Validation of Satellite Sounder Environmental Data Records: Application to S-NPP

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Introduction: JPSS CrIMSS

- **Joint Polar Satellite System (JPSS) Cross-track Infrared Microwave Sounder Suite (CrIMSS) sounder system:**
  - Cross-track Infrared Sounder (CrIS) and Advanced Technology Microwave Sounder (ATMS)
  - Designed to retrieve atmospheric vertical temperature and moisture profiles (AVTP and AVMP), with optimal vertical resolution under non-precipitating conditions (cloudy, partly cloudy and clear)

- **CrIMSS Operational EDR Algorithms**
  - NOAA Unique CrIS/ATMS Processing System (NUCAPS)
    - Exact line-for-line modular implementation of the iterative, multistep AIRS Science Team retrieval algorithm
    - AVTP, AVMP and trace gas profiles (O₃, CO, CO₂, CH₄, etc.; e.g., see 16ATCHEM Oral 5.3, Smith and Nalli)
    - See 10GOESRPSS Oral 9.1 (Gambacorta et al.)
  - Original IDPS Algorithm
    - Optimal Estimation (OE) algorithm originally developed by AER
    - See 10GOESRPSS Poster 353 (Divakarla et al.)

NUCAPS Ozone retrieval 450 hPa
15 May 2013
The Importance of Validating Sounder EDRs

- **Validation** is “the process of ascribing uncertainties to these radiances and retrieved quantities through comparison with correlative observations” (Fetzer et al., 2003).
- Validation of EDRs provides implicit validation of SDRs.
- Includes validation of retrieved cloud-cleared radiances (CCRs), which are known to have positive impact on NWP (e.g., Le Marshall et al., 2008).
- Enables development/improvement of algorithms.
- Sounder EDR (AVTP, AVMP and trace gas) users include
  - WFOs (AWIPS)
  - Science users/investigators (e.g., Pagano et al., 2013)
JPSS Cal/Val Program

- **JPSS Cal/Val Phases**
  - Pre-Launch / Early Orbit Checkout (EOC)
  - Intensive Cal/Val (ICV)
    - Validation of EDRs against multiple correlative datasets
  - Long-Term Monitoring (LTM)
    - Characterization of all EDR products and long-term demonstration of performance

- In accordance with the JPSS phased schedule, the **S-NPP CrIMSS EDR cal/val plan** was devised to ensure the EDR would meet the mission Level 1 requirements (*Barnet*, 2009)

- The **EDR validation methodology** draws upon previous work with AIRS and IASI and is summarized in this talk (after *Nalli et al.*, 2013b)

### Atmospheric Vertical Temperature Profile (AVTP)

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>THRESHOLD</th>
</tr>
</thead>
<tbody>
<tr>
<td>AVTPClear, surface to 300 mb</td>
<td>1.6 K / 1-km layer</td>
</tr>
<tr>
<td>AVTPClear, 300 to 30 mb</td>
<td>1.5 K / 3-km layer</td>
</tr>
<tr>
<td>AVTPClear, 30 mb to 1 mb</td>
<td>1.5 K / 5-km layer</td>
</tr>
<tr>
<td>AVTP Clear, 1 mb to 0.5 mb</td>
<td>3.5 K / 5-km layer</td>
</tr>
<tr>
<td>AVTPCloudy, surface to 700 mb</td>
<td>2.5 K / 1-km layer</td>
</tr>
<tr>
<td>AVTPCloudy, 700 mb to 300 mb</td>
<td>1.5 K / 1-km layer</td>
</tr>
<tr>
<td>AVTPCloudy, 300 mb to 30 mb</td>
<td>1.5 K / 3-km layer</td>
</tr>
<tr>
<td>AVTPCloudy, 30 mb to 1 mb</td>
<td>1.5 K / 5-km layer</td>
</tr>
<tr>
<td>AVTPCloudy, 1 mb to 0.5 mb</td>
<td>3.5 K / 5-km layer</td>
</tr>
</tbody>
</table>

