NOAA-20 and SNPP NUCAPS Validation Updates

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Acknowledgments

- **Sounder EDR Validation Dataset collection**
  - **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
  - **AirCore:** *Colm Sweeney, Bianca Baier (NOAA/ESRL)*
- The **NOAA Joint Polar Satellite System (JPSS-STAR) Office** (*M. D. Goldberg, et al.*) and the NOAA/STAR Satellite Meteorology and Climatology Division.
- **Sounder validation effort (past and present)**: *C. D. Barnet* (STC); *A.K. Sharma, F. Iturbide-Sanchez, M. Pettey, C. Brown, E. Maddy, W. W. Wolf* (STAR); *L. Borg, R. O. Knuteson, D. Tobin* (UW/CIMSS)

Outline

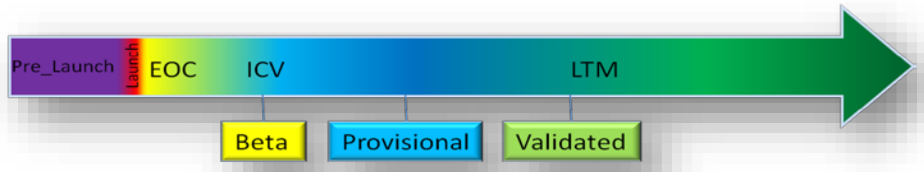
- **JPSS Sounder EDR Cal/Val Recap**
  - JPSS Level 1 Requirements
  - Validation Hierarchy recap
  - NUCAPS Algorithm
    - Overview of Recent Version Upgrades
- **NUCAPS Validation Status**
  - *T*/H_2O/O_3 EDRs
    - SNPP CrIS Side-2
    - NOAA-20
  - Carbon Trace Gas (CO/CH_4/CO_2) EDRs SNPP/NOAA-20
    - TCCON (ground-based spectrometers)
    - AirCore (balloon-borne *in sit*u)

NUCAPS Validation

JPSS SOUNDER EDR CAL/VAL RECAP

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 as "transfer standard" (via double-differences), 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

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

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

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

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)

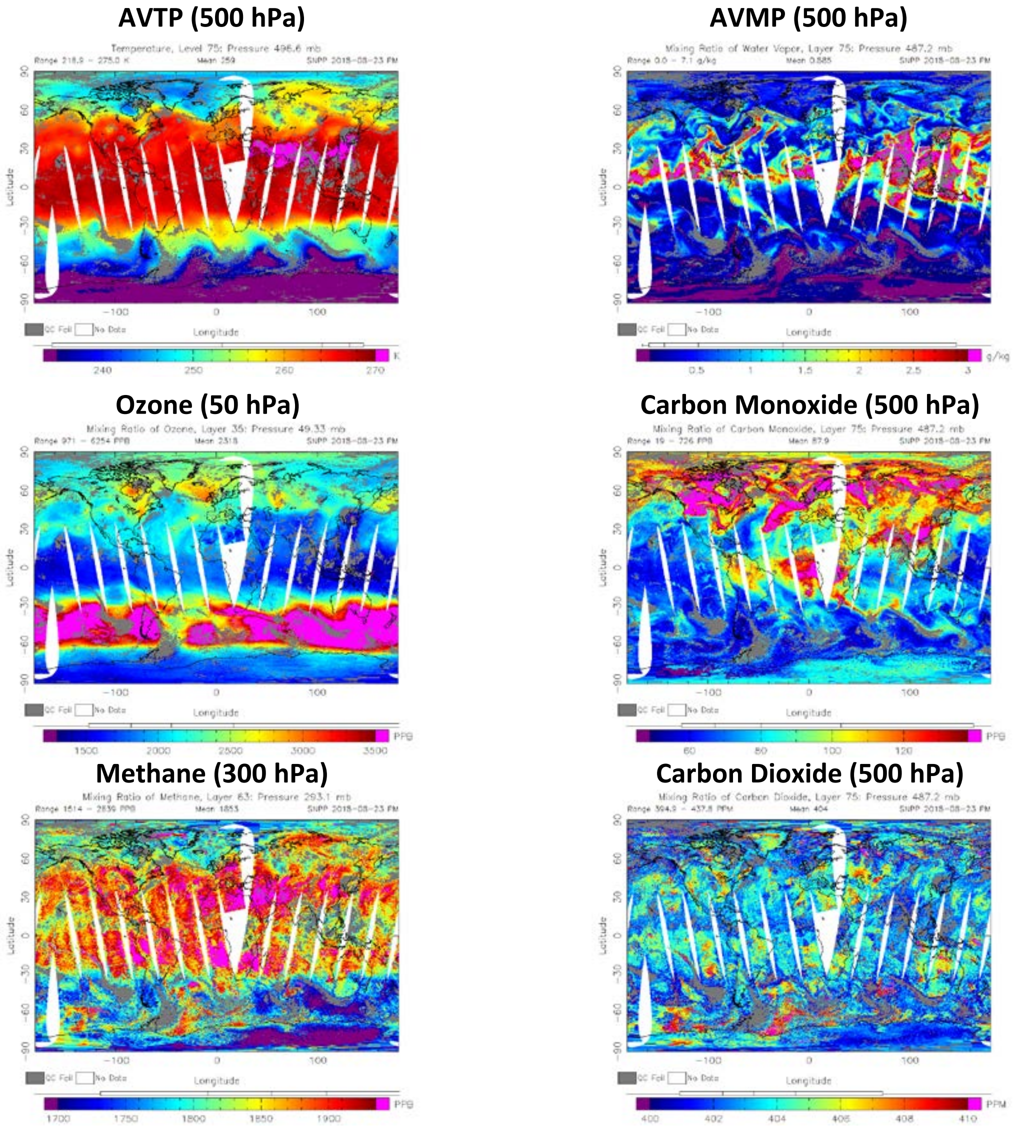
	CrIS Infrared Trace Gases Specification Performance Requirements		
	PARAMETER	THRESHOLD	OBJECTIVE
Ozone Profile	O_3 **(Ozone)** Profile Precision, 4–260 hPa (6 statistic layers)	20%	10%
	O_3 **(Ozone)** Profile Precision, 260 hPa to sfc (1 statistic layer)	20%	10%
	O_3 **(Ozone)** Profile Accuracy, 4–260 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	15% (CrIS FSR)	3%
	CO (Carbon Monoxide) Total Column Accuracy	±5% (CrIS FSR)	±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 (AST v5.9; after *Susskind, Barnet and Blaisdell,* 2003)
  - 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 (e.g., *Bloch et al.* 2019; *Iturbide-Sanchez et al.* 2018)



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

NUCAPS Updates and Offline Versioning

- **Version 1 (CrIS NSR)**
  - **V1.5**
    - **Operational system beginning in June 2015**
    - Ran on **CrIS nominal spectral-resolution (NSR)**
    - **Validated Maturity** for AVTP/AVMP EDR attained Sep 2014
- **Version 2 (Phase 4, CrIS FSR)**
  - Transition to **CrIS full-res (FSR)** data (FSR SARTA by L. Strow et al., UMBC)
  - Included **IR-only version** (risk-mitigation for ATMS loss)
  - Phase 4 Algorithm Readiness Review (ARR) delivered July 2017
    - ATBD delivered August 2017
    - V2.1.1 Direct Broadcast capability
  - V2.1.11
    - New CO channels to 2200 cm^{-1}
    - New CO and CH_4 Tunings
  - V2.1.12
    - V2.1.12c
      - **NOAA-20 Provisional Maturity for AVTP/AVMP, Beta Maturity for O3/CO/CH4/CO2, June 2018**
      - Delivered to OPS June 2018
    - V2.1.12d
      - Cloud-clearing channel update
      - Current delivered version
  - **V2.5.2.x** (current offline test versions)
    - Full spectral tunings for SNPP and N-20
    - Regression update for N-20
    - MW tuning updates for SNPP and N-20
    - Candidate for October 2019 DAP

NUCAPS Validation

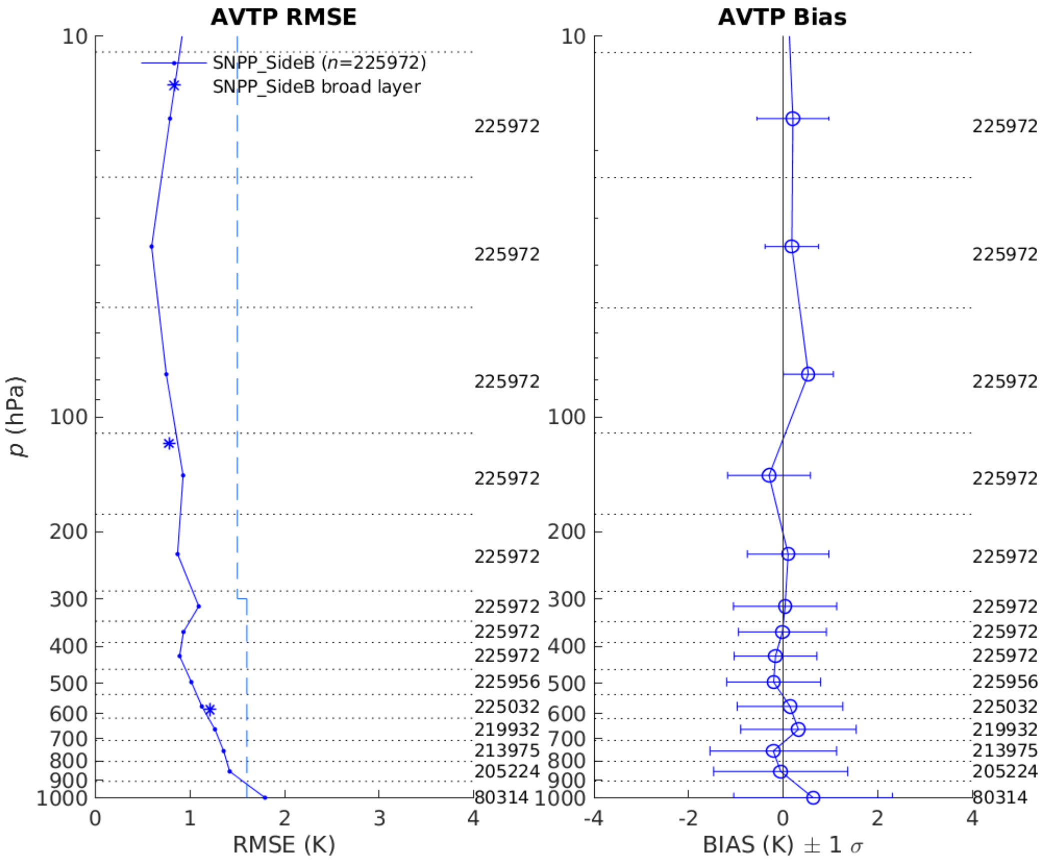
SNPP CRIS SIDE-2 $T/H_2O/O_3$

SNPP CrIS Side-2 NUCAPS AVTP vs ECMWF

Global Focus Days (NUCAPS v2.2)

