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

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One reason why we care


Satellites and Ground Sensors Observe Smoke Blanketing California

Nov 14, 2018 @ 10:04 UTC
PM2.5 (µg/m³)

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

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

<table>
<thead>
<tr>
<th>Variable/ Parameter</th>
<th>Horizontal Resolution</th>
<th>Vertical Resolution</th>
<th>Temporal Resolution</th>
<th>Accuracy</th>
<th>Stability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aerosol optical depth</td>
<td>5-10km</td>
<td>N/A</td>
<td>4h</td>
<td>Max (0.03; 10%)</td>
<td>0.01</td>
</tr>
<tr>
<td>Single-scattering albedo</td>
<td>5-10km</td>
<td>N/A</td>
<td>4h</td>
<td>0.03</td>
<td>0.01</td>
</tr>
<tr>
<td>Aerosol-layer height</td>
<td>5-10km</td>
<td>N/A</td>
<td>4h</td>
<td>1km</td>
<td>0.5km</td>
</tr>
<tr>
<td>Aerosol-extinction coefficient profile</td>
<td>200-500km</td>
<td>&lt;1km near tropopause, ~2km in middle stratosphere</td>
<td>weekly</td>
<td>10%</td>
<td>20%</td>
</tr>
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Global Climate Observing System (GCOS) requirements for **Aerosol Optical Depth (AOD)** climate data record (CDR):

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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)

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

The two MODIS instruments are **TWINS**!
Do they observe the world in the same way?

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)

• Deal with differences in resolution, etc.

• Retrieve on new sensors (compared with retrieval on MODIS):
MODIS-Terra vs MODIS-Aqua vs SNPP-VIIRS

- 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)

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<td>Temporal Resolution</td>
<td>4 h</td>
<td>2+ / day (Terra + Aqua/VIIRS)</td>
</tr>
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</table>

What’s still missing?

**Temporal variability!**
Break the Temporal Barrier!

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

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

<table>
<thead>
<tr>
<th></th>
<th>MODIS</th>
<th>VIIRS</th>
<th>AHI</th>
<th>ABI</th>
</tr>
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<tbody>
<tr>
<td>Blue</td>
<td>0.47/0.5</td>
<td>0.49/0.75</td>
<td>0.47/1.0</td>
<td>0.47/1.0</td>
</tr>
<tr>
<td>Green</td>
<td>0.55/0.5</td>
<td>0.55/0.75</td>
<td>0.51/1.0</td>
<td></td>
</tr>
<tr>
<td>Red</td>
<td>0.66/0.25</td>
<td>0.67/0.75</td>
<td>0.64/0.5</td>
<td>0.64/0.5</td>
</tr>
<tr>
<td>NIR</td>
<td>0.86/0.25</td>
<td>0.86/0.75</td>
<td>0.86/1.0</td>
<td>0.86/1.0</td>
</tr>
<tr>
<td>NIR</td>
<td>1.24/0.5</td>
<td>1.24/0.75</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cirrus</td>
<td>1.38/0.5</td>
<td>1.38/0.75</td>
<td></td>
<td>1.38/2.0</td>
</tr>
<tr>
<td>SWIR</td>
<td>1.61/0.5</td>
<td>1.61/0.75</td>
<td>1.61/2.0</td>
<td>1.61/1.0</td>
</tr>
<tr>
<td>SWIR</td>
<td>2.11/0.5</td>
<td>2.25/0.75</td>
<td>2.25/2.0</td>
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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, etc²⁰
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!!

KORUS_Taehwa

XiangHe

KORUS_Olympic_Park

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
But are there systematic biases?
• 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

AOT at 0.55 micron for both ocean (Average) and land (corrected) with all quality data (Quality flag = 0, 1, 2,...)
And now for a movie...
Towards synergy of aerosol observations

MAS/eMAS (aboard ER2 aircraft)

MODIS-Terra (10:30)

MODIS-Aqua (13:30)

VIIRS (SNPP 13:30)

VIIRS on JPSS-1, -2, -3, -4

AHI

ABI (GEOS-R/16), Additional GEO

EPIC (DSCOVR at L1)


Suborbital

LEO

GEO

Beyond?
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<td>Where GEOs:</td>
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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

GEO: Breaking the Temporal Barrier

Polar orbiting satellites only provides 1-2 observations per day

a new era in satellite remote sensing of aerosol SYNERGY!
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.
• Wisconsin running Dark Target in NRT for AHI.
• Using GFS “forecast” as ancillary for H$_2$O, 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

https://darktarget.gsfc.nasa.gov

Thank you!