Creating an unified airborne database from multi-aircraft field campaigns

Assessment of Tropospheric Airborne Measurements

Gao Chen, Amy Rowell, Keaton Belli, Ashley Mertens, and Mary Kleb
NASA Langley Research Center
Motivation

• Advantages:
  – Large suite of simultaneous measurements, e.g., O3 and its precursors, particle optical and chemical properties.
  – Good spatial (both vertical and horizontal) resolutions.

• Challenges:
  – Lack of standardized format and central archives.
  – Lack of adequate metadata describing variables, and other critical information.
  – Lack of well defined uncertainties.
Highlights of Recent Progress

• Tropospheric Airborne Measurement Panel (TAbMEP) was assembled for reviewing, certifying, and distributing analysis results.
• First TAbMEP meeting held in August, 2008 in Baltimore, MD focused discussion on ICARTT data intercomparison results for supporting the on-going HTAP Experiment Set 3.
• Data driven algorithms have been established and further refined to Independently assess the random uncertainty $\sigma_R$, when possible, as well as systematic uncertainty (bias).
  • Random uncertainty: inherently unpredictable, cannot be removed, but magnitude may be reduced by averaging.
  • Systematic uncertainty: bias of the measurement means, can be corrected through mathematical models.
• Through intercomparisons, unified ICARTT data defined by the average of all measurements involved, except “outliers” or measurements with identified problems.
• Systematic uncertainty for individual measurement is practically defined as the difference from the unified measurement.
Highlights of Recent Progress (cont.)

• Analysis algorithm requires all aircraft involved participate at least one intercomparison exercise.

For example: 4 ICARTT aircraft and 5 intercomparisons:
3 comparisons between NASA DC-8 and NOAA WP-3D.
1 comparison between NASA DC-8 and FAAM BAe-146.
1 comparison between FAAM BAe-146 and DLR Falcon.
NASA DC-8 and FAAM BAe-146 were used as transferrable standard.

• ICARTT analysis near completion and panel report draft on-going.
• Second TAbMEP meeting is scheduled in July with primary focus on review of the ICARTT assessment report and the POLARCAT intercomparison results. Much more aerosol measurement discussions.
• Central archive development on schedule.
• Additional information: www-air.larc.nasa.gov
ICARTT CO Intercomparison
DC-8 vs. BAe-146

- Coordinated wing-tip-to-wing tip intercomparison with distance between aircraft less than 200 m to ensure sampling the same airmass.
- Initial ICARTT results posted at: http://www-air.larc.nasa.gov/missions/intexna/meas-comparison.htm
Systematic Uncertainty (Bias) Assessment - ICARTT CO Example -

<table>
<thead>
<tr>
<th>Aircraft Platform</th>
<th>Instrument</th>
<th>Apparent Bias (ppbv)</th>
<th>Best Estimate Bias (ppbv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NASA DC-8</td>
<td>DACOM</td>
<td>0</td>
<td>+0.49</td>
</tr>
<tr>
<td>NASA DC-8</td>
<td>WAS</td>
<td>+0.67</td>
<td>+1.16</td>
</tr>
<tr>
<td>NOAA WP-3D</td>
<td>VUVF</td>
<td>-1.48</td>
<td>-0.96</td>
</tr>
<tr>
<td>FAAM BAe-146</td>
<td>VUVF</td>
<td>-6.97*</td>
<td>-6.48</td>
</tr>
<tr>
<td>DLR Falcon</td>
<td>VUVF</td>
<td>-1.16</td>
<td>-0.67</td>
</tr>
<tr>
<td>DLR Falcon</td>
<td>TDLAS</td>
<td>Not assessed</td>
<td>Not assessed</td>
</tr>
</tbody>
</table>

* Outlier, not included in the average

- **Apparent bias = Measurement – Reference Measurement**
  
  Reference can be arbitrarily selected. DC-8 DACOM was chosen here for convenience.

- The unified measurement is defined by the average of all measurements, except the outlier. The apparent bias values are averaged and:

  **Best Estimated Bias = Apparent Bias – Average bias, average bias = 0.49 ppbv.**

- In some other cases, the bias is a function of the measured values or some other variables.
Random Uncertainty ($\sigma_R$) Assessment

Random uncertainty = inherently unpredictable uncertainties, that cannot be corrected.

Internal Estimate of Instrument Precision (IEIP) analysis:

- Assuming the ambient variability was sufficiently small over a short time period, $\Delta t$, so that the observed variability mostly due to instrument precision.
- Advantage: Data driven and objective.
- Limitations: difficult to apply to intermittent or slow measurements. This method cannot detect the instrument variability at much larger time scale.

$\sigma_R = 0.7 \text{ ppbv}$

$\sigma_R = 1.3\%$
Random Uncertainty \( (\sigma_R) \) Assessment (cont.)

- IEIP analysis may not account for some uncertainties with longer time scales, e.g., uncorrelated changes in zero levels or instrument sensitivities.
- Comparison of expected variability with the observed variability provides further adjustments necessary to account for additional uncertainties.
- The observed variability is evaluated after correcting the bias between the paired measurements.

