AERONET-The Ground-based Aerosol Satellite/Links to AQ?

International Workshop on Air Quality in Asia
Hanoi, Vietnam, 26 June 2014
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Outline

• The players
• 20+ Years of AERONET
• 7-SEAS SE Asia
• DRAGONs, Field Campaigns, and Future Deployments
• Recent Research
• Improved Instrumentation
• Version 3 Algorithm Development
• Summary
AERONET—Internationally Federated Network

Provide a long-term data set to:
• Characterize aerosol optical properties
• Validate Satellite & model aerosol retrievals
• Synergism with Satellite obs., assimilation models, climate change

• 541 instruments
• 85 countries
• Network Partners
  – GSFC
  – PHOTONS (France)
  – RIMA (Spain)
  – AEROSPAN (Australia)
  – AEROCAN (Canada)
  – AEROSIBNET (-Russia)
  – Many institutes and individual PIs


Parameters measured: $\tau$, $\omega_o$, $\Theta$, size, $n$, $\kappa$ and WV, clds, $L_n$
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)
The AERONET Approach

• Impose Standardization
  – Instrumentation
  – Calibration
  – Data processing
  – Data Availability-Public domain data-base
Cloud screening and quality control

AERONET web site

Level 2.0

Cloud screening and quality control

Level 1.5

Main archive

Level 1.0

Cloud screening

Raw archive

NASA Server and distributed global backup servers

Jabaru National Park, AU
Climatology of Aqua/MODIS AOD during prevalent biomass-burning month over northern and southern SEA. The circles in AOD map denoted the climatology AOD based on AERONET observation.

The underestimating of satellite AOD observation suggests the challenges of satellite retrievals for the regions with heavy aerosol loading and complex terrain.
Seasonal variation of AOD from 5 selected AERONET sites
λ–dependent SSA for selected sites with biomass-burning influence

- As similar to Amazonian and Australian forest, aerosol absorption of Chiang-Mai (northern IC forest) shows $\omega \sim 0.86$ at 440nm, implying higher concentrations of black carbon.

- As contrast, higher $\omega \sim 0.93$ at 440nm were found at a biomass-burning downwind site (Lulin) and a site in southern SEA (Singapore).

- The wide range of $\omega$ has an implication for black carbon fraction in carbonaceous aerosols within different biomass-burning regions.
AERONET daily data at Doi Ang Khang and Maeson

Mean AOD = 0.76
Mean AOD = 1.24

<table>
<thead>
<tr>
<th>Date of year 2014</th>
<th>AOD$_{500}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>3/01</td>
<td>0.2</td>
</tr>
<tr>
<td>3/06</td>
<td>0.4</td>
</tr>
<tr>
<td>3/11</td>
<td>0.8</td>
</tr>
<tr>
<td>3/16</td>
<td>1.2</td>
</tr>
<tr>
<td>3/21</td>
<td>3.0</td>
</tr>
<tr>
<td>3/26</td>
<td>4.0</td>
</tr>
<tr>
<td>3/31</td>
<td>3.5</td>
</tr>
<tr>
<td>4/05</td>
<td>2.5</td>
</tr>
<tr>
<td>4/10</td>
<td>1.5</td>
</tr>
<tr>
<td>4/15</td>
<td>0.5</td>
</tr>
</tbody>
</table>

THAILAND

MYANMAR

LAOS
Daily 24hr mean AOD$_{500}$ at DAK and Maeson, during 01-Mar-2014 to Present

- **Mean AOD** = 0.76
- **Mean AOD** = 1.24

- **Mean AE** = 1.52
- **Mean AE** = 1.55

- **Mean FMF** = 0.93
- **Mean FMF** = 0.95
Summary for aerosol optical and microphysics properties over northern SEA

<table>
<thead>
<tr>
<th>Location</th>
<th>TAOD</th>
<th>FAOD</th>
<th>AE</th>
<th>SSA</th>
<th>AF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bangkok</td>
<td>0.50</td>
<td>0.46</td>
<td>1.46</td>
<td>0.85</td>
<td>0.66</td>
</tr>
<tr>
<td>Chiang Mai</td>
<td>1.18</td>
<td>1.13</td>
<td>1.57</td>
<td>0.86</td>
<td>0.62</td>
</tr>
<tr>
<td>Doi Ang Khang</td>
<td>0.72</td>
<td>0.69</td>
<td>1.57</td>
<td>0.87</td>
<td>0.62</td>
</tr>
<tr>
<td>Luang Namtha</td>
<td>1.16</td>
<td>1.10</td>
<td>1.43</td>
<td>0.83</td>
<td>0.63</td>
</tr>
<tr>
<td>Son La</td>
<td>1.40</td>
<td>1.37</td>
<td>1.49</td>
<td>0.88</td>
<td>0.64</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td><strong>1.00</strong></td>
<td><strong>0.95</strong></td>
<td><strong>1.50</strong></td>
<td><strong>0.86</strong></td>
<td><strong>0.63</strong></td>
</tr>
</tbody>
</table>

Notes:
(1) data is presented at wavelength of 500 nm
(2) statistics were made for coincident day between all sites
MPL

Normalized Relative Backscattering (NRB, Level 1) at Doi Ang Khang

CALIPSO

Aerosol layer over DAK is about 2 km thick!

