NUCAPS SNPP and NOAA-20 Validation Status

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2018 NASA Sounder Science Team Meeting
Greenbelt, Maryland, USA
October 2018

Acknowledgments

- **Sounder EDR Validation Dataset collection**
  - **U.S. DOE Atmospheric Radiation Measurement (ARM) program dedicated RAOBs**
    - *D. Holdridge* and *J. Mather* (ARM Climate Research Facility)
  - **NOAA AEROSE:** *Veronon Morris, E. Joseph, M. Oyola, E. Roper* (HU/NCAS); *P. J. Minnett* (UM/RSMAS); *D. Wolfe* (NOAA/ESRL)
  - **CalWater/ACAPEX:** *R. Spackman* (NASA); *R. Leung* (PNNL); *C. Fairall, J. Intrieri* (NOAA)**;** *N. Hickmon, M. Ritsche*, and ARM Mobile Facility 2 (AMF2)
  - **Beltsville Site:** *R. Sakai, Siwei Li* (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.)
  - **Carbon Trace Gases:** *Monika Kopacz (NOAA/UCAR), Greg Frost (NOAA/ESRL)*
  - **NASA Sounder Science Team:** *E. Olsen, T. Pagano, E. Fetzer (NASA/JPL)*
  - **Total Carbon Column Observing Network (TCCON)** (*D. Wunch et al.*), TCCON Data Archive, hosted by the Carbon Dioxide Information Analysis Center (CDIAC), tccon.onrl.gov
  - **Atmospheric Tomography (ATom) Mission:** *Kathryn McCain*, *Colm Sweeney (NOAA/ESRL)*, https://doi.org/10.3334/ORNLDAAC/1581

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

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

Outline

- **JPSS Sounder EDR Cal/Val Overview**
  - JPSS Level 1 Requirements
  - Validation Hierarchy recap
  - NUCAPS Algorithm
    - Overview of Recent Upgrades

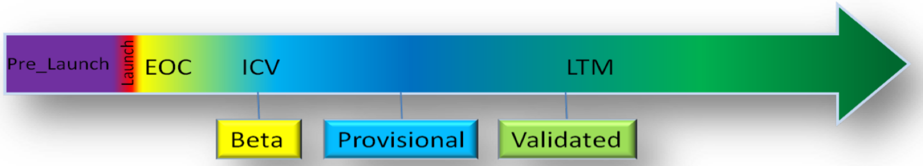
- **NUCAPS Validation Status**
  - NUCAPS NOAA-20 Provisional Maturity
    - $T/H_2O/O_3$ EDRs versus ECMWF
    - $CO/CH_4/CO_2$ versus TCCON
    - O_3 versus ozonesondes
  - NUCAPS Carbon Trace Gas (SNPP) Status of Validated Maturity Effort
    - CO, CH_4, CO_2 versus ATom

NUCAPS Validation

JPSS SOUNDER EDR CAL/VAL OVERVIEW

JSTAR Cal/Val Program (*Zhou, Divakarla, and Liu* 2016)

- **JSTAR 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



- Sounder EDR validation methodology is based upon AIRS and IASI (*Nalli et al.*, 2013, *JGR Special Section on SNPP Cal/Val*)

- **J-1 (NOAA-20) sounder EDR Cal/Val Plan** (Dec 2015)
  - The Cal/Val Plan included for the first time the validation of carbon trace gas EDRs (CO, CH_4 and CO_2), but the details had not been completely ironed out at that time.

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, AEROSE, RIVAL, CalWater**, JAIVEX, AWEX-G, EAQUATE

Carbon Trace Gases

1. **Numerical Model Global *Comparisons***
   - Examples: NOAA CarbonTracker (*Lan et al.* 2017), 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 observations (*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)
   - **ATom**, **WE-CAN**, **ACT-America**, **FIREX**

JPSS Specification Performance Requirements
CrIS/ATMS Temperature and Moisture Profile EDR Uncertainty

Temperature Profile

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

Moisture Profile

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

"Clear to Partly-Cloudy"
(Cloud Fraction < 50%)
⇕
IR+MW 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
Ozone Profile	**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%
Carbon Gases	**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

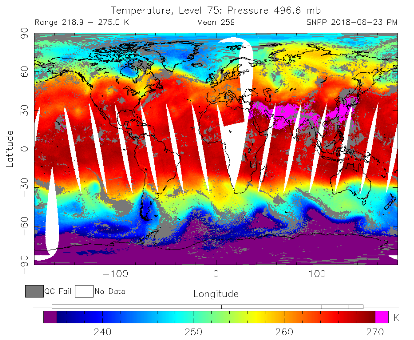
Source:
(L1RD, 2014, pp. 45-49)

NOAA Unique Combined Atmospheric Processing System (NUCAPS) Algorithm

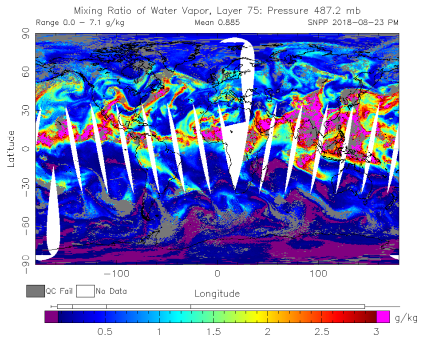
- **Operational algorithm**
  - **NOAA Enterprise Algorithm** for CrIS/IASI/AIRS (*Susskind, Barnet and Blaisdell,* 2003; *Gambacorta et al.,* 2014)
    - **Cf. Antonia Gambacorta's talk**
  - Global non-precipitating conditions
  - **Atmospheric Vertical Temperature** and **Moisture Profiles** (**AVTP**, **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)
    - Stability Indices (cf. Callyn Bloch's talk)

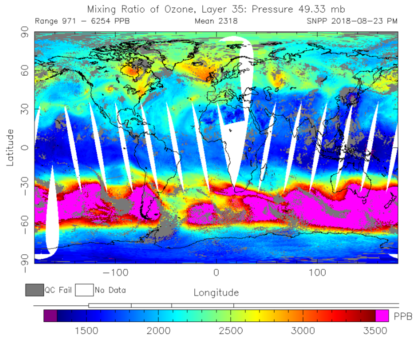
AVTP (500 hPa)



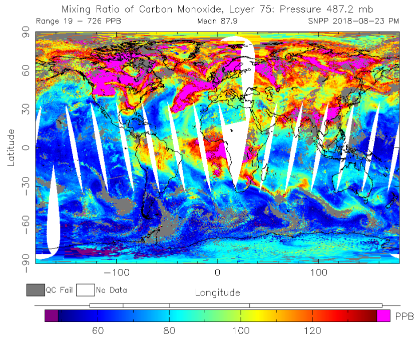
AVMP (500 hPa)



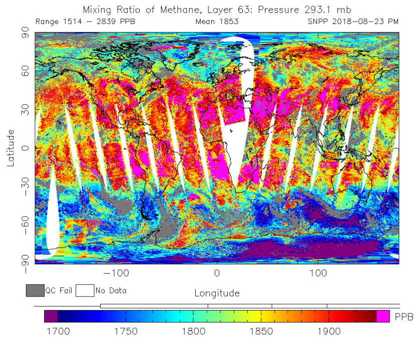
Ozone (50 hPa)



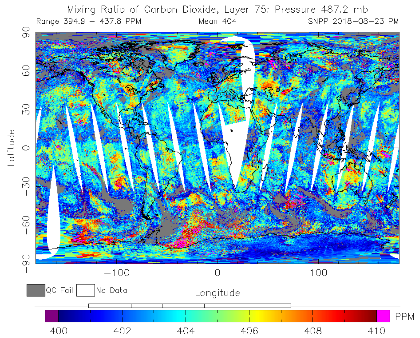
Carbon Monoxide (500 hPa)



Methane (300 hPa)



Carbon Dioxide (500 hPa)



https://www.star.nesdis.noaa.gov/jpss/EDRs/products_Soundings_2018.php
http://www.ospo.noaa.gov/Products/atmosphere/soundings/nucaps/index.html

NUCAPS Development and Offline Versioning

- **Version 1 (CrIS NSR)**
  - **V1.5**
    - **Operational system beginning in September 2013**
    - Ran on **CrIS nominal spectral-resolution (NSR)**
    - **Validated Maturity** for AVTP/AVMP EDR attained Sep 2014
  - V1.8 to V1.9
    - 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 (Phase 4, CrIS FSR)**
  - Runs on **CrIS full-res (FSR)** data (FSR SARTA by L. Strow et al., UMBC)
  - 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
    - V2.1.2 code delivered and transitioned into operations
  - V2.1.4
    - New "clouds" namelist including new channel selections from Chris Barnet (STC) for cloud clearing and cloud heights
  - V2.1.9 (builds on v2.1.V2.1.10a
    - New CO *a priori*
  - V2.1.10n (builds on v2.1.9)
    - New CO *a priori*
    - New *T, Q*, CCR channels
    - CO QC
    - Old Tuning
  - V2.1.11a, b
    - New CO channels to 2200 cm^{-1}
    - New CO and CH_4 Tunings
  - V2.1.12
    - Modified "preferred" CO QC to new "relaxed" CO QC, allowing regions over Africa (for example) to pass where they previously failed
    - V2.1.12b
      - New tuning/rtaerr, returned to the truncated 35 channel CO list ending at 2191.25.
      - These tuning sets caused more issues than they solved.
    - V2.1.12c
      - Partial compromise between the issues in the V2.1.12 namelists and the improvements in V2.1.11 and the code changes. Uses V2.1.11a, but included the truncated CO channels (35) in the ozone namelists and the new "relaxed" CO tuning introduced at NUCAPS V2.1.12.
      - **NOAA-20 Provisional Maturity for AVTP/AVMP, Beta Maturity for O3/CO/CH4/CO2, 15 June 2018**
    - V2.1.12d
      - Deletes a cloud-clearing channel from version v2.1.12c
      - Current delivered version
  - V2.2 (current offline test version)
    - Cf. Letitia Soulliard's talk

