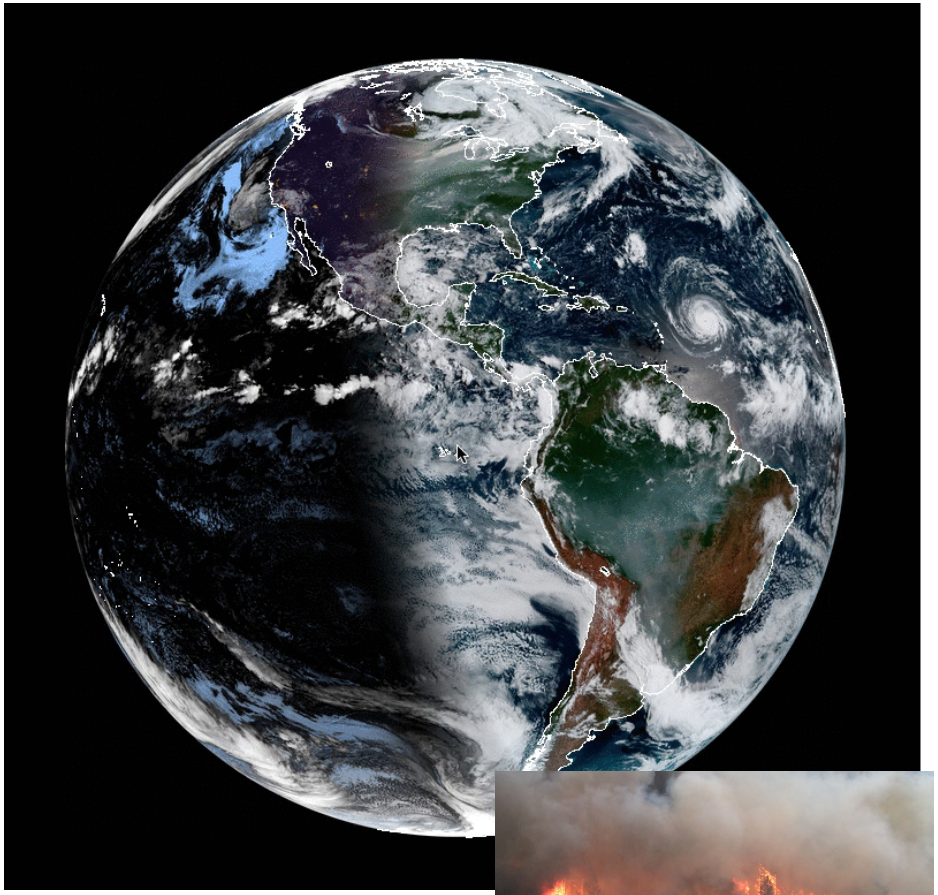
Some details need to be worked out (e.g. lack of "cirrus" band on AHI);

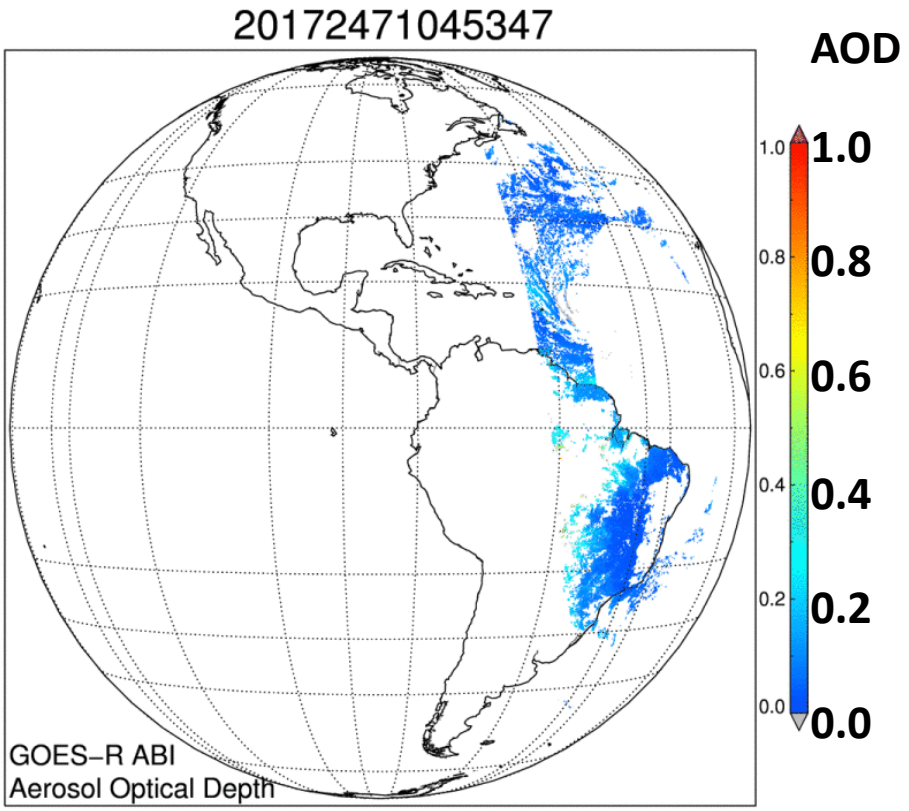
Green band: MODIS/VIIRS @ 0.55 μm, AHI @ 0.51 μm, ABI @ none

