Version 3 AERONET processing – data product assessment for model validation and assimilation

AEROCOM Workshop, Steamboat Springs, Colorado, September 29 – October 3, 2014
AERONET (Aerosol Robotic Network)

- Alexander (Sasha) Smirnov - presenter on behalf of the AERONET Project Leader Brent Holben and AERONET Team

Piers Sellers is on our side!

We Have Friends in High Places
**Principal Investigator:**
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**Data Processing, Database, & Web Support:**
Ilya Slutsker, David Giles

**Scientific Research:**
Brent Holben, Thomas Eck, Alexander Smirnov, Aliaksandr Sinyuk, David Giles, Joel Schafer
AERONET - the ground based Satellite
Over 20 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
- >400 sites
- Over 80 countries

AERONET Federated Calibration Center Coordination:
NASA GSFC (U.S.), PHOTONS (France), RIMA (Spain)
Elements of Data Structure

- Every data point is geo-referenced
- Every data point is time stamped for each processing or data management action
- Data files organized by instrument rather than location—Multiple sites
- Data Processing—Auto processing of all requests—crash proof, faster processing
- Daily data indexing—small reprocessing jobs and up-to-date database
- Condensed data storage: levels stored by product
V3 development schedule

- Demonstrat Development and implementation (Ilya)
  - Level 1
    - O3 correction: use current V2 corrections
    - NO2 correction Monthly diurnal high res: (Tom and Dave late August)
    - Reanalysis: (Dave ~Sept. 1)
    - Temperature correction (Fraction filters remain): (Ilya and Joel end of August)
    - Recalibrations: (Ilya and Tom late August)
    - Case study computations of AOD (use 70 clrd cleaning case studies Sept. team to evaluate)
    - Case study computations of sky radiances w/all corrections: (Sept. team to evaluate)
    - Case study computations of inversion products: (Sept. 15 Ilya & Sinyuk)
  - Level 1.5
    - Clr screening: Completed, Algorithm defined.
  - Level 1.5v 2.0
    - QA Instrument Check, Dave/Brent September
    - Pattern recognition: Ilya and Joel September
    - AOD: comparisons to V2 results (mid Sept)
    - Inversions (Sinyuk)
      - Vector Code assessment (Sinyuk late August)
      - Timing & Code selection
      - Quality assessment: SSA (dependence, fine vs coarse, dynamic criteria) (Sinyuk)
      - SSA, size dist. etc Comparison to V2 results using V3 criteria (Sinyuk / September)
      - Inversion products re-computation and assessment (October 15)

- AOD V3 database re-computation and assessment (Oct. 1)
- Inversion V3 re-computation and assessment (Nov. 1-77)
- Release of V3 Jan 1 2014 (rather optimistic)
- New product development

V3 QA Instrument checks

- first steps (refer to current weekly checks)
  - Assess fraction of L2 retrieval database affected by:
    - Dark current check (Mikhail to provide written explanation of digital DC and effect on voltages)
    - Temperature jumps (±Δ12°C/15 min)
    - Temperature limits (>55°C or <30°C)
    - A or K voltages Too low (<0.3v) 4.8x and 5.x standard only
    - A/K Discrepancy (A> 10% of K) 4.8x and 5.x standard only
      - Evaluate A & K from PP & Almucantars
    - Asymmetric Almucantars/PP/Hybrids (scattering angle: 3 to 6°)
    - InGaAs vs Si 1020 nm (±Δ 0.06/m) AOD 5.x extended only
    - Retrieval limits (SSA 440 < 0.70?)
    - AOD Diurnal Dependence (refer to wkly check for details)
    - AOD triplet variability for each channel
    - Dual filter wheel/polar instrument?????
Current cloud screening algorithm

Advantages:
- Simplicity
- Reliability
- Standardization
- Proven to be operational
- Treats all aerosol types equally
Current cloud screening algorithm

Problems:
- Thin stable cirrus clouds
- Highly variable dust or smoke

Flowchart:
1. Raw daily voltage and $\tau$ data not cloud screened
2. $\tau < 0.01$
3. $\tau$ range within a triplet is higher than
   $\text{MAX} \{0.02, 0.03\}$
4. Standard deviation ($\sigma$) of the $\tau$ (500 nm) for the entire day is less than 0.015
5. Smoothness criteria $D < 16$
6. Check if any measurements have exceeded the limits of $\tau$ (500 nm) $\pm 3\sigma$ and $\alpha \pm 3\sigma$
7. Find the term with the maximum input in $D$ and eliminate the maximum $\tau$ associated with it
8. Cloud screened Database
9. Identified as Cloudy or Poor Quality
attempt to modify AERONET cloud screening algorithm in 2006
Current cloud screening algorithm

