Status of SNPP NUCAPS Validation

Nicholas R. Nalli[1,2], A. Gambacorta[3,2], C. Tan[1,2], F. Iturbide-Sanchez[1,2], T. Reale[2], B. Sun[1,2], M. Wilson[1,2], K. Zhang[1,2], C. D. Barnet[3], L. Borg[4], *et al.*

[1]*IMSG, Rockville, Maryland, USA*
[2]*NOAA/NESDIS/STAR, College Park, Maryland, USA*
[3]*STC, Columbia, Maryland, USA*
[4]*CIMSS, University of Wisconsin-Madison, USA*

2017 STAR JPSS Annual Meeting
College Park, Maryland, USA
August 2017

Acknowledgments

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

- 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.

- **SNPP sounder validation effort (past and present)**: Q. Liu, A.K. Sharma, M. Pettey, C. Brown, M. Divakarla, W. W. Wolf (STAR); R. O. Knuteson (UW/CIMSS)

Outline

- **JPSS Sounder Validation Overview**
  - JPSS Level 1 Requirements
  - Validation Hierarchy recap
  - NUCAPS Algorithm
    - v1.5, nominal spectral-resolution (NSR) CrIS
    - v2.0 Phase 4, full spectral-resolution (FSR) CrIS
- **NUCAPS Validation Status**
  - **v1.5 NSR Review**
    - Global dedicated RAOB ensemble
  - **v2.0 FSR (Phase 4) Status**
    - Global Focus Day ECMWF
    - Dedicated RAOBs (March to July 2017)

SNPP NUCAPS Validation Status

JPSS SOUNDER VALIDATION OVERVIEW

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 radiosondes
  - RAOBs assimilated into numerical models

4. Dedicated/Reference RAOB Matchup *Assessments*

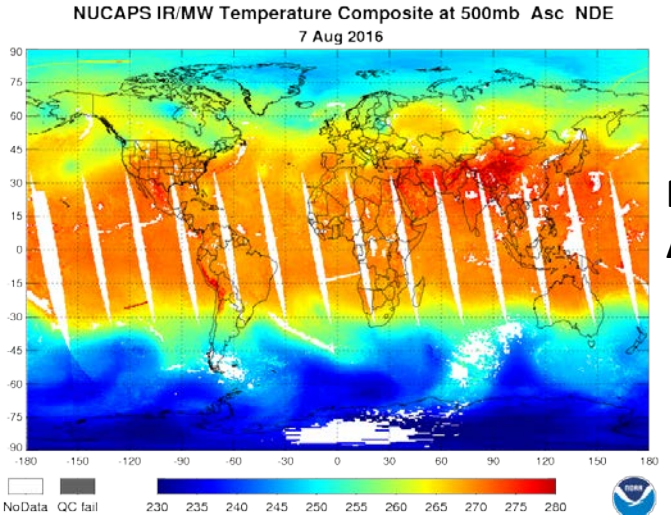
- *Dedicated* for the purpose of satellite validation
  - Known measurement uncertainty, optimal accuracy
  - Minimal mismatch errors
  - "best estimates" or "merged soundings"
- Reference sondes: CFH, **GRUAN** corrected RS92/RS41
  - Traceable measurement
  - Uncertainty estimates
- Limitation: Small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

5. Intensive Field Campaign *Dissections*

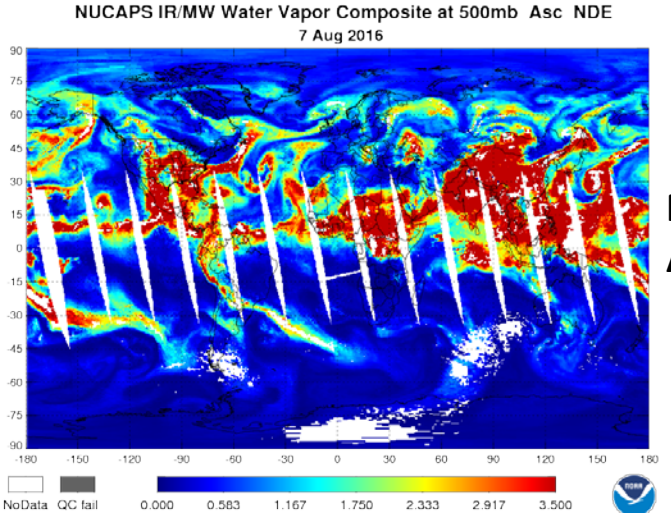
- Include dedicated RAOBs, some *not* assimilated into NWP models
- Include ancillary datasets (e.g., ozonesondes, lidar, M-AERI, MWR, sunphotometer, etc.)
- Ideally include funded aircraft campaign using IR sounder (e.g., NAST-I, S-HIS)
- Detailed performance specification; state specification; SDR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

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

- **Operational algorithm**
  - NOAA Enterprise Algorithm for CrIS/IASI/AIRS (*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)
- **Users**
  - **Weather Forecast Offices (AWIPS)**
    - Nowcasting / severe weather
    - Alaska (cold core)
  - NOAA/CPC (OLR)
  - NOAA/ARL (IR ozone, trace gases)
  - NOAA TOAST product (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)