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

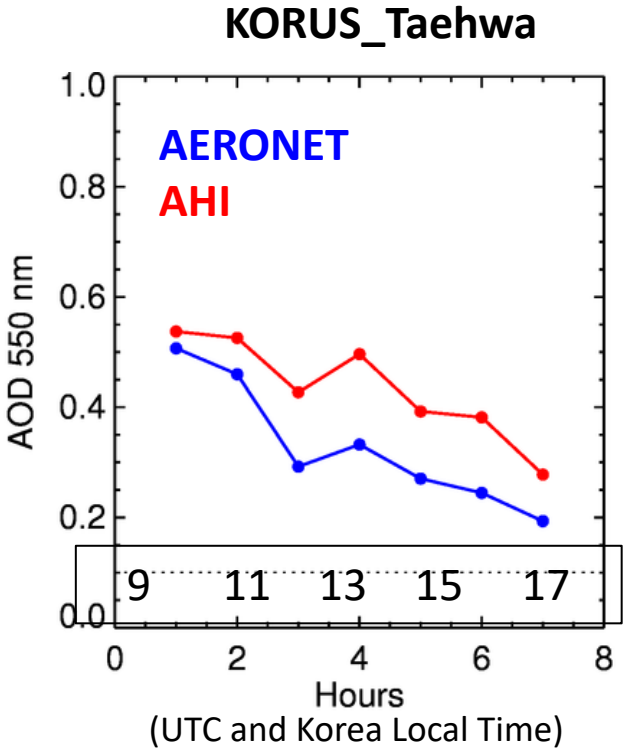


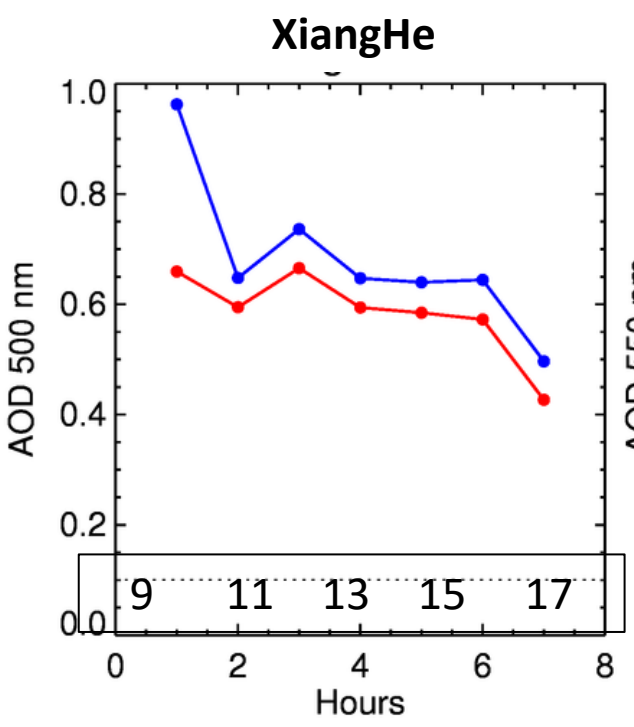


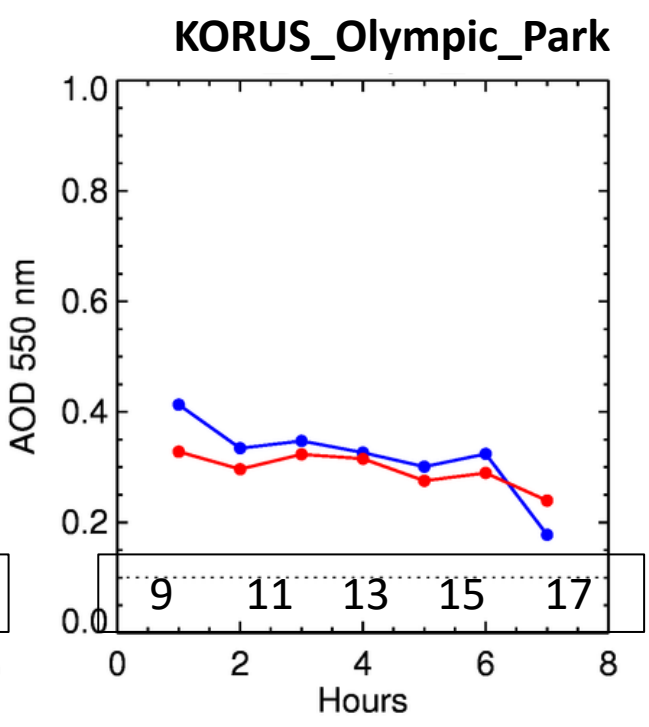
ABI = Advanced Baseline Imager

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

-→ GEO does have sensitivity to Diurnal Cycle!!