Problems:
- Thin stable cirrus clouds
- Highly variable dust or smoke

AOD data not cloud screened

AOD < -0.01

AOD range within a triplet is higher than MAX \{0.02, 0.03 \times \tau_a\}

Standard deviation (\sigma) of the \tau_a(500 \text{ nm}) for the entire day is less than 0.015

Smoothness criterion D < 16

Check if any measurement have exceeded the limits of \tau_a(500 \text{ nm})\pm3\sigma and \alpha\pm3\sigma

Find the term with the maximum input in D and eliminate the maximum \tau_a associated with it

Identified as cloudy or poor quality

Cloud screened database
Air mass range will be extended from 7 to 7.

Compute number of potential measurements: It is equal to number of SUN measurements plus a number of humidity statuses. We will reject a day if after all checks below are applied the number of the remaining measurements is less than 3 or 10% of “potential” measurements (whatever is greater).

Triplet criterion – only THREE channels (675, 870 and 1020 nm) are considered. Measurement is considered “cloudy” when at ALL THREE wavelengths within a triplet (tau_max – tau_min) exceeds 0.01 or 0.015*tau (whatever is greater).

AOD stability check – if daily averaged AOD at 500 nm (or 440 nm if 500 nm channel is not available) is less than 0.015 we do not perform a 3 sigma check.

3 sigma check – AODs at 500 nm (or 440 nm) and corresponding Alphas (computed using available channels within 440-870 nm range) should be within MEAN +/- 3 Standard deviations.

Smoothness check – instead of D16 as in the current version we presume that AOD at 500 nm (or 440 nm) should not change greater than by 0.01 per minute. For any pair when AOD exceeds this threshold the highest AOD is eliminated. Then the process repeats itself.

Curvature check – we compute curvature for measured at 1020 nm sky radiances within 3 – 6 degrees SCATTERING angle. If curvature computed for the first available scattering angle is greater than 0.001 we do not apply a “curvature check”. If curvature is less than 0.001 we compute a slope of Ln Curvature vs Ln Scat Angle. If the slope is greater than 8 (empirically found) we consider point to be “cloud contaminated”. Also we expand this to +/- 30 minute time period and eliminated points within.

Standalone and Extras. We call a point a “standalone” point when it does not have any measurements left within plus or minus one hour. In this case we reject a standalone point. However if Alpha for such point is greater than 1 (one) we retain it.

Number of measurements left should be either 3 or 10% of the potential (actual plus humidity statuses) measurements, whatever is greater.

If the number of measurements left is LESS than 3 or 10% of the potential measurements we eliminate measurements with Alpha<1 and keep measurements with Alpha>1.
Suggested modifications

- Triplet criterion – only THREE channels (675, 870 and 1020 nm) are considered. Measurement is considered “cloudy” when at ALL THREE wavelengths within a triplet ($\tau_{\text{max}} - \tau_{\text{min}}$) exceeds 0.01 or 0.015*$\tau$ (whatever is greater).

- Smoothness check – instead of D16 as in the current version we presume that AOD at 500 nm (or 440 nm) should not change greater than by 0.01 per minute.
Parameterization of sky radiance shape

The angular shape of sky radiances is conveniently parameterized by curvature which give the rate of turning of tangent vector, see below

\[ k = \lim_{\Delta s \to 0} \frac{\Delta \varphi}{\Delta s} = \frac{|\dot{f}|}{(1 + \dot{f}^2)^{3/2}} \]

According to the formula above the stronger the forward scattering peak the smaller the curvature value (it is inverse proportional to the first derivative)
The first curvature value: fine mode aerosols

Curvature value at the smallest scattering angle (K) in the 3 to 6 range is sensitive to the presence of large particles. The fraction of clouds with K greater than 0.001 is relatively small. This can be used as an additional constrain in cloud screening.
Slope of curvature in ln - ln scale for the 3 to 6 degrees range of scattering angles is sensitive to cirrus cloud presence.
Suggested modifications

