AERONET Version 3
Aerosol Optical Depth and Inversion Products

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E-Poster Presentation
AeroCenter Poster Bash
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Outline

- Need for Higher Quality NRT Observations
- V3 AOD Cloud Screening and Quality Control Improvements
- V3 AOD Assessment
- Version 3 Inversion Updates and Improvements
- Quality Assured Data Release

http://aeronet.gsfc.nasa.gov
AERONET Aerosol Robotic Network - Over Twenty Years of Observations and Research

The AERONET program is a federation of ground-based remote sensing aerosol networks established by NASA and LOA-PHOTONS (CNRS) and has been expanded by collaborators from international agencies, institutes, universities, individual scientists and partners.

AERONET provides a long-term, continuous public database of aerosol optical, microphysical, and radiative properties for aerosol research and characterization, validation of satellite measurements, and synergism with other databases.

- >7000 citations
- >450 sites
- Over 90 countries and territories
Multi-Platform Need for Near Real-time Aerosol Observations

• Polar Orbiting and Geostationary Satellites
  – VIIRS, MODIS, MISR, OMI, GOES, Himawari-8, Sentinel 3, GOCI

• Surface-based Instrumentation
  – MPLNET, SPARTANS, GreenNet

• Aerosol Forecasts, Assimilation, and Reanalysis
  – ICAP, GOCART, NAAPS, MERRA-2

• Weather Prediction Models
  – NCEP, ECMWF, GEOS-5

• Field Campaign Support
  – KORUS-AQ, ORACLES, FIREX, CAMPex
AERONET Version 3: AOD

- **V3 Level 1.0**: Unscreened data (NRT)
  - Applies new temperature characterizations
  - Applies NO2 and Ozone OMI L3 climatology (2004-2013)
  - Applies updated absorption coefficients (Literature/HITRAN)
- **V3 Level 1.5**: Based on Level 1.0 (NRT)
  - Improved cloud screening
  - New quality controls applied
- **V3 Level 2.0**: Based on Level 1.5 with pre- and post-calibration and temperature characterization applied
  - Level 2.0 data quality confirmed during post-field calibration evaluation and released 30 days afterwards to allow for updates to ancillary databases
  - Significantly improves timeliness of Level 2.0 data availability

- Giles et al. 2018, in preparation
- AERONET Version 3 AOD Algorithm Quality Control Technical Description (2018)
<table>
<thead>
<tr>
<th>Algorithm/Parameter</th>
<th>Version 2</th>
<th>Version 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very High AOD Restoration</td>
<td>N/A</td>
<td>( \tau_{870} &gt; 0.5; \alpha_{675-1020} &gt; 1.2 ) or ( \alpha_{870-1020} &gt; 1.3 ), restore if eliminated by cloud screening</td>
</tr>
<tr>
<td>Air Mass Range</td>
<td>1 to 5</td>
<td>1 to 7</td>
</tr>
<tr>
<td>Number of Potential Measurements</td>
<td>( N &lt; 3 ), reject day</td>
<td>After all checks applied, reject day if ( N_{\text{remain}} &lt; \text{MAX} {3 \text{ or } &lt;10% \text{ of } N } )</td>
</tr>
</tbody>
</table>
| Triplet Criterion                   | All \( \lambda \); AOD range > MAX \{0.02 or 0.03*\( \tau_a \) \} | \( \lambda = 675, 870, 1020 \text{nm} \)
  AOD range > MAX\{0.01 or 0.015*\( \tau_a \) \} |
| Angstrom Limitation                 | N/A                                            | If AE less than -1.0 or AE greater than 4.0, then eliminate measurement.  |
| Smoothness Check                    | \( D < 16 \)                                   | For AOD 500nm (or 440nm) \( \Delta \tau_a > 0.01 \) per minute, remove larger \( \tau_a \) in pair. Then, the process repeats until no more removal. |

- V2: Smirnov et al. 2000, Cloud screening and quality control algorithms for the AERONET database, Rem.Sens.Env., 73, 337-349
- AERONET Version 3 AOD Algorithm Quality Control Technical Description (2018)
# V2 vs. V3 Cloud Screening

