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

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Outline

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  - Satellite EDR Intercomparisons
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  - Statistical Metrics for Sounder EDR Validation
  - Use of Averaging Kernels
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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)

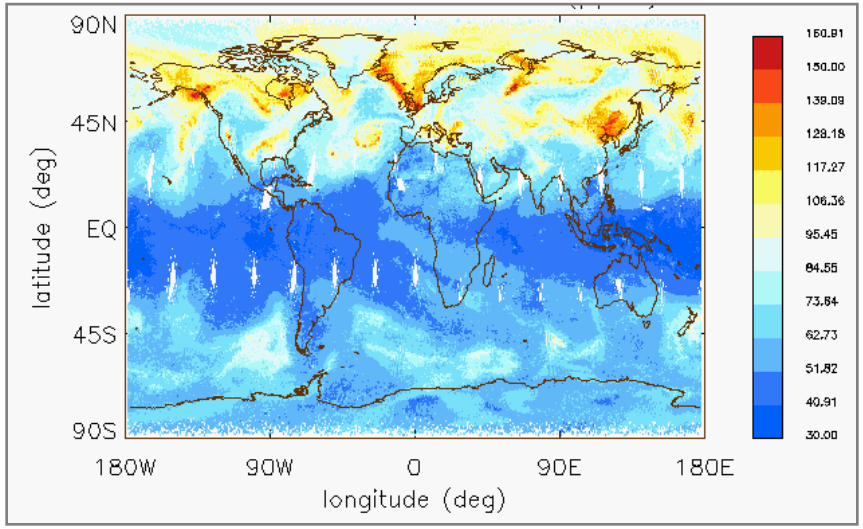
CrIMSS Operational EDR Algorithms

- **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*)

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

Validation of NUCAPS Operational Retrieval Products

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 (*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, $\mathbf{x}$, on forward model layers:

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

- **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 → column abundances), interpolate to RTA (arbitrary) levels, then compute then RTA layer quantities, e.g.,

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

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 (e.g., Q. Liu's presentation).

AVTP

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

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

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

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

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

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

Assessment Methodology: Use of Averaging Kernels (AKs)

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

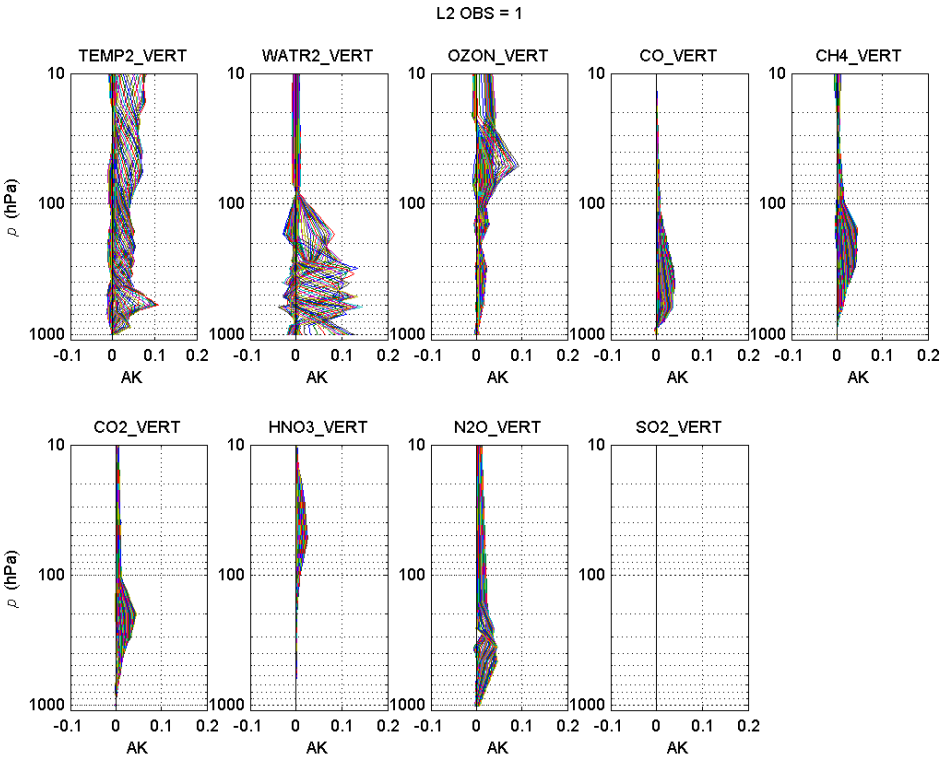
$$\mathbf{A} \equiv \frac{\partial \hat{\mathbf{x}}}{\partial \mathbf{x}}$$