### Atmospheric Vertical Moisture Profile (AVMP)

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>THRESHOLD</th>
</tr>
</thead>
<tbody>
<tr>
<td>AVMPClear, surface to 600 mb</td>
<td>Greater of 20% or 0.2 g/kg / 2-km layer</td>
</tr>
<tr>
<td>AVMPClear, 600 to 300 mb</td>
<td>Greater of 35% or 0.1 g/kg / 2-km layer</td>
</tr>
<tr>
<td>AVMPClear, 300 to 100 mb</td>
<td>Greater of 35% or 0.1 g/kg / 2-km layer</td>
</tr>
<tr>
<td>AVMPCloudy, surface to 600 mb</td>
<td>Greater of 20% or 0.2 g/kg / 2-km layer</td>
</tr>
<tr>
<td>AVMPCloudy, 600 mb to 400 mb</td>
<td>Greater of 40% or 0.1 g/kg / 2-km layer</td>
</tr>
<tr>
<td>AVMPCloudy, 400 mb to 100 mb</td>
<td>Greater of 40% or 0.1 g/kg / 2-km layer</td>
</tr>
</tbody>
</table>
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VALIDATION METHODOLOGY
Validation Methodology Hierarchy (1/2)

1. Numerical Model (e.g., ECMWF, NCEP/GFS) Global Comparisons
   - Large, global samples acquired from Focus Days
   - Useful for early sanity checks, bias tuning and regression
   - However, not independent truth data

2. Satellite EDR (e.g., AIRS, ATOVS, COSMIC) Intercomparisons
   - Global samples acquired from Focus Days (e.g., AIRS)
   - Consistency checks; merits of different retrieval algorithms
   - However, IR sounders have similar error characteristics; must take rigorous account of averaging kernels of both systems (e.g., Rodgers and Connor, 2003)

3. Conventional RAOB Matchup Assessments
   - Conventional WMO/GTS operational sondes launched ~2/day for NWP (e.g., NPROVS)
   - Useful for representation of global zones and long-term monitoring
   - Large statistical samples acquired after a couple months’ accumulation
   - Limitations:
     - Skewed distribution toward NH-continental sites
     - Significant mismatch errors
     - Non-uniform, less-accurate and poorly characterized radiosonde types used in data sample
4. **Dedicated/Reference RAOB Matchup Assessments**
   - Dedicated sondes: Vaisala RS92-SGP dedicated for the purpose of satellite validation
     - Well-specified error characteristics and optimal accuracy
     - Minimal mismatch errors
     - Include atmospheric state “best estimates” or “merged soundings”
   - Reference sondes: CFH, corrected RS92, Vaisala RR01 under development
     - Traceable measurement
   - Detailed performance specification and regional characterization
   - Limitation: Small sample sizes and geographic coverage
   - E.g., ARM sites (e.g., Tobin et al., 2006), ideally GRUAN

5. **Intensive Field Campaign Dissections**
   - Include dedicated RAOBs, especially those not assimilated into NWP models
   - Include ancillary datasets (e.g., ozonesondes, lidar, M-AERI, MWR, sunphotometer, etc.)
   - Ideally include funded aircraft campaign using aircraft IR sounder (e.g., NAST-I, S-HIS) underflights (See 10GOESRJPSS Poster 690, Taylor et al.)
   - Detailed performance specification; state specification; SDR cal/val; EDR “dissections”
   - E.g., AEROSE, JAIVEX, WAVES, AWEX-G, EAQUATE
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ASSESSMENT METHODOLOGY
Assessment Methodology: Reducing Truth to Correlative Layers

- The relationship between the forward and inverse problem (Rodgers, 1990) requires that high-resolution truth measurements (e.g., dedicated RAOB) should be reduced to correlative RTA layers

\[
\hat{x} = I[F(x,b), b, c]
\]

- Basic approach is to integrate quantities over the atmospheric path (e.g., number densities → column abundances), interpolate to RTA (arbitrary) levels, then compute then RTA layer quantities

\[
\sum_x(z) = \int_{z_t}^{z} N_x(z') \, dz'
\]
Assessment Methodology: Statistical Metrics

- Level 1 AVTP and AVMP accuracy requirements are defined over coarse layers, roughly 1–5 km for tropospheric AVTP and 2 km for AVMP (Table, Slide 5).

