Comparison of Remote Sensor and In-Situ Aerosol Properties


ACTIVATE Science Team Meeting, 11/15/23
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Science question
How do we compare ambient aerosol measurements (King Air) with in-situ measurements (Falcon)?

Method
Step 1: Retrieve dry imaginary refractive index (IRI)
- Spectral dry scattering and absorption coefficients ($C$)
- Dry aerosol size resolved number concentration ($n^0$) of particles with diameters from 3 to 3162 nm
Step 2: Retrieve hygroscopicity ($\kappa$)
- Ambient scattering coefficients
- Ambient relative humidity (RH)
Step 3: Cloud filtering and calculation of total ambient aerosol properties
- Ambient aerosol $n^0$ of particles with diameters from 2 to 50 µm
Step 4: Collocation of remote sensors and in-situ data
Step 1: Retrieve dry imaginary refractive index (IRI)

\[ CRI = RRI \pm IRI \times i \]

**RRI:** 1.55  
**IRI:** <0.0001,0.001:0.001,0.04>

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**Measured dry scattering and absorption \( C \)**

\[ \zeta_{sca} = \left| \frac{C_{calc} - C_{meas}}{C_{meas}} \right|_{450,550,700} \times 100\% \]

\[ \zeta_{abs} = \left| \frac{C_{calc} - C_{meas}}{C_{meas}} \right|_{470,532,660} \]

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**Measured Dry \( n^0 \)**

**Calculated scattering and absorption \( C \) (MOPSMAP)**

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**IRI** = mean(IRI), For all IRI where \( \zeta_{sca} < 20\% \) and \( \zeta_{abs} < 1 \text{ Mm}^{-1} \) in all three wavelengths.
Algorithm

Step 2: Retrieve hygroscopicity ($\kappa$)

\[
\left( \frac{\text{Ambient Diameter}}{\text{Dry Diameter}} \right)^3 = \left( \frac{D_{amb}}{D_{dry}} \right)^3 = g^3 = 1 + \kappa \times \frac{RH}{100 - RH}
\]

$\kappa$: <0.01:0.01:1.40>

IRI

Measured Dry

$n^o$

Ambient RH

Measured ambient scattering $C$

Calculated scattering $C$ (MOPSMAP)

$\zeta_{sca} = \frac{|C_{calc} - C_{meas}|_{sca}}{C_{meas}}_{550} \times 100\%

\bar{\kappa} = \kappa$, for smallest $\kappa$

where $\zeta_{sca} < 1\%$
- Ambient extinction at 532 nm agrees to within 0.5%
- Ambient SSA at 532 nm agrees to within 3%
- $f(RH)$ agrees to within 4%

Normalized-range mean absolute deviation (NMAD)

$$\sum_{j=1}^{n} \left| \frac{Y_j - X_j}{n \cdot \frac{\max(X) - \min(X)}} \right| \cdot 100\%$$

where $Y_j$ is set of calculated data, $X_j$ is set of measurement data, and $n$ is the total number of points.

