Validation of the SNPP and NOAA-20 NOAA Unique Combined Atmospheric Processing System (NUCAPS)

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  - **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
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Outline

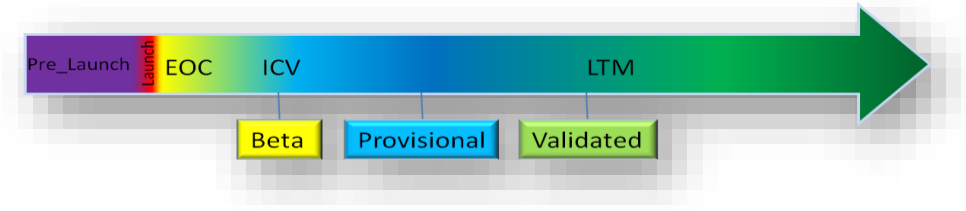
- **JPSS Sounder EDR Cal/Val Overview**
  - JPSS Level 1 Requirements
  - Validation Hierarchy recap
  - NUCAPS Algorithm
    - Overview of Recent Upgrades
- **NUCAPS Validation Status**
  - NUCAPS NOAA-20 Status
    - T/H2O/O3 EDRs versus ECMWF
  - NUCAPS Carbon Trace Gas Status (SNPP)
    - CO, CH4, CO2 versus ATom

NUCAPS Validation

JPSS SOUNDER EDR CAL/VAL OVERVIEW

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 **JPSS-1 (NOAA-20) sounder EDR Cal/Val Plan** (v1.1) was completed in Dec 2015
  - Although the Cal/Val Plan included validation of carbon trace gas EDRs (CO, CH_4 and CO_2), the details had not been completely mapped 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

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 $g \cdot kg^{-1}$ / 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**
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

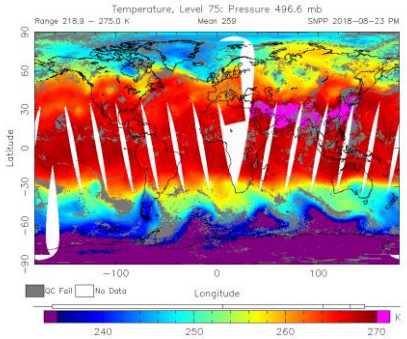
Source:
(L1RD, 2014, pp. 45-49)

NOAA Unique Combined Atmospheric Processing System (NUCAPS) Algorithm

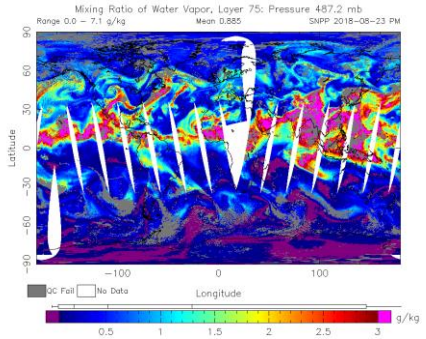
- **Operational algorithm**
  - **NOAA Enterprise Algorithm** for CrIS/IASI/AIRS (*Susskind, Barnet and Blaisdell,* IEEE 2003; *Gambacorta et al.,* 2014)
  - Global non-precipitating conditions
  - **Atmospheric Vertical Temperature** and **Moisture Profiles** (**AVTP**, **AVMP**)
  - **Trace gases: 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)

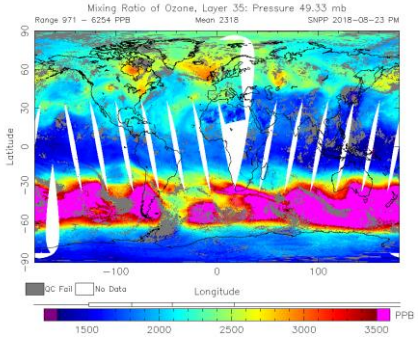
AVTP (500 hPa)



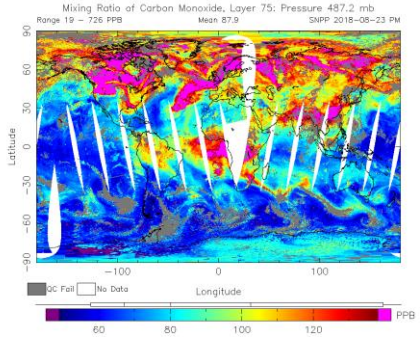
AVMP (500 hPa)