- 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



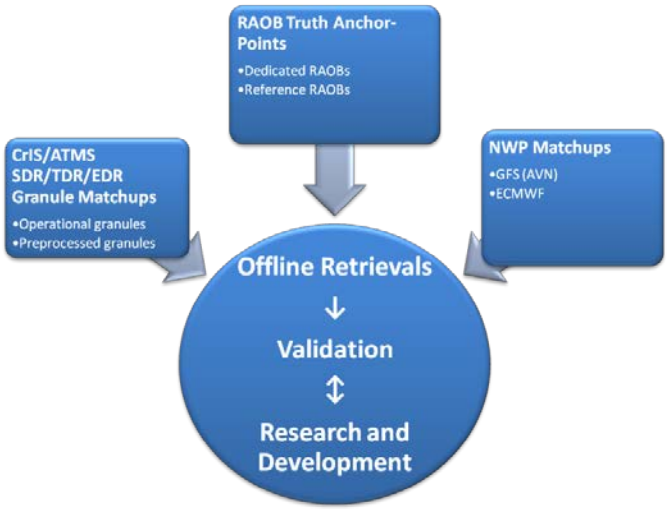
Validation of NUCAPS Operational Retrieval Products

STAR VALIDATION ARCHIVE (VALAR)

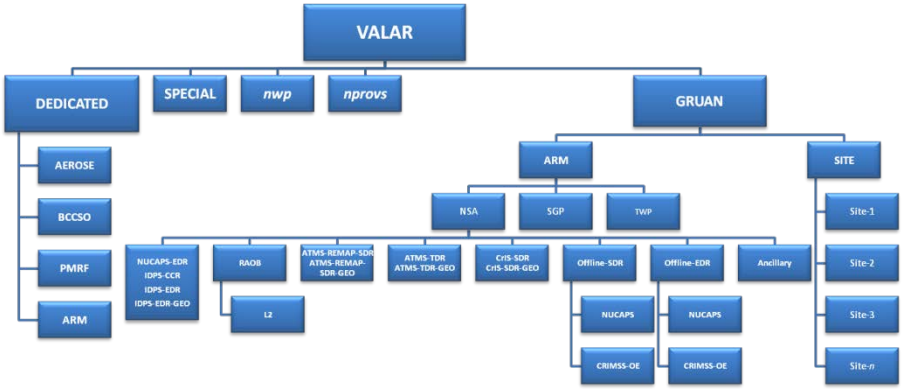
Validation Archive (VALAR)

