



NOAA Unique CrIS/ATMS Processing System (NUCAPS) Products Validation

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ITSC-20

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- **JPSS Sounder EDR Cal/Val Overview**

- JPSS EDR validation
 - NOAA-Unique CrIS/ATMS Processing System (NUCAPS)
 - JPSS Level 1 Requirements
- Validation Methodology
 - Validation Hierarchy
 - Statistical Metrics
- JPSS SNPP Validation Datasets
 - STAR Validation Archive (VALAR)
 - NOAA Products Validation System (NPROVS/NPROVS+)

- **NUCAPS EDR Product Validation**

- Temperature and Moisture (AVTP and AVMP) EDR
- IR Ozone profile EDR
- Long-Term Monitoring (LTM)

- **Future Work**

- SNPP ICV and LTM



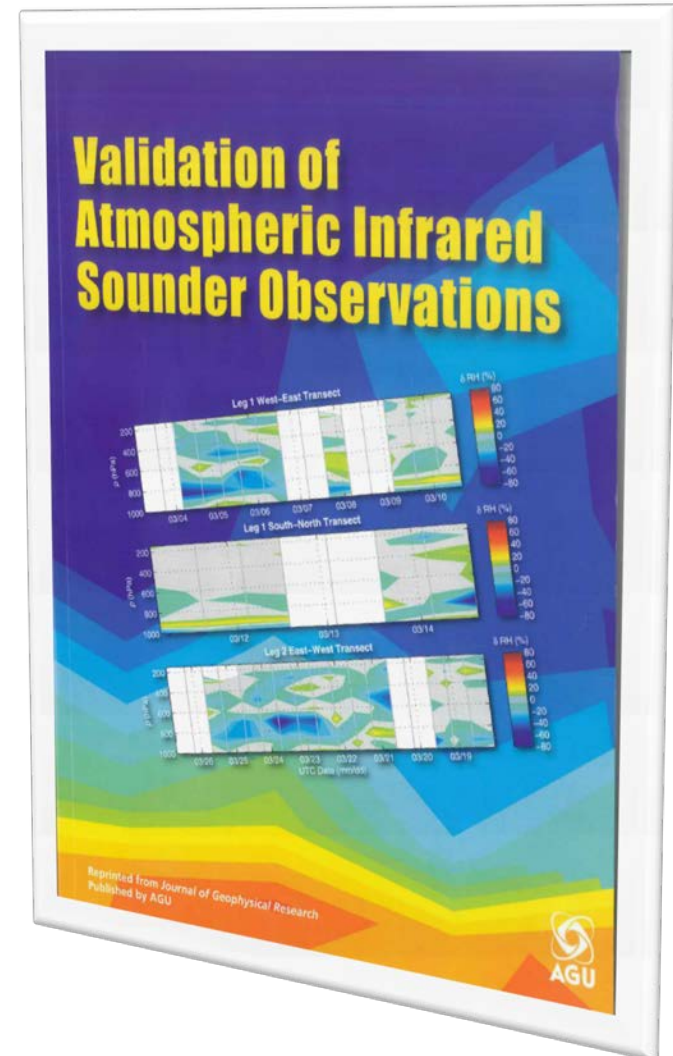
NUCAPS Products Validation

JPSS SOUNDER EDR CAL/VAL OVERVIEW

Intro: JPSS Sounder EDR Validation



- **Validation** is “the process of ascribing uncertainties to... radiances and retrieved quantities through comparison with correlative observations” (*Fetzer et al., 2003*).
 - Sounder EDR validation supports monitoring of sounder SDRs and cloud-cleared radiances (a Level 2 product shown to have positive impact on NWP; e.g., *Le Marshall et al., 2008*)
 - EDR validation enables development/improvement of algorithms



SNPP/JPSS Program Cal/Val



- **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)**
 - Routine characterization of all EDR products and long-term demonstration of performance



- In accordance with the JPSS phased schedule, the **SNPP CrIS/ATMS 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*)
 - Classification of various approaches into a “Validation Methodology Hierarchy”
- The **J-1 CrIS/ATMS EDR Cal/Val Plan** was drafted during Jul–Aug 2015 and v1.0 was submitted on 20 August 2015

CrIS/ATMS Sounder Operational EDR: NOAA Unique CrIS/ATMS Processing System (NUCAPS)



NUCAPS Algorithm

(Susskind, Barnet and Blaisdell, IEEE 2003;
Gambacorta et al., 2014)

- **Operational algorithm**

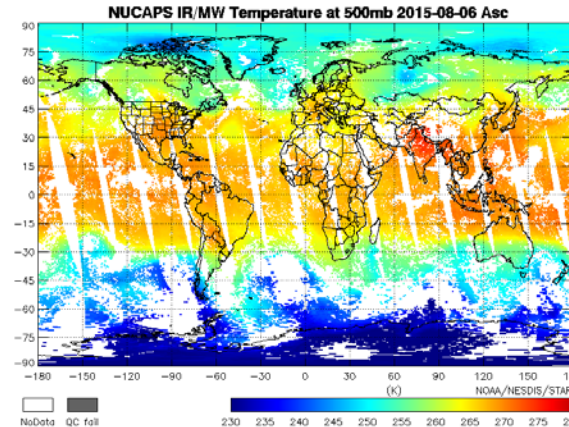
- Superseded original IDPS CrIMSS algorithm in Sep 2013
- Unified Sounder Science Team (AIRS/IASI/CrIS) retrieval algorithm
- Global non-precipitating conditions
- Atmospheric Vertical Temperature, Moisture Profiles (**AVTP, AVMP**) and trace gas (**O₃, CO, CO₂, CH₄**)
- **Stage-1 Validated Maturity achieved in Sep 2014**

- Original IDPS CrIMSS EDR was validated through Beta and Provisional Maturities (Divakarla et al., 2014)

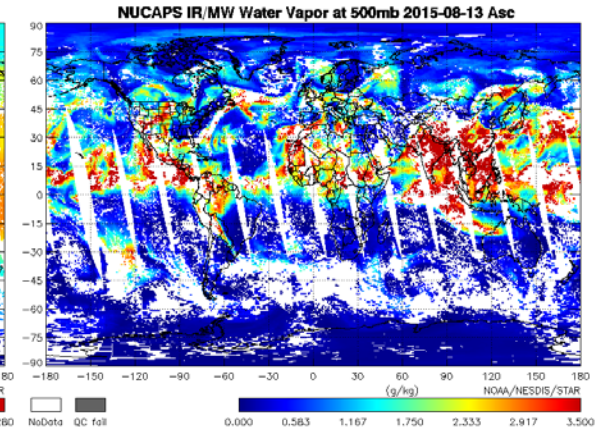
- **Users**

- **Weather Forecast Offices (AWIPS)**
 - Nowcasting / severe weather
 - Alaska (cold core)
- NOAA/CPC (OLR)
- NOAA/ARL (IR ozone and trace gases)
- TOAST (IR ozone)
- Basic and applied science research (e.g., Pagano et al., 2014)
 - Via NOAA Data Centers (e.g., NGDC, CLASS)
 - Universities, peer-reviewed pubs

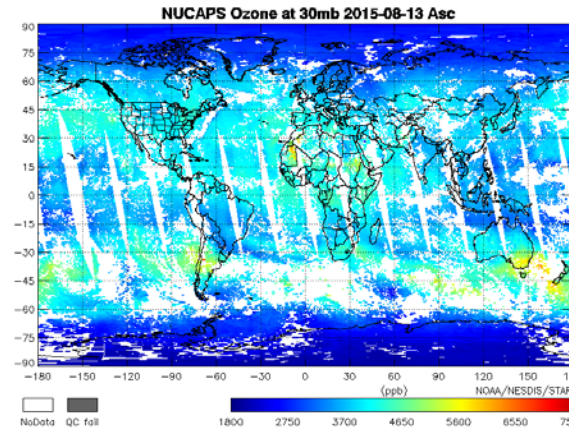
NUCAPS AVTP



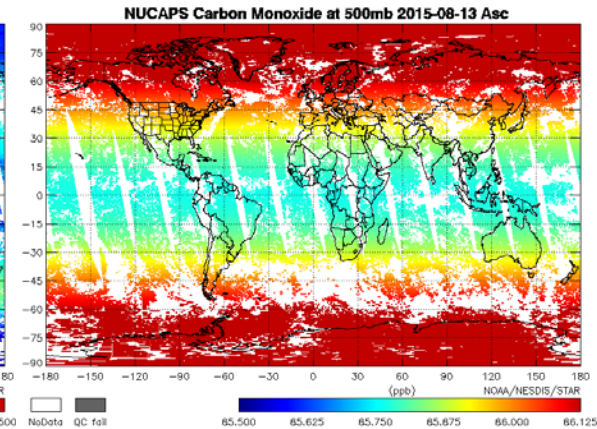
NUCAPS AVMP



NUCAPS O₃



NUCAPS CO



Long Term Monitoring

http://www.star.nesdis.noaa.gov/jps/EDRs/products_Soundings.php

<http://www.ospo.noaa.gov/Products/atmosphere/soundings/nucaps/index.html>

CrIS/ATMS Sounder EDR L1 Requirements



AVTP and AVMP EDR

CrIS/ATMS Atmospheric Vertical Temperature Profile (AVTP) Measurement Uncertainty – Layer Average Temperature Error	
PARAMETER	THRESHOLD
AVTP, Cloud fraction < 50%, surface to 300 hPa	1.6 K / 1-km layer
AVTP, Cloud fraction < 50%, 300–30 hPa	1.5 K / 3-km layer
AVTP, Cloud fraction < 50%, 30–1 hPa	1.5 K / 5-km layer
AVTP, Cloud fraction < 50%, 1–0.5 hPa	3.5 K / 5-km layer
AVTP, Cloud fraction ≥ 50%, surface to 700 hPa	2.5 K / 1-km layer
AVTP, Cloud fraction ≥ 50%, 700–300 hPa	1.5 K / 1-km layer
AVTP, Cloud fraction ≥ 50%, 300–30 hPa	1.5 K / 3-km layer
AVTP, Cloud fraction ≥ 50%, 30–1 hPa	1.5 K / 5-km layer
AVTP, Cloud fraction ≥ 50%, 1–0.5 hPa	3.5 K / 5-km layer

CrIS/ATMS Atmospheric Vertical Moisture Profile (AVMP) Measurement Uncertainty – 2-km Layer Average Mixing Ratio % Error	
PARAMETER	THRESHOLD
AVMP, Cloud fraction < 50%, surface to 600 hPa	Greater of 20% or 0.2 g·kg ⁻¹ / 2-km layer
AVMP, Cloud fraction < 50%, 600–300 hPa	Greater of 35% or 0.1 g·kg ⁻¹ / 2-km layer
AVMP, Cloud fraction < 50%, 300–100 hPa	Greater of 35% or 0.1 g·kg ⁻¹ / 2-km layer
AVMP, Cloud fraction ≥ 50%, surface to 600 hPa	Greater of 20% of 0.2 g·kg ⁻¹ / 2-km layer
AVMP, Cloud fraction ≥ 50%, 600–400 hPa	Greater of 40% or 0.1 g·kg ⁻¹ / 2-km layer
AVMP, Cloud fraction ≥ 50%, 400–100 hPa	Greater of 40% or 0.1 g·kg ⁻¹ / 2-km layer

Source: L1RD (2014), pp. 41, 43

Trace Gas EDR

CrIS Infrared Trace Gases Specification Performance Requirements	
PARAMETER	THRESHOLD
CO (Carbon Monoxide) Total Column Precision	35%, or full res mode 15%
CO (Carbon Monoxide) Total Column Accuracy	±25%, or full res mode ±5%
CO ₂ (Carbon Dioxide) Total Column Precision	0.5% (2 ppmv)
CO ₂ (Carbon Dioxide) Total Column Accuracy	±1% (4 ppmv)
CH ₄ (Methane) Total Column Precision	1% (≈20 ppbv)
CH ₄ (Methane) Total Column Accuracy	±4% (≈80 ppmv)
O ₃ (Ozone) Profile Precision, 4–260 hPa (6 statistic layers)	20%
O ₃ (Ozone) Profile Precision, 260 hPa to sfc (1 statistic layer)	20%
O ₃ (Ozone) Profile Accuracy, 4–260 hPa (6 statistic layers)	±10%
O ₃ (Ozone) Profile Accuracy, 260 hPa to sfc (1 statistic layer)	±10%
O ₃ (Ozone) Profile Uncertainty, 4–260 hPa (6 statistic layers)	25%
O ₃ (Ozone) Profile Uncertainty, 260 hPa to sfc (1 statistic layer)	25%

Source: L1RD (2014), pp. 45-49

Global requirements defined for lower and upper atmosphere subdivided into 1-km and 2-km layers for AVTP and AVMP, respectively.