- Curvature check – we compute curvature for measured at 1020 nm sky radiances within 3 – 6 degrees SCATTERING angle. If curvature computed for the first available scattering angle is greater than 0.001 we do not apply a “curvature check”. If curvature is less than 0.001 we compute a slope of Ln Curvature vs Ln Scat Angle. If the slope is greater than 8 (empirically found) we consider point to be “cloud contaminated”. Also we expand this to +/- 30 minutes time period and eliminate points within.
AERONET – MPL Validation Dataset

- MPLNET cirrus only detection within ±10 minutes of AERONET measurement
- AERONET measurement within various solar zenith angles (e.g., 30°)
- Homogeneous cirrus conditions assumed
## Singapore, #22, 2007-2011
Fine mode aerosol and Ci

<table>
<thead>
<tr>
<th>Level</th>
<th>N</th>
<th>AOD</th>
<th>Alpha</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lev 1.0</td>
<td>25500</td>
<td>0.61</td>
<td>0.58</td>
</tr>
<tr>
<td>Lev 1.5</td>
<td>8680</td>
<td>0.45</td>
<td>0.79</td>
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<td>Lev 2.0</td>
<td>6920</td>
<td>0.34</td>
<td>1.21</td>
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<tr>
<td>NEW</td>
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<tr>
<td>Lev 1.5 (no/CURV)</td>
<td>8640</td>
<td>0.35</td>
<td>1.17</td>
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<tr>
<td>Lev 1.5 (w/CURV)</td>
<td>5029</td>
<td>0.33</td>
<td>1.40</td>
</tr>
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<td>Level</td>
<td>N</td>
<td>AOD</td>
<td>Alpha</td>
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<tr>
<td>--------------</td>
<td>-------</td>
<td>------</td>
<td>-------</td>
</tr>
<tr>
<td>Lev 1.0</td>
<td>25579</td>
<td>0.23</td>
<td>0.09</td>
</tr>
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<td>Lev 1.5</td>
<td>13326</td>
<td>0.11</td>
<td>0.33</td>
</tr>
<tr>
<td>Lev 2.0</td>
<td>9371</td>
<td>0.08</td>
<td>0.58</td>
</tr>
<tr>
<td>NEW</td>
<td></td>
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<tr>
<td>Lev 1.5 (no/CURV)</td>
<td>13048</td>
<td>0.09</td>
<td>0.45</td>
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<tr>
<td>Lev 1.5 (w/CURV)</td>
<td>7879</td>
<td>0.08</td>
<td>0.55</td>
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## Ilorin, #29, 1998-2013

### Biomass Burning and Dust

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<th>Alpha</th>
</tr>
</thead>
<tbody>
<tr>
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<td>0.84</td>
<td>0.42</td>
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<tr>
<td>Lev 1.5</td>
<td>37370</td>
<td>0.84</td>
<td>0.46</td>
</tr>
<tr>
<td>Lev 2.0</td>
<td>35392</td>
<td>0.77</td>
<td>0.51</td>
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</tr>
<tr>
<td>Lev 1.5 (no/CURV)</td>
<td>32601</td>
<td>0.73</td>
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<tr>
<td>Lev 1.5 (w/CURV)</td>
<td>29348</td>
<td>0.76</td>
<td>0.55</td>
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</table>
## Fine mode aerosol

<table>
<thead>
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<th>Level</th>
<th>N</th>
<th>AOD</th>
<th>Alpha</th>
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</thead>
<tbody>
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<td>26354</td>
<td>0.44</td>
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<tr>
<td>Lev 1.5</td>
<td>11394</td>
<td>0.32</td>
<td>1.45</td>
</tr>
<tr>
<td>Lev 2.0</td>
<td>10548</td>
<td>0.31</td>
<td>1.54</td>
</tr>
<tr>
<td>NEW</td>
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<td></td>
</tr>
<tr>
<td>Lev 1.5 (no/CURV)</td>
<td>14534</td>
<td>0.32</td>
<td>1.61</td>
</tr>
<tr>
<td>Lev 1.5 (w/CURV)</td>
<td>12070</td>
<td>0.32</td>
<td>1.67</td>
</tr>
</tbody>
</table>
Observation at Nes_Ziona
N 31°55'21", E 34°47'21", Alt 40 m,
Since 27:05:2005
Until 27:05:2005
Device 132
35 points displayed
Level 1.0 - Raw Data