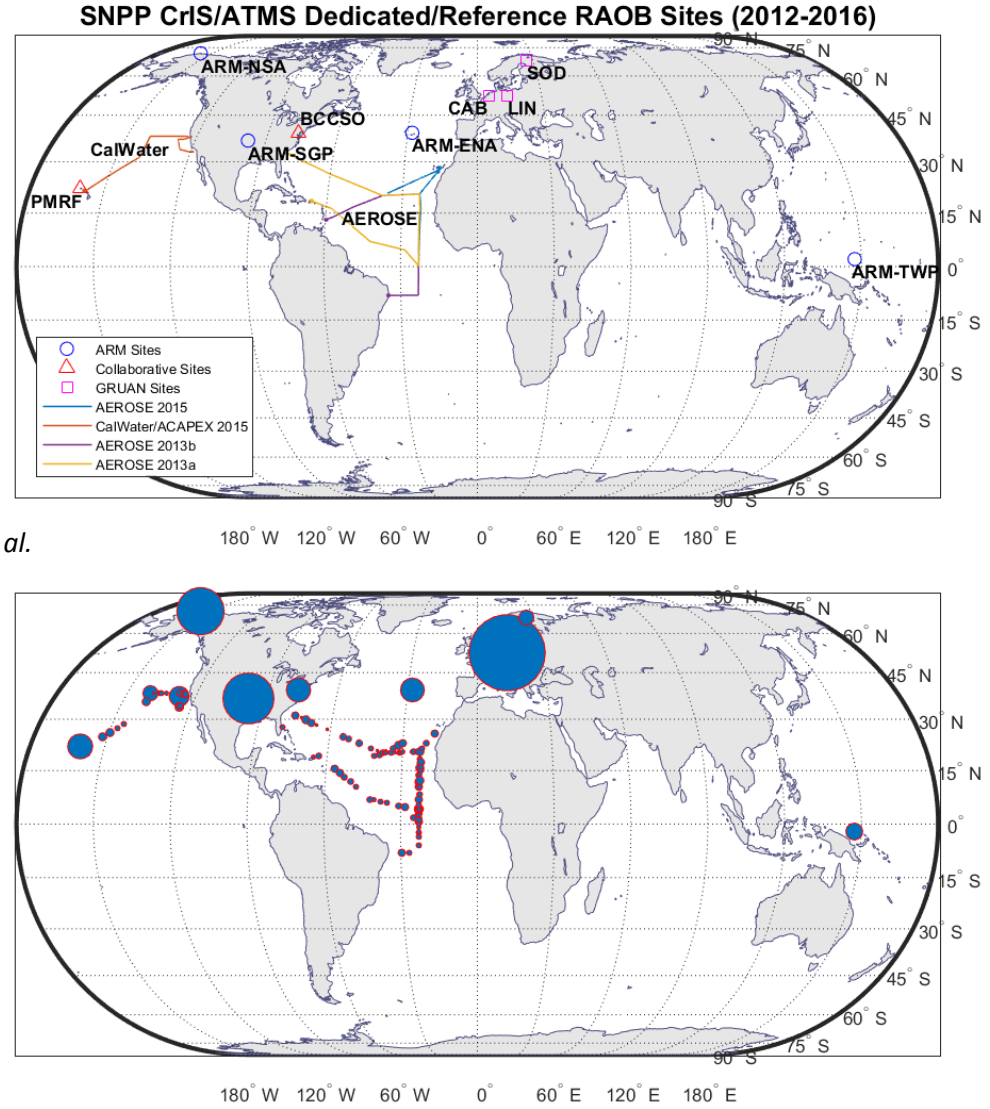
NUCAPS Offline Code Versioning

- **Version 1.5**
  - Operational system beginning in September 2013
  - Runs on CrIS nominal spectral-resolution (NSR) data
  - Validated Maturity for AVTP/AVMP EDR attained Sep 2014
- **Versions 1.8.x to 1.9.x**
  - Preliminary offline experimental algorithms in preparation for CrIS full-spectral (FSR) resolution data
  - *Ad hoc* CrIS full-resolution radiative transfer algorithm (RTA) and bias correction coefficients
- **Version 2.0 (Phase 4)**
  - Uses **UMBC CrIS full-res (FSR) RTA** (L. Strow et al.)
  - Includes **IR-only version** (risk-mitigation for ATMS loss)
  - **Phase 4 Algorithm Readiness Review (ARR)** delivered on 6 July 2017
    - Draft ATBD delivered August 2017
    - Code currently being delivered and transitioned into operations

SNPP NUCAPS Validation Status

NUCAPS V1.5 NSR VALIDATION REVIEW

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



From Nalli et al. (2017a)

JPSS SNPP-Dedicated and GRUAN Reference RAOB Sites

Geographic Sample Histogram (Equal Area)

FOR Collocation Criteria
$\delta x \leq 75$ km, $-60 < \delta t < 0$ min

NUCAPS v1.5 NSR IR+MW AVTP Coarse-Layer Statistics
VALAR Dedicated/Reference RAOB Collocation Sample

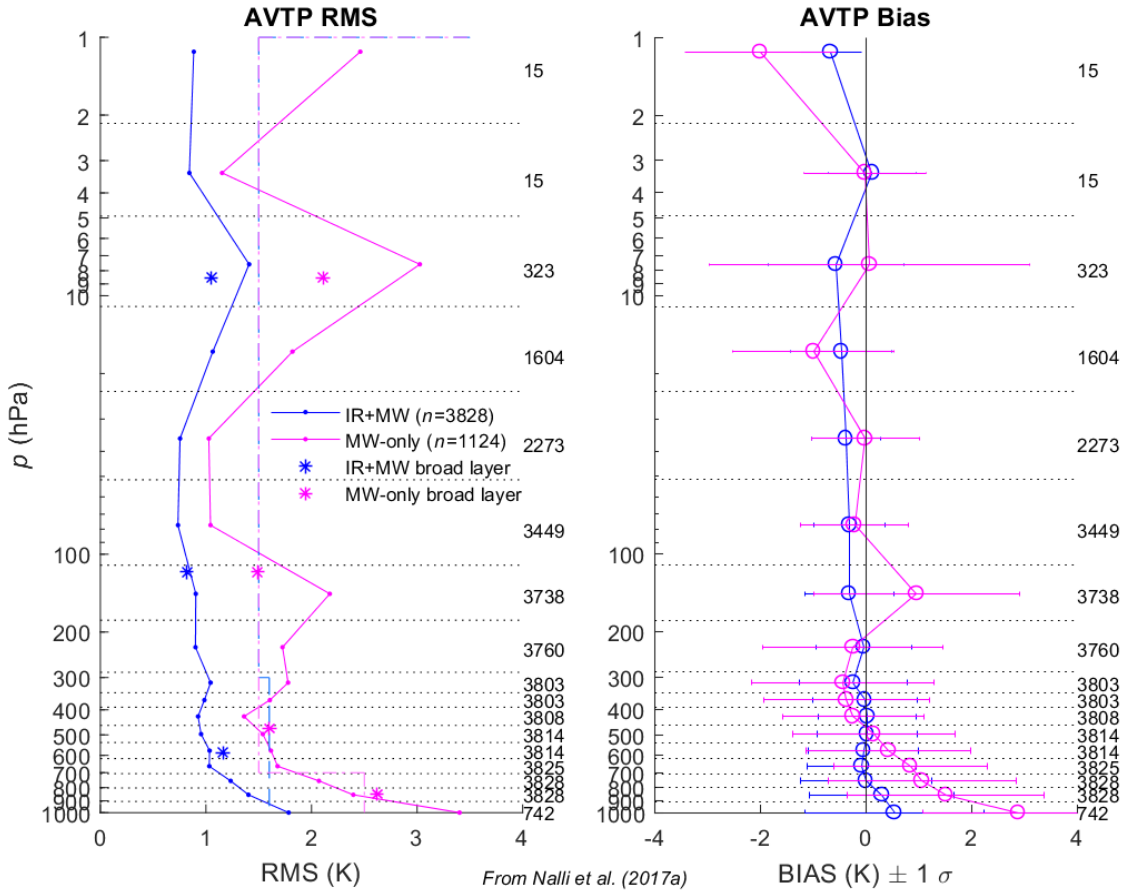
AVTP Versus RAOB

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

IR+MW
MW-Only

IR+MW Yield = 63.3%

MW-only Yield = 91.9%



NUCAPS v1.5 NSR IR+MW AVMP Coarse-Layer Statistics
VALAR Dedicated/Reference RAOB Collocation Sample

