NOAA Unique Combined Atmospheric Processing System (SNPP NUCAPS) Products and Validation

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  - **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)

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Outline

- **JPSS Sounder EDR Cal/Val Overview**
  - JPSS Level 1 Requirements
  - Validation Hierarchy
  - JPSS SNPP Validation Tools
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    - NOAA Products Validation System (NPROVS/NPROVS+)
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      - Nominal resolution CrIS
    - Experimental – v1.8.1
      - Full resolution CrIS
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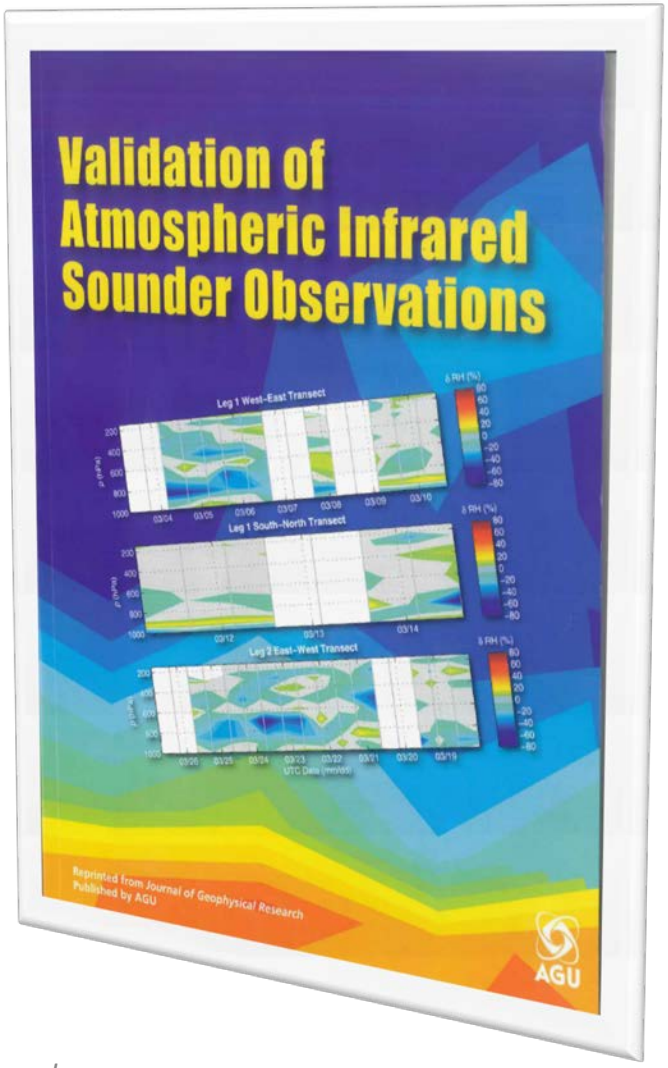
    - Global Focus Day
    - Dedicated/Reference RAOB ensemble
  - v1.8.1 (full-res CrIS)
    - Global Focus Day comparison
    - 2015 AEROSE campaign dedicated RAOB case
- **Summary and Future Work**
  - SNPP ICV and LTM

SNPP NUCAPS Products and Validation

JPSS SOUNDER EDR CAL/VAL OVERVIEW

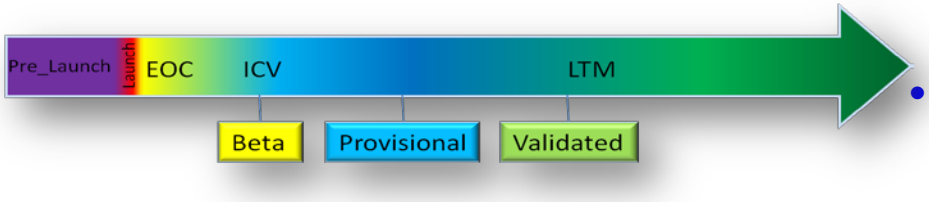
Sounder EDR Validation

- **Validation** is "the process of ascribing uncertainties to… radiances and retrieved quantities through comparison with correlative observations" (*Fetzer et al.,* 2003).
  - EDR validation supports monitoring of SDRs and cloud-cleared radiances
  - 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)
- **EDR validation methodology** based upon 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; the revised draft v1.1 was submitted on 31 December 2015

JPSS Specification Performance Requirements
CrIS/ATMS AVTP/AVMP EDR Uncertainty

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

"Clear to Partly-Cloudy"
(Cloud Fraction < 50%)
↕
IR retrieval

"Cloudy"
(Cloud Fraction >= 50%)
↕
MW-only retrieval

CrIS/ATMS Atmospheric Vertical Moisture Profile (AVMP) Measurement Uncertainty – 2-km Layer Average Mixing Ratio % Error		
PARAMETER	**THRESHOLD**	**OBJECTIVE**
AVMP, Cloud fraction < 50%, surface to 600 hPa	Greater of 20% or 0.2 $g \cdot kg^{-1}$ / 2-km layer	10%
AVMP, Cloud fraction < 50%, 600–300 hPa	Greater of 35% or 0.1 $g \cdot kg^{-1}$ / 2-km layer	10%
AVMP, Cloud fraction < 50%, 300–100 hPa	Greater of 35% or 0.1 $g \cdot kg^{-1}$ / 2-km layer	10%
AVMP, Cloud fraction ≥ 50%, surface to 600 hPa	Greater of 20% of 0.2 $g \cdot kg^{-1}$ / 2-km layer	10%
AVMP, Cloud fraction ≥ 50%, 600–400 hPa	Greater of 40% or 0.1 $g \cdot kg^{-1}$ / 2-km layer	10%
AVMP, Cloud fraction ≥ 50%, 400–100 hPa	Greater of 40% or 0.1 $g \cdot kg^{-1}$ / 2-km layer	NS

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

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

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

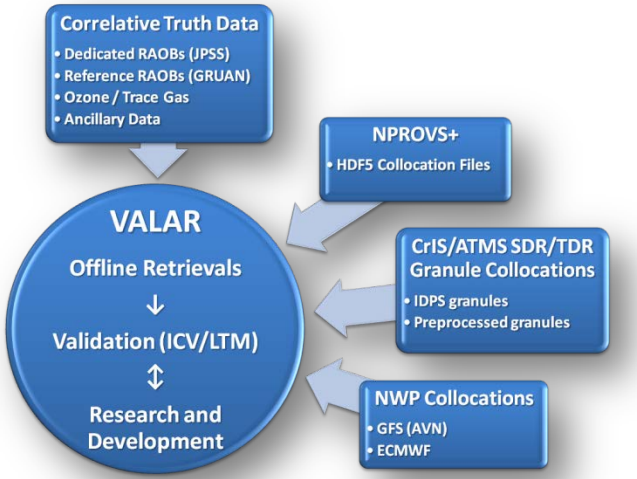
5. **Intensive Field Campaign *Dissections***
   - Include dedicated RAOBs, some *not* assimilated into NWP models
   - Include ancillary datasets (e.g., ozonesondes, lidar, M-AERI, MWR, sunphotometer, etc.)
   - Ideally include funded aircraft campaign using IR sounder (e.g., NAST-I, S-HIS)
   - Detailed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

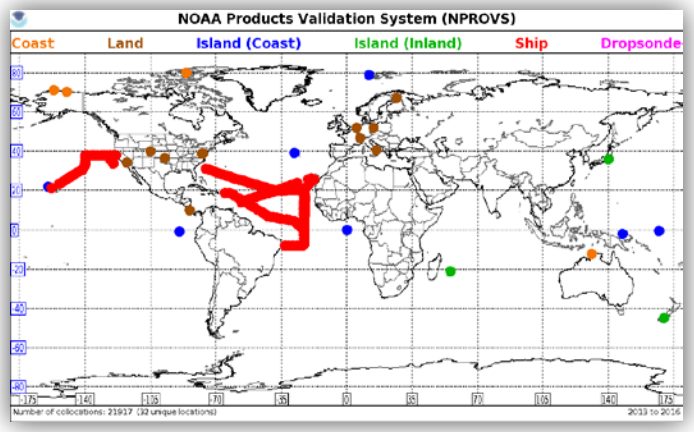
JPSS SNPP Validation Tools

- **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)

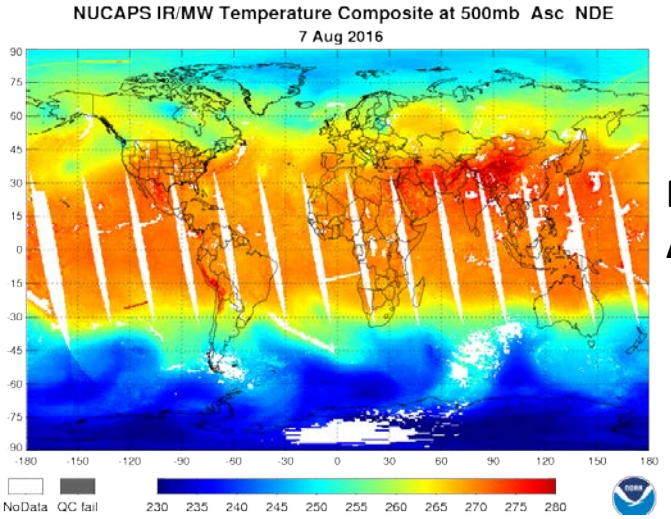
VALAR Concept and Objectives



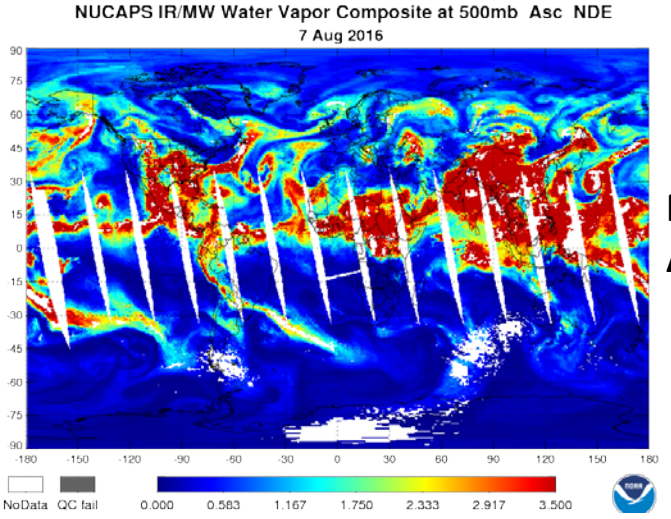


NOAA Unique Combined Atmospheric Processing System (NUCAPS) Algorithm (1/2)

- **Operational algorithm**
  - Unified Sounder Science Team (AIRS/IASI/CrIS) retrieval algorithm (*Susskind, Barnet and Blaisdell,* IEEE 2003; *Gambacorta et al.,* 2014)
  - Global non-precipitating conditions
  - Atmospheric Vertical Temperature , Moisture Profiles (**AVTP**, **AVMP**)
  - Trace gases (**O_3, CO, CO_2, CH_4**)
    - See presentation in **Session 11 Trace Gases** on Thursday
  - Validated Maturity for AVTP/AVMP, Sep 2014
- **Users**
  - **Weather Forecast Offices (AWIPS)**
    - Nowcasting / severe weather
    - Alaska (cold core)
  - NOAA/CPC (OLR)
  - NOAA/ARL (IR ozone, trace gases)
  - TOAST (IR ozone)
  - Basic and applied science research (e.g., *Pagano et al.,* 2014)
    - Via NOAA Data Centers (e.g., CLASS)
    - Universities, peer-reviewed pubs



NUCAPS AVTP



NUCAPS AVMP

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

NOAA Unique Combined Atmospheric Processing System (NUCAPS) Algorithm (2/2)

- **NUCAPS Offline Code Versioning**
  - **Version 1.5**
    - **Current operational system**
    - Runs on **nominal CrIS spectral resolution** data
  - **Version 1.8.1**
    - **Offline experimental** algorithm
    - Runs on **CrIS full spectral resolution** data
    - Uses conventional regression algorithm for the IR/MW first guess (as opposed to MW retrieval as in v1.7 full-res)
    - Upgrades
      - Updated IR radiative transfer algorithm (RTA) bias correction coefficients (based on the best combination resulted after testing the use of several atmospheric states and trace gaseous profiles)
      - IR emissivity threshold decreased from 1.05 to 1.0 in the `temp_cris.nl` namelist.
      - Replaced the Taylor expansion to the Exponential formula in the `fasttau_co2.F` program.
      - Updated MW bias correction (as in v1.6)
      - Updated MW RTA model error coefficients (as in v1.6)
      - Removal of MW channel 16 (as in v1.6)

