SNPP NUCAPS Validation Status: *T*/H_2O/O_3

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2017 NASA Sounder Science Team Meeting
Greenbelt, Maryland
26 October 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:** 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
  - **World Ozone and Ultraviolet Radiation Data Centre (WOUDC)** data contributors (DWD-GRUAN, & INPE, & KNMI, & NASA-WFF, & SMNA. http://www.woudc.org
  - **SHADOZ: Southern Hemisphere Additional Ozonesondes** (*A. Thompson* et al.)

- 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, X. Xiong (STAR); R. O. Knuteson (UW/CIMSS)

Outline

- **JPSS Sounder EDR Cal/Val Overview**
  - JPSS Level 1 Requirements
  - Validation Hierarchy recap
  - NUCAPS Algorithm
    - v1.5, CrIS Nominal Spectral Resolution (NSR)
    - v2.0 Phase 4, CrIS Full Spectral Resolution (FSR)
- **SNPP NUCAPS Algorithm Validation Status**
  - v1.5, CrIS NSR
    - AVTP and AVMP versus Global Radiosondes
    - IR Ozone Profile EDR versus Global Ozonesondes
  - v2.0 Phase 4, CrIS FSR
    - IR+MW Results
    - IR-Only Algorithm Results

SNPP NUCAPS Validation

JPSS SOUNDER EDR CAL/VAL OVERVIEW

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

- Well-established **sounder EDR validation methodology** is 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 sounder EDR Cal/Val Plan** was submitted on 31 Dec 2015
  - We are ready for the J-1 launch scheduled for November 2017

Validation Methodology Hierarchies

$T/H_2O/O_3$ Profiles

(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)
   - Limitation: Similar error characteristics
3. **Conventional PTU/O3 Sonde Matchup *Assessments***
   - WMO/GTS operational sondes or O3-sonde network (e.g., SHADOZ)
   - 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 distributions; mismatch errors; non-uniform radiosondes, assimilated into NWP
4. **Dedicated/Reference PTU/O3 Sonde Matchup *Assessments***
   - *Dedicated* for the purpose of satellite validation
   - Reference sondes: CFH, **GRUAN** corrected RS92/RS41
   - E.g., **ARM sites** (e.g., *Tobin et al.,* 2006), **AEROSE**, **CalWater/ACAPEX ,** BCCSO, PMRF
   - Limitation: Small sample sizes, geographic coverage
5. **Intensive Field Campaign *Dissections***
   - Include dedicated sondes, some *not* assimilated into NWP models
   - Include ancillary datasets, ideally funded aircraft campaign(s)
   - E.g., **SNAP, SNPP, AEROSE, CalWater**, JAIVEX, AWEX-G, EAQUATE

Carbon Trace Gases

1. **Numerical Model Global *Comparisons***
   - Examples: **ECMWF, NCEP/GFS**
   - Large, truly global samples acquired from Focus Days
   - Limitation: Not independent truth data
2. **Satellite Sounder EDR *Intercomparisons***
   - Examples: **AIRS, OCO-2, MLS**
   - Global samples acquired from Focus Days (e.g., AIRS)
   - Limitation: Similar error characteristics
3. **Surface-Based Network Matchup *Assessments***
   - **Total Carbon Column Observing Network (TCCON)** spectrometers (*Wunch et al.* 2010, 2011)
   - **AirCore** balloon-borne ***in situ* profile measurements** (*Membrive et al.* 2017)
   - Provide routine independent measurements representing global zones akin to RAOBs
   - Limitations: Small sample sizes, uncertainties in unit conversions, different sensitivities to atmospheric layers
4. **Intensive Field Campaign *In Situ* Data *Assessments***
   - Include ancillary datasets, ideally funded aircraft campaign(s)
   - E.g., **ATom**, **ACT-America**, FIREX, HIPPO

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

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·kg^{-1} / 2-km layer	10%
AVMP, Cloud fraction < 50%, 600–300 hPa	Greater of 35% or 0.1 g·kg^{-1} / 2-km layer	10%
AVMP, Cloud fraction < 50%, 300–100 hPa	Greater of 35% or 0.1 g·kg^{-1} / 2-km layer	10%
AVMP, Cloud fraction ≥ 50%, surface to 600 hPa	Greater of 20% of 0.2 g·kg^{-1} / 2-km layer	10%
AVMP, Cloud fraction ≥ 50%, 600–400 hPa	Greater of 40% or 0.1 g·kg^{-1} / 2-km layer	10%
AVMP, Cloud fraction ≥ 50%, 400–100 hPa	Greater of 40% or 0.1 g·kg^{-1} / 2-km layer	NS

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

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

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)

JPSS Specification Performance Requirements
CrIS Trace Gas EDR Uncertainty (O_3, CO, CO_2, CH_4)

CrIS Infrared Trace Gases **Specification Performance Requirements**		
PARAMETER	**THRESHOLD**	**OBJECTIVE**
O_3 (Ozone) Profile Precision, 4–260 hPa (6 statistic layers)	20%	10%
O_3 (Ozone) Profile Precision, 260 hPa to sfc (1 statistic layer)	20%	10%
O_3 (Ozone) Profile Accuracy, 4–260 hPa (6 statistic layers)	±10%	±5%
O_3 (Ozone) Profile Accuracy, 260 hPa to sfc (1 statistic layer)	±10%	±5%
O_3 (Ozone) Profile Uncertainty, 4–260 hPa (6 statistic layers)	25%	15%
O_3 (Ozone) Profile Uncertainty, 260 hPa to sfc (1 statistic layer)	25%	15%
CO (Carbon Monoxide) Total Column Precision	35%, or full res mode 15%	3%
CO (Carbon Monoxide) Total Column Accuracy	±25%, or full res mode ±5%	±5%
CO_2 (Carbon Dioxide) Total Column Precision	0.5% (2 ppmv)	1.05 to 1.4 ppmv
CO_2 (Carbon Dioxide) Total Column Accuracy	±1% (4 ppmv)	NS
CH_4 (Methane) Total Column Precision	1% (≈20 ppbv)	NS
CH_4 (Methane) Total Column Accuracy	±4% (≈80 ppmv)	NS

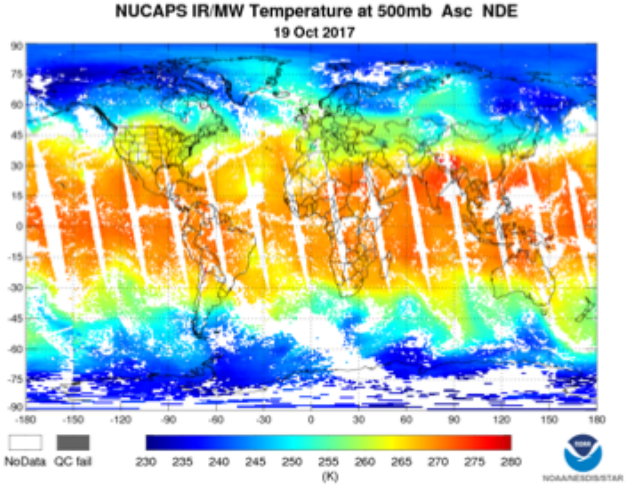
Source:
(L1RD, 2014, pp. 45-49)

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

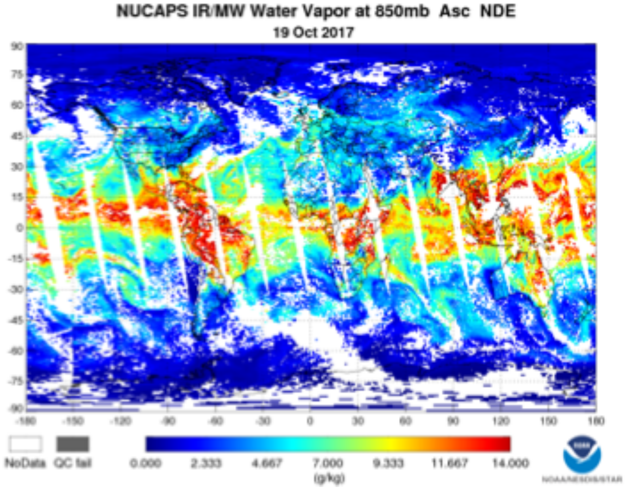
- **Operational algorithm**
  - NOAA Enterprise Algorithm for CrIS/IASI/AIRS (*Susskind, Barnet and Blaisdell,* IEEE 2003; *Gambacorta et al.,* 2014)
  - Global non-precipitating conditions
  - Atmospheric Vertical Temperature , Moisture Profiles (**AVTP**, **AVMP**)
  - Trace gases (**O_3**, CO, CO_2, 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 EDR)
  - Basic and applied science research (e.g., *Pagano et al.,* 2014)
    - Via NOAA Data Centers (e.g., CLASS)
    - Universities, peer-reviewed pubs