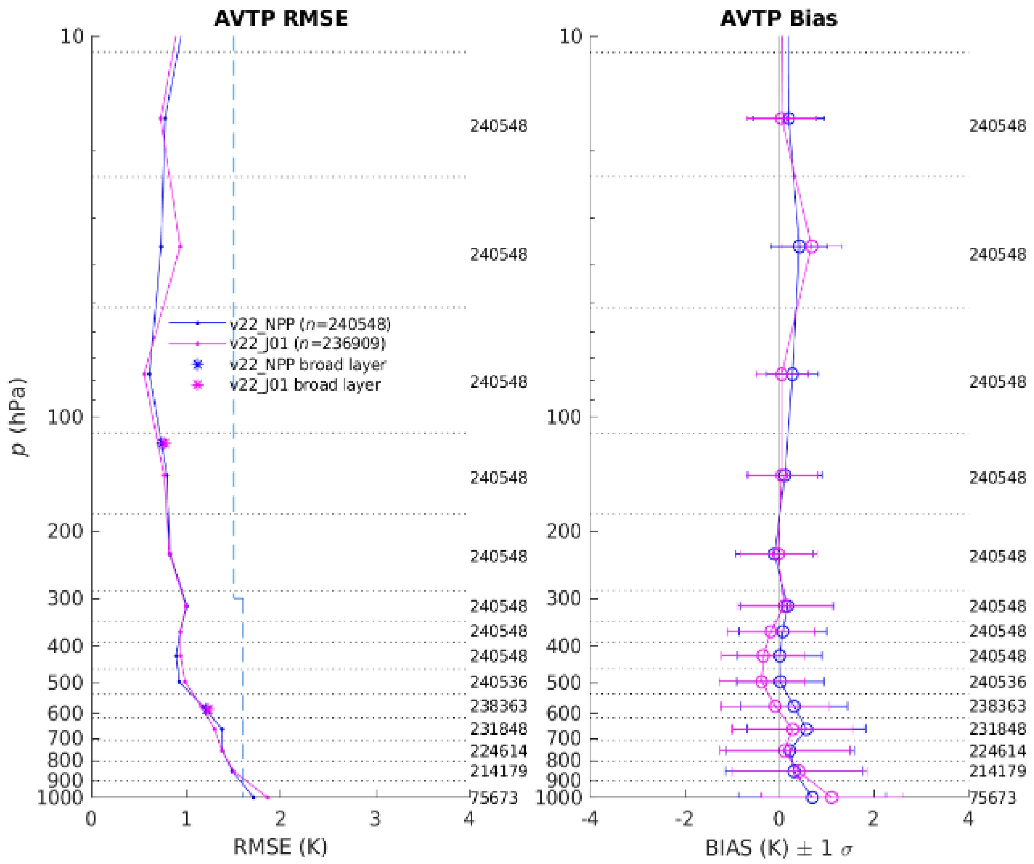
SNPP Side-2

SNPP CrIS Side-2
29 June 2019



SNPP
NOAA-20

CrIS Side-1
20 August 2018

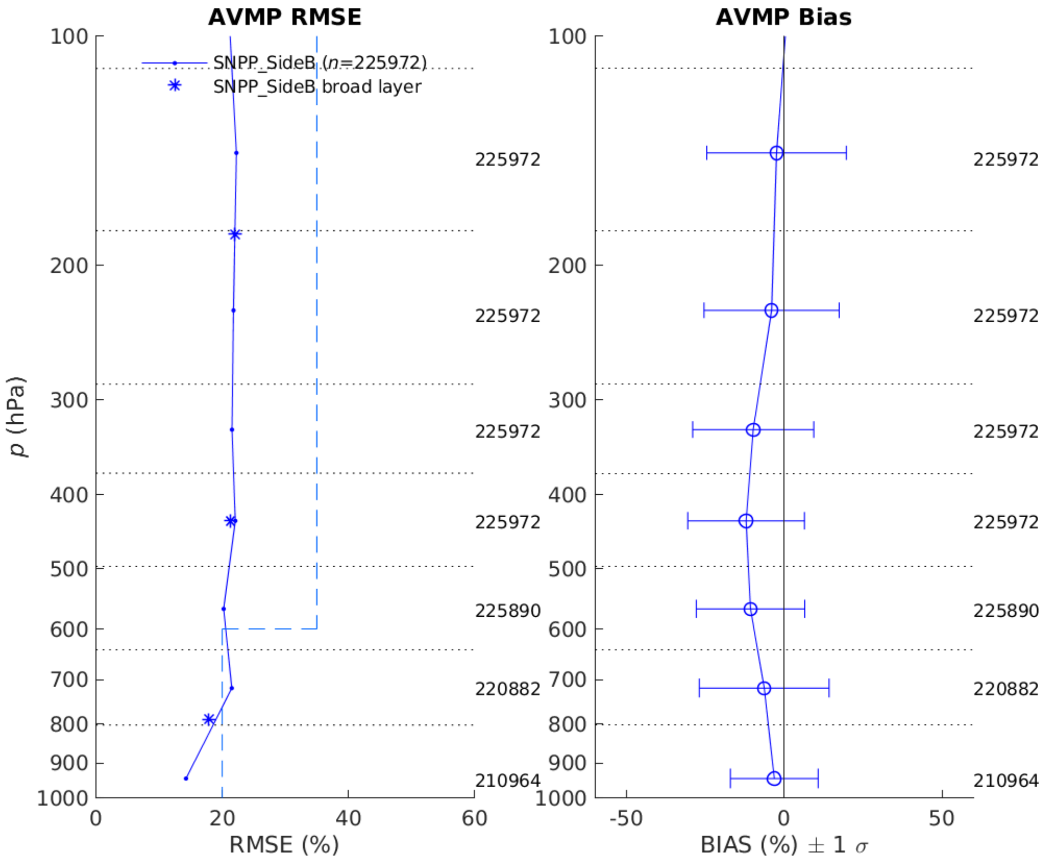


SNPP CrIS Side-2 NUCAPS AVMP (H_2O) vs ECMWF

Global Focus Days (NUCAPS v2.2)

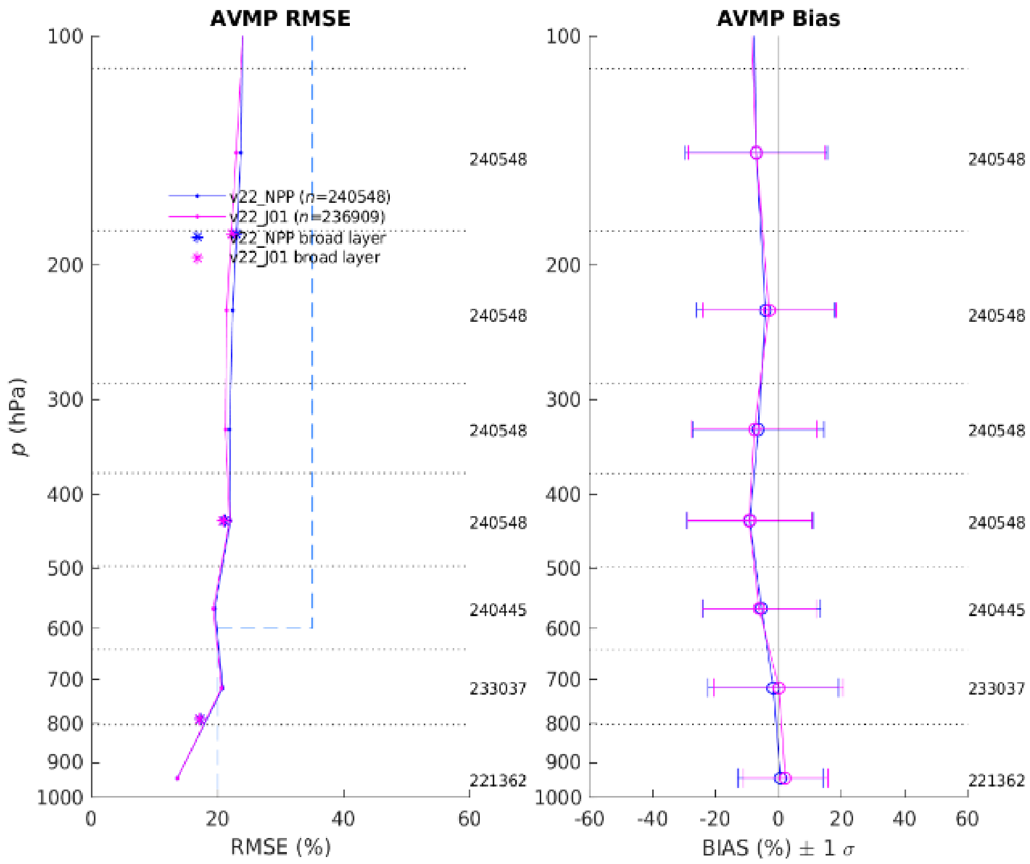
SNPP Side-2

SNPP CrIS Side-2
29 June 2019



SNPP
NOAA-20

CrIS Side-1
20 August 2018

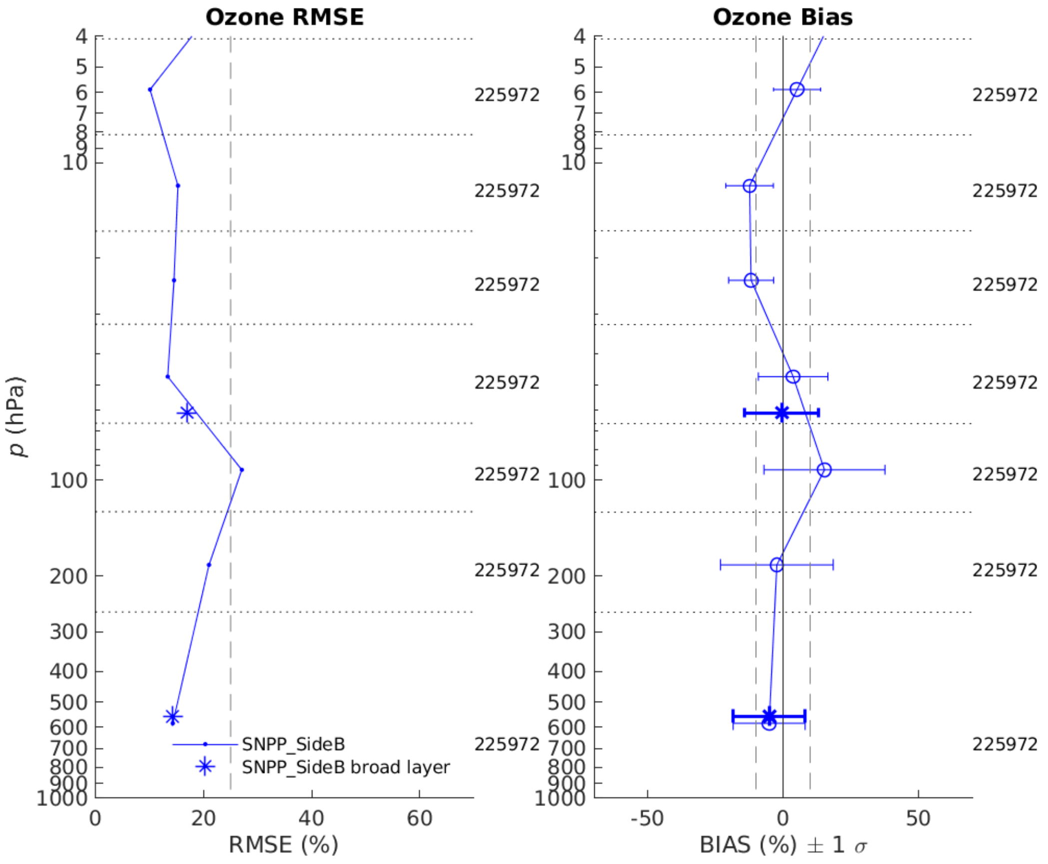


SNPP CrIS Side-2 NUCAPS IR Ozone Profile (O_3) vs ECMWF

Global Focus Days (NUCAPS v2.2)