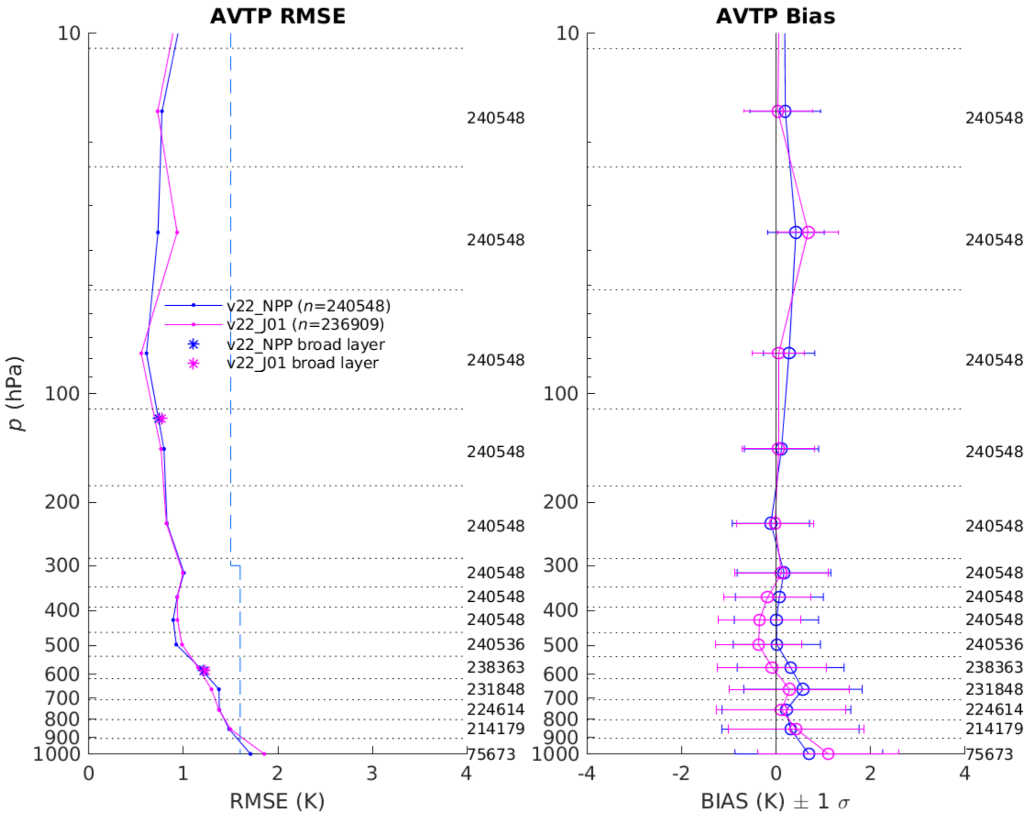
NUCAPS Validation

NUCAPS NOAA-20 VALIDATION STATUS

NUCAPS NOAA-20 (v2.2) IR+MW T/H_2O EDR Coarse-Layer Stats
Baseline: ECMWF Global Focus Day 20-Aug-2018

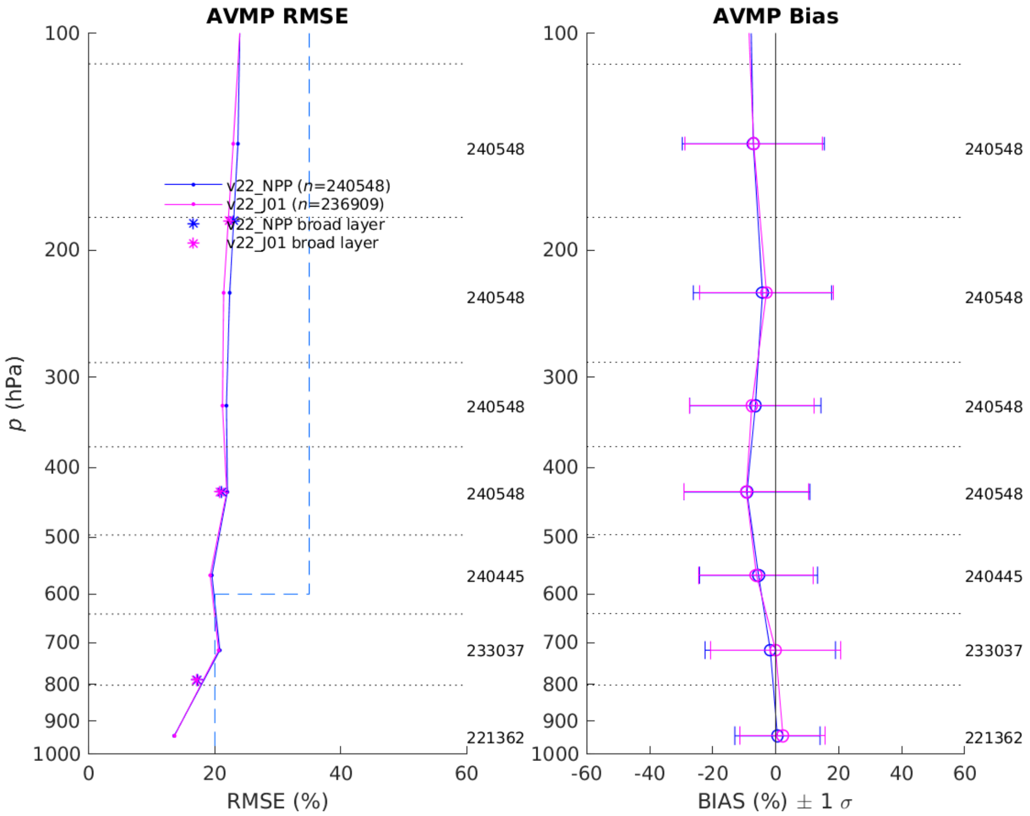
SNPP
NOAA-20

AVTP Versus ECMWF



SNPP
NOAA-20

AVMP Versus ECMWF



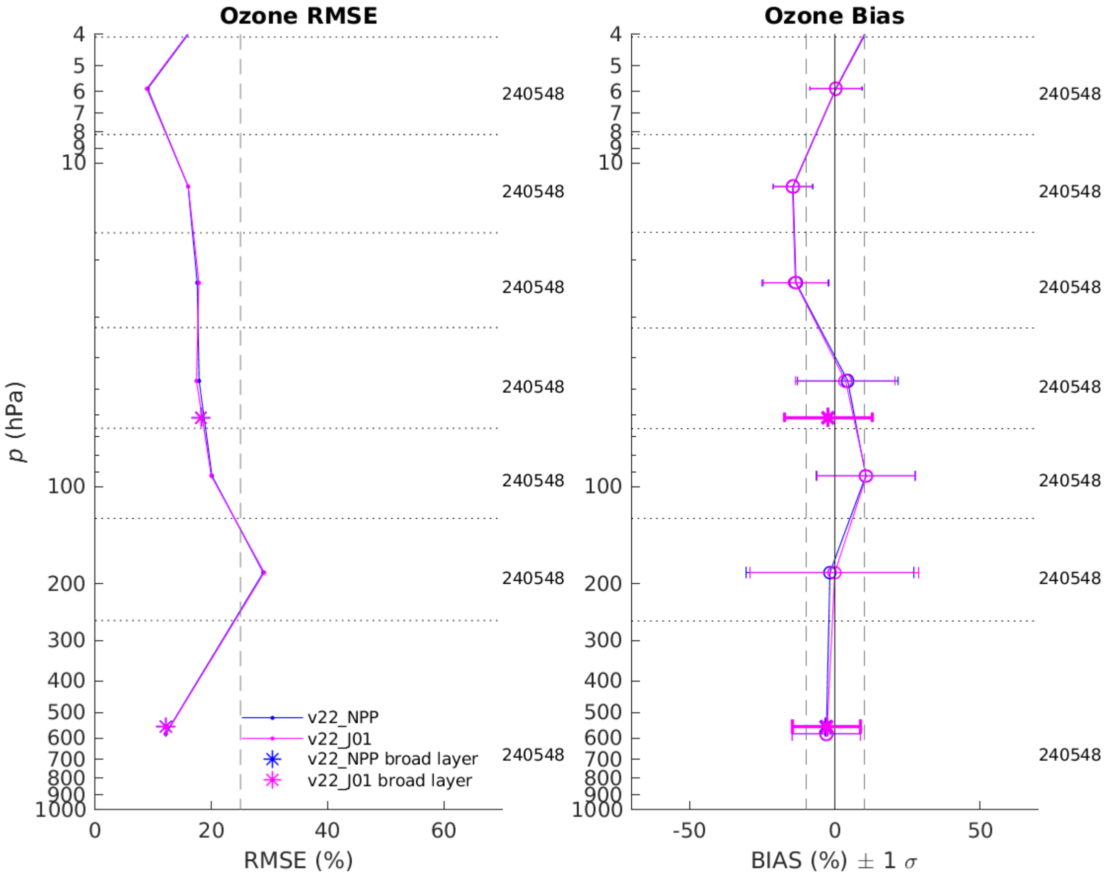
NOAA-20 Yield = 73.3%
SNPP Yield = 76.4%