SNPP NUCAPS Products and Validation

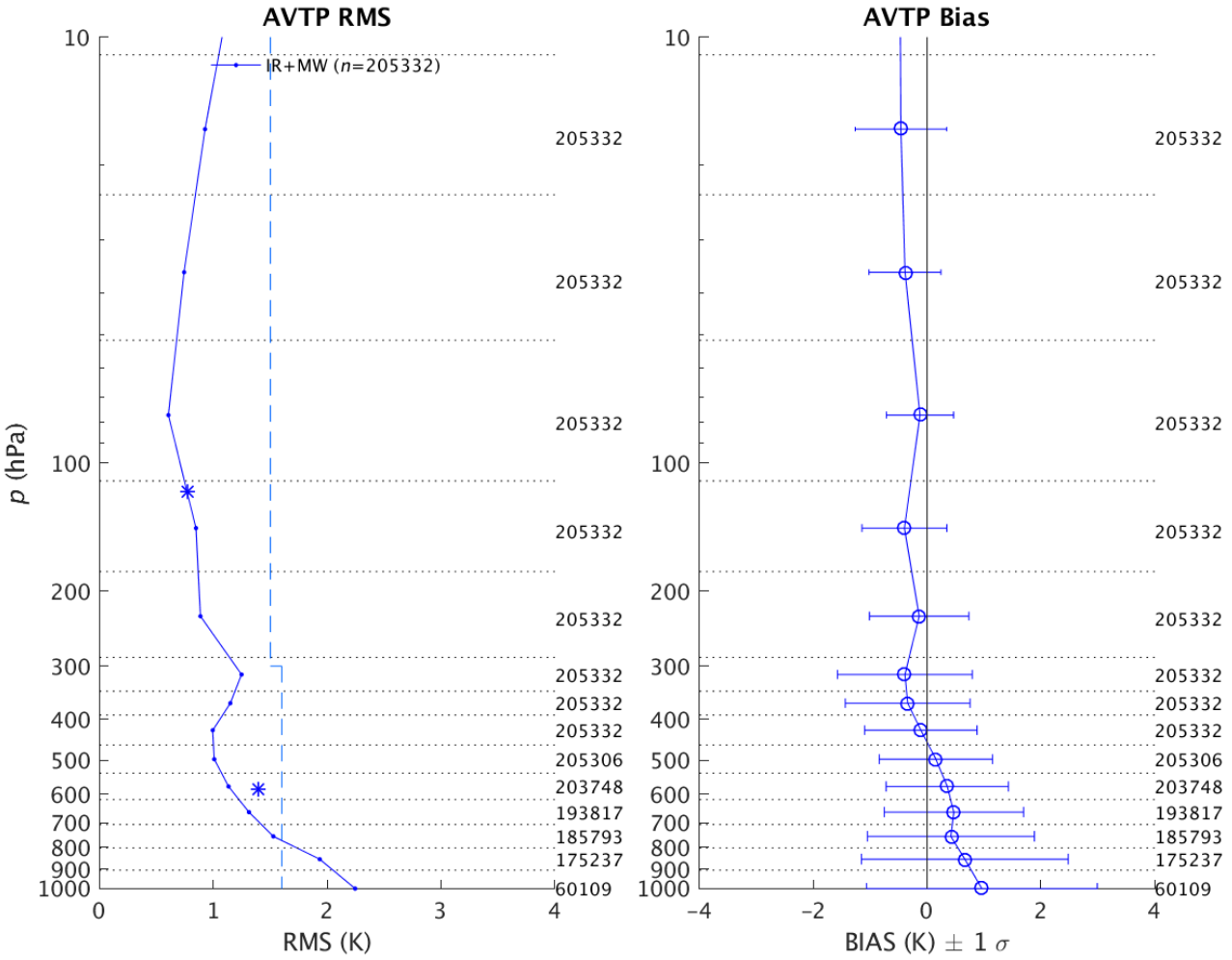
NUCAPS EDR EVALUATION: V1.5, NOMINAL CRIS RESOLUTION

NUCAPS Offline (v1.5) AVTP Coarse-Layer Statistics (1/2)
Global Focus Day 17-Feb-2015

AVTP Versus ECMWF

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

IR+MW Yield = 63.4%

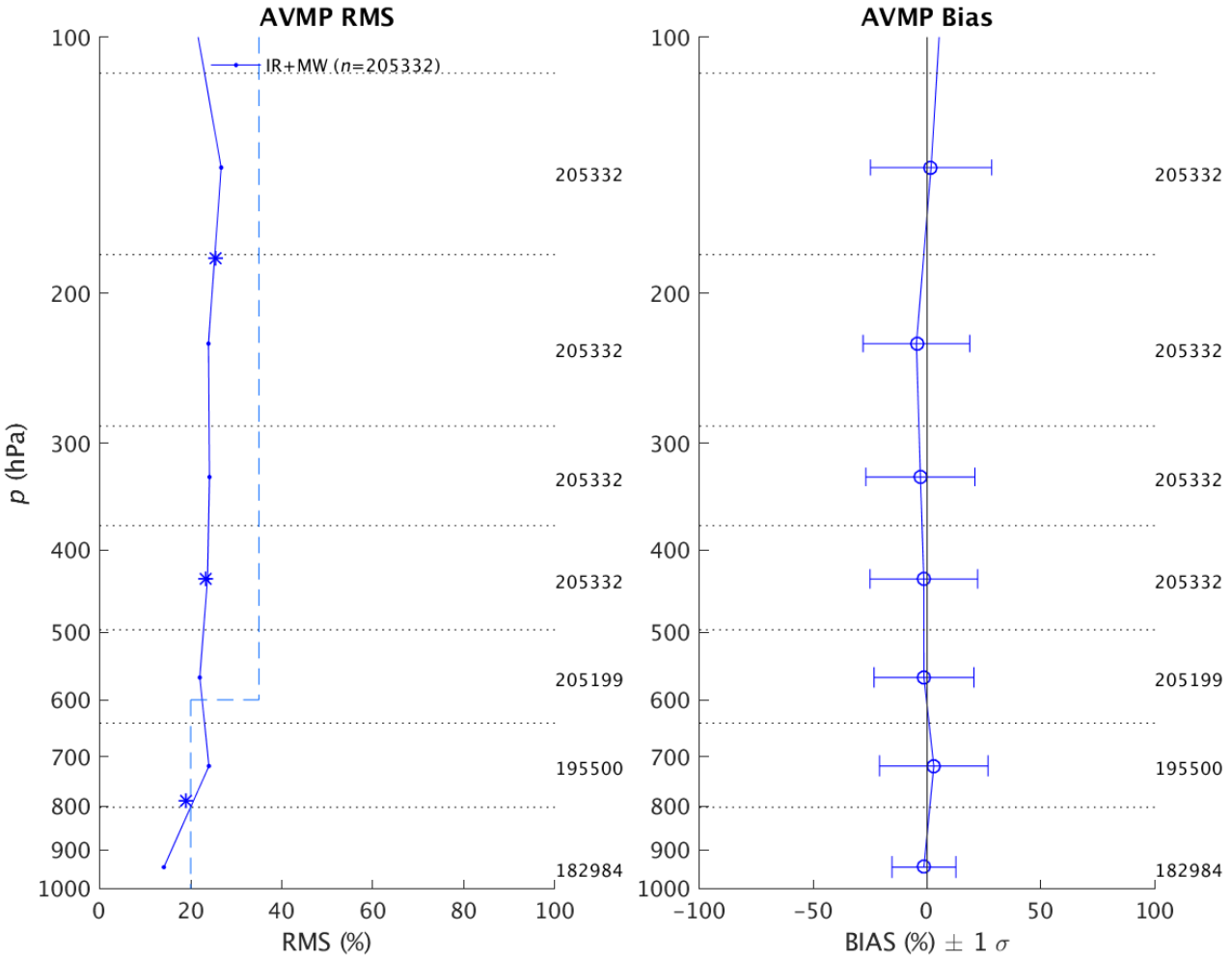


NUCAPS Offline (v1.5) AVMP Coarse-Layer Statistics (2/2)
Global Focus Day 17-Feb-2015

AVMP Versus ECMWF

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

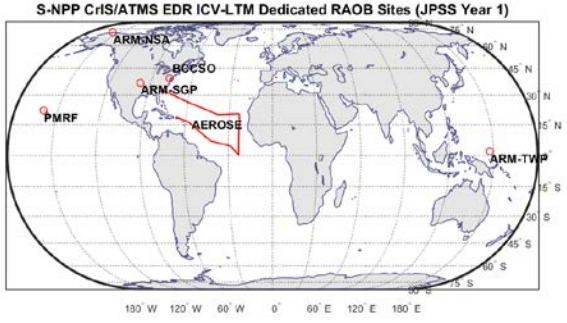
IR+MW Yield = 63.4%



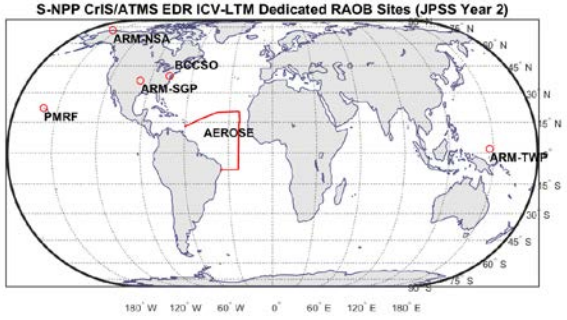
JPSS SNPP Dedicated and Reference RAOBs

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

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

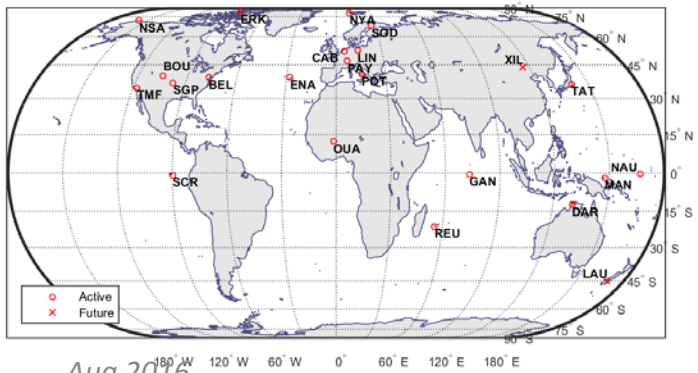


S-NPP CrIS/ATMS EDR ICV-LTM Dedicated RAOB Sites (JPSS Year 2)



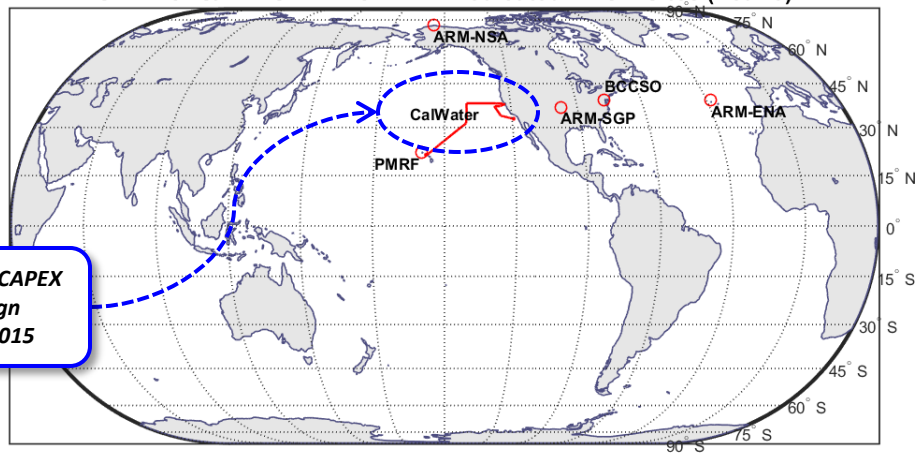
GRUAN Reference Sites

GRUAN RAOB Sites for Sounder EDR ICV-LTM



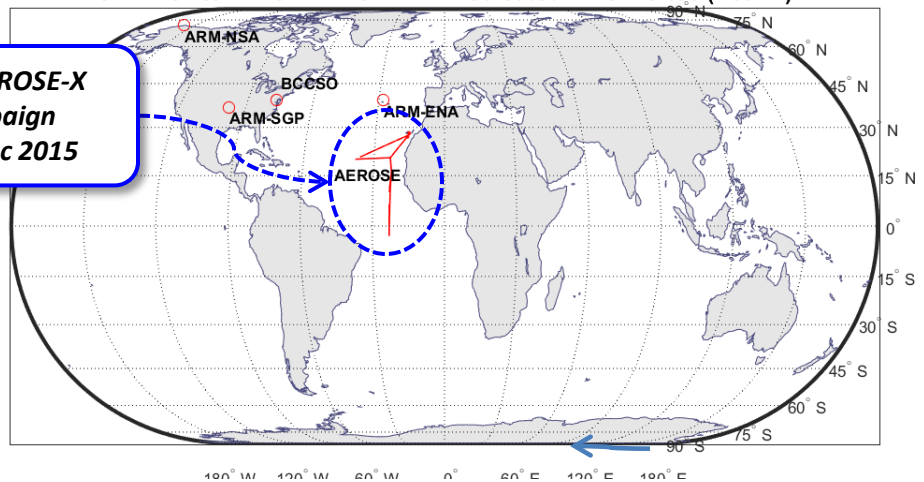
JPSS SNPP Dedicated Years 3–4 (2014-2016)