### AVTP

\[
\text{RMS}(\Delta T_G) = \sqrt{\frac{1}{n_j} \sum_{j=1}^{n_j} (\Delta T_{G,j})^2} \\
\text{BIAS}(\Delta T_G) \equiv \Delta T_G = \frac{1}{n_j} \sum_{j=1}^{n_j} \Delta T_{G,j} \\
\text{STD}(\Delta T_G) \equiv \sigma(\Delta T_G) = \sqrt{[\text{RMS}(\Delta T_G)]^2 - [\text{BIAS}(\Delta T_G)]^2}
\]

### AVMP and O₃

- W2 weighting was used in determining Level 1 Requirements
- To allow compatible STD calculation, W2 weighting should be consistently used for both RMS and BIAS

\[
\text{RMS}(\Delta q_G) = \sqrt{\frac{\sum_{j=1}^{n_j} W_{G,j} (\Delta q_{G,j})^2}{\sum_{j=1}^{n_j} W_{G,j}}}, \quad \text{water vapor weighting factor, } W_{G,j},
\]

\[
\text{BIAS}(\Delta q_G) = \frac{\sum_{j=1}^{n_j} W_{G,j} \Delta q_{G,j}}{\sum_{j=1}^{n_j} W_{G,j}}, \quad W_{G,j} = \begin{cases} 
1 & , \quad W^0 \\
q_{G,j} & , \quad W^1 \\
(q_{G,j})^2 & , \quad W^2
\end{cases}
\]

\[
\text{STD}(\Delta q_G) = \sqrt{[\text{RMS}(\Delta q_G)]^2 - [\text{BIAS}(\Delta q_G)]^2}
\]
Assessment Methodology: Use of Averaging Kernels (AKs)

- **AKs** define the **vertical sensitivity** of the sounder measurement system
  \[ A \equiv \frac{\partial \hat{x}}{\partial x} \]
- Facilitates intercomparisons of profiles obtained by two different observing systems
- Retrieval AKs can be used to “smooth” correlative truth (RAOBs reduced to RTA layers), thereby **removing null-space errors** otherwise present
  \[ x_s = A(x - x_0) + x_0 \]
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APPLICATION TO S-NPP
Conventional RAOB Matchups

- NOAA Products Validation System (NPROVS) (Reale et al., 2012)
  - See 10GOESRJPSS Posters 675 (Sun et al.) and 677 (Pettey et al.)

- Matchup Sample Jul-Dec 2013, $N = 34234$
JPSS S-NPP Dedicated RAOBs

- **PMRF** (Kauai, Hawaii)
  - 2012 SNPP testbed site
- **BCCSO** (Beltsville, MD)
  - Howard University
  - continent, urban
- **ARM Sites**
  - TWP (Manus Island)
  - SGP (Oklahoma)
  - NSA (Alaska)
  - See 10GOESRJPSS Poster 700 (*Borg et al.*)
- **AEROSE Campaigns**
  - Tropical Atlantic Ocean
  - See 10GOESRJPSS Poster 681 (*Nalli et al.*)
Reference RAOBs

- GRUAN reference RAOB matchups with S-NPP are currently being acquired via the NPROVS+ system
  - Traceable measurements
  - See 10GOESRJPSS Poster 675 (Reale et al.)
A VALAR “stamp” is roughly defined as a granule-level input file (matched with a RAOB anchor point) needed for performing re-retrievals.

SDR stamps consist of 4-scan line granules within ±1 minute of overpass, ≈500 km radius.
Future Work

• **SNPP CrIMSS NUCAPS Stages 1-3 Validated Maturities**
  — NUCAPS Phase II algorithm improvements

• **Long Term Monitoring (LTM) of S-NPP CrIMSS**
  — Apply averaging kernels in NUCAPS error analyses
  — Ensemble statistics versus GRUAN and dedicated RAOB
  — calc – obs (e.g., CCR) analyses (e.g., Nalli et al., 2013a)
  — NUCAPS trace gas profile validation (e.g., O₃, CO, etc.)
  — NUCAPS skin SST validation
  — NUCAPS EDR algorithm development (e.g., AVTP/AVMP uncertainty estimates)
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