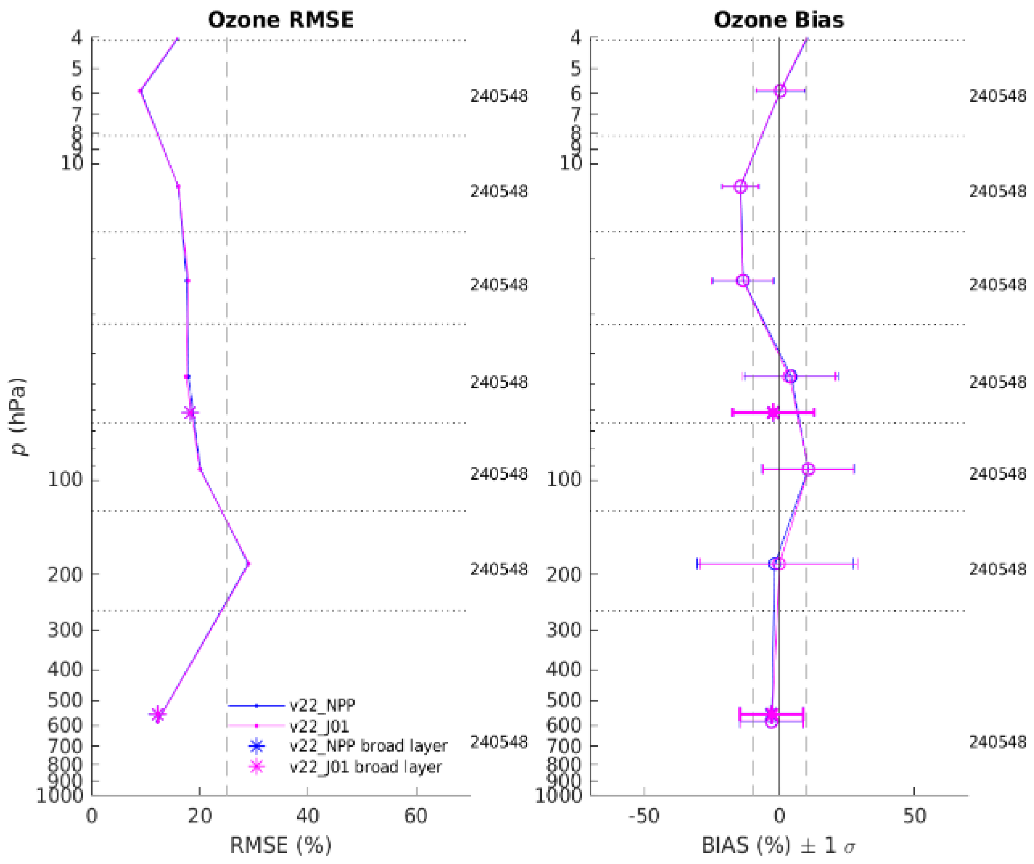
SNPP Side-2

SNPP CrIS Side-2
29 June 2019



SNPP
NOAA-20

CrIS Side-1
20 August 2018



NUCAPS Validation

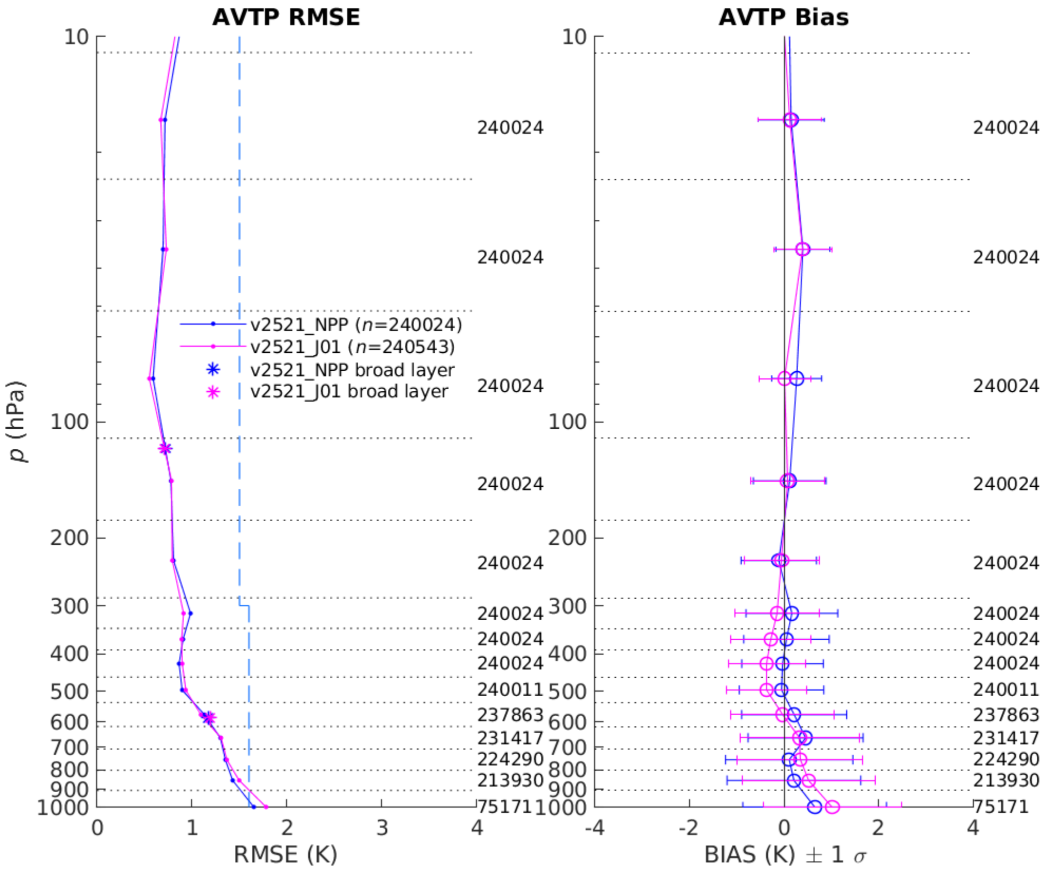
NOAA-20 *T*/H_2O/O_3

NOAA-20 NUCAPS v2.5.2.x AVTP vs ECMWF

Focus Day 20 August 2018

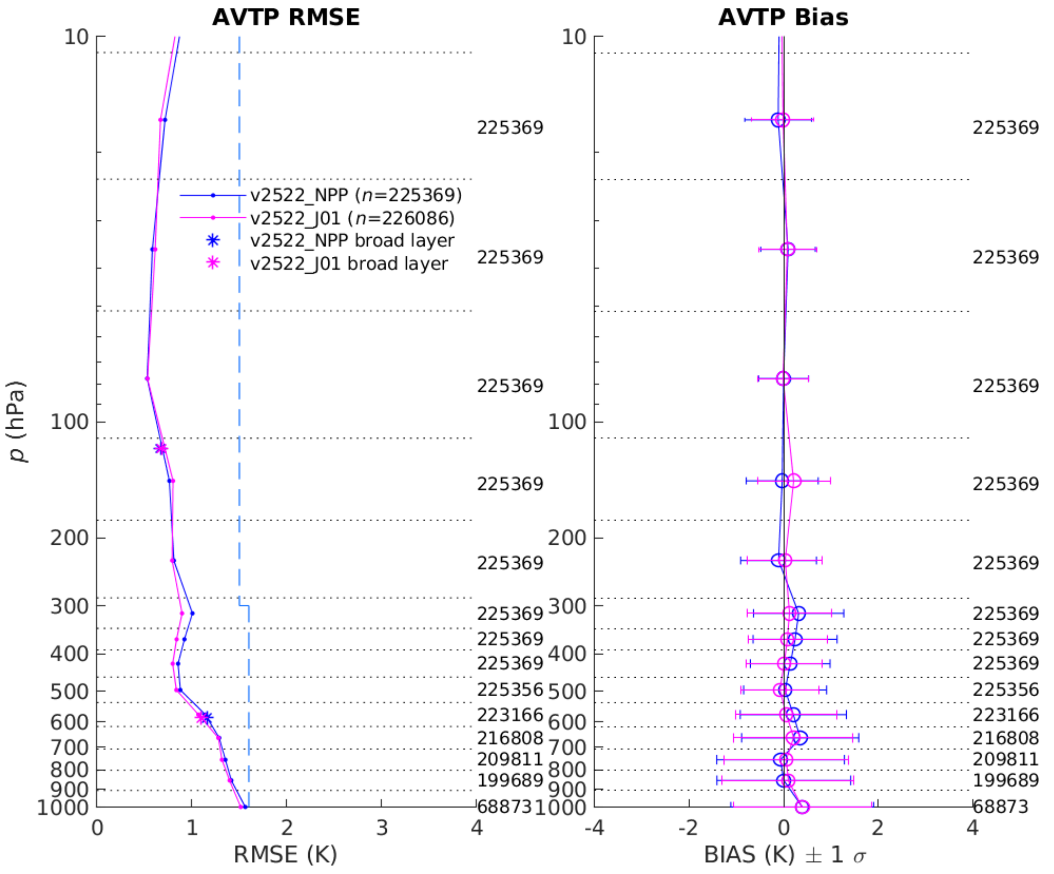
SNPP
NOAA-20

V2.5.2.1



SNPP
NOAA-20

V2.5.2.2

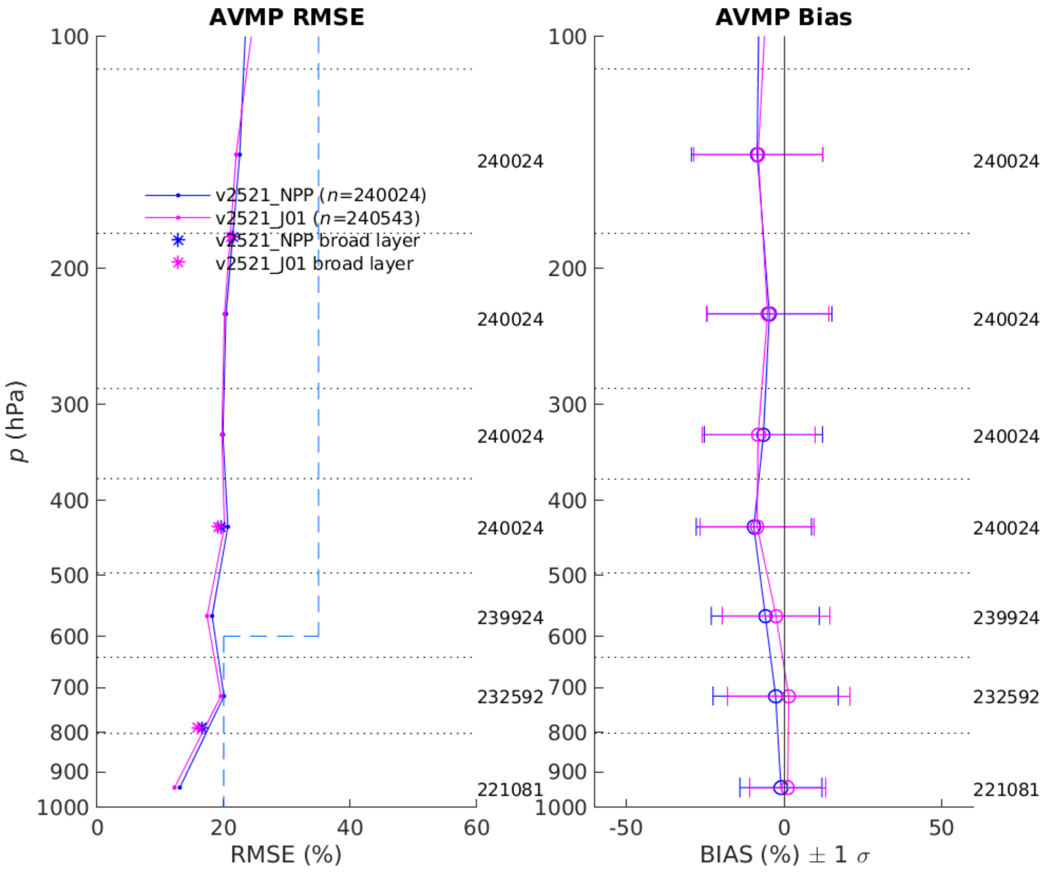


NOAA-20 NUCAPS v2.5.2.x AVMP (H_2O) vs ECMWF

Focus Day 20 August 2018

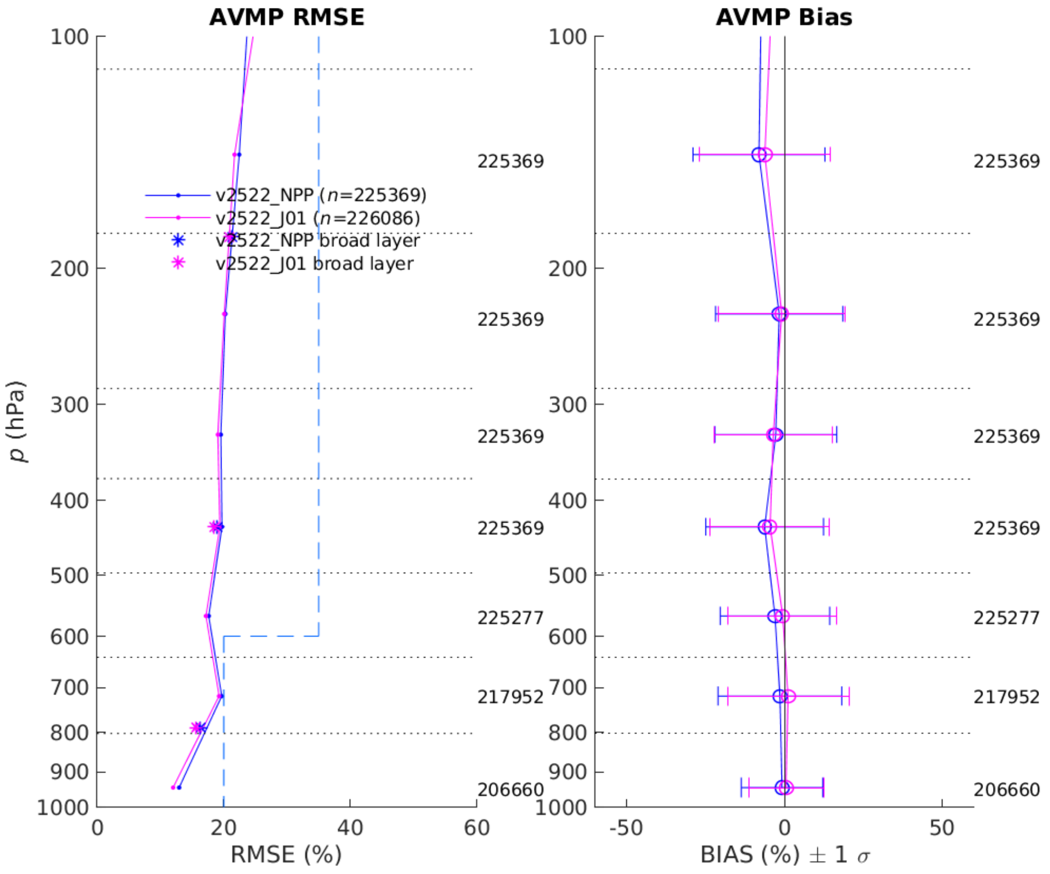
SNPP
NOAA-20

V2.5.2.1



SNPP
NOAA-20

V2.5.2.2

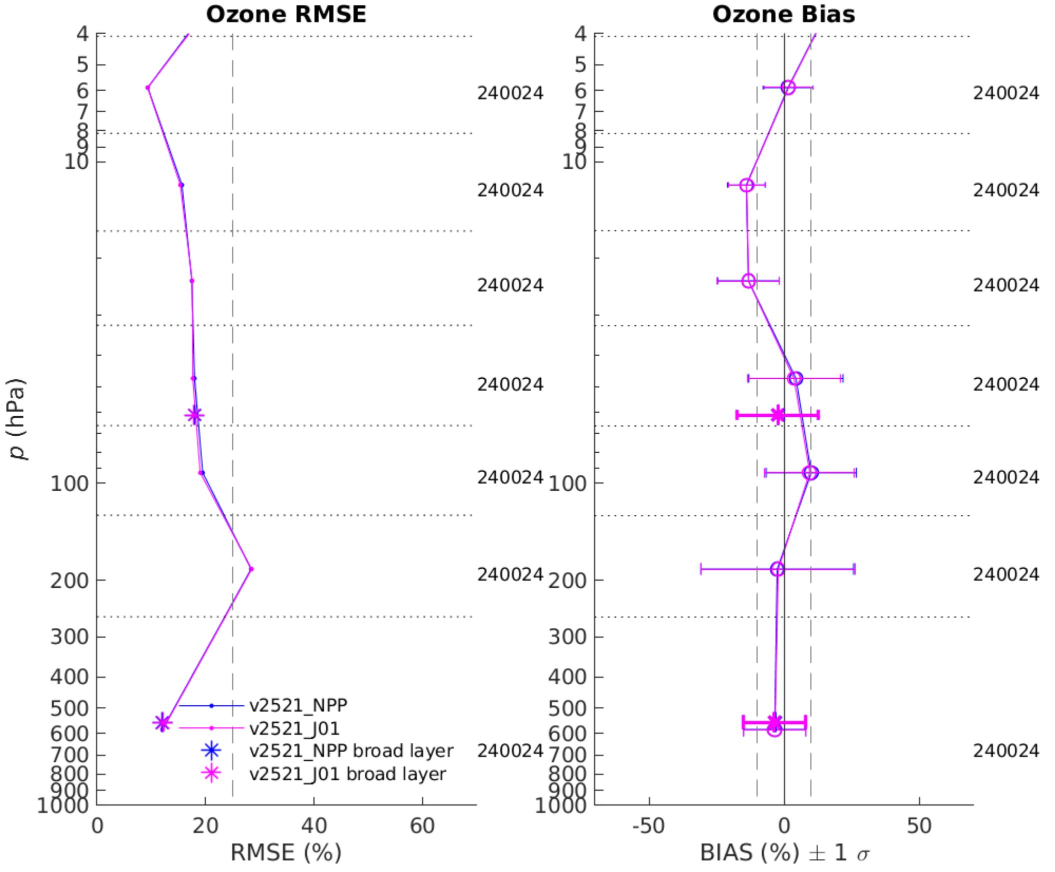


NOAA-20 NUCAPS v2.5.2.x IR Ozone Profile (O_3) vs ECMWF

Focus Day 20 August 2018

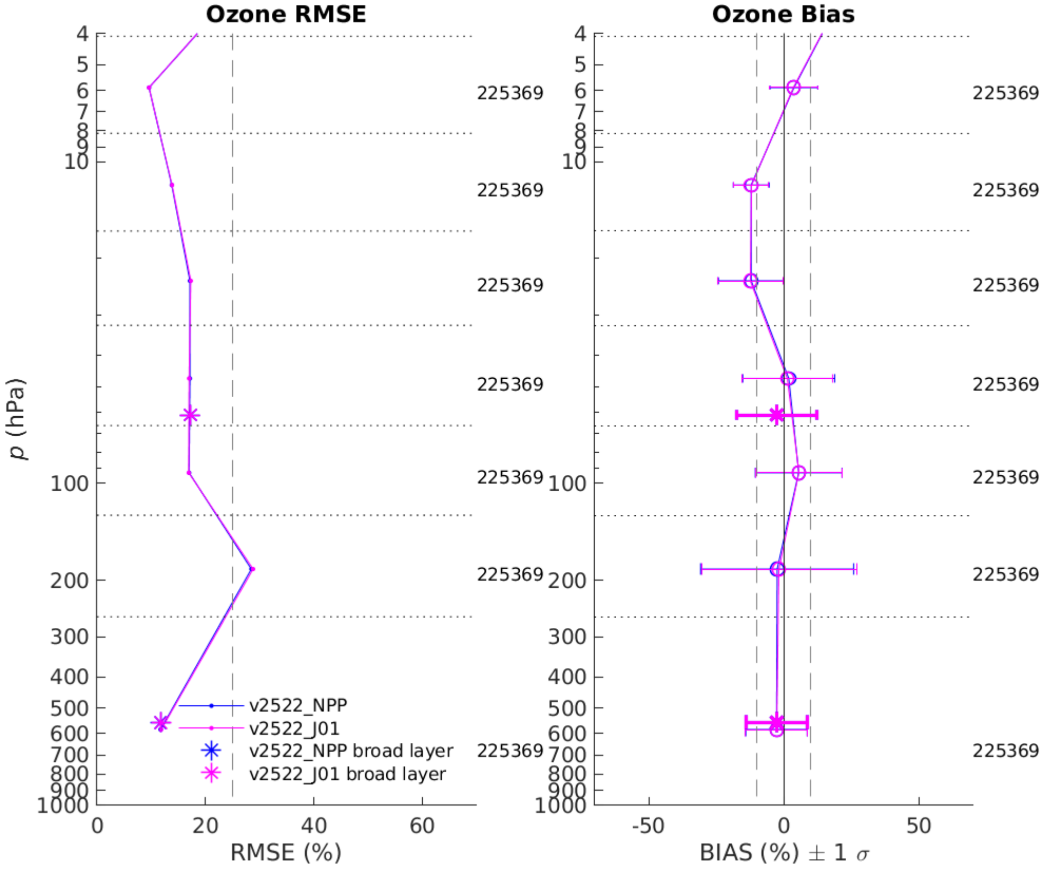
SNPP
NOAA-20

V2.5.2.1



