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

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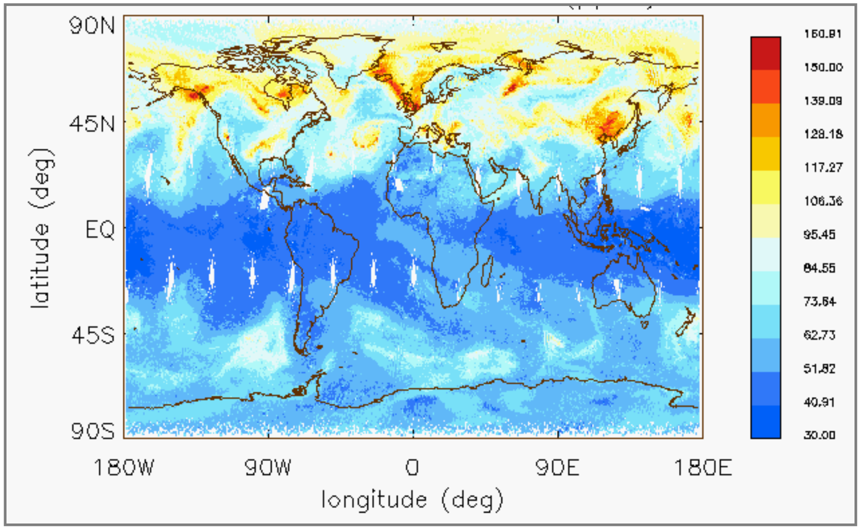
Introduction: JPSS CrIMSS

- **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 (O_3, CO, CO_2, CH_4, etc.; e.g., see 16ATCHEM Oral 5.3, *Smith and Nalli*)
    - **See 10GOESRJPSS Oral 9.1 (*Gambacorta et al.*)**
  - Original IDPS Algorithm
    - Optimal Estimation (OE) algorithm originally developed by AER
    - See 10GOESRJPSS 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)
Measurement Uncertainty – Layer Average Temperature Error

PARAMETER	THRESHOLD
AVTP Clear, surface to 300 mb	1.6 K / 1-km layer
AVTP Clear, 300 to 30 mb	1.5 K / 3-km layer
AVTP Clear, 30 mb to 1 mb	1.5 K / 5-km layer
AVTP Clear, 1 mb to 0.5 mb	3.5 K / 5-km layer
AVTP Cloudy , surface to 700 mb	2.5 K / 1-km layer
AVTP Cloudy, 700 mb to 300 mb	1.5 K / 1-km layer
AVTP Cloudy, 300 mb to 30 mb	1.5 K / 3-km layer
AVTP Cloudy, 30 mb to 1 mb	1.5 K / 5-km layer
AVTP Cloudy, 1 mb to 0.5 mb	3.5 K/ 5-km layer

Atmospheric Vertical Moisture Profile (AVMP)
Measurement Uncertainty – 2-km Layer Average Mixing Ratio % Error

PARAMETER	THRESHOLD
AVMP Clear, surface to 600 mb	Greater of 20% or 0.2 g/kg / 2-km layer
AVMP Clear, 600 to 300 mb	Greater of 35% or 0.1 g/kg / 2-km layer
AVMP Clear, 300 to 100 mb	Greater of 35% or 0.1 g/kg / 2-km layer
AVMP Cloudy, surface to 600 mb	Greater of 20% of 0.2 g/kg / 2-km layer
AVMP Cloudy, 600 mb to 400 mb	Greater of 40% or 0.1 g/kg / 2-km layer
AVMP Cloudy, 400 mb to 100 mb	Greater of 40% or 0.1 g/kg / 2-km layer

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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

Validation Methodology Hierarchy (2/2)

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

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

- 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

$$\Sigma_x(z) = \int_{z_t}^{z} N_x(z')\,dz'$$

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

$$\mathrm{RMS}(\Delta T_{\mathcal{L}}) = \sqrt{\frac{1}{n_j}\sum_{j=1}^{n_j}(\Delta T_{\mathcal{L},j})^2} \qquad \mathrm{BIAS}(\Delta T_{\mathcal{L}}) \equiv \overline{\Delta T_{\mathcal{L}}} = \frac{1}{n_j}\sum_{j=1}^{n_j}\Delta T_{\mathcal{L},j}$$

$$\mathrm{STD}(\Delta T_{\mathcal{L}}) \equiv \sigma(\Delta T_{\mathcal{L}}) = \sqrt{[\mathrm{RMS}(\Delta T_{\mathcal{L}})]^2 - [\mathrm{BIAS}(\Delta T_{\mathcal{L}})]^2}$$