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



CalWater/ACAPEX Campaign Jan-Feb 2015

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

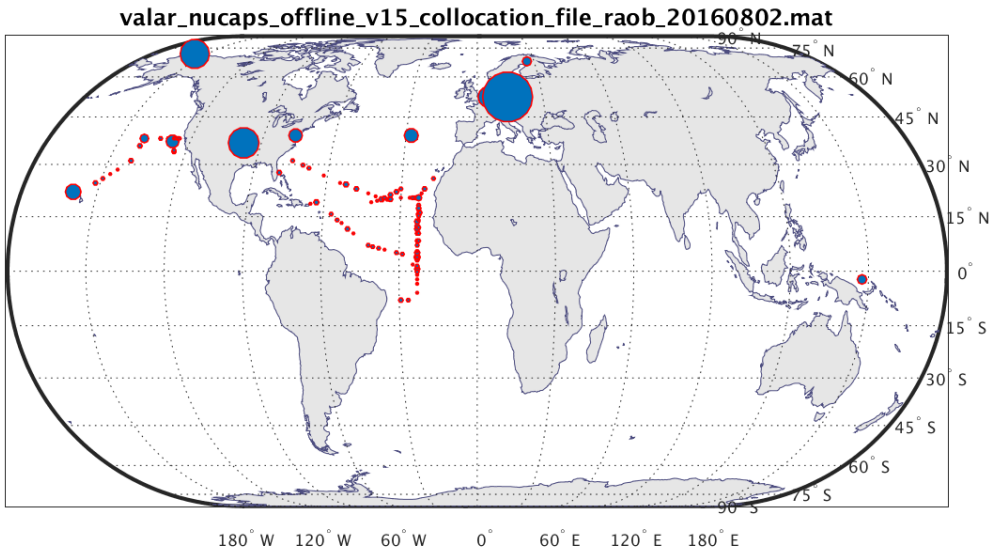


PNE/AEROSE-X Campaign Nov-Dec 2015

VALAR/NPROVS+ Dedicated/Reference RAOB-FOR Collocation Sample

VALAR Geographic Histogram

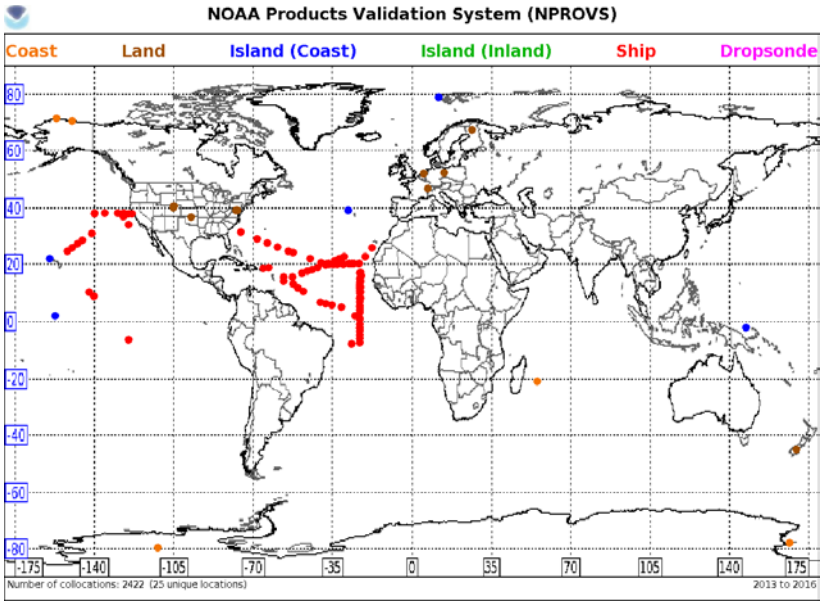
FOR Collocation Criteria: $\delta x \leq 50$ km, $-75 < \delta t < 0$ min



VALAR map projection is equal-area.

NPROVS+ Collocation Map

FOR Collocation Criteria: Single Closest, $-75 < \delta t < 0$ min



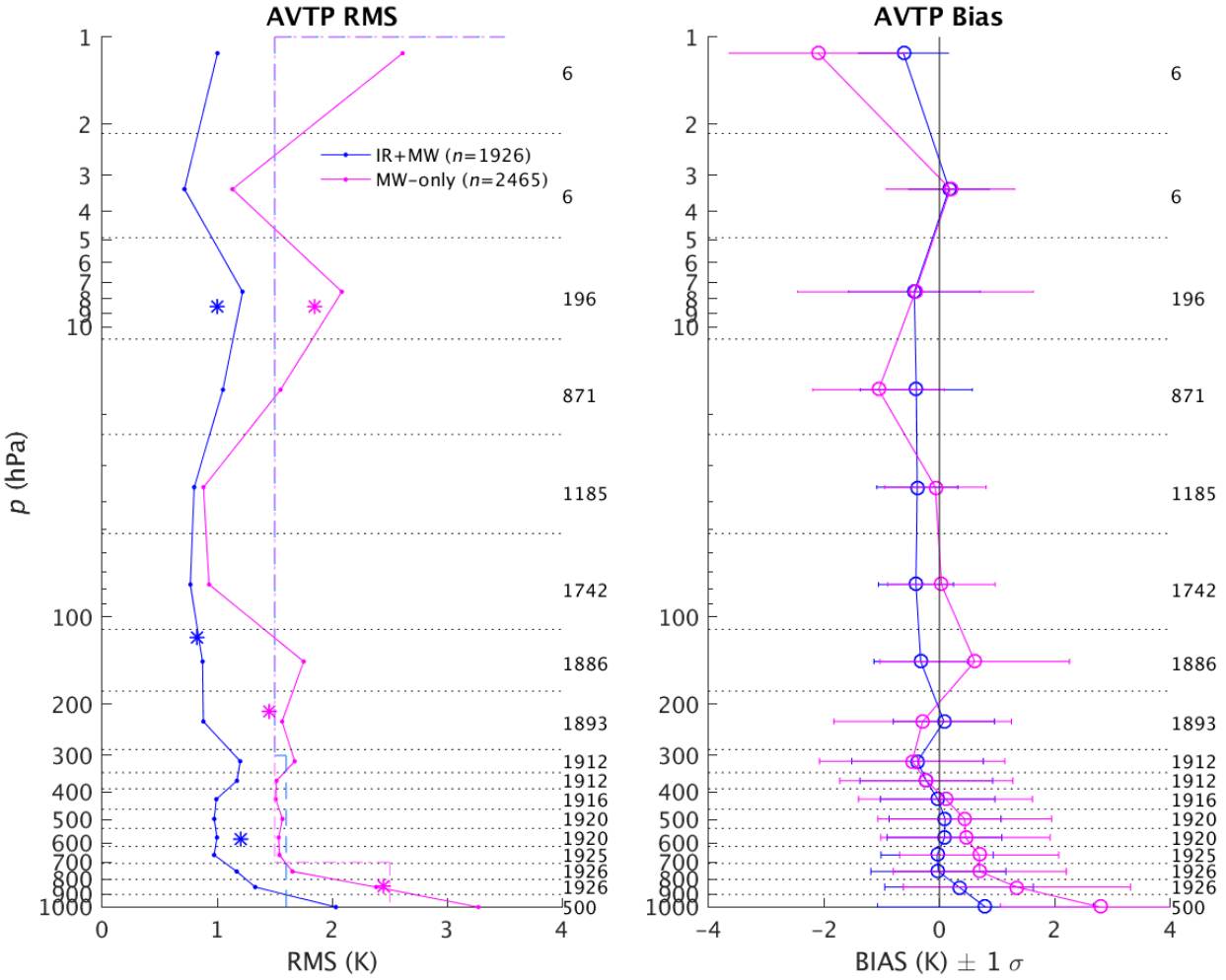
NUCAPS Offline (v1.5) AVTP Coarse-Layer Statistics
VALAR Dedicated/Reference RAOB Collocation Sample

AVTP Versus RAOB

** **Broad-Layer Stats (Per JPSS Level 1 Requirements)**

IR+MW
MW-Only

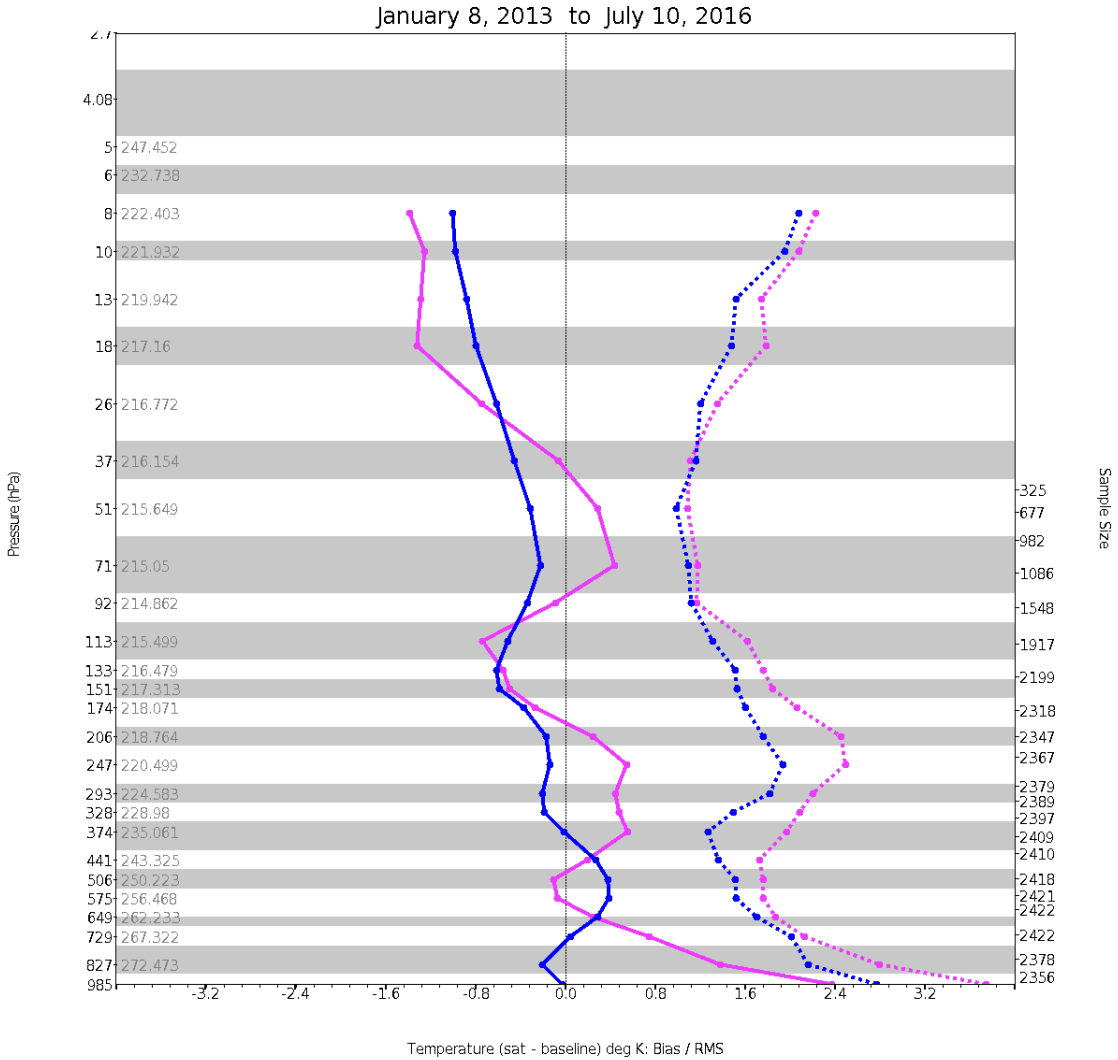
IR+MW Yield = 63.3%



NUCAPS Operational AVTP Coarse-Layer Statistics
NPROVS+ Dedicated/Reference RAOB Collocation Sample