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<tr>
<th>Algorithm/Parameter</th>
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<tr>
<td>Solar Aureole Radiance Curvature Check</td>
<td>N/A</td>
<td>Compute curvature (ƙ) for 1020nm aureole radiances from 3.2°-6.0° $\phi$. If $ƙ &lt; 2.0E^{-5}$ for first point, compute a slope of $\ln k$ vs $\ln \phi$. If slope is greater than 4.3 (empirically derived), then point is “cloud contaminated.” For ALM, PP, and HYB, all $\tau_a$ points will be removed in the ±30 minutes period from sky measurement. For CCS, all $\tau_a$ points will be removed ±2 minutes period.</td>
</tr>
<tr>
<td>Standalone Points</td>
<td>N/A</td>
<td>No data ±1 hour of point, then reject it unless $\alpha_{440-870nm} &gt; 1.0$, then keep point</td>
</tr>
<tr>
<td>AOD Stability Check</td>
<td>Same as V3</td>
<td>Daily Averaged AOD 500nm (or 440nm) has $\sigma$ less than 0.015, then do not perform 3-Sigma Check</td>
</tr>
<tr>
<td>3-Sigma Check</td>
<td>Same as V3</td>
<td>AOD 500nm and $\alpha_{440-870nm}$ should be within MEAN ± 3σ; otherwise reject point(s)</td>
</tr>
</tbody>
</table>
Slope of Curvature

• Input:
  – Natural logarithm of Scattering Angles (\(\Phi\)) between 3.2° and 6°
  – Natural logarithm of Radiances (R) (\(\mu W/cm^2/sr/nm\)) for 1020nm
  – Must be more than 3 scattering angles (usually 4 or 5)

• Perform linear regression fit (\(\ln R \text{ vs } \ln \Phi\)) and determine the intercept (A) and slope (\(b\)) when correlation coefficient >0.99
Curvature of Aureole Radiances

- The curvature \((K)\) at the first \(\Phi\) is defined by
  \[
  K = \frac{y''}{(1 + y'^2)^{3/2}}
  \]
- \(y = A \times \Phi^b\) : power law function
- \(y' = A \times b \times \Phi^{b-1}\)
- \(y'' = A \times b \times (b-1) \times \Phi^{b-2}\)

- Calculate slope of curvature \((M)\) assuming \(y'^2 \gg 1\):
  \[
  M = 1 - 2b
  \]
Lidar-Assisted Empirically Derived Curvature Coefficients

- $K < 2E-5$ indicates increased probability of coarse particles
- $M > 4.3$ indicates increased probability of coarse particles
- Combining these two thresholds provides a much better assessment of cloud presence

- Utilized MPLNET LIDAR database (8 sites) cirrus and liquid cloud identification
  - LIDAR cloud base height corresponding to MERRA geopotential height temperature $<-37^\circ C$ designated as cirrus
  - Coincident with AERONET to determine cloud phase and determine thresholds up to $30^\circ$ solar zenith angle

MPLNET Data Acknowledgement: James Campbell, Jasper Lewis, Judd Welton
All Slope of Curvature Points without K 2E-5 threshold
GSFC (Alm & PP)
Using First Point Curvature < 2E-5

- Mainly Clear
- Mainly Clouds

All Slope of Curvature Points with 2E-5 threshold
Dusty site also shows distinction between clear and cirrus
All 8 Sites (Alm & PP)
Using First Point Curvature < 2E-5

Note:
Additional removal of data ±30 minutes of sky scan for Alm/PP/Hyb (and ±2 minutes for CCS) likely removes much more cirrus after this screening

COVE, GSFC, Kanpur, SEDE_BOKER, Santa Cruz Tenerife, Singapore, Ragged Point, Trinidad Head
AERONET V3 L1.5 Quality Control: AOD Diurnal Dependence

- Robust linear regression fit of AOD and cos(SZA)
  - $\lambda$(nm)=440, 675, 870, 1020 (Si), and 1640(In)
  - Slope, $R^2$, and RMS

- AM, PM, and full day evaluated

- Independent AOD DD removal only with strong thresholds for linear fit

- Dependent AOD DD removal with weaker thresholds for linear fit but other Level 1.5V flags set

- Multi-day removal (at least 3 days out of last 20)
AERONET V3 L1.5: AOD Diurnal Dependence

**Level 1.5 Cloud Screened Only**

**Levels 1.5 & 2.0**

Only AOD 340nm data removed
AERONET V3 L1.5 Quality Control: AOD Spectral Dependence

- Utilize mainly 1\textsuperscript{st} or 2\textsuperscript{nd} order fit
- Number of wavelengths
- AOD magnitude

- Uses \textit{robust} regression technique less influenced by outliers

- Employ iterative approach to remove outliers based on fit (fit-measurement)

- Combine with other screening techniques

**Level 1.5 Cloud Screened Only**

**Anomalously low AOD 380nm**
AERONET Version 3 L1.5: Solar Eclipse Screening

Level 1.5 Cloud Screened Only

Eclipse Obs. is 0.42

Levels 1.5 & 2.0

* AOD correction may be implemented
NRT Level 1.0 and 1.5 AOD Processing

• Data processing
  – Data are received generally within 30 minutes (often within 15 minutes) of the instrument measurement
    • A few sites delay data transmission for a week or two
  – Processing occurs last 90 days every 5 minutes (data only modified if inputs changed)
  – Full reprocessing every night (data only modified if inputs changed)

• Final NCEP pressure and temperature reanalysis fields received 3 days after initial measurements

• For some quality controls, up to 3 weeks of data from real-time are evaluated for data anomalies, which may impact data availability
Level 2.0 AOD Processing

- Utilize Level 1.5 cloud screened and quality controlled data set from deployment
- After post-field calibration is applied, saved, and confirmed, data will typically be available at Level 2.0 within 30 days.
  - Delay is necessary for pre and post field calibration assessments and to ensure final ancillary data sets are updated for final processing.
  - Some data may be sequestered from Level 2.0 due to instrument calibration issues
- After 30 days from post-field calibration, Level 2.0 is generally not expected to be modified.

- Level 2.0 data should be used for publications unless an anomalous situation exists and is justified.
Indonesian Fires 2015 (Palangkaraya) – V2

Cloud cleared data (V2 Level 1.5)

Observation at Palangkaraya
5°2’18.1”, E 123°56’48“, alt 27 m,
Since 13/01/2015
Until 21/12/2015
Device 079
3451 points displayed
Level 1.5 - Cloud Screened Data

Symb Lam <R0(λ)> Std

- R0 1013 : 0.1804 ± 0.0434
- R0 1638 : 0.1864 ± 0.0432
- R0 870 : 0.2106 ± 0.0510
- R0 674 : 0.2689 ± 0.0573
- R0 440 : 0.3138 ± 0.0654
- R0 500 : 0.3687 ± 0.0700
- R0 379 : 0.4847 ± 0.0824
- R0 340 : 0.4856 ± 0.0873

Cirrus contamination
Removed by V2 cloud screening

Aqua MODIS
20151005T06:05 UTC

Palangkaraya
Version 3 L1.0
Raw Data

Detectable Signal
Optically thin cirrus clouds removed

Biomass burning smoke restored for high aerosol loading events

Mainly NIR and SWIR λ Range

Version 3 L2.0 QA Data
More measurements overall especially for AE ≥ 1.0
These estimated AOD levels at mid-visible exceed (to our knowledge) any values ever reported in the published literature. This biomass-burning event in 2015 in Indonesia was the largest magnitude AOD event in terms of AOD levels ever monitored by AERONET to date, in the 24-year history of the network.

Eck et al., 2018, in preparation
Seoul, S. Korea – Major 5 day pollution event from May 27-31, 2012
Version 2 Level 2 Cloud Screening eliminated 3 days – May 28-30
These 3 days are retained in Version 3 level 2 data

DRAGON Korea Univ Site, Seoul, South Korea
May 27 - 31, 2012 SDA Fine and Coarse Mode AOD

Fine or Coarse Mode AOD - 500 nm

May 2012
AERONET V2 vs. V3

- New Level 1.5 AOD$_{500nm}$ and $\alpha_{440-870nm}$ statistically very close to V2 Level 2.0

- Improperly filtered highly variable AODs (dominated by fine aerosols) may be restored in the V3 database

- Stable thin cirrus becomes less of an issue (less residual contamination)

- V3 L1.5 and V3 L2.0 in many cases are expected to be very similar

### Nauru, #168, 2000-2005, 2010

<table>
<thead>
<tr>
<th>Level</th>
<th>N</th>
<th>AOD</th>
<th>$\alpha$</th>
</tr>
</thead>
<tbody>
<tr>
<td>V2 L1.0</td>
<td>25579</td>
<td>0.23</td>
<td>0.31</td>
</tr>
<tr>
<td>V2 L1.5</td>
<td>13326</td>
<td>0.11</td>
<td>0.47</td>
</tr>
<tr>
<td>V2 L2.0</td>
<td>9371</td>
<td>0.08</td>
<td>0.54</td>
</tr>
<tr>
<td>V3 L1.5 CldScr</td>
<td>10233</td>
<td>0.07</td>
<td>0.47</td>
</tr>
<tr>
<td>V3 L1.5</td>
<td>8917</td>
<td>0.06</td>
<td>0.52</td>
</tr>
<tr>
<td>V3 L2.0</td>
<td>8917</td>
<td>0.06</td>
<td>0.52</td>
</tr>
</tbody>
</table>

### Singapore, #22, 2007-2011

<table>
<thead>
<tr>
<th>Level</th>
<th>N</th>
<th>AOD</th>
<th>$\alpha$</th>
</tr>
</thead>
<tbody>
<tr>
<td>V2 L1.0</td>
<td>25500</td>
<td>0.61</td>
<td>0.86</td>
</tr>
<tr>
<td>V2 L1.5</td>
<td>8680</td>
<td>0.46</td>
<td>1.03</td>
</tr>
<tr>
<td>V2 L2.0</td>
<td>6920</td>
<td>0.35</td>
<td>1.20</td>
</tr>
<tr>
<td>V3 L1.5 CldScr</td>
<td>6876</td>
<td>0.35</td>
<td>1.52</td>
</tr>
<tr>
<td>V3 L1.5</td>
<td>6597</td>
<td>0.35</td>
<td>1.51</td>
</tr>
<tr>
<td>V3 L2.0</td>
<td>6597</td>
<td>0.35</td>
<td>1.51</td>
</tr>
</tbody>
</table>
Climatology

Clouds removed; cloud processed retained

N_{V2} = 138115
N_{V3} = 155710

GSFC

V2 L2 and V3 L2
1993-2016

Improved temperature correction

Lulin

V2 L2 and V3 L2
2006-2017

N_{V2} = 19939
N_{V3} = 25148
**Climatology**

**Kanpur**

V2 L2 and V3 L2
2001-2017

N\textsubscript{V2}=87471
N\textsubscript{V3}=100828

**Solar Village**

V2 L2 and V3 L2
1999-2013

N\textsubscript{V2}=157894
N\textsubscript{V3}=168440
Precipitable Water (cm)
GSFC
2007-2013

\[ y = 0.9188x + 0.0651 \]
\[ R^2 = 0.9856 \]

N=12921

Coincident within 15 minutes
AERONET Version 3 - Inversions

• MERRA-2 aerosol extinction and O$_3$ profiles (Randles et al., 2016; Wargan et al. 2017)

• Snow-free (with permanent snow) MODIS BRDF Gap-Filled Climatology (2003-2015) (Sun et al., 2017)

• Snow MODIS BRDF (2000-2014) (Schaaf et al., 2002; 2008; 2011)

• Full Vector radiative transfer code using Successive ORDers of scattering (SORD) (Korkin et al., 2016)
  – Radiation field in UV (e.g., 380 nm retrieval)
  – Degree of linear depolarization
Forward Modelling with RT code **SORD**

- New publicly available polarized RT code: SORD (Successive ORDers of scattering)
- The SORD code is local to the AERONET: easy to support and further develop
- Both speed and accuracy are published in JQRST manuscript using 52 benchmarks
- Manuscript explains how to get SORD and independently reproduce all the tests

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**Journal of Quantitative Spectroscopy & Radiative Transfer**

*Vector radiative transfer code SORD: Performance analysis and quick start guide*

Sergey Korkin\textsuperscript{a,b,*}, Alexei Lyapustin\textsuperscript{b}, Alexander Sinyuk\textsuperscript{c,b}, Brent Holben\textsuperscript{b}, Alexander Kokhanovsky\textsuperscript{d,e}
AERONET Version 3 - Inversions

- **Solar Spectrum Irradiance (SSI) for Quiet Sun** developed by Univ. of Colorado LASP and NRL based on Solar Radiation and Climate Experiment (SORCE) data (Coddington et al., 2016)

- Lidar and depolarization ratio products (Dubovik et al., 2006)

- V2 inversion product quality assurance (Holben et al., 2006)

- NASA High End Computing (NCCS/GSFC) inversion processing (ongoing)

- Inversion product estimated uncertainties (in progress and to be released later)
AERONET

New Instrumentation/Enhancements

• Improved solar tracking reducing triplet variance
• Greater control over instrument measurement scenarios (e.g., Hybrid)
• Lunar measurements
  – 1st to 3rd quarter lunar phase (waxing to waning gibbous)
  – Processing for lunar measurements (e.g., ROLO, Tom Stone)
• Development toward attachment for CO2 measurements (Emily Wilson)
• Synergism with MPLNET, PANDORA, and in situ measurements

Cimel Sun/Sky/Lunar Radiometer
Aerosols and More

Zibordi et al. [2009], JAOT
Smirnov et al. [2009], JGR
Chiu et al. [2010], JGR
Schafer et al. [2004], JGR
Summary and Outlook

• Higher quality NRT AOD data will be available in V3
  – *Due to temperature characterization and automatic cloud screening and quality controls*

• Level 2.0 utilizes Level 1.5 automatic screening and available within 30 days of post-field calibration application

• V3 inversions will utilize new radiative transfer, ancillary data sets, and provide new products
Version 3 Releases

- V3 AOD Level 1.0 and Level 1.5 NRT: July 14, 2016
- V3 AOD Level 2.0 release: January 5, 2018
- V3 Inversions release (Levels 1.5 and 2.0): January 5, 2018
Upcoming Product V3 Release

- Normalized Water Leaving Radiances
- Lunar AOD
- Hybrid Sky Scan Inversions
- Inversion Uncertainty Estimates
- Expanded Wavelength Inversions (including 380nm and 1640nm)
Hybrid Scan results in many more retrievals at AOD > 2 at 440 nm since Hybrid scans can be made at mid-day with low Solar Zenith Angle (SZA). Almucantar scans require SZA > 50 degrees – this results in insufficient signal to measure 440 nm AOD when AOD is very high.