AVMP and O_3

- 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

$$\mathrm{RMS}(\Delta q_{\mathcal{L}}) = \sqrt{\frac{\sum_{j=1}^{n_j} W_{\mathcal{L},j}(\Delta q_{\mathcal{L},j})^2}{\sum_{j=1}^{n_j} W_{\mathcal{L},j}}}, \qquad \text{water vapor weighting factor, } W_{\mathcal{L},j},$$

$$\mathrm{BIAS}(\Delta q_{\mathcal{L}}) = \frac{\sum_{j=1}^{n_j} W_{\mathcal{L},j}\,\Delta q_{\mathcal{L},j}}{\sum_{j=1}^{n_j} W_{\mathcal{L},j}}, \qquad W_{\mathcal{L},j} = \begin{cases} 1 & , \mathrm{W}^0 \\ q_{\mathcal{L},j} & , \mathrm{W}^1 \\ (q_{\mathcal{L},j})^2 & , \mathrm{W}^2 \end{cases}$$

$$\mathrm{STD}(\Delta q_{\mathcal{L}}) = \sqrt{[\mathrm{RMS}(\Delta q_{\mathcal{L}})]^2 - [\mathrm{BIAS}(\Delta q_{\mathcal{L}})]^2}$$

Assessment Methodology: Use of Averaging Kernels (AKs)

- **AKs** define the **vertical sensitivity** of the sounder measurement system

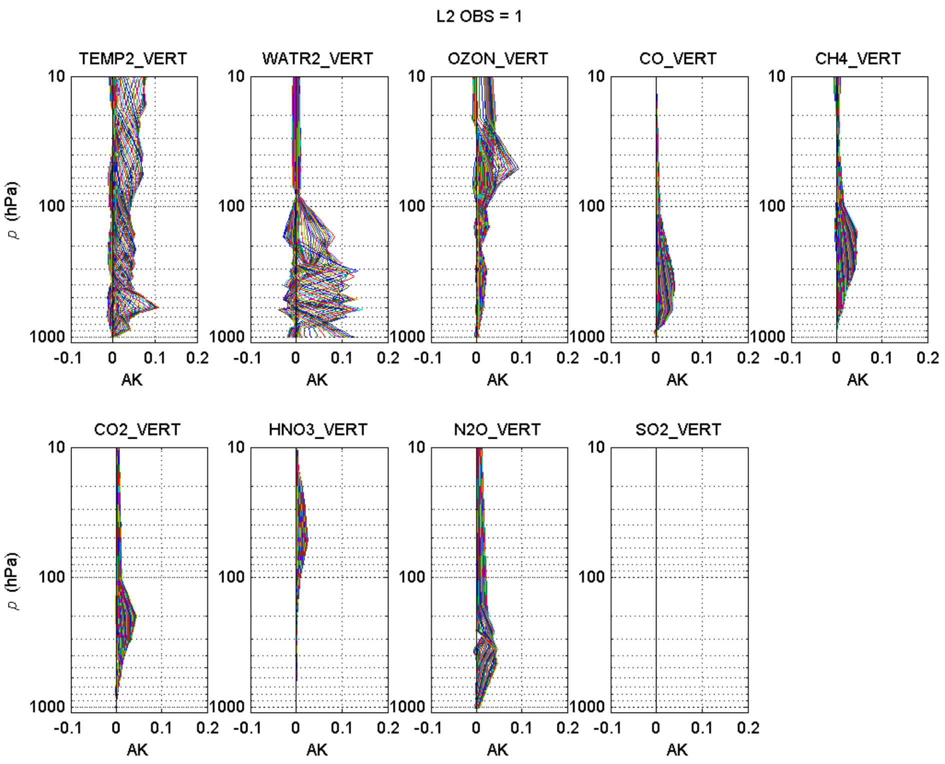
$$\mathbf{A} \equiv \frac{\partial \hat{\mathbf{x}}}{\partial \mathbf{x}}$$