IEIP Assessed precisions:
- \( \sigma_R(DC-8) = 2.4\% \) and \( \sigma_R(BAe-146) = 2.8\% \)
- Expected relative residual SD = 3.68%
- Adjusted Precisions: 2.5% and 2.9%.
Example: Uncertainty Recommendation for ICARTT CO Measurements

<table>
<thead>
<tr>
<th>Aircraft</th>
<th>Instrument</th>
<th>Reported Uncertainty</th>
<th>Assessed $\sigma_R$ (2σ)</th>
<th>Assessed Bias (pptv)</th>
<th>Recommended Uncertainty (2σ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NASA DC-8</td>
<td>DACOM</td>
<td>2% or 2 ppbv</td>
<td>2%</td>
<td>+0.5</td>
<td>2% or 2 ppbv</td>
</tr>
<tr>
<td>NASA DC-8</td>
<td>WAS</td>
<td>5%</td>
<td>11%</td>
<td>+1.2</td>
<td>$((0.11 \text{ CO})^2 + 1.4)^{\frac{1}{2}}$ ppbv</td>
</tr>
<tr>
<td>NOAA WP-3D</td>
<td>VUVF</td>
<td>5%</td>
<td>3.6%</td>
<td>-1.0</td>
<td>5%</td>
</tr>
<tr>
<td>FAAM BAe-146</td>
<td>VUVF</td>
<td>None</td>
<td>3.2%</td>
<td>-6.5</td>
<td>$((0.032 \text{ CO})^2 + 42)^{\frac{1}{2}}$ ppbv</td>
</tr>
<tr>
<td>DLR Falcon</td>
<td>VUVF</td>
<td>10%</td>
<td>3.2%</td>
<td>-0.7</td>
<td>10%</td>
</tr>
<tr>
<td>DLR Falcon</td>
<td>TDLAS</td>
<td>5%</td>
<td>6.8%</td>
<td>Not assessed</td>
<td>$&gt;6.8%$^b</td>
</tr>
</tbody>
</table>

Assessed Bias = Measurement (e.g., DACOM, WAS) – Unified ICARTT CO
Example: Uncertainty Recommendation for ICARTT O₃ Measurements

<table>
<thead>
<tr>
<th>Aircraft</th>
<th>Instrument</th>
<th>Reported Uncertainty</th>
<th>Assessed $\sigma_R$ (1σ)</th>
<th>Assessed Bias (ppbv)</th>
<th>Recommended Uncertainty (2σ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NASA DC-8</td>
<td>NO CLD</td>
<td>3% or 3 ppbv</td>
<td>1.3%</td>
<td>$1.11 - 0.0260 \text{O}_3$-DC8</td>
<td>3% or 3 ppbv</td>
</tr>
<tr>
<td>NOAA WP-3D</td>
<td>NO CLD</td>
<td>0.1 ppbv + 3%</td>
<td>1.4%</td>
<td>$-0.0965 - 0.0138 \text{O}_3$-WP3D</td>
<td>0.1 ppbv + 3%</td>
</tr>
<tr>
<td>FAAM BAe-146</td>
<td>TECO UVP</td>
<td>None</td>
<td>1.5%</td>
<td>$-2.26 + 0.0491 \text{O}_3$-BAe146</td>
<td>${(-0.0491 \text{O}_3 + 2.26)^2 + (0.03 \text{O}_3)^2}^{1/2}$ ppbv</td>
</tr>
<tr>
<td>DLR Falcon</td>
<td>TECO UVP</td>
<td>5%</td>
<td>1.0%</td>
<td>$-0.959 + 0.0375 \text{O}_3$-Falcon</td>
<td>2 ppbv or 5%</td>
</tr>
</tbody>
</table>

Assessed Bias = Measurement (e.g., NO CLD) – Unified ICARTT O₃
Example: $2\sigma$ Uncertainty Recommendation for ICARTT O$_3$ Measurements (cont.)
Example: Uncertainty Recommendation for POLARCAT CO Measurements

<table>
<thead>
<tr>
<th>Aircraft</th>
<th>Instrument</th>
<th>Reported Uncertainty (1σ)</th>
<th>Assessed $\sigma_{R}$ (1σ)</th>
<th>Assessed Bias (ppbv)</th>
<th>Recommended Uncertainty (2σ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NASA DC-8 DC-8</td>
<td>DACOM</td>
<td>2% or 2 ppbv</td>
<td>0.8%</td>
<td>-0.31</td>
<td>2% or 2 ppbv</td>
</tr>
<tr>
<td>NASA P3-B</td>
<td>VUVF</td>
<td>3%</td>
<td>9.6%</td>
<td>-0.97</td>
<td>10%</td>
</tr>
<tr>
<td>NOAA WP-3D</td>
<td>VUVF</td>
<td>3%</td>
<td>1.5%</td>
<td>0.95</td>
<td>$(1 + (0.03 \text{ CO})^2)^{\frac{1}{2}}$ ppbv</td>
</tr>
<tr>
<td>DLR Falcon</td>
<td>VUVF</td>
<td>10%</td>
<td>2.1%</td>
<td>-4.09</td>
<td>$(4.1^2 + (0.042 \text{ CO})^2)^{\frac{1}{2}}$ ppbv</td>
</tr>
<tr>
<td>ATR-42</td>
<td>VUVF</td>
<td>Not Given</td>
<td>4.3%</td>
<td>0.97</td>
<td>$(1 + (0.086 \text{ CO})^2)^{\frac{1}{2}}$ ppbv</td>
</tr>
</tbody>
</table>

Assessed Bias = Measurement (e.g., DACOM, ) – Unified POLACAT CO
Looking forward:

- Unified ICARTT data will be released before the end of 2009 in NetCDF format, with TAbMEP certified uncertainty assessment.
- POLARCAT uncertainty assessment and data are scheduled release after July 2010.
- Hope to work with modeling communities to reconcile the model and observation differences and to gain better understanding of the processes.
- Comments, suggestions, requests?
- Additional information available: www-air.larc.nasa.gov
- Feel free to contact me for in-situ data questions gao.chen@nasa.gov