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

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ITSC-20
Lake Geneva, Wisconsin, USA
October 2015

Acknowledgments

- The **NOAA Joint Polar Satellite System (JPSS-STAR) Office** (M. D. Goldberg, L. Zhou, et al.) and the **NOAA/STAR Satellite Meteorology and Climatology Division** (F. Weng and I. Csiszar).

- **SNPP Sounder EDR Validation Dataset collection**
  - **NOAA AEROSE:** E. Joseph, V. R. Morris, M. Oyola (HU/NCAS); P. J. Minnett (UM/RSMAS); D. Wolfe (NOAA/ESRL); J. W. Smith (STAR, NRC)
    - AEROSE works in collaboration with the NOAA PIRATA Northeast Extension (PNE) project (R. Lumpkin, G. Foltz and C. Schmid), and is supported by the NOAA Educational Partnership Program (EPP) grant NA17AE1625, NOAA grant NA17AE1623, JPSS and STAR
  - **U.S. DOE Atmospheric Radiation Measurement (ARM) program dedicated RAOBs**
    - L. Borg, D. Tobin (UW/CIMSS)
    - D. Holdridge and J. Mather (ARM Climate Research Facility)
  - **CalWater:** R. Spackman (STC); C. Fairall, J. Intrieri (NOAA)
  - **ACAPEX:** N. Hickmon, M. Ritsche, A. Haruta, and the ARM Mobile Facility 2 (AMF2)
  - **PMRF Site:** A. K. Mollner, J. E. Wessel (Aerospace)
  - **BCCSO Site:** R. Sakai, B. Demoz, M. Oyola (HU/NCAS)
  - **GRUAN Lead Center:** Ruud Dirksen
  - **NASA Sounder Science Team:** T. Pagano, E. Fetzer (NASA/JPL)

- **NUCAPS/CrIMSS validation effort (past and present)**: W. W. Wolf, A.K. Sharma, M. Divakarla, E. S. Maddy, H. Xie (STAR); R. O. Knuteson and M. Feltz (UW/CIMSS); X. Liu (NASA/LaRC); M. Pettey, C. Brown (NPROVS team).

Outline

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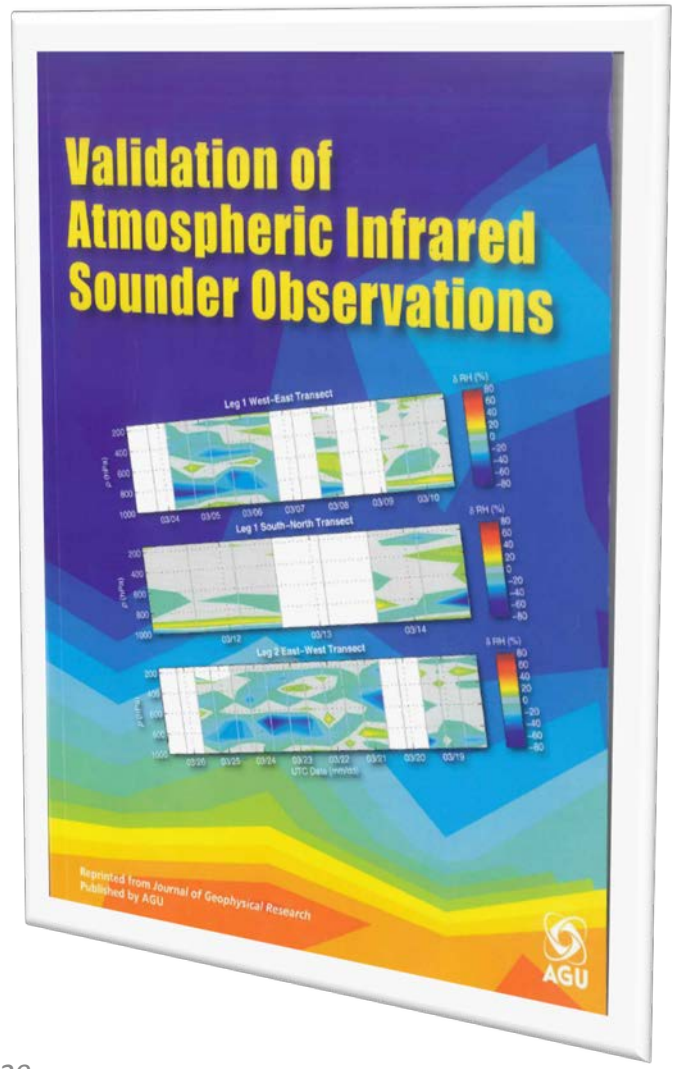
    - NOAA-Unique CrIS/ATMS Processing System (NUCAPS)
    - JPSS Level 1 Requirements
  - Validation Methodology
    - Validation Hierarchy
    - Statistical Metrics
  - JPSS SNPP Validation Datasets
    - STAR Validation Archive (VALAR)
    - NOAA Products Validation System (NPROVS/NPROVS+)
- **NUCAPS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

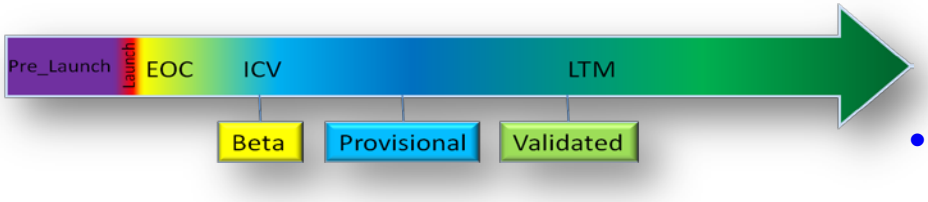
Intro: JPSS Sounder EDR Validation

- **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

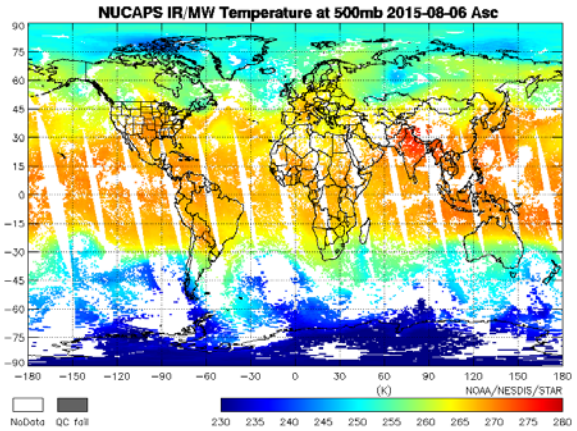
CrIS/ATMS Sounder Operational EDR: NOAA Unique CrIS/ATMS Processing System (NUCAPS)

NUCAPS Algorithm

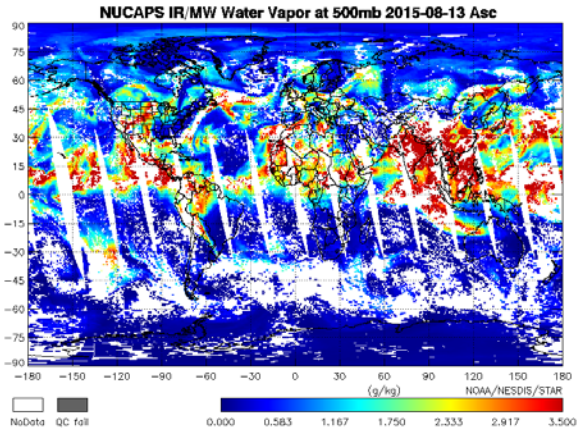
(*Susskind, Barnet and Blaisdell,* IEEE 2003; *Gambacorta et al.,* 2014)

- **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 (O_3, CO, CO_2, CH_4)**
  - **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

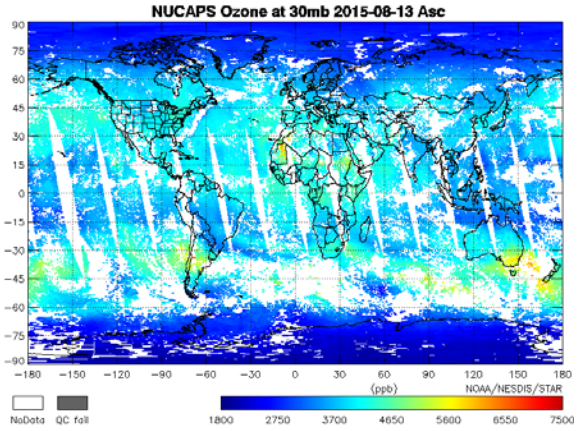
NUCAPS AVTP



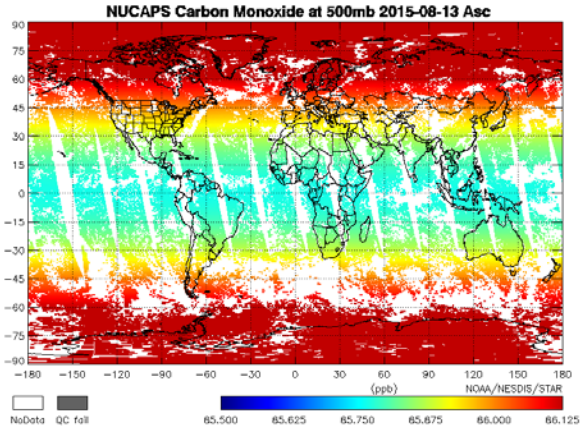
NUCAPS AVMP



NUCAPS O_3



NUCAPS CO



Long Term Monitoring

http://www.star.nesdis.noaa.gov/jpss/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 $g \cdot kg^{-1}$ / 2-km layer
AVMP, Cloud fraction < 50%, 600–300 hPa	Greater of 35% or 0.1 $g \cdot kg^{-1}$ / 2-km layer
AVMP, Cloud fraction < 50%, 300–100 hPa	Greater of 35% or 0.1 $g \cdot kg^{-1}$ / 2-km layer
AVMP, Cloud fraction ≥ 50%, surface to 600 hPa	Greater of 20% of 0.2 $g \cdot kg^{-1}$ / 2-km layer
AVMP, Cloud fraction ≥ 50%, 600–400 hPa	Greater of 40% or 0.1 $g \cdot kg^{-1}$ / 2-km layer
AVMP, Cloud fraction ≥ 50%, 400–100 hPa	Greater of 40% or 0.1 $g \cdot kg^{-1}$ / 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-continents
  - 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***