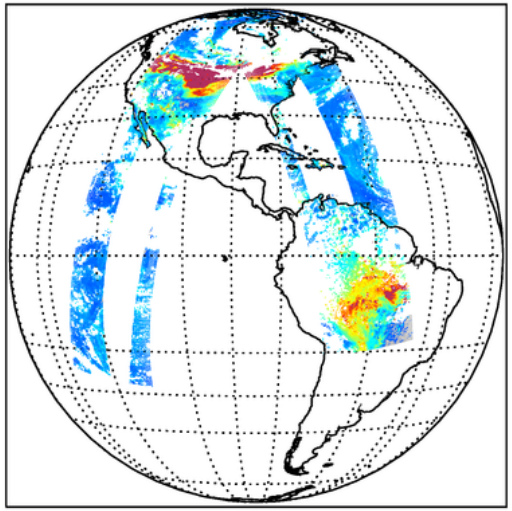




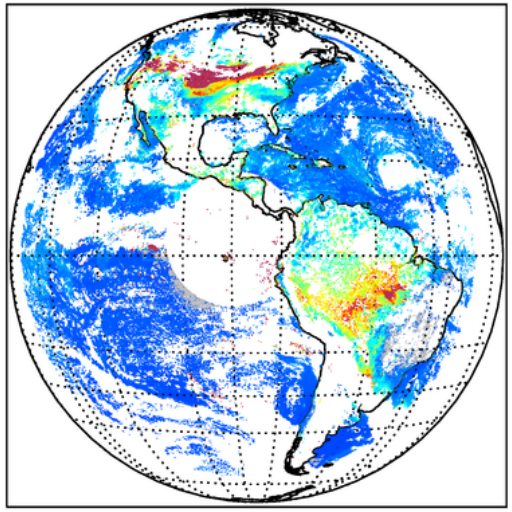
Pawan Gupta

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

Terra and Aqua
MODIS.20172471800

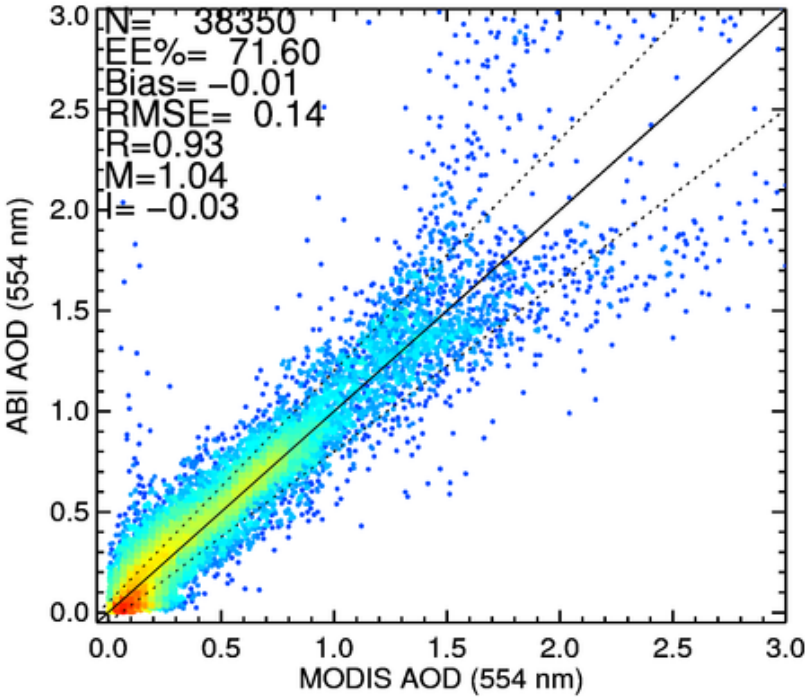


GOES-16
ABI.20172471800

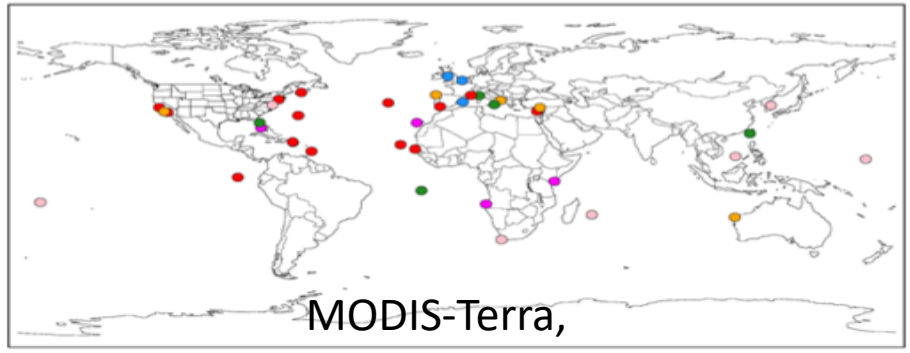


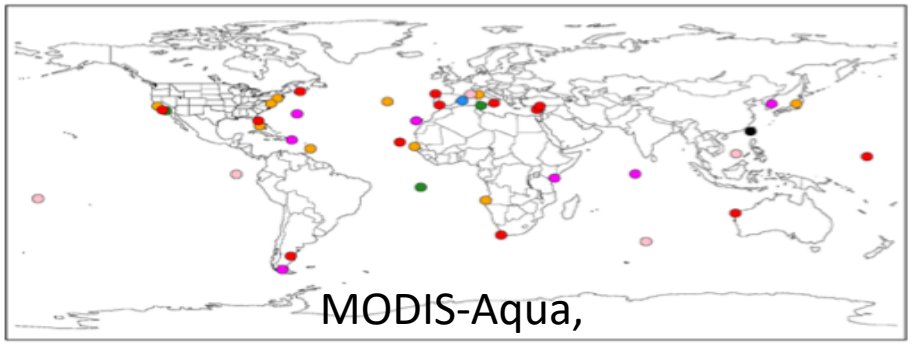
Overall, not too bad

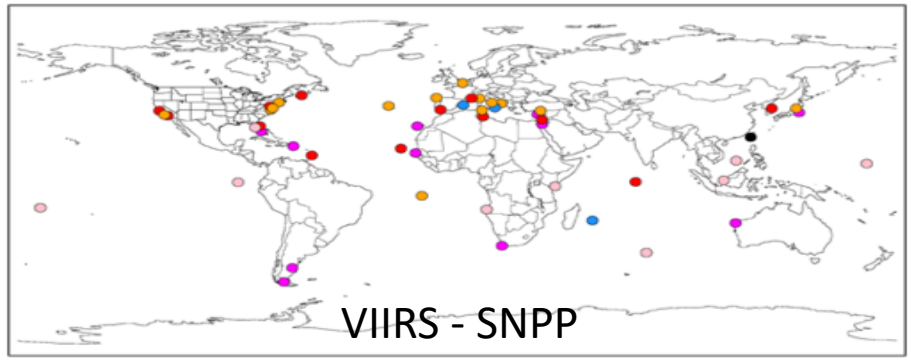
ABI versus MODIS

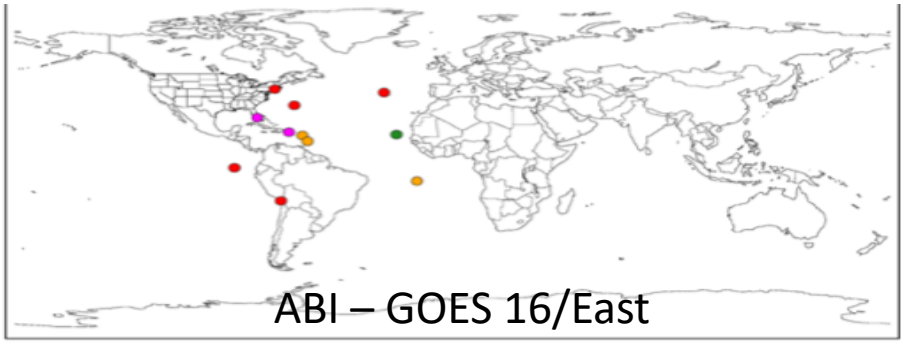


Reasonable consistency at sites (Satellite – AERONET: Ocean, Dec 2018)

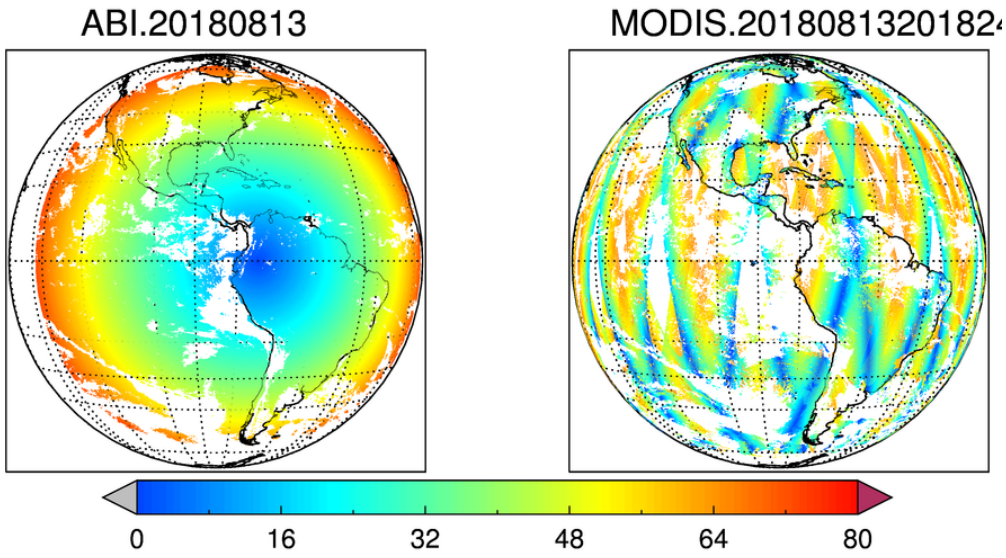






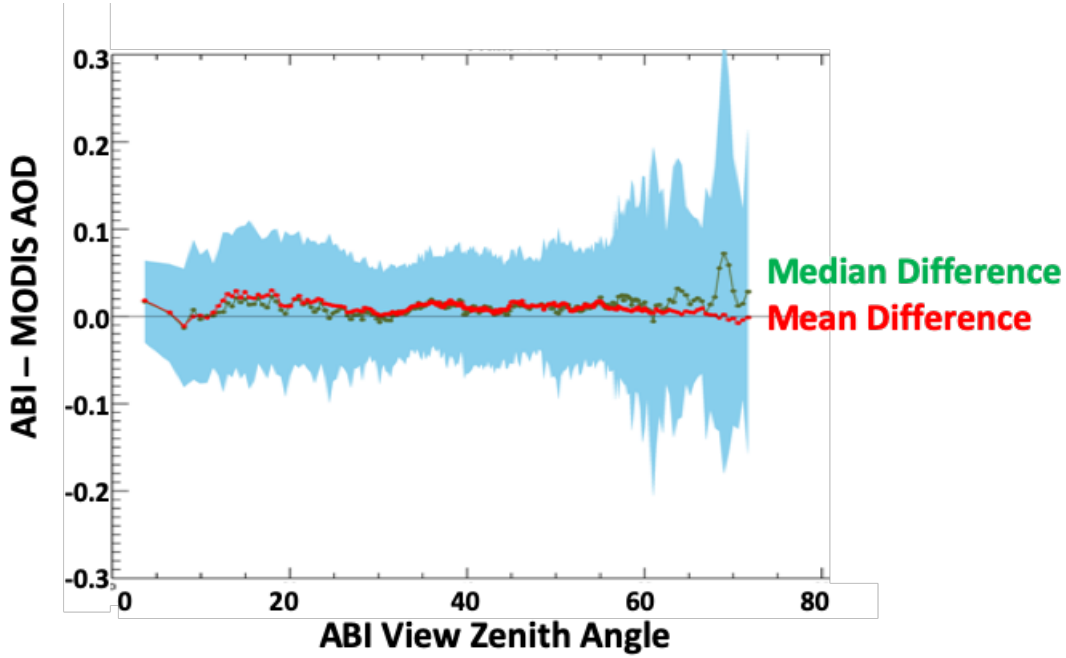


GEO vs LEO: Sensor View Zenith angle biases?