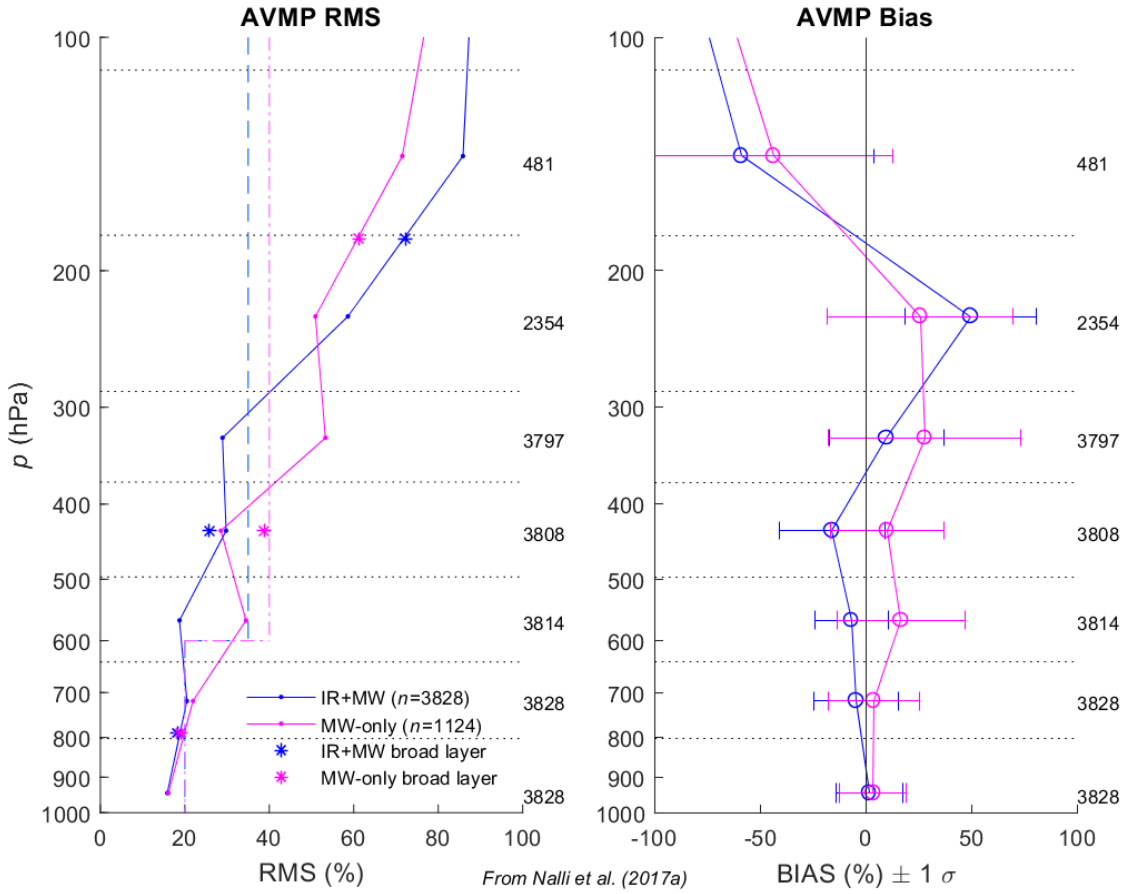
AVMP Versus RAOB

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

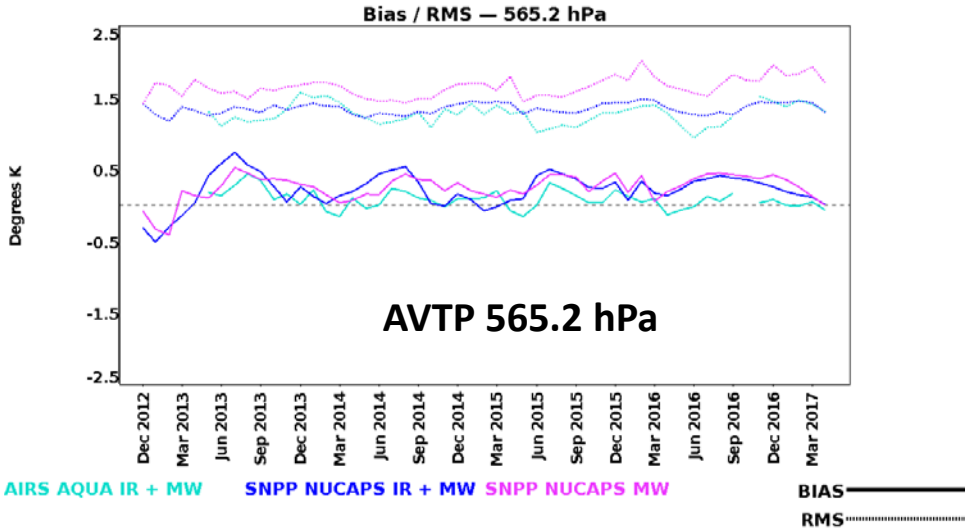
IR+MW
MW-Only

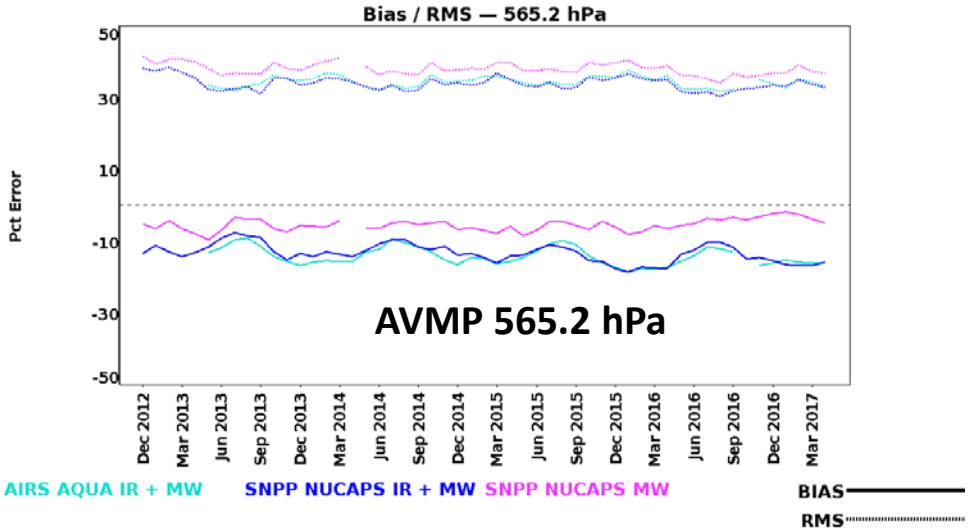
IR+MW Yield = 63.3%

MW-only Yield = 91.9%



Long-Term Monitoring NUCAPS

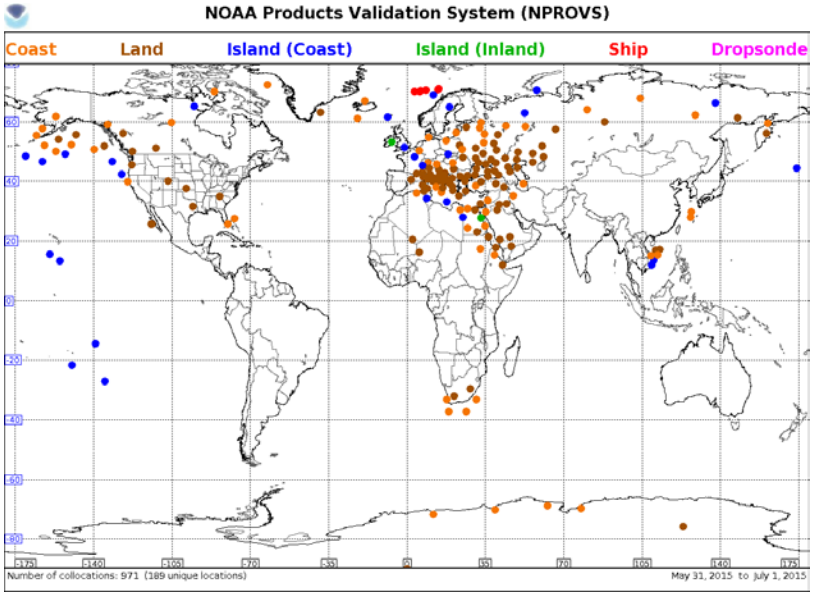