“Clear to Partly-Cloudy” (Cloud Fraction < 50%) ↔ IR retrieval
 “Cloudy” (Cloud Fraction ≥ 50%) ↔ MW-only retrieval

Validation Methodology Hierarchy

(e.g., Nalli et al., JGR Special Section, 2013)



1. Numerical Model (e.g., ECMWF, NCEP/GFS) Global Comparisons

- Large, truly global samples acquired from Focus Days
- Useful for sanity checks, bias tuning and regression
- Limitation: *Not* independent truth data

2. Satellite Sounder EDR (e.g., AIRS, ATOVS, COSMIC) Intercomparisons

- Global samples acquired from Focus Days (e.g., AIRS)
- Consistency checks; merits of different retrieval algorithms
- Limitation: Similar error characteristics; must take rigorous account of averaging kernels of both systems (e.g., Rodgers and Connor, 2003)

3. Conventional RAOB Matchup Assessments

- WMO/GTS operational sondes launched ~2/day for NWP
- Representation of global zones, long-term monitoring
- Large samples after a couple months (e.g., Divakarla et al., 2006; Reale et al. 2012)
- Limitations:
 - Skewed distribution toward NH-continent
 - Mismatch errors, potentially systematic at individual sites
 - Non-uniform, less-accurate and poorly characterized radiosondes
 - RAOBs assimilated, by definition, into numerical models

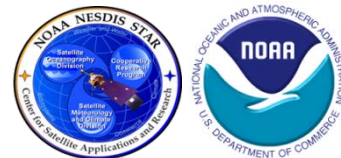
4. Dedicated/Reference RAOB Matchup Assessments

- *Dedicated* for the purpose of satellite validation
 - Known measurement uncertainty and optimal accuracy
 - Minimal mismatch errors
 - Atmospheric state “best estimates” or “merged soundings”
- Reference sondes: CFH, **GRUAN** corrected RS92/RS41
 - Traceable measurement
 - Uncertainty estimates
- Limitation: Small sample sizes and limited geographic coverage
- E.g., **ARM sites** (e.g., Tobin et al., 2006), **AEROSE**, **CalWater/ACAPEX**, **BCCSO**, **PMRF**

5. Intensive Field Campaign Dissections

- Include dedicated RAOBs, some *not* assimilated into NWP models
- Include ancillary datasets (e.g., ozonesondes, lidar, M-AERI, MWR, sunphotometer, etc.)
- Ideally include funded aircraft campaign using IR sounder (e.g., NAST-I, S-HIS)
- Detailed performance specification; state specification; SDR cal/val
- E.g., **SNAP**, **SNPP-1,-2**, **AEROSE**, **CalWater/ACAPEX**, **JAIVEX**, **WAVES**, **AWEX-G**, **EAQUATE**

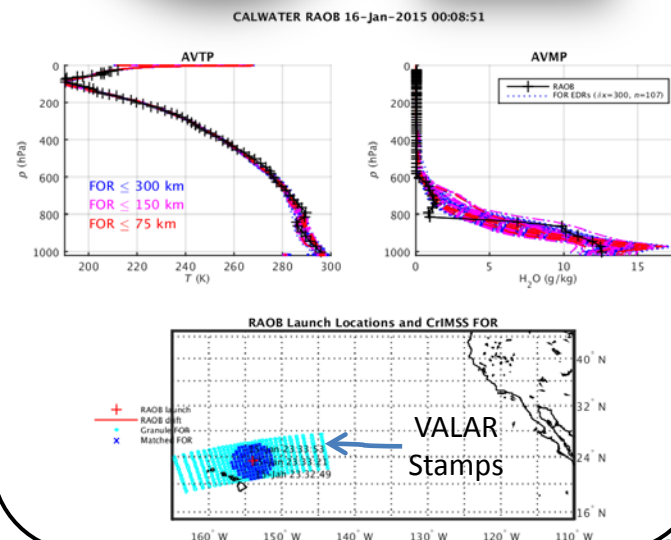
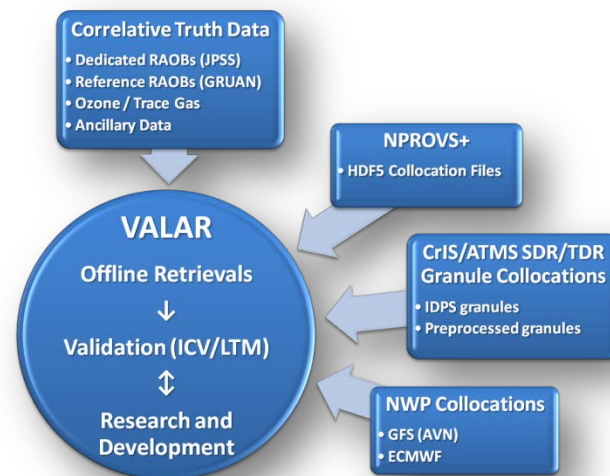
JPSS SNPP Validation Datasets and Tools



- **STAR Validation Archive (VALAR)**
 - Low-level research data archive designed to meet needs of Cal/Val Plan
 - Dedicated/reference and intensive campaign RAOBs
 - SDR/TDR granule-based collocations (“stamps”) within 500 km radius acquired off SCDR (past 90 days) or CLASS (older than 90 days)
 - Trace Gas EDR validation
 - Offline retrievals / retrospective reprocessing
 - MATLAB and IDL statistical codes and visualization software tools for monitoring
 - Rigorous coarse-layer (1-km, 2-km) product performance measures based on statistical metrics corresponding to Level 1 Requirements detailed in *Nalli et al. (2013)*

- **NOAA Products Validation System (NPROVS)** (*Reale et al., 2012*)
 - Conventional RAOBs (NPROVS+ dedicated/reference), “single closest FOR” collocations
 - HDF5-formatted Collocation Files facilitates GRUAN RAOB matchups within VALAR
 - NRT monitoring capability
 - Satellite EDR intercomparison capability
 - Java based graphical user interface tools for monitoring
 - Profile Display (PDISP)
 - NPROVS Archive Summary (NARCS)