AVTP Versus RAOB

IR+MW
MW-Only



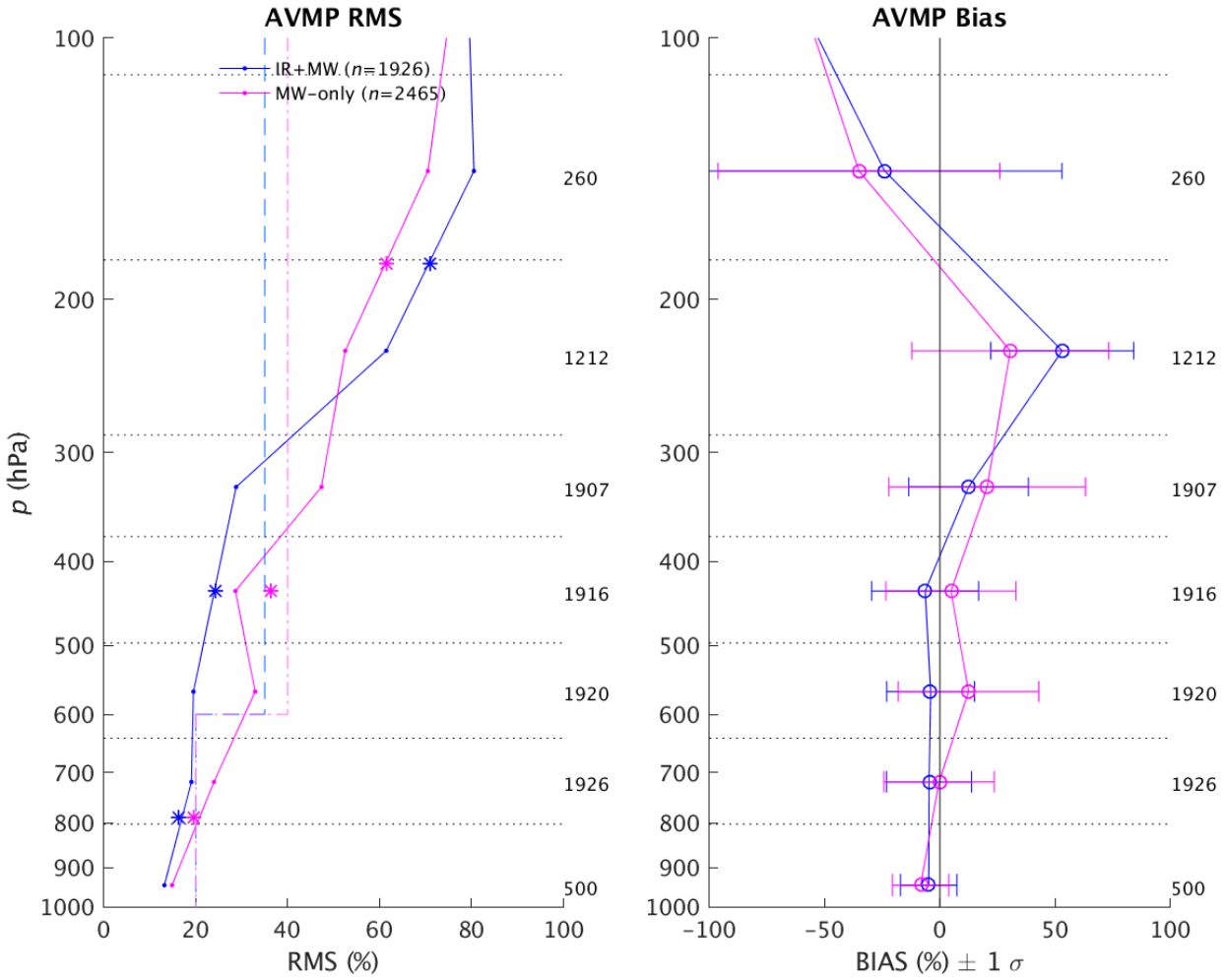
NUCAPS Offline (v1.5) AVMP Coarse-Layer Statistics
VALAR Dedicated/Reference RAOB Collocation Sample

AVMP Versus RAOB

** Broad Layer Stats (Per JPSS Level 1 Requirements)

IR+MW
MW-Only

IR+MW Yield = 63.3%

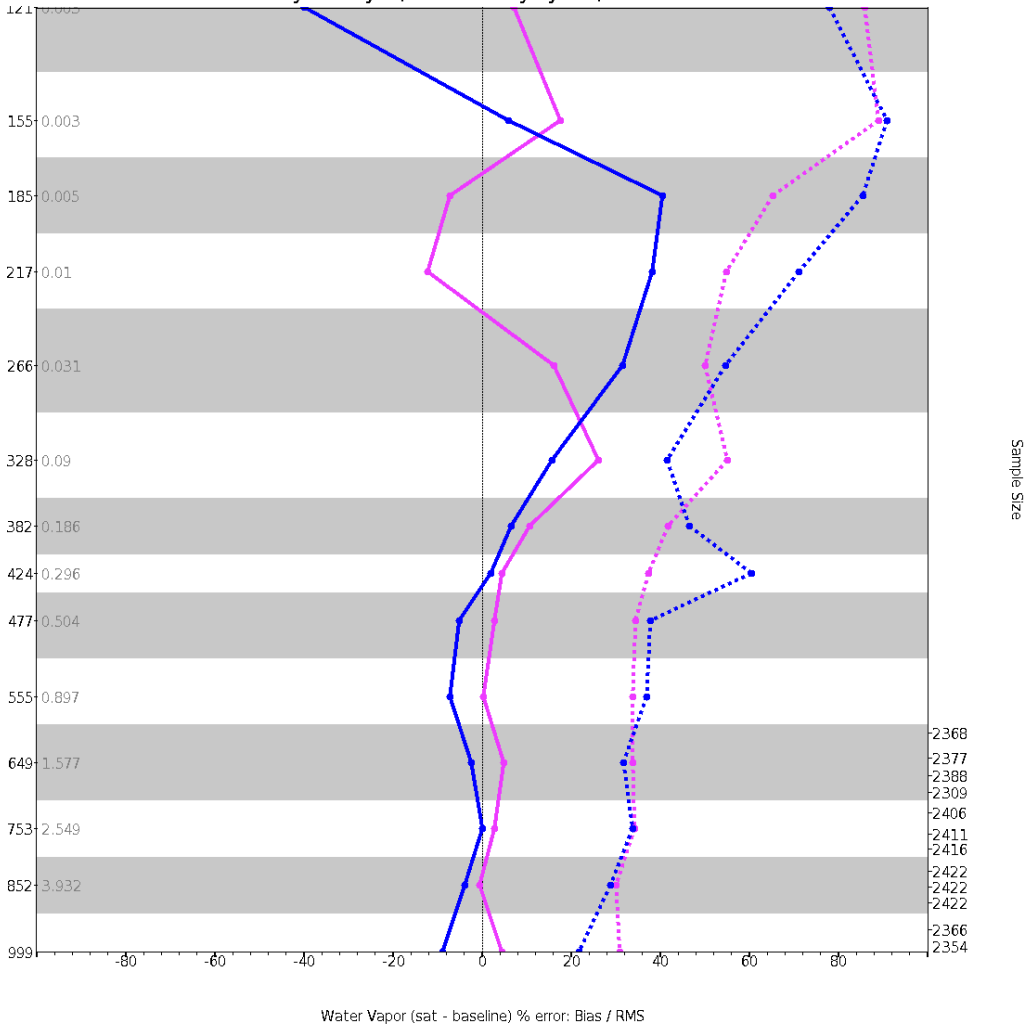


NUCAPS Operational AVMP Coarse-Layer Statistics
NPROVS+ Dedicated/Reference RAOB Collocation Sample

AVMP Versus RAOB

January 8, 2013 to July 10, 2016

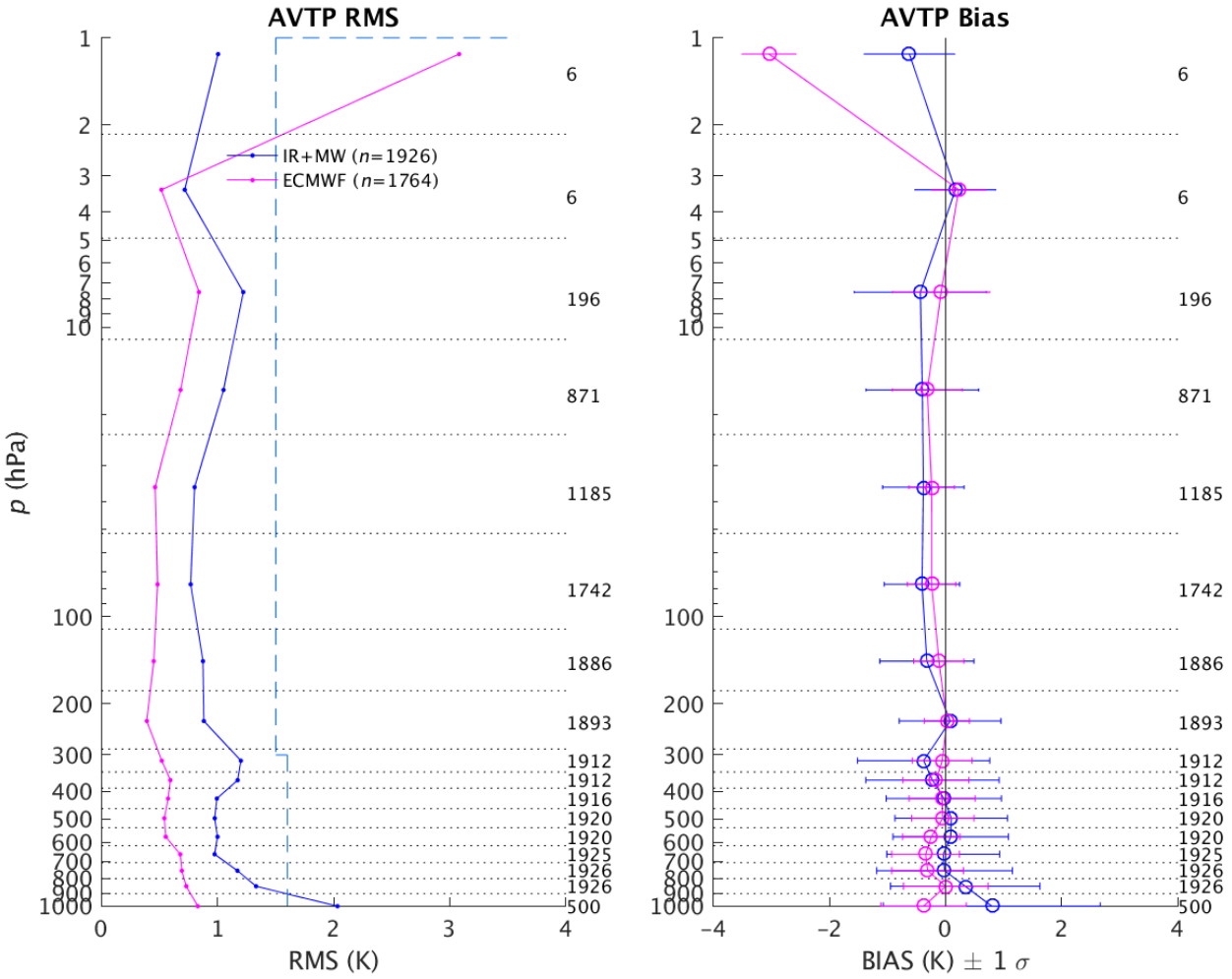
IR+MW
MW-Only



NUCAPS Offline (v1.5) AVTP and ECMWF Coarse-Layer Statistics
VALAR Dedicated/Reference RAOB Collocation Sample