<table>
<thead>
<tr>
<th></th>
<th>Extinction</th>
<th>SSA</th>
<th>$f(RH)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>NMAD (%)</td>
<td>0.1</td>
<td>2.4</td>
<td>1.8</td>
</tr>
</tbody>
</table>
• Most data have low-absorption and generally low hygroscopicity
• Synthetic data are generated by randomly selecting values for IRI, $\kappa$, and the size distribution.
  o RRI is fixed to 1.55.
  o IRI is randomly selected from 0.0001 to 0.040
  o $\kappa$ is randomly selected from 0.01 to 1.40
  o Size distribution is randomly selected from a normal distribution around the mean of the ACTIVATE size distributions.
• Accuracy (systematic uncertainty) and precision (random uncertainty) are 1 standard deviation assuming a normal distribution.
• After synthetic data are generated, the precision offset is applied followed by the accuracy offset.
  o Offsets are applied uniformly to each instrument’s measurements.
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<table>
<thead>
<tr>
<th>Instrument</th>
<th>Measurement</th>
<th>Resolution (s)</th>
<th>Systematic</th>
<th>Random</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tricolor Particle Soot Absorption Photometer (PSAP)</td>
<td>Dry Absorption Coefficients at 470, 532, and 660 nm</td>
<td>1</td>
<td>15%</td>
<td>1 Mm⁻¹</td>
</tr>
<tr>
<td>Nephelometers</td>
<td>Dry Scattering Coefficients at 450, 550, and 700 nm Ambient Scattering Coefficient at 550 nm</td>
<td>1</td>
<td>20%</td>
<td>2 Mm⁻¹</td>
</tr>
<tr>
<td>Scanning Mobility Particle Sizer (SMPS)</td>
<td>Size resolved number concentration for particles with diameters between 3 and 94 nm</td>
<td>45</td>
<td>20%</td>
<td>-</td>
</tr>
<tr>
<td>Laser Aerosol Spectrometer (LAS)</td>
<td>Size resolved number concentration for particles with diameters between 94 and 3162 nm</td>
<td>1</td>
<td>20%</td>
<td>-</td>
</tr>
</tbody>
</table>
• From Monte Carlo simulations, retrieved IRI and $\kappa$ have expected NMAD of 9.6% and 8%, respectively.
• Out of 10,000 simulations, 37% had successful IRI retrievals and 34% had successful retrievals of both IRI and $\kappa$.

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<tr>
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<th>IRI</th>
<th>$\kappa$</th>
</tr>
</thead>
<tbody>
<tr>
<td>NMAD (%)</td>
<td>9.6</td>
<td>8.0</td>
</tr>
</tbody>
</table>
• Total ambient aerosol calculations require probe measurements of coarse aerosol.
  • Cloud Droplet Probe (CDP)
• All ambiguous and cloud data filtered out using the liquid water content (LWC) and CDP droplet number concentration \(N_{\text{CDP}}\) upper limits of 0.001 g m\(^{-3}\) and 5 cm\(^{-3}\), respectively (Schlosser et al., 2022).
• Additionally, the counterflow virtual impactor (CVI) inlet flag was used to ensure no cloud contamination.

• RSP/HSRL-2 data are collocated using the collocation method developed and demonstrated in Schlosser et al., 2023.

• 73.0% of the valid time segments are within 5 minutes and 6 km.

• Maximum 6 min-15 km spatiotemporal threshold applied for the King Air and the Falcon separation.

Schlosser, J. S., and Coauthors, (TBD): Maximizing the volume of collocated data from two coordinated suborbital platforms, submitted to Journal of Atmospheric and Oceanic Technology
• RSP-derived vs. in-situ-derived fine-mode effective radius ($r_{eff,f}$)
• NMAD: 16%
• Count: 133
• RSP Resolution: Number of RSP scans × scan duration = 5 scans × $(\frac{60 \text{ seconds}}{72 \text{ scans}}) \approx 4.167 \text{ seconds}$
• Remove data where normalized cost function > 0.15 and where ambient particle diameter > 1.5 um
• Collocated to nearest level leg and vertical profile
Comparing In-situ and Remote Sensor Data

- HSRL-2-derived vs. in-situ derived extinction coefficient at 532 nm ($\varepsilon_{532\text{nm}}$)
- NMAD: 4.5%
- Count: 14,153
- R: 0.59
- p-value: <10^{-4}
- Resolution: 10 seconds x 175 m
Comparing In-situ and Remote Sensor Data

- RSP-derived vs. in-situ-derived fine-mode effective single scattering albedo ($\text{SSA}_t$) at 555 nm
- NMAD: 24%
- Count: 133
Comparing In-situ and Remote Sensor Data

- HSRL-2- & RSP-derived vs. in-situ derived aerosol number concentration ($N_a$) of particles with ambient diameters greater than 90 nm
- NMAD: 8.5%
- Count: 1151
- R: 0.12
- p-value: $<10^{-4}$
- Filtered according to Schlosser et al., 2022
Questions?