- 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 Concept and Objectives



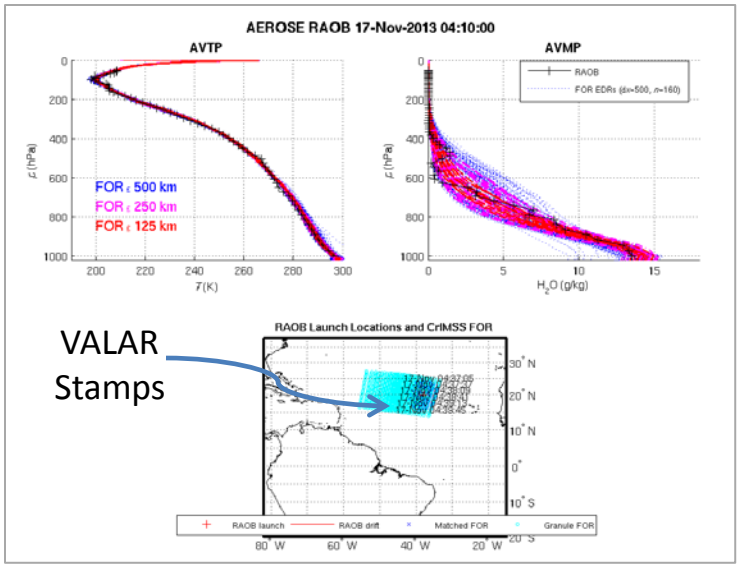
VALAR Data Organization

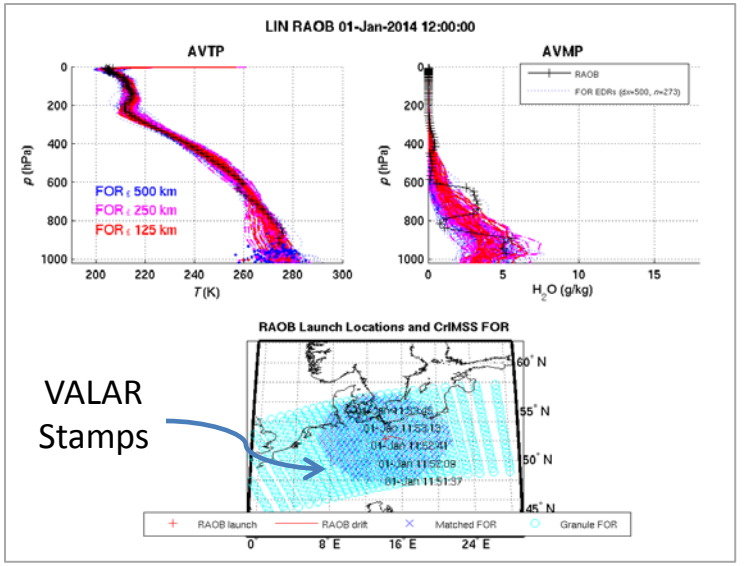


VALAR Data

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

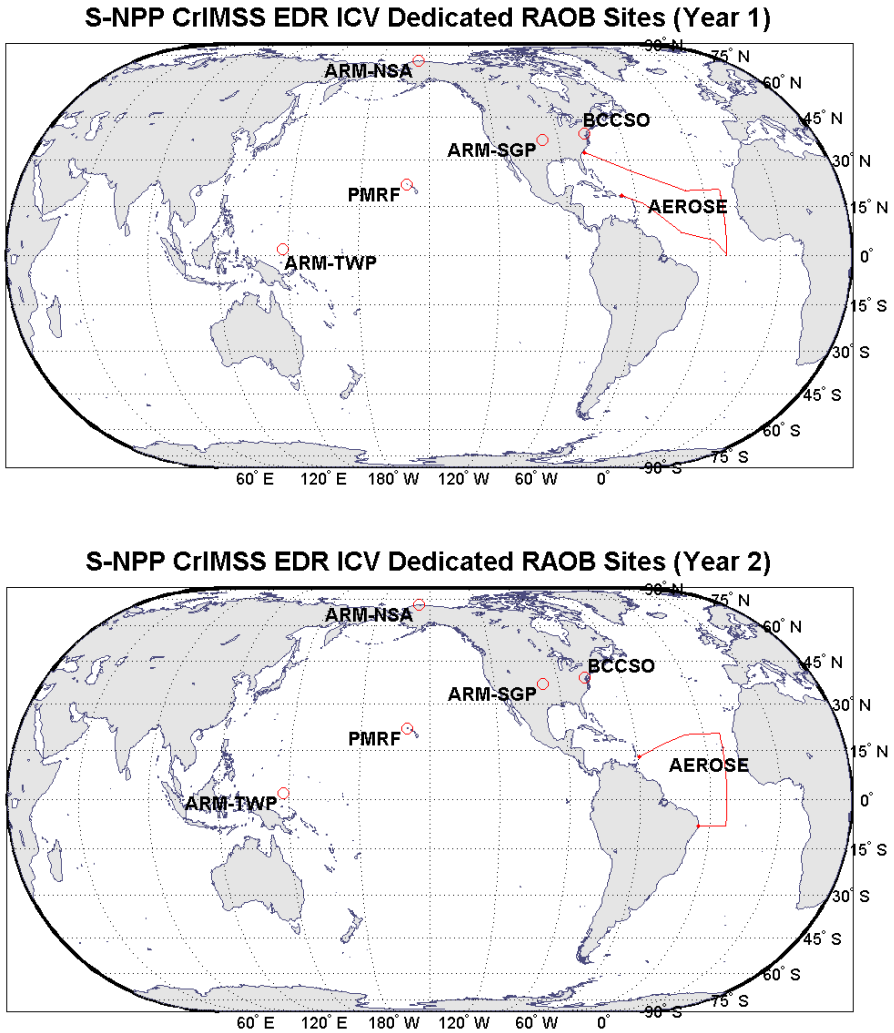
- **CrIS/ATMS SDR/TDR/EDR Granule “Stamps”**
  - A VALAR “stamp” is roughly defined as a granule file matched with a RAOB anchor point needed for offline retrievals and validation
  - SDR/TDR/EDR stamps consist of 4-scan line granules within ±1 minute of overpass (≈500 km radius, usually 4-5 granules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