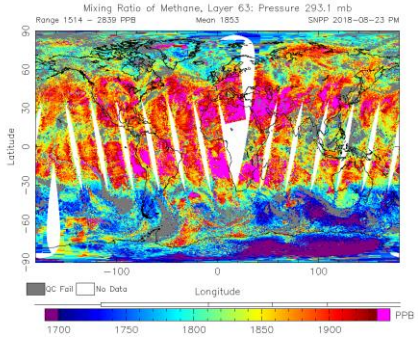
Ozone (50 hPa)



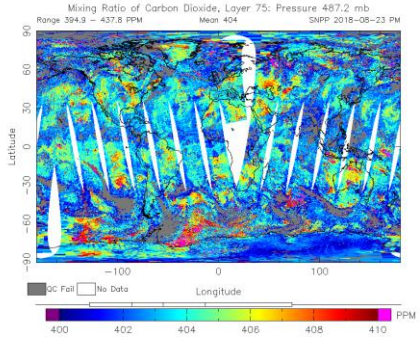
Carbon Monoxide (500 hPa)



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 v2.1.4)
    - New *T, Q*, CCR channels
  - 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 from Juying Warner (UMCP) 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

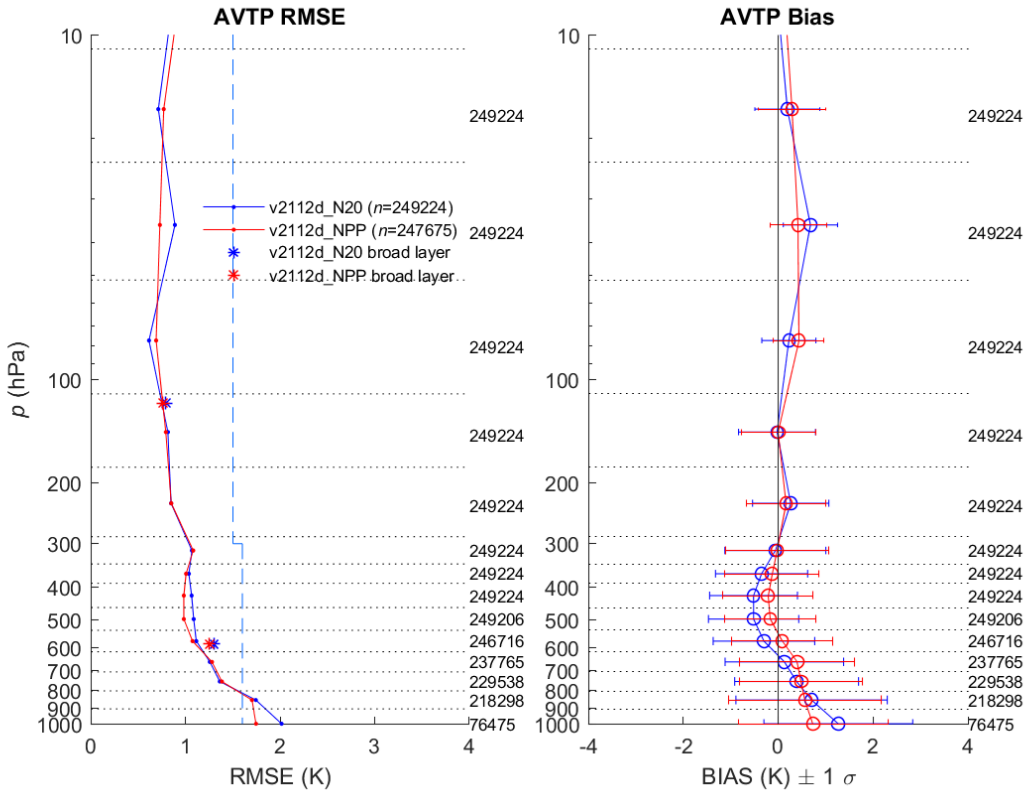
NUCAPS Validation

NUCAPS NOAA-20 VALIDATION STATUS

NUCAPS (v2.1.12d) IR+MW T/H_2O EDR Coarse-Layer Statistics Baseline: ECMWF Global Focus Day 10-Apr-2018