IR+MW AVTP and ECMWF Versus RAOB

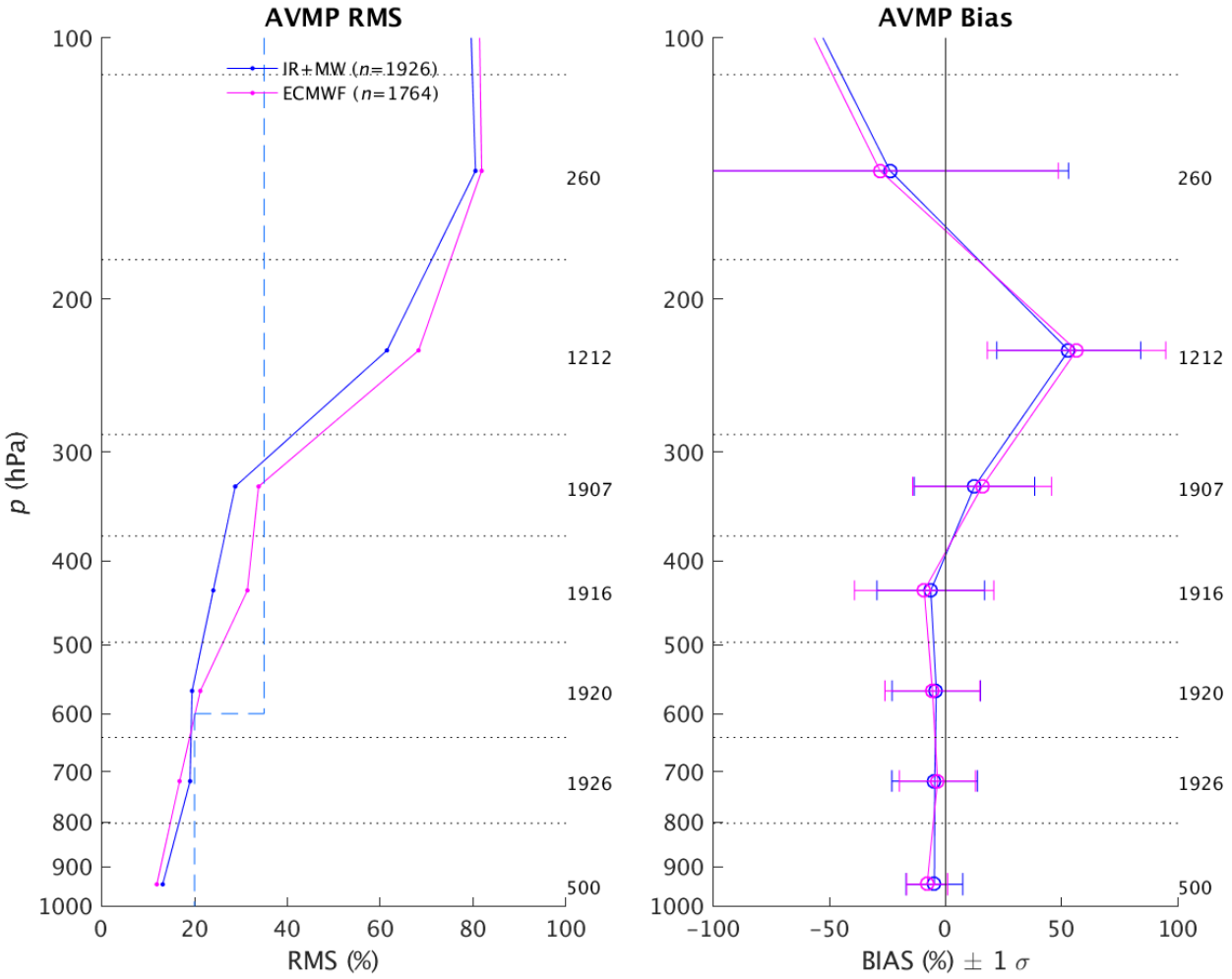
IR+MW Yield = 63.3%



NUCAPS Offline (v1.5) AVMP and ECMWF Coarse-Layer Statistics
VALAR Dedicated/Reference RAOB Collocation Sample

IR+MW AVMP and ECMWF Versus RAOB

IR+MW Yield = 63.3%



SNPP NUCAPS Products and Validation

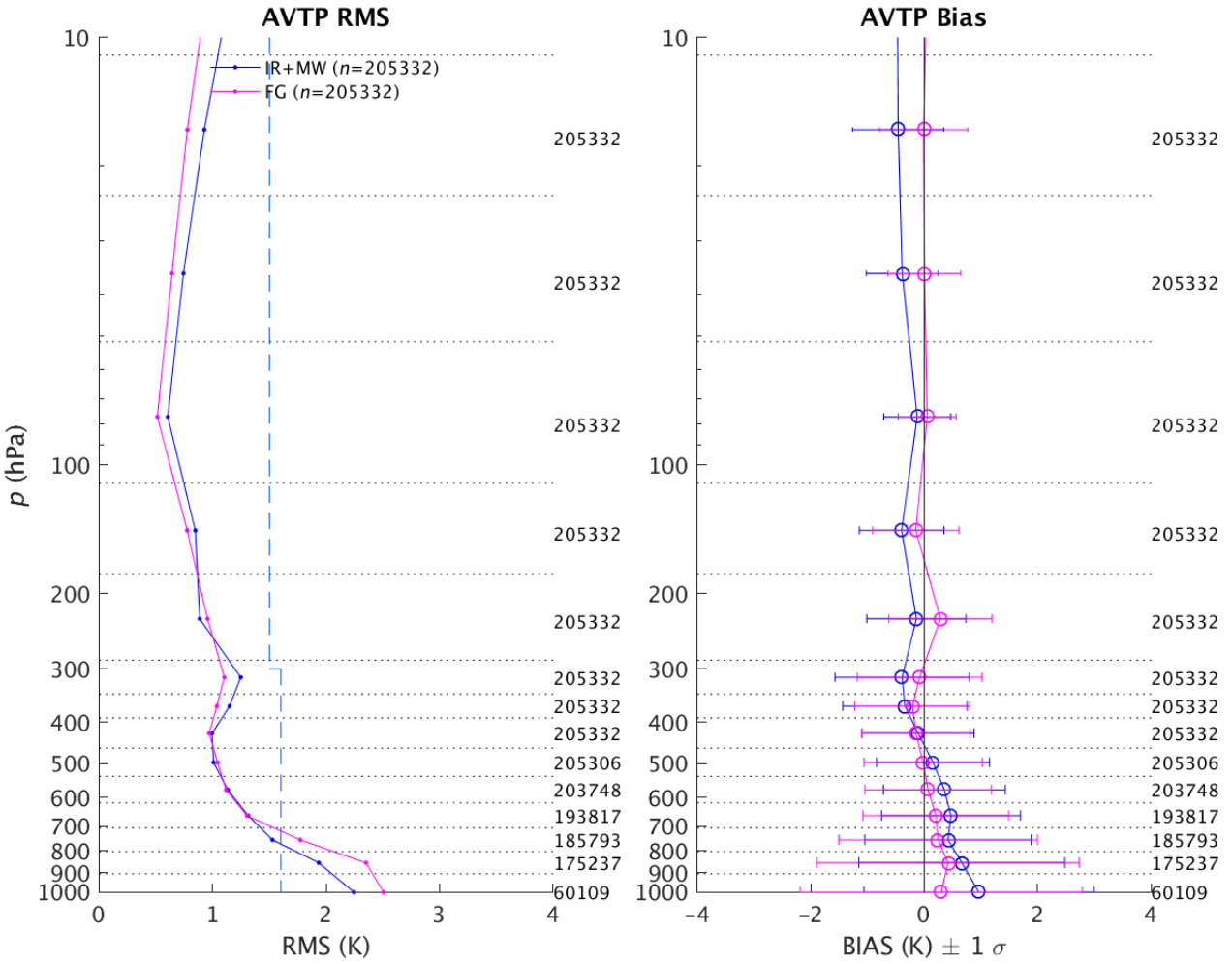
NUCAPS EDR EVALUATION: V1.8.1, FULL RESOLUTION CRIS

NUCAPS Offline (v1.5) AVTP Coarse-Layer Statistics
Global Focus Day 17-Feb-2015

AVTP Versus ECMWF

IR+MW
First Guess

NUCAPS v1.5
Yield = 63.4%

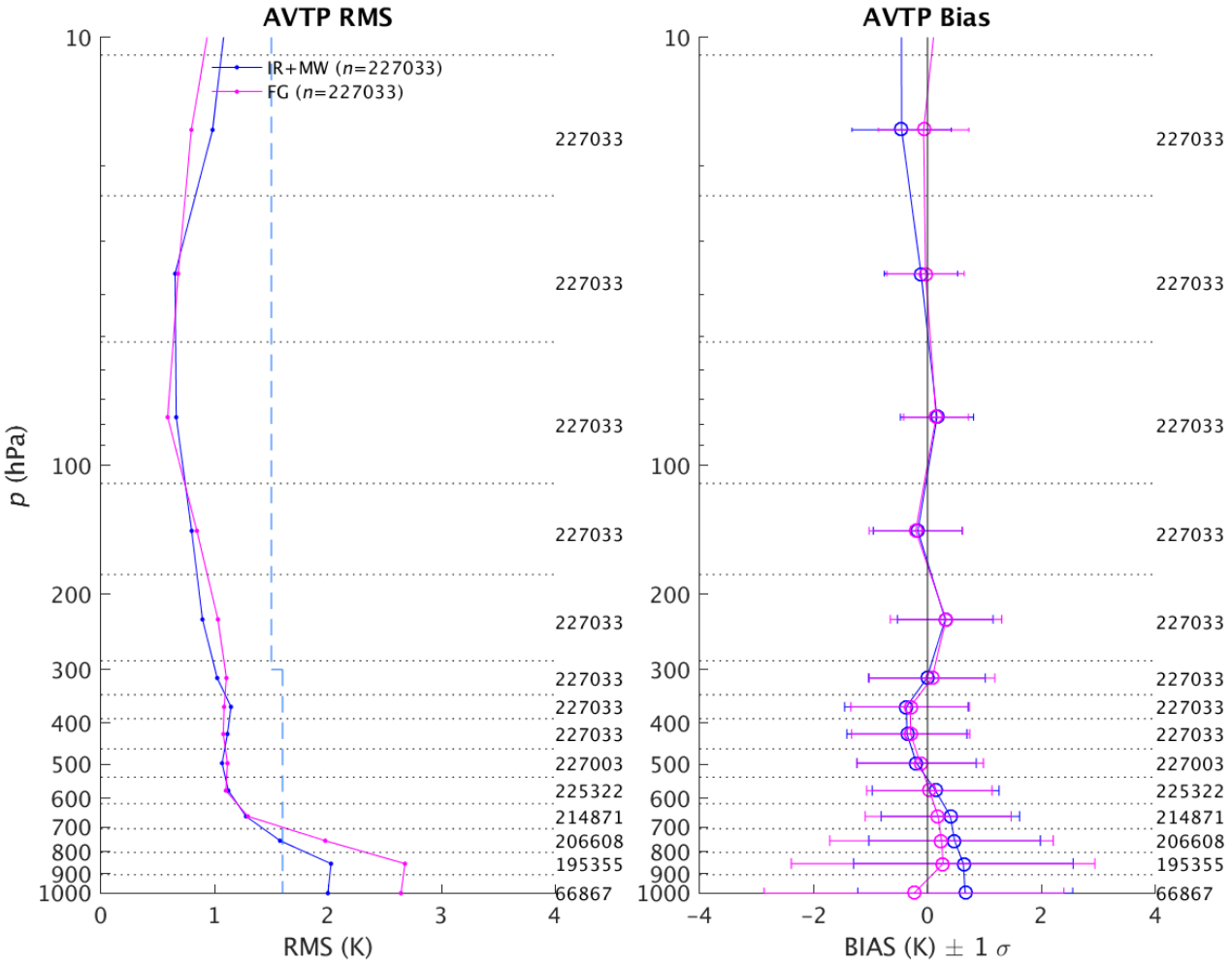


NUCAPS Offline (v1.8.1) AVTP Coarse-Layer Statistics Global Focus Day 17-Feb-2015