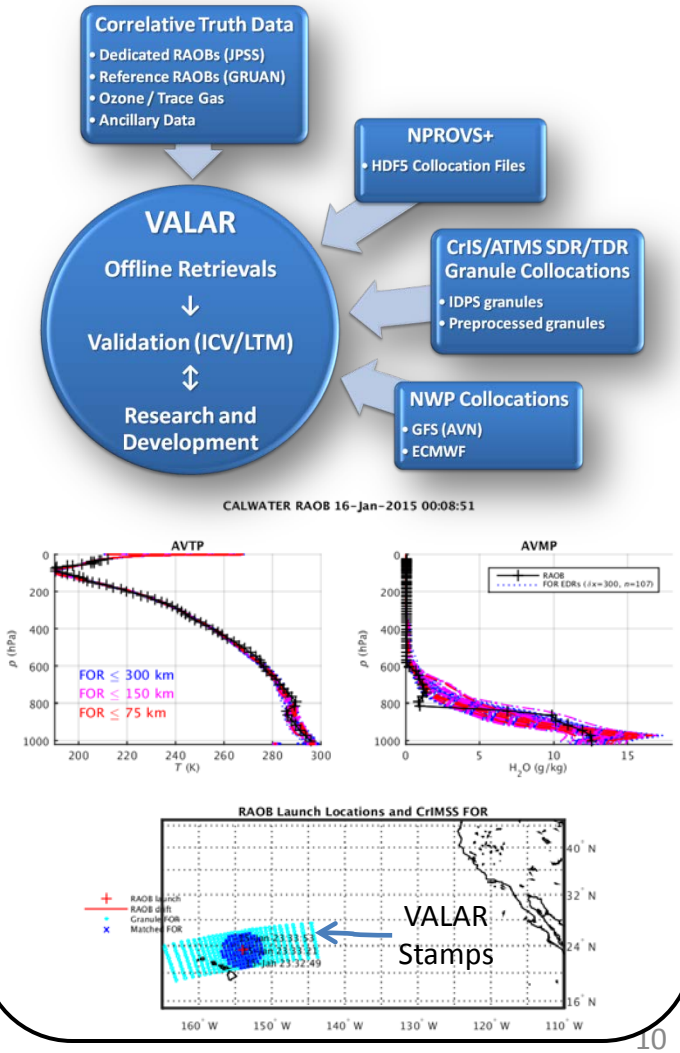
- Include dedicated RAOBs, some *not* assimilated into NWP models
- Include ancillary datasets (e.g., ozonesondes, lidar, M-AERI, MWR, sunphotometer, etc.)
- Ideally include funded aircraft campaign using IR sounder (e.g., NAST-I, S-HIS)
- Detailed performance specification; state specification; SDR 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

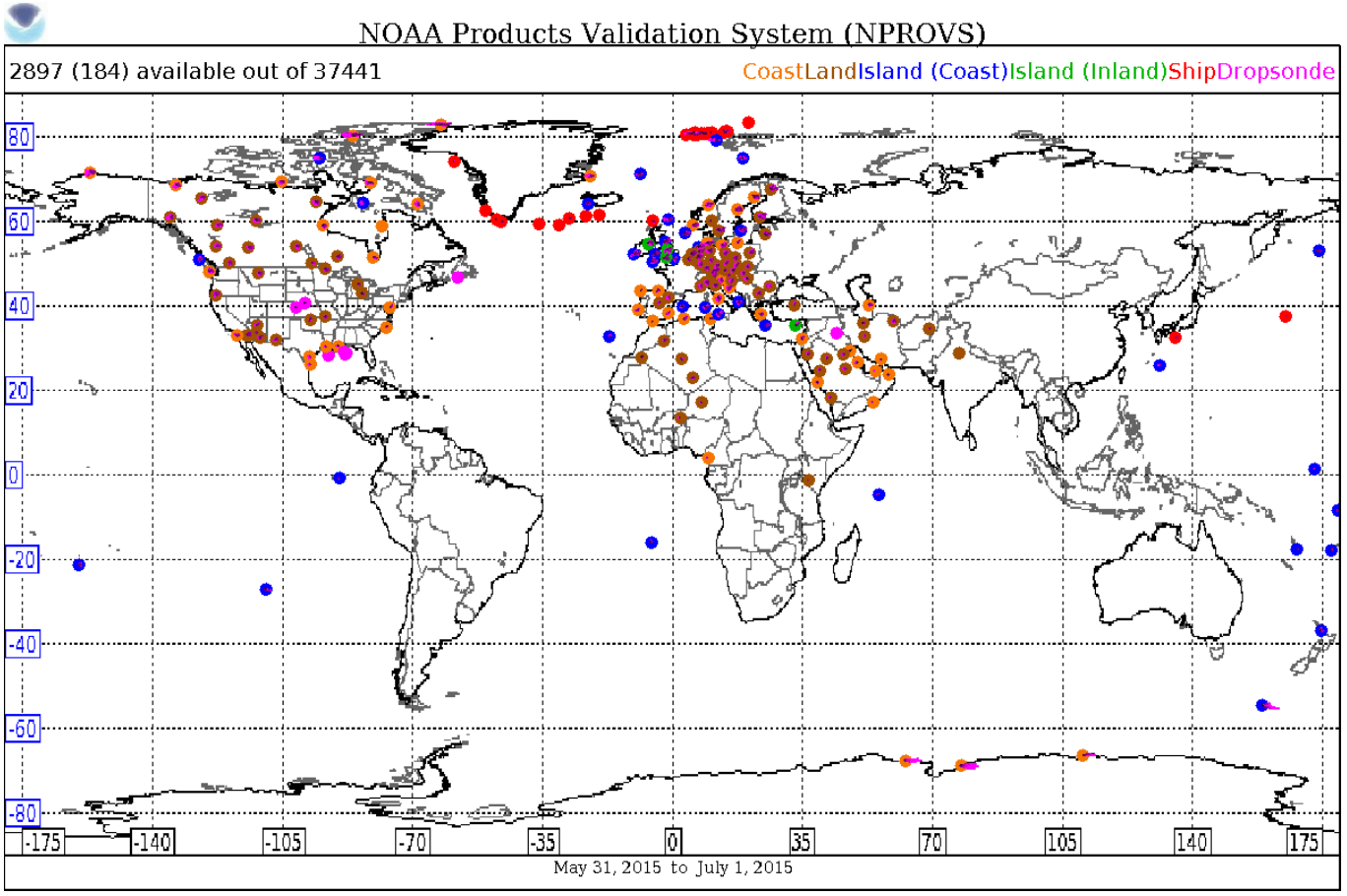


NUCAPS Products Validation

NUCAPS EDR PRODUCT VALIDATION

NPROVS Conventional RAOB Collocation Sample

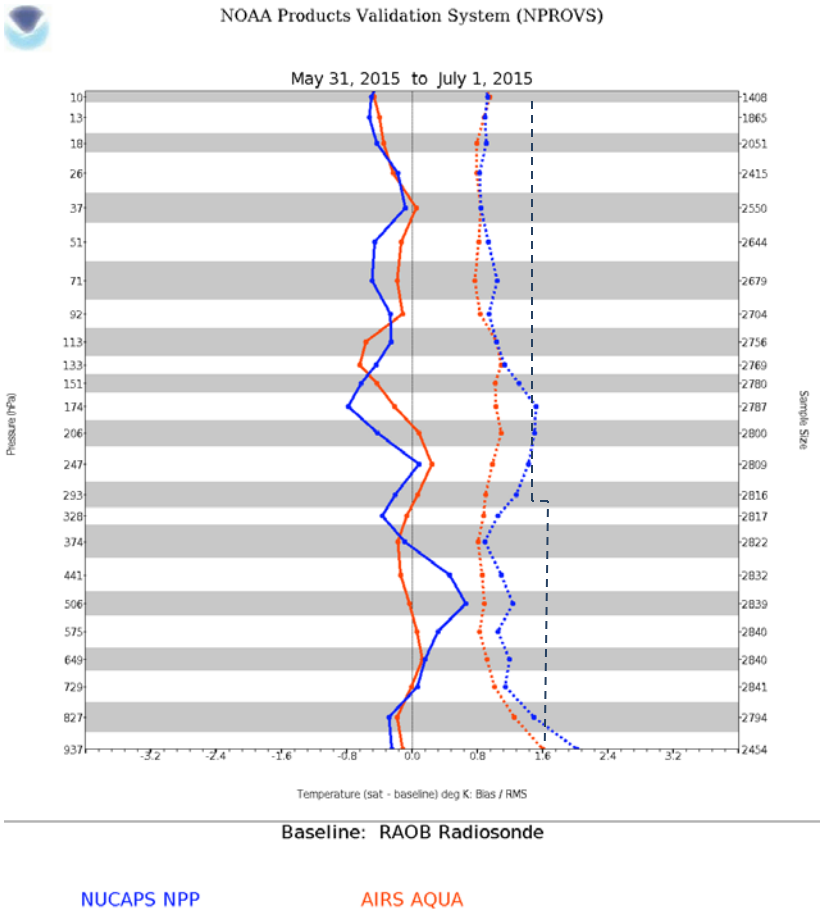
Single Closest FOR



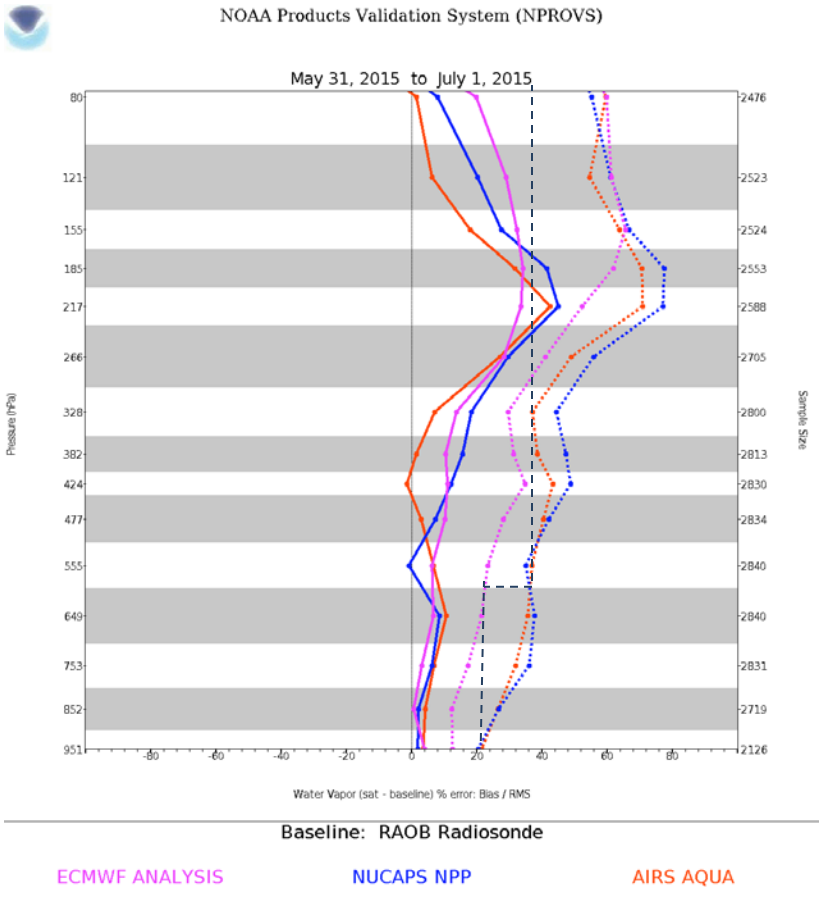
- June 2015
- **RS92 and RS41 sondes**
- Single-closest FOR
- **Space-time window [1]**
  - **±3 h before/after overpass**
  - **75 km**
- **Sample size [1]** ***N*** **= 2897**