NOAA-20
SNPP

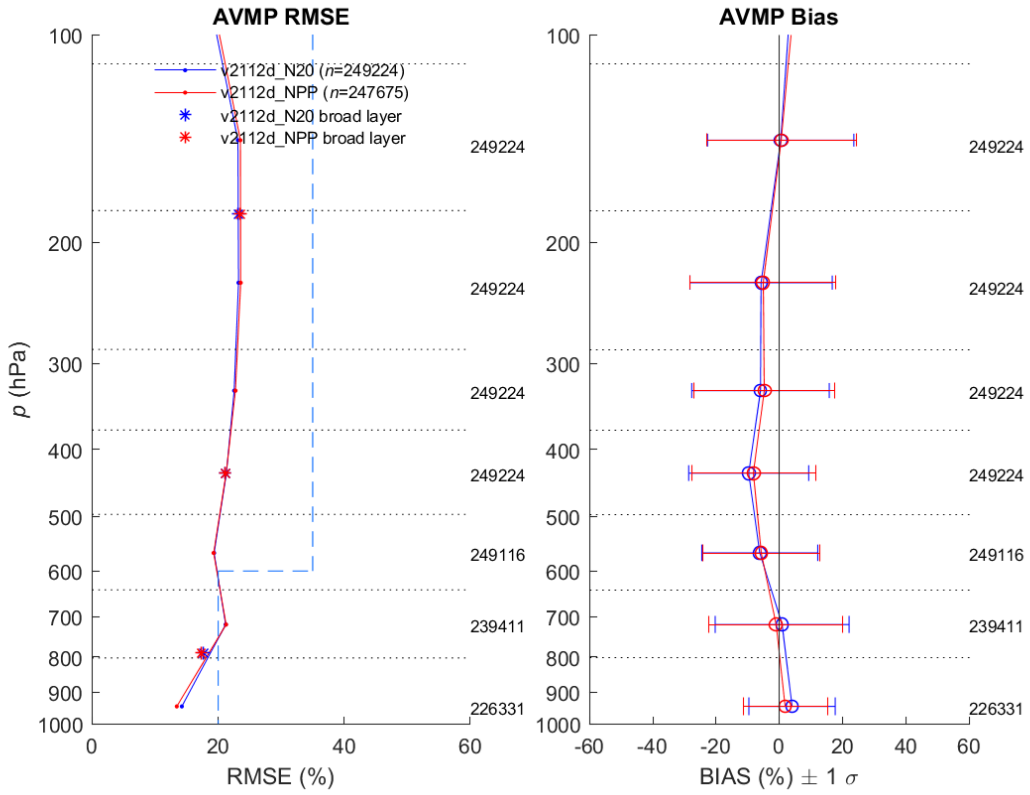
AVTP Versus ECMWF



NOAA-20 Yield = 76.9%
SNPP Yield = 79.1%

NOAA-20
SNPP

AVMP Versus ECMWF

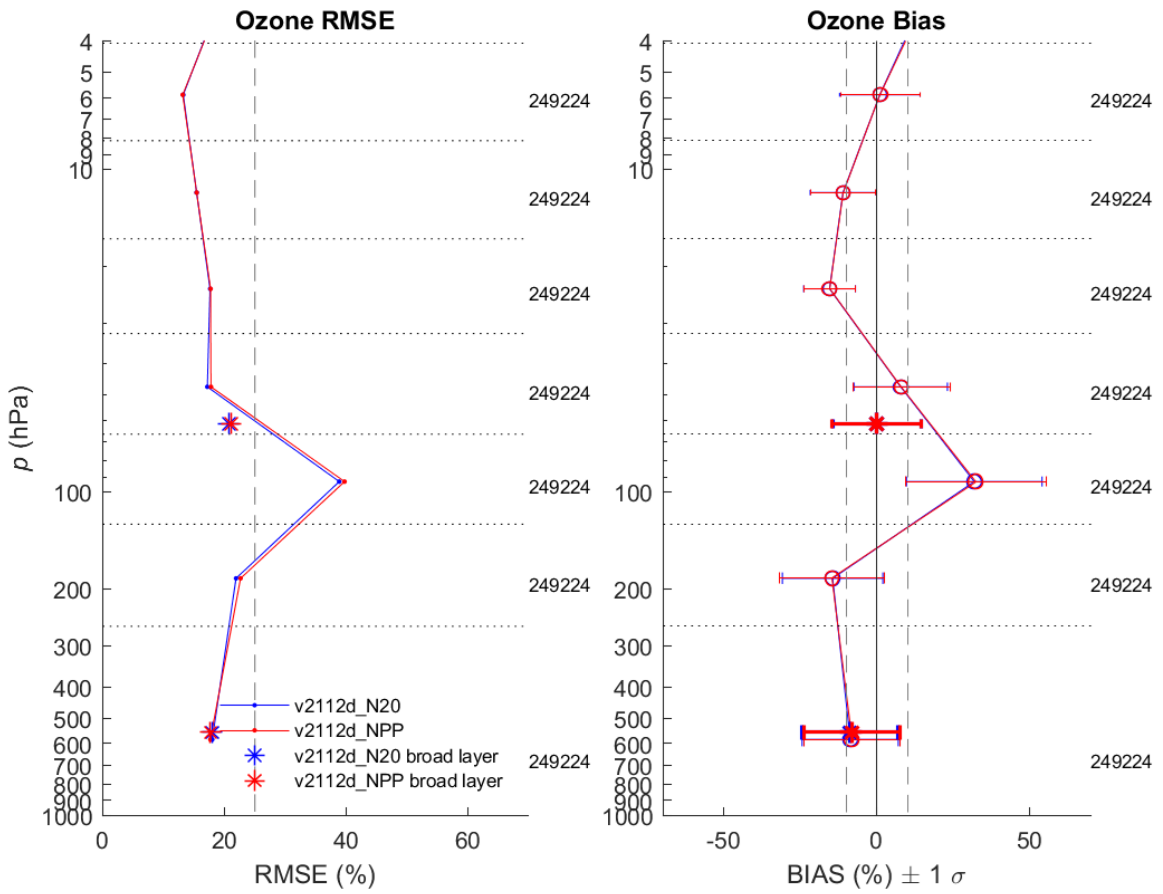