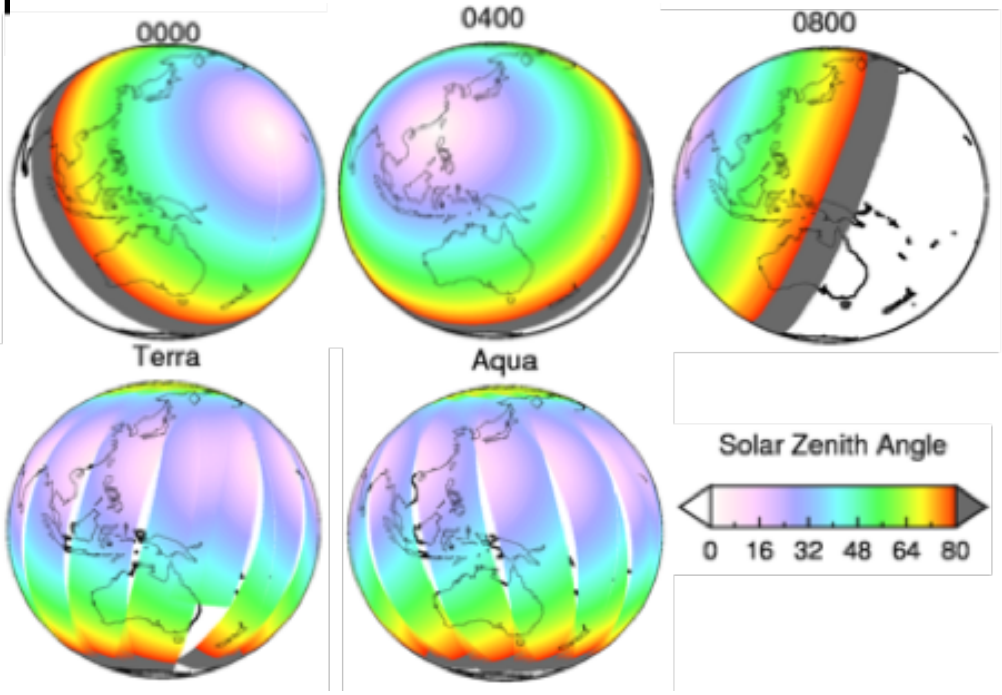


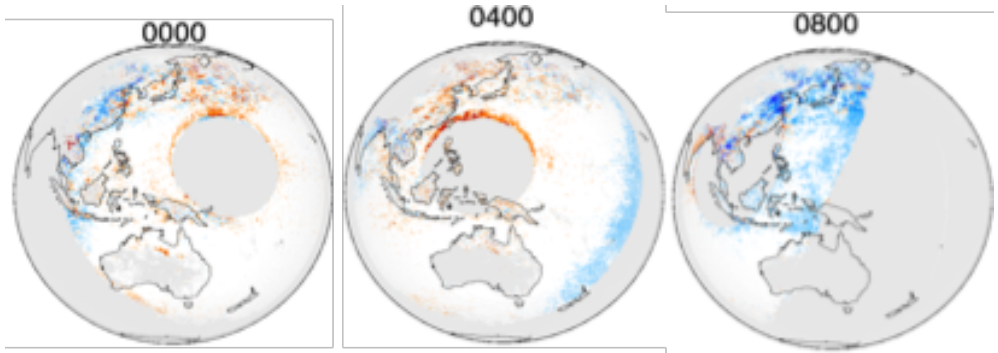
- From Aug 13, 2018
- GEO Sensor view distribution for all disk images
- LEO sensor view distribution varies along orbit

- **Larger angles ≥ 60° have biases of ABI versus MODIS**



Also some solar angle issues

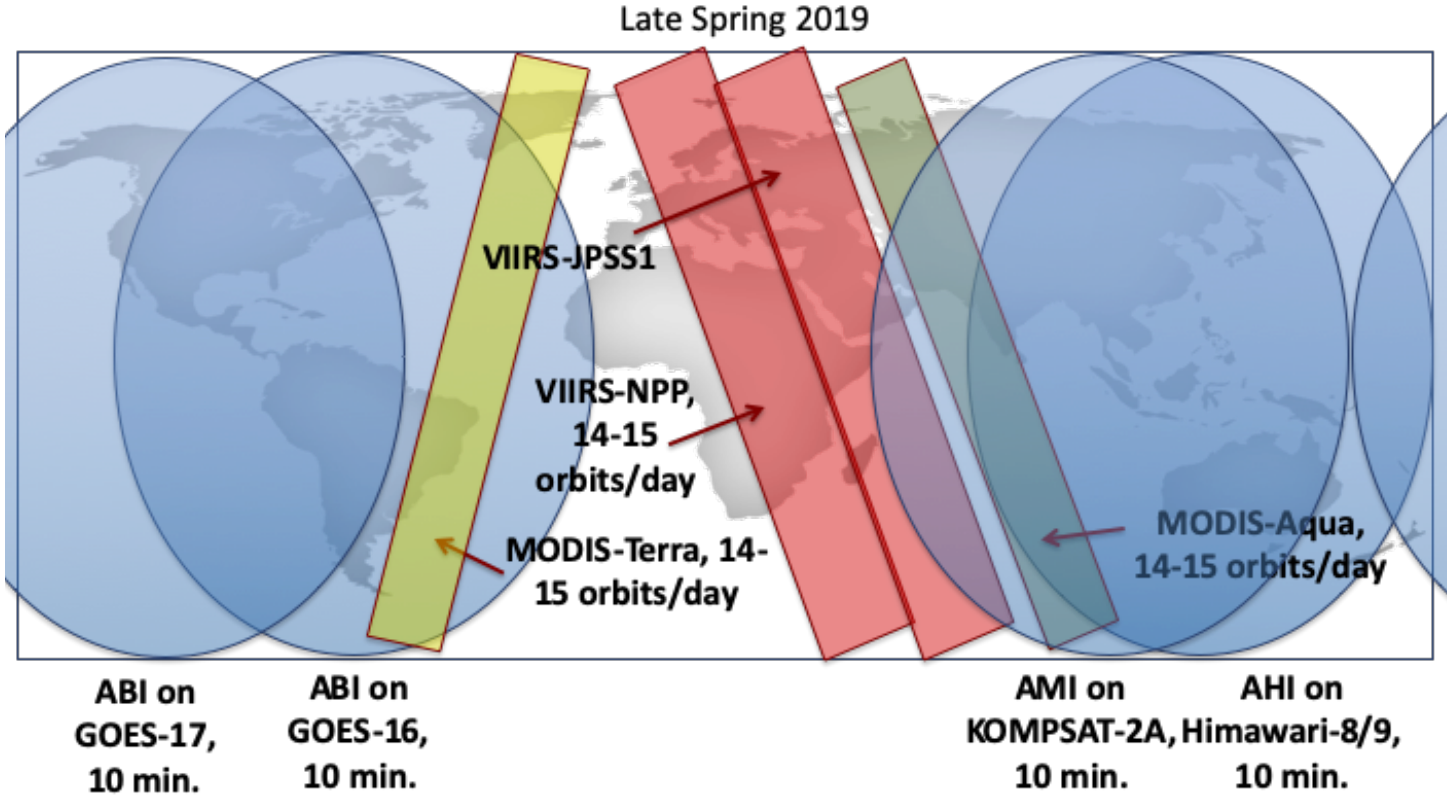




Difference in AHI hourly mean AOD versus daily mean

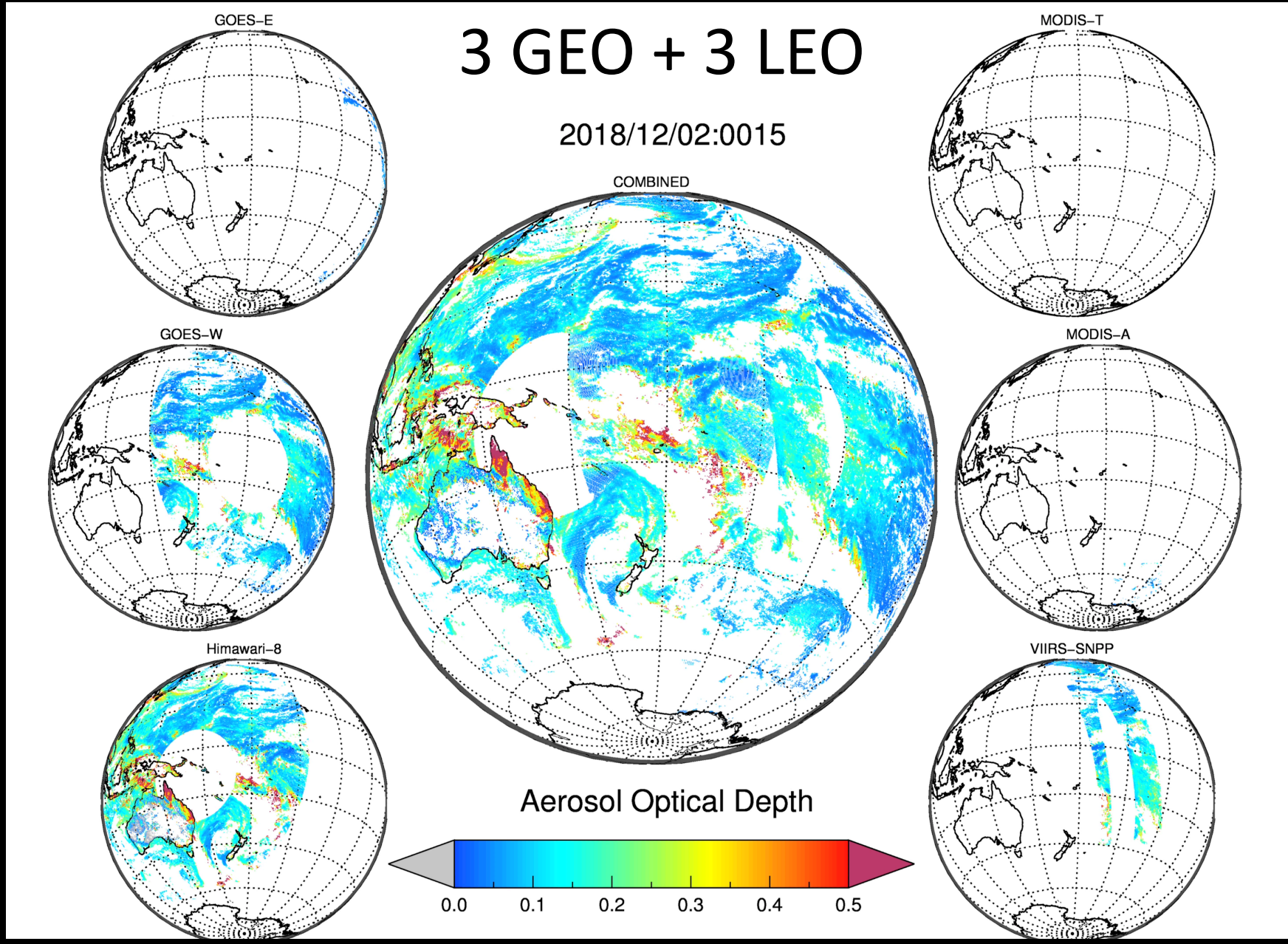
- Solar/Viewing (Zenith & Azimuth Angles) geometry is new to us.
- Constant VZA at fixed grids
- High SZA near sunrise/sunset never observed by MODIS/VIIRS
- Distribution of glint/scattering angle patterns / phase function?
- Radiative Transfer challenge for very large angles?
- “Spherical” earth has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