NPROVS Archive Statistics (NARCS) Utility
(*Reale et al.* 2012)

June 2015 NPROVS conventional RAOBs collocated with SNPP

single closest NUCAPS FOR within 50 km and 0-30 min following launches



SNPP NUCAPS Validation Status

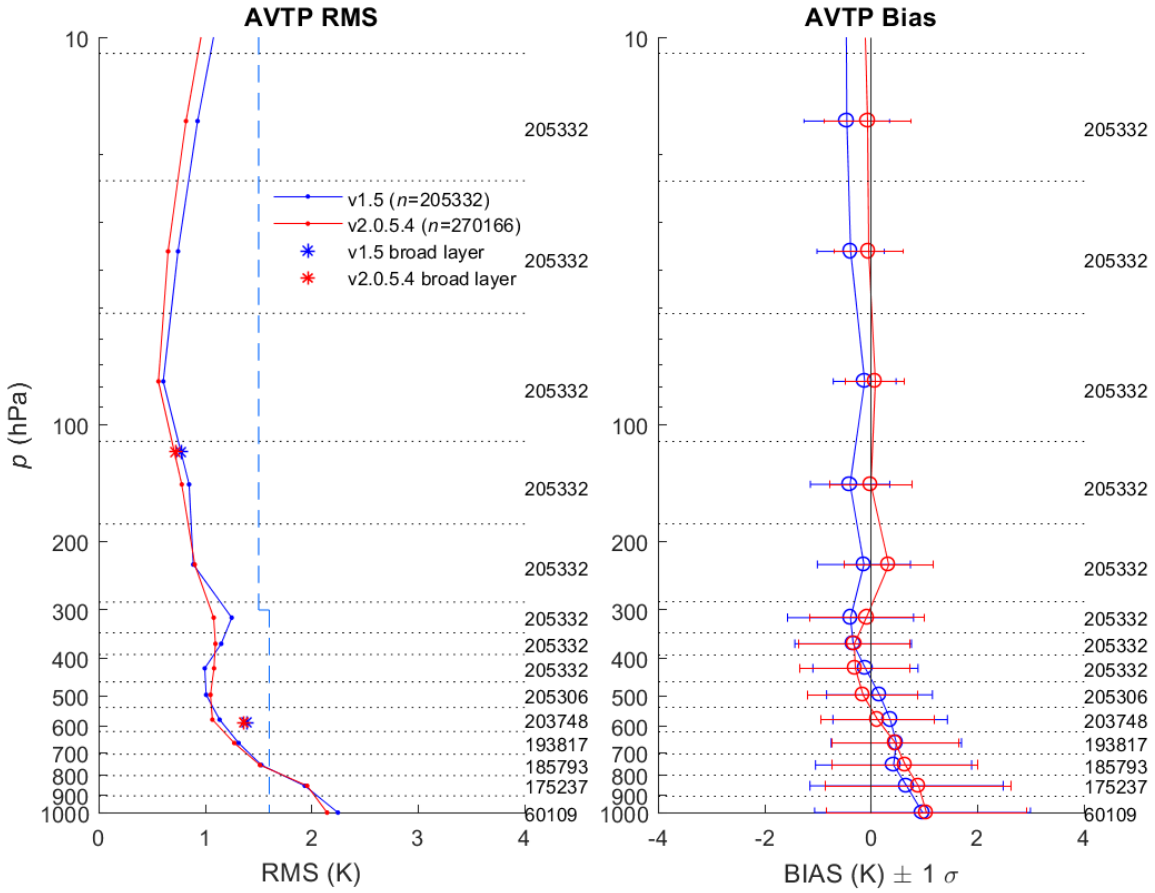
NUCAPS PHASE 4 V2.0 FSR VALIDATION STATUS