NUCAPS OPS-EDR and AIRS versus NPROVS Collocated Conventional RAOB

AVTP (BIAS and RMS)

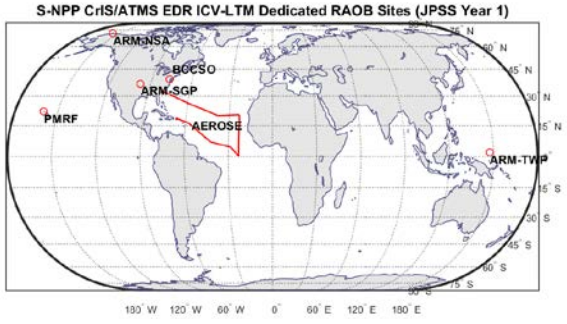


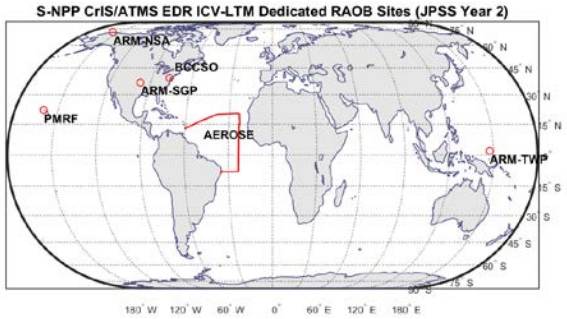
AVMP (BIAS and RMS)



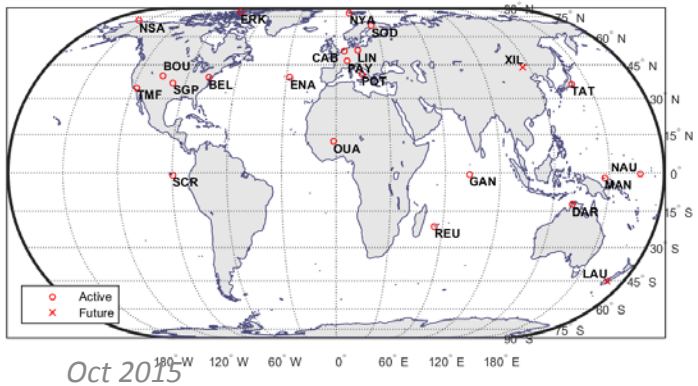
VALAR/NPROVS+ SNPP Dedicated and Reference RAOBs

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

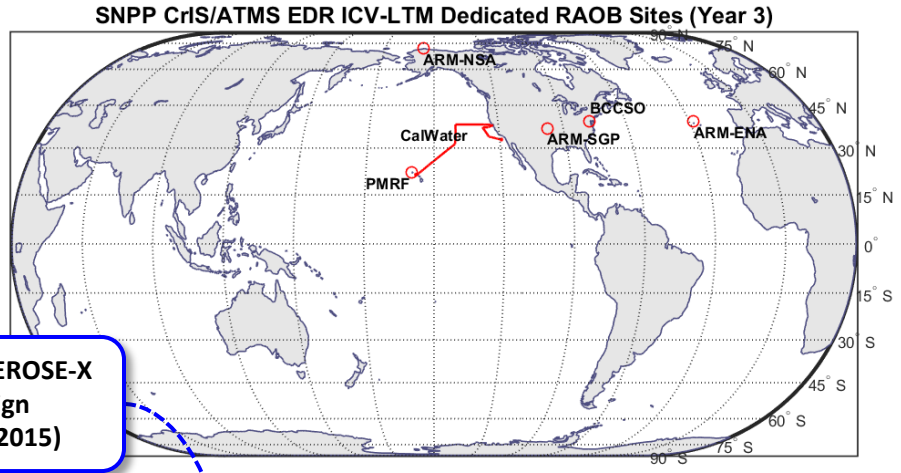




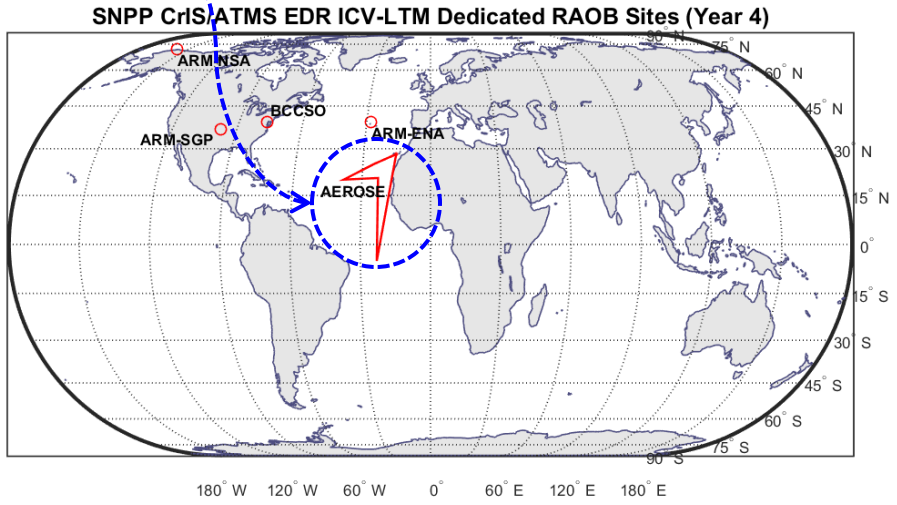
GRUAN Reference Sites



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



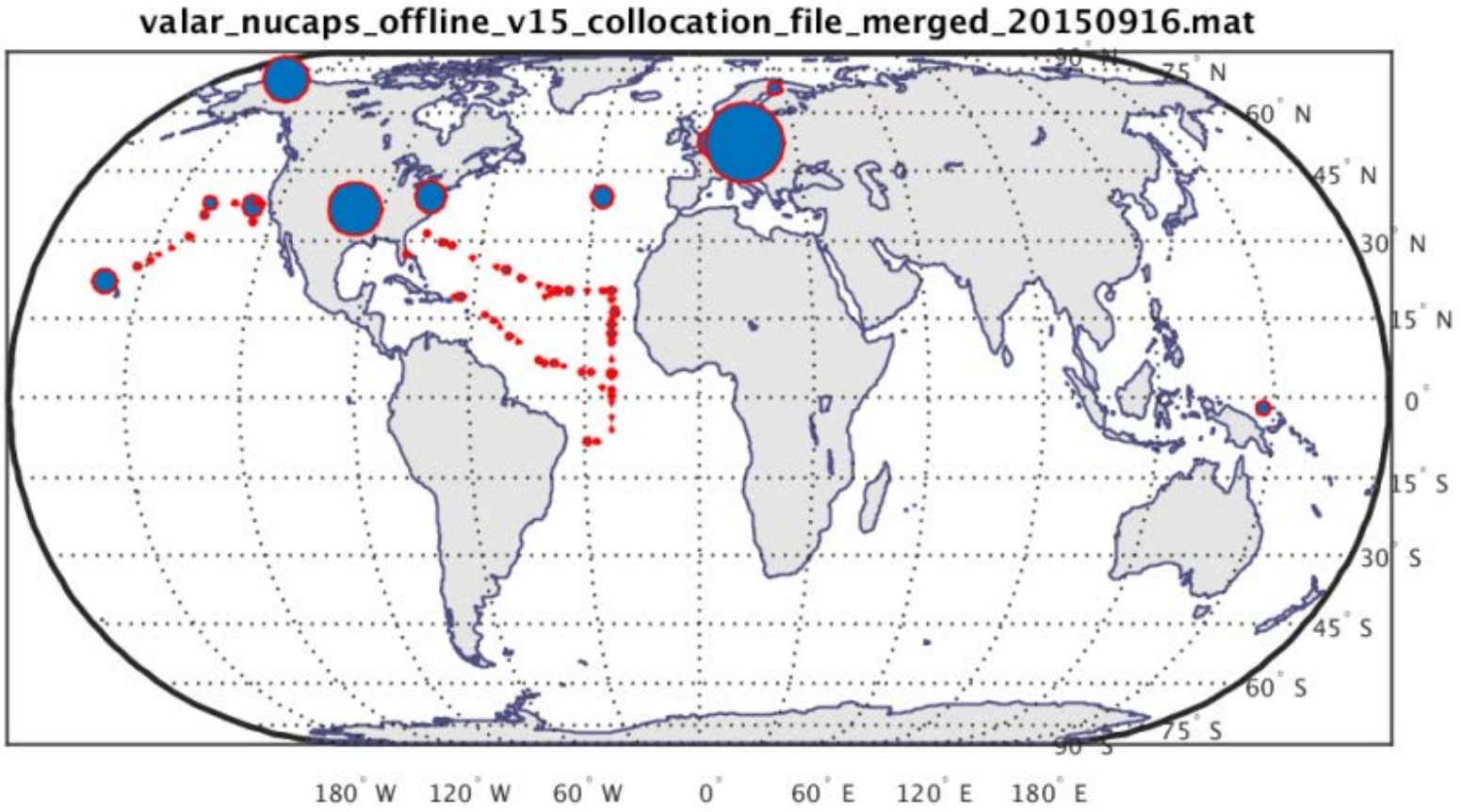
2015 PNE/AEROSE-X Campaign (Nov-Dec 2015)