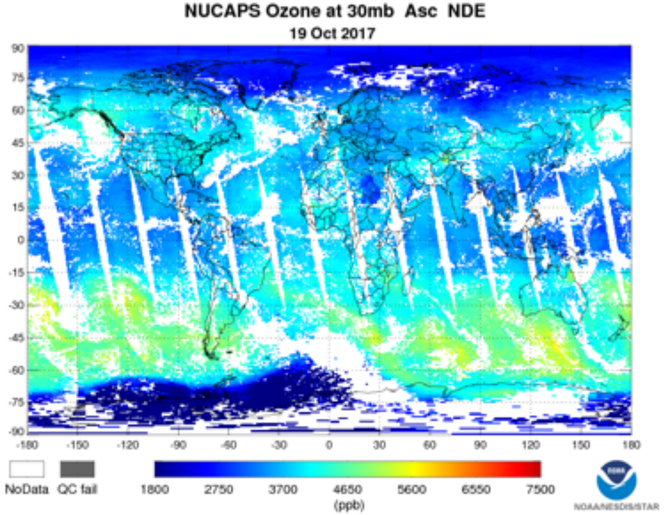
NUCAPS AVTP



NUCAPS AVMP



NUCAPS IR O_3



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

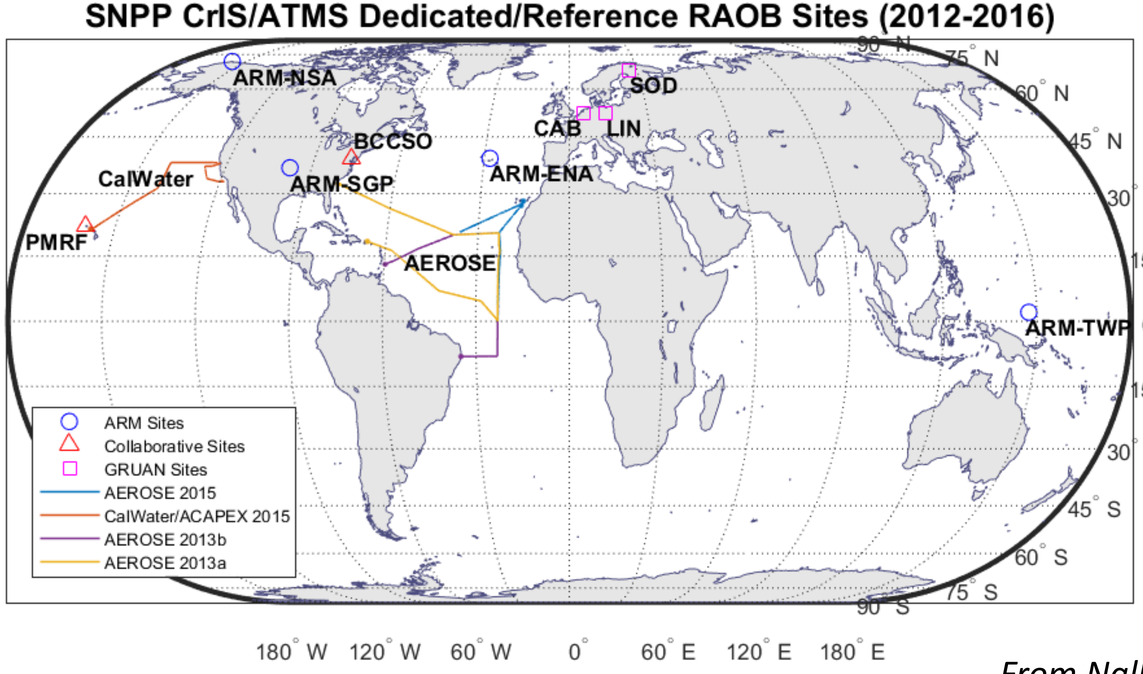
- **Version 1.5**
  - Operational system beginning in September 2013
  - Runs on CrIS nominal spectral-resolution (NSR) data
  - Validated Maturity for AVTP/AVMP EDR attained Sep 2014
- **Versions 1.8.x to 1.9.x**
  - Preliminary offline experimental algorithms in preparation for CrIS full-spectral (FSR) 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

NUCAPS V1.5 NSR VALIDATION REVIEW

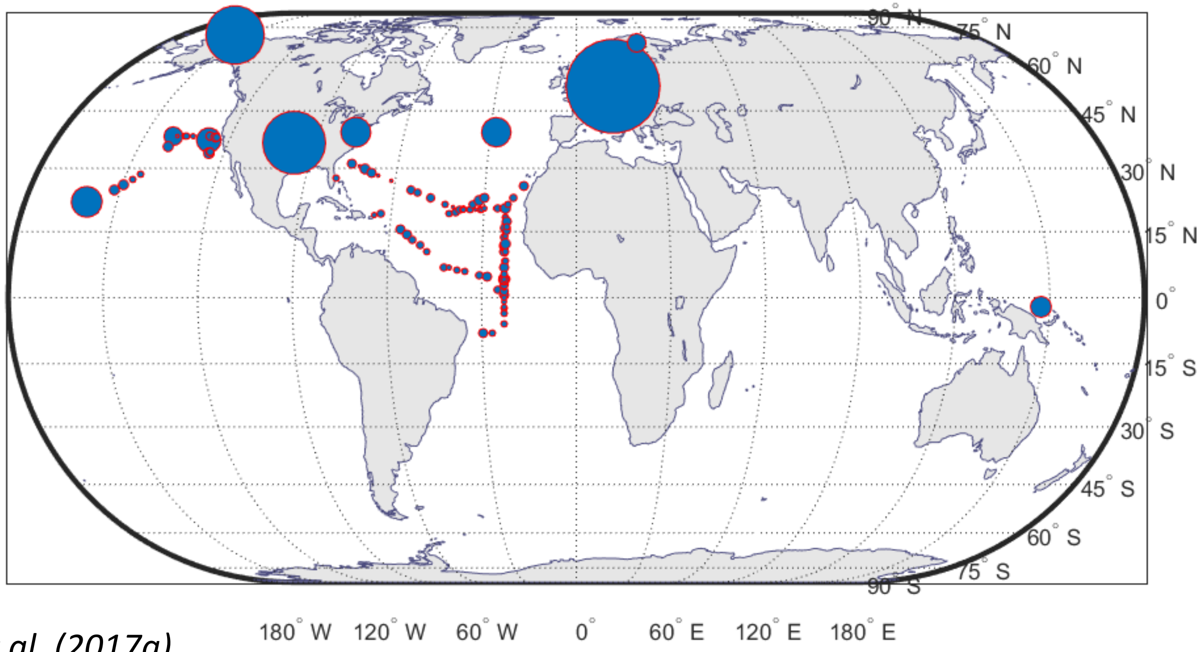
SNPP NUCAPS (NSR v1.5) Dedicated/Reference RAOB Collocation Sample

JPSS SNPP-Dedicated and GRUAN Reference RAOB Sites



Geographic Sample Histogram

(Equal Area)



From Nalli et al. (2017a)

FOR Collocation Criteria

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

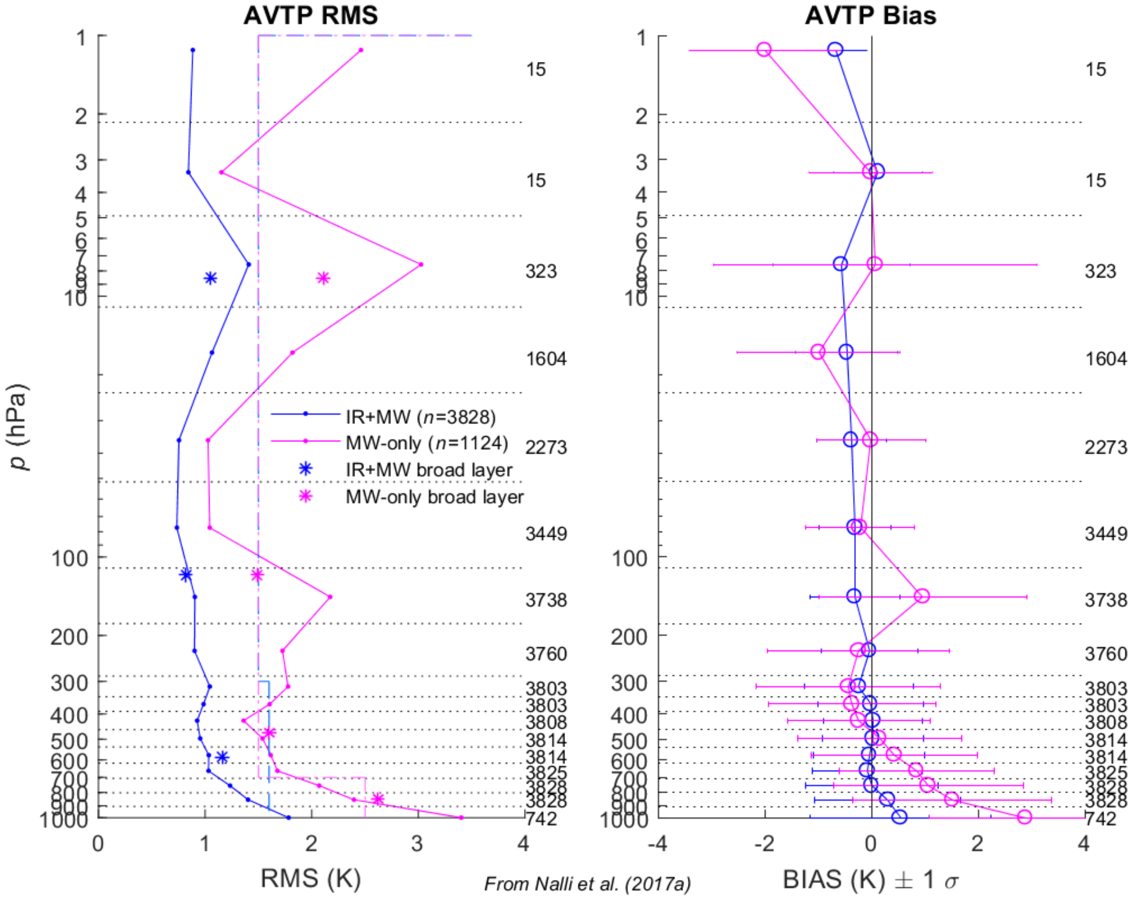
Collocations of CrIS/ATMS granules facilitated via NPROVS+ system