AVTP Versus ECMWF

IR+MW
First Guess

NUCAPS v1.8.1
Yield = 70.1%

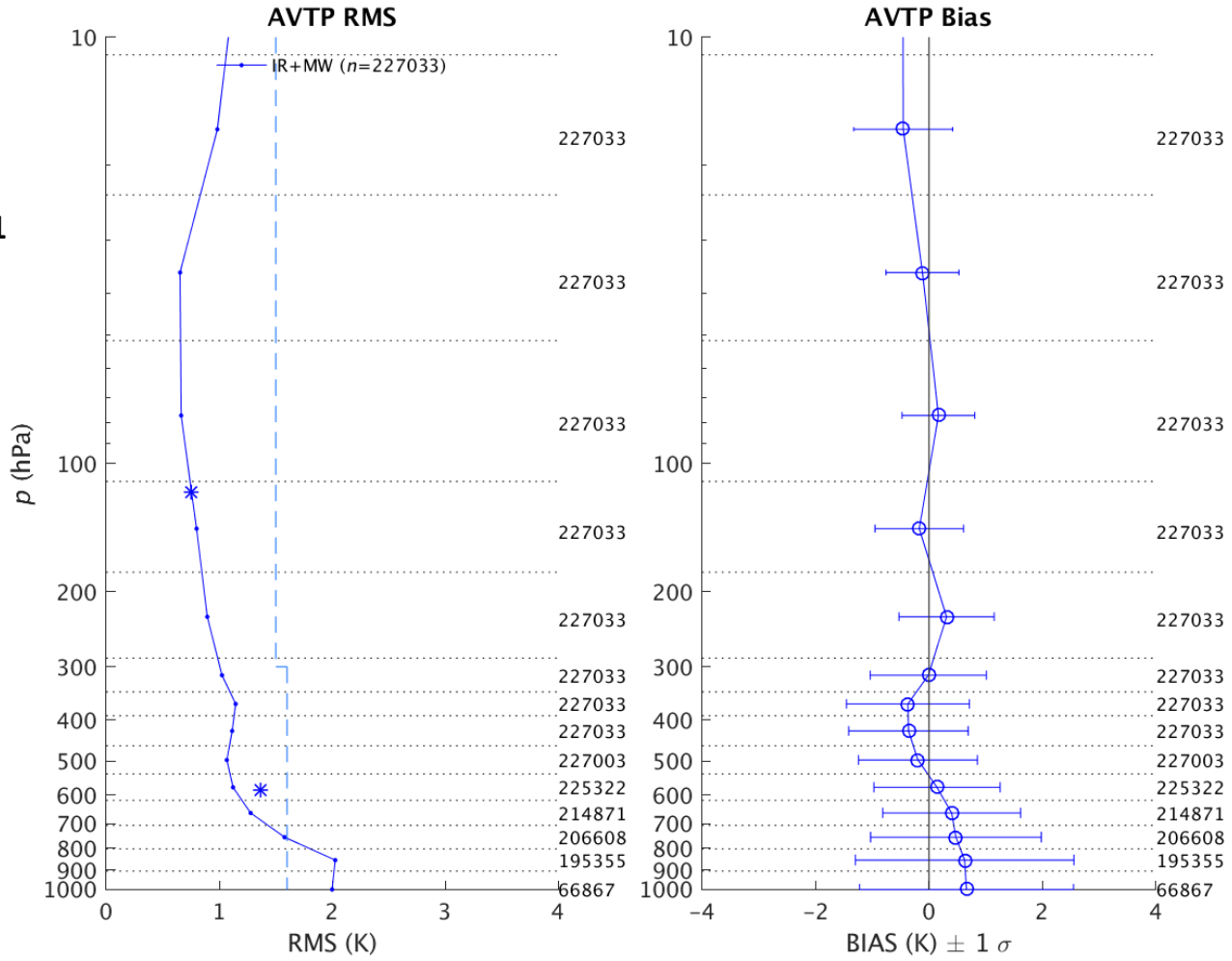


NUCAPS Offline (v1.8.1) AVTP Coarse-Layer Statistics Global Focus Day 17-Feb-2015

AVTP Versus ECMWF

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

NUCAPS v1.8.1
Yield = 70.1%

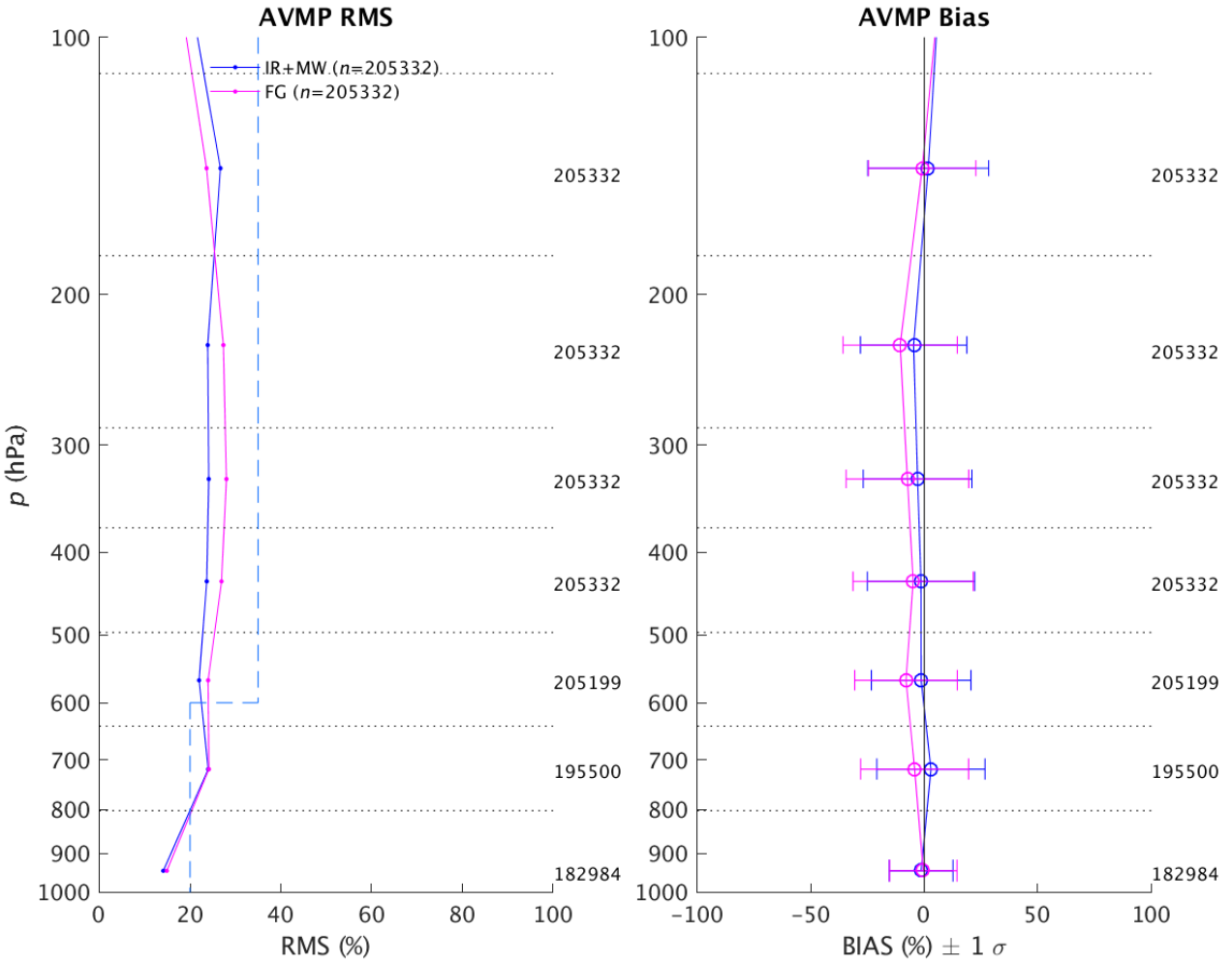


NUCAPS Offline (v1.5) AVMP Coarse-Layer Statistics
Global Focus Day 17-Feb-2015

AVMP Versus ECMWF

IR+MW
First Guess

NUCAPS v1.5
Yield = 63.4%

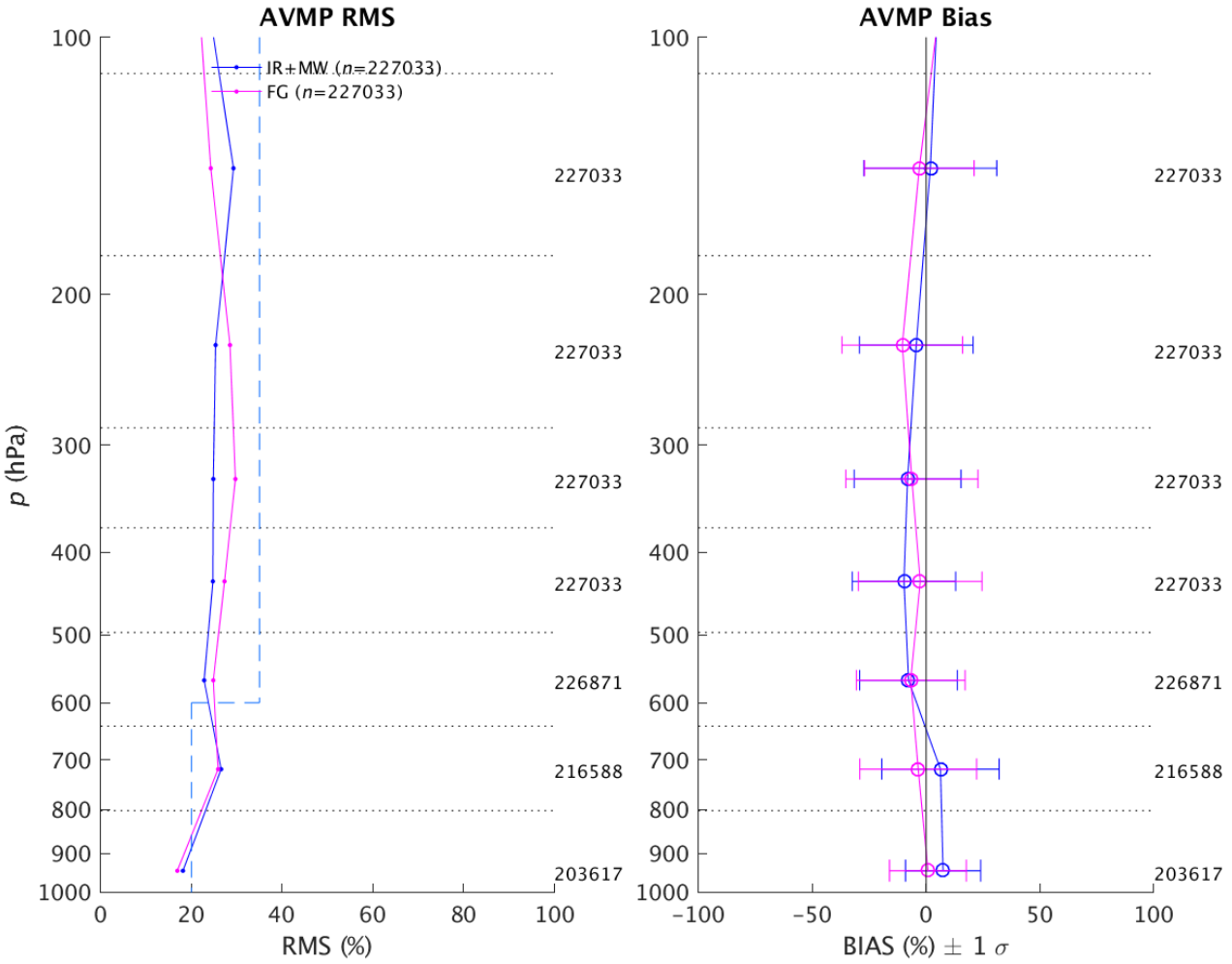


NUCAPS Offline (v1.8.1) AVMP Coarse-Layer Statistics Global Focus Day 17-Feb-2015