NUCAPS (v2.1.12d) IR Ozone Profile EDR Coarse-Layer Statistics Baseline: ECMWF Global Focus Day 10-Apr-2018

IR Ozone Profile Versus ECMWF

NOAA-20
SNPP

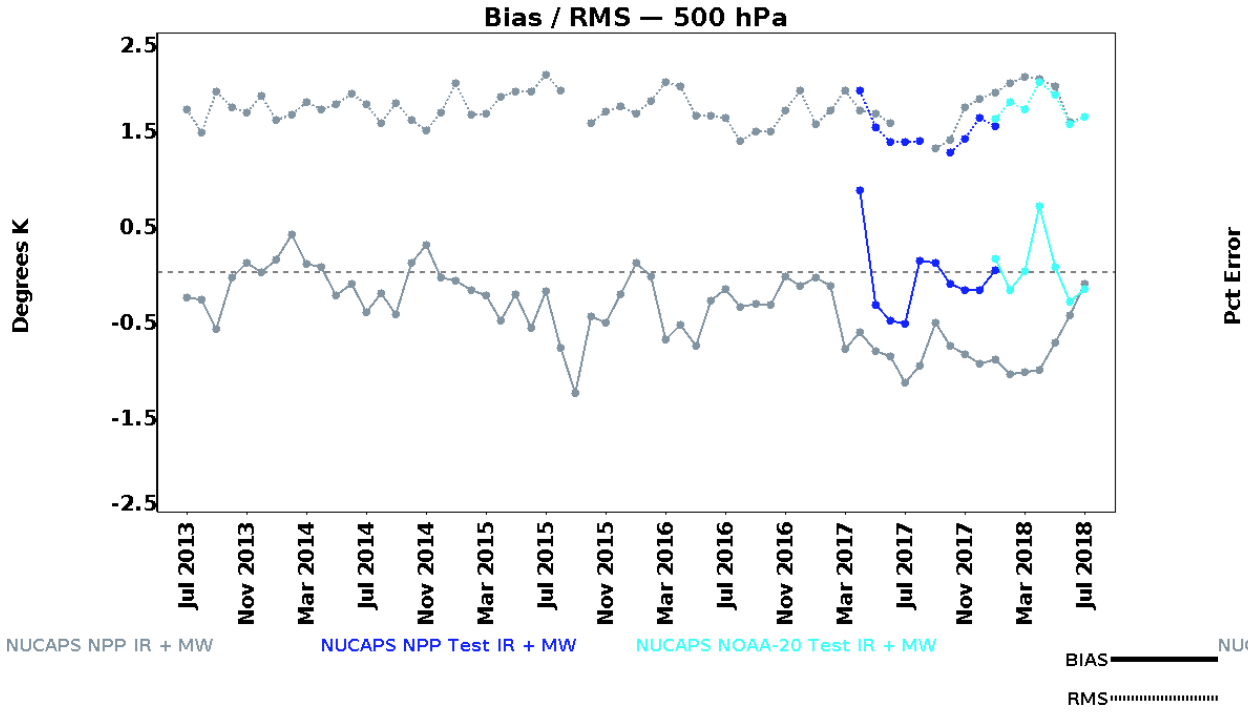
NOAA-20 Yield = 76.9%
SNPP Yield = 79.1%



