Validation of the NOAA Unique CrIS/ATMS Processing System (NUCAPS) Operational Retrieval Products

Nicholas R. Nalli$^{1,2}$, A. Gambacorta$^{1,2}$, T. Reale$^3$, B. Sun$^{1,3}$, Q. Liu$^2$, C. Barnet$^4$, T. S. King$^{1,2}$, W. W. Wolf$^2$, F. Iturbide-Sanchez$^{1,2}$, C. Tan$^{1,2}$, D. Tobin$^5$, L. Borg$^5$, E. Joseph$^6$, V. R. Morris$^6$, A. K. Mollner$^7$, F. Tilley$^{1,2}$, X. Xiong$^{1,2}$, M. Wilson$^{1,2}$, et al.

$^1$IMSG, Rockville, Maryland, USA
$^2$NOAA/NESDIS/STAR, College Park, Maryland, USA
$^3$NOAA/NESDIS/STAR, Suitland, Maryland, USA
$^4$STC, Columbia, Maryland, USA
$^5$University of Wisconsin-Madison, Madison, Wisconsin, USA
$^6$Howard University, Washington, D.C., USA
$^7$The Aerospace Corp., El Segundo, California, USA

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Outline

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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).
  - EDR validation provides implicit validation of SDRs
- EDR validation enables development/improvement of algorithms
- Includes validation of the cloud-cleared radiances (a Level 2 product shown to have positive impact on NWP; e.g., Le Marshall et al., 2008)
- Users of sounder EDR observations (AVTP, AVMP and trace gas) include
  - Weather Forecast Offices (AWIPS)
    - Nowcasting / severe weather
  - NOAA Data Centers (e.g., NGDC, CLASS)
  - Basic and applied science research/investigation (e.g., Pagano et al., 2013)
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
  - Non-precipitating conditions (cloudy, partly cloudy, clear)
  - AVTP, AVMP and trace gas profiles (O$_3$, CO, CO$_2$, CH$_4$, etc.)
  - Operational algorithm starting Sep 2013

- **Original IDPS Algorithm**
  - Optimal Estimation (OE) algorithm originally developed by AER
  - CrIMSS operational product (MX7.1) validated through Beta and Provisional maturities (*Divakarla et al.*, 2014)
  - Replaced by NUCAPS in Sep 2013; validation transition to NUCAPS

NUCAPS Ozone retrieval 450 hPa
15 May 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 **SNPP 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 (*Nalli et al., 2013, JGR Special Section on SNPP Cal/Val*).

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<th>Atmopheric Vertical Temperature Profile (AVTP)</th>
<th>Measurement Uncertainty – Layer Average Temperature Error</th>
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<td>AVMP Cloudy, 400 mb to 100 mb</td>
<td>Greater of 40% or 0.1 g/kg / 2-km layer</td>
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Validation of NUCAPS Operational Retrieval Products

VALIDATION METHODOLOGY
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 (Tobin et al., 2006), merged soundings (e.g., lidar) and uncertainty estimates (dual launches)
   – Reference sondes: CFH, GRUAN-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, PMRF, BCCSO, AEROSE, 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)
   – Detailed performance specification; state specification; SDR cal/val; EDR “dissections”
   – E.g., AEROSE, JAIVEX, WAVES, AWEX-G, EAQUATE
Validation of NUCAPS Operational Retrieval Products

ASSESSMENT METHODOLOGY
Assessment Methodology: Reducing Truth to Correlative Layers

- The **measurement equation** (e.g., Taylor and Kuyatt, 1994) for retrieval includes forward and inverse operators (Rodgers, 1990) to estimate the measurand, $x$, on forward model layers:

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

- **Rigorous validation** therefore requires high-resolution truth measurements (e.g., dedicated RAOB) be **reduced to correlative RTA layers** (Nalli et al., 2013, JGR Special Section on SNPP Cal/Val)

- **Radiative transfer approach** is to integrate quantities over the atmospheric path (e.g., number densities $\rightarrow$ column abundances), interpolate to RTA (arbitrary) levels, then compute then RTA layer quantities, e.g.,

  $$\sum_x(z) = \int_{z_t}^{z} N_x(z') dz'$$
Level 1 AVTP and AVMP accuracy requirements are defined over coarse layers, roughly 1–5 km for tropospheric AVTP and 2 km for AVMP (e.g., Q. Liu’s presentation).