VALAR Concept and Objectives



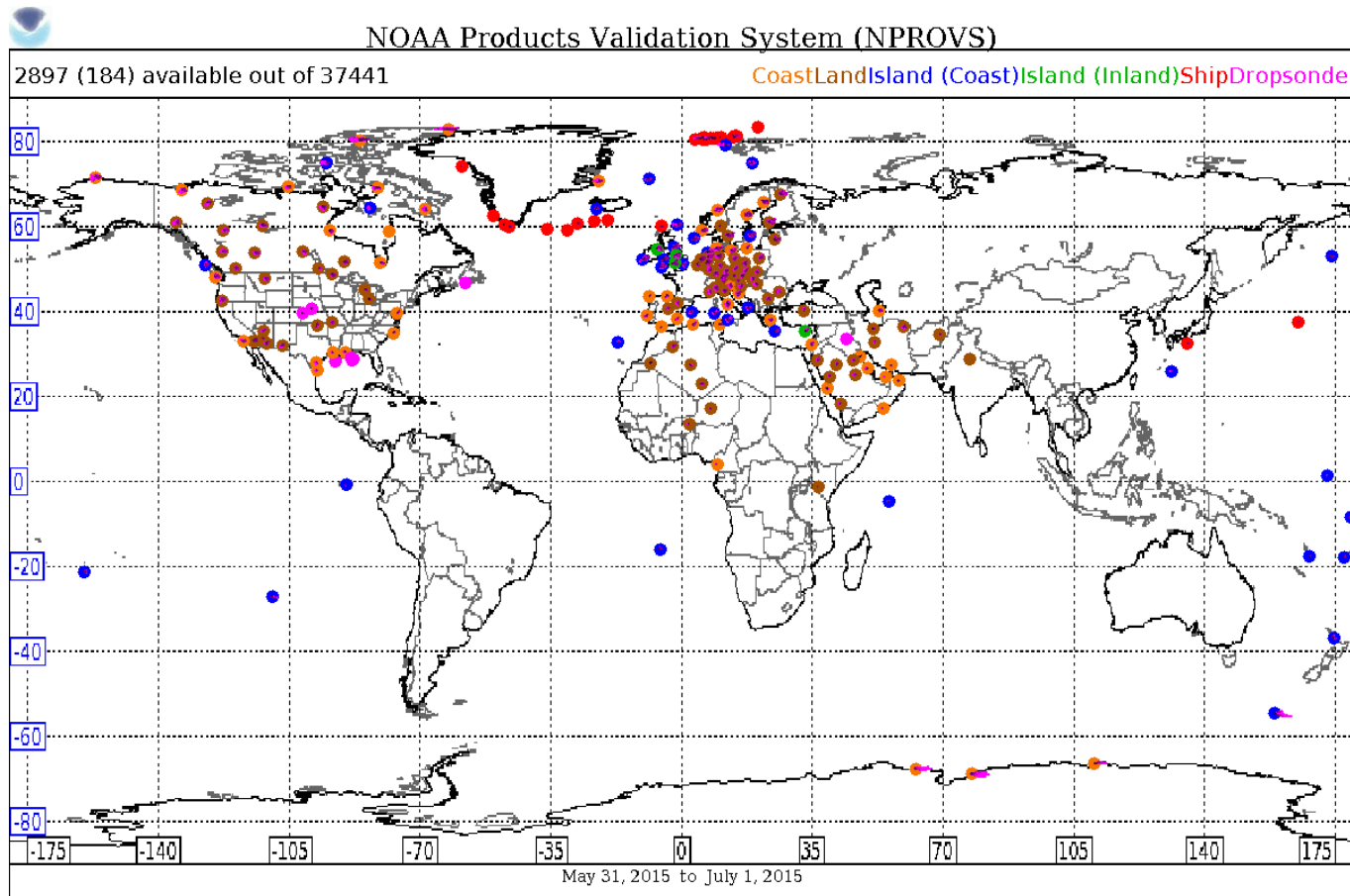


NUCAPS Products Validation

NUCAPS EDR PRODUCT VALIDATION

NPROVS Conventional RAOB Collocation Sample

Single Closest FOR



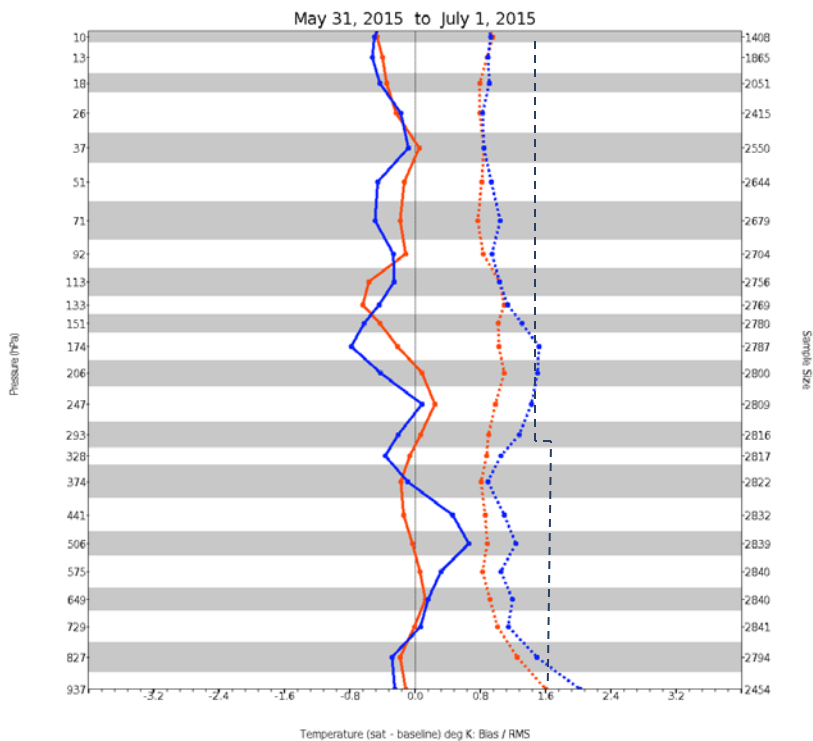
- June 2015
- RS92 and RS41 sondes
- Single-closest FOR
- Space-time window [1]
 - ± 3 h before/after overpass
 - 75 km
- Sample size [1]
 $N = 2897$

NUCAPS OPS-EDR and AIRS versus NPROVS Collocated Conventional RAOB



AVTP (BIAS and RMS)

NOAA Products Validation System (NPROVS)



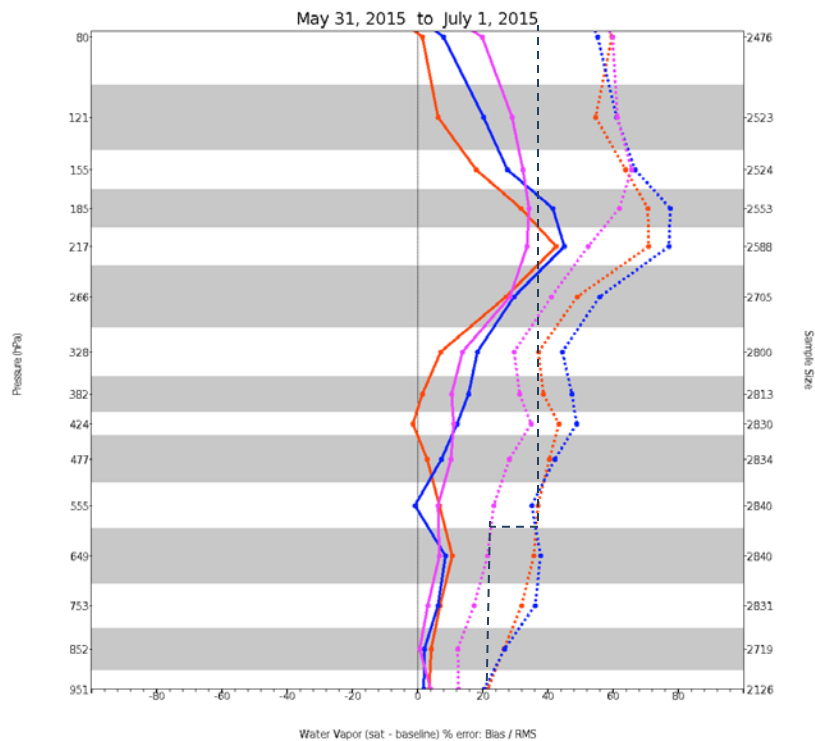
Baseline: RAOB Radiosonde

NUCAPS NPP

AIRS AQUA

AVMP (BIAS and RMS)

NOAA Products Validation System (NPROVS)



Baseline: RAOB Radiosonde

ECMWF ANALYSIS

NUCAPS NPP

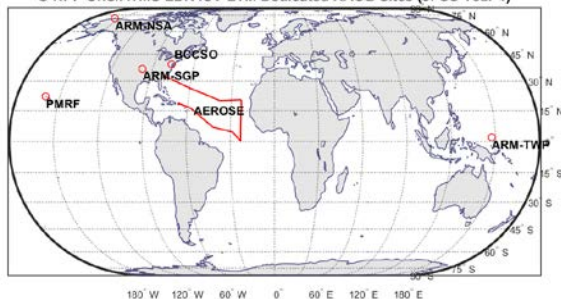
AIRS AQUA

VALAR/NPROVS+ SNPP Dedicated and Reference RAOBs

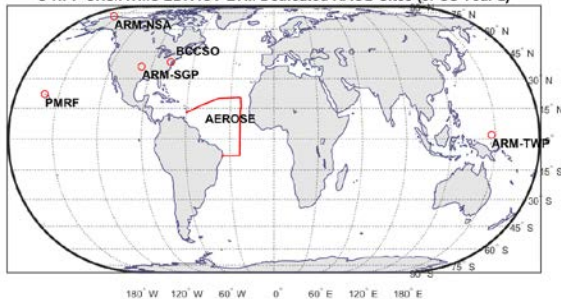


JPSS SNPP Dedicated Years 1–2 (2012–2014)

S-NPP CrIS/ATMS EDR ICV-LTM Dedicated RAOB Sites (JPSS Year 1)

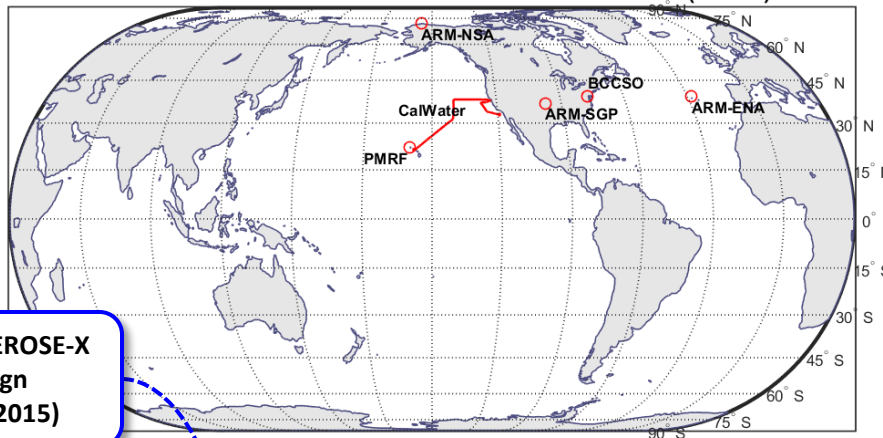


S-NPP CrIS/ATMS EDR ICV-LTM Dedicated RAOB Sites (JPSS Year 2)



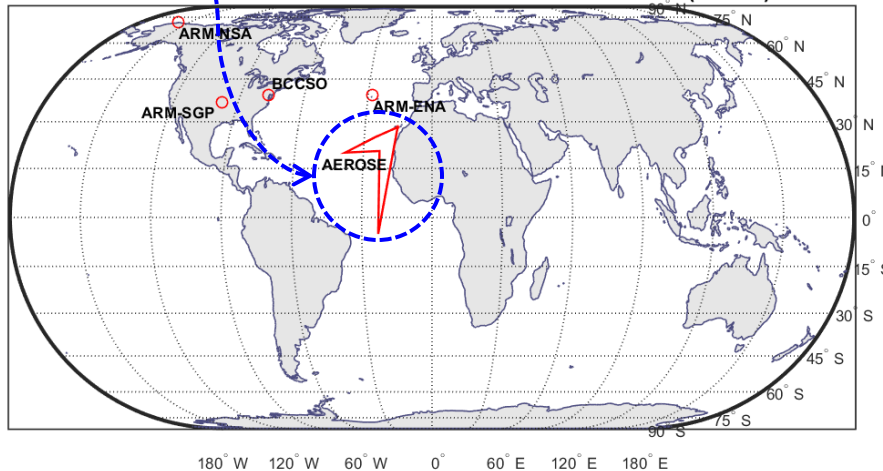
JPSS SNPP Dedicated Years 3–4 (2014–2016)

SNPP CrIS/ATMS EDR ICV-LTM Dedicated RAOB Sites (Year 3)



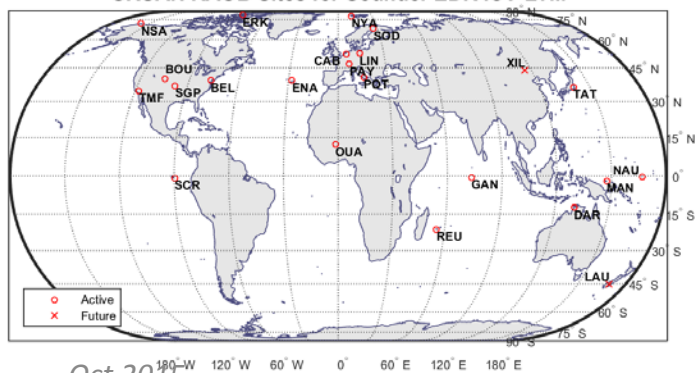
2015 PNE/AEROSE-X Campaign (Nov-Dec 2015)

SNPP CrIS/ATMS EDR ICV-LTM Dedicated RAOB Sites (Year 4)