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

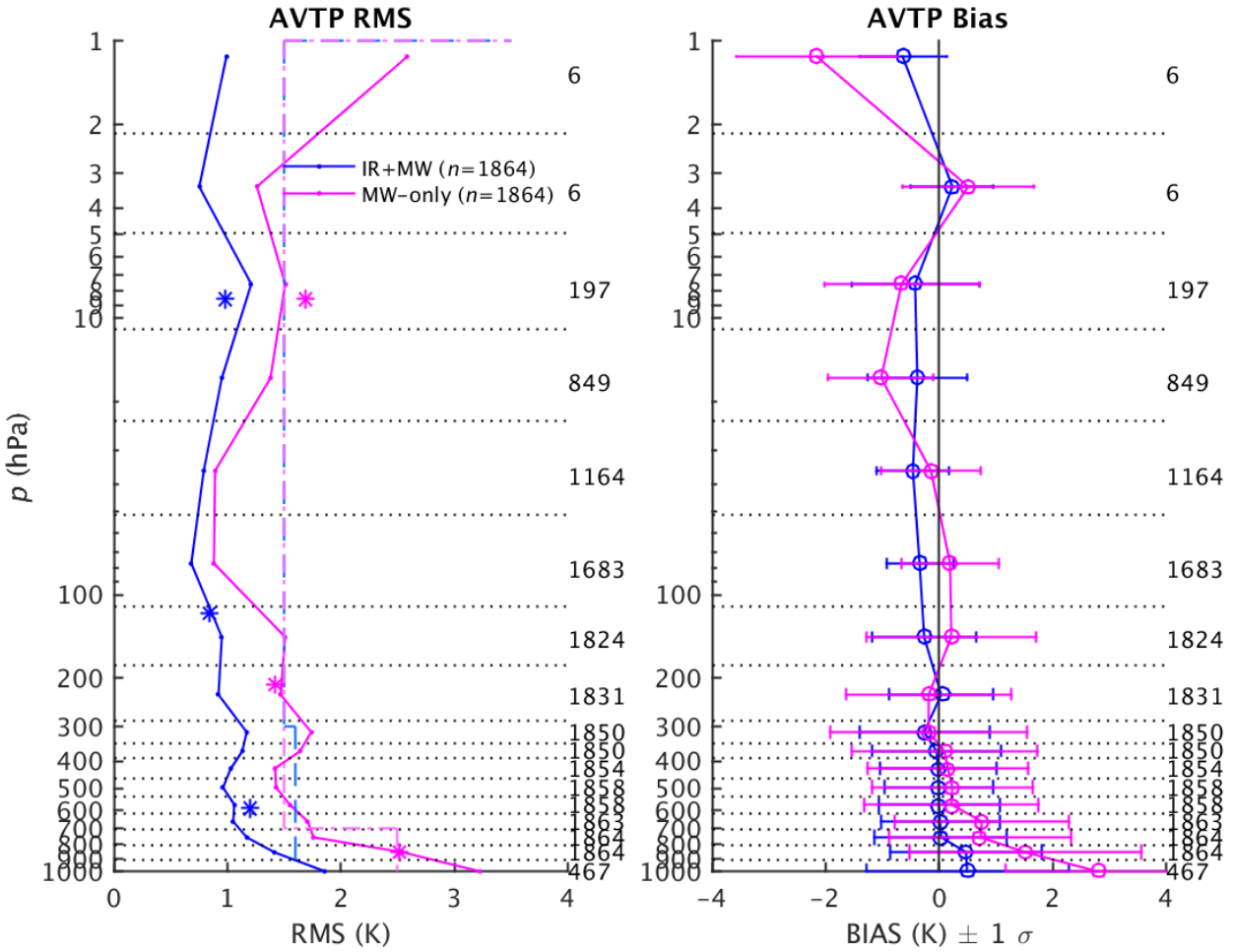


NUCAPS Offline (v1.5) EDR Coarse-Layer Statistics
VALAR Dedicated/Reference RAOB Collocation Sample (1/4)

AVTP Versus RAOB

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

IR+MW
MW-Only

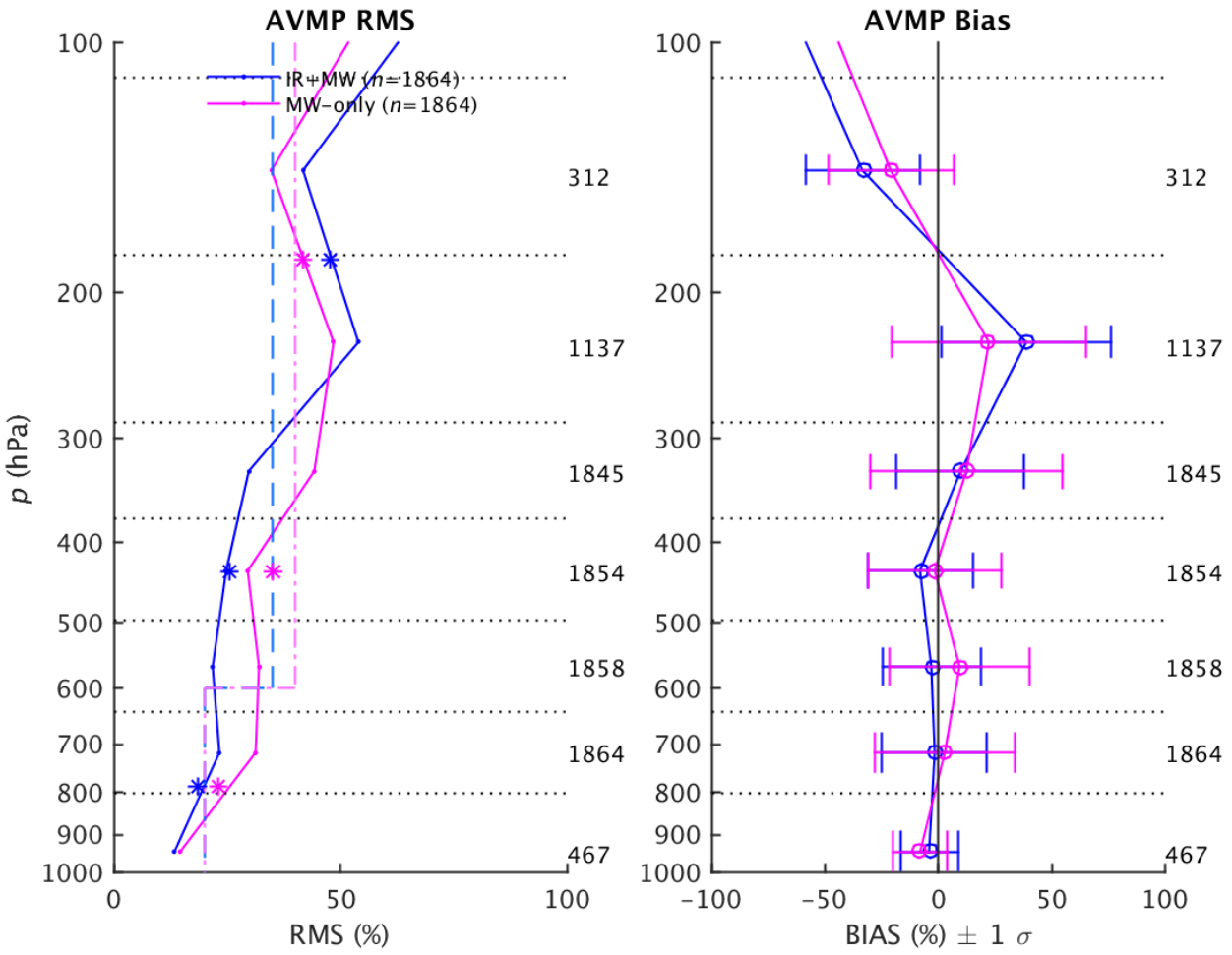


NUCAPS Offline (v1.5) EDR Coarse-Layer Statistics
VALAR Dedicated/Reference RAOB Collocation Sample (2/4)

AVMP Versus RAOB

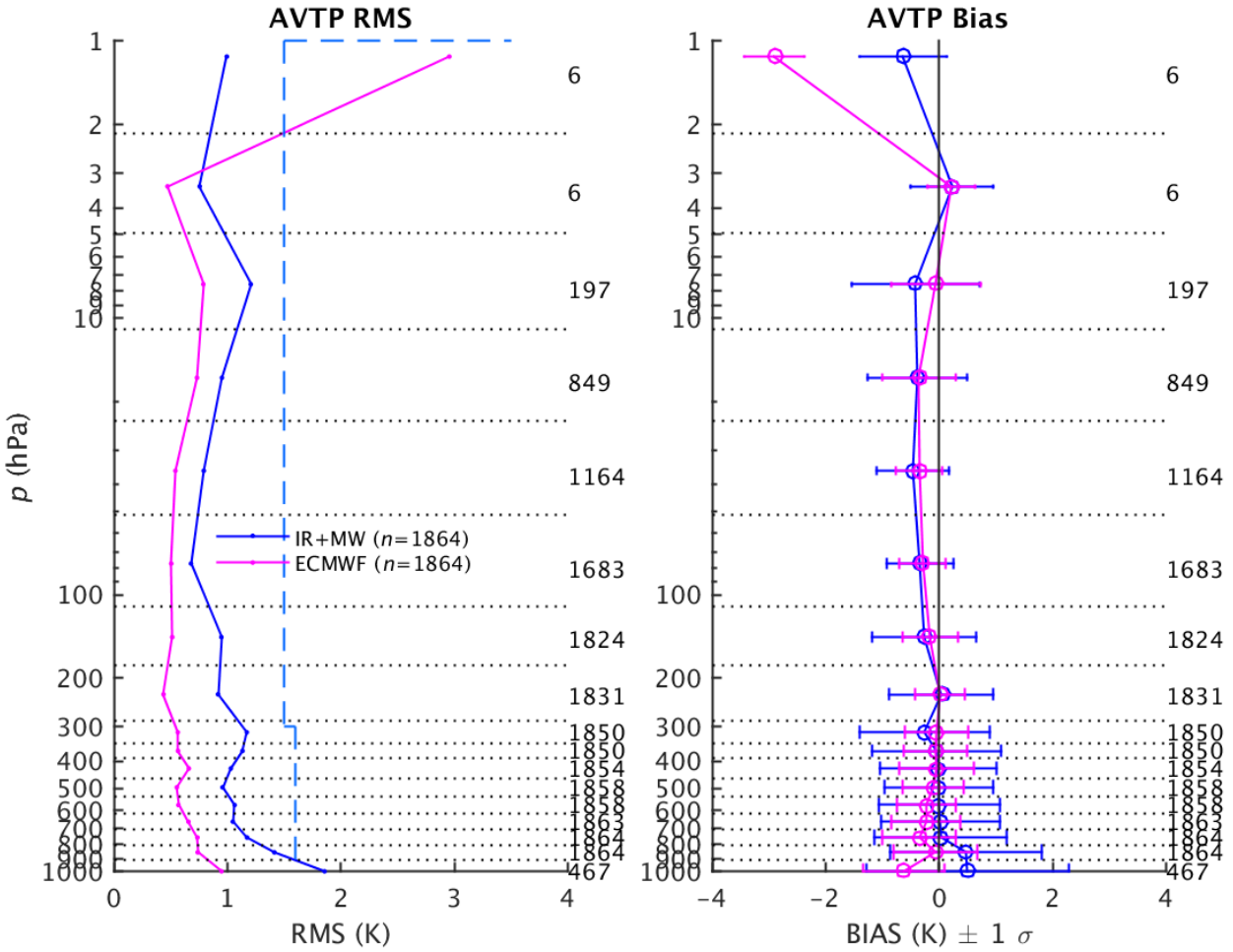
** "Coarse Coarse-Layer" Stats (Per JPSS Level 1 Requirements)