SNPP
NOAA-20

V2.5.2.2



NUCAPS Validation

SNPP/NOAA-20 CARBON TRACE GAS

Overview of Carbon Trace Gas Validation

- **Carbon trace gas EDR validation** versus JPSS program established uncertainty specifications is a relatively **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**; **TROPOMI**; 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
  - **AirCore** (Cal/Val Method #3)
  - **ATom campaigns** (Cal/Val Method #4; not shown here)

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

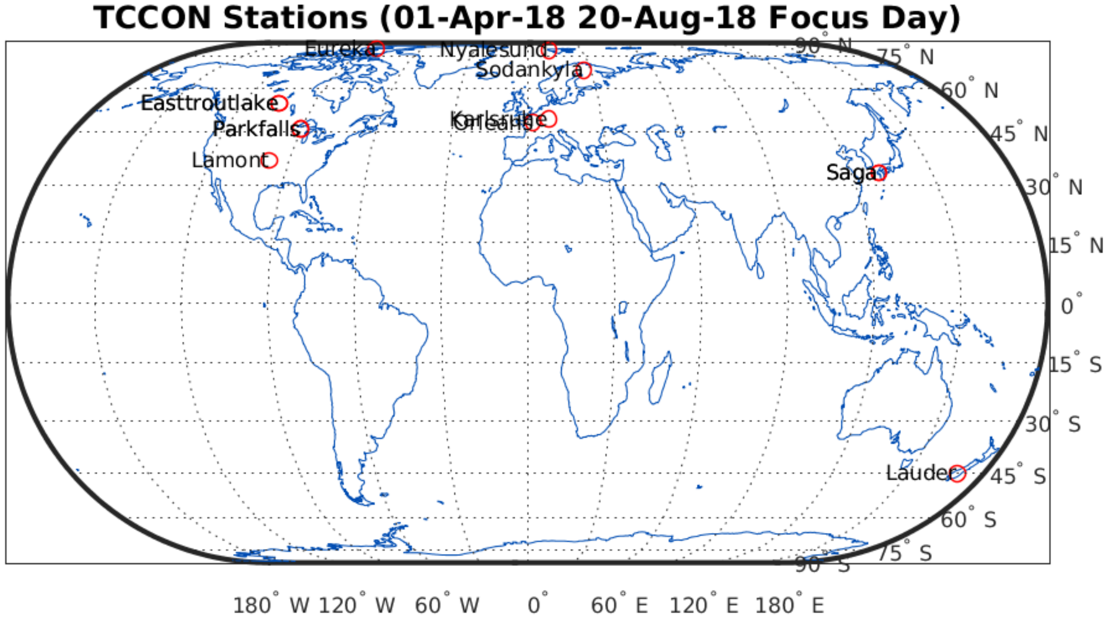
- **Trace Gas Quality assurance (QA)**
  - NUCAPS IR+MW quality flag
  - NUCAPS trace gas QA flags
    - CO trace gas flags developed and tested
    - CH4 and CO2 trace gas flags still undergoing development