GRUAN Reference Sites

GRUAN RAOB Sites for Sounder EDR ICV-LTM



Oct 2015

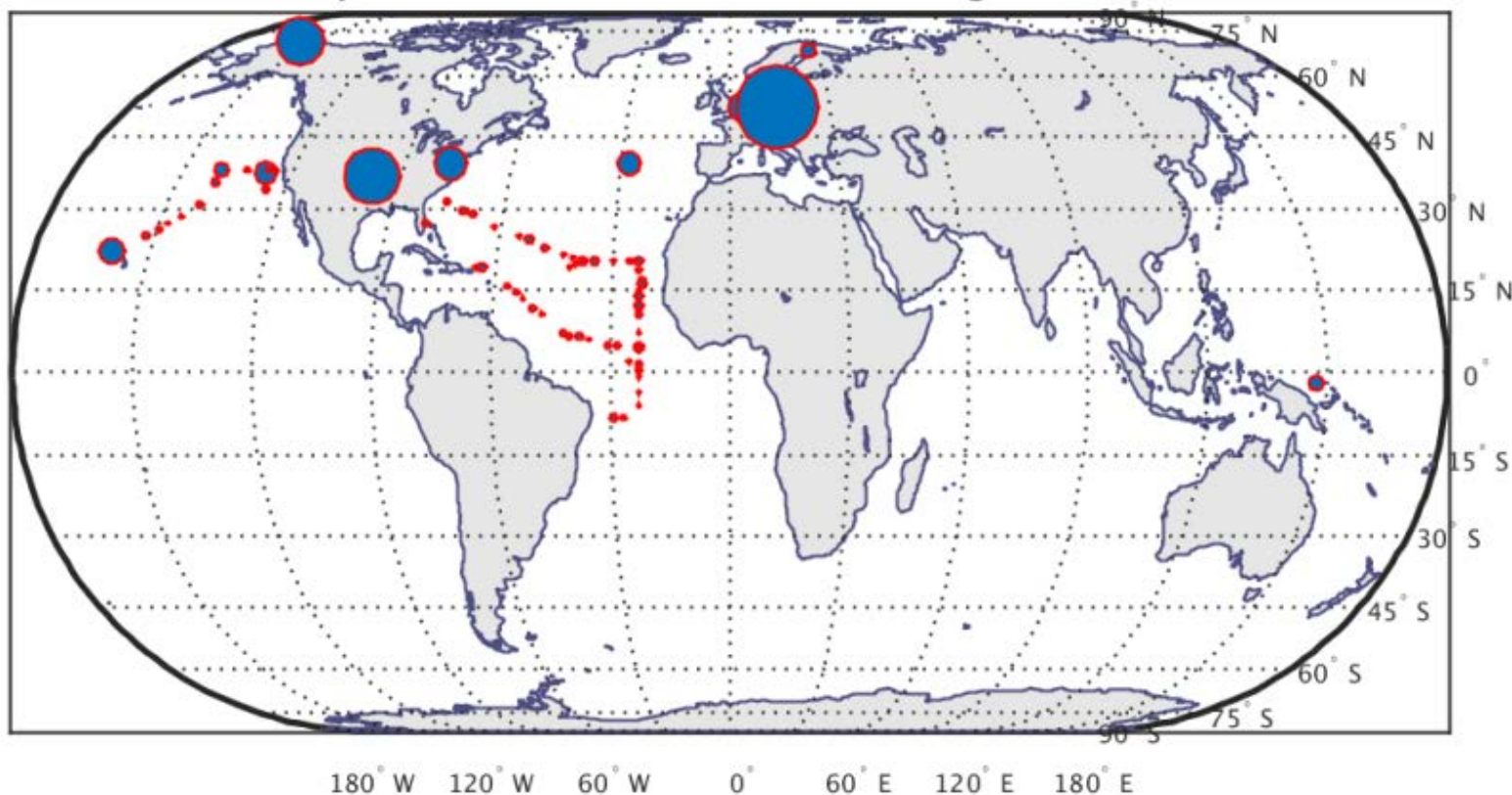
VALAR Dedicated/Reference RAOB-FOR Collocation Sample ($n = 1864$)



Geographic Histogram (Equal Area)

FOR Collocation Criteria: $\delta x \leq 50$ km, $-75 < \delta t < 0$ min

valar_nucaps_offline_v15_collocation_file_merged_20150916.mat



NUCAPS Offline (v1.5) EDR Coarse-Layer Statistics

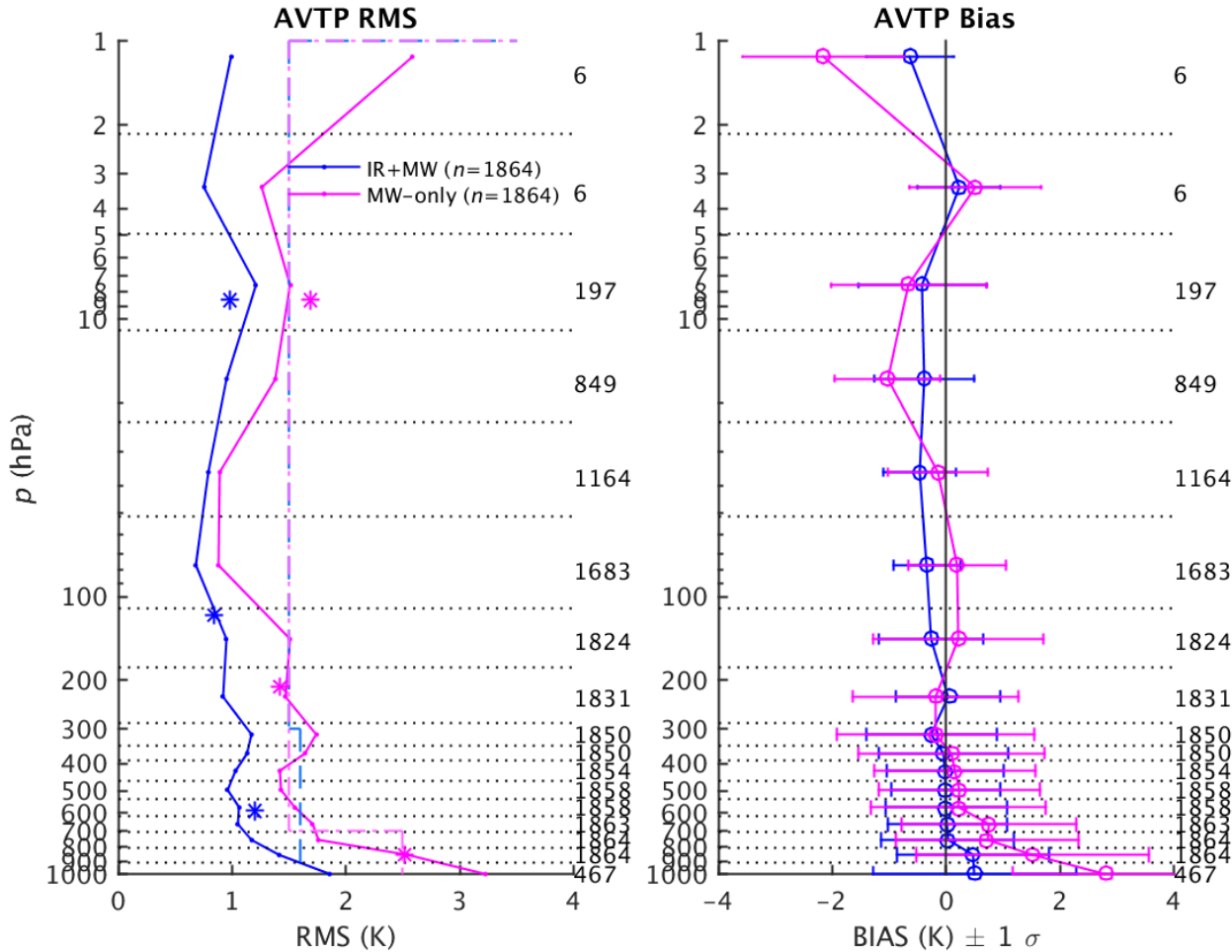
VALAR Dedicated/Reference RAOB Collocation Sample (1/4)



AVTP Versus RAOB

* * "Coarse Coarse-Layer" Stats (Per JPSS Level 1 Requirements)

IR+MW
MW-Only



NUCAPS Offline (v1.5) EDR Coarse-Layer Statistics

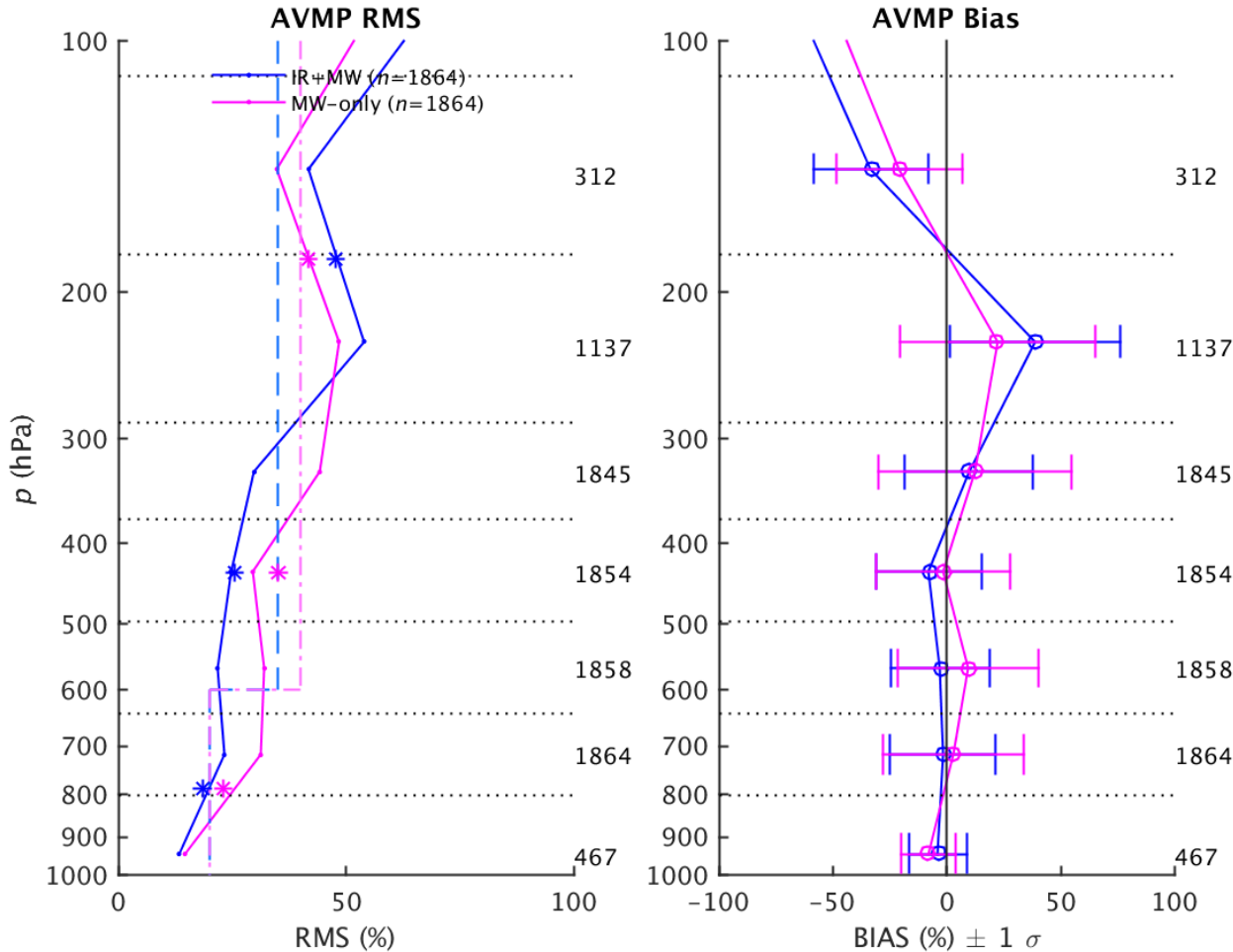
VALAR Dedicated/Reference RAOB Collocation Sample (2/4)