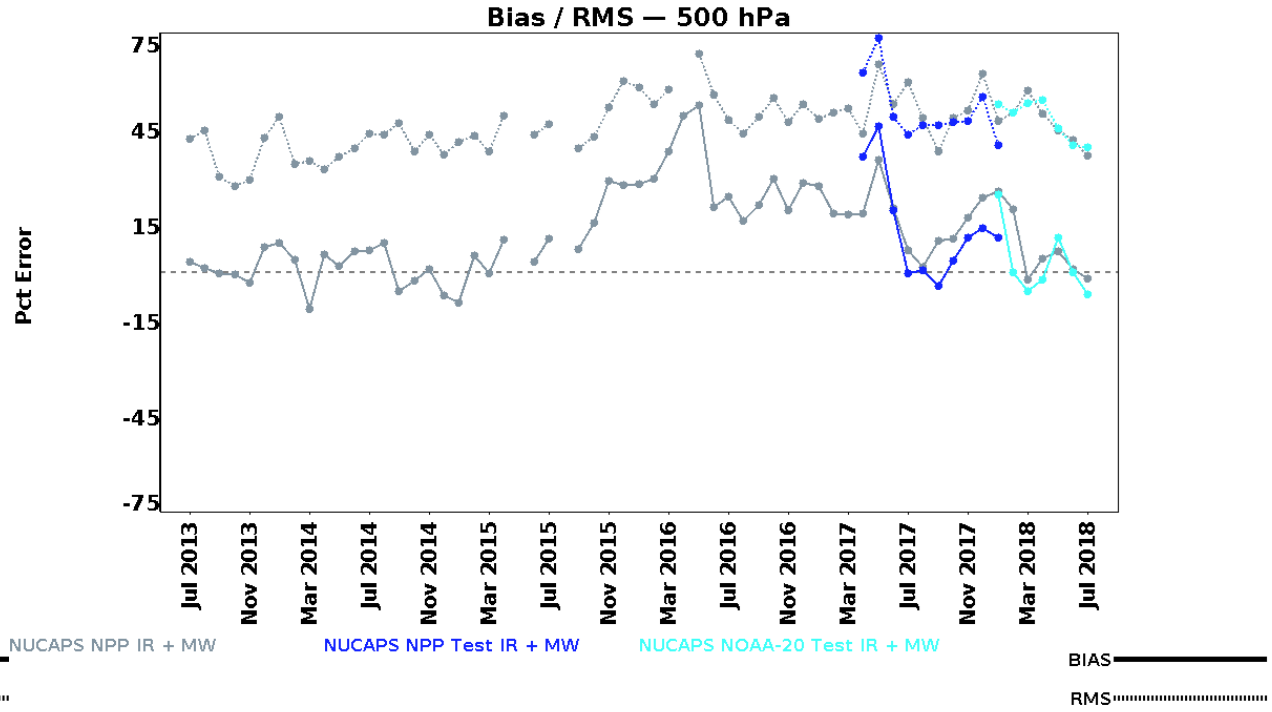
From Nalli et al. (2017b)

SNPP and NOAA-20 NUCAPS Long-Term Monitoring
(via NPROVS NARCS)

AVTP (500 hPa)



AVMP (500 hPa)