IR+MW
MW-Only



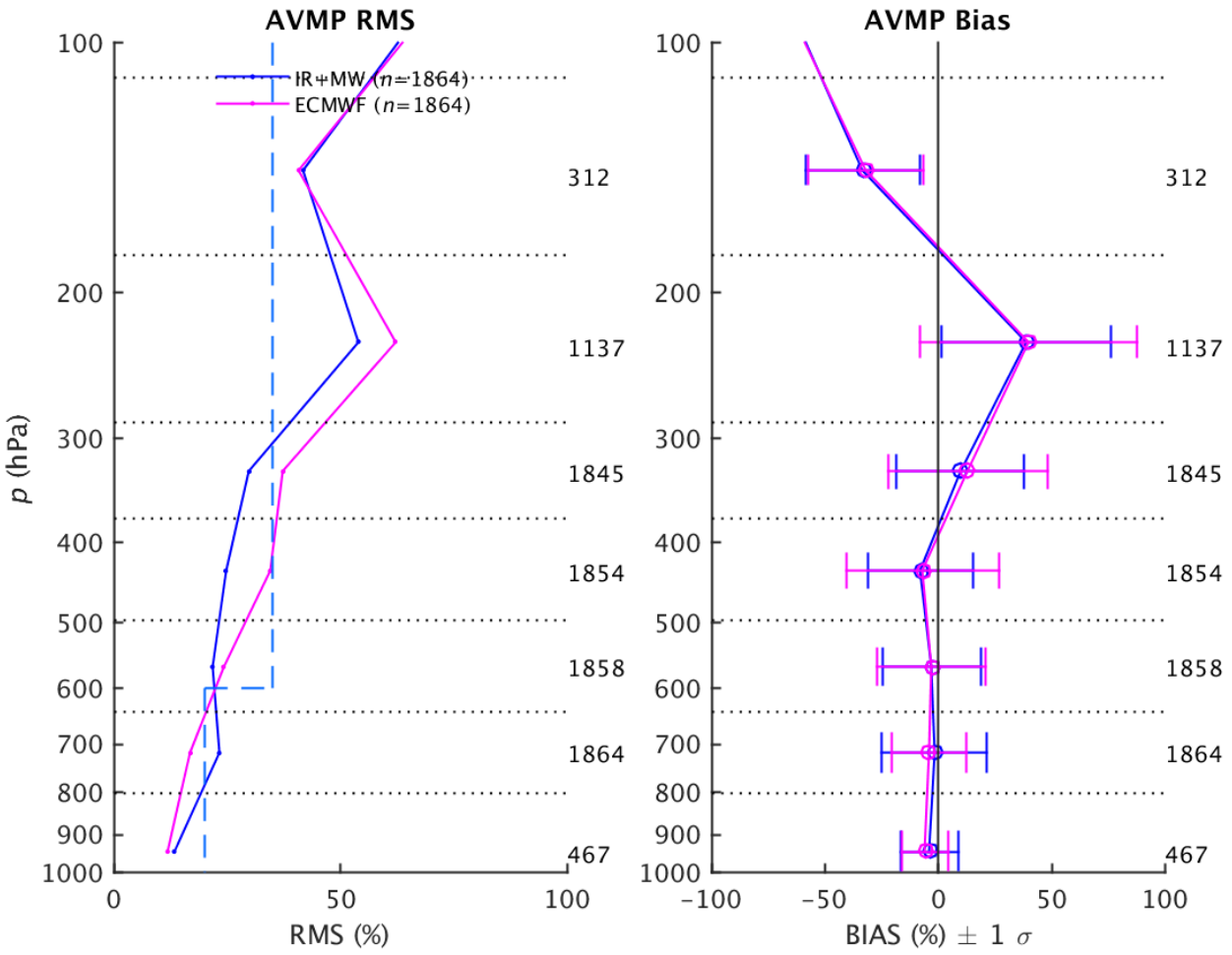
NUCAPS Offline (v1.5) EDR Coarse-Layer Statistics
VALAR Dedicated/Reference RAOB Collocation Sample (3/4)

IR+MW AVTP and ECMWF Versus RAOB



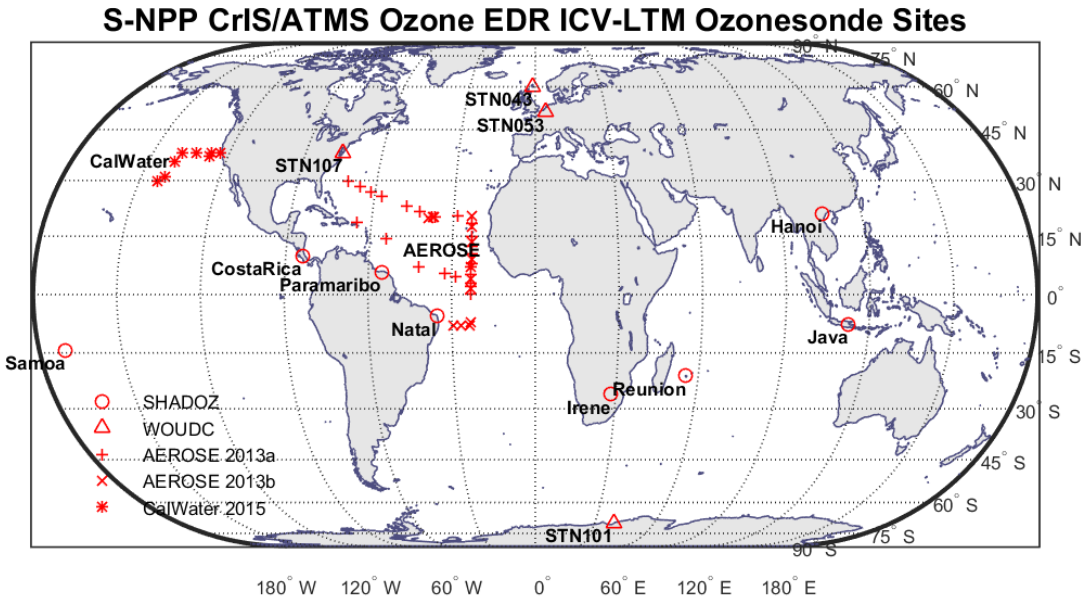
NUCAPS Offline (v1.5) EDR Coarse-Layer Statistics
VALAR Dedicated/Reference RAOB Collocation Sample (4/4)

IR+MW AVMP and ECMWF Versus RAOB



NUCAPS IR Ozone Profile Validation *In Situ* Truth Datasets

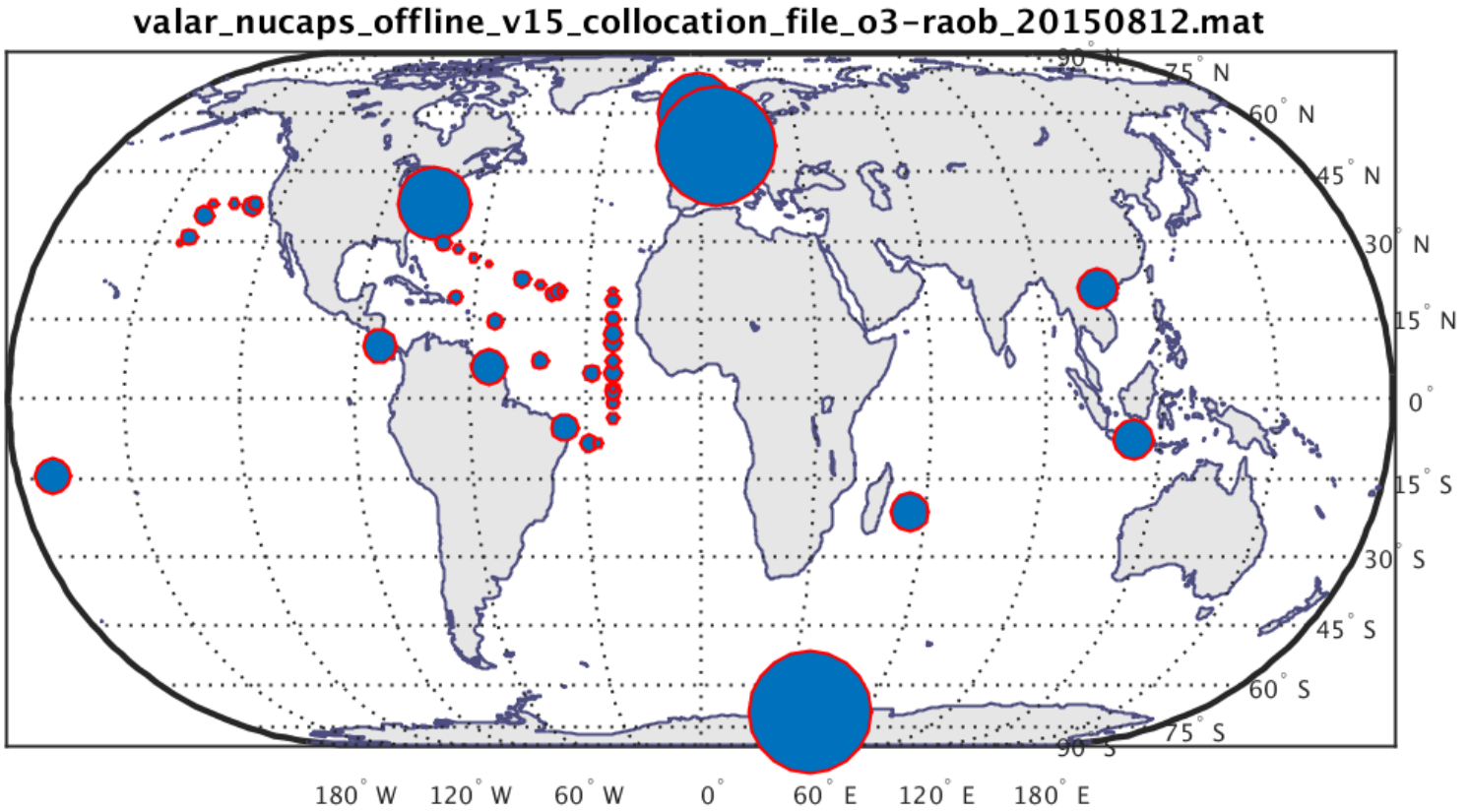
- **Collocated ozonesondes** for **O_3 (ozone) profile EDR**
  - **Dedicated Ozonesondes**
    - **NOAA AEROSE** (*Nalli et al.* 2011)
    - **CalWater/ACAPEX 2015**
  - **Sites of Opportunity**
    - **SHADOZ**
      - Costa Rica
      - Hanoi
      - Irene
      - Java
      - Natal
      - Paramaribo
      - Reunion
      - American Samoa
    - **WOUDC**
      - STN043
      - STN053
      - STN107
      - STN101