AVMP Versus RAOB

* * "Coarse Coarse-Layer" Stats (Per JPSS Level 1 Requirements)

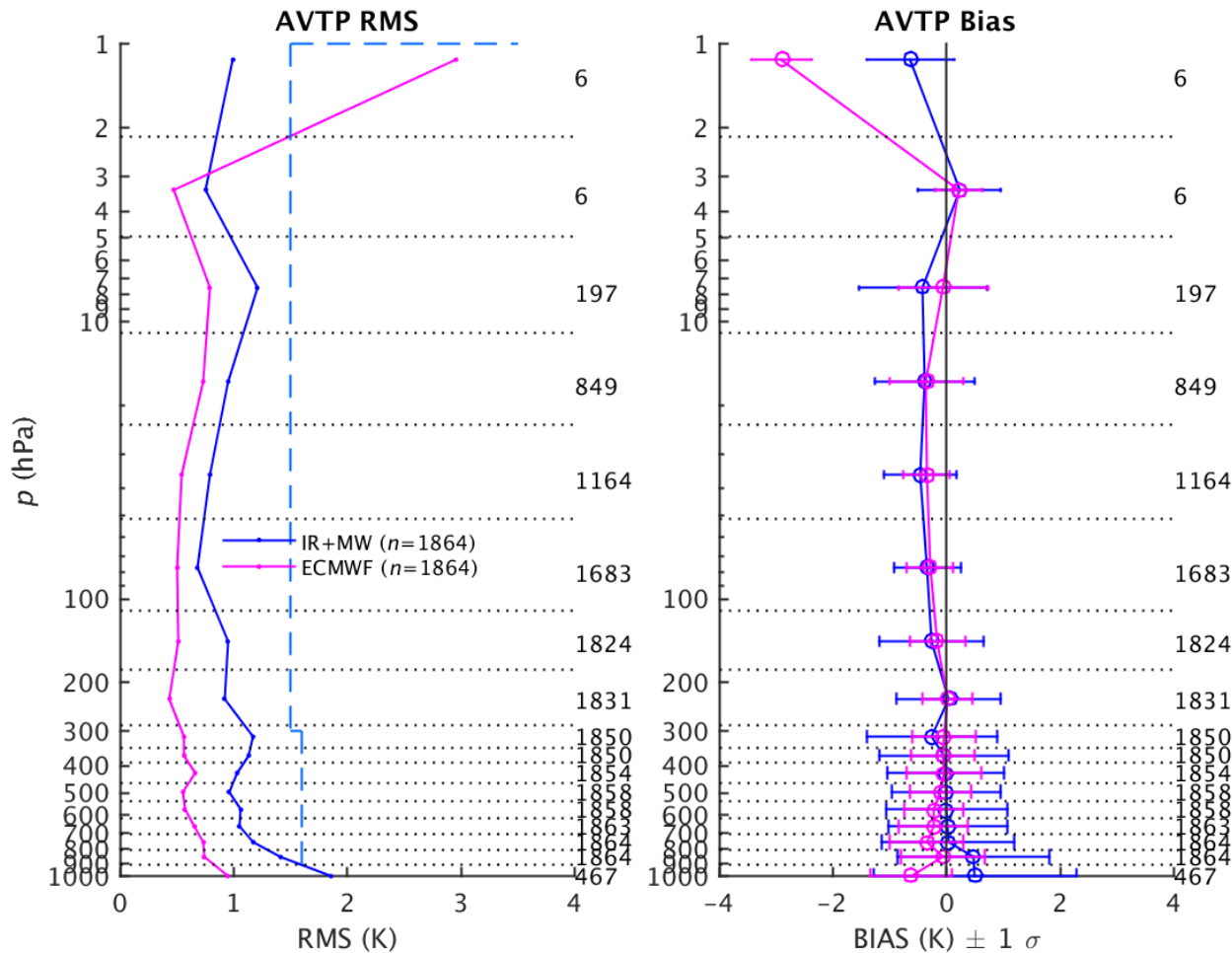
IR+MW
MW-Only



NUCAPS Offline (v1.5) EDR Coarse-Layer Statistics VALAR Dedicated/Reference RAOB Collocation Sample (3/4)



IR+MW AVTP and ECMWF Versus RAOB

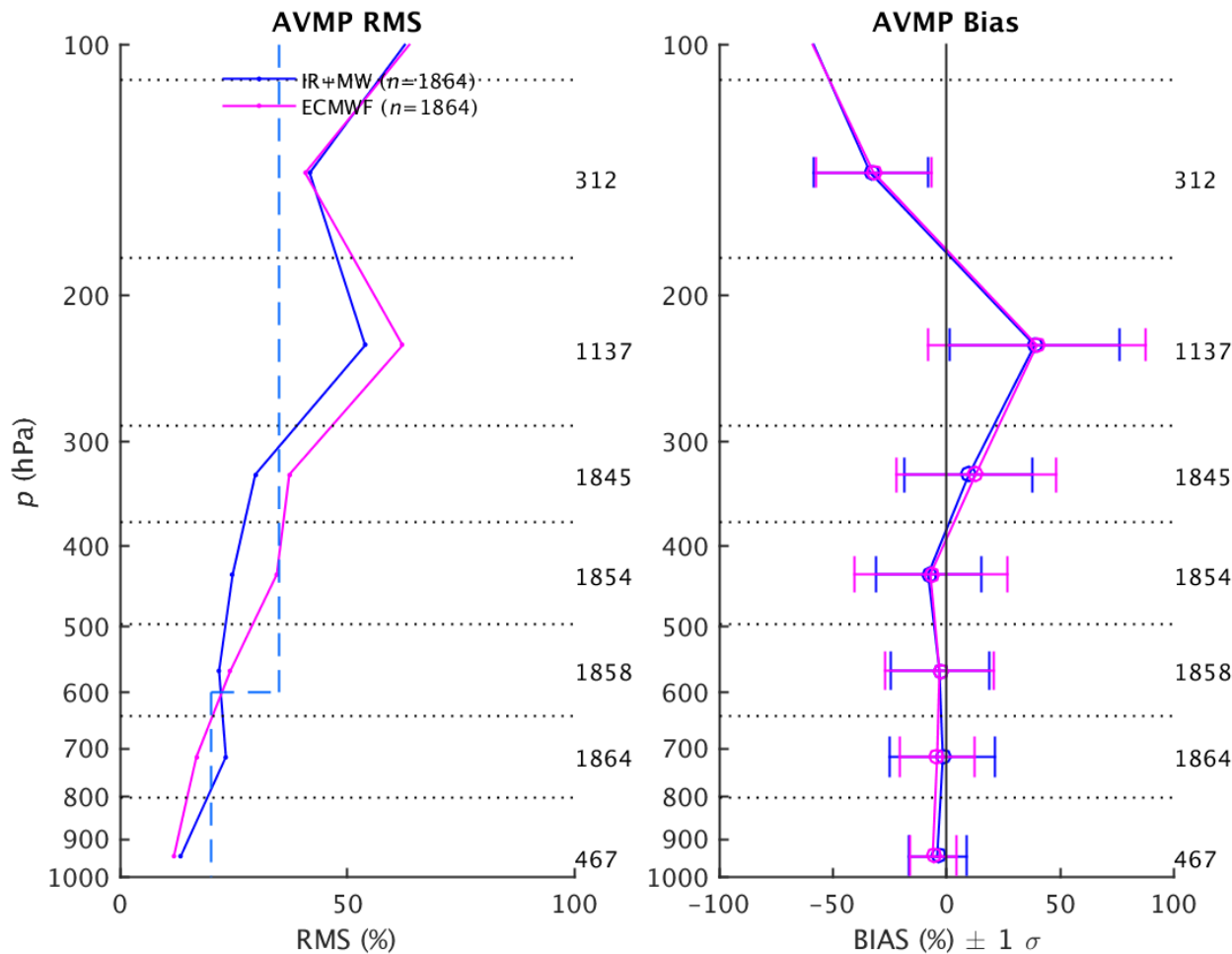


NUCAPS Offline (v1.5) EDR Coarse-Layer Statistics

VALAR Dedicated/Reference RAOB Collocation Sample (4/4)



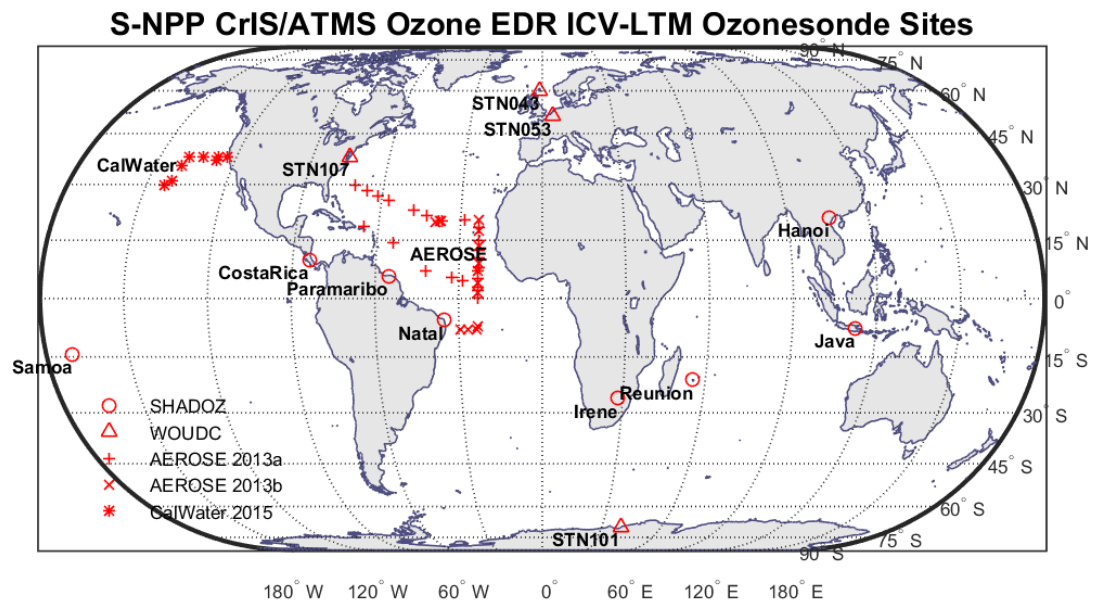
IR+MW AVMP and ECMWF Versus RAOB



NUCAPS IR Ozone Profile Validation *In Situ* Truth Datasets



- Collocated ozonesondes for O₃ (ozone) profile EDR
 - Dedicated Ozonesondes
 - NOAA AEROSE (*Nalli et al.* 2011)
 - CalWater/ACAPEX 2015
 - Sites of Opportunity
 - SHADOZ
 - Costa Rica
 - Hanoi
 - Irene
 - Java
 - Natal
 - Paramaribo
 - Reunion
 - American Samoa
 - WOUDC
 - STN043
 - STN053
 - STN107
 - STN101