- 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

$$\mathbf{x}_s = \mathbf{A}(\mathbf{x} - \mathbf{x}_0) + \mathbf{x}_0$$

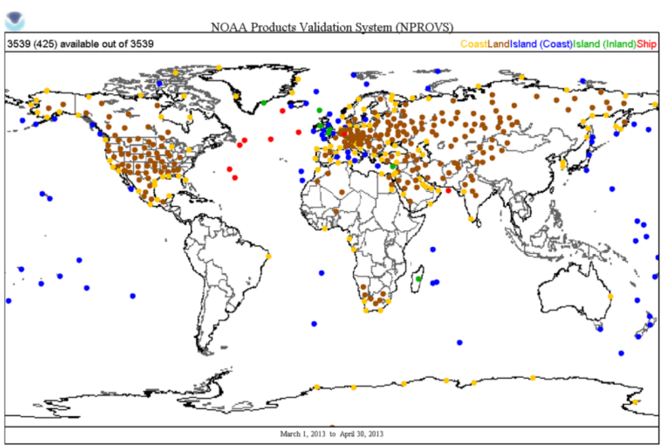
NOAA-Unique IASI Averaging Kernels

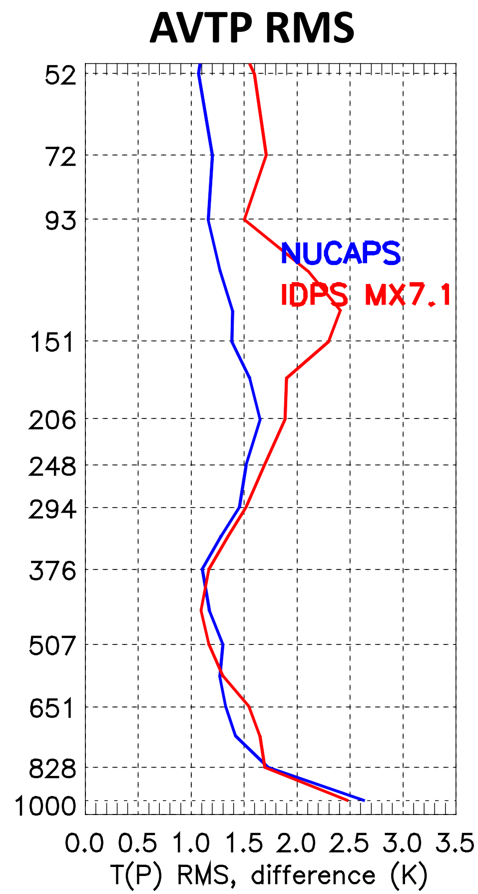


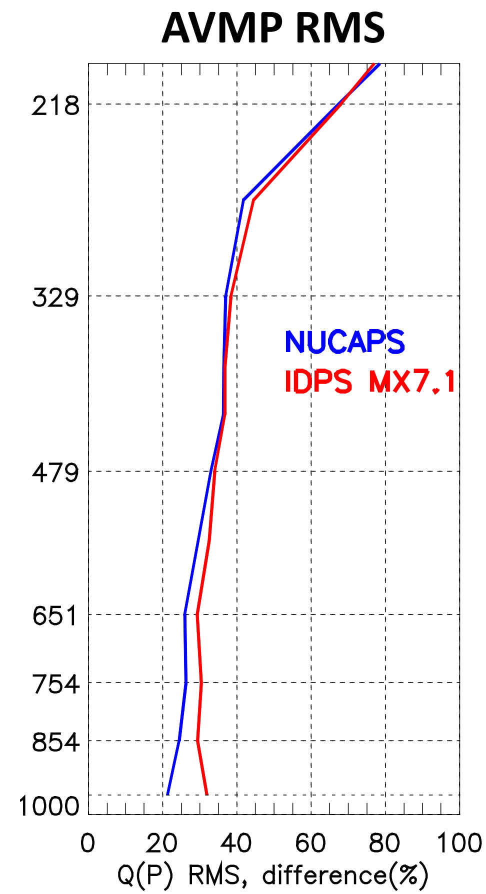