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

Geographic Histogram (Equal Area)

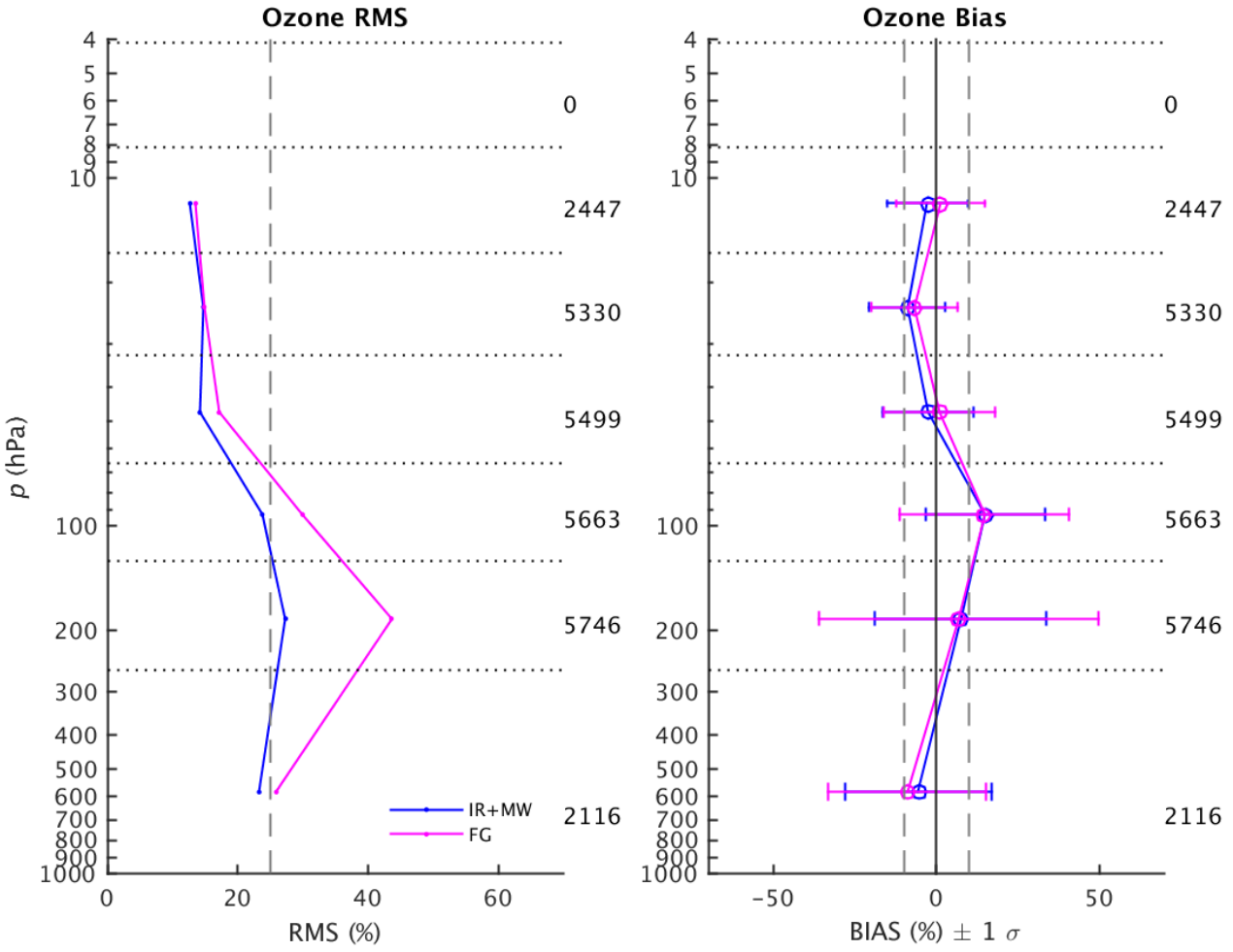
FOR Collocation Criteria: $\delta x \leq 125$ km, $-240 < \delta t < +120$ min



Stage-2 Ozone Profile Validation (1/3)

NUCAPS Offline (v1.5) EDR versus Global Ozonesondes

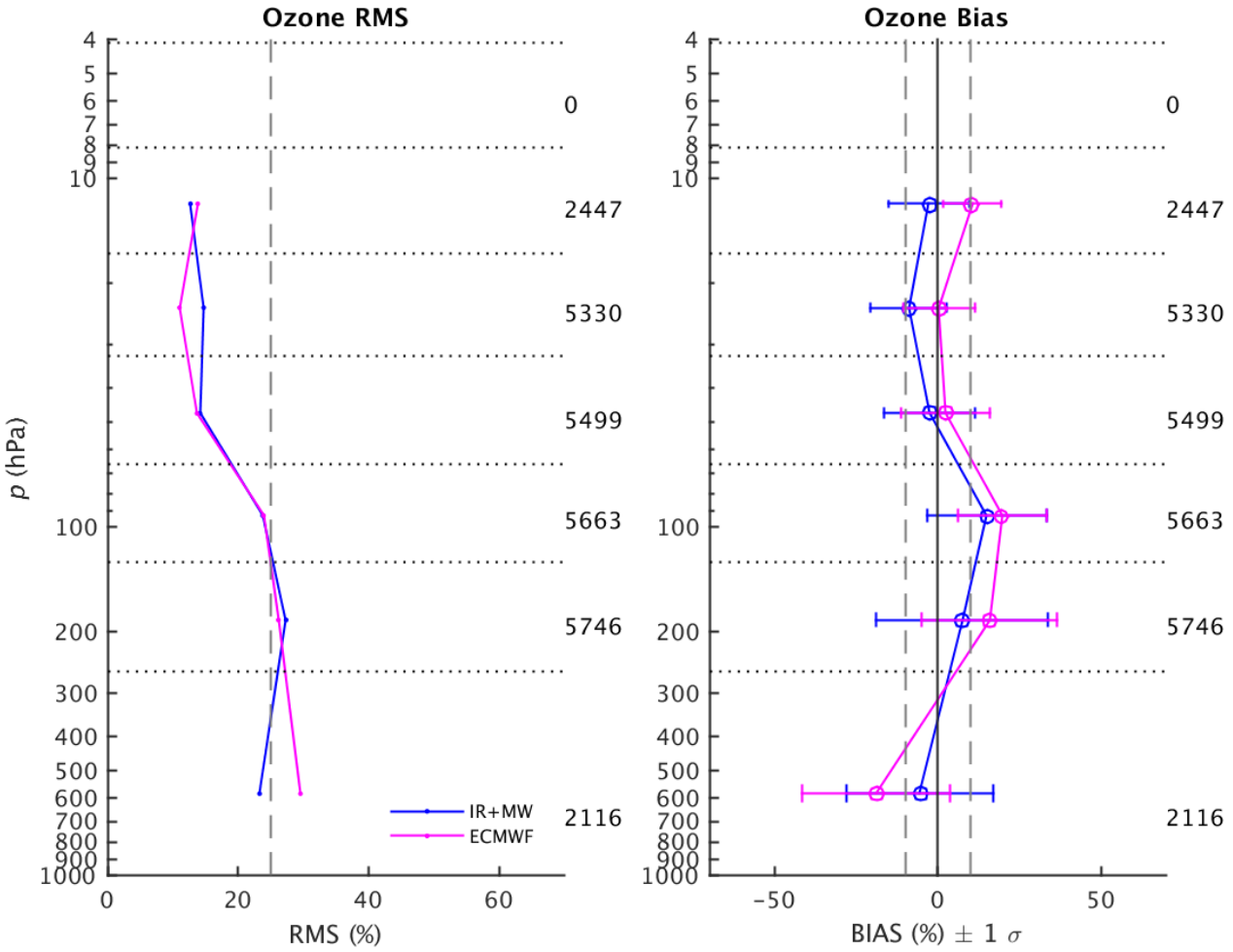
Retrieval and ***A Priori*** **First Guess**



Stage-2 Ozone Profile Validation (2/3)