NUCAPS v1.5 NSR IR+MW T/H_2O Coarse-Layer Statistics
Dedicated/Reference RAOB Collocation Sample

AVTP Versus RAOB

IR+MW
MW-Only

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

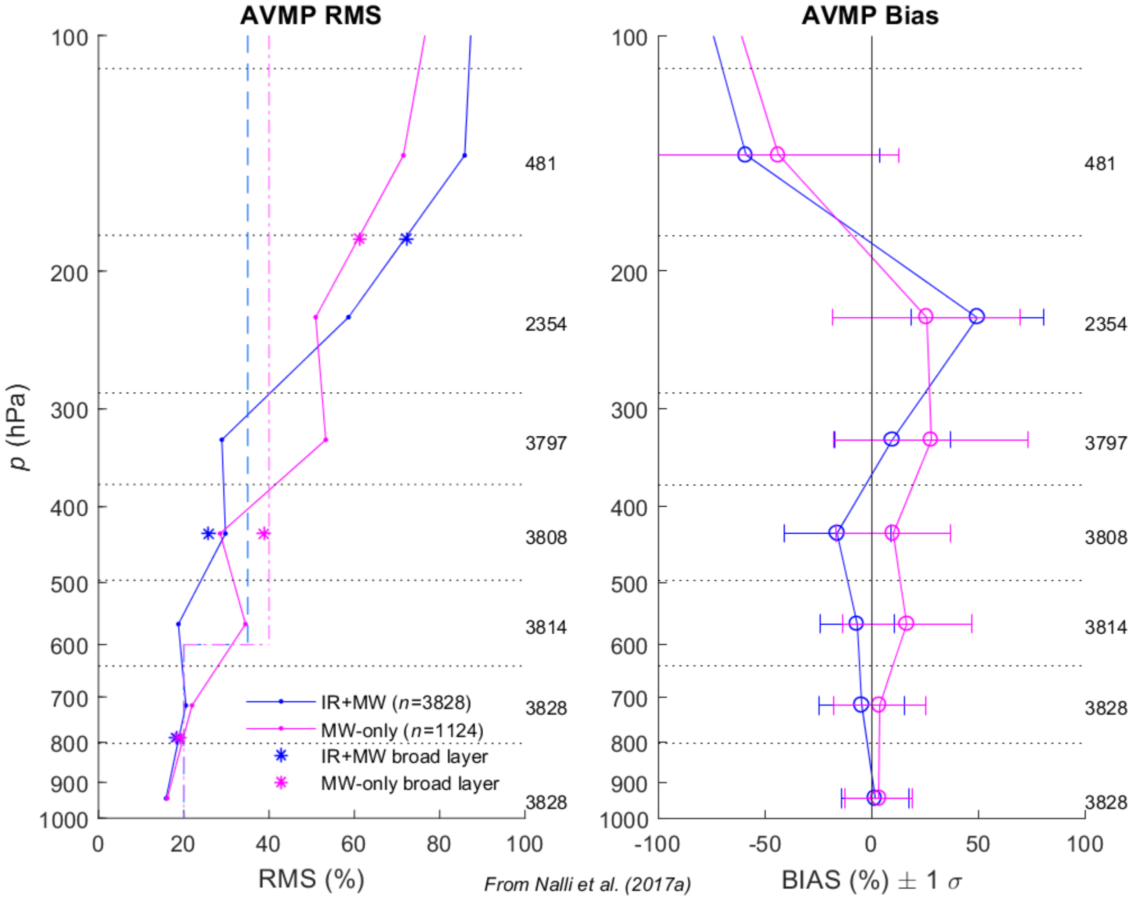


IR+MW Yield = 63.3%
MW-only Yield = 91.9%

AVMP Versus RAOB

IR+MW
MW-Only

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



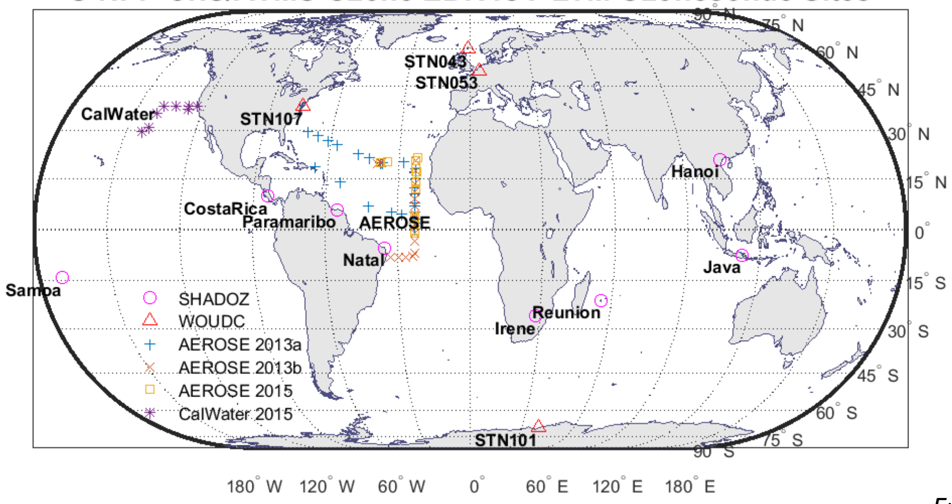
From Nalli et al. (2017a)

SNPP NUCAPS (NSR v1.5) Dedicated/Reference Ozonesonde Collocation Sample

Collocated Ozonesondes for O_3 Profile EDR

- **Dedicated Ozonesondes**
  - **NOAA AEROSE** (*Nalli et al.* 2011)
  - **CalWater/ACAPEX 2015**
- **Sites of Opportunity**
  - **SHADOZ** (*Thompson et al.* 2007)
    - Costa Rica
    - Hanoi
    - Irene
    - Java
    - Natal
    - Paramaribo
    - Reunion
    - American Samoa
  - **WOUDC**
    - STN043
    - STN053
    - STN107
    - STN101

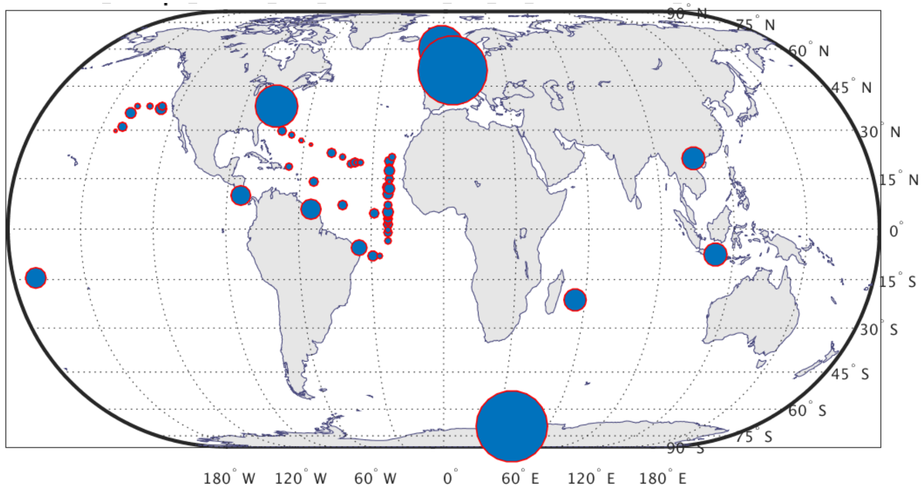
S-NPP CrIS/ATMS Ozone EDR ICV-LTM Ozonesonde Sites



From Nalli et al. (2017b)

Geographic Sample Histogram (Equal Area)