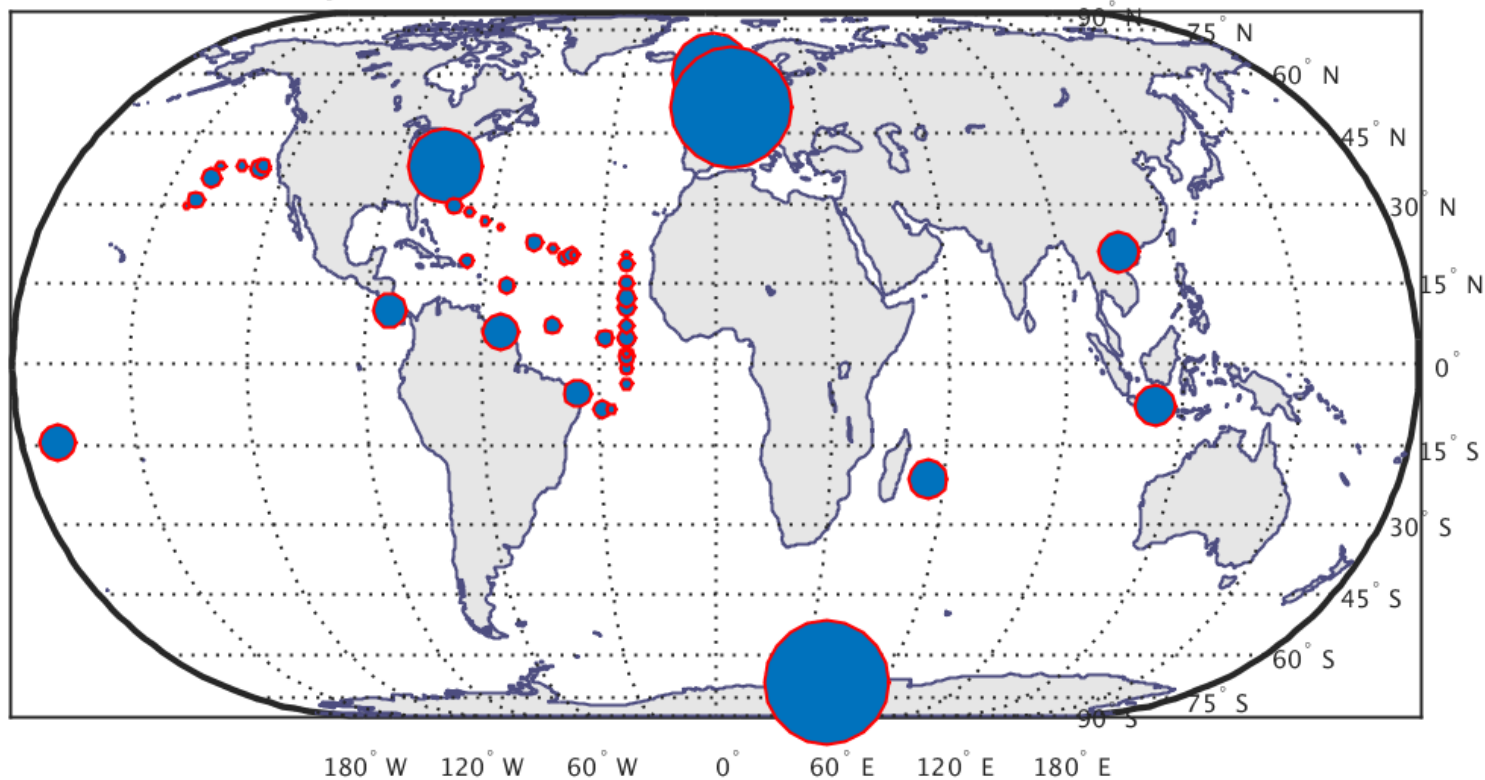
VALAR Ozonesonde-FOR Collocation Sample ($n = 5824$)



Geographic Histogram (Equal Area)

FOR Collocation Criteria: $\delta x \leq 125$ km, $-240 < \delta t < +120$ min

valar_nucaps_offline_v15_collocation_file_o3-raob_20150812.mat

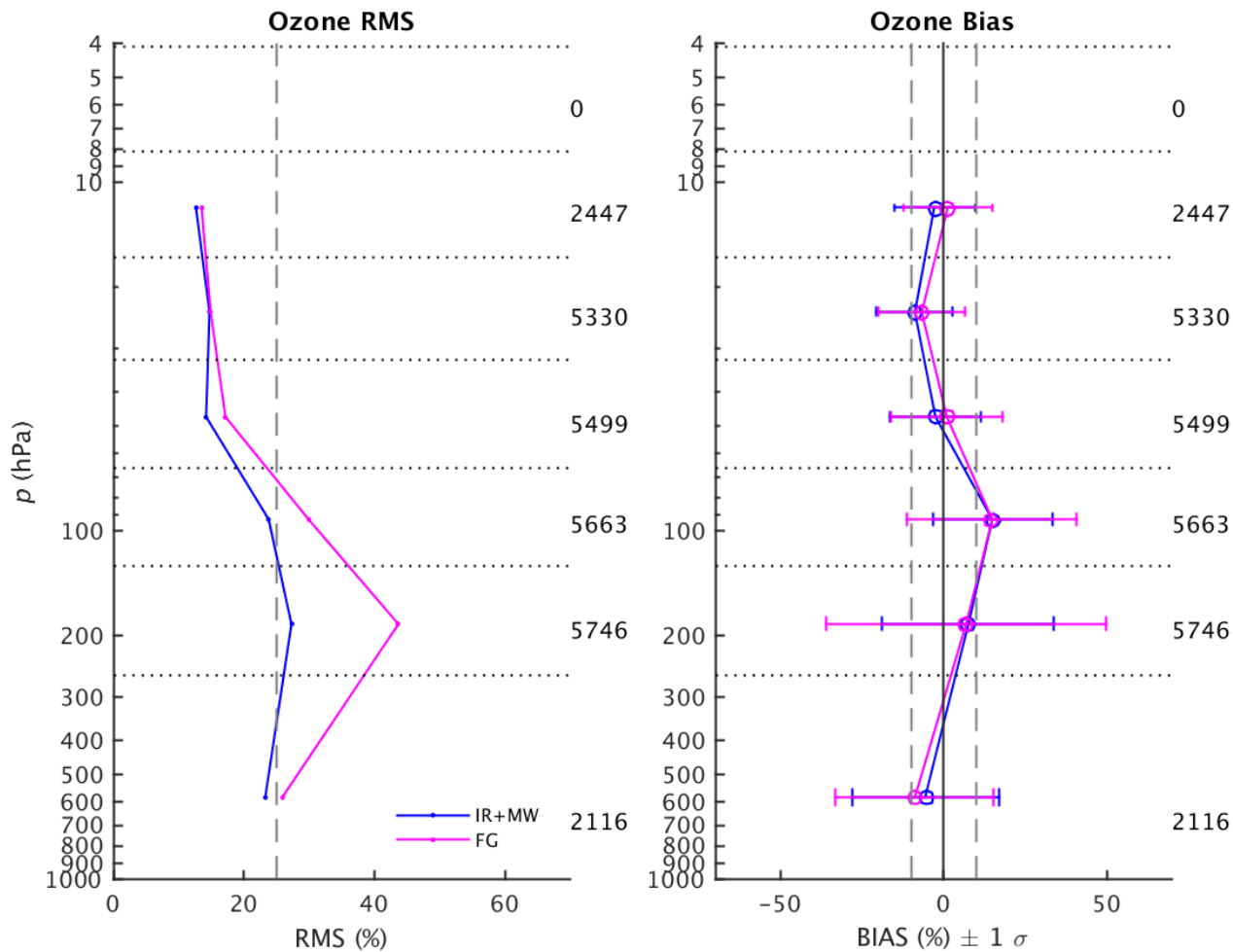


Stage-2 Ozone Profile Validation (1/3)

NUCAPS Offline (v1.5) EDR versus Global Ozonesondes



Retrieval and *A Priori* First Guess

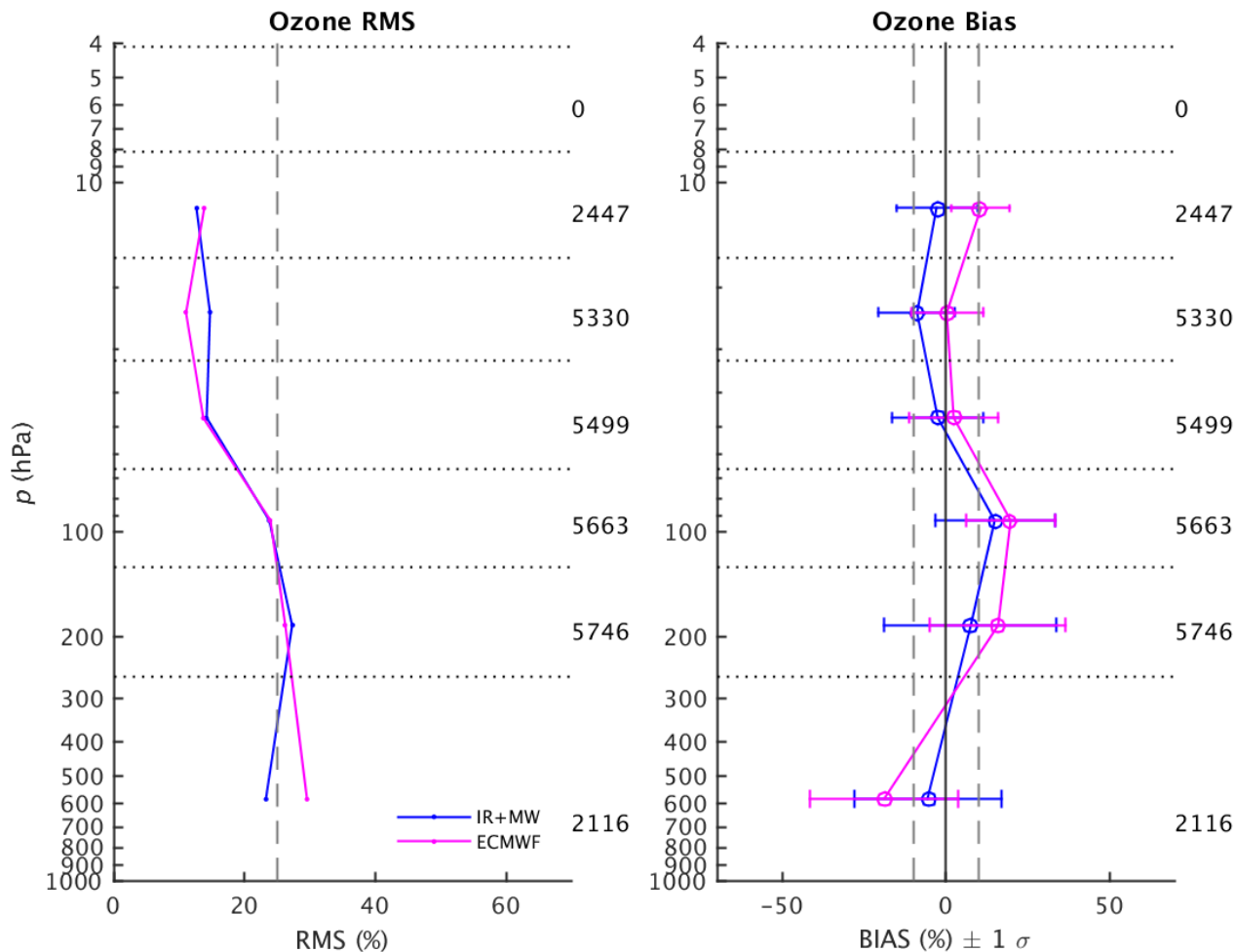


Stage-2 Ozone Profile Validation (2/3)