**AVTP**

\[
\text{RMS}(\Delta T) = \sqrt{\frac{1}{n_j} \sum_{j=1}^{n_j} (\Delta T_{j})^2}
\]

\[
\text{BIAS}(\Delta T) = \frac{1}{n_j} \sum_{j=1}^{n_j} \Delta T_{j}
\]

\[
\text{STD}(\Delta T) = \sigma(\Delta T) = \sqrt{[\text{RMS}(\Delta T)]^2 - [\text{BIAS}(\Delta T)]^2}
\]

**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

\[
\text{RMS}(\Delta q) = \sqrt{\frac{\sum_{j=1}^{n_j} W_{q,j}(\Delta q_{j})^2}{\sum_{j=1}^{n_j} W_{q,j}}}
\]

\[
\text{BIAS}(\Delta q) = \frac{\sum_{j=1}^{n_j} W_{q,j} \Delta q_{j}}{\sum_{j=1}^{n_j} W_{q,j}}
\]

\[
\text{STD}(\Delta q) = \sqrt{[\text{RMS}(\Delta q)]^2 - [\text{BIAS}(\Delta q)]^2}
\]

\[
W_{q,j} = \begin{cases} 
1, & W^0 \\
q_{q,j}, & W^1 \\
(q_{q,j})^2, & W^2 
\end{cases}
\]
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

\[ x_s = A (x - x_0) + x_0 \]
Validation of NUCAPS Operational Retrieval Products

STAR VALIDATION ARCHIVE (VALAR)
Validation Archive (VALAR)

- We are in the process of building a **Validation Archive (VALAR)** for satellite sounder research (viz., CrIS/ATMS, IASI)

- **VALAR** is intended to serve as a go-to archive for the life of the SNPP mission to directly support validation and development
**VALAR Data**

- **High-quality RAOB Anchor Points** (dedicated and reference sondes)
  - Original native files “untouched” at full resolution
  - Reduced 100 RTA layers (i.e., correlative truth)

- **CrIS/ATMS SDR/TDR/EDR Granule “Stamps”**
  - A VALAR “stamp” is roughly defined as a granule file matched with a RAOB anchor point needed for offline retrievals and validation
  - SDR/TDR/EDR stamps consist of 4-scan line granules within ±1 minute of overpass (≈500 km radius, usually 4-5 granules centered on RAOB)
JPSS SNPP Dedicated RAOB Truth

- **PMRF** (Kauai, Hawaii)
  - 2012 SNPP testbed site
- **BCCSO** (Beltsville, MD)
  - Howard University
  - Continent, urban
- **ARM Sites** (*Tobin et al.*, 2006)
  - TWP (Manus Island)
  - SGP (Oklahoma)
  - NSA (Alaska)
- **AEROSE Campaigns** (*Nalli et al.*, 2006, 2011)
  - Tropical Atlantic Ocean
  - Dust/smoke aerosols, Saharan air layers
  - Dedicated Ozonesondes
  - Truly independent dataset
Reference RAOB Truth

- GRUAN reference RAOB (Seidel et al., 2009) collocations (00:00 and 12:00 UTC) are currently being acquired via the NPROVS+ system (e.g., Reale et al., 2012)
  - Traceable reference measurements
- NPROVS+ collocations support development of the STAR Validation Archive (VALAR)
VALAR and NPROVS+

NPROVS+

- 7-day delay GRUAN and dedicated RAOB collocation
- Nearest-FOR Operational-EDR Collocation Files
- Nearest-FOR Reprocessed-EDR Collocation Files
- User Interface Tools: PDISP, NARCS and ODS
- Routine ICV and LTM

VALAR

- Reduced 100 layer collocated RAOB
- SDR/TDR/EDR Granule Stamps
- Host Offline Retrievals
- Reprocessed EDR Granule Stamps
- Research ICV and LTM
- Facilitate Algorithm Research/Development
Validation of NUCAPS Operational Retrieval Products

NUCAPS VALIDATION
NUCAPS AVTP/AVMP – VALAR Tropics

VALAR Site Accepted Matchups ($\delta x \leq 100$ km)

Tropics

AVTP RMS ($n_{qa} = 499$)

AVMP RMS ($n_{qa} = 499$)

AVTP Bias ($n_{qa} = 499$)

AVMP Bias ($n_{qa} = 499$)
NUCAPS Ozone – VALAR AEROSE Year-1
Dedicated Ozonesondes

VALAR Year-1 AEROSE Ozonesonde NUCAPS Accepted Matchups ($\delta x \leq 150$ km)

Ozone RMS ($n_w=218$)

Ozone Bias ($n_w=218$)
Future Work

- **SNPP NUCAPS Stages 1-3 Validated Maturities**
  - Support short-term NUCAPS algorithm updates/improvements

- **Intensive Cal/Val (ICV) and Long Term Monitoring (LTM) of NUCAPS EDRs**
  - VALAR growth, development and enhancements
  - **Operational and offline AVTP and AVMP validation**
    - Coarse-layer ensemble statistical analyses versus dedicated and reference RAOB truth
  - **Trace gas profile EDR (e.g., O₃, CO) validation**
    - Ozonesondes (e.g., AEROSE, SHADOZ)
    - WRF-CHEM modeling (e.g., Smith and Nalli, 2014)
  - **GRUAN reprocessing** of RS92 RAOB data (e.g., AEROSE)
  - **Apply averaging kernels** in NUCAPS error analyses
  - **calc – obs** (e.g., CCR) analyses
  - Skin SST EDR validation
  - Support long-term NUCAPS EDR algorithm development
    - A priori
    - AVTP/AVMP uncertainty estimates
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