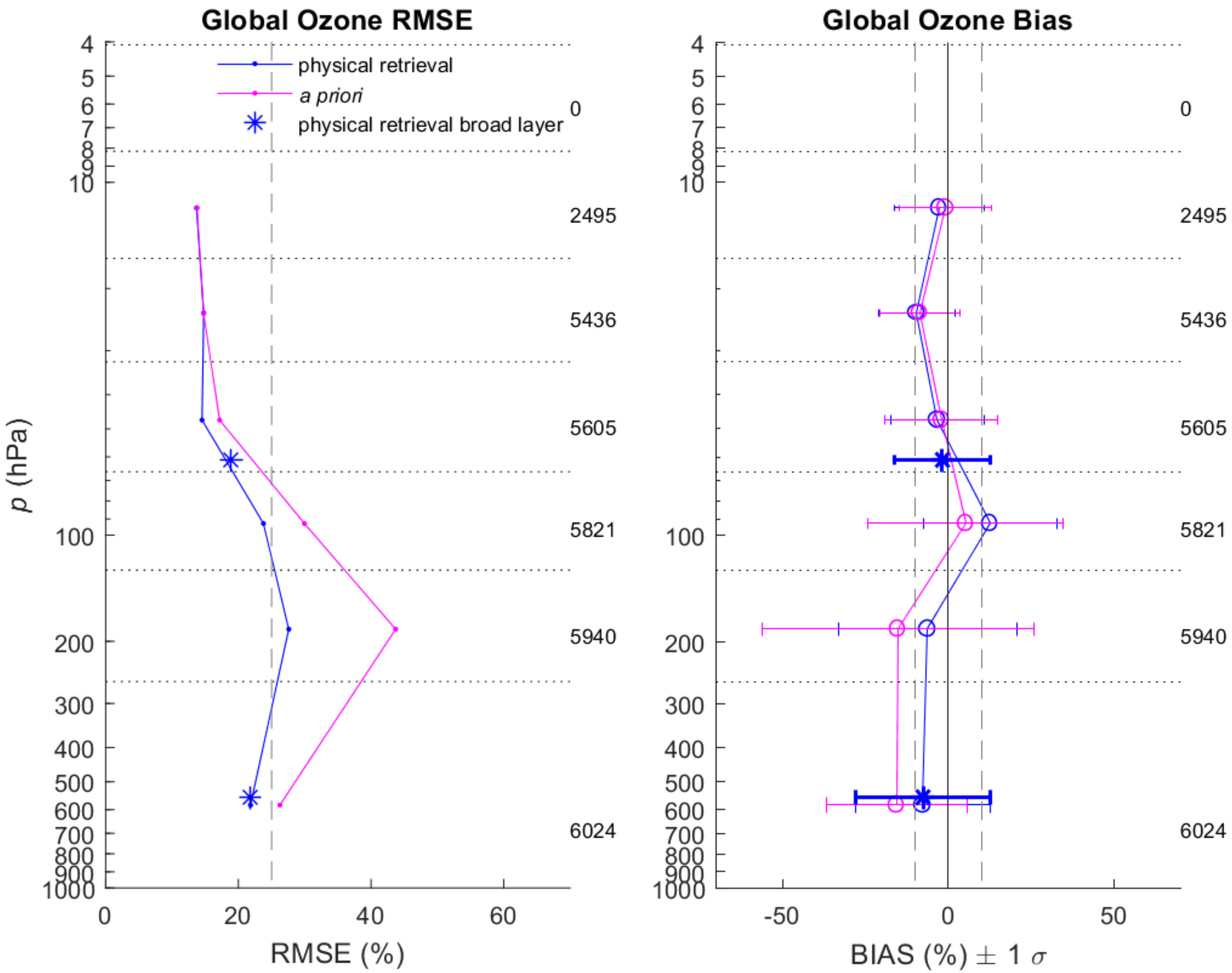
FOR Collocation Criteria: $\delta x \leq 125$ km, $-240 < \delta t < +120$ min



NUCAPS IR Ozone Profile Coarse-Layer Statistics
NSR (v1.5) versus Global Ozonesondes

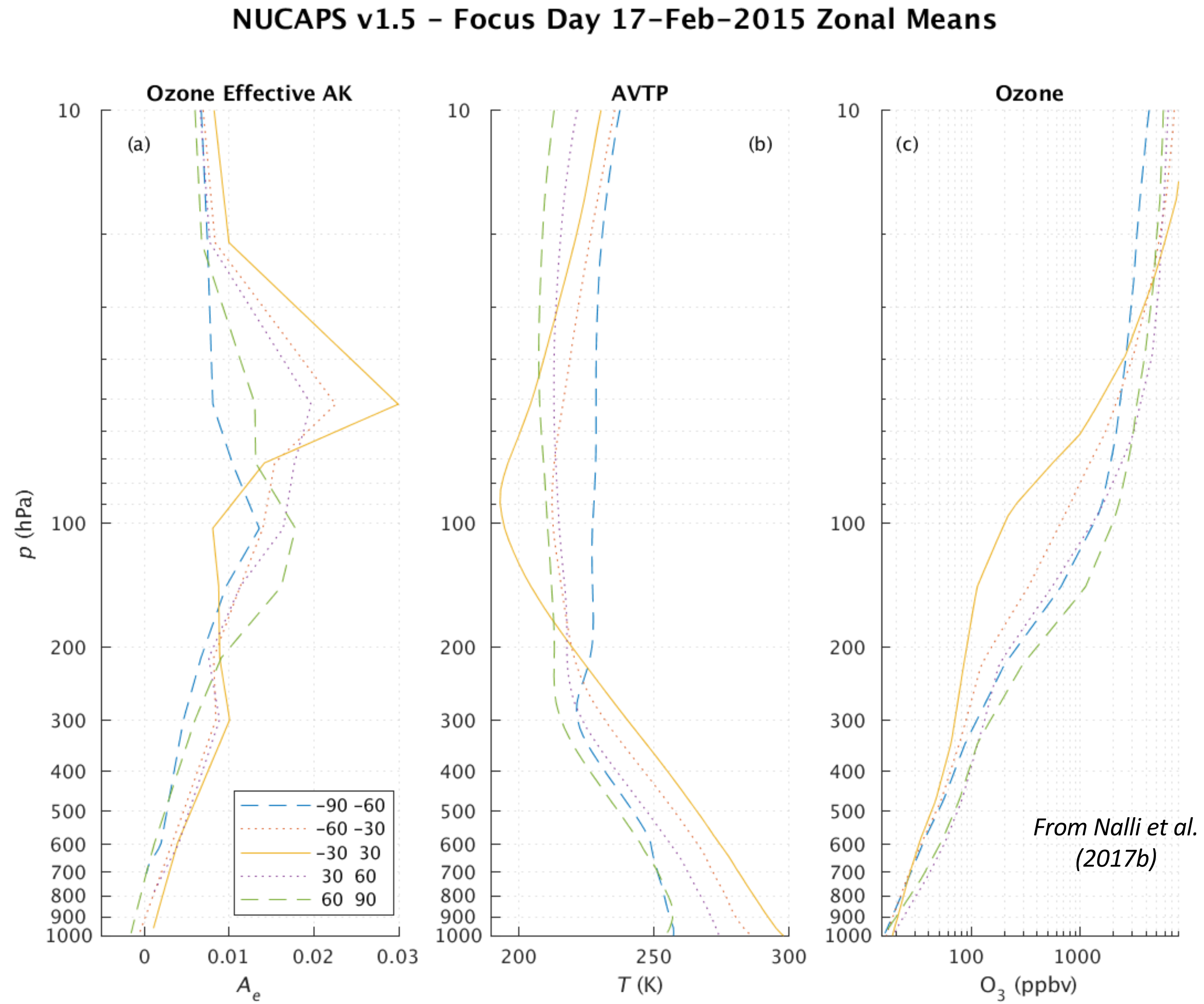
Retrieval and ***A Priori***

IR+MW Yield = 62.2%



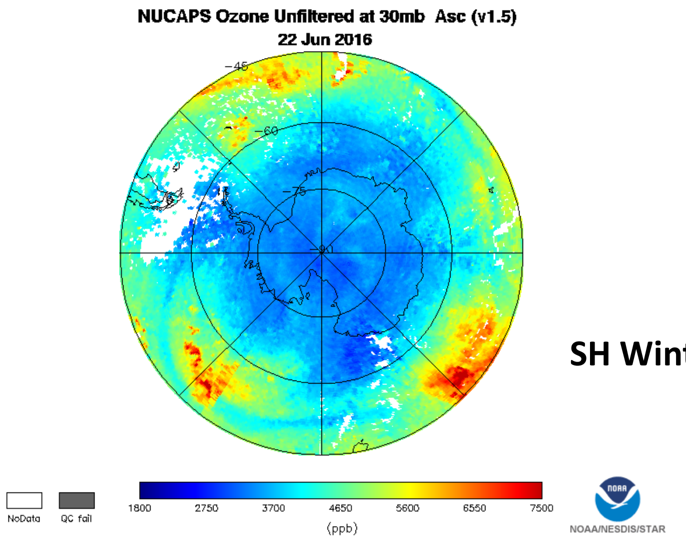
From Nalli et al. (2017b)

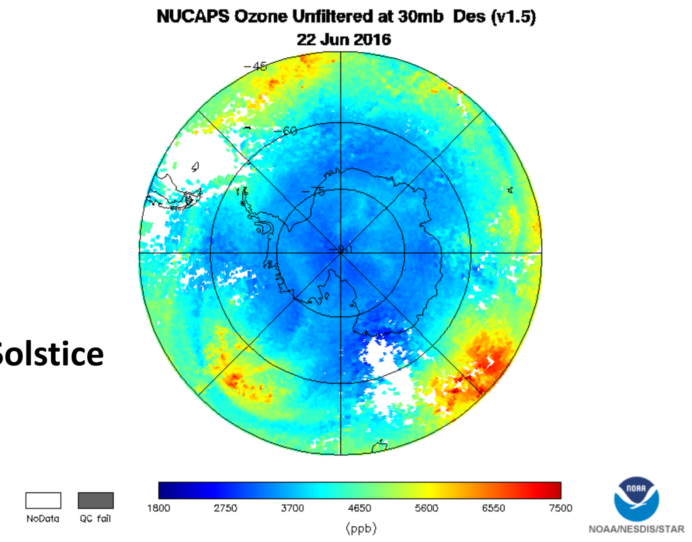
NUCAPS IR Ozone Zonal Mean Sensitivity



From Nalli et al. (2017b)