NUCAPS v2.0 FSR IR+MW AVTP Coarse-Layer Statistics Global Focus Day 17-Feb-2015

AVTP Versus ECMWF

V1.5 IR+MW
V2.0 IR+MW

v1.5 Yield = 63.4%
v2.0 Yield = 88.5%

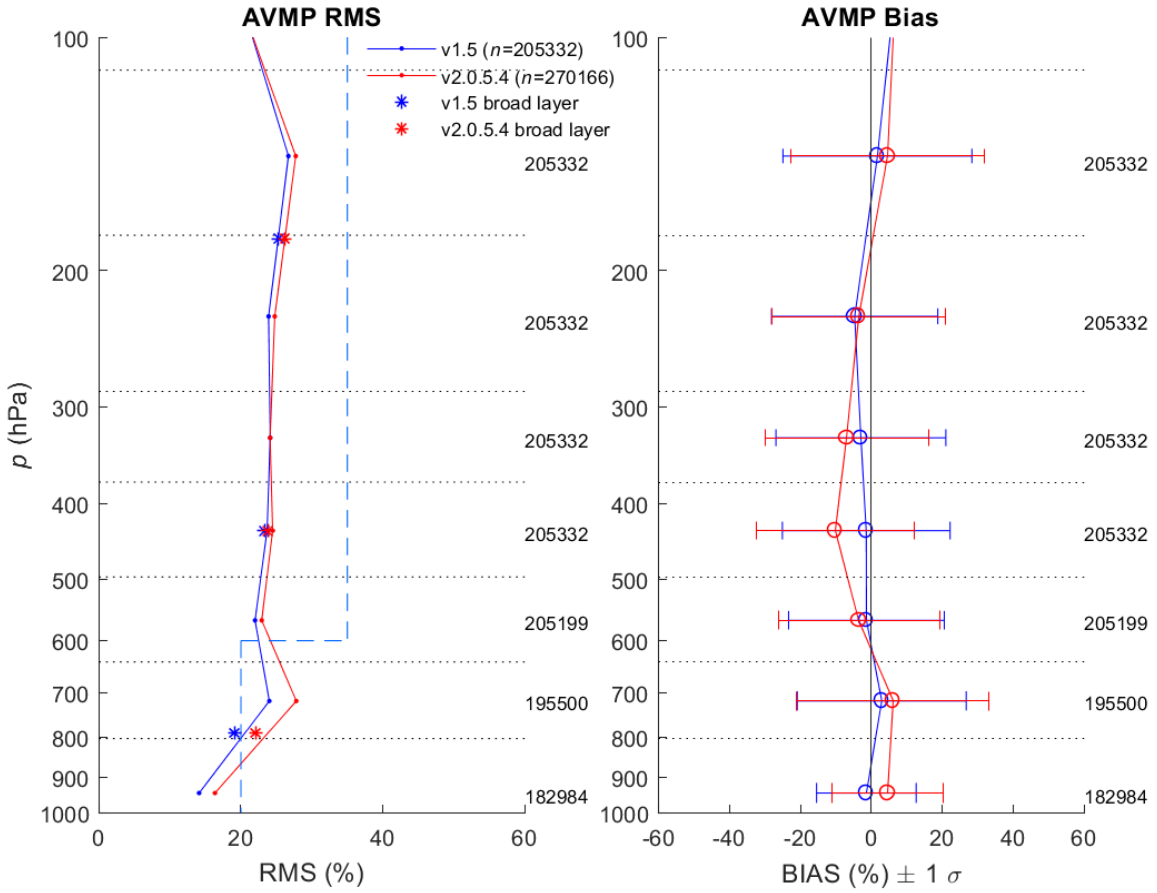


NUCAPS v2.0 FSR IR+MW AVMP Coarse-Layer Statistics Global Focus Day 17-Feb-2015

AVMP Versus ECMWF

V1.5 IR+MW
V2.0 IR+MW

v1.5 Yield = 63.4%
v2.0 Yield = 88.5%

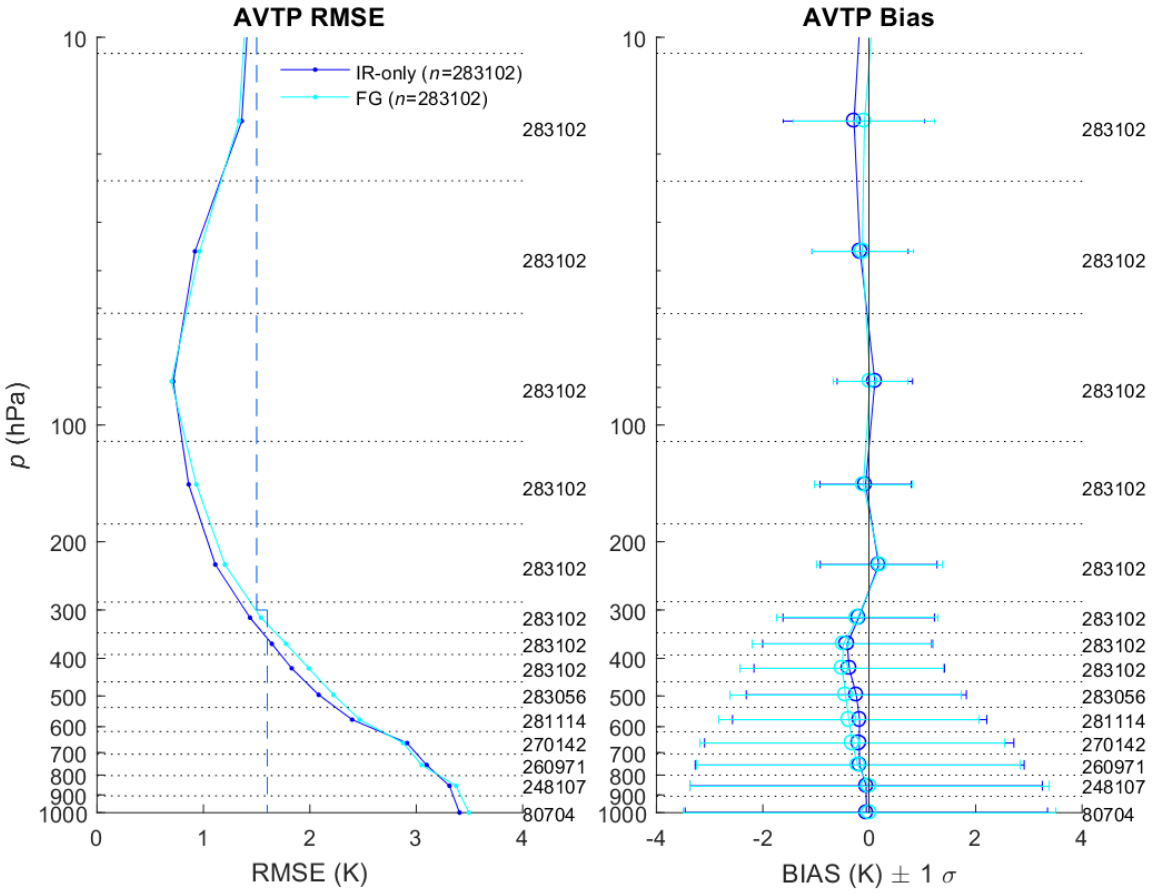


NUCAPS v2.0 FSR IR-Only AVTP Coarse-Layer Statistics Global Focus Day 17-Feb-2015