NUCAPS Offline (v1.5) EDR versus Global Ozonesondes



Retrieval and ECMWF

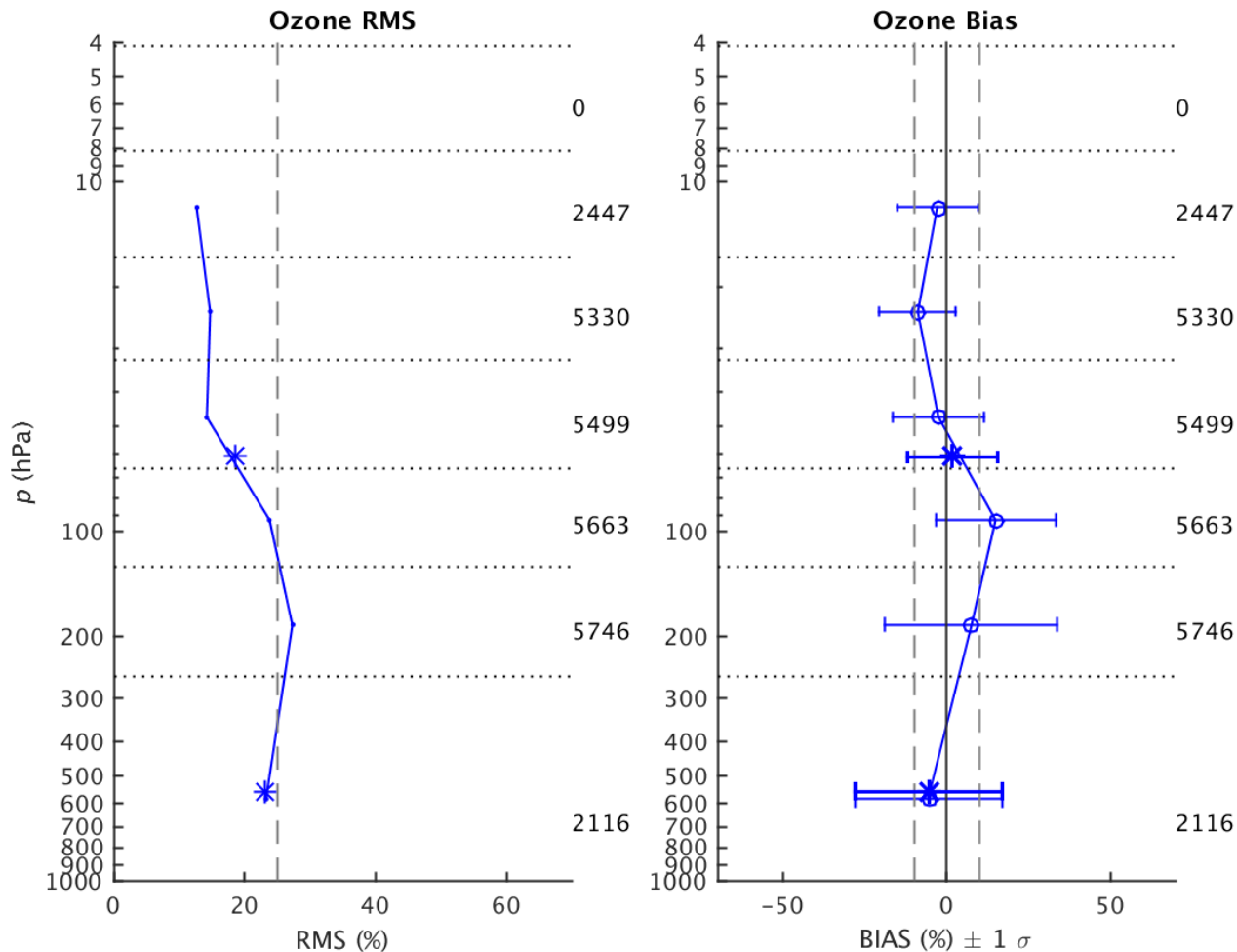


Stage-2 Ozone Profile Validation (3/3)

NUCAPS Offline (v1.5) EDR versus Global Ozonesondes



* "Coarse Coarse-Layer" Statistics (Per JPSS Level 1 Requirements)



- **NUCAPS Stages 3-4 Validated Maturities, Long-Term Monitoring**
 - **AVTP/AVMP, IR O₃ validation** for operational and offline code versions
 - **Apply averaging kernels** in NUCAPS error analyses, including ozone profile EDR
 - Carbon Trace Gas validation
 - Acquire truth data suitable for carbon product CO, CO₂, CH₄
 - NOAA AEROSE Campaigns
 - MOZAIC aircraft (CO)
 - NOAA ESRL flask data (CO)
 - Satellite data (MLS, OCO-2, etc.)
 - VALAR expansion, development and enhancements
 - Support **AEROSE-X campaign (Atlantic Ocean, Nov-Dec 2015)**
 - Continue support of ARM dedicated RAOBs (including dual-launches, “best estimates”)
 - Continue leveraging GRUAN reference RAOBs
 - **GRUAN reprocessing** of RS92 RAOB data (viz., entire AEROSE data record)
 - Support short- and long-term NUCAPS EDR algorithm development, updates, improvements
- **Other Related Work**
 - Collocation uncertainty estimates
 - calc – obs analyses (CRTM, LBLRTM, SARTA, etc.)
 - Support skin SST EDR validation
 - Support EDR applications (AWIPS, AR/SAL, atmospheric chemistry users)



NUCAPS Products Validation

EXTRA SLIDES

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 \rightarrow column abundances), interpolate to RTA (arbitrary) levels, then compute RTA layer quantities, e.g.,

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

Assessment Methodology: Use of Averaging Kernels (AKs)



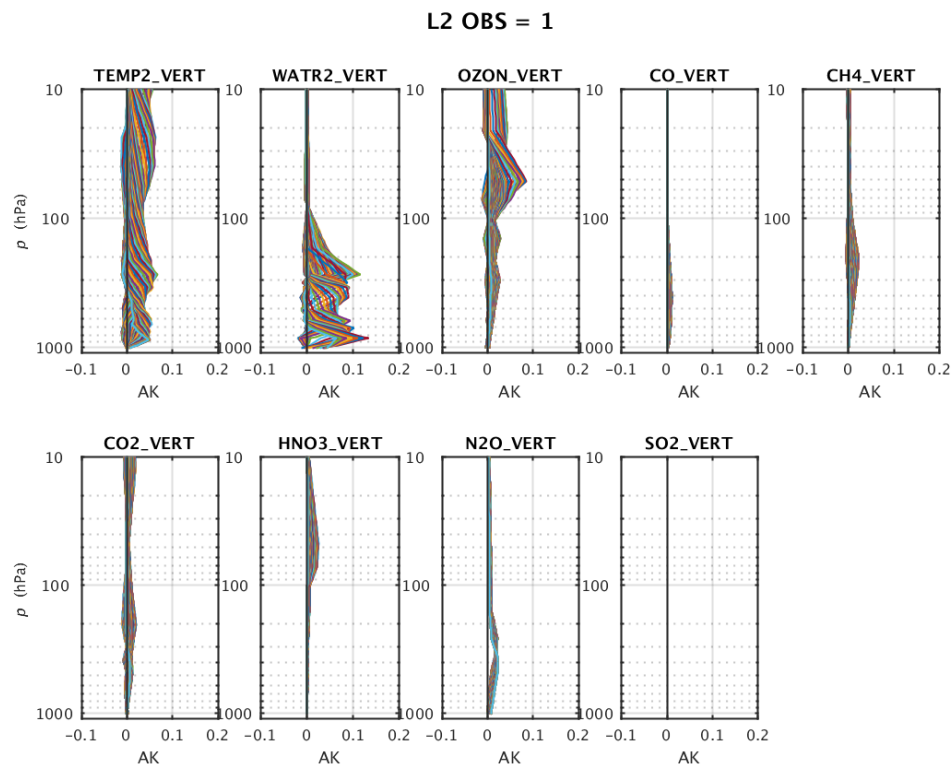
NUCAPS Effective Averaging Kernels, A_e (Maddy and Barnett 2008) AEROSE 16-Nov-13

- **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

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



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 6).
- We have recently introduced rigorous **zonal/land/sea surface area weighting** capabilities to these schemes for dedicated/reference RAOB samples

AVTP

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

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

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

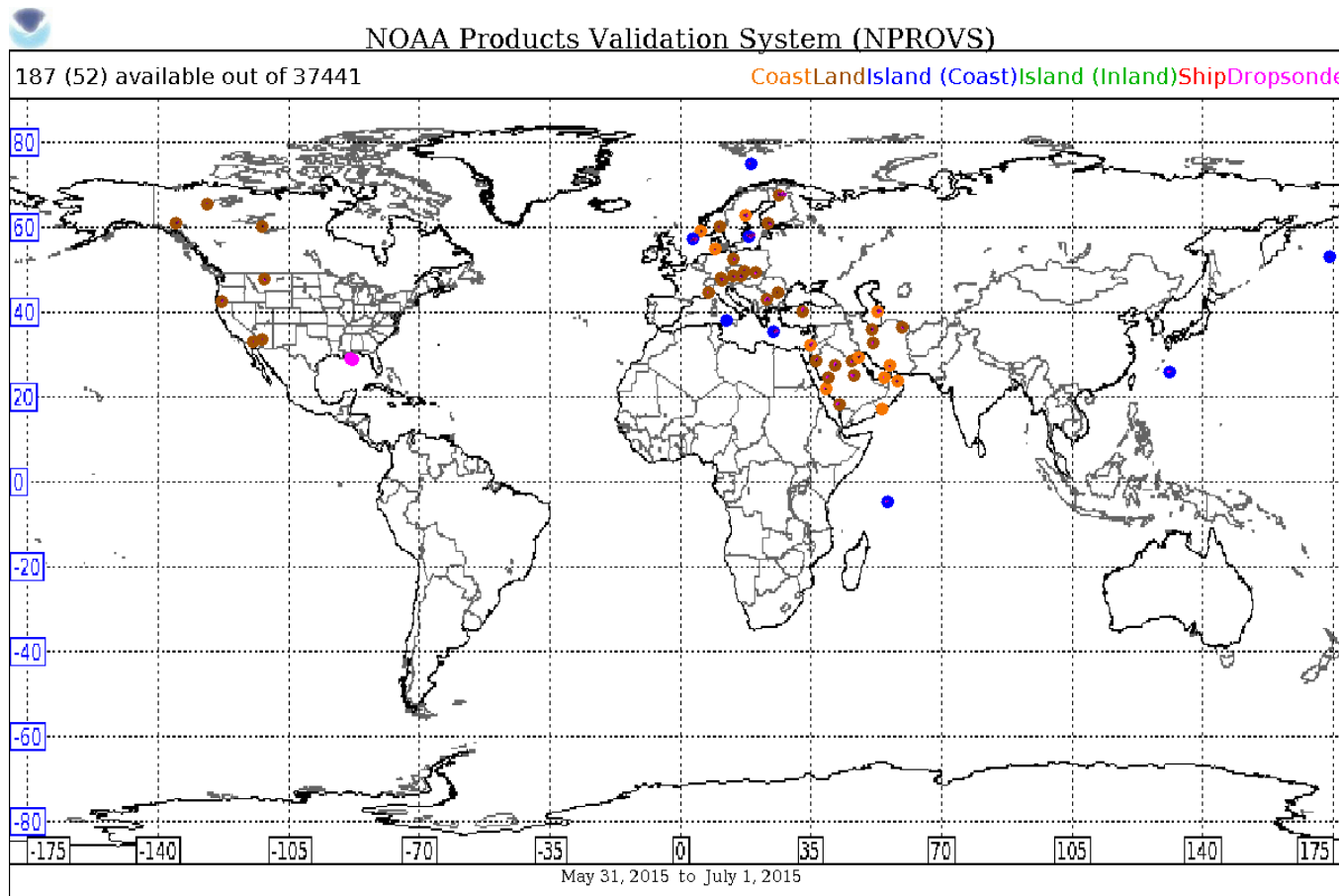
$$\Delta q_{\mathcal{L},j} \equiv \frac{\hat{q}_{\mathcal{L},j} - q_{\mathcal{L},j}}{q_{\mathcal{L},j}} \quad \text{RMS}(\Delta q_{\mathcal{L}}) = \sqrt{\frac{\sum_{j=1}^{n_j} W_{\mathcal{L},j} (\Delta q_{\mathcal{L},j})^2}{\sum_{j=1}^{n_j} W_{\mathcal{L},j}}}, \quad \text{water vapor weighting factor, } W_{\mathcal{L},j},$$