NUCAPS (v2.2) IR Ozone Profile EDR Coarse-Layer Statistics
Baseline: ECMWF Global Focus Day 20-Aug-2018

IR Ozone Profile Versus ECMWF

SNPP
NOAA-20

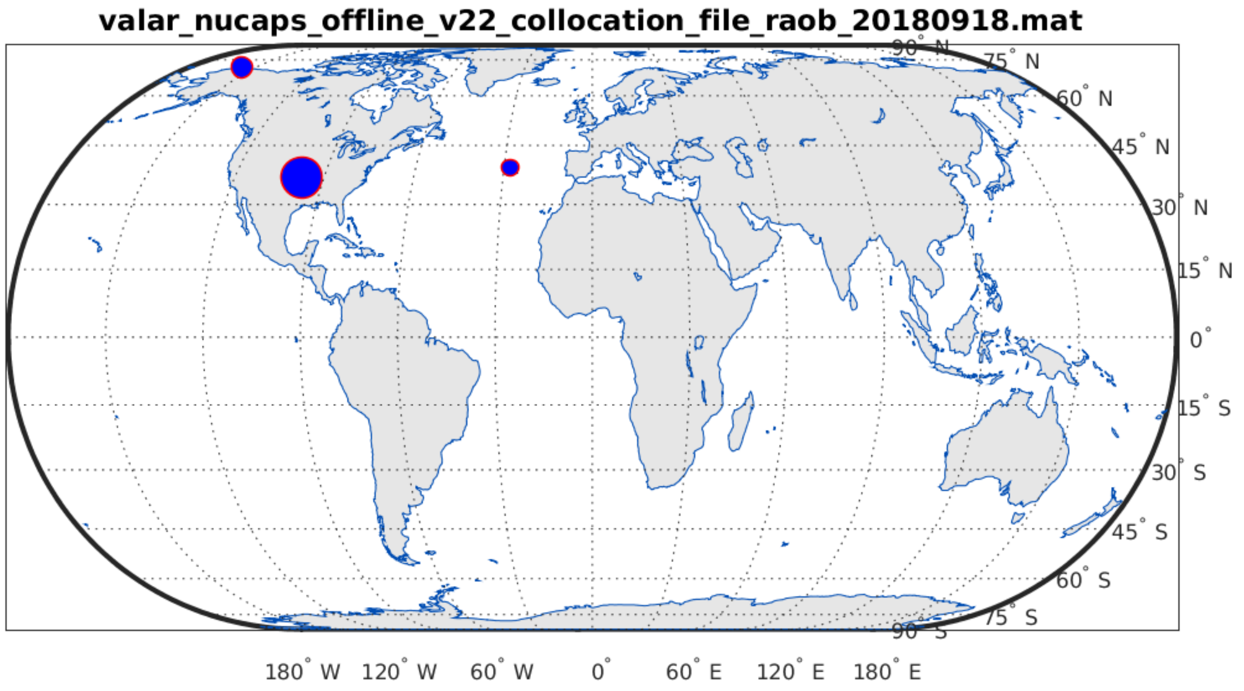
NOAA-20 Yield = 73.3%
SNPP Yield = 76.4%



From Nalli et al. (2017b)

Preliminary NUCAPS NOAA-20 T/H_2O Statistical Assessment versus ARM Site Dedicated RAOBs

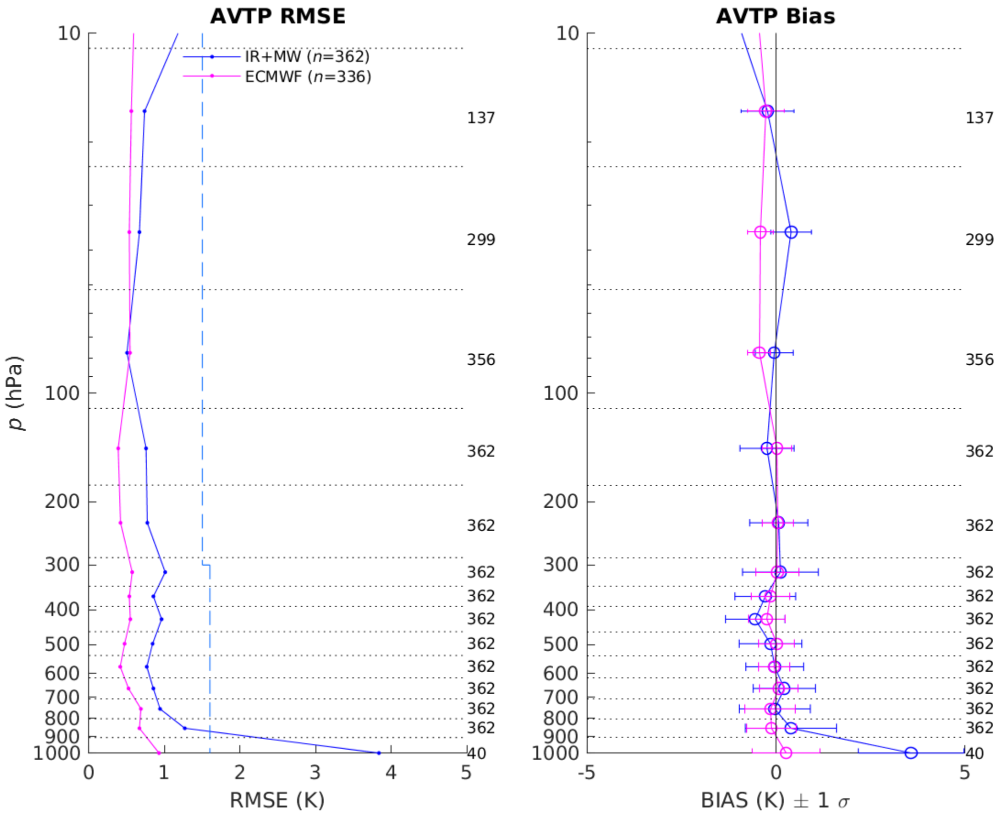
- **NOAA-20 dedicated radiosondes** have been launched at **Atmospheric Radiation Measurement (ARM)** sites beginning in February 2018
  - **Southern Great Plains (SGP)**
    - **Radiosonde Intercalibration and Validation (RIVAL) campaign** (Lori Borg, UW/CIMSS, et al.)
  - **Eastern North Atlantic (ENA)**
  - **North Slope of Alaska (NSA)**
  - **Currently lacking Tropical site;** hopefully **2019 AEROSE campaign will mitigate this**
- RAOB data are collocated with satellite overpasses via the **NOAA Products Validation System (NPROVS)** (*Reale et al.* 2012; *Sun et al.* 2017)
  - HDF formatted collocation files provided to NUCAPS team
- NOAA-20 NUCAPS field-of-regard (FOR) matches from **NPROVS** are then used to acquire SDR/TDR granules in a **validation archive (VALAR)** for offline test and operational versions of NUCAPS



NUCAPS NOAA-20 (v2.2) IR+MW *T*/H_2O EDR Coarse-Layer Stats
Baseline: ARM-Site Dedicated RAOBs