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

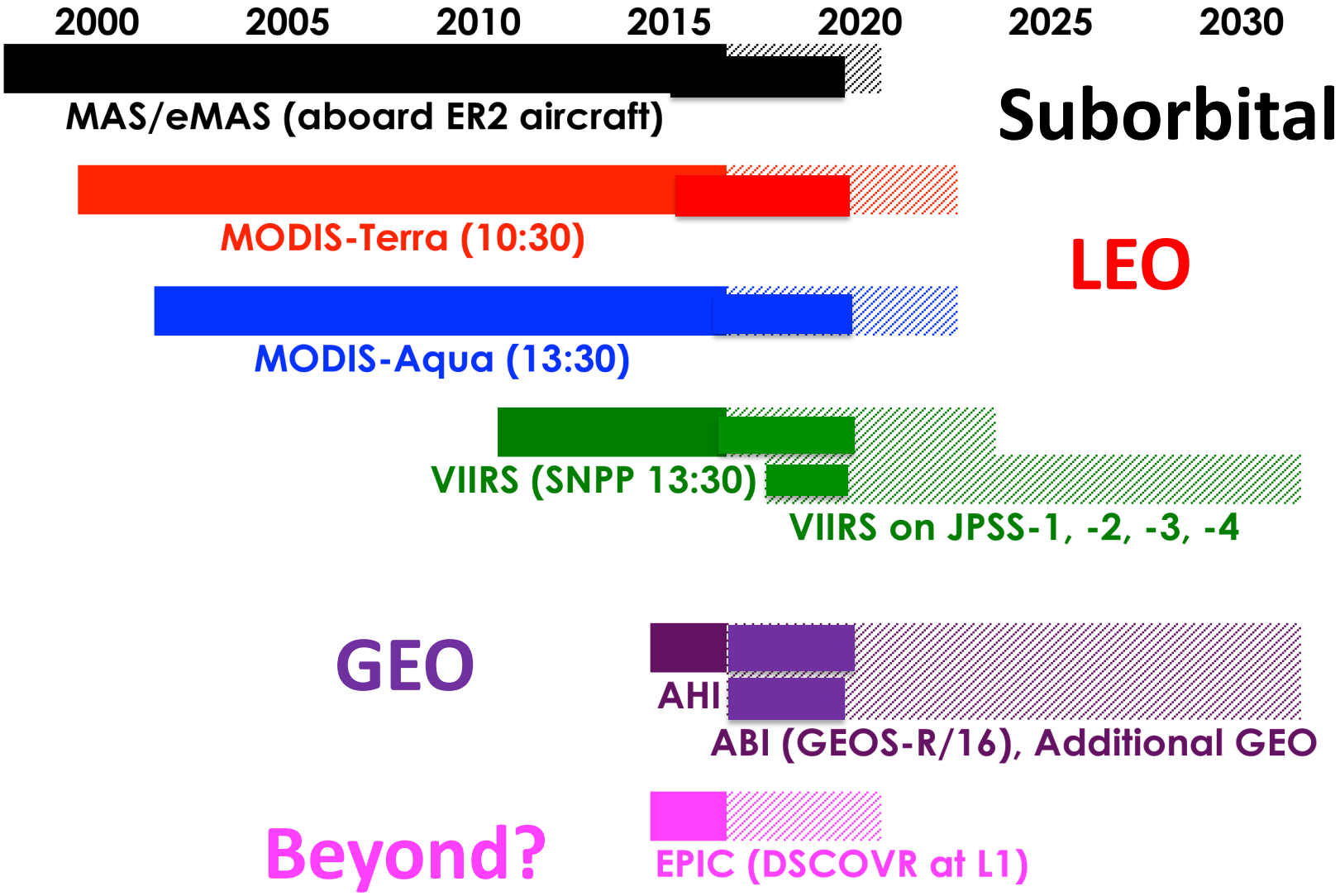


- Can we observe climatology (and diurnal cycle and transport) of global aerosol?
- Coming soon: FCI on MTG over Europe and Africa!

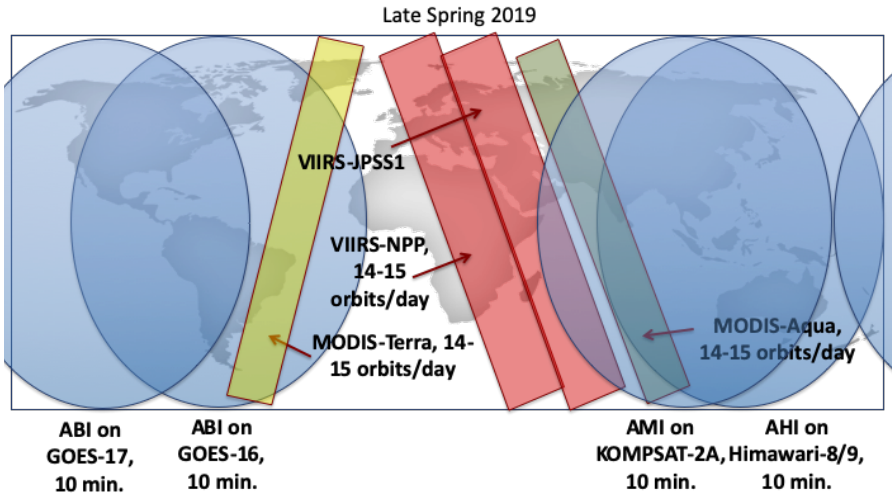
And now for a movie…


3 GEO + 3 LEO
2018/12/02:0015
GOES–E
MODIS–T
COMBINED
GOES–W
MODIS–A
Himawari–8
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)



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	Where GEOs:

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

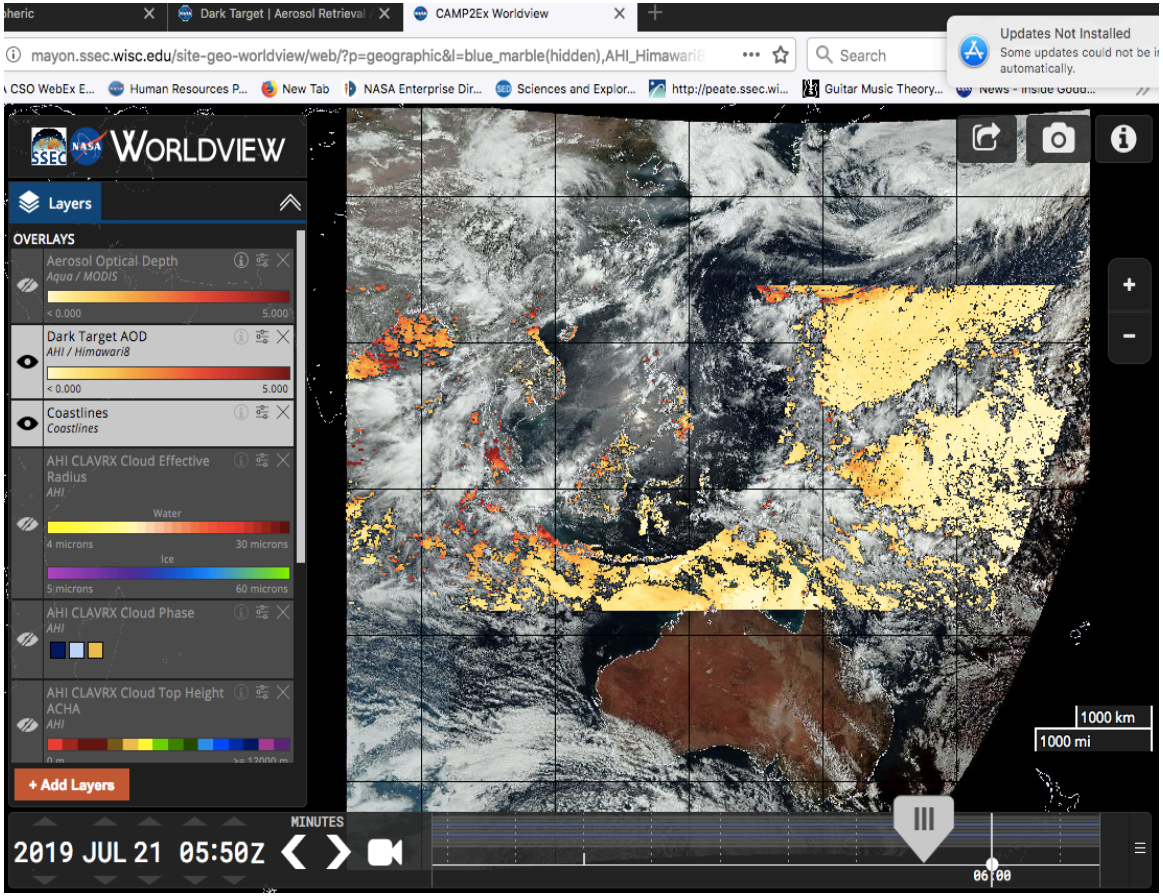
We are getting there!

We still have 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
- Effective and useful imagery

Data are useful: AHI during CAMP2EX (2019)

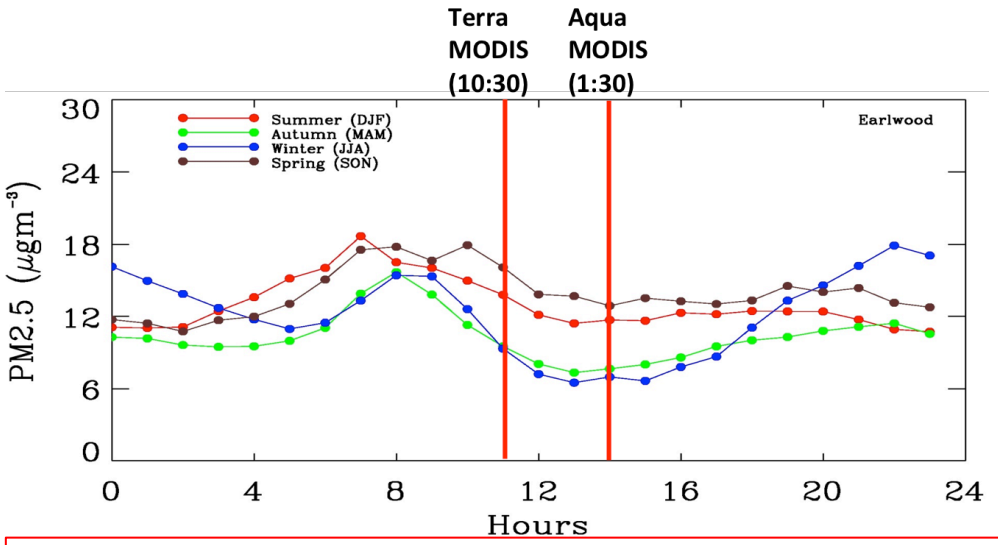
- Wisconsin ran Dark Target in NRT for AHI.
- Using GFS “forecast” as ancillary for H_2O, O_3, wind speed.
- Domain centered over Philippines
- imagery within instance of Worldview



Bob Holz, U Wisconsin

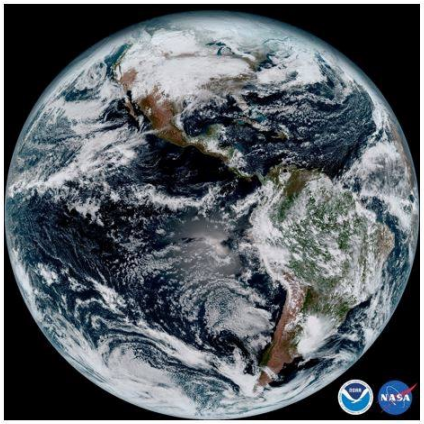
GEO / LEO synergy

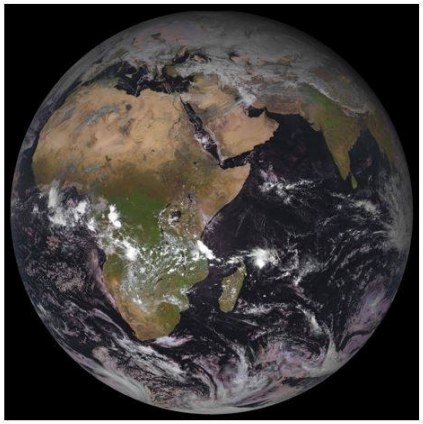
- ✓ Aerosol measurements for LEO have long history , validation and use for AQ and climate applications.
- ✓ Aerosol measurements from GEO orbit is a step forward in breaking the temporal barrier.
- ✓ GEO constrains multiple LEO sensors, .and LEO constrains multiple GEO. Synergy!
- ✓ For the global climate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