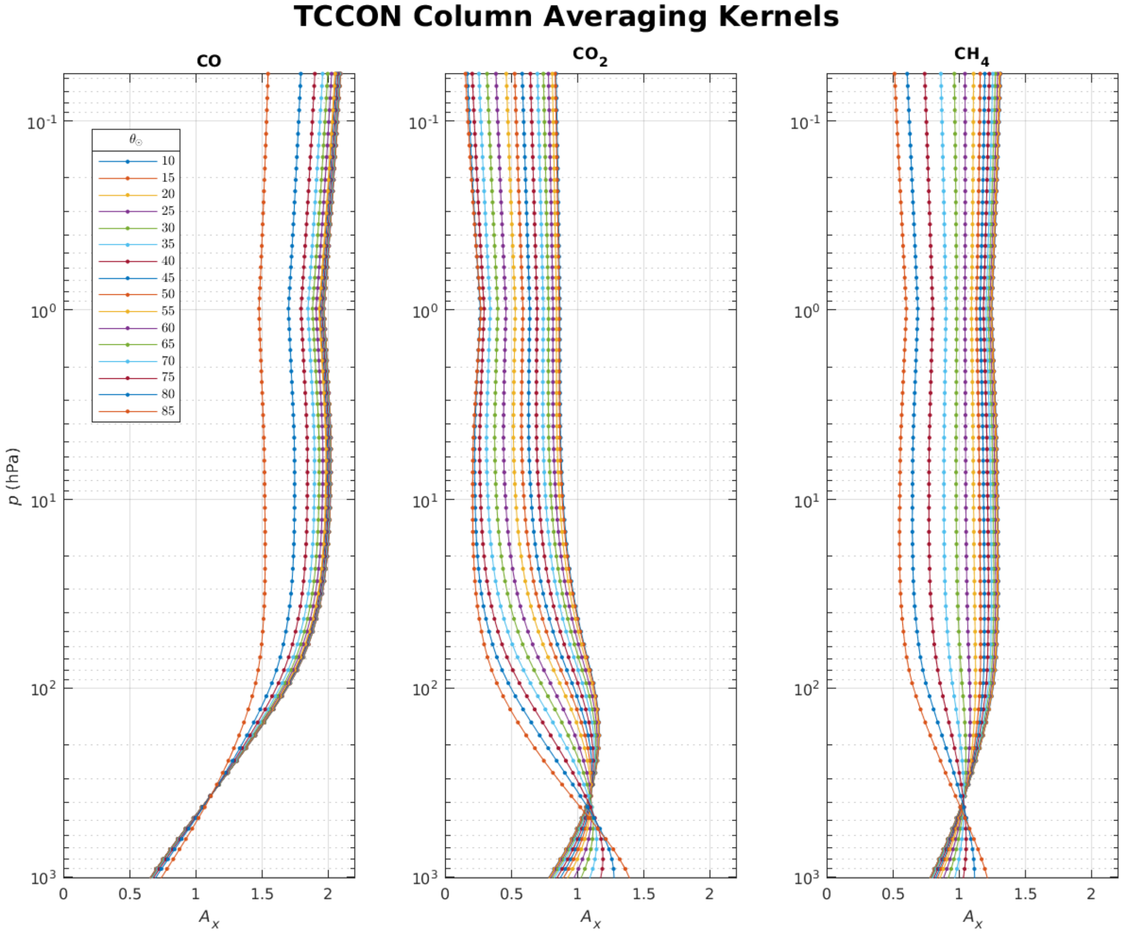
Total Carbon Column Observing Network (TCCON)

(*Wunch et al.* 2011)

Focus Day Station Collocations

(1-Apr-18, 20-Aug-18)



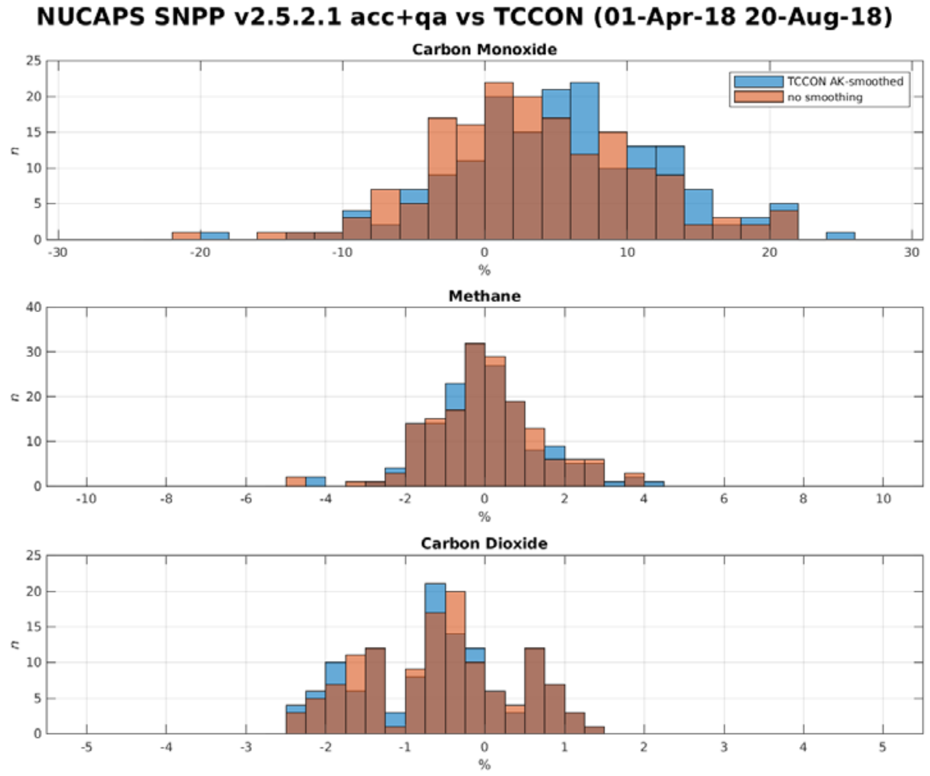


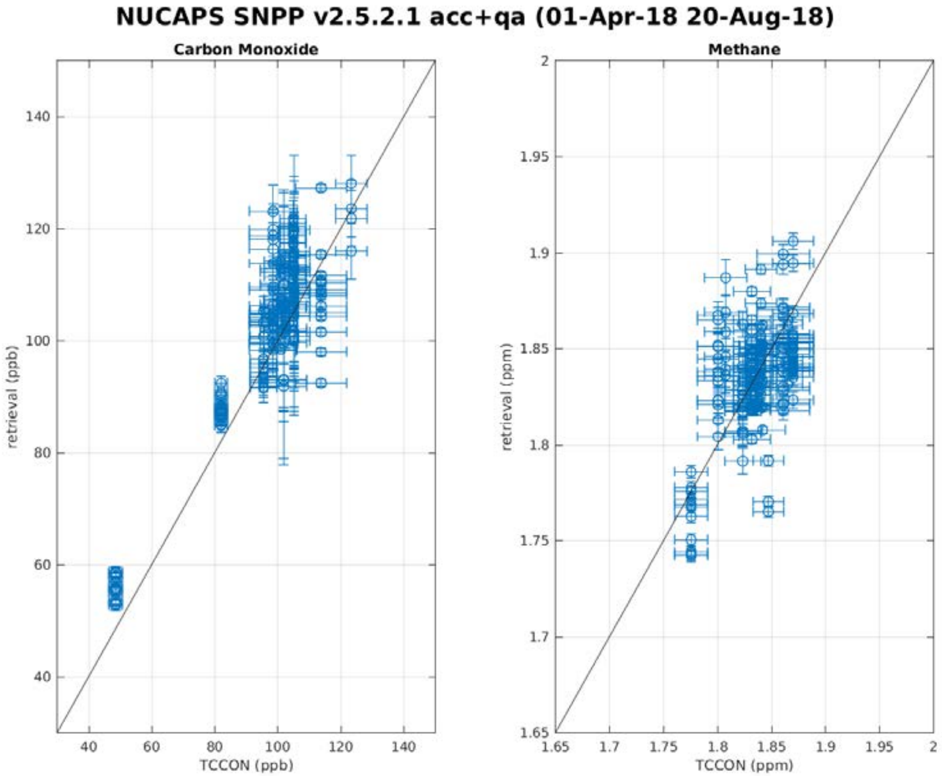
SNPP NUCAPS v2.5.2.1 Total Column Trace Gases vs TCCON

Focus Days: 1 April 208, 20 August 2018

TCCON

(*Wunch et al.* 2011)



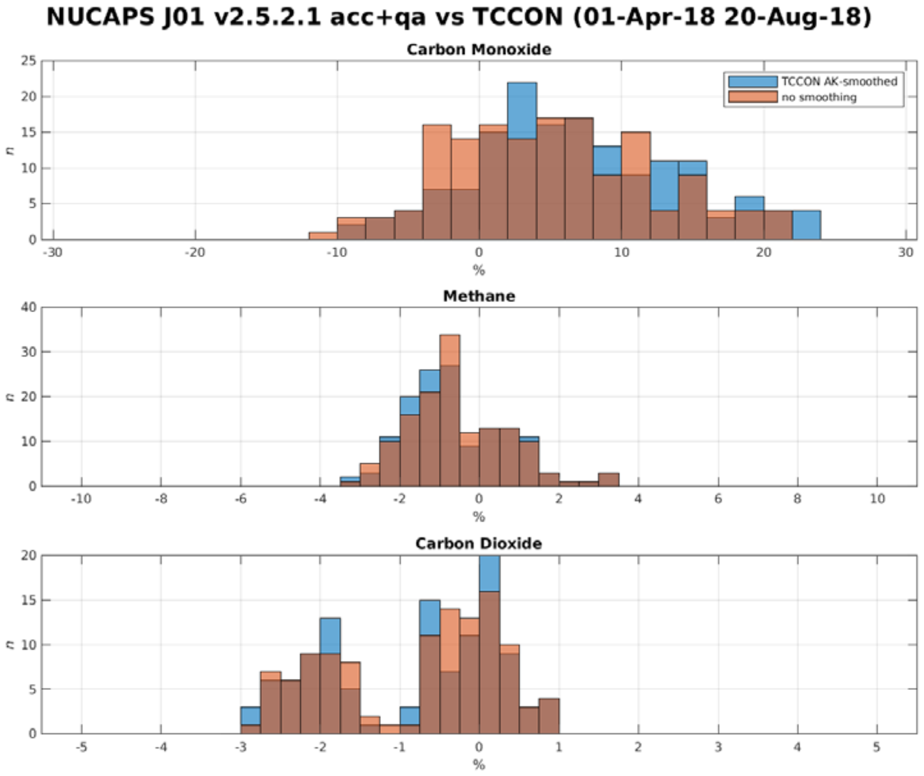


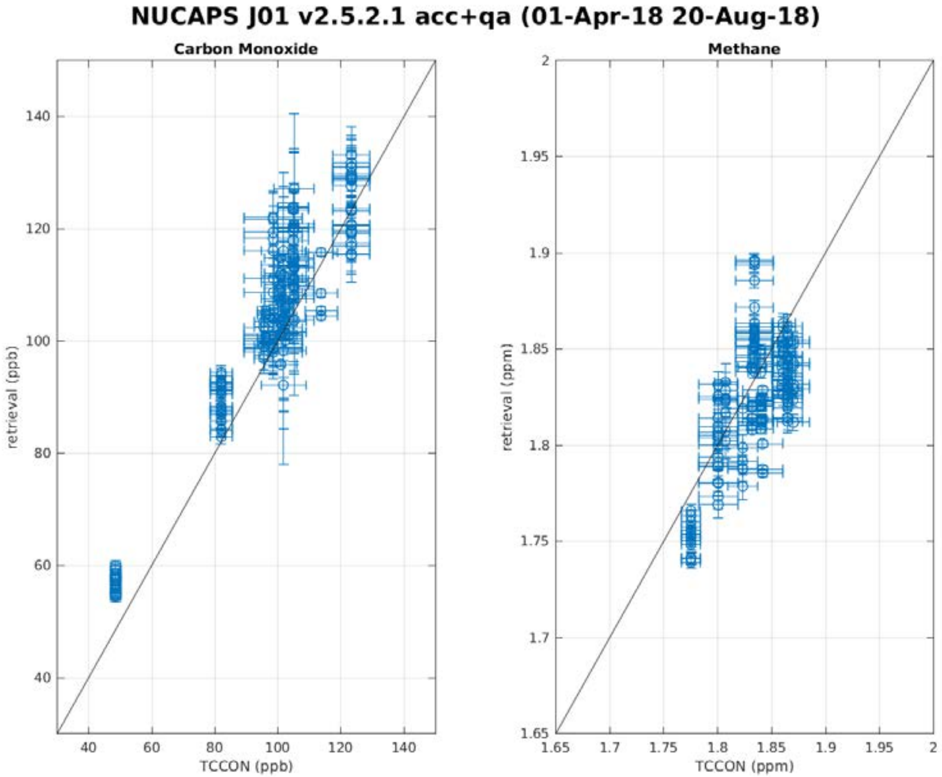
NOAA-20 NUCAPS v2.5.2.1 Total Column Trace Gases vs TCCON