IR+MW
ECMWF

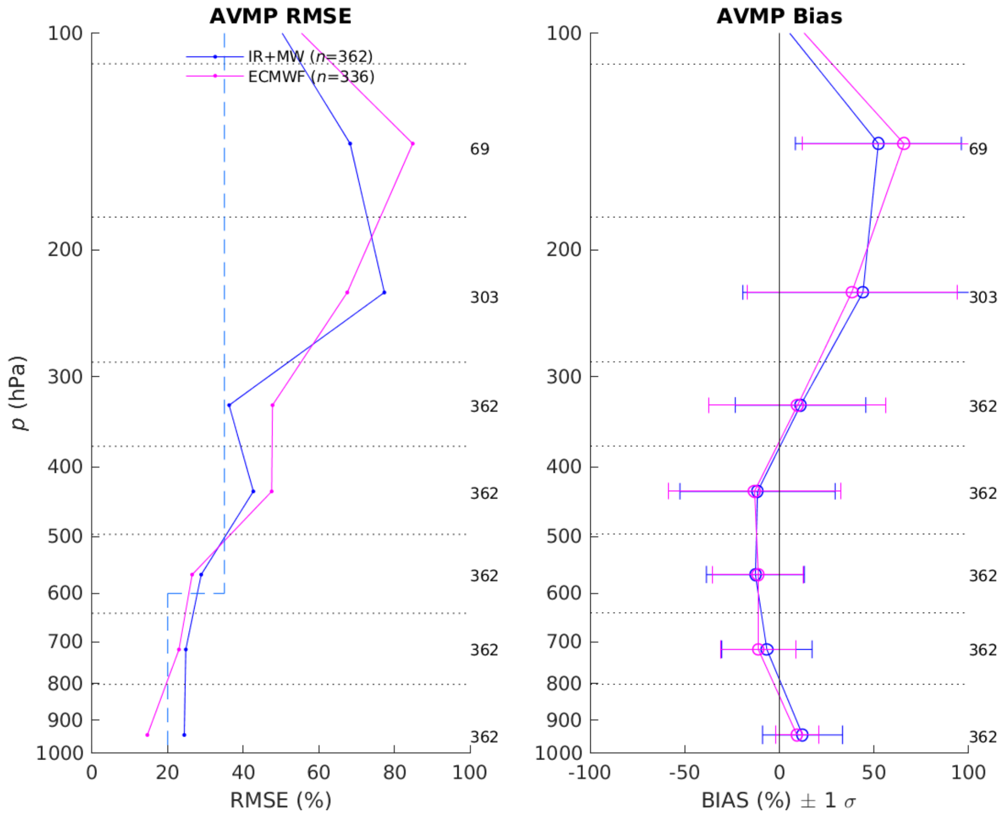
AVTP Versus RAOB



NOAA-20 Yield = 79.6%

IR+MW
ECMWF

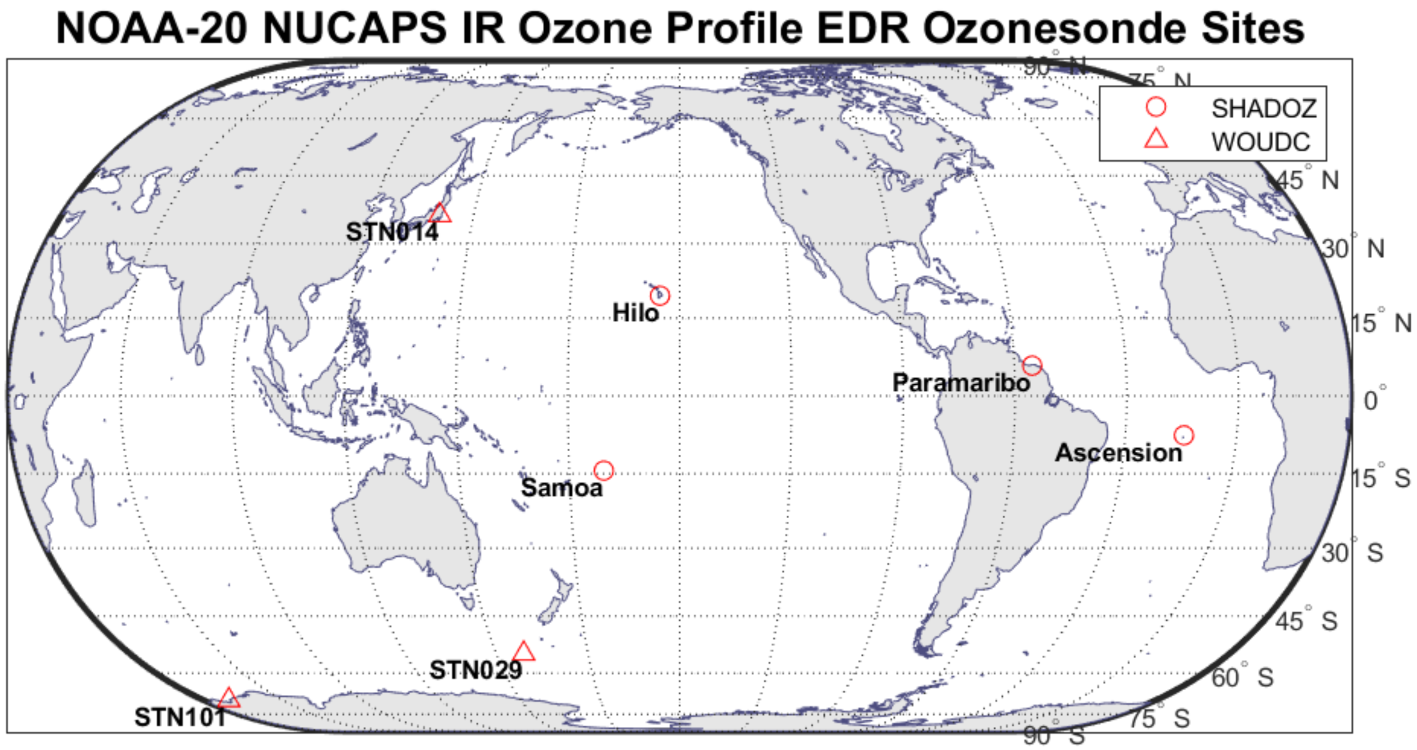
AVMP Versus RAOB



Preliminary NUCAPS NOAA-20 O_3 Statistical Assessment vs SHADOZ and WOUDC Ozonesondes

NOAA-20 collocated ozonesondes

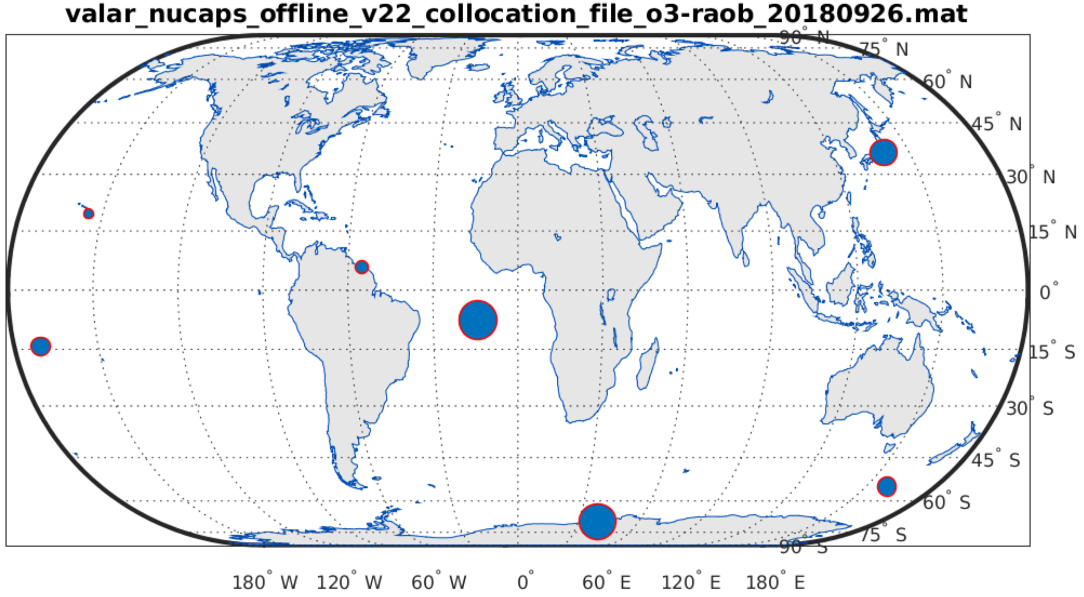
- **Sites of Opportunity**
  - **SHADOZ** (*Thompson et al.* 2007)
    - Paramaribo
    - Hilo, Hawaii
    - Ascension Island
    - American Samoa
  - **WOUDC**
    - STN014
    - STN029
    - STN101