AVTP Versus ECMWF

IR-Only
First Guess

IR-Only Yield = 87.4%

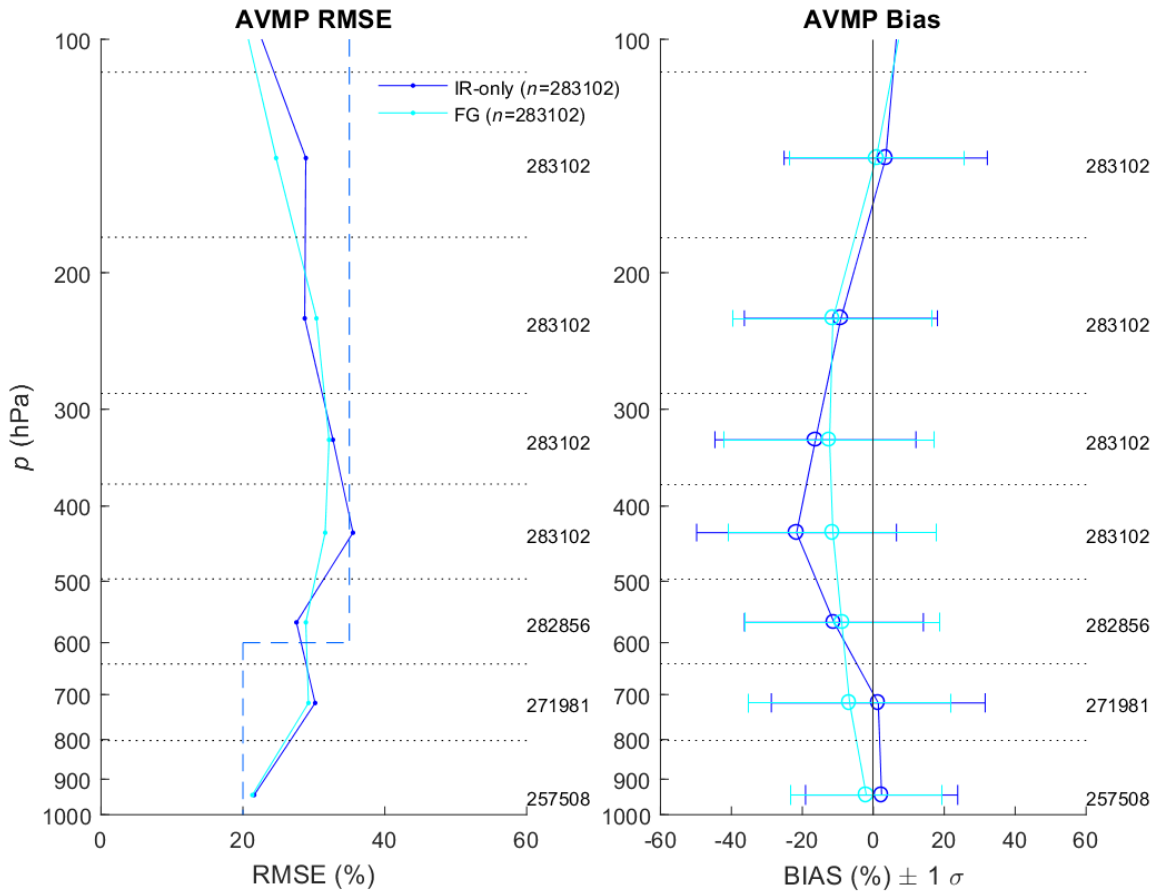


NUCAPS v2.0 FSR IR-Only AVMP Coarse-Layer Statistics Global Focus Day 17-Feb-2015

AVMP Versus ECMWF

IR-Only
First Guess

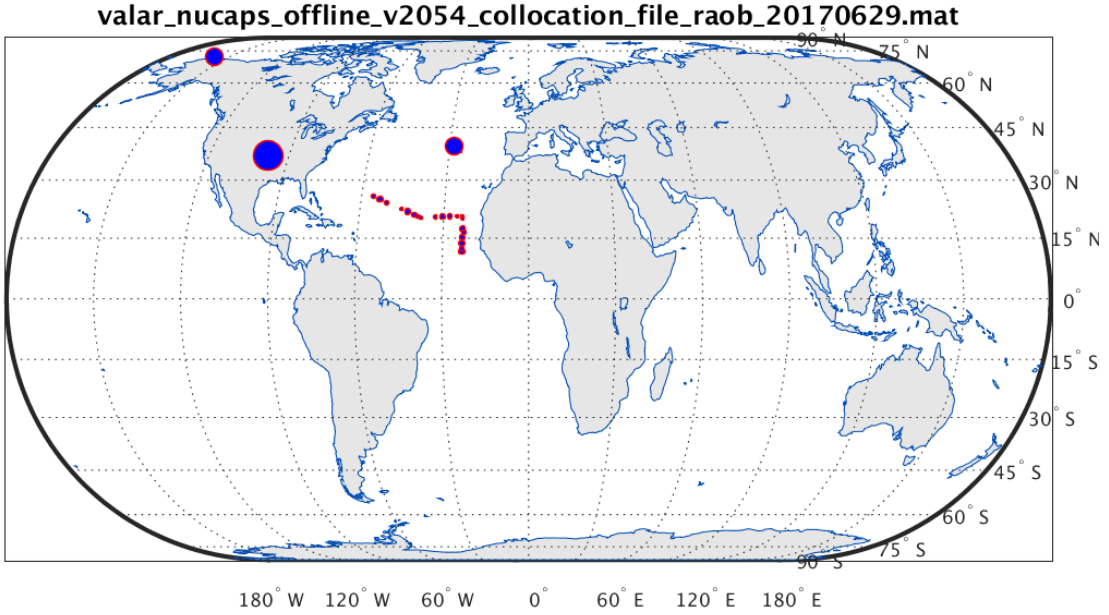
IR-Only Yield = 87.4%



JPSS Dedicated RAOBs March to July 2017

- **Full-res CrIS SDRs** became operationally available on the STAR Central Data Repository (SCDR) beginning in March 2017
  - We have collected full-res CrIS granule collocations for **JPSS dedicated RAOBs** since this time
- **Atmospheric Radiation Measurement (ARM)** sites
  - Eastern North Atlantic (ENA)
  - Southern Great Plains (SGP)
  - North Slope of Alaska (NSA)
- **2017 NOAA AEROSE campaign** (*Nalli et al.* 2011)
  - Feb-Mar 2017, tropical Atlantic Ocean
  - Unfortunately, approximately only one-half the launched RAOBs could thus be utilized