APPLICATION TO S-NPP

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



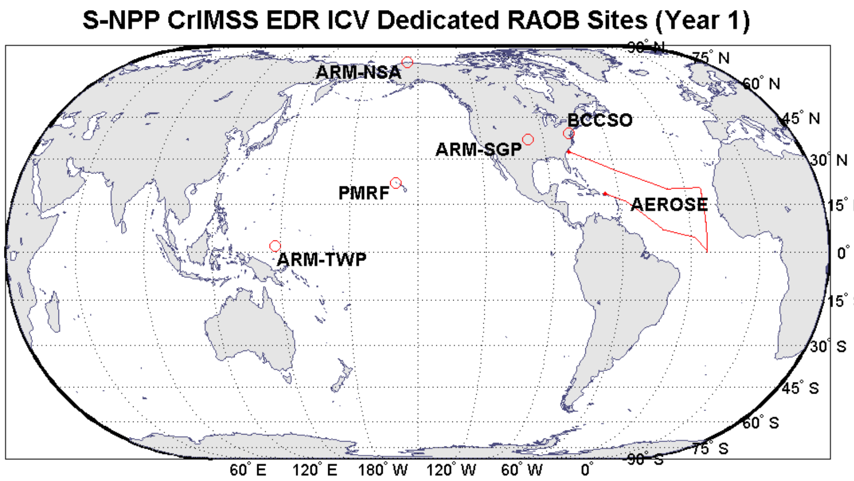


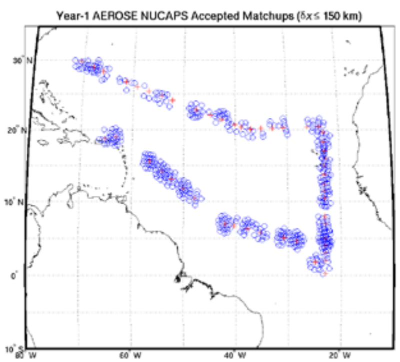


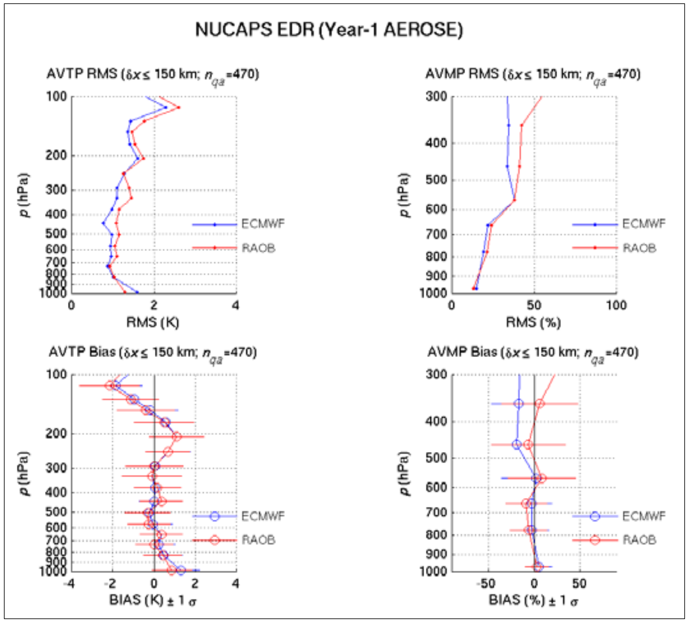
Courtesy of B. Sun

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.*)