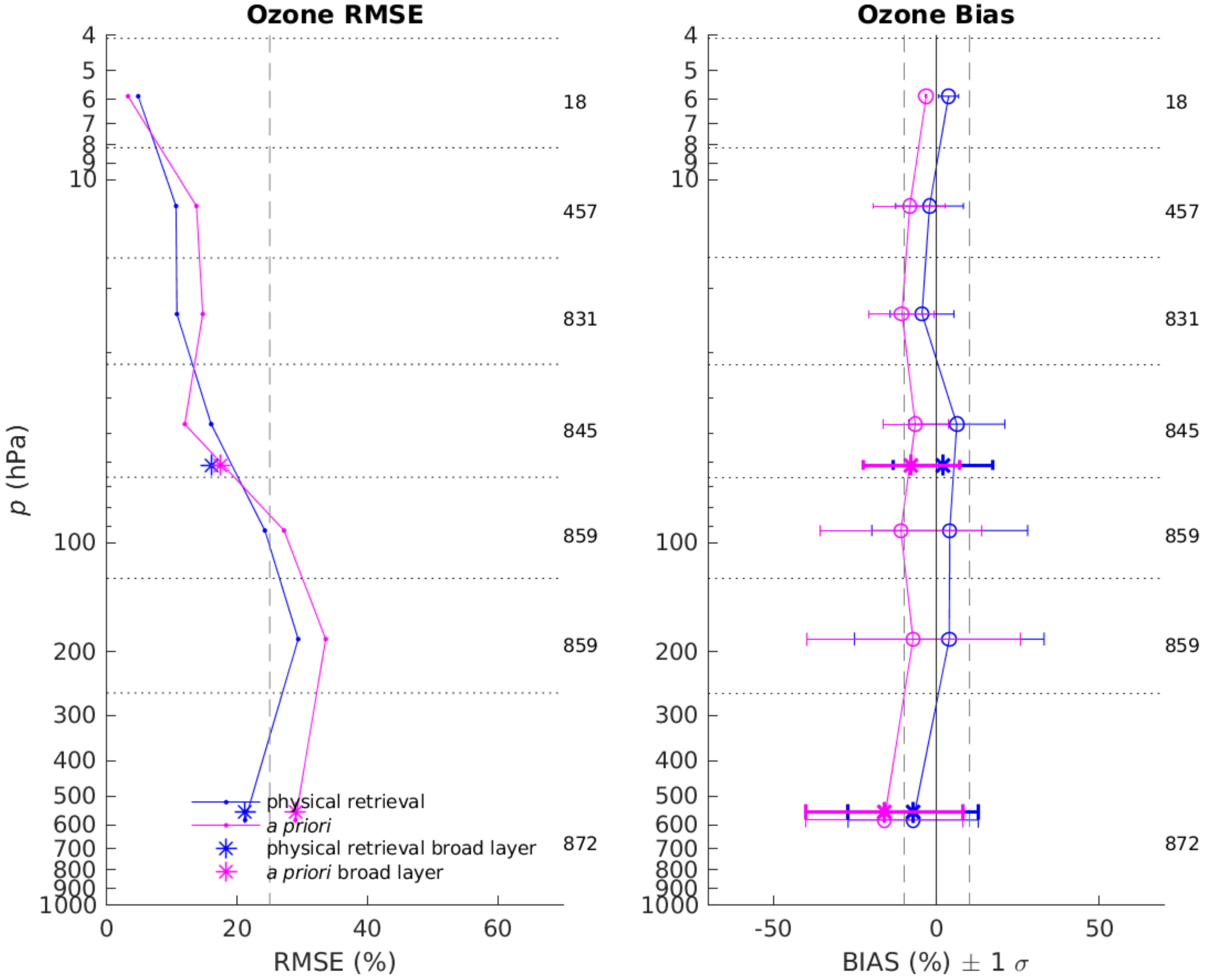


NUCAPS NOAA-20 (v2.2) IR Ozone Profile EDR Coarse-Layer Stats
Baseline: SHADOZ and WOUDC Ozonesondes

NOAA-20 Ozonesonde Collocations

(125 km, −4 to +2 hours)





NUCAPS Validation

NUCAPS SNPP CARBON TRACE GAS STATUS

Overview of Carbon Trace Gas Validation

- **Carbon trace gas EDR validation** versus JPSS program established uncertainty specifications is a **new sounder validation requirement** that began during the transition period to the **FSR CrIS NUCAPS**

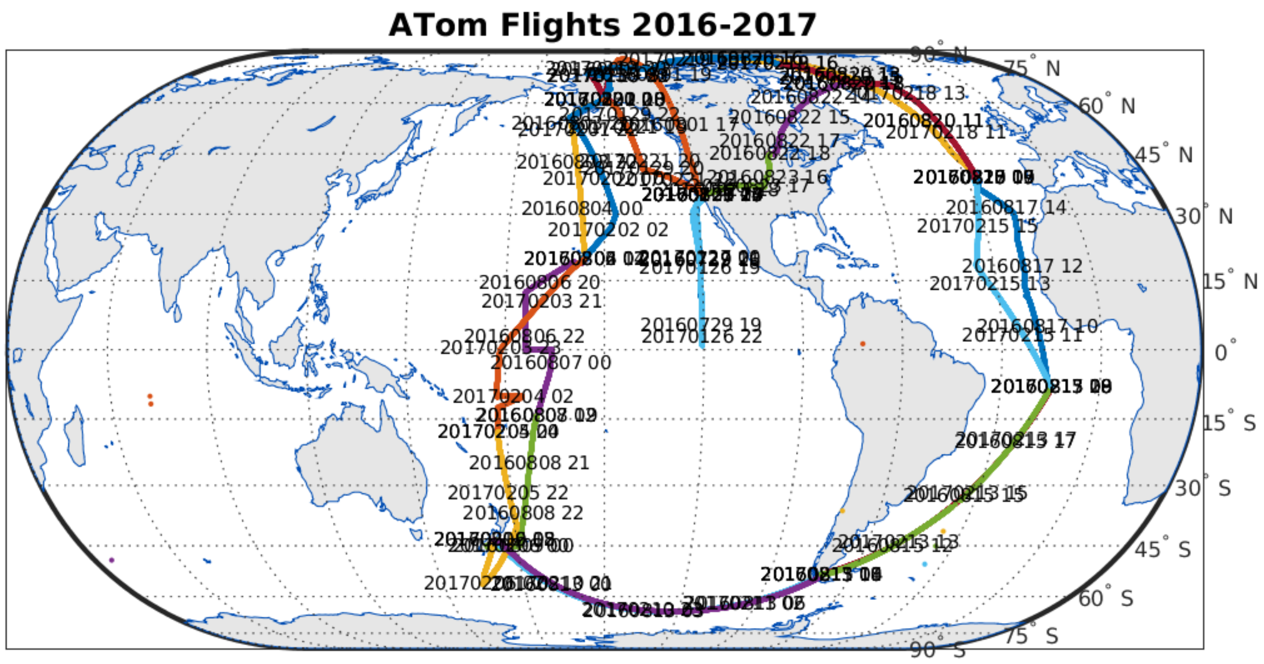
- Validation strategy leverages **global truth datasets**, including
  - **Satellite EDRs** from Global Focus Days (Cal/Val Method #2)
    - Valuable for inter-satellite stability
    - Aqua AIRS; potential future work: OCO-2, MLS
  - **Total Carbon Column Observing Network (TCCON)** (*Wunch et al.* 2011) (Cal/Val Method #3)
    - Global network of ground-based FTS that accurately measure total column abundances of CO_2, CO, CH_4, N_2O trace gases
    - Provides "spot checks" for verifying NUCAPS and AIRS
  - **ATom campaigns** (Cal/Val Method #4)
  - **AirCore** (Cal/Val Method #3, future work)

- **Collocation Methodology**
  - Include all FOR within threshold radius (e.g., 150 km) time window (e.g., ±2 hours)

- **Trace Gas Quality assurance (QA)**
  - NUCAPS IR+MW quality flag
  - NUCAPS trace gas QA flags
    - CO trace gas flags developed and tested
    - CH4 and CO2 trace gas flags still undergoing development

Atmospheric Tomography (ATom) Mission
(*Wofsy et al.* 2018)

- **ATom** deployed extensive gas and aerosol payloads on the **NASA DC-8** aircraft for global-scale sampling of the atmosphere, **profiling continuously from 0.2–12 km altitude**
- **Flights** occurred spanning 4 seasons originating from the Armstrong Flight Research Center, Palmdale, California
  - North to western Arctic, south to South Pacific, east to Atlantic, north to Greenland, and return to CA across central North America
- In this work we use the **NOAA PICARRO** ATom-1 and -2 datasets
  - PIs: Kathryn McKain and Colm Sweeney (CIRES, U. of Colorado, NOAA/ESRL)
- ***Source:*** [***https://espo.nasa.gov/atom/***](https://espo.nasa.gov/atom/)



Applying NUCAPS Effective Averaging Kernels (AKs)

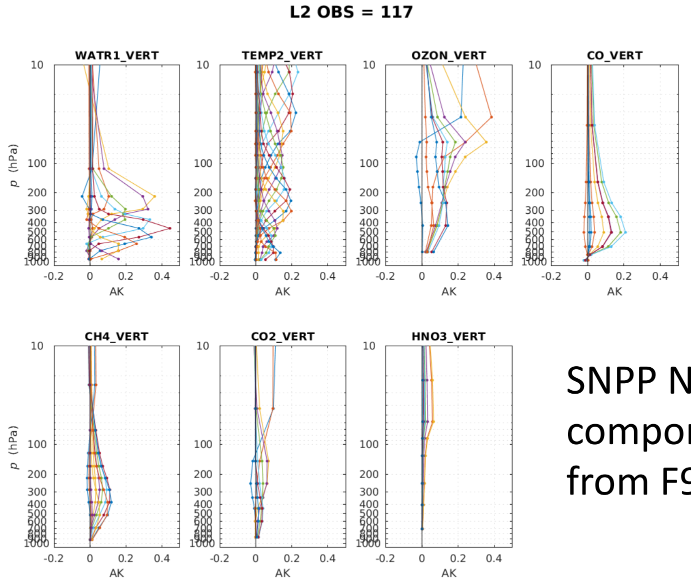
- **AKs** define the **vertical sensitivity** of the sounder measurement system

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

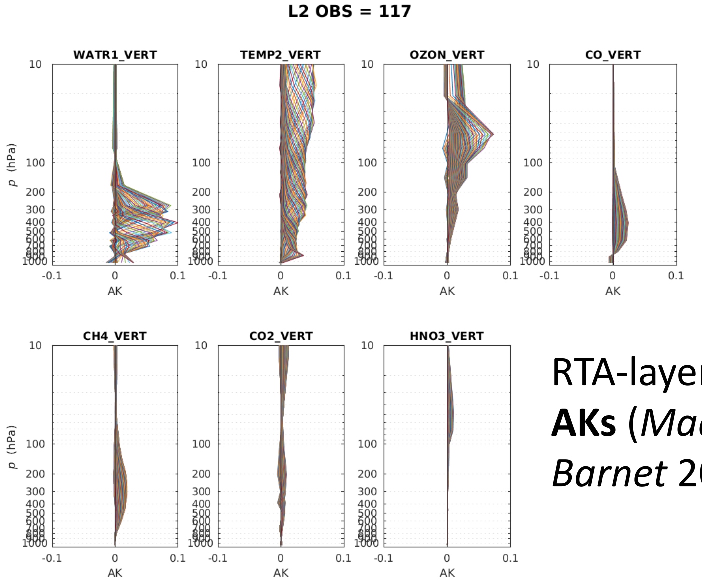
- This facilitates **intercomparisons** of measurements obtained by two different observing systems