Focus Days: 1 April 208, 20 August 2018

TCCON

(*Wunch et al.* 2011)





NOAA ESRL AirCore Sampling System
(*Membrive et al.* 2017; *Karion et al.* 2010)

- Innovative, balloon-borne *in situ* sampling system
- Uses long stainless steel tube, open at one end and closed at the other
- Collects a sample (or "core") of the ambient atmospheric air column during its descent
- The "core" is physically recovered, sealed, then brought back to the lab for analysis using a Picarro trace gas analyzer.
- Measures mole fractions for trace gases CO, CH_4 and CO_2
- Advantages
  - Geographic coverage over land
  - Relatively high vertical resolution profiles over full tropospheric column

- We obtained ~27 soundings since March 2018 for the NOAA-20 validation effort (courtesy of Colm Sweeny and Monika Kopacz)
  - Balloon launches were timed for satellite overpasses
  - The original "high density" soundings have been rigorously reduced to 100 layer RTA

O. Membrive et al.: AirCore-HR: a high-resolution column measurement

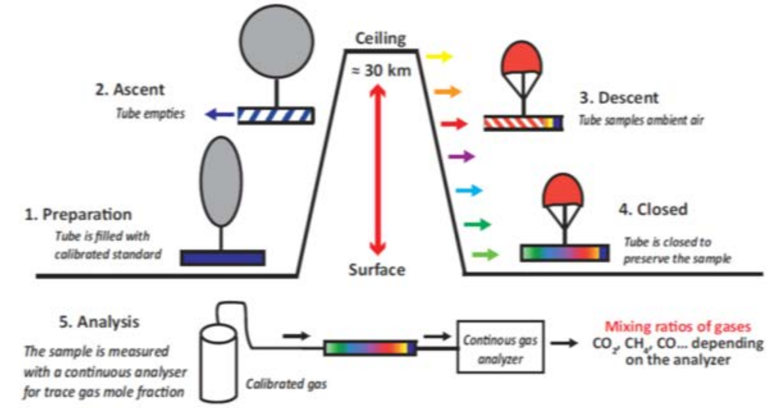
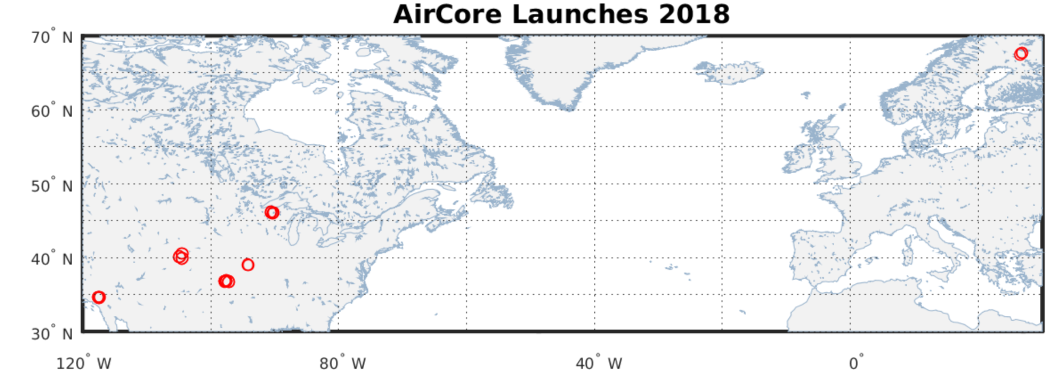


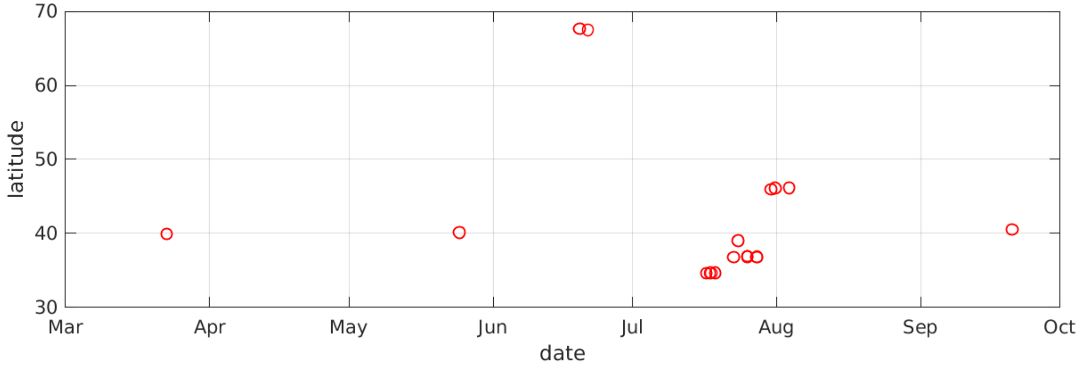
Figure 1. Schematic description of the five steps of the AirCore sampling method.

From *Membrive et al.* (2017)

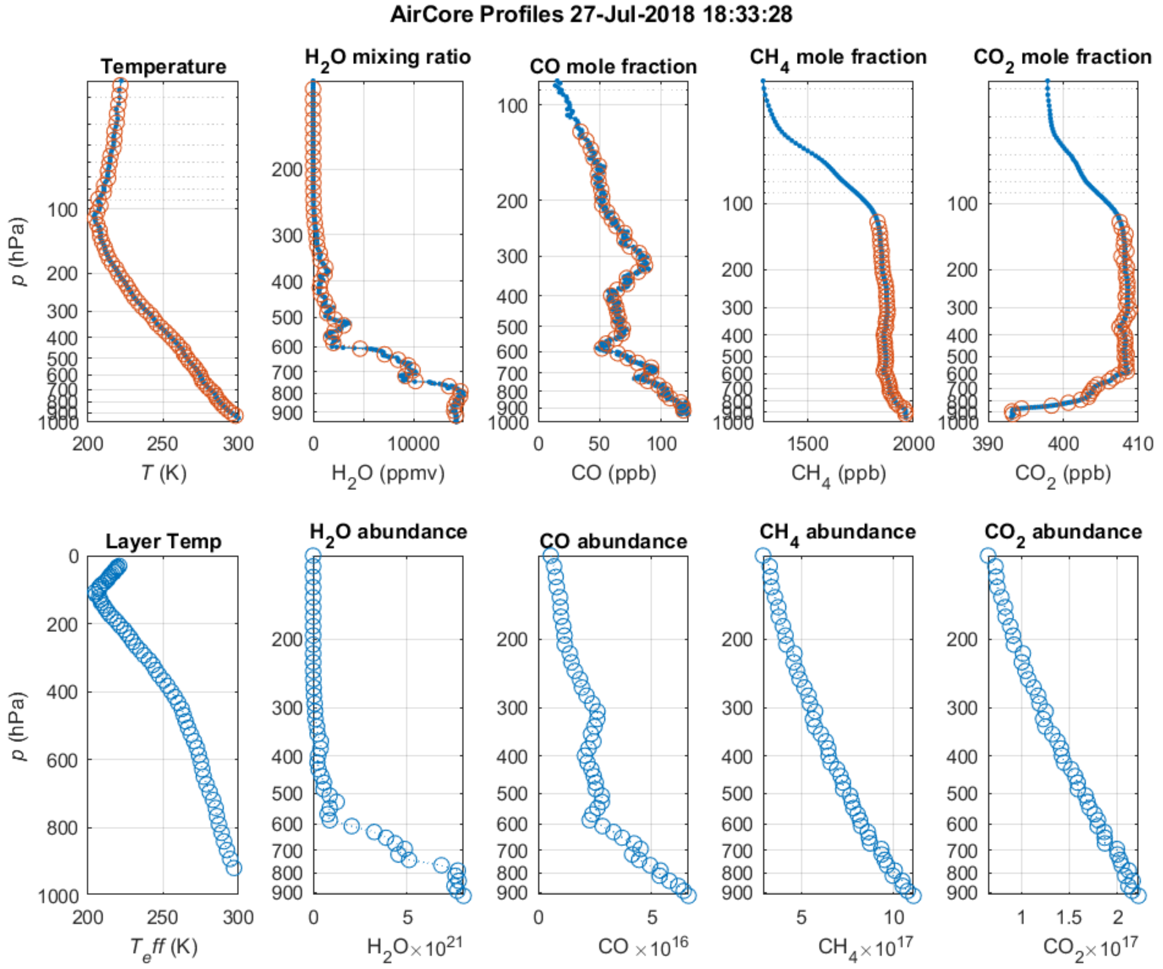
AirCore Profile Sample

Launch Space-Time Locations





Sample 100 Layer RTA



Applying NUCAPS Effective Averaging Kernels (AKs)

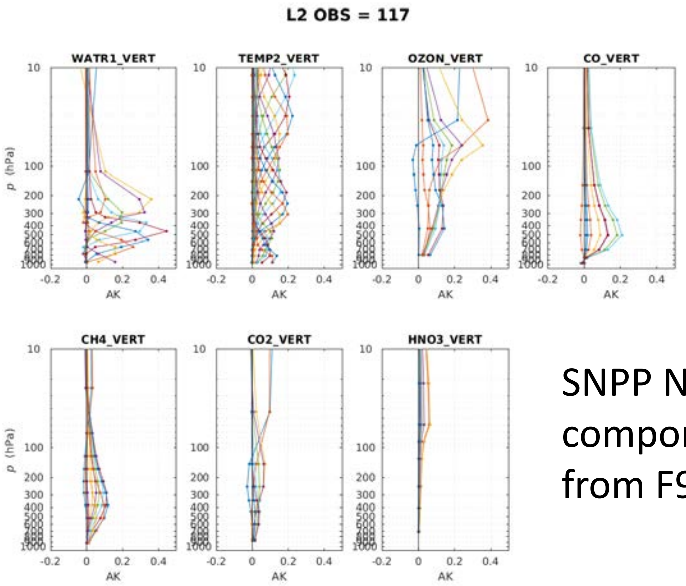
- **AKs** define the **vertical sensitivity** of the sounder measurement system