(a) 2013 March 18

(b) 2013 April 3
## Closure Table

<table>
<thead>
<tr>
<th>Parameter\Type</th>
<th>Urban</th>
<th>Biomass Burning</th>
<th>Dust</th>
<th>Sea Salt Maritime</th>
<th>Mixed</th>
</tr>
</thead>
<tbody>
<tr>
<td>SSA ($\omega_o$)</td>
<td>-Ra†#</td>
<td>-H@#, +L, B, C†, Sc&amp;</td>
<td>+T</td>
<td></td>
<td>-O@, +J@, E†</td>
</tr>
<tr>
<td>Size Distribution $dV/dlnr, r_x$</td>
<td>-Re*</td>
<td>+H@#</td>
<td>+Rp#, +Ru</td>
<td>-S†#</td>
<td>+J@</td>
</tr>
<tr>
<td>Real Index (n)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Imaginary (κ)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Asymmetry (g)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>+J@</td>
</tr>
<tr>
<td>% Sphericity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

†Regional comparisons  
*Nakajima retrievals  
#Version 1  
@ Single point  
& surface comparison  

Table 1, shows the principle parameters measured by sun and sky scanning spectral radiometers for the aerosol types likely encountered. Eleven published validations/comparisons were made during field campaigns over the last 16 years; these are Ra=Ramanathan et al, 2000; Re=Remer et al., 1998; H=Haywood et al, 2003; L=Leahy et al., 2008; B=Bergstrom et al., 2003; Chand et al., 2006; E=Eck et al., 2010; Rp=Reid et al, 2003; Ru=Reid et al., 2008; S=Smirnov et al., 2003; Sc=Schafer et al., 2008; T=Toledano et al., 2011; O=Osborne et al., 2008 and J=Johnson et al., 2009. Note that most categories are incomplete, regionally based, not updated and/or lack relevance.
AERONET DRAGONs
Distributed Regional Aerosol Gridded Observation Networks

- Past DRAGONs
  - 2011 Maryland (Urban)
  - 2012 South Korea (Urban/Asia Outflow)
  - 2012 Japan (Urban/Asia Outflow)
  - 2012 Singapore (Urban)
  - 2012 Penang, Malaysia (Urban)
  - 2013 San Joaquin Valley, California (Urban)

- Past DRAGONs (cont.)
  - 2013 Germany (Industrial)
  - 2013 Houston (Urban/Industrial)

- Current DRAGON
  - 2014 Colorado

- 7-SEAS Mission (2007-present)
AERONET DRAGONs

- Spatially distributed sun photometers deployed around aerosol sources (e.g., cities and industrial regions) over surfaces challenging for satellite remote sensing

- Provide 1 to several months of data in mesoscale distribution at high temporal sampling

Schafer et al., 2014: Intercomparison of aerosol single scattering albedo derived from AERONET surface radiometers and LARGE in-situ aircraft profiles during the 2011 DRAGON-MD and DISCOVER-AQ experiments, J. Geophys. Res.
Cloud and Aerosol Interactions: Cumulus Cloud Regime

- AOD jumps ~0.3 at DRAGON Essex just after solar noon
- Angstrom exponent (440-870 nm) remains very high (>1.9) possibly due to new particle formation in the cloud environment
- Larger variance of AOD (1 min intervals) in the afternoon versus morning indicating relatively high frequency variation in columnar aerosol

AOD enhancement possibly due to rapid conversion of SO2/NO2 to sulfates/nitrates, SOA production, and/or aerosol hygroscopic growth in-cloud or near cloud environment

T. F. Eck, et al. (2014), *Observations of Rapid Aerosol Optical Depth Enhancements in the Vicinity of Polluted Cumulus Clouds*, submitted to ACP Special Issue: Meso-scale aerosol processes, comparison and validation studies from DRAGON networks
Spectral de-convolution algorithm (SDA) retrievals can provide an estimate of the magnitude of the fine mode AOD during periods of optically thin clouds providing aerosol measurements in regions often affected by clouds (e.g., east and southeast Asia).