- The **NUCAPS effective AKs, $\mathbf{A_e}$**, (*Maddy and Barnet* 2008) can be used to "smooth" correlative truth (at RTA layers), thereby **removing null-space errors** otherwise present, i.e.

$$\mathbf{x_S} = \exp\{\ln(\mathbf{x_0}) + \mathbf{A_e}[\ln(\mathbf{x}) - \ln(\mathbf{x_0})]\}$$



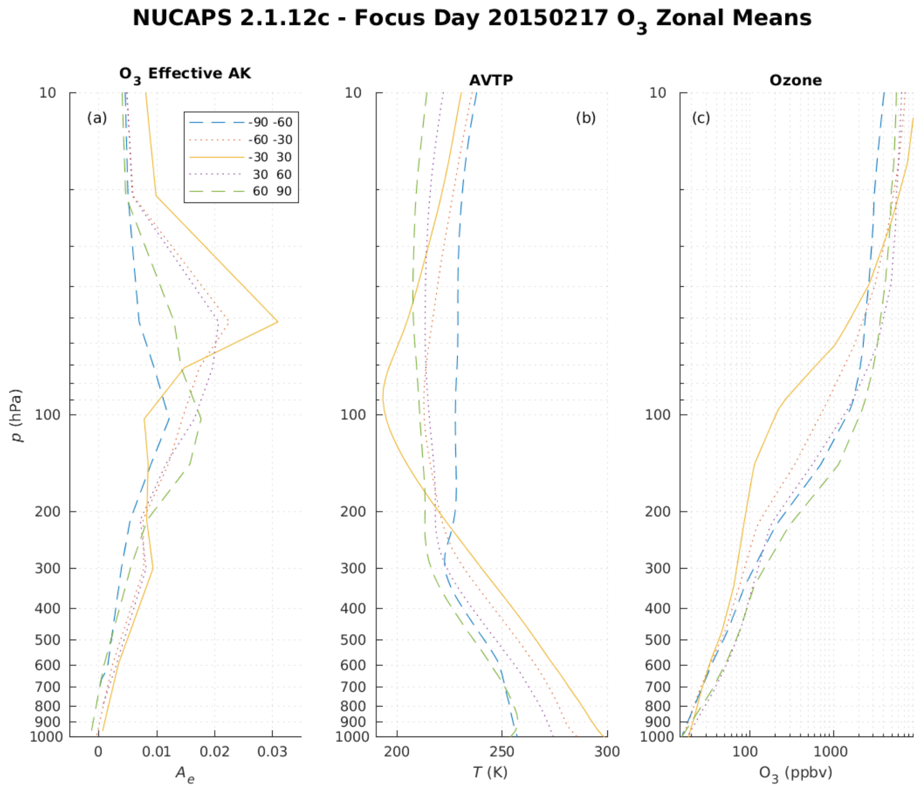
SNPP NUCAPS component AKs from F93 files



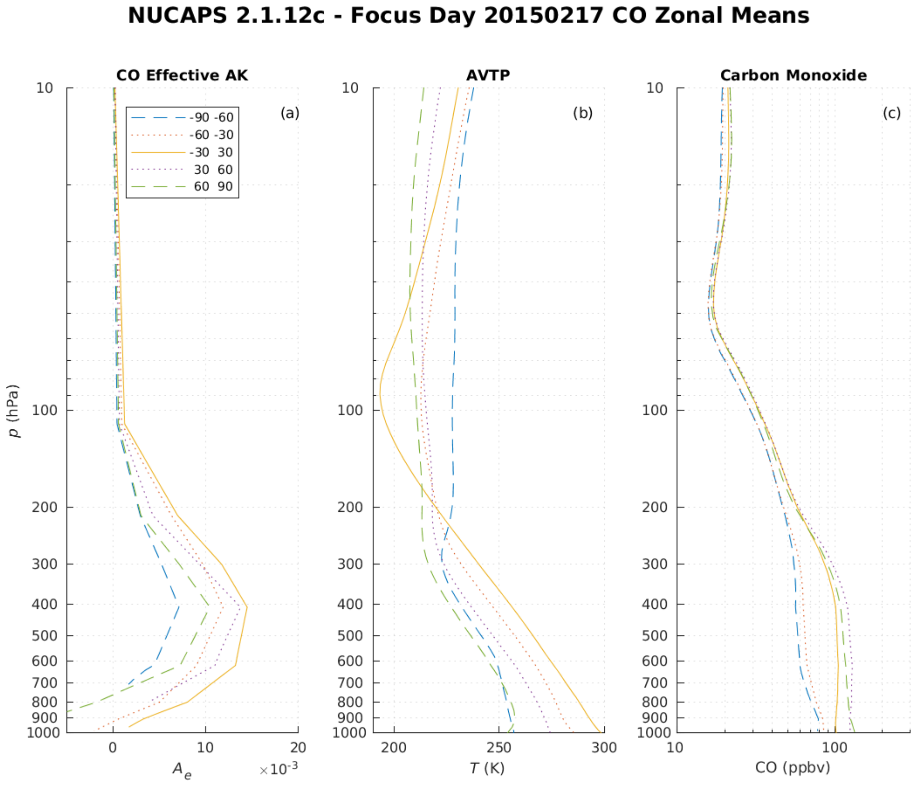
RTA-layer **effective AKs** (*Maddy & Barnet* 2008)