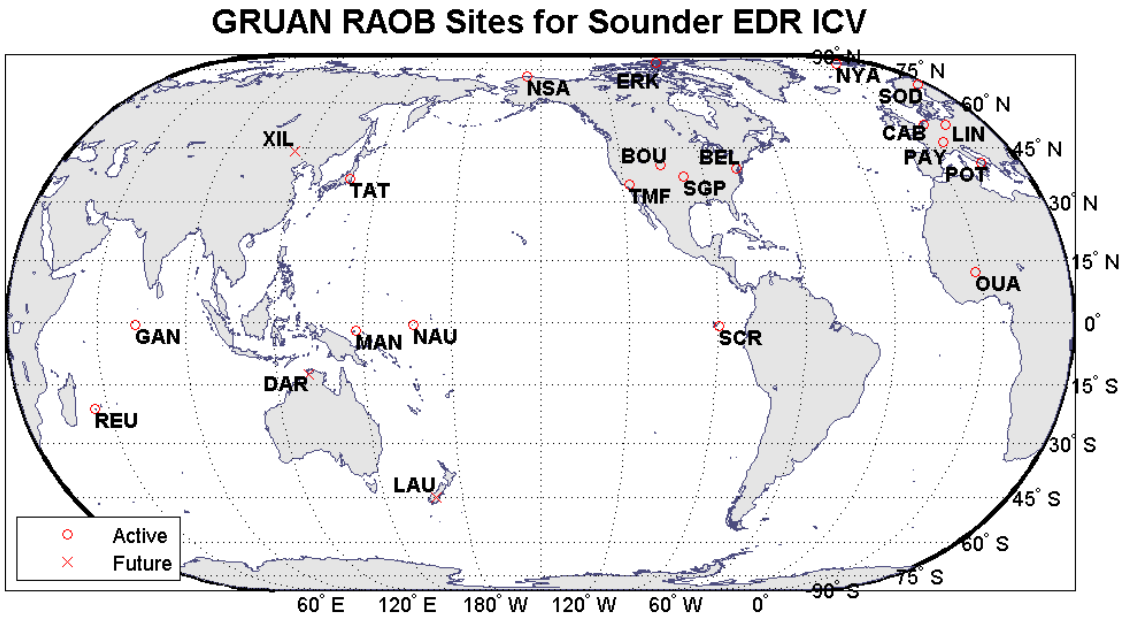
JPSS SNPP Dedicated RAOB Truth

- **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

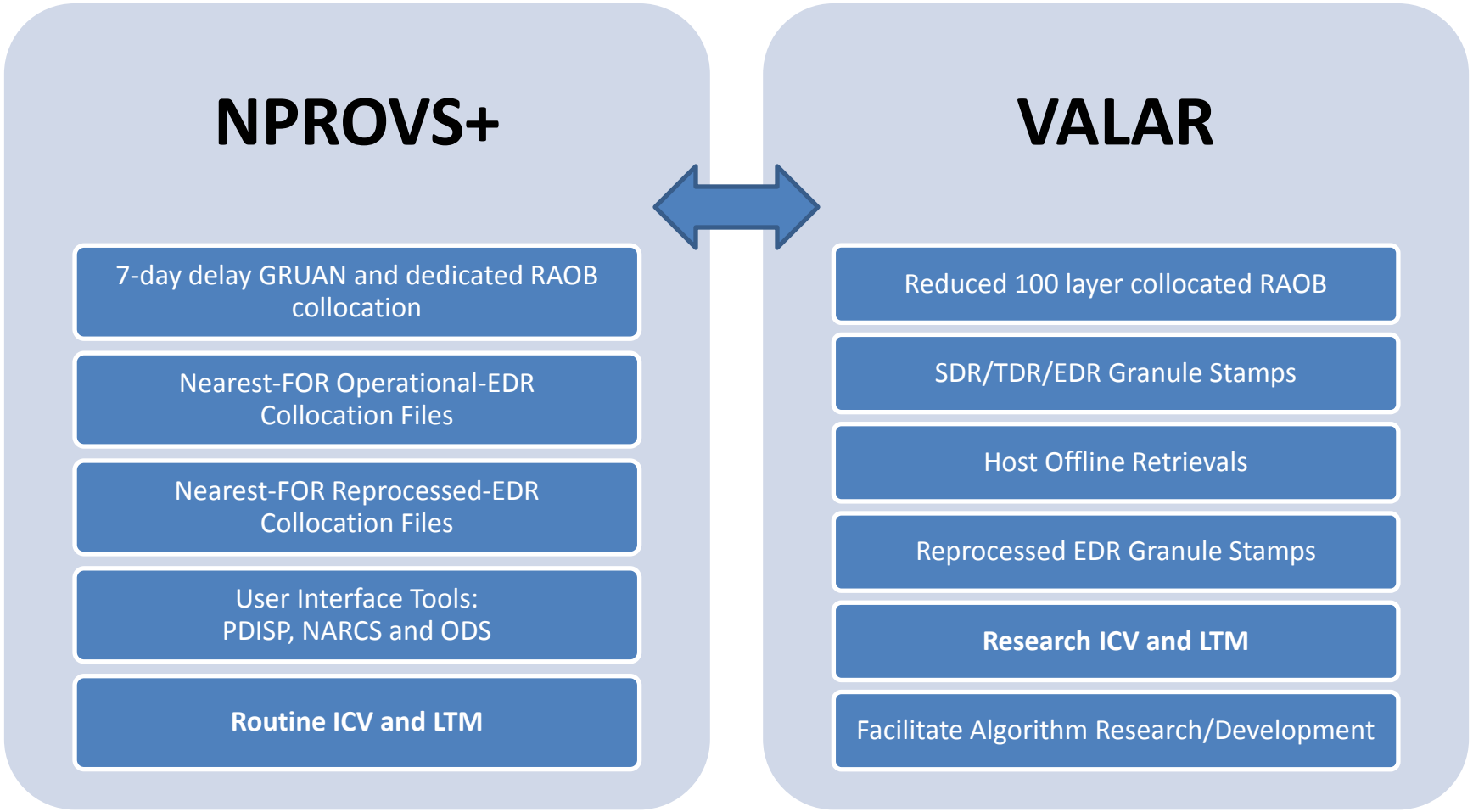


Reference RAOB Truth