NUCAPS IR Ozone Profile EDR: Ozone Hole Over Antarctica

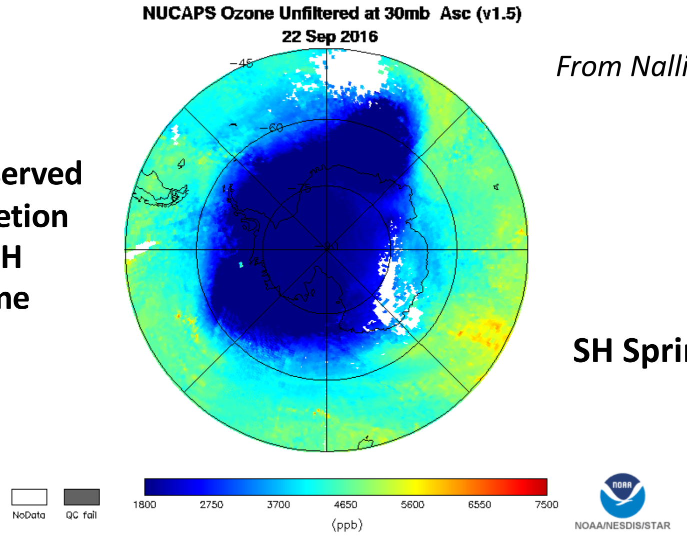


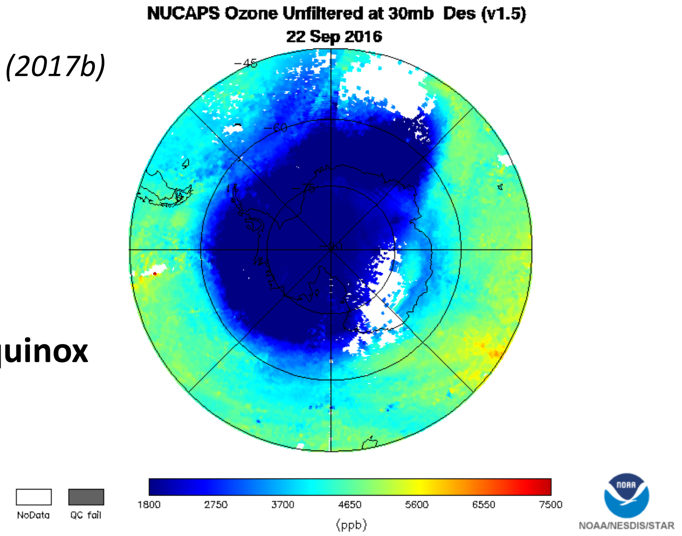


SH Winter Solstice

From Nalli et al. (2017b)

NUCAPS observed ozone depletion during SH springtime





SH Spring Equinox

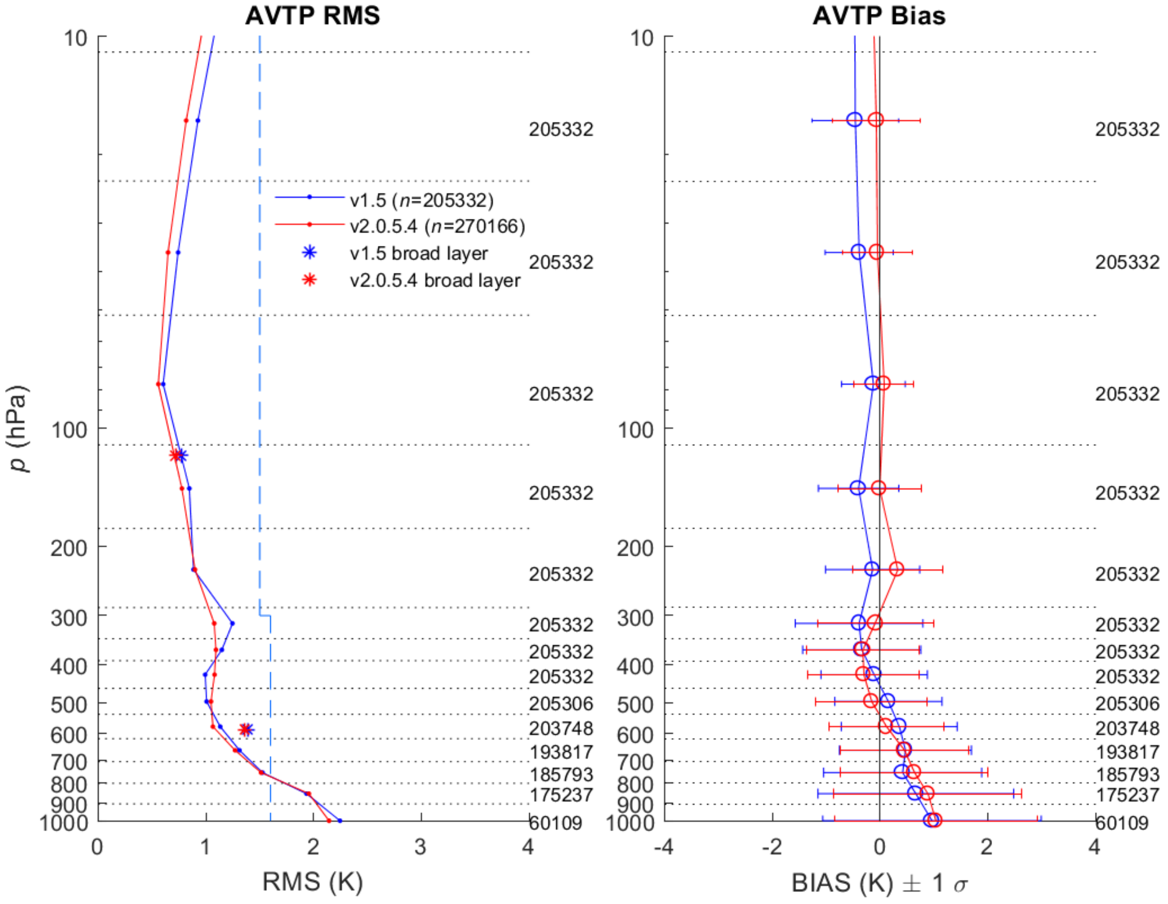
SNPP NUCAPS Validation

NUCAPS PHASE 4 V2.0 FSR VALIDATION STATUS

NUCAPS v2.0 FSR IR+MW T/H_2O Coarse-Layer Statistics
Global Focus Day 17-Feb-2015

