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

<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>
</tbody>
</table>

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

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, 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: $±(0.15\tau + 0.05)$
  - Ocean: $±(0.10\tau + 0.04)$
- We are getting close to CDR accuracy requirements!
  - But....
Terra – Aqua: Near lockstep, but offset

Mean 0.86μm AOD
Offset of 0.015 is nearly everywhere!

except for “smoke” regions where known maximum in afternoon!
Overpass time differences?

Terra Local Observation Time, 2008

Terra: 10:30 (Descending)

Aqua Local Observation Time, 2008

Aqua: 13:30 (Ascending)

More than 4.5 hours!

Only 1.5 hours!

Terra – Aqua = 3 hours

Later

Earlier

Later

Earlier

Average Difference in Local Observation Time, 2008

Terra – Aqua (hours)

Data Min = -9.5, Max = 7.5, Mean = -2.9
“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)
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 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 to 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

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

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.

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

<table>
<thead>
<tr>
<th></th>
<th>MODIS</th>
<th>VIIRS</th>
<th>AHI</th>
<th>ABI</th>
</tr>
</thead>
<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>
<td>2.25/2.0</td>
</tr>
</tbody>
</table>

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)

\[ \rightarrow \text{GEO does have sensitivity to Diurnal Cycle!!} \]
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

Suborbital

MAS/eMAS (aboard ER2 aircraft)
MODIS-Terra (10:30)
MODIS-Aqua (13:30)
VIIRS (SNPP 13:30)
VIIRS on JPSS-1, -2, -3, -4

LEO

GEO

AHI
ABI (GEOS-R/16), Additional GEO

Beyond?

EPIC (DSCOVR at L1)
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.

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