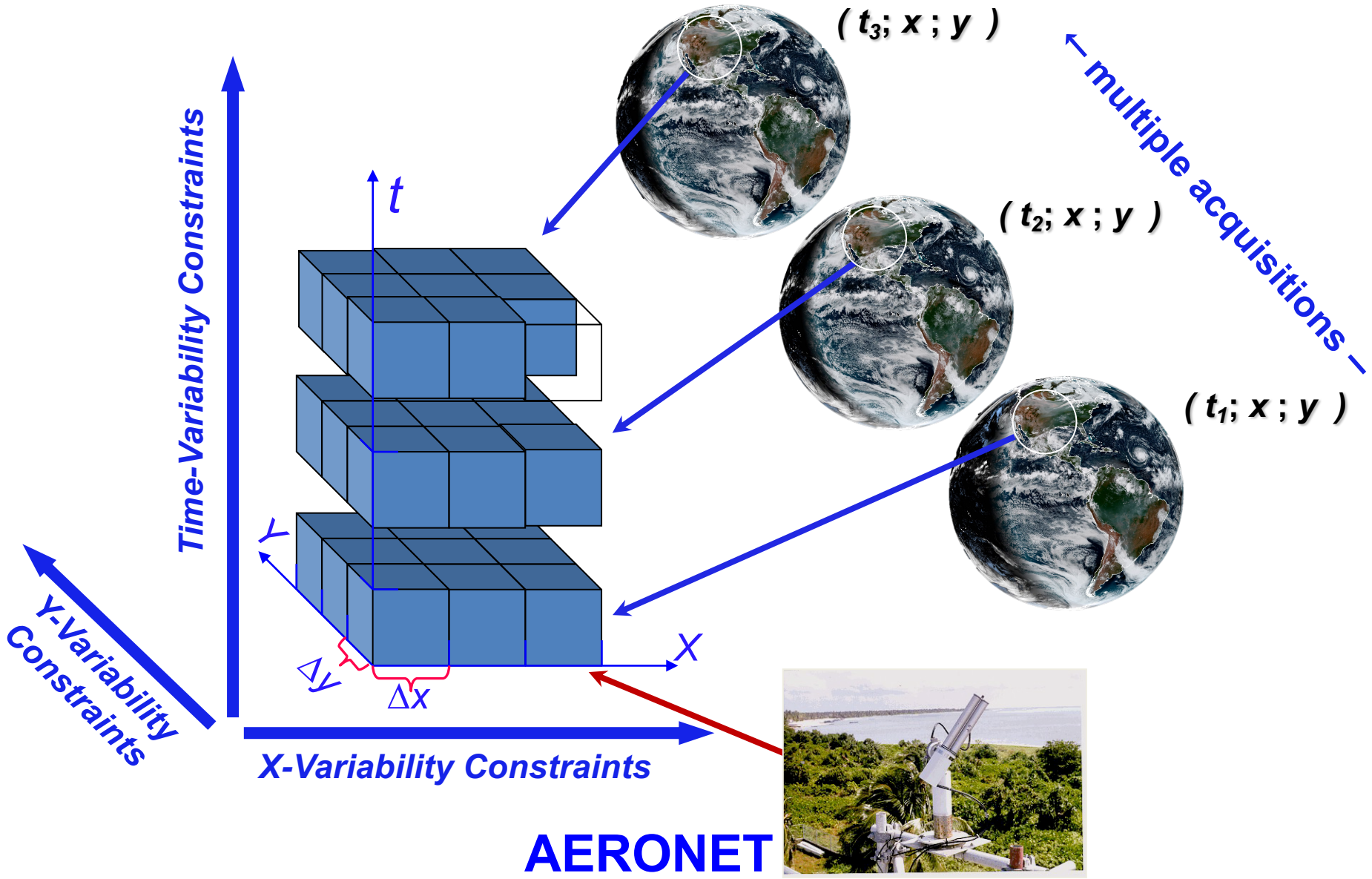

HIMAWARI-9

a new era in satellite remote sensing of aerosol SYNERGY!

Some thoughts about potential GEO/LEO-based aerosol studies

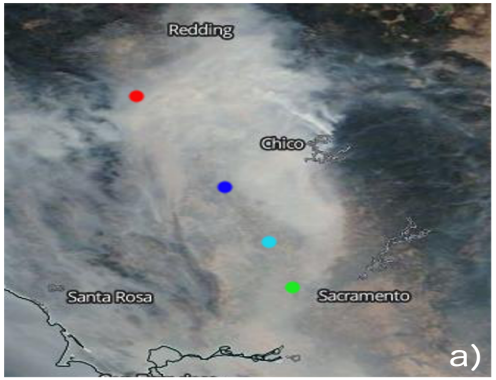
- possible datasets that ”could” become Program of Record?

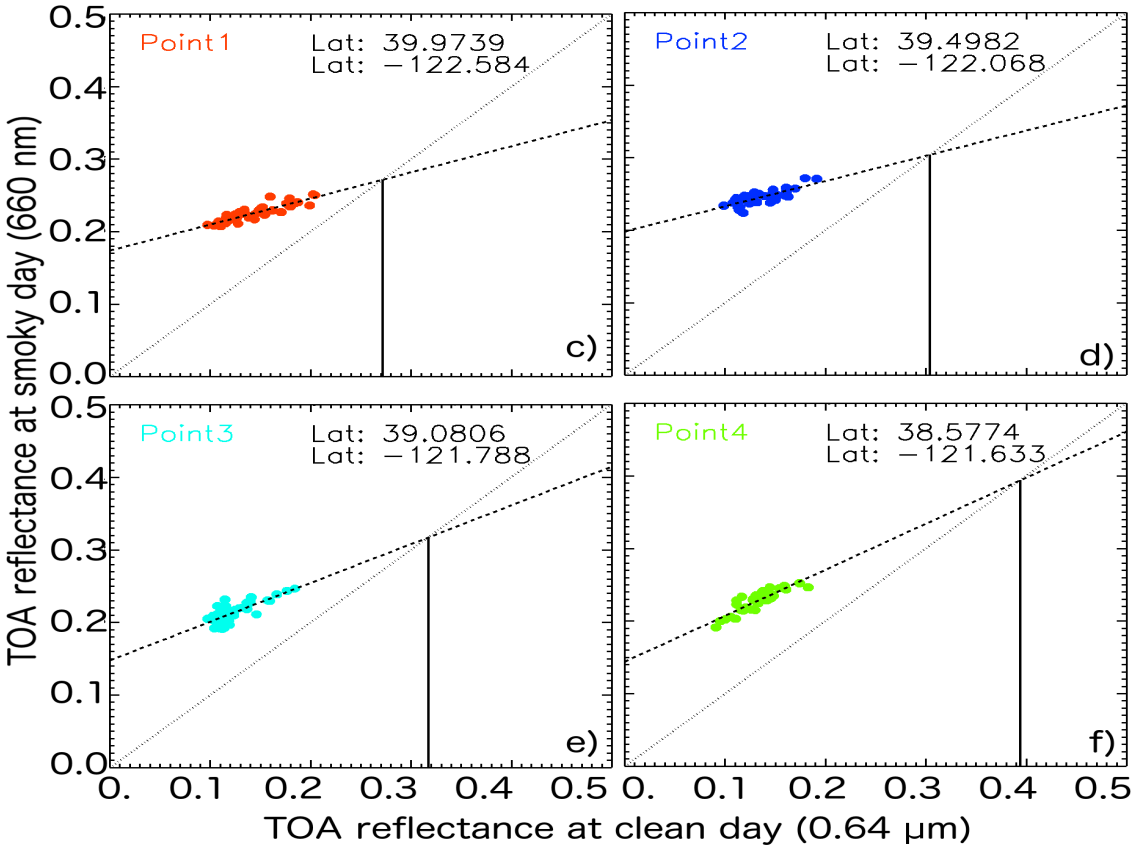
Multi-angle/Multi-temporal retrieval using GRASP

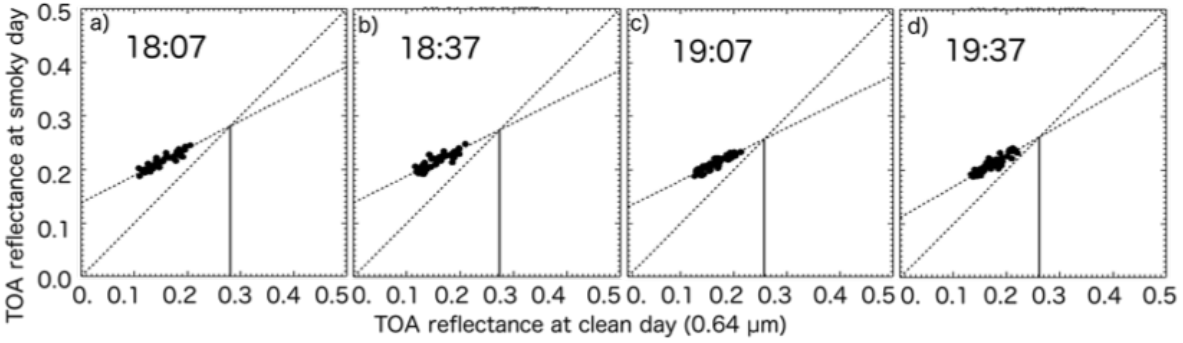


(Reed Espinosa)

Deriving critical reflectance and SSA (Case studies from 2018 Camp Fire)