NUCAPS Validation

NUCAPS CARBON TRACE GAS VALIDATION STATUS (SNPP)

Overview of Carbon Trace Gas Validation

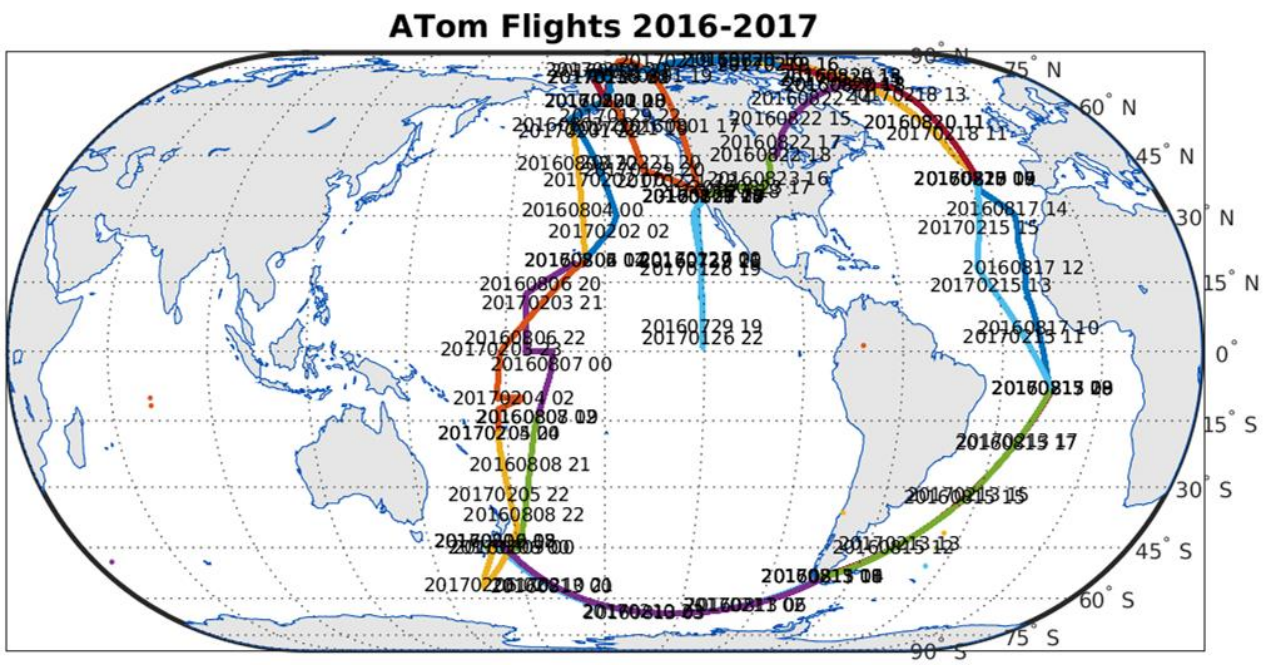
- **Carbon trace gas EDR validation** versus JPSS program established uncertainty specifications is a **new sounder validation requirement** that began during the transition period to the FSR CrIS NUCAPS

- **In response to these new requirements, a validation strategy was devised** with preliminary validation of NUCAPS carbon trace gas EDRs conducted leveraging global truth datasets, including
  - ECMWF from Global Focus Days (Cal/Val Method #1)
  - **Satellite EDRs from Global Focus Days** (Cal/Val Method #2)
    - Of particular value for **inter-satellite stability**
    - **Aqua AIRS v6**
    - 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 Methodologies**
  - 2-D linearly interpolated FOR – used for AIRS versus NUCAPS
  - "VALAR method"
    - NUCAPS/AIRS versus mean TCCON
    - NUCAPS versus ATom profiles
    - Include all FOR within threshold radius (e.g., 150 km) time window (e.g., ±3 hours)
  - Quality assurance (QA)
    - NUCAPS IR+MW quality flag and AIRS trace gas quality flags
    - NUCAPS trace gas QA flags are undergoing development