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

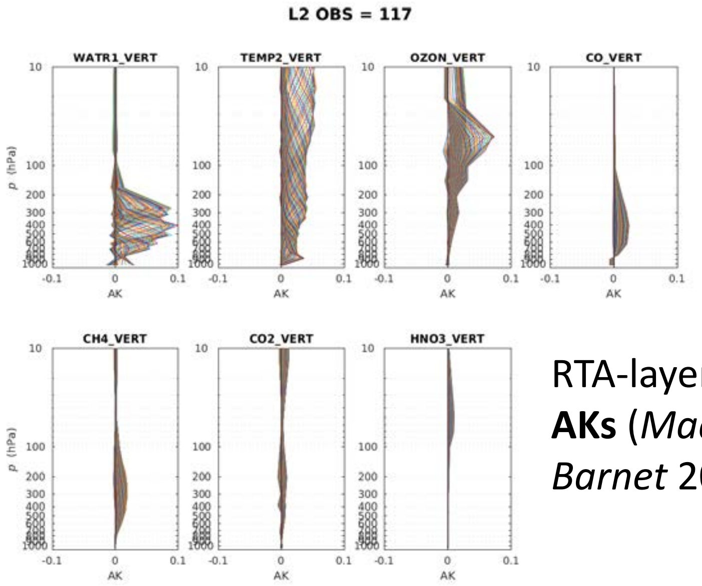
- This facilitates **intercomparisons** of measurements obtained by two different observing systems

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

$$\mathbf{x}_\mathbf{S} = \exp\{\ln(\mathbf{x}_\mathbf{0}) + \mathbf{A}_\mathbf{e}[\ln(\mathbf{x}) - \ln(\mathbf{x}_\mathbf{0})]\}$$



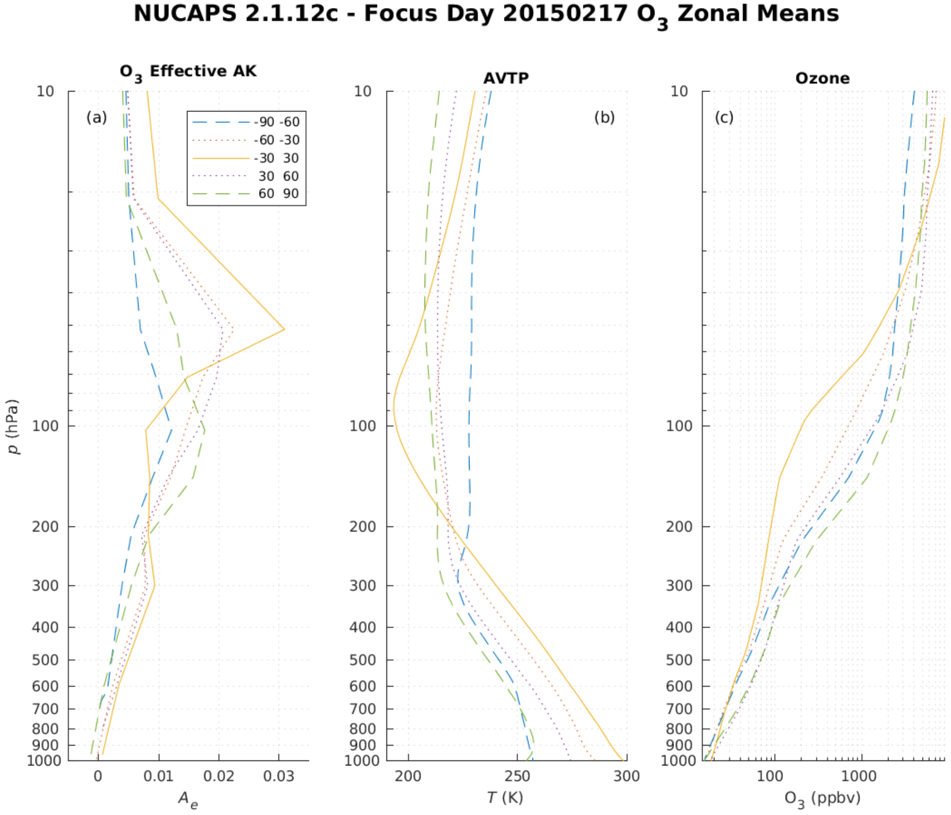
SNPP NUCAPS component AKs from F93 files



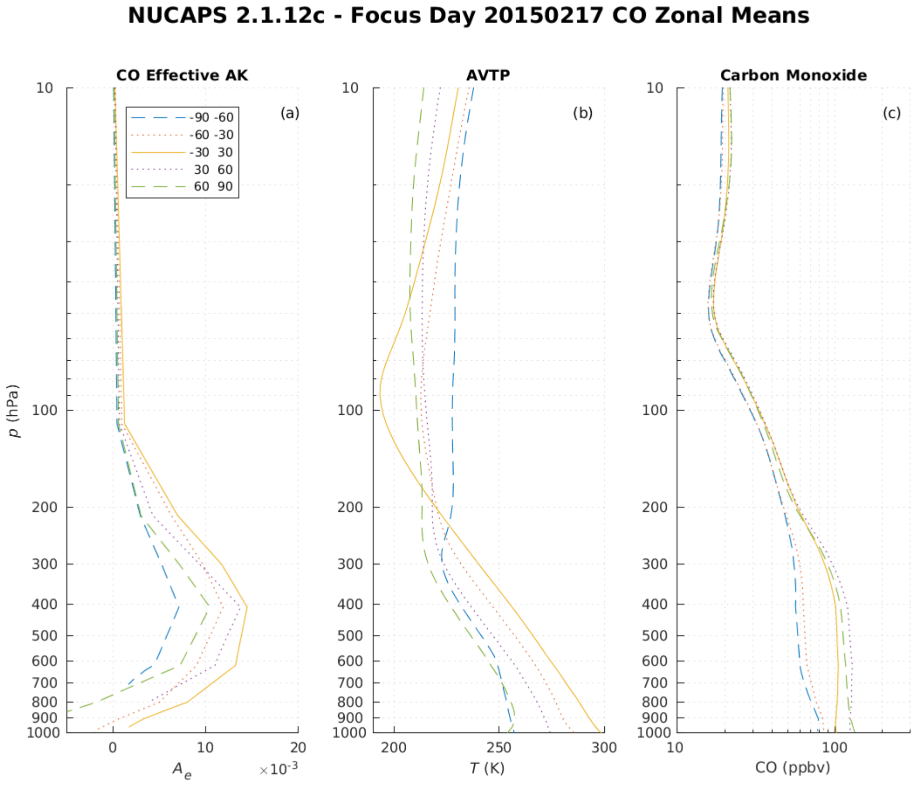
RTA-layer **effective AKs** (*Maddy & Barnet* 2008)