T. F. Eck, et al. (2014), *in preparation*
AERONET Distribution

- Current holes in the net:
  - Most of Africa
  - Northern and Central Asia
  - Northern South America
  - Northeastern and Western Australia

- Plan: Fill in the gaps;
  Need increase in funding, staff, and facilities
AEROENT Asian distribution
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
  – 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 such as SPARTAN

Cimel Sun/Sky/Lunar Radiometer
AERONET Processing Versions

• Version 0:
  – 1993-2001
  – Simple corrections/Nakajima inversion

• Version 1:
  – 2001 to 2005
  – Improved Cld screening/Dubovik Inversion/green Earth

• Version 2:
  – 2006 to Present
  – Improved corrections/BRDF
AERONET V3, Why?

• Fundamental change in AOD database
  – Improved cld screening
  – Improved Temperature characterization
  – Auto QA—Level 1.5V

• Fundamental change in Inversion database
  – Vector RT code includes polarization
  – Uncertainty estimates
  – Auto QA—Level 1.5 V
AERONET Version 3 Update - AOD

• Version 3 Automated Cloud Screening
  – New Level 1.5 AOD$_{500\text{nm}}$ and $\alpha_{440-870\text{nm}}$ statistically very close to V2 Level 2.0
  – Improperly filtered highly variable AODs (dominated by fine aerosols) will be, at least partly, restored in the V3 database
  – Stable thin cirrus becomes less of a problem (less residual contamination)

<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>N</strong></td>
</tr>
<tr>
<td>Lev 1.0</td>
<td>25579</td>
</tr>
<tr>
<td>Lev 1.5</td>
<td>13326</td>
</tr>
<tr>
<td>Lev 2.0</td>
<td>9371</td>
</tr>
<tr>
<td>NEW Lev 1.5</td>
<td>7879</td>
</tr>
</tbody>
</table>

Smirnov et al. 2015, in preparation
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 depolarization
- Integrate CALIOP monthly climatology of extinction profiles 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

Version 3 database release expected early 2015
Summary

- **Version 3 algorithm development**
  - Completion and first results: Summer 2014
  - Final integration, processing, evaluation: Fall 2014
  - V3 database release: Expected early 2015
- **New V3 Level 1.5V product** will provide near real time AOD data at the highest quality possible for satellite, forecast model, and data assimilation applications
- **New lunar measurement capability** provides potential for nighttime AOD (in development)
- **AERONET expansion** globally would improve temporal and spatial resolution of AOD and retrieved properties allowing for mesoscale and local aerosol process studies
- **Comparisons between RS products and in situ measurements** are a continuing need
- **AERONET continues** to participate in and support national and international field campaign and research activities such as DRAGONs, 7-SEAS etc.
- **Participation in 7-SEAS** contact Prof. George Lin (NCU) or myself, Sept 2-4 mtg.
- **7-SEAS data portal:** [http://www.nrlmry.navy.mil/aerosol_web/7seas/7seas.html](http://www.nrlmry.navy.mil/aerosol_web/7seas/7seas.html)
- **Translating to AQ index** is tricky at best
We Thank you! Questions??
Backup slides
AERONET Version 3 Update - AOD

- More highly variable AOD preserved

Nes Ziona, 5/27/2005 – New Level 1.5

Smirnov et al. 2015, in preparation
AERONET Version 3 Update – AOD

- 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)
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
Above-Water Radiometry with SeaPRISM

\[
L_W (\varphi, \theta, \lambda) = L_T (\varphi, \theta, \lambda) - \rho(\varphi, \theta, \theta_0, W)L_i (\varphi, \theta', \lambda)
\]

Fundamentals

\[
L_W (\lambda) = L_W (\varphi, \theta, \lambda)C_{3Q} (\lambda, \theta, \varphi, \theta_0, \tau_a, Chla, W)
\]

\[
L_{WN} (\lambda) = L_W (\lambda)(D^2 t_d (\lambda) \cos \theta_0)^{-1} C_{f/Q} (\lambda, \theta_0, \tau_A, Chla)
\]

Uncertainties

<table>
<thead>
<tr>
<th>(\lambda)</th>
<th>412</th>
<th>443</th>
<th>490</th>
<th>560</th>
<th>670</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\varepsilon) [%]</td>
<td>5.1</td>
<td>4.5</td>
<td>4.7</td>
<td>4.7</td>
<td>7.8</td>
</tr>
</tbody>
</table>

Maritime Aerosol Network (MAN) represents an important strategic sampling initiative and shipborne data acquisition complements island-based AERONET measurements. MAN has global coverage from October 2006 to May 2014.