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

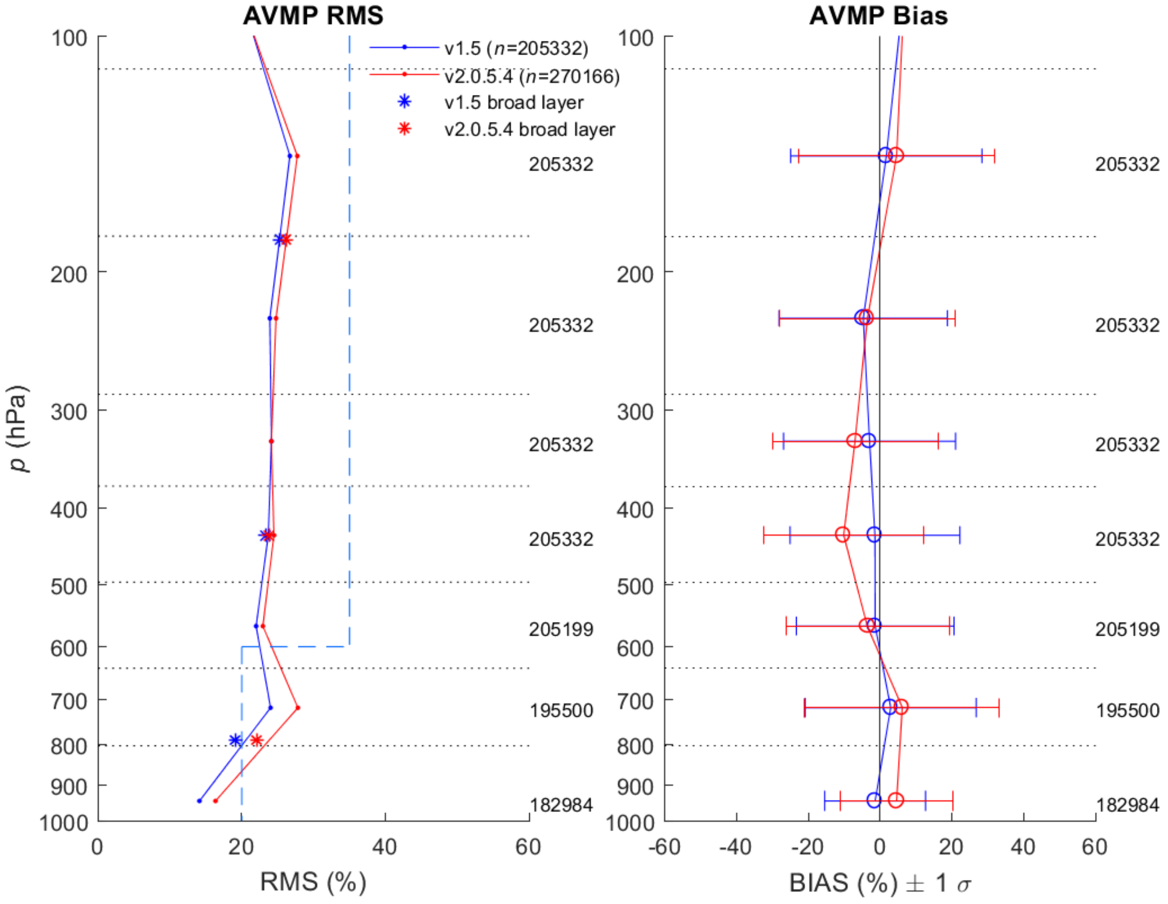
AVTP Versus ECMWF



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

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

AVMP Versus ECMWF



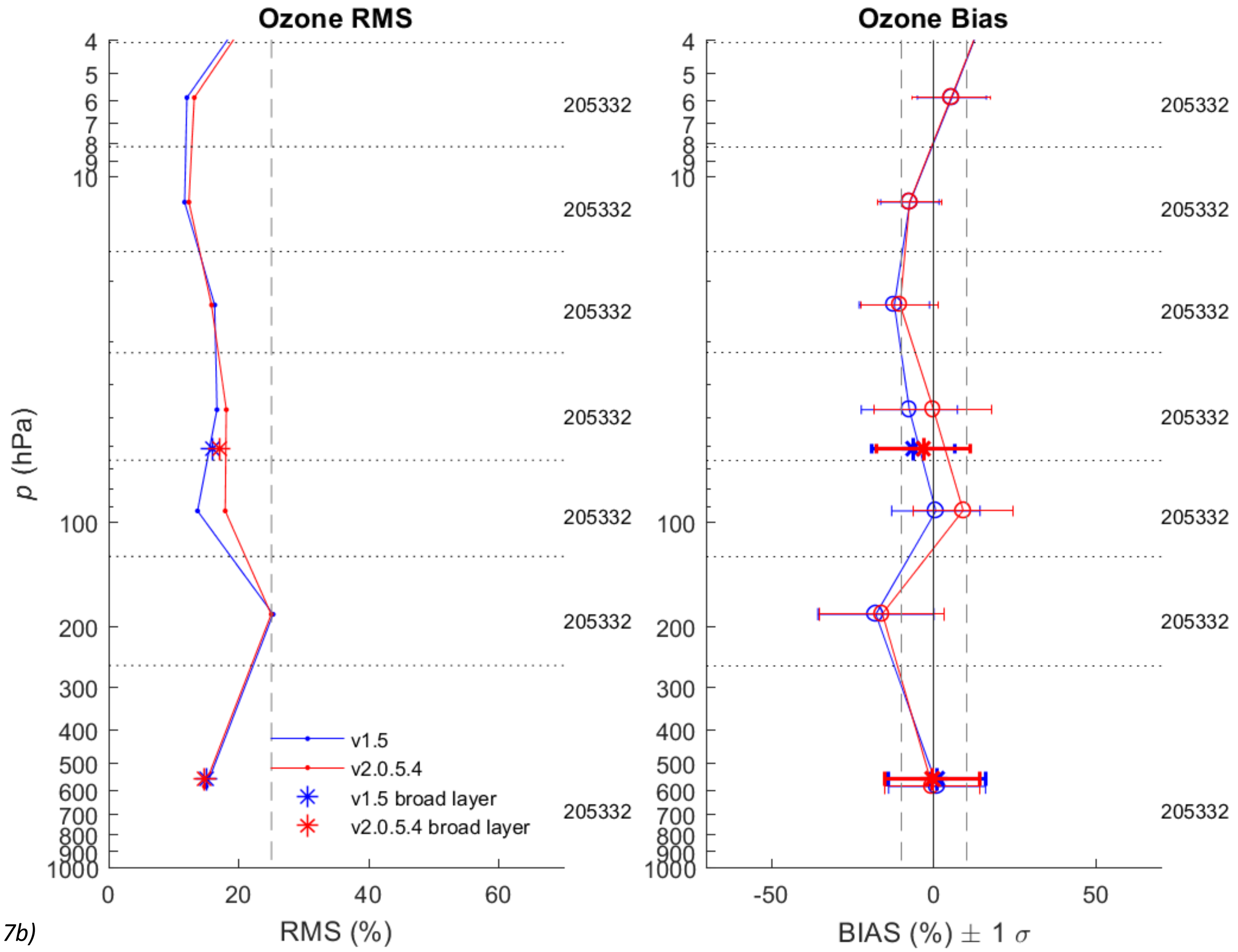
From Nalli et al. (2017a)

NUCAPS v2.0 FSR Ozone Profile Coarse-Layer Statistics
Global Focus Day 17-Feb-2015

IR Ozone Profile Versus ECMWF

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

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

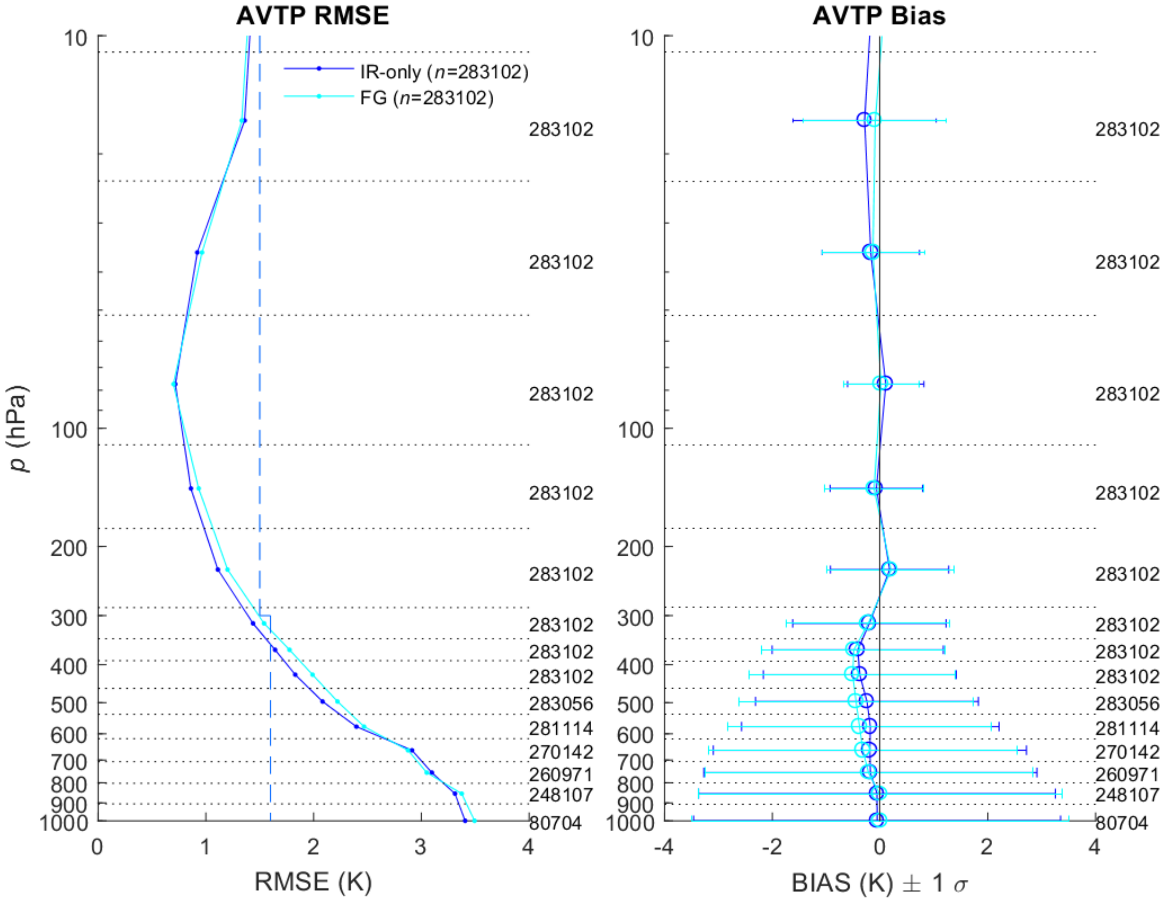


From Nalli et al. (2017b)

NUCAPS v2.0 FSR <u>IR-Only</u> T/H_2O Coarse-Layer Statistics
Global Focus Day 17-Feb-2015