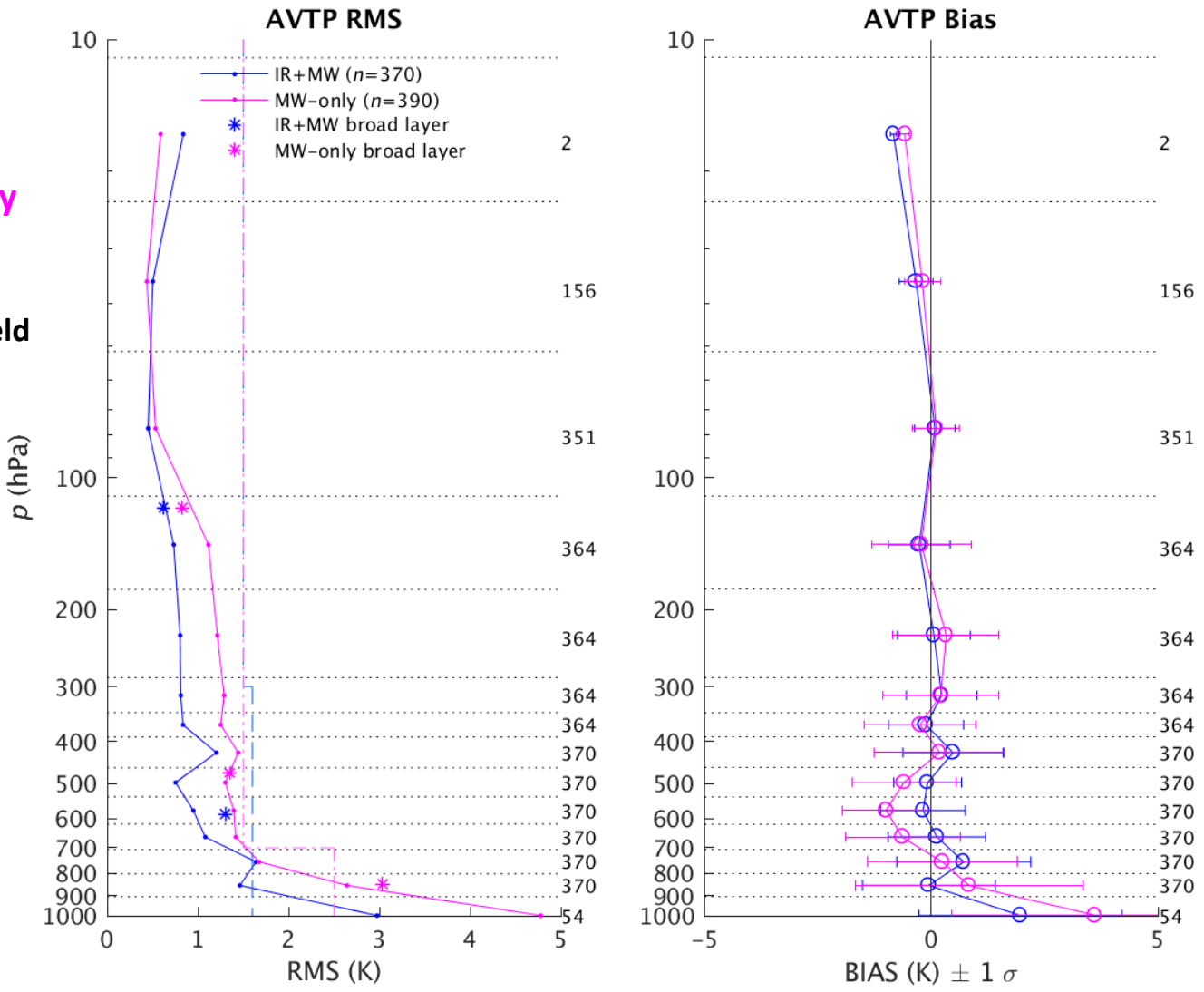
NUCAPS-RAOB Collocations
JPSS Dedicated RAOBs
δx = 75 km, δt = −90 to +5 min