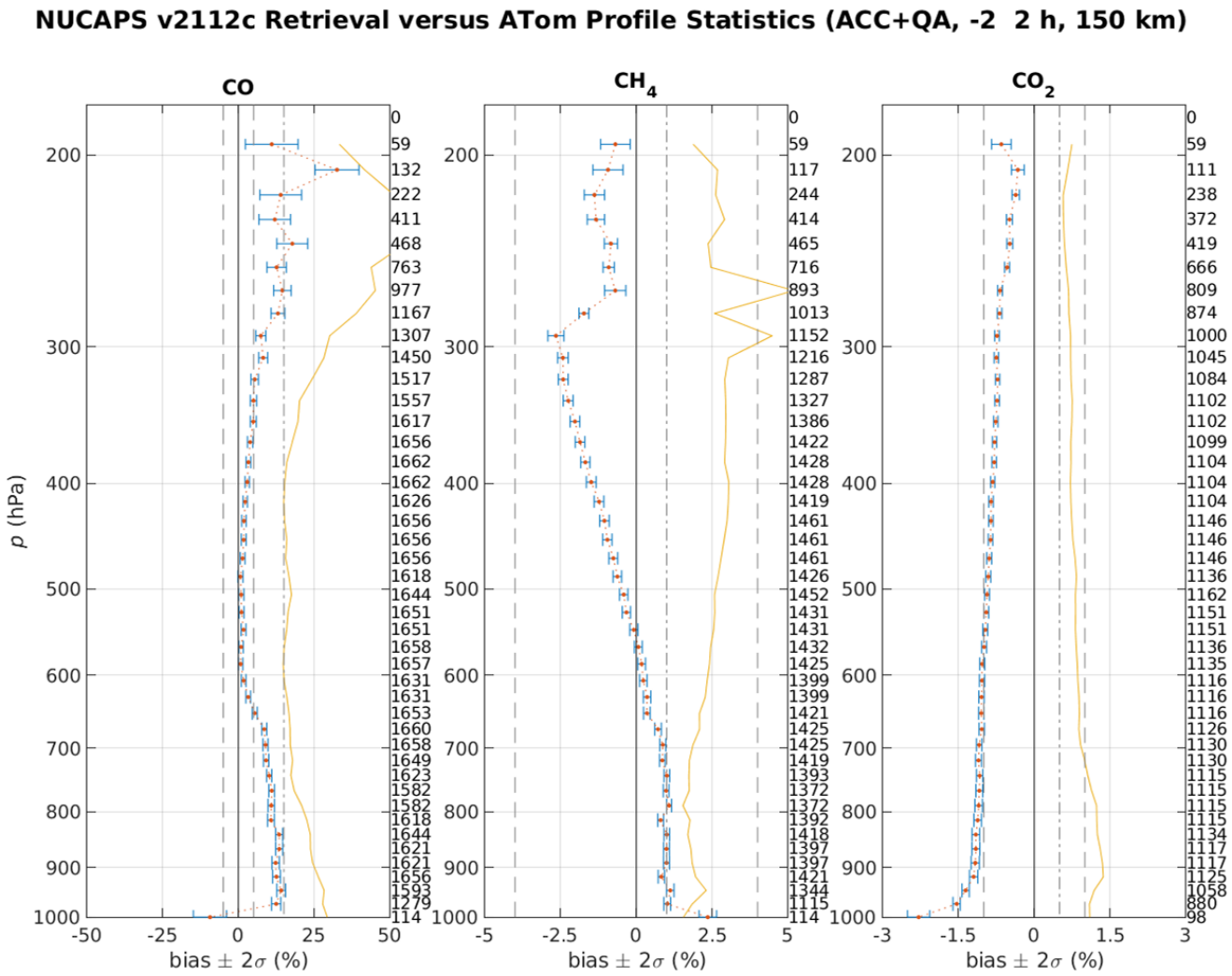
Atmospheric Tomography (ATom) Mission
(*Wofsy et al.* 2018)