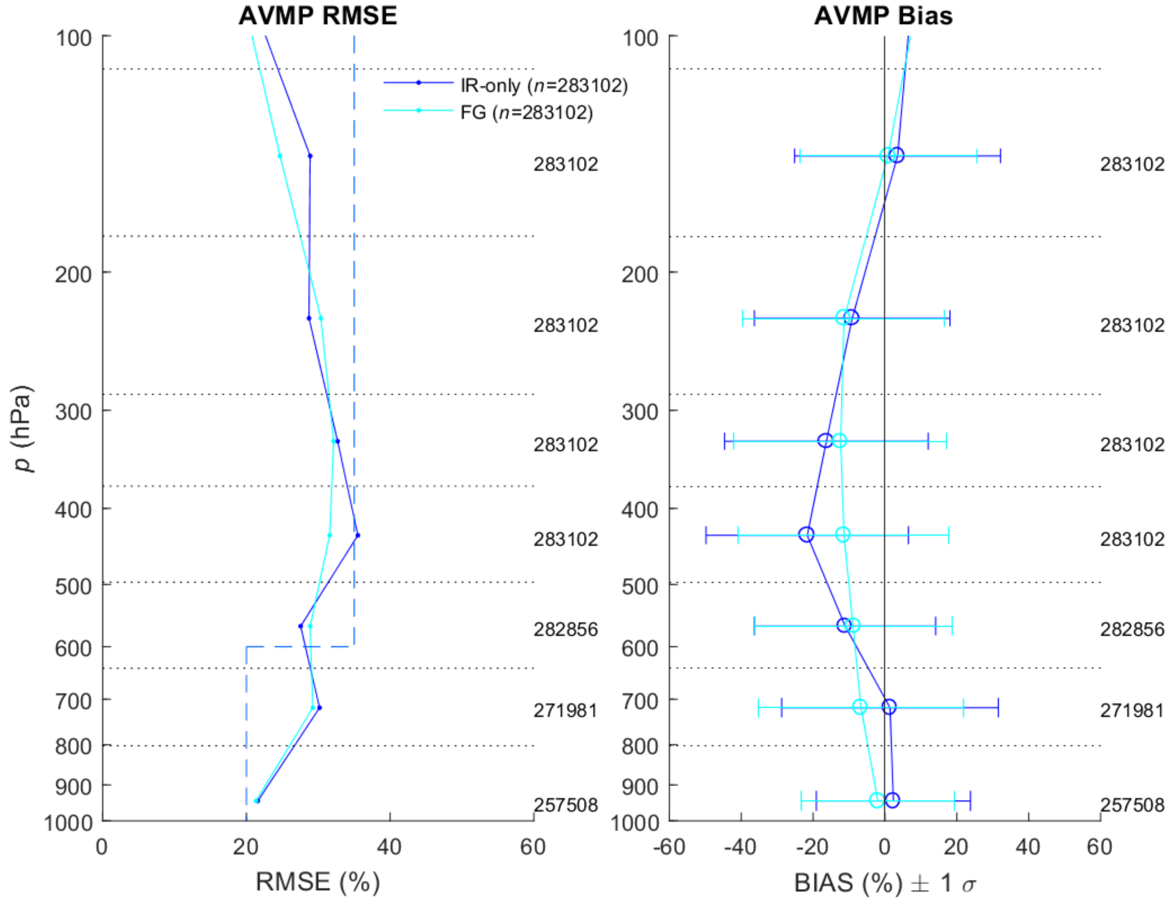
IR-Only
First Guess

AVTP Versus ECMWF



IR-Only Yield = 87.4%

AVMP Versus ECMWF



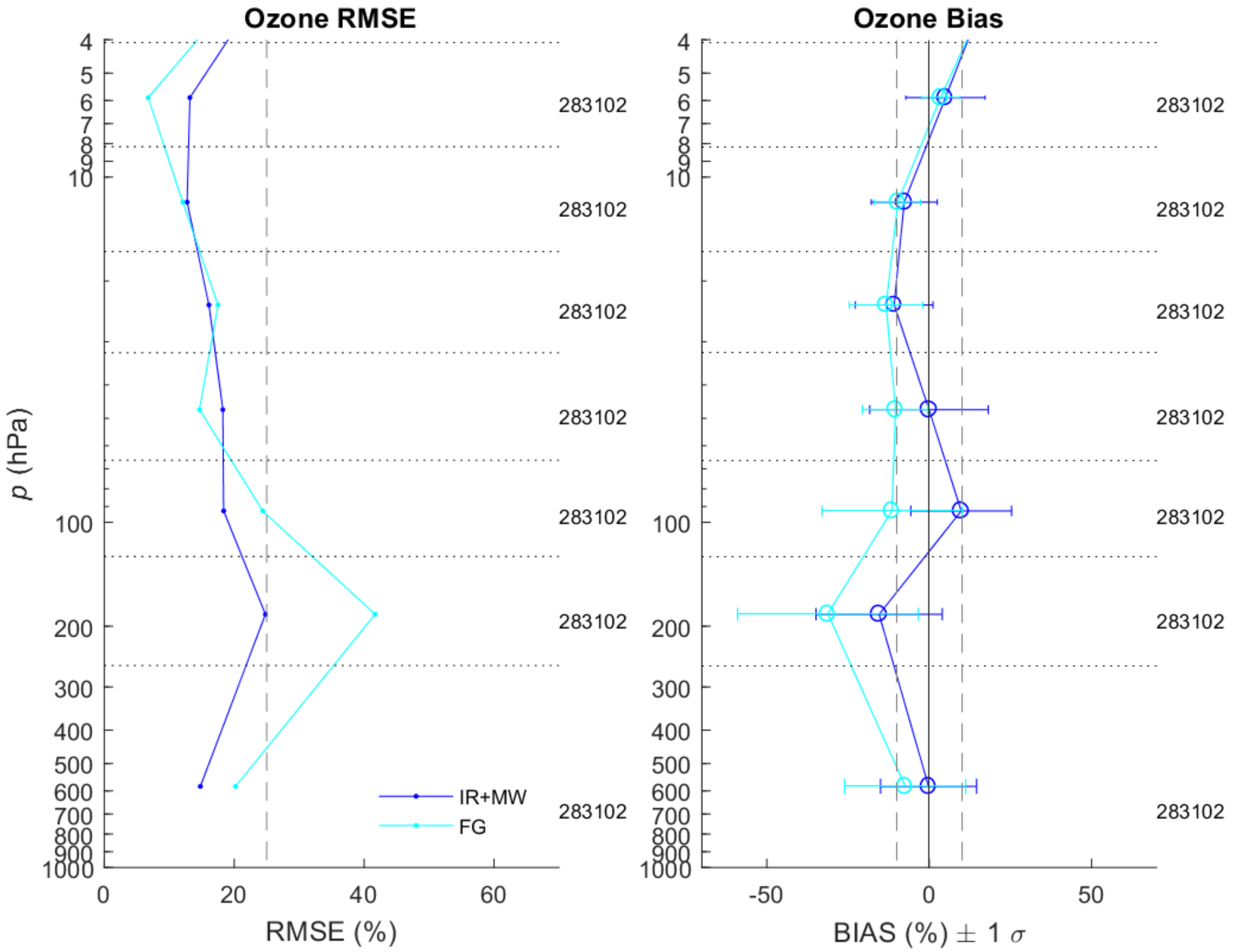
NUCAPS v2.0 FSR IR-Only Ozone Coarse-Layer Statistics
Global Focus Day 17-Feb-2015