Zonal Mean Column Effective Averaging Kernels: O_3, CO

Ozone

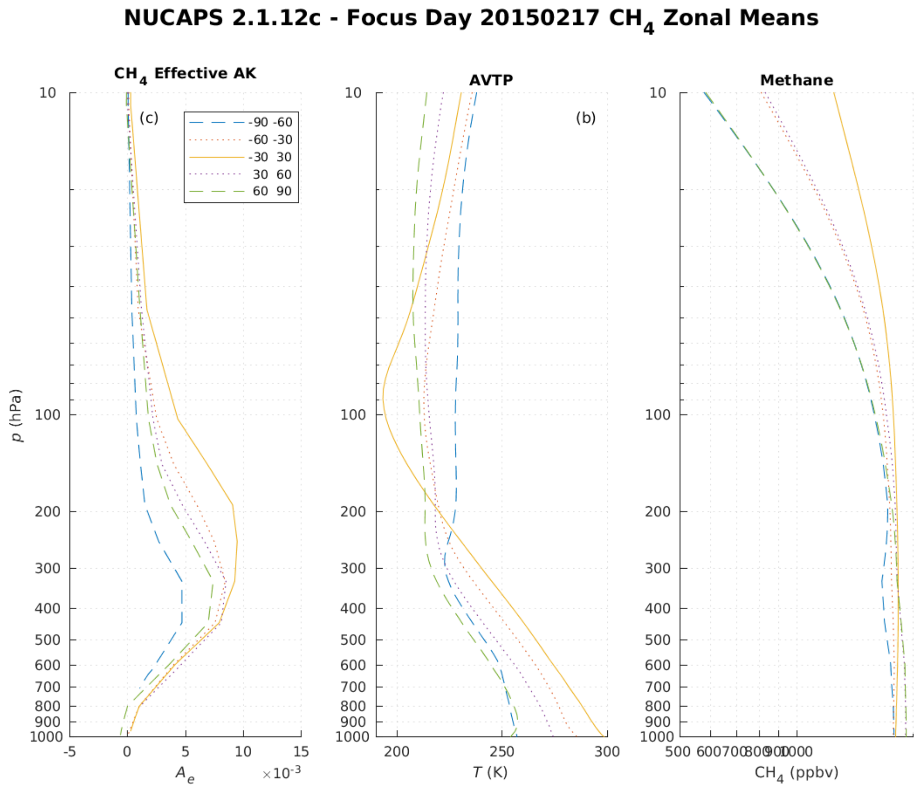


Carbon Monoxide

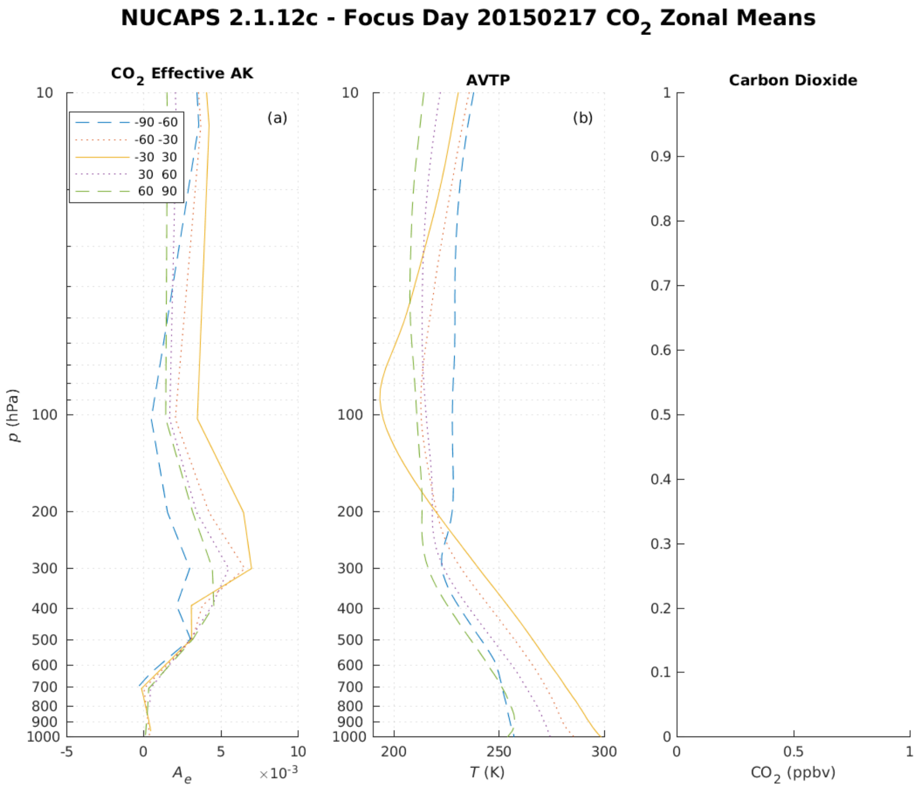


Zonal Mean Column Effective Averaging Kernels: CH_4, CO_2

Methane

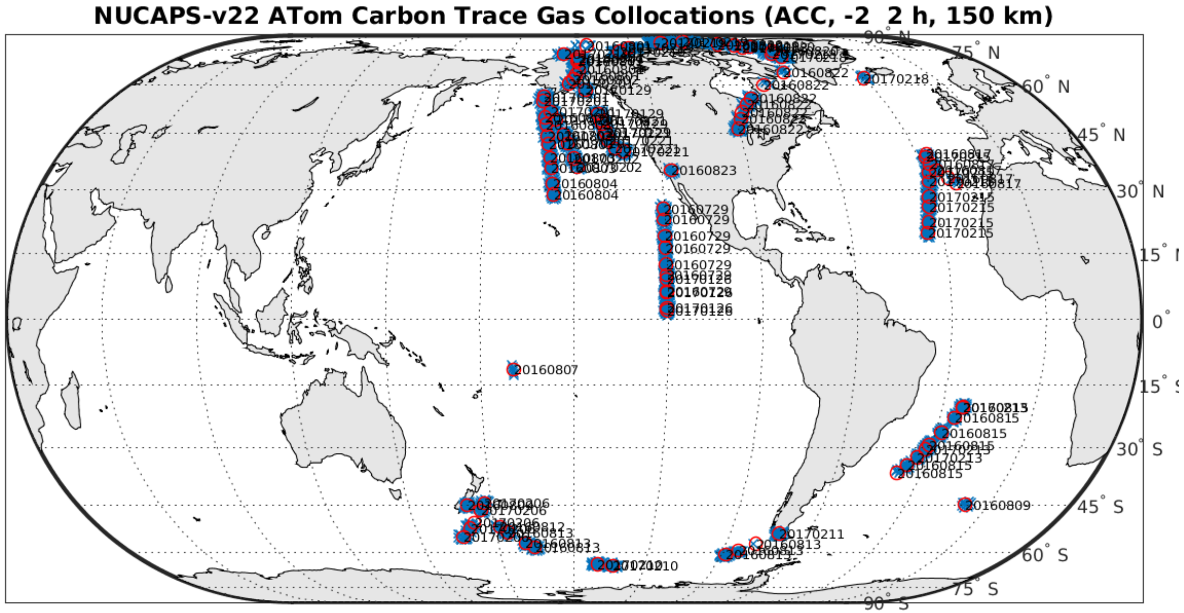


Carbon Dioxide

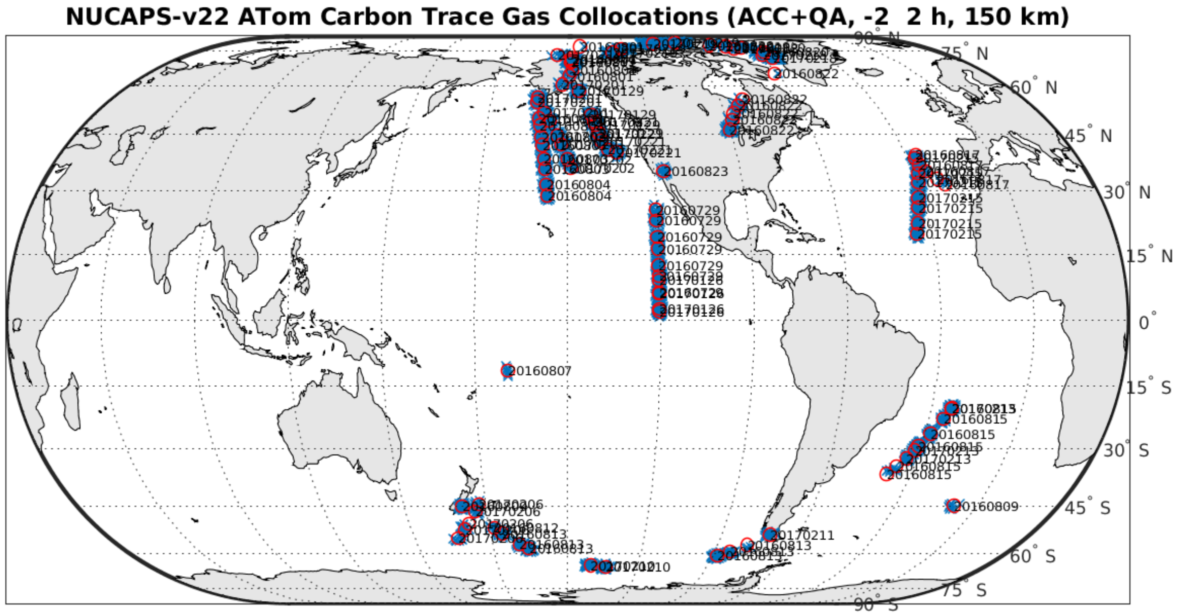


SNPP NUCAPS-ATom Collocations

Accepted Cases



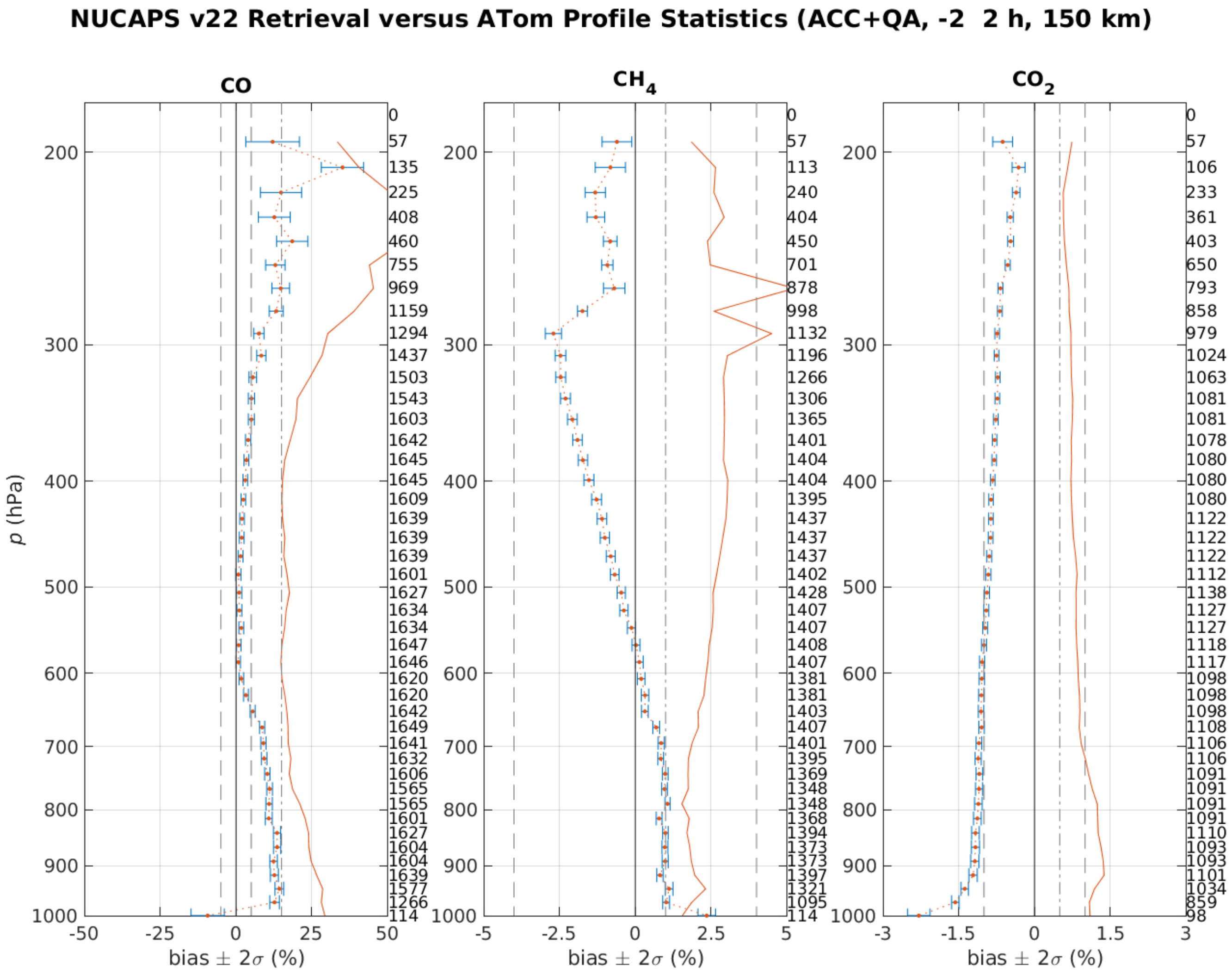
Accepted + CO Trace Gas QA

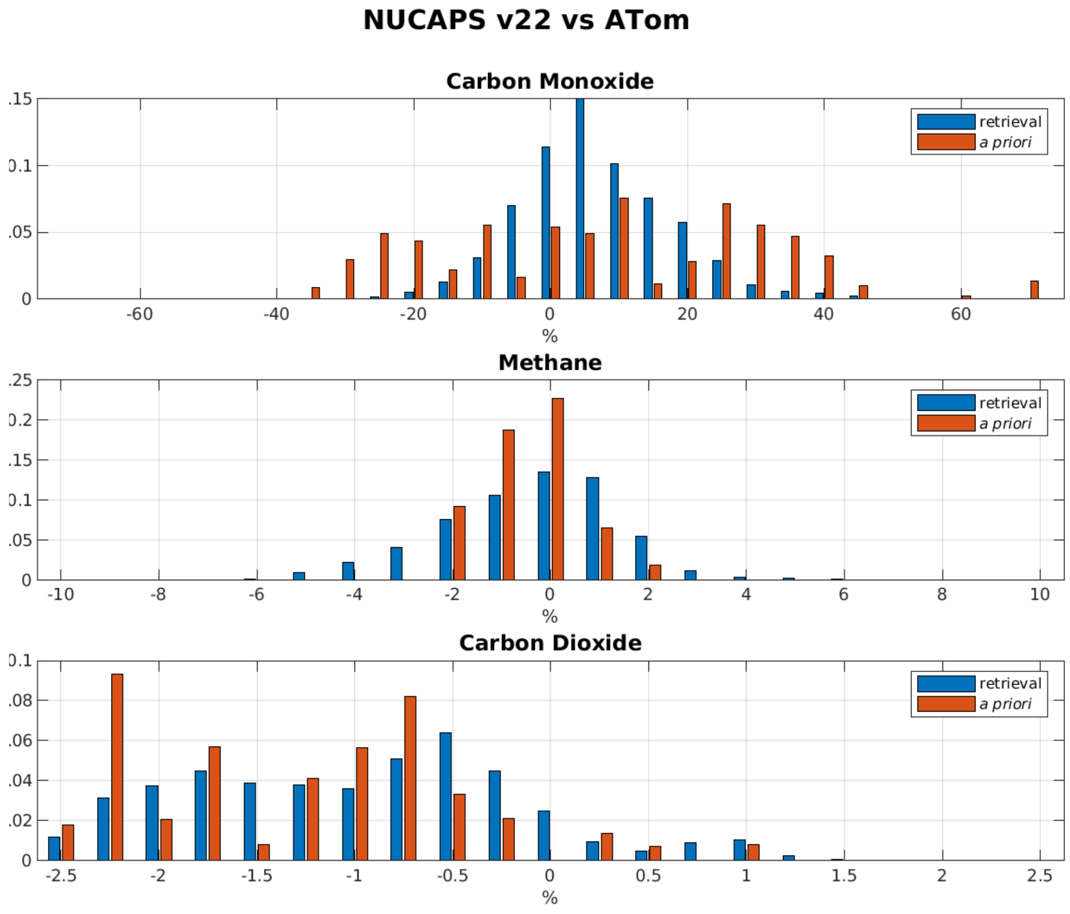


ATom (*Wofsy et al.* 2018)

NUCAPS SNPP (v2.2) versus ATom

Accepted+QA, ±2 hr, 150 km

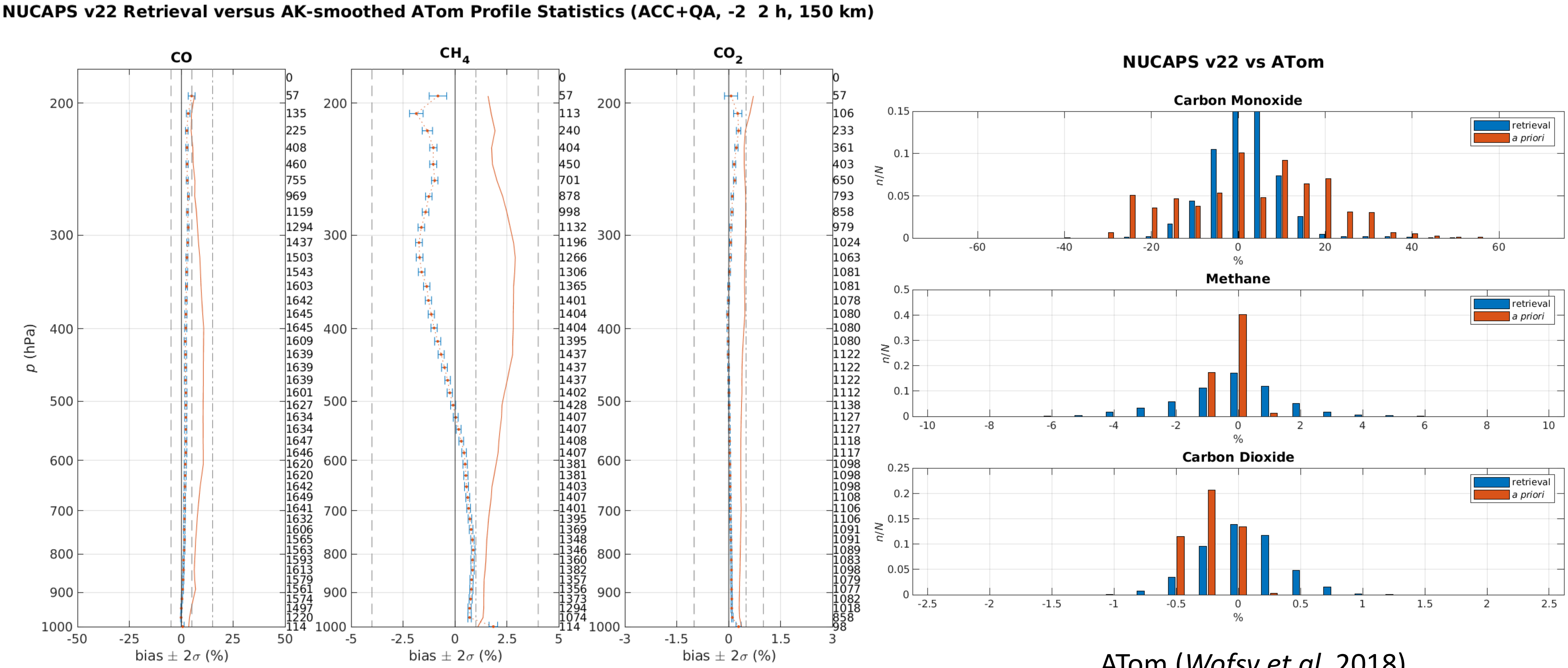




ATom (*Wofsy et al.* 2018)

NUCAPS SNPP (v2.2) versus ATom AK-Smoothed

Accepted+QA, ±2 hr, 150 km



ATom (*Wofsy et al.* 2018)

Summary and Future Work

- **NUCAPS NOAA-20 and SNPP (v2.x FSR)**
  - **AVTP/AVMP EDRs** attained **Provisional Maturity** in **June 2018**
  - **IR Ozone Profile EDR** has attained **Provisional Maturity** as of **2 Oct 2018** Maturity Review
  - **Carbon trace gas EDR validation** versus program-established uncertainty specifications was a **new task** beginning with transition to **FSR CrIS**