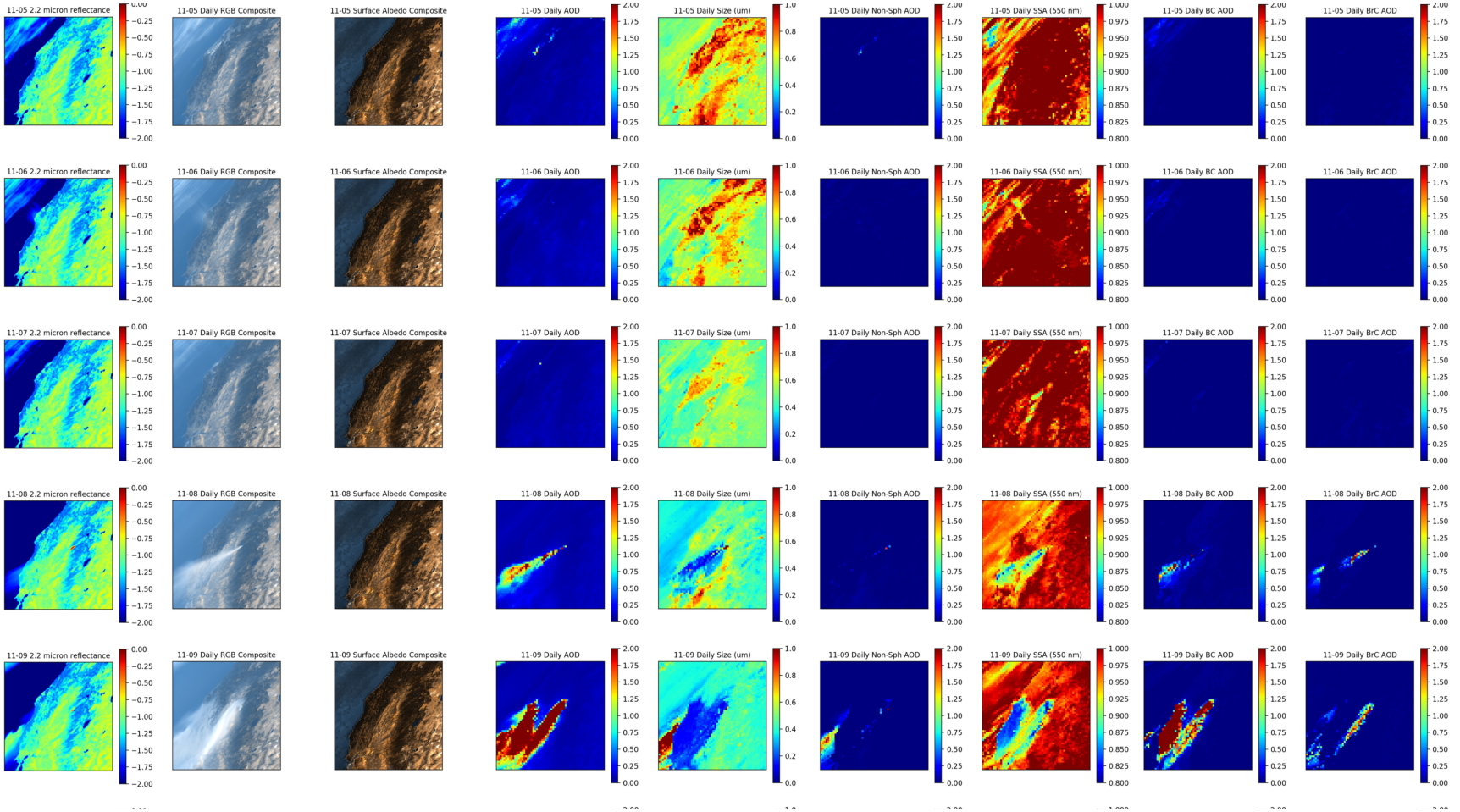






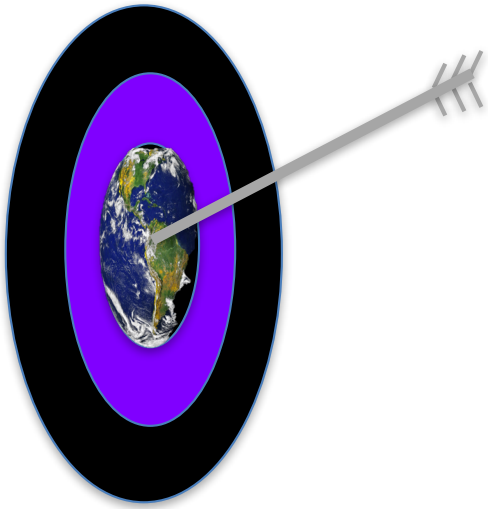
(Yingxi Shi)

MISR-like algorithm using GEO multi-angular information (Camp Fire, 2018)

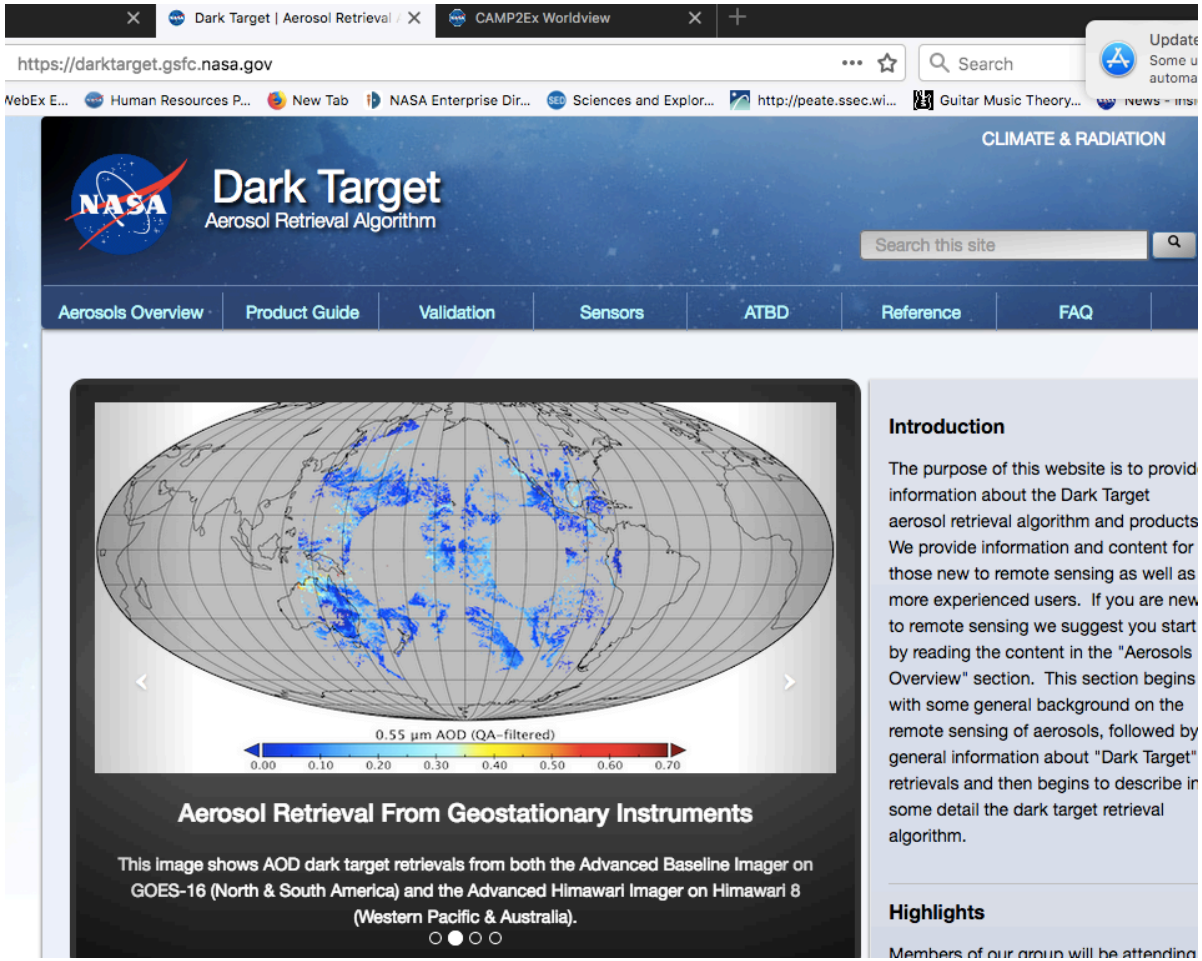


(Jim Limbacher)

Thank you!



Thank you!



https://darktarget.gsfc.nasa.gov