AVMP Versus ECMWF

IR+MW
First Guess

NUCAPS v1.8.1
Yield = 70.1%

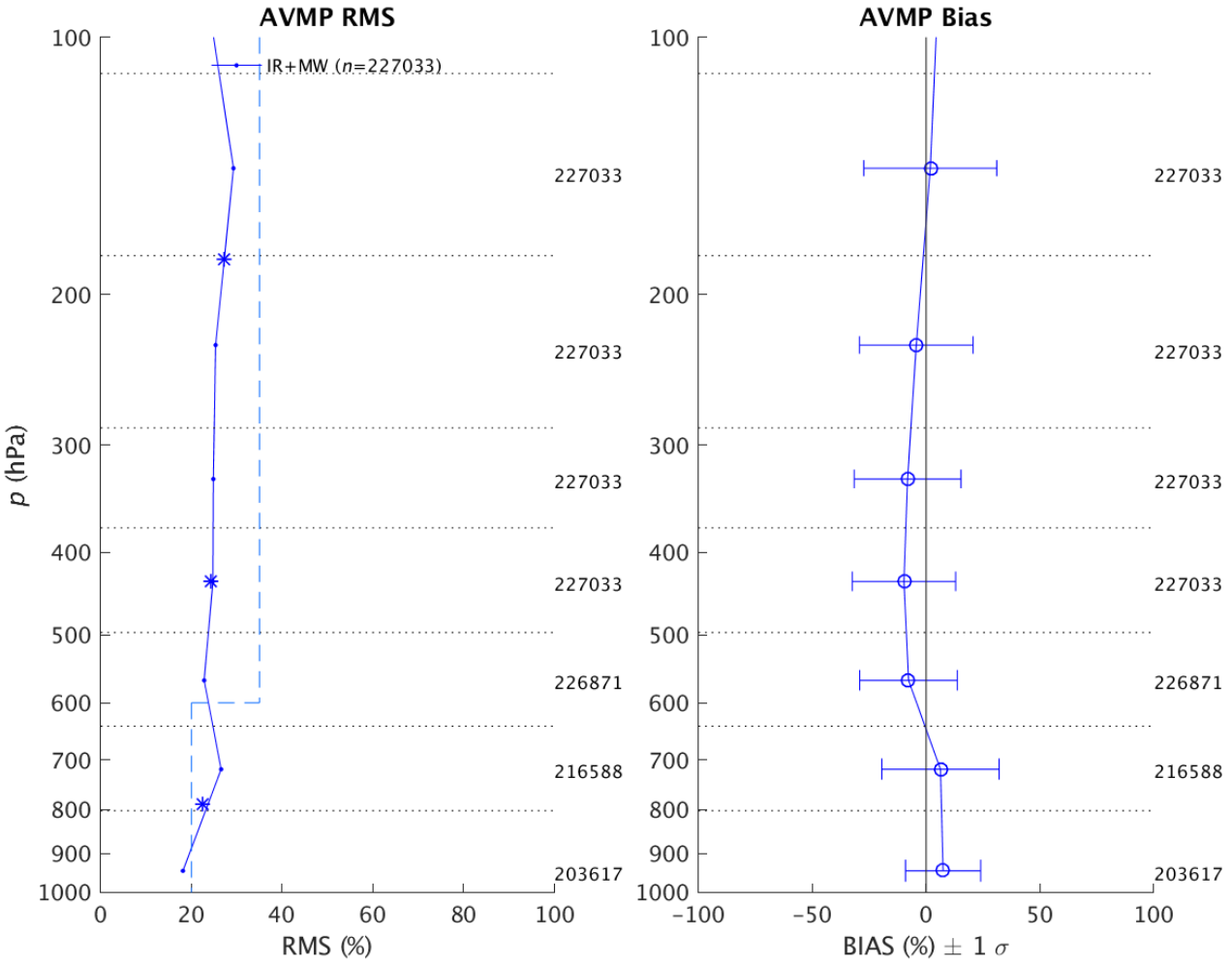


NUCAPS Offline (v1.8.1) AVMP Coarse-Layer Statistics Global Focus Day 17-Feb-2015

AVMP Versus ECMWF

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

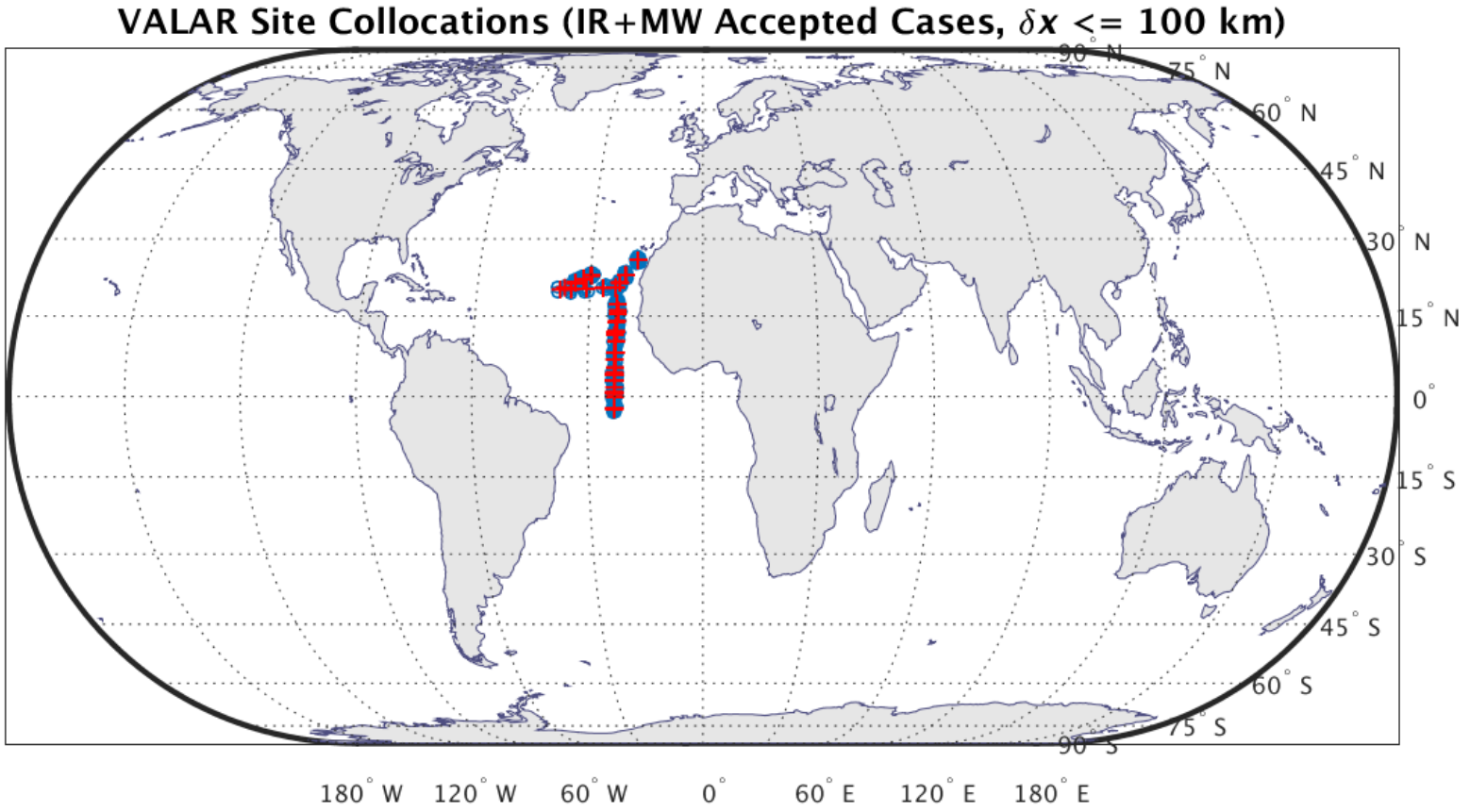
NUCAPS v1.8.1
Yield = 70.1%



NUCAPS v1.8.1 versus v1.5
Nov-Dec 2015 AEROSE Campaign (JPSS Year-4)

VALAR Collocation Map – AEROSE 2015

FOR Collocation Criteria: $\delta x \leq 100$ km, $-75 < \delta t < 0$ min

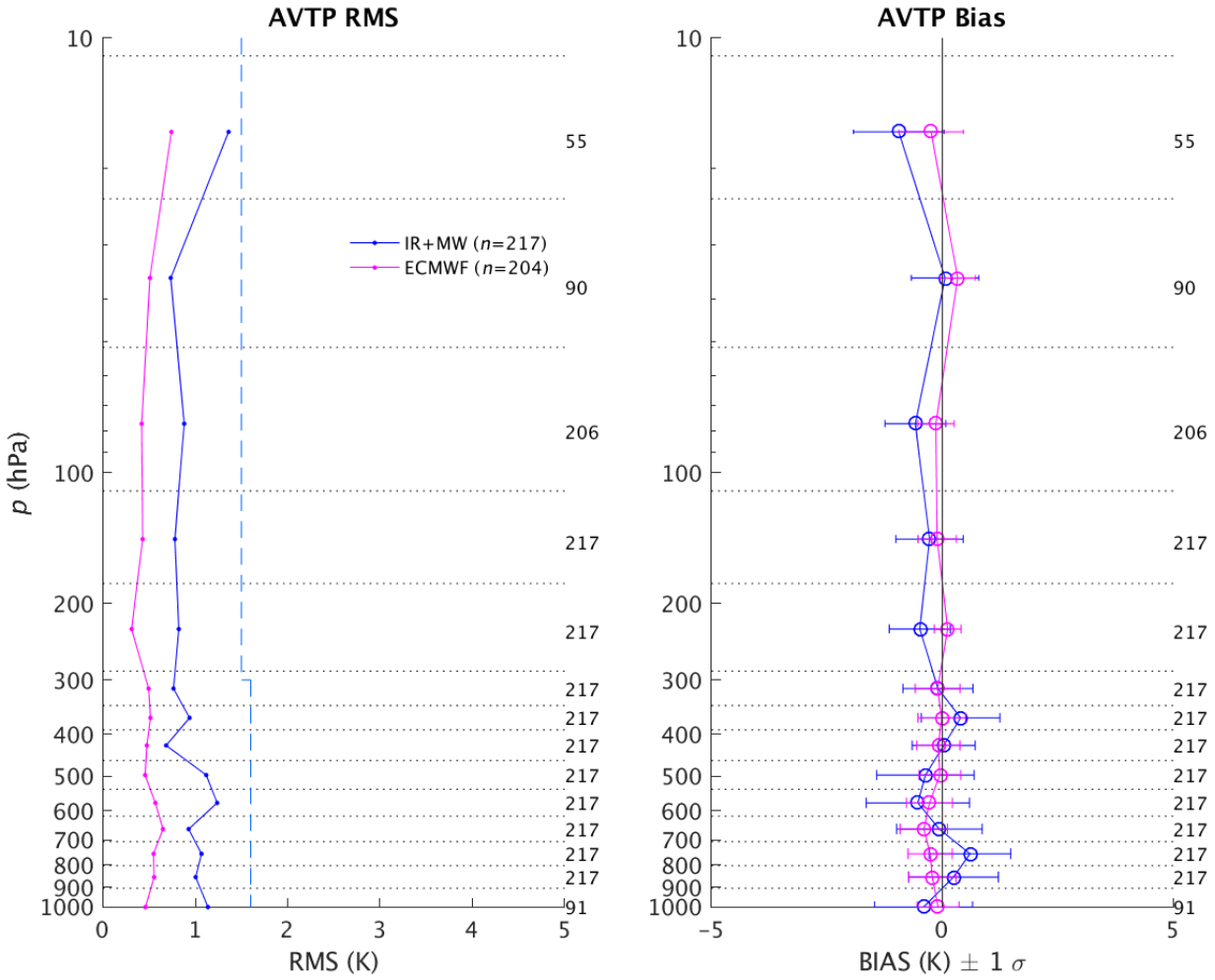


NUCAPS Offline (v1.5) AVTP Coarse-Layer Statistics
Nov-Dec 2015 AEROSE Campaign (JPSS Year-4)