- 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+



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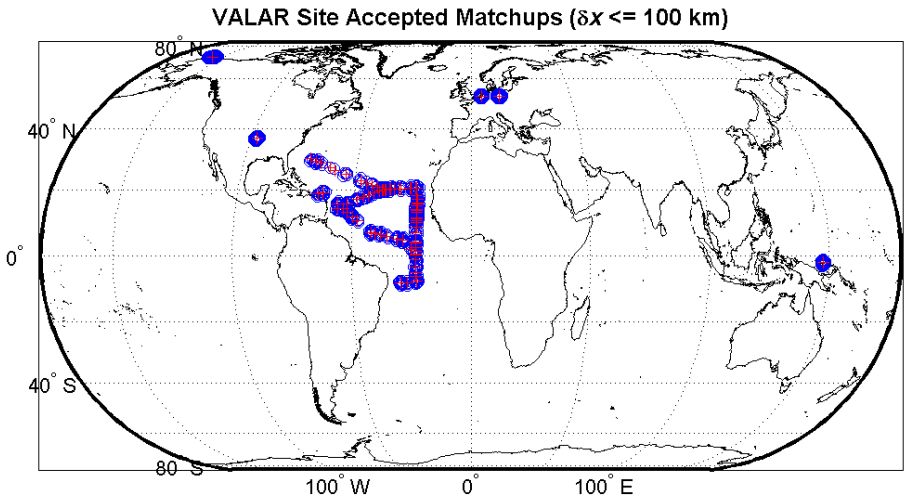
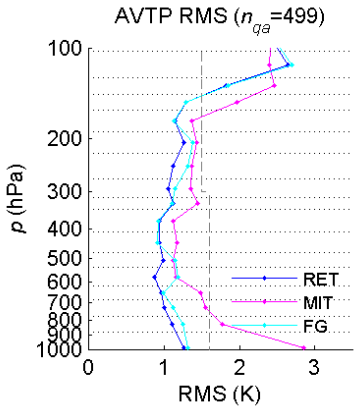
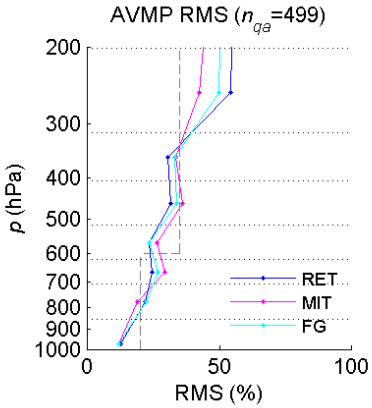
NUCAPS VALIDATION