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

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

NPROVS Conventional RAOB Collocations

Single Closest FOR



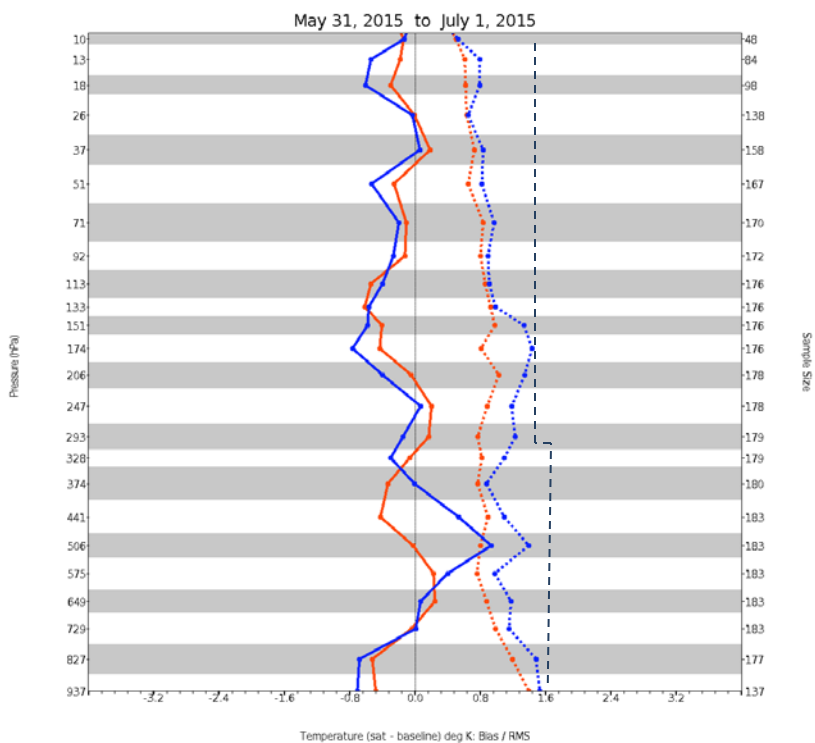
- June 2015
- RS92 and RS41 sondes
- Single-closest FOR
- Space-time window [2]
 - -2 to +0.5 h before/after overpass
 - 75 km
- Sample size [2]
N = 187

NUCAPS OPS-EDR and AIRS versus NPROVS Collocated Conventional RAOB: Sample [2]



AVTP (BIAS and RMS)

NOAA Products Validation System (NPROVS)



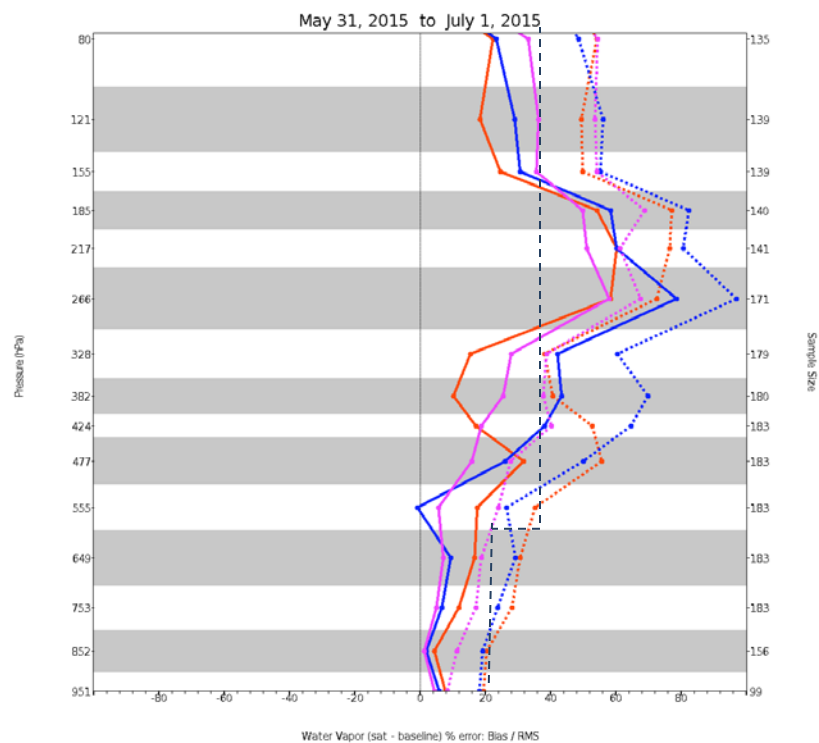
Baseline: RAOB Radiosonde

NUCAPS NPP

AIRS AQUA

AVMP (BIAS and RMS)

NOAA Products Validation System (NPROVS)



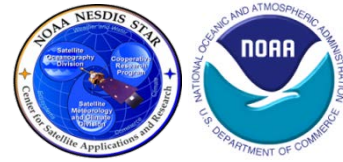
Baseline: RAOB Radiosonde

ECMWF ANALYSIS

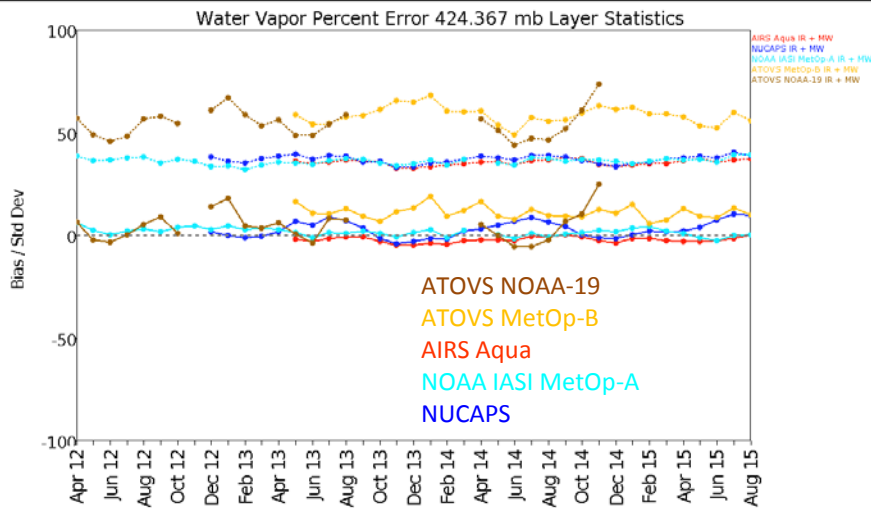
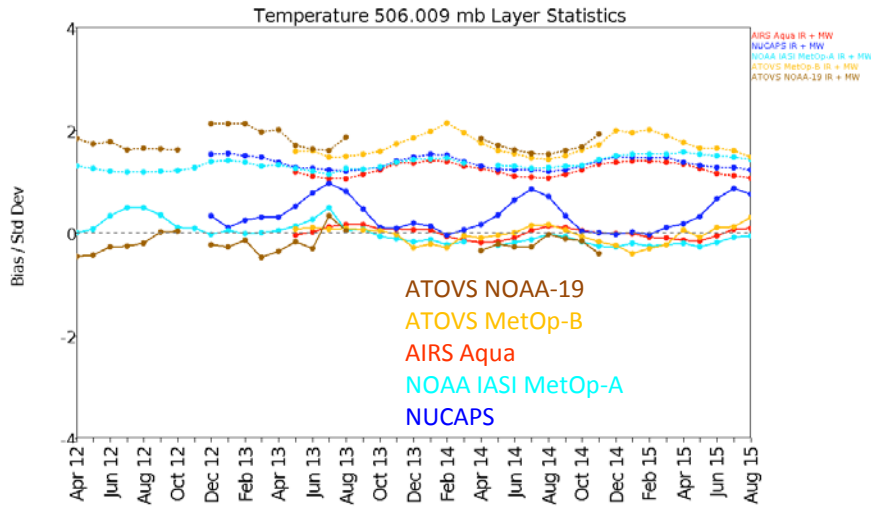
NUCAPS NPP

AIRS AQUA

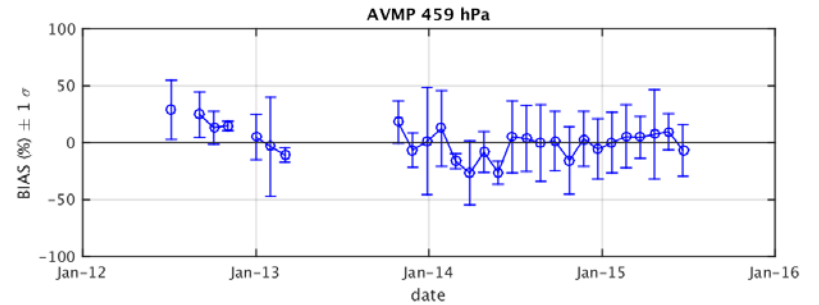
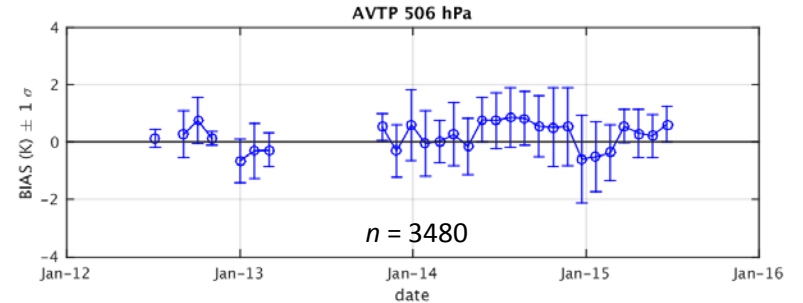
Long-Term Monitoring (LTM)



NPROVS NARCS Conventional RAOB Collocation (OPS-EDR)



VALAR Dedicated/GRUAN Collocation (OPS-EDR)



VALAR Ozonesonde Collocation (Offline v1.5)