    - **Recent NUCAPS upgrades** have focused on upgrades/optimizations of the **CO trace gas EDR product**
    - **Ongoing validation of SNPP NUCAPS CO/CH4/CO2** versus **TCCON** and **ATom** truth datasets show
      - **CO currently meets JPSS Requirements**
      - CH4 and CO2 are close to meeting requirements

- **Future Work**
  - **Ongoing NUCAPS development, Cal/Val and Long-Term Monitoring**
    - **Continue v2.x algorithm optimizations**
    - **SNPP NUCAPS Trace Gas Validated Maturity Review**
      - **Upgrades/optimizations for CH_4 and CO_2 products**
    - **NOAA-20 NUCAPS validation**
      - Continue support of dedicated RAOBs (**ARM, RIVAL, AEROSE**)
      - **Next AEROSE campaign is scheduled for Feb-Mar 2019**
  - **Other Related Work**
    - **Apply averaging kernels** in all NUCAPS error analyses, including carbon trace gases and ozone profile EDRs
    - **Surface emissivity upgrades/updates**
      - **IR ocean surface emissivity model upgrades**
    - Collocation uncertainty estimates
    - calc − obs analyses (CRTM, LBLRTM, SARTA, etc.)
    - Support EDR user applications (**AWIPS**, **AR/SAL**, **atmospheric chemistry users**)

NUCAPS Validation

THANK YOU! QUESTIONS?

NUCAPS Validation

BACKUP SLIDES