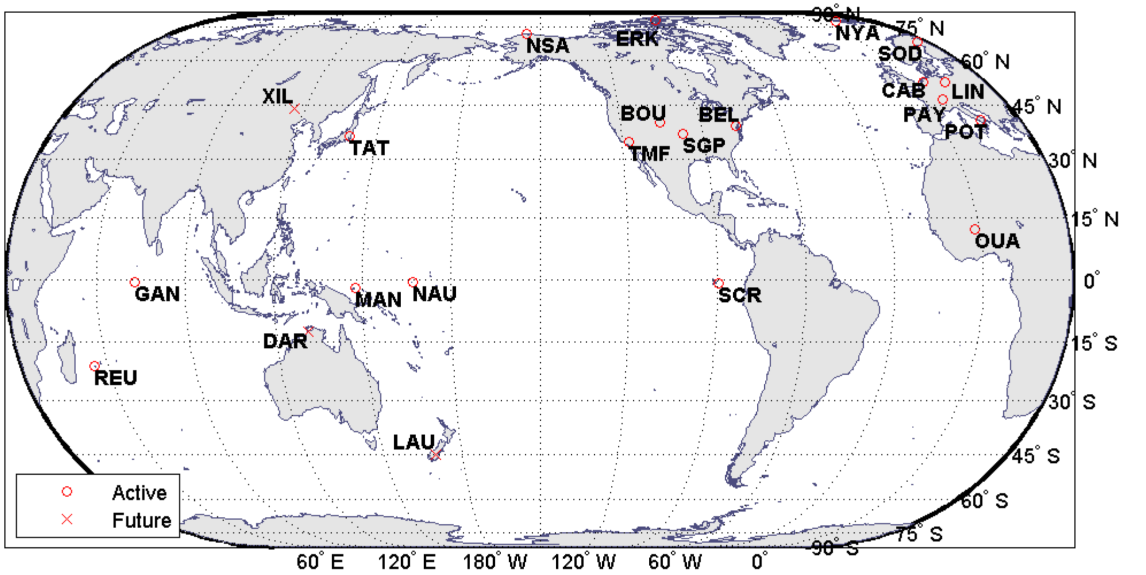




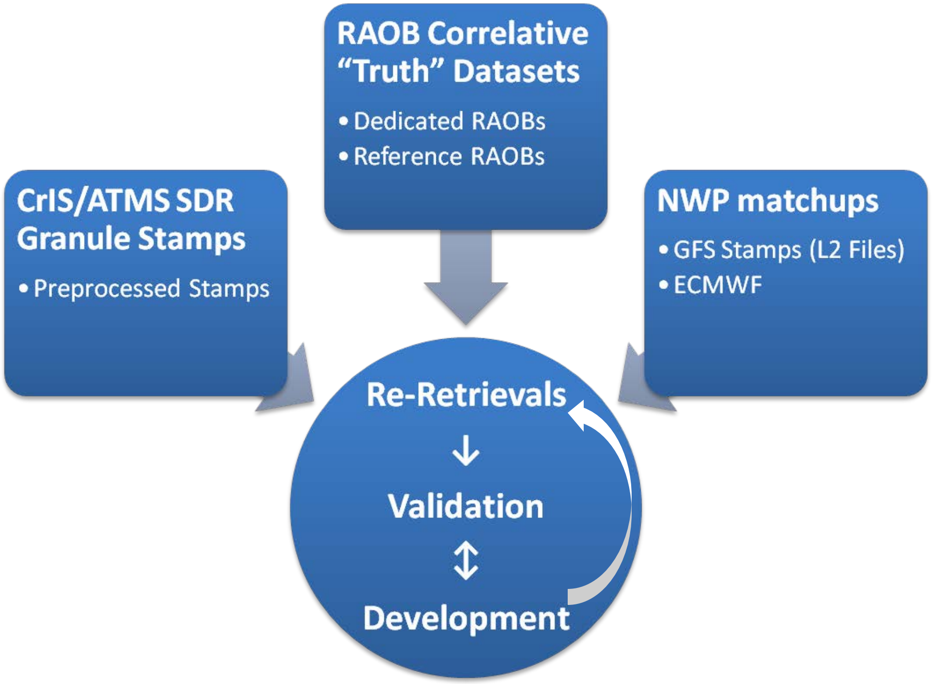
Reference RAOBs

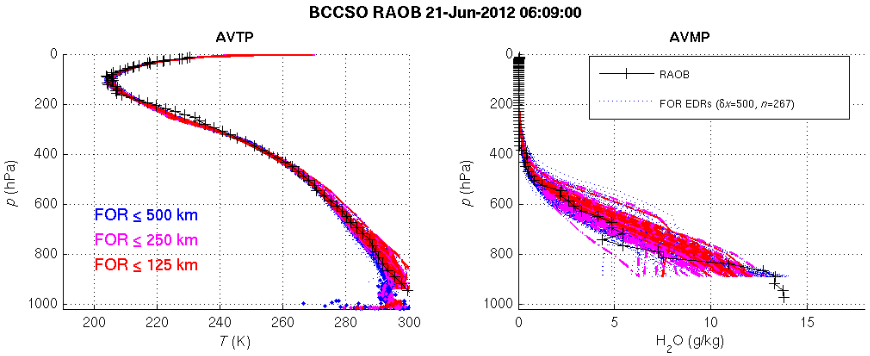
- GRUAN reference RAOB matchups with S-NPP are currently being acquired via the **NPROVS+** system
  - Traceable measurements
  - See 10GOESRJPSS Poster 675 (*Reale et al.*)

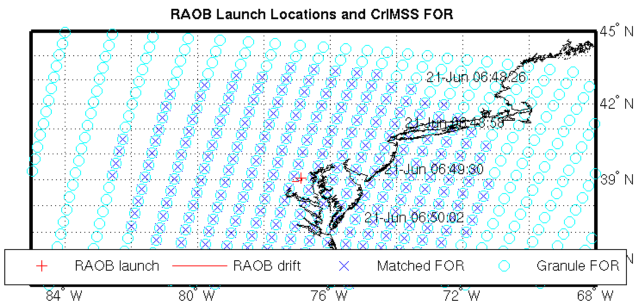
GRUAN RAOB Sites for Sounder EDR ICV



STAR Validation Archive (VALAR)







- 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., O_3, CO, etc.)
  - NUCAPS skin SST validation
  - NUCAPS EDR algorithm development (e.g., AVTP/AVMP uncertainty estimates)

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