IR Ozone Profile Versus ECMWF

IR-Only

First Guess

IR-Only Yield = 87.4%

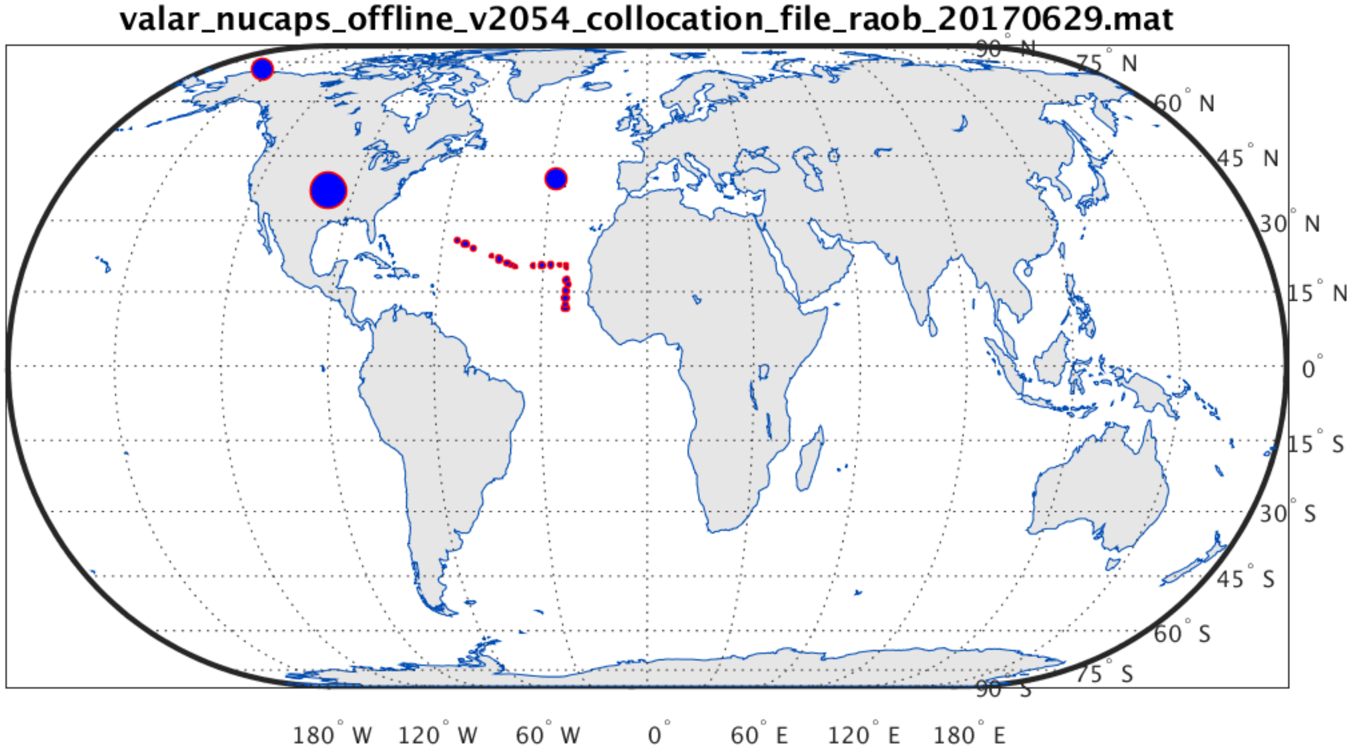


JPSS Dedicated RAOBs (March to July 2017)

- **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

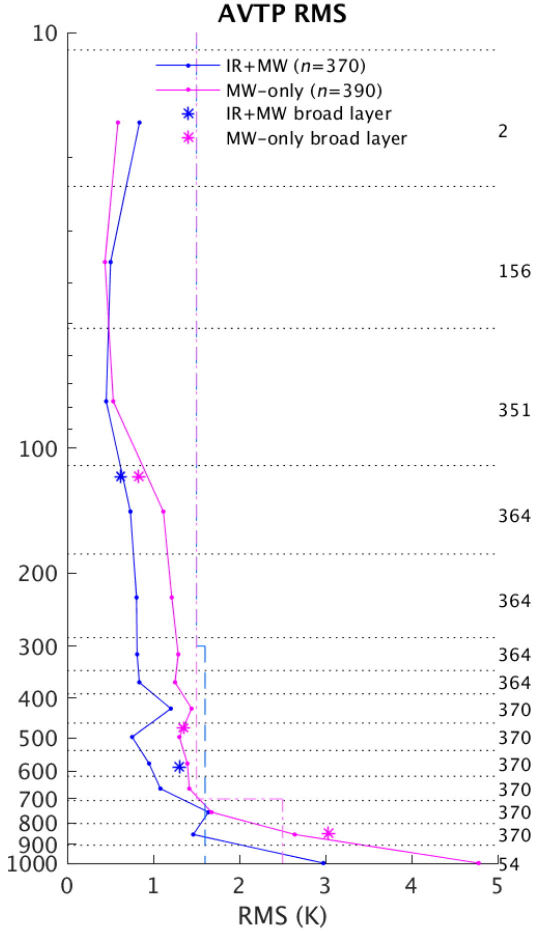
δx = 75 km, δt = −90 to +5 min

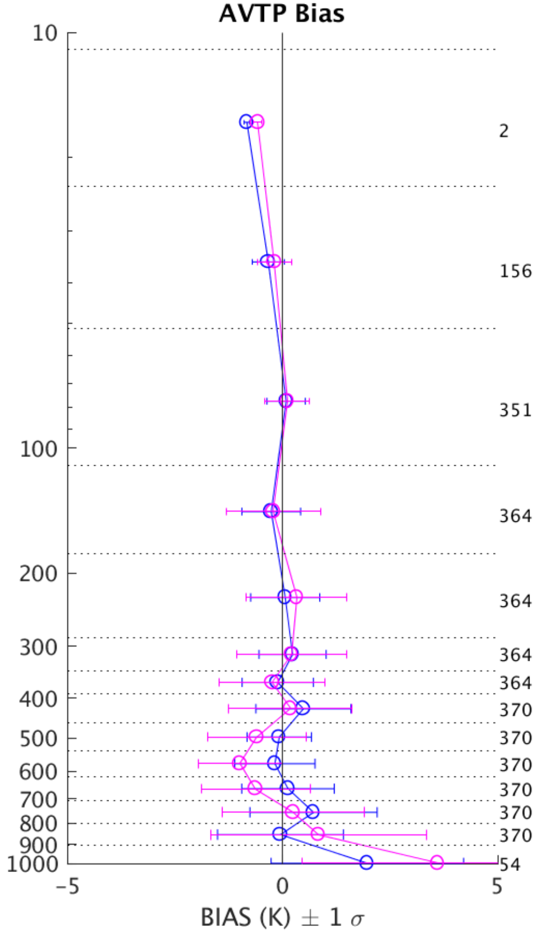


NUCAPS v2.0 FSR IR+MW T/H_2O Coarse-Layer Statistics Versus JPSS Dedicated RAOBs

AVTP Versus RAOB

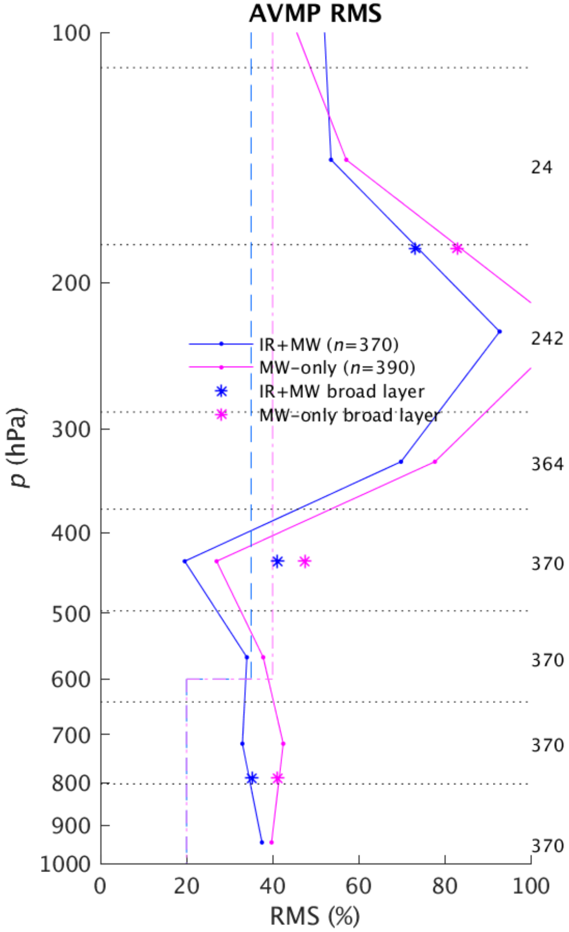
IR+MW
MW-Only

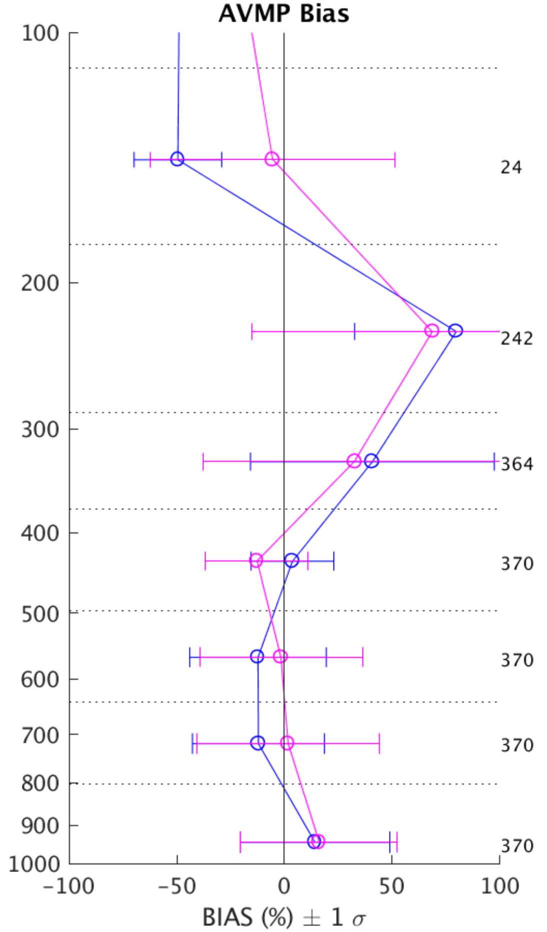




AVMP Versus ECMWF

IR+MW
MW-Only





IR+MW Yield = 75.7%

NUCAPS EDR Maturity Status

Slide courtesy of Lihang Zhou, STAR/JPSS

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

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Summary and Future Work

- **SNPP NUCAPS NSR (v1.5) T/H_2O/O_3 EDRs meet JPSS global requirements**
  - Validated Maturity attained for AVTP/AVMP/O3 EDRs
- 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 Validated Maturity Review**
    - **Ready 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

THANK YOU! QUESTIONS?

SNPP NUCAPS Validation

EXTRA SLIDES