<table>
<thead>
<tr>
<th>Symb</th>
<th>lam</th>
<th>&lt;AOT&gt;</th>
<th>Std</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1020</td>
<td>0.1036 ± 0.0268</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1637</td>
<td>0.0750 ± 0.0183</td>
<td></td>
</tr>
<tr>
<td></td>
<td>869</td>
<td>0.1273 ± 0.0324</td>
<td></td>
</tr>
<tr>
<td></td>
<td>675</td>
<td>0.1678 ± 0.0443</td>
<td></td>
</tr>
<tr>
<td></td>
<td>439</td>
<td>0.2868 ± 0.0723</td>
<td></td>
</tr>
<tr>
<td></td>
<td>500</td>
<td>0.2434 ± 0.0610</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1020</td>
<td>0.1508 ± 0.0381</td>
<td></td>
</tr>
<tr>
<td></td>
<td>380</td>
<td>0.3393 ± 0.0817</td>
<td></td>
</tr>
<tr>
<td></td>
<td>333</td>
<td>0.3753 ± 0.0818</td>
<td></td>
</tr>
</tbody>
</table>
Observation at Nes Ziona
N 31°55’21”, E 34°47’21”, Alt 40 m,
Since 27/05/2005
Until 27/05/2005
Device 132
8 points displayed
Level 1.5 – Cloud Screened Data

Spectral AOT

Aerosol thickness
NCURV CURV8
Wavelength exponent
Temperature
Precip Water Vapor
CV IV BL EX DT CM
Bird Model
KaleidaGraph
CV Reff VHR STD
Norm(1st) Norm(new)
Whole Curve
Quit

Send Screen to
Alexander,Smirnov-10@nasa.gov
Send Raw Alms & PPs to
Alexander,Smirnov-10@nasa.gov
SEND Error bars On/Off Filter [Daily] Temps Time Shift Cal Shift Show Alpha Show Ascii
Advantages of the new cloud screening algorithm

- Automated algorithm delivers AODs and $\alpha$ at Level 1.5 statistically very close to current Level 2.0
- Stable thin cirrus clouds became a lesser problem (less residual cloud contamination)
- Wrongly filtered in the current version highly variable AODs (dominated by fine aerosols) will be (at least partly) restored in the database
What is behind new cloud screening
AERONET Version 3 Update – AOD Additional Modifications

- Implement spectral temperature corrections (-40°C to +60°C)
- Update to OMI L3 NO₂ climatology (2004-2013)
- Continue to use TOMS O₃ climatology (1978-2004)
- Continue to use NCEP Reanalysis for atmospheric pressure (1993-present)
Need a temperature characterization for every filter+detector combination
Also, filter response differences between manufacturers often require separate characterization for each
1020Si filters are the most temperature sensitive (> 3x greater). Other filters exhibit sensitivity ranging from negligible to moderate.
For a typical 1020Si case, a 10 degree change in temperature results in ~ 3% change in signal
All valid temperature data files are used in calculation of defaults, with a 2 sigma outlier filter. Individual CIMELs may have temperature sensitivity that departs significantly from the default values—default only used for some of the older historical data. Agreement between independent characterizations at GSFC and Lille is good for all manufacturers.
Individual Cimel temperature response curves

**Bold Curves Key**

- Red: Spectragon (mean)
- Blue: Barr (mean)
- Green: POC/Opt (mean)
- Black-dash: Current default
Average TRC Comparison: Three Manufacturers

- Spectr
- POC/Opt
- Barr

Temperature Response Coefficient vs. Wavelength (nm)
AERONET Version 3 Update - AOD

• Level 2.0 Automated Quality Assurance
  – Temperature anomalies
    • Allows for restoration of 1020nm data affected by bad sensor temperatures partly based on NCEP surface temperature climatology
  – AOD diurnal dependence
    • Removes persistently affected data mainly due to obstruction in collimator or debris on window
AERONET Version 3 Update - AOD

- Level 2.0 Automated Quality Assurance (in development)
  - AOD with channel out of spectral wavelength dependence
    - Remove channel due to systematic instrument anomaly
  - Solar eclipse AOD increase
    - Remove AOD affected during solar eclipse period
    - Possibly implement an eclipse correction
AERONET Version 3 Update - Inversions

- Implement a vector radiative transfer code
  - radiation field in UV (e.g., 380 nm retrieval)
  - degree of linear polarization
- Integrate CALIOP monthly climatology of extinction profiles (or MERRA assimilated profile) to estimate aerosol vertical profile
- Provide lidar and depolarization ratio products
- Estimate uncertainties for each retrieval (e.g., random error plus biases due uncertainty in AOD and sky radiance calibration)
- Update inversion quality assurance criteria
Accounting for polarization in modeling of atmospheric radiation is important:
- at short wavelengths where contribution of molecular scattering is significant
- for fine mode aerosol particles exhibiting high degree of linear polarization
  
  In version 3 scalar RT model is replaced by vector RT model.