Coarse-Layer AVTP Stats
Versus VALAR JPSS Dedicated RAOBs

IR+MW
MW-Only

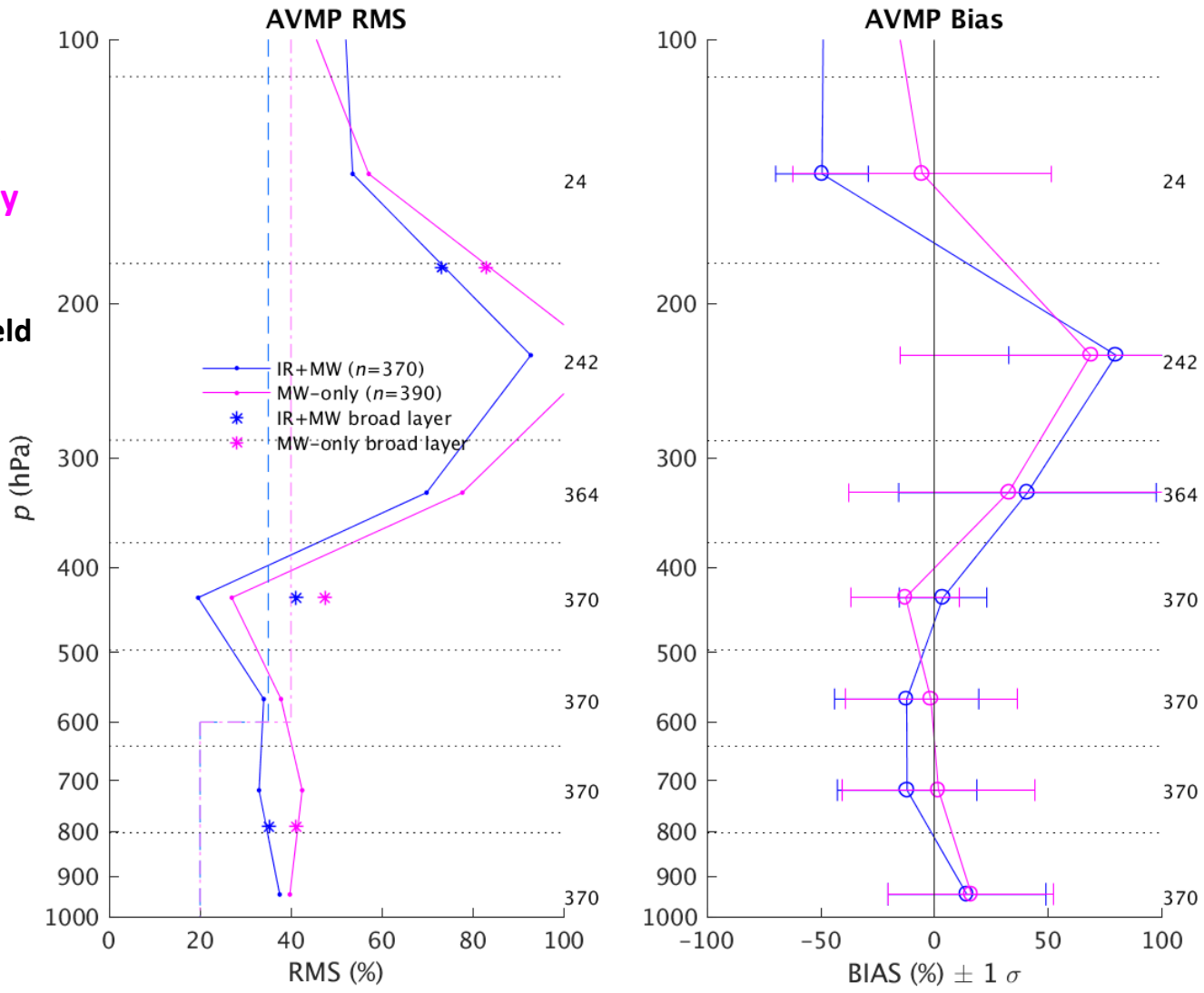
IR+MW Yield = 75.7%



Coarse-Layer AVMP Stats
Versus VALAR JPSS Dedicated RAOBs

IR+MW
MW-Only

IR+MW Yield = 75.7%



NUCAPS v2.0 AVTP Uncertainty Summary Table

Versus ECMWF

SUMMARY OF AVTP EDR VERSUS L1RD REQUIREMENTS		
Broad-Layer	**Result vs ECMWF**	**JPSS L1RD**
Cloud-Free to Partly Cloudy (IR+MW)		
1014 to 300 hPa	**1.3 K**	1.6 K
300 to 30 hPa	**1.1 K**	1.5 K
Cloudy (MW-Only)		
1014 to 700 hPa	**3.0 K**	2.5 K
700 to 300 hPa	**2.3 K**	1.5 K
300 to 30 hPa	**2.1 K**	1. 5 K

NUCAPS v2.0 AVMP (H_2O) Uncertainty Summary Table Versus ECMWF

SUMMARY OF AVMP EDR VERSUS L1RD REQUIREMENTS		
Broad-Layer	**Result vs ECMWF**	**JPSS L1RD**
Cloud-Free to Partly Cloudy (IR+MW)		
1014 to 600 hPa	**22.7% or 1.1 g/kg**	Greater of 20% or 0.2 g/kg
600 to 300 hPa	**24.9%, 0.2 g/kg**	Greater of 35% or 0.1 g/kg
300 to 100 hPa	**22.7%, 0.01 g/kg**	Greater of 35% or 0.1 g/kg
Cloudy (MW-Only)		
1014 to 600 hPa	**29.2%**	Greater of 20% or 0.2 g/kg
600 to 300 hPa	**35.6%**	Greater of 40% or 0.1 g/kg
300 to 100 hPa	**39.8**	Greater of 40% or 0.1 g/kg

NUCAPS EDR Maturity Status

Slide courtesy of Lihang Zhou, STAR/JPSS

S-NPP EDR Validated Maturity Oct. 2016-Current: NUCAPS

Sensor	Product	Priority	Validated Maturity Review Date & Status		Review Panel Recommendations
CrIS/ATMS	Atm. Vertical Moisture Profile (AVMP)	3	*	✓ V	September 2014
CrIS/ATMS	Atm. Vertical Temperature Profile (AVTP)	3	*	✓ V	September 2014
CrIS/ATMS	Ozone Profile EDR	3	Oct-2016	✓ V	Panel recommended the following: (1) Work with EMC and NWS on user applications (2) Validate against OMPS NP data (3) Extend validation to more ozonesondes
CrIS	Outgoing Longwave Radiation	3	Oct-2016	✓ V	Panel recommended the following: (1) Investigate the use of VIIRS for helping to understand the differences between OLR from CrIS and CERES. (2) Compare anomaly events from CERES OLR (e.g. ENSO, MJO) to CrIS OLR data (3) Provide information about how algorithm will be updated to utilize CrIS FS data
CrIS/ATMS	Carbon Monoxide	4	&	✓ P	Validated Maturity Review for Fall 2017
CrIS/ATMS	Carbon Dioxide	4	&	✓ P	Validated Maturity Review for Fall 2017
CrIS/ATMS	Methane	4	&	✓ P	Validated Maturity Review for Fall 2017

*Product reached validated maturity in September 2014.

&Product reached provisional maturity in January 2013. NUCAPS Phase IV/Part II ARR completed on July 6, 2017.

✓ Validated ✓ Provisional

5

Summary and Future Work

- **SNPP NUCAPS NSR (v1.5) AVTP/AVMP EDRs have met JPSS global requirements**
  - Validated Maturity for AVTP/AVMP EDR attained Sep 2014

- Offline **NUCAPS Phase 4 FSR (v2.0)** has been successfully implemented and tested. Based on Global Focus Day ECMWF model comparison and limited RAOB matchups
  - IR+MW EDR products have attained **Provisional Maturity**
  - IR-Only EDR products have been successfully implemented and show reasonable performance

- **Future Work**
  - **Ongoing NUCAPS development, Cal/Val and Long-Term Monitoring**
    - **Continue v2.0 algorithm optimizations**
    - **NUCAPS Trace Gas cal/val** (*Nalli et al.* presentation, trace gas session)
    - **Prepare for JPSS-1 launch**
    - Continue support of dedicated RAOBs (including ARM, AEROSE)
  - **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
    - Support EDR user applications (AWIPS, AR/SAL, atmospheric chemistry users)

SNPP NUCAPS Validation Status

THANK YOU! QUESTIONS?

SNPP NUCAPS Validation Status

EXTRA SLIDES