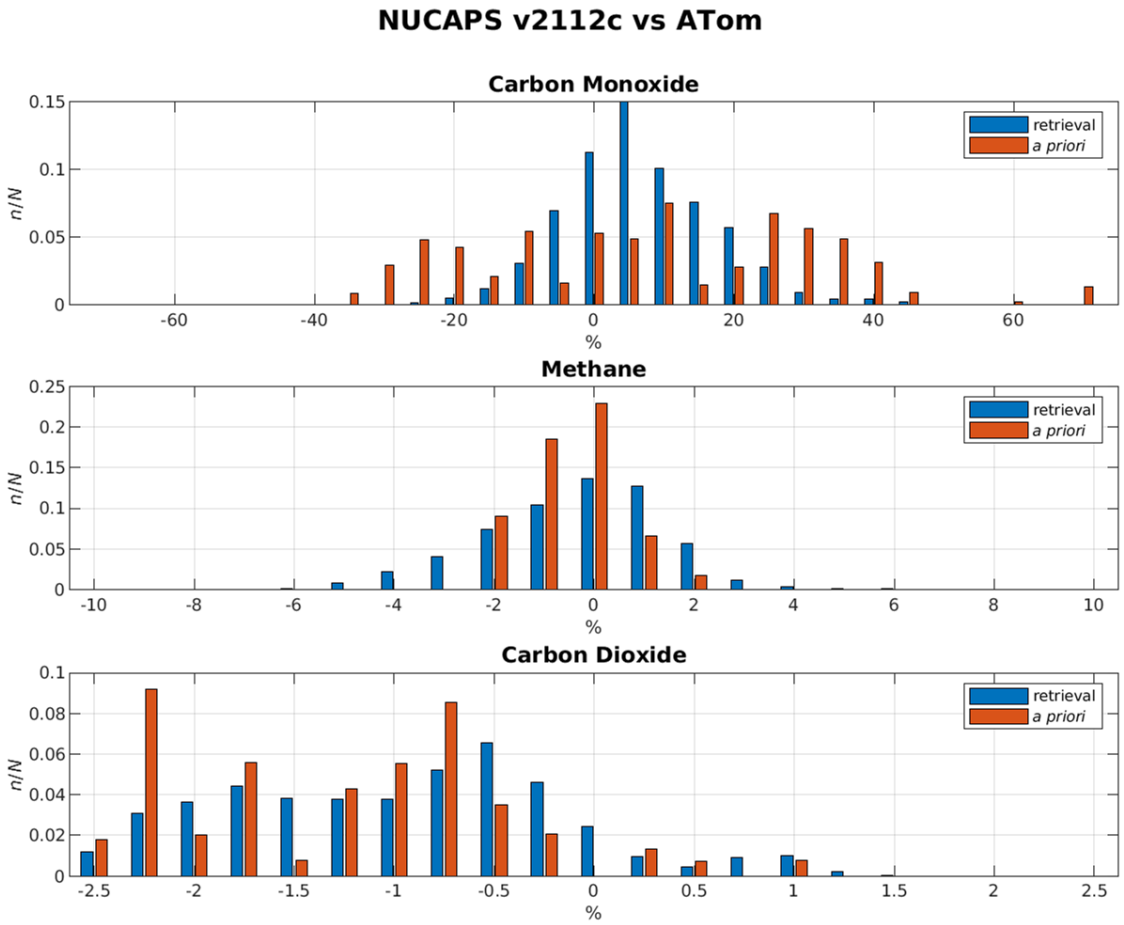
- **ATom** deploys extensive gas and aerosol payloads on the **NASA DC-8** aircraft for global-scale sampling of the atmosphere, profiling continuously from 0.2–12 km altitude
- **Flights** occur in each of 4 seasons over a 4-year period, originating from the Armstrong Flight Research Center in Palmdale, California
  - North to western Arctic, south to South Pacific, east to the Atlantic, north to Greenland, and return to California across central North America
  - ATom establishes a single, contiguous global-scale data set
- **Source:** https://espo.nasa.gov/atom/



NUCAPS SNPP (v2.1.12c) versus ATom

Accepted+QA, ±2 hr, 150 km





SNPP 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) $T/H_2O/O_3$ EDRs have all met JPSS global requirements
  - Validated Maturity attained
- Offline **NOAA-20 and SNPP NUCAPS (v2.x FSR)** have been successfully implemented and tested. Based on Global Focus Day ECMWF model comparisons and limited RAOBs
  - **AVTP/AVMP EDRs** have attained **Provisional Maturity**
  - **IR Ozone Profile EDR** has attained **Beta Maturity**
  - IR-Only EDR products have been successfully implemented and show reasonable performance
  - **Carbon trace gas EDR validation** versus program-established uncertainty specifications was a **new task** beginning with the transition to the FSR CrIS