AVTP Versus Dedicated RAOB

IR+MW
ECMWF

IR+MW Yield = 75.7%

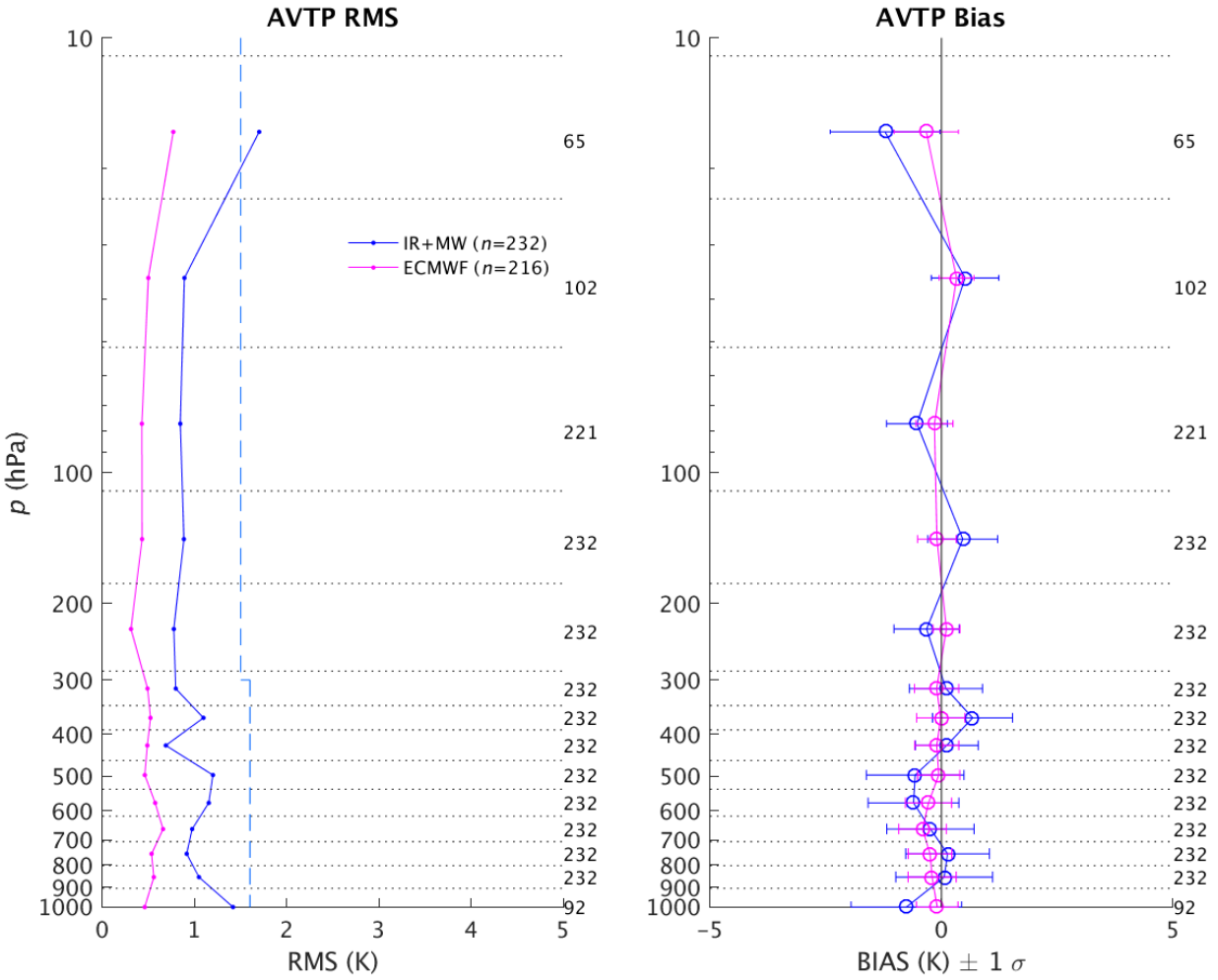


NUCAPS Offline (v1.8.1) AVTP Coarse-Layer Statistics
Nov-Dec 2015 AEROSE Campaign (JPSS Year-4)

AVTP Versus Dedicated RAOB

IR+MW
ECMWF

IR+MW Yield = 85.0%

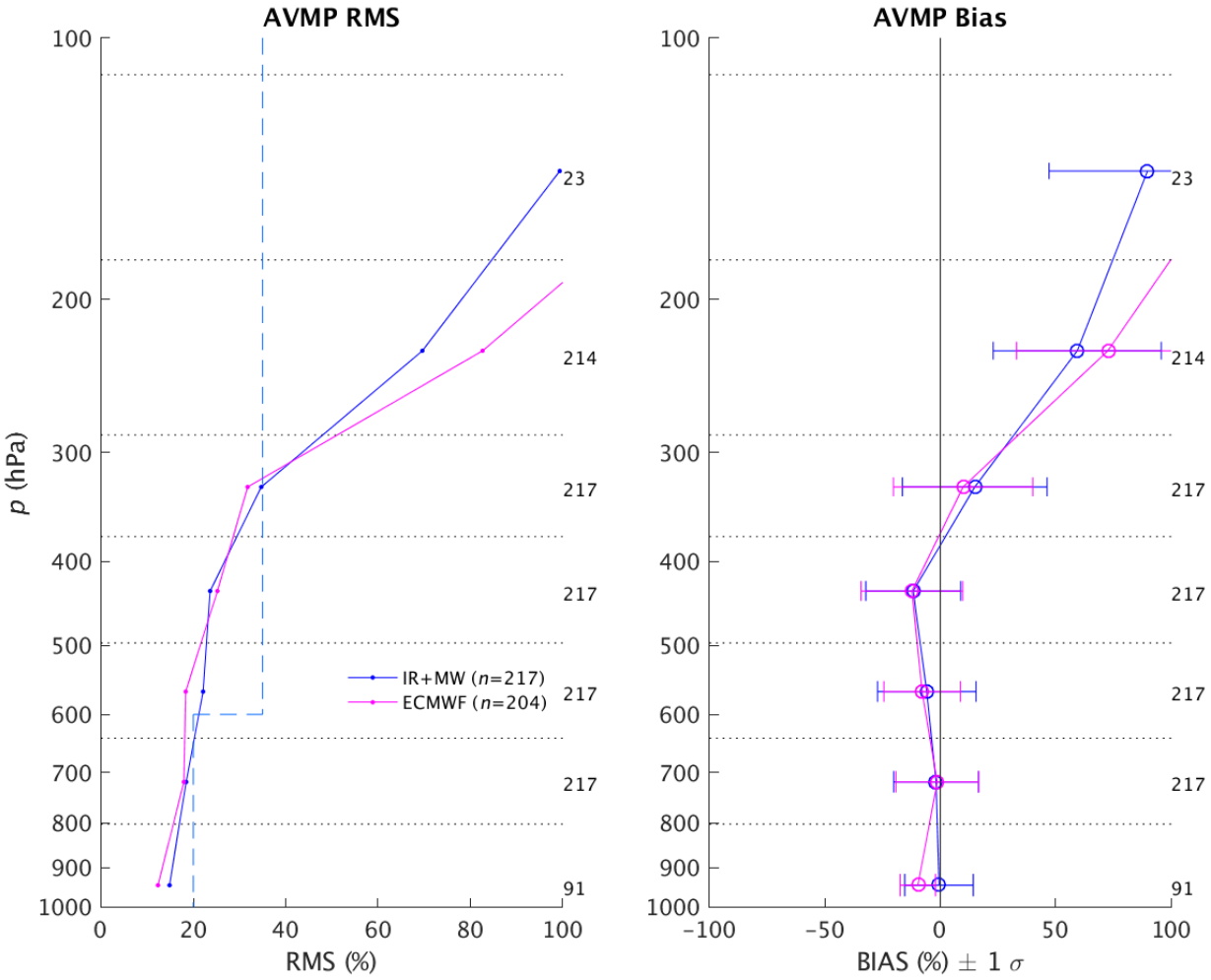


NUCAPS Offline (v1.5) AVMP Coarse-Layer Statistics
Nov-Dec 2015 AEROSE Campaign (JPSS Year-4)

AVMP Versus Dedicated RAOB

IR+MW
ECMWF

IR+MW Yield = 75.7%

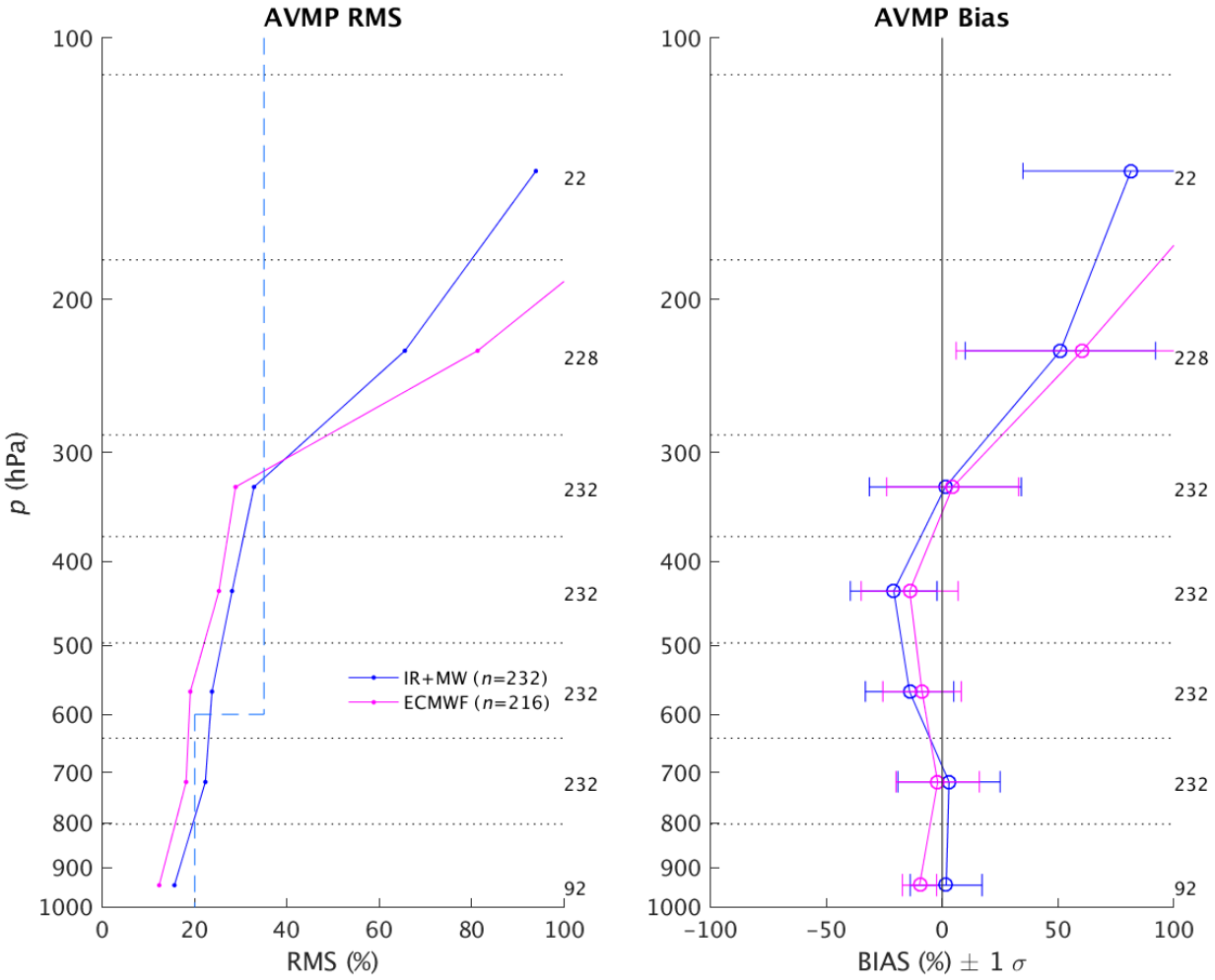


NUCAPS Offline (v1.8.1) AVMP Coarse-Layer Statistics
Nov-Dec 2015 AEROSE Campaign (JPSS Year-4)

AVMP Versus Dedicated RAOB

IR+MW
ECMWF

IR+MW Yield = 85.0%



Summary and Future Work

- **Operational** (offline v1.5) **NUCAPS AVTP/AVMP EDRs** using **CrIS nominal resolution data** are shown to **meet JPSS global requirements**.

- Offline code of **NUCAPS algorithm for full-res CrIS data** (currently v1.8.1) has been **successfully implemented** and is undergoing optimization. Based on Global Focus Day ECMWF model comparison, we find
  - **V1.8.1 AVTP meets JPSS Level 1 requirements** based on Global Focus Day; AVMP meets requirements except lowest layer
  - **V1.8.1 stats agree well with the validated operational version** (offline v1.5).

- **Future Work**
  - **Ongoing NUCAPS Validation and Long-Term Monitoring**
    - Transition operational NUCAPS to full-resolution CrIS SDR
    - **NUCAPS Trace Gas validation** (see presentation in **Session 11 Trace Gases** on Thursday)
    - **Prepare for J-1**
    - VALAR expansion, development and enhancements
      - Participate in the **AEROSE-XI campaign (Atlantic Ocean, Jan-Feb 2017)**
      - 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)
  - **Other Related Work**
    - **Apply averaging kernels** in NUCAPS error analyses, including ozone profile EDR
    - Collocation uncertainty estimates
    - calc – obs analyses (CRTM, LBLRTM, SARTA, etc.)
    - Support skin SST EDR validation (e.g., *Oyola et al.* 2016)
    - Support aerosol impact studies
    - Support EDR user applications (AWIPS, AR/SAL, atmospheric chemistry users)

SNPP NUCAPS Products and Validation

THANK YOU! QUESTIONS?

SNPP NUCAPS Products and 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: 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, $W_{\mathfrak{L},j}$,

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

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