SolRad-Net + Contributors as of May 2014

Circle - AERONET
Triangle - BSRN
Square - Other

Blue - Active
Red - Former/Temporary
First Organically grown Mesoscale sun photometer network

Grown by Science, Operational and institutional interests from well funded entities.
Cloud Mode!?

• Cloud OD, two retrievals
  – Liquid phase clds
  – Ice phase clds

• Issues
  – Interferes with high frequency measurements
  – Wet sensor failure results in a rain gauge
  – Requires more active local support
  – Retrievals very difficult to validate
  – Comparisons not impressive

• Future
  – Combine with polarization and cld radar to assess cld phase
Cloud and Aerosol Interactions: Stratiform Clouds and Fog

These cases show bimodal size distributions in the accumulation mode with the large size mode at \(~0.4-0.5\mu m\); the smaller mode at \(~0.15-0.2\mu m\) may be aerosol that were not modified by cloud droplets, which was observed at several sites (e.g., Seoul, Beijing, and Kanpur).

AERONET Data Synergy Tool

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

http://aeronet.gsfc.nasa.gov/cgi-bin/bamgomas_interactive
Complimentary Regional and Global Networks

- GAW PFR network (AOD)
- SKYNET-East Asian sun and sky network
- MPLNET-Micropulse Lidar Network
- PANDORA-Trace Gas network (O$_3$ & NO$_2$)
- LHR-Laser Hetrodyne Radiometer (CO$_2$, CH$_4$)
## AOD$_{500\text{nm}}$ Historical Comparisons

<table>
<thead>
<tr>
<th>Years/Site</th>
<th>Wash. DC</th>
<th>Baltimore</th>
<th>New York City</th>
</tr>
</thead>
<tbody>
<tr>
<td>1903-'07</td>
<td>0.24</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1961-'66</td>
<td>0.37 ± 0.04</td>
<td>0.51 ± 0.04</td>
<td>0.39 ± 0.04</td>
</tr>
<tr>
<td>1993-'09</td>
<td>0.22 ± 0.01</td>
<td>0.22 ± 0.02</td>
<td>0.20 ± 0.02</td>
</tr>
</tbody>
</table>
Early History

Pierre Bouguer’s Essay on the Gradation of Light (1729):

\[ I_\lambda = I_{o\lambda} / d^2 \exp(-\tau_\lambda m) \]

Knut Johan Ångström (1857-1910) invented Pyroheliometer (1893) Quantitative measure of Total solar flux
Solar Measurements

Research to understand the solar constant led to efforts to Remove the atmosphere, thus the genesis of sun photometry

Samuel P. Langley: Invented the bolometer (1884)

Spectral flux: ‘...The accuracy of the bolometric observations becomes, indeed, notable when we admit this consideration, for it is at any rate a far more accurate measure of radiation than the best photometer.’ Annals of the Astrophysical Observatory of the Smithsonian Institution, Volume IPart 2, Chapter 2, Page 239, US Gov. Printing Office 1900.

\[ \ln V_\lambda = \ln \left( \frac{V_{0\lambda}}{d^2} \right) - (\tau_\lambda m) \]

Samuel P. Langley Charles Greeley Abbot
# The dawn of networks

F.E. Volz developed the Volz sun photometer
- Schott interference filters
- Stable photodiodes
- Small, portable and accurate instruments

<table>
<thead>
<tr>
<th>Flowers et al. 1969</th>
<th>M. D. King et al., 1978</th>
</tr>
</thead>
<tbody>
<tr>
<td>• US Turbidity Network</td>
<td>• Size distribution from Inversion of Spectral AOD</td>
</tr>
<tr>
<td>• 5 yr record</td>
<td>• Monthly averages</td>
</tr>
<tr>
<td>• Monthly averages</td>
<td>• ~35 sites</td>
</tr>
</tbody>
</table>
The dawn of networks

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Flowers et al. 1969
• US Turbidity Network
• 5 yr record
• Monthly averages
• ~35 sites

M. D. King et al., 1978
• Size distribution from Inversion of Spectral AOD
Anybody can take these measurements!

Observations on every continent
• National Met programs
• University scientists
• NASA scientists
• Students
• Sailors

BAPMoN (Background Air Pollution Monitoring Network)
• WMO program to coordinate and archive measurements
• 15 yr global record
• Utter Failure
Add the sky radiance

Tanaka, M. et al., 1982
• Inversion yielded improved particle size distributions
• skyrad.pak
• Required accurately pointing sun sky radiometer
• Lost portability/convenience

Enter: Kaufman, Tanre, Buis
The next step

Kaufman and Tanre, 1989

Smirnov with J.P. Buis