NUCAPS Offline (v1.5) EDR versus Global Ozonesondes

Retrieval and **ECMWF**

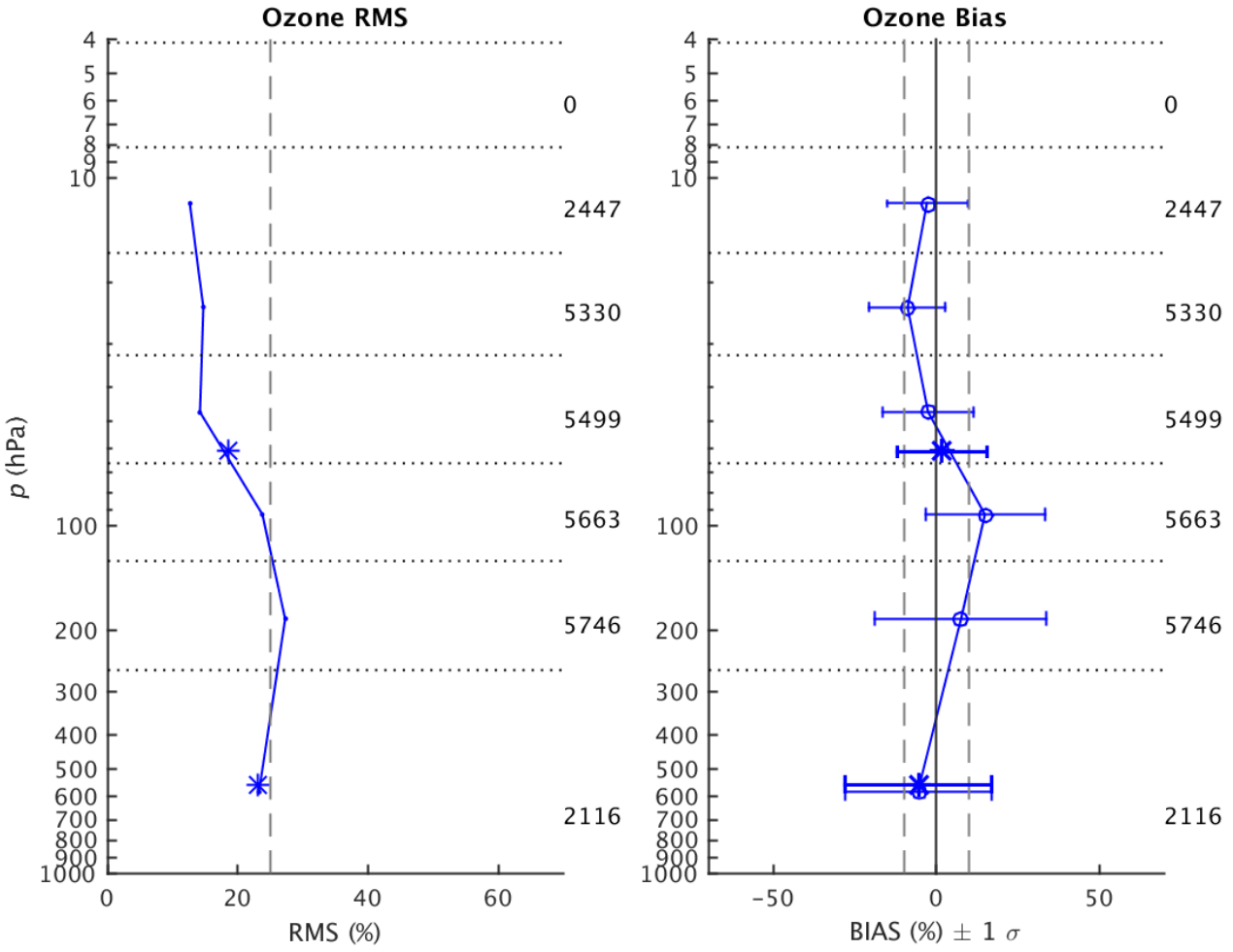


Stage-2 Ozone Profile Validation (3/3)

NUCAPS Offline (v1.5) EDR versus Global Ozonesondes

* "Coarse Coarse-Layer" Statistics

(Per JPSS Level 1 Requirements)



Future Work: SNPP ICV and LTM

- **NUCAPS Stages 3-4 Validated Maturities, Long-Term Monitoring**
  - **AVTP/AVMP, IR O_3 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, CO_2, CH_4
      - 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 → 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)

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

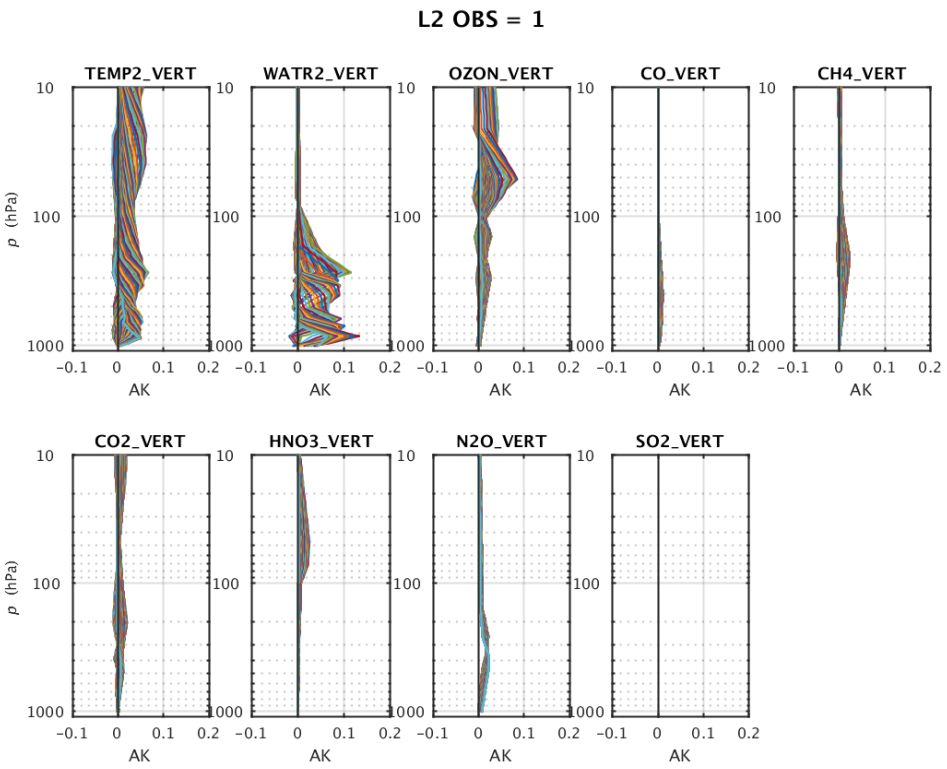
$$\mathbf{A} \equiv \frac{\partial \hat{\mathbf{x}}}{\partial \mathbf{x}}$$

- 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

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

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



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

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

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

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

$$\Delta q_{\mathfrak{L},j} \equiv \frac{\hat{q}_{\mathfrak{L},j} - q_{\mathfrak{L},j}}{q_{\mathfrak{L},j}} \qquad \mathrm{RMS}(\Delta q_{\mathfrak{L}}) = \sqrt{\frac{\sum_{j=1}^{n_j} W_{\mathfrak{L},j}(\Delta q_{\mathfrak{L},j})^2}{\sum_{j=1}^{n_j} W_{\mathfrak{L},j}}},$$

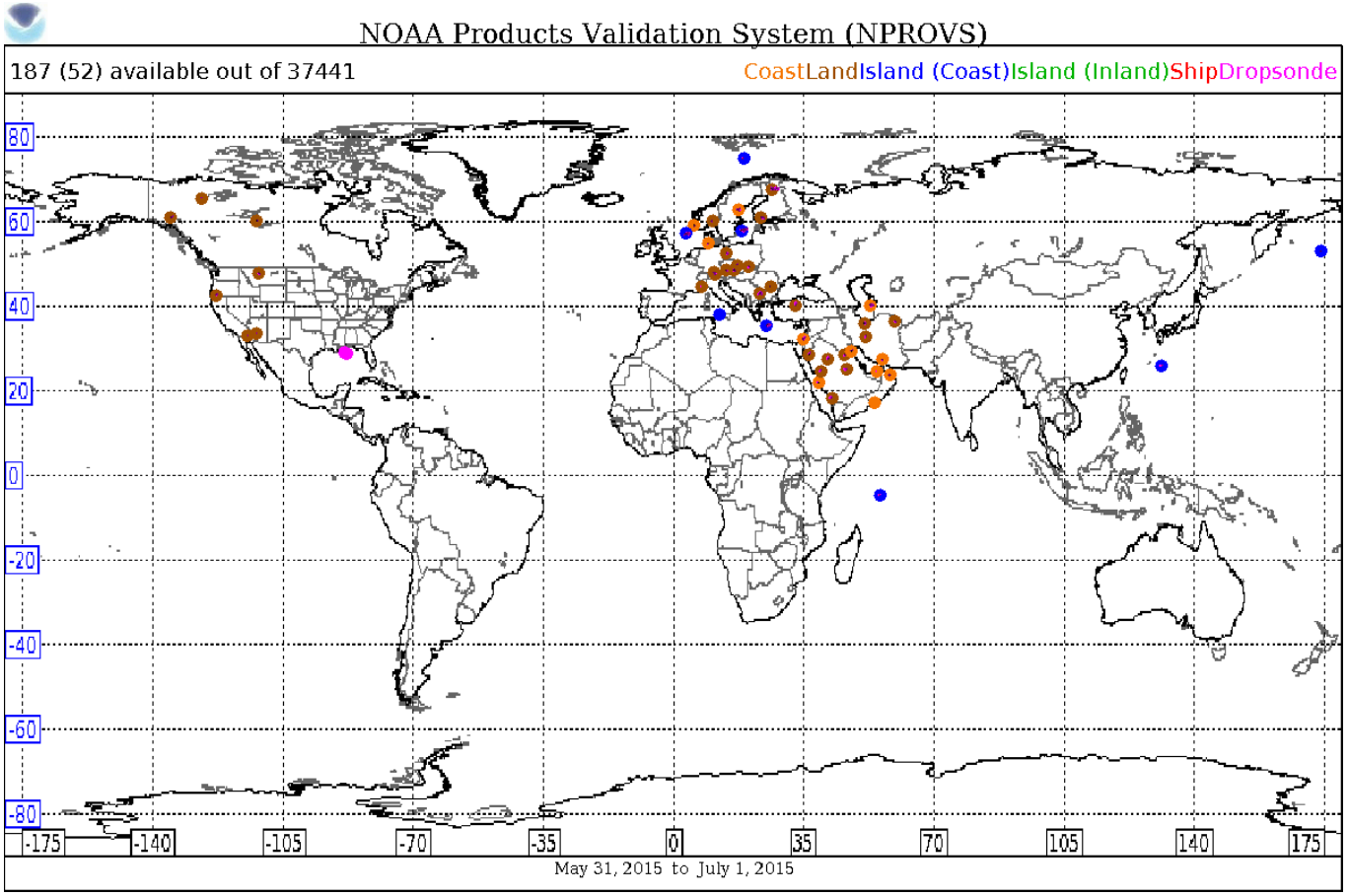
water vapor weighting factor, $W_{\mathfrak{L},j}$,