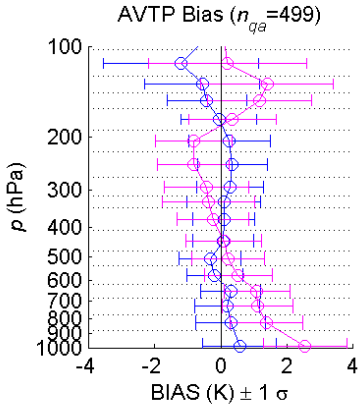
NUCAPS AVTP/AVMP – VALAR Tropics

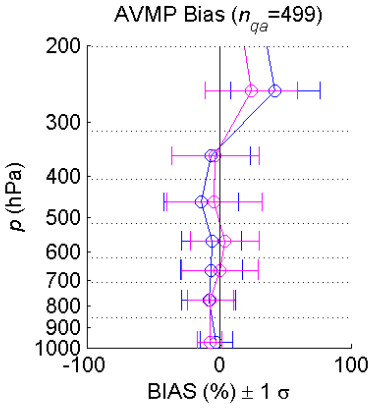


Tropics



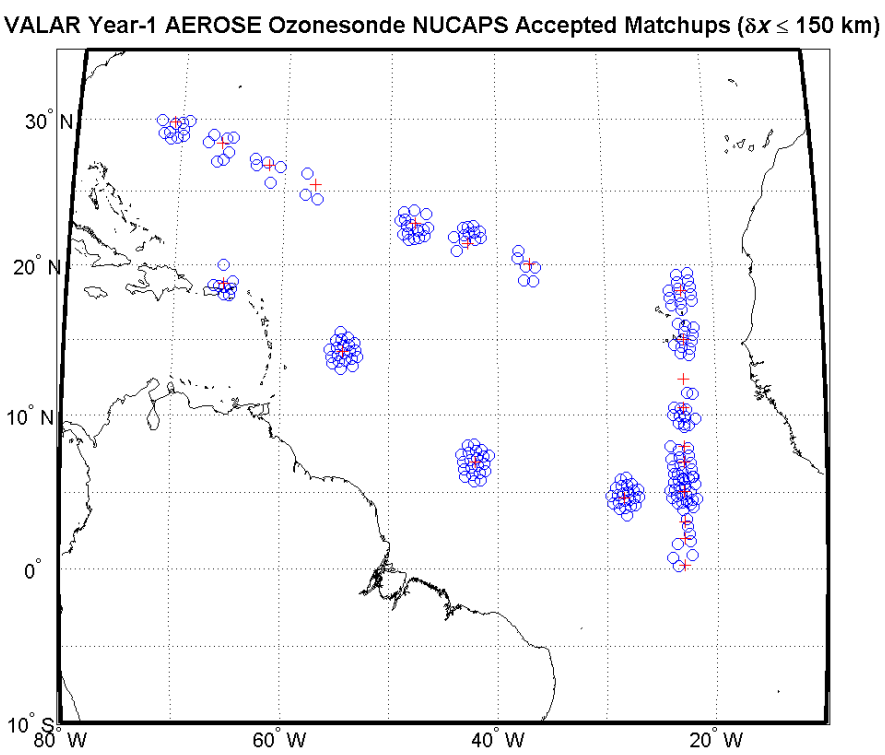


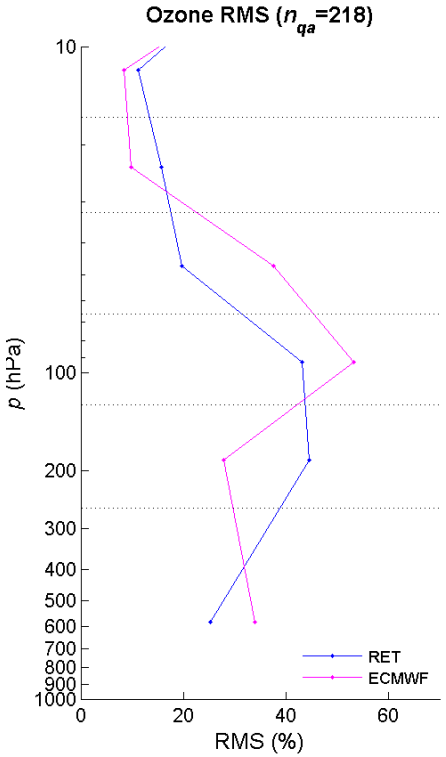


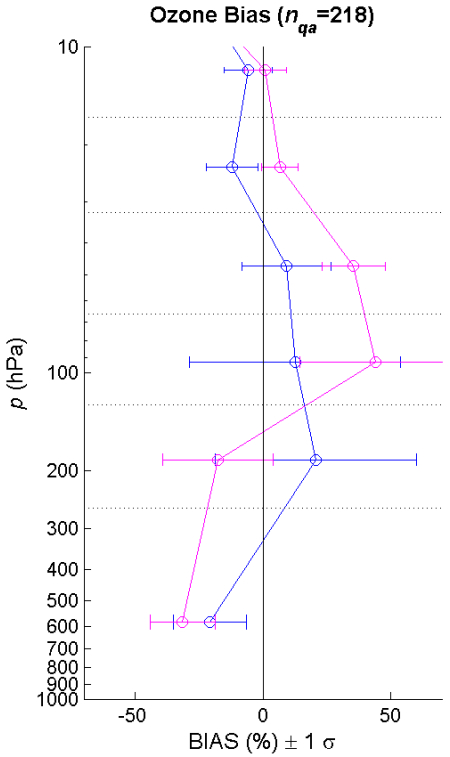


NUCAPS Ozone – VALAR AEROSE Year-1

Dedicated Ozonesondes







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., O_3, 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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