Zonal Mean Column Effective Averaging Kernels: O_3, CO

Ozone

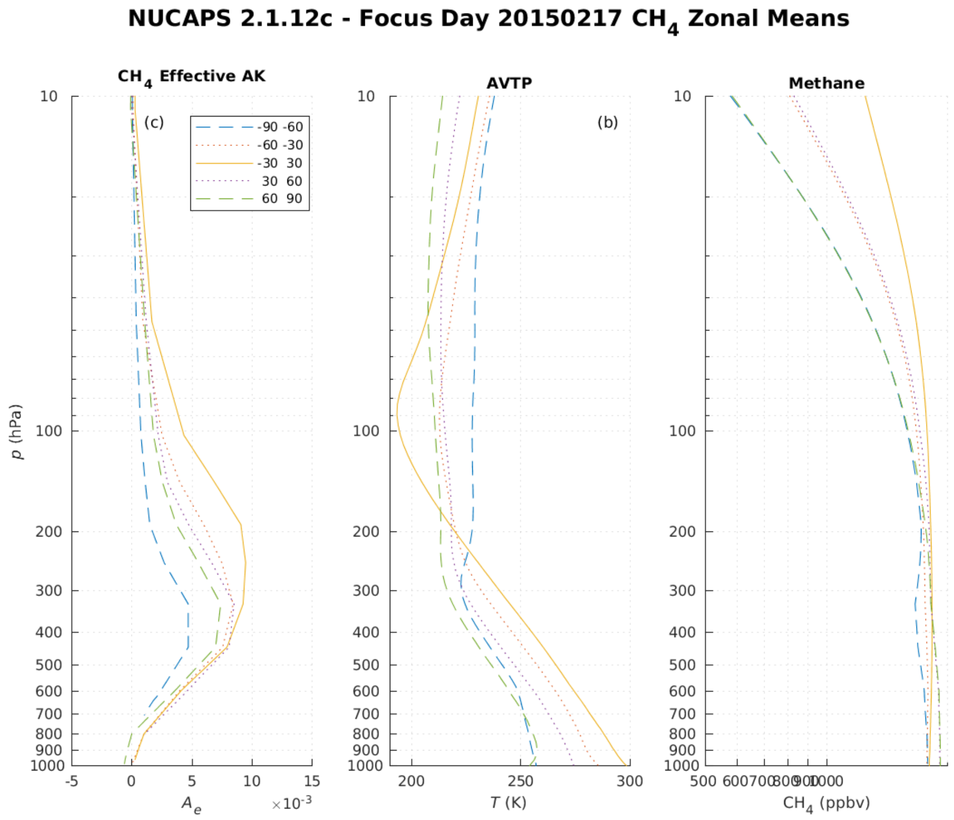


Carbon Monoxide

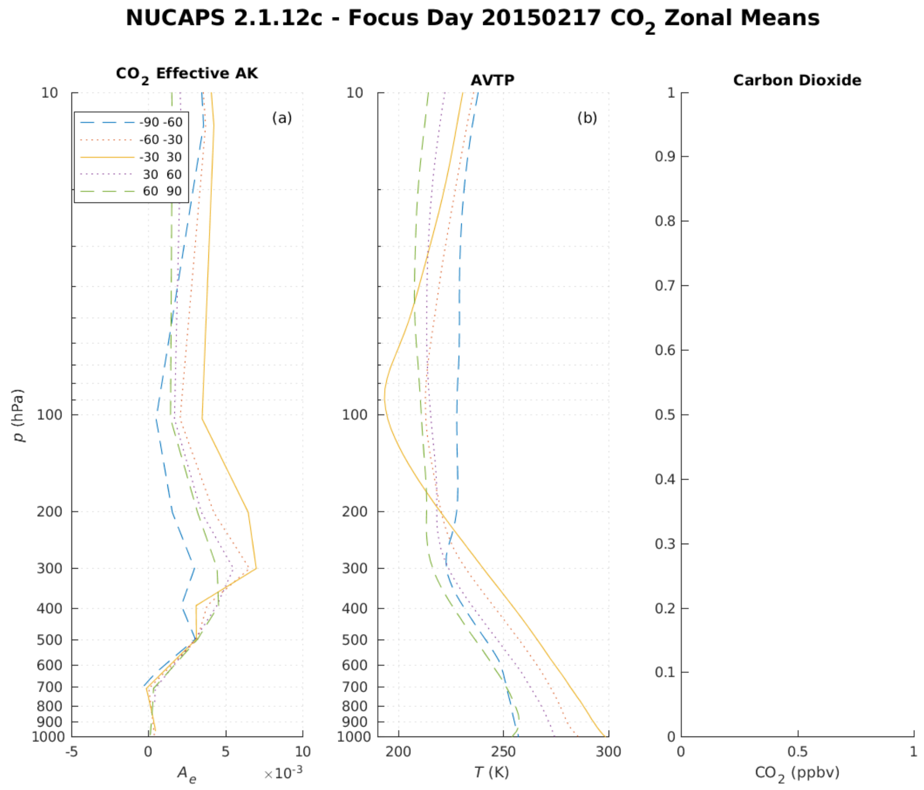


Zonal Mean Column Effective Averaging Kernels: CH_4, CO_2

Methane



Carbon Dioxide

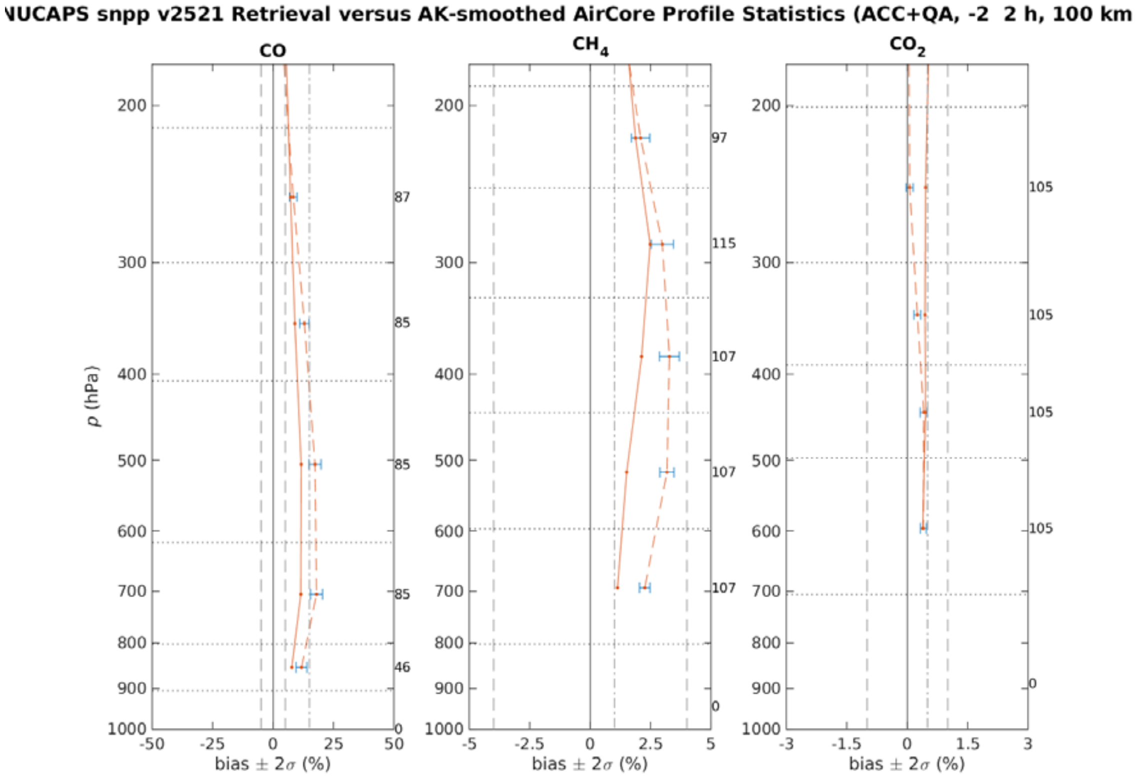


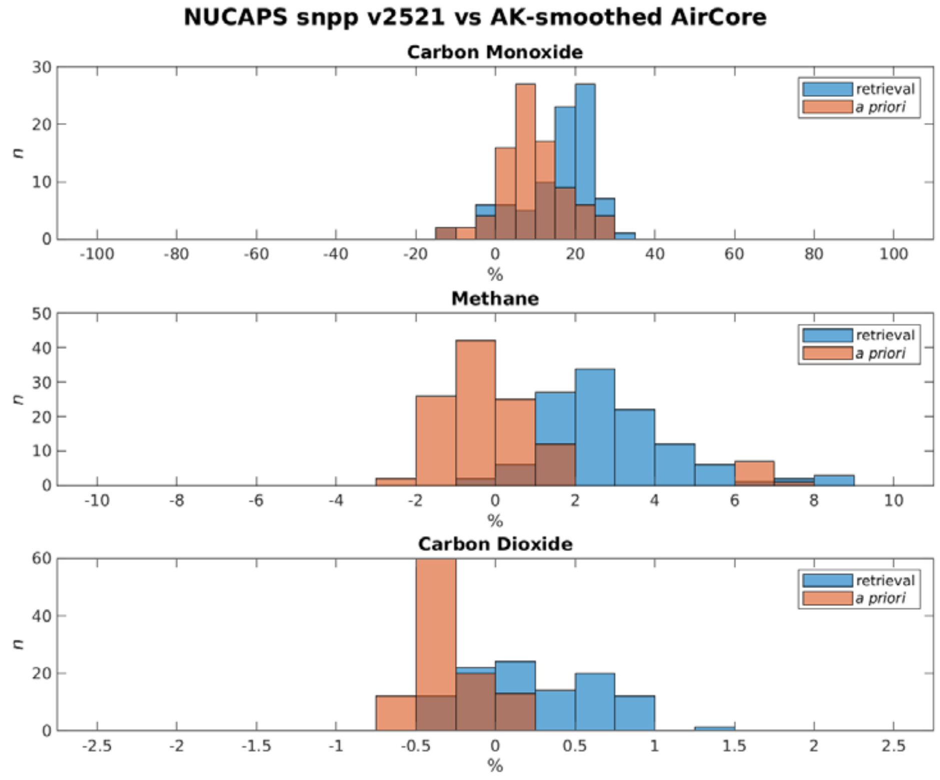
SNPP NUCAPS (v2.5.2.1) versus AirCore

AK-Smoothed, Accepted Cases + QA, ±2 hr, 100 km

AirCore

(*Membrive et al.* 2017; *Karion et al.* 2010)



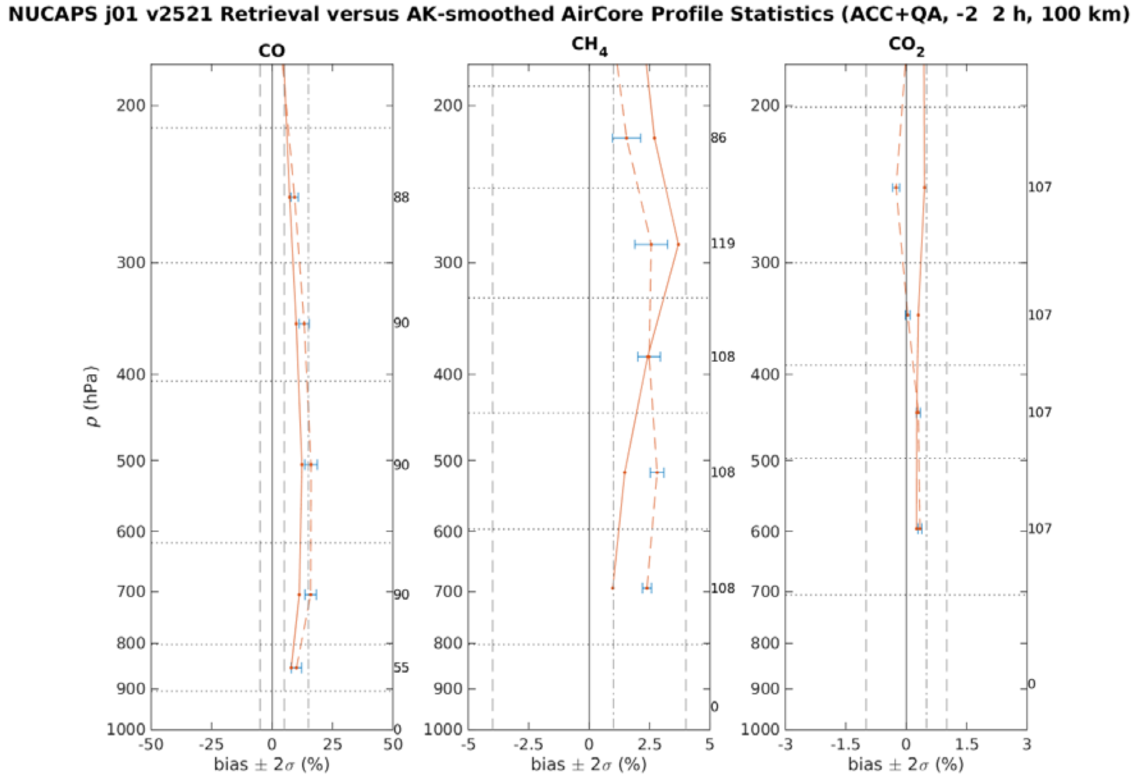


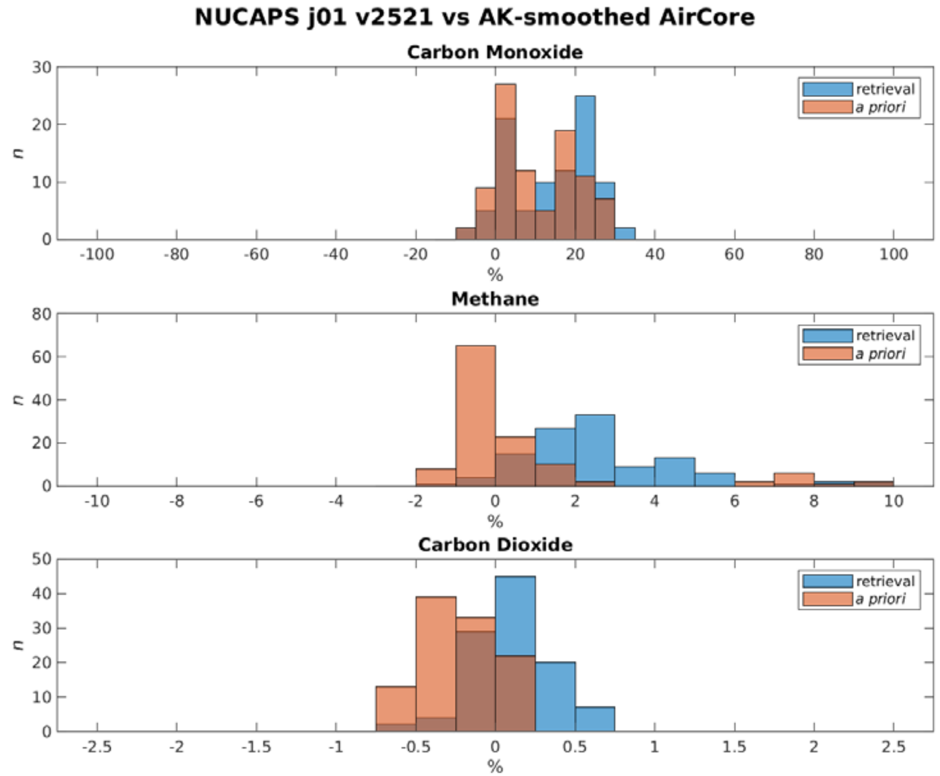
NOAA-20 NUCAPS (v2.5.2.1) versus AirCore

AK-Smoothed, Accepted Cases + QA, ±2 hr, 100 km

AirCore

(*Membrive et al.* 2017; *Karion et al.* 2010)





Summary and Future Work

- **Validated Maturity Review** scheduled for 15 Oct 2019
  - **NOAA-20 $T/H_2O/O_3$ Validated Maturity**
  - **SNPP/NOAA-20 Carbon Trace Gases**
    - **CO Validated Maturity**
    - **CH_4 Beta-Provisional Maturity**
    - **CO_2 Beta Maturity**
    - **Recent NUCAPS upgrades** have focused on upgrades/optimizations of the **CO and CH4 trace gas EDRs**
    - **Ongoing Validation of SNPP NUCAPS CO/CH4/CO2** versus **ATom** truth datasets show
      - **CO currently meets JPSS Requirements**
      - CH4 and CO2 are close to meeting requirements
    - **TCCON**, **AirCore** and **AIRS** will be used as **"transfer standards"** between SNPP and NOAA-20

- **Future Work**
  - **Ongoing NUCAPS development, Cal/Val and Long-Term Monitoring**
    - **Continue v2.x algorithm optimizations**
    - **Further upgrades/optimizations for CH_4 and CO_2 products**
    - Continue support of dedicated RAOBs (**ARM, RIVAL, AEROSE**)
  - **Other Related Work**
    - **Surface emissivity upgrades/updates**
      - **IR sea surface emissivity (IRSSE) model upgrades (cf. *Nalli et al.* talk Thursday)**
    - Continued support EDR user applications (**AWIPS**, **AR/SAL**, **atmospheric chemistry users**)

NUCAPS Validation

THANK YOU! QUESTIONS?

NUCAPS Validation

BACKUP SLIDES