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

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

NPROVS Conventional RAOB Collocations

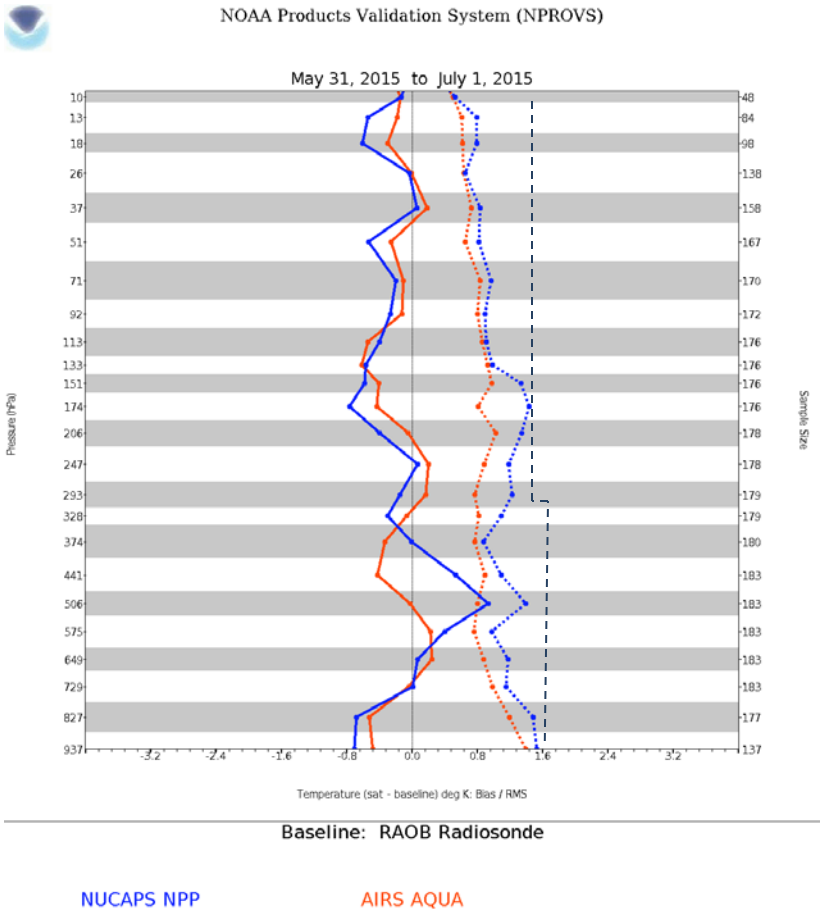
Single Closest FOR



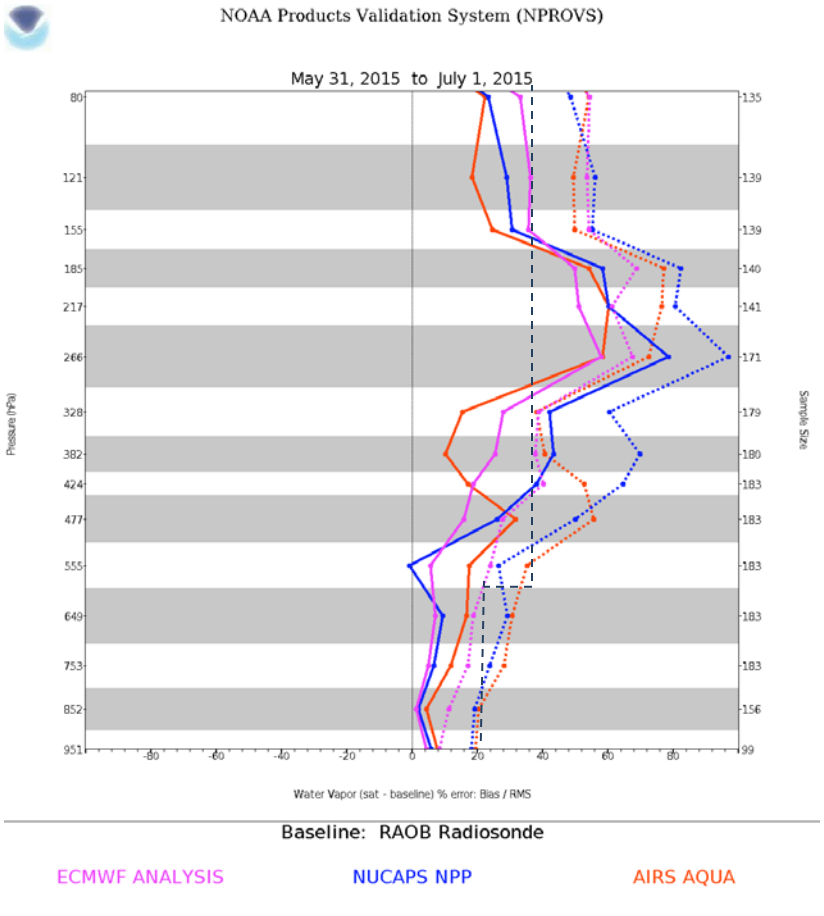
- June 2015
- **RS92 and RS41 sondes**
- Single-closest FOR
- **Space-time window [2]**
  - **–2 to +0.5 h before/after overpass**
  - **75 km**
- **Sample size [2]**
  ***N* = 187**

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

AVTP (BIAS and RMS)

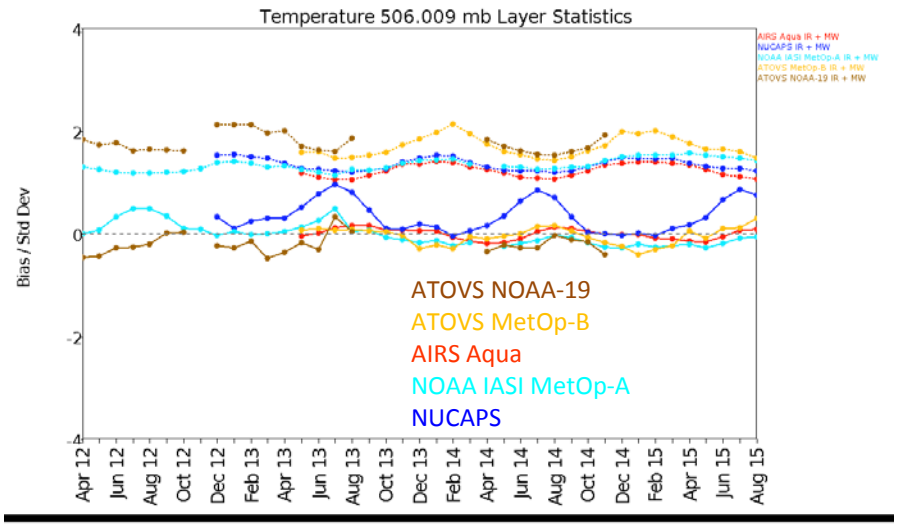


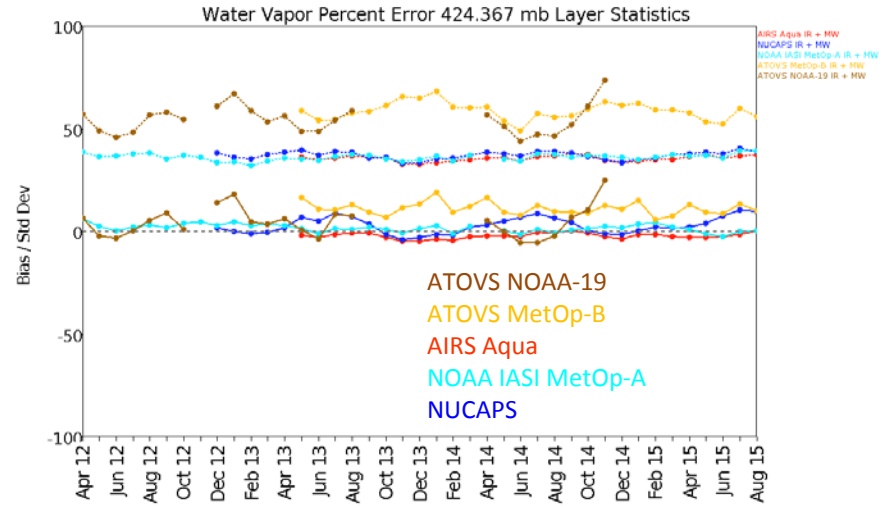
AVMP (BIAS and RMS)



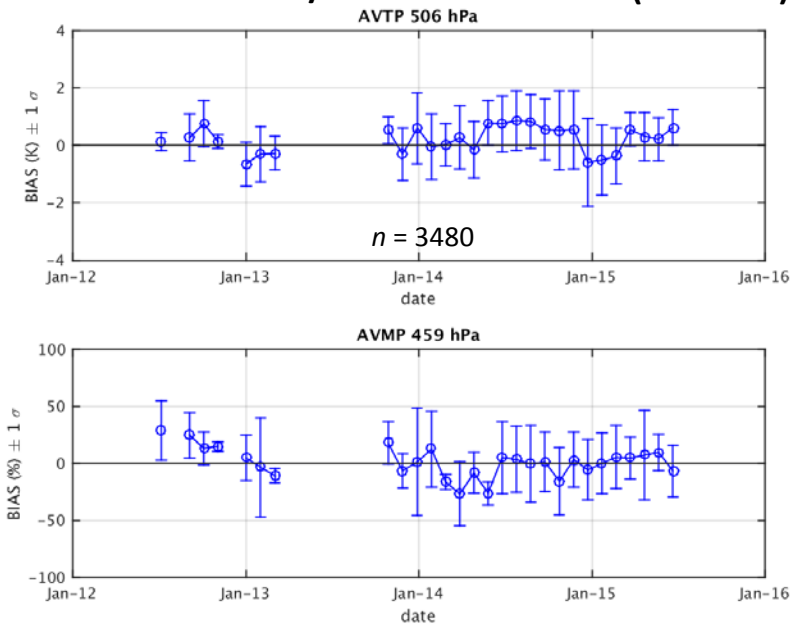
Long-Term Monitoring (LTM)

NPROVS NARCS Conventional RAOB Collocation (OPS-EDR)





VALAR Dedicated/GRUAN Collocation (OPS-EDR)



VALAR Ozonesonde Collocation (Offline v1.5)