Approach:
- several well known RT models were selected as candidate for version 3:
  Adding/Doubling (AD; GISS), Discrete Ordinate (DOM; Korkin, Lyapustin, GSFC), Successive Order of Scattering (SO; Lille)
- the agreement between different RT models was found to be within 1%
- SO RT model finally was selected due to its superior speed for small and moderate AOSs
As an alternative to error bars based on sensitivity studies, new error bars estimates will be provided for each individual retrieval:
- The approach is based on Dubovik, 2004
- The error bars estimates accounts for effect of random errors in optical measurements as well as effect of biases such as calibration uncertainty.

The above approach does not account for errors due to model assumptions such as uncertainties in prescribed surface albedo or BRDF. These uncertainties are estimated using sensitivity studies assuming maximum absolute error in surface albedo $\sim 0.05$ (according to MODIS team estimations).

Error bars for the following aerosol parameters will be provided:
- Particle size distribution, complex refractive index,
- Single scattering albedo, aerosol phase function,
- Sphericity parameter.
Large jump in AOD (~0.3 at 440 nm) at the DRAGON Essex site occurred just after solar noon on July 5 (No Cloud Screening). However, the Angstrom exponent (440-870 nm) remains very high (>1.9) suggesting possible new particle formation in the cloud environment since a particularly dense cluster of clouds is seen in the vicinity of the Essex site. Also note the larger variance of AOD (1 min intervals) in the afternoon versus morning indicating relatively high frequency variation in columnar aerosol.
Average AOD computed for each Hour independently – Mid Afternoon drop in AOD in L2 (Cloud Screened & QA) likely due to missing Variable AOD associated with enhanced aerosol near Cumulus clouds

Observations of rapid aerosol optical depth enhancements in the vicinity of polluted cumulus clouds


Atmos. Chem. Phys. Discuss., 14, 18785-18848, 2014
AERONET
New Instrumentation/Enhancements

• Greater control over instrument measurement scenarios (e.g., Hybrid)
• Additional capabilities such as SD card storage, GPS, USB, and Zigbee
• Lunar measurements
  – 1<sup>st</sup> to 3<sup>rd</sup> 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
Maritime Aerosol Network as a Component of AERONET

- MAN represents an important strategic sampling initiative and ship-borne data acquisition complements island-based AERONET measurements.
- In the last several years data acquisition was extended to the areas that previously had very little or no coverage at all.
- Data are easily accessible in the web-based public data archive and will stimulate research and international collaboration in various scientific areas.

Cruise tracks and daily averages of aerosol optical depth at 500 nm (squares are colored with respect to AOD values, i.e. blue – AOD<0.10, green – 0.1≤AOD<0.2, yellow – 0.2≤AOD<0.3, orange – 0.3≤AOD<0.5, red – 0.5≤AOD<0.7, purple – AOD≥0.7).

Cruise tracks and daily averages of aerosol optical depth at 500 nm (squares are colored with respect to AOD values, i.e. blue – AOD<0.10, green – 0.1≤AOD<0.2, yellow – 0.2≤AOD<0.3, orange – 0.3≤AOD<0.5, red – 0.5≤AOD<0.7, purple – AOD≥0.7).
SolRad-net and contributed flux data

Circle = AERONET
Triangle = BSRN
Square = Other

Blue = Active
Red = Former/Short-term
AERONET Data Synergy Tool

http://aeronet.gsfc.nasa.gov/cgi-bin/bamgomas_interactive

- Utilized for data discovery, data download, and analysis
- New Product: HYSPLIT back trajectories
Acknowledgments

- We thank the EOS Project Science Office and Cal/Val Program for their support
- We thank Dr. Hal Maring of the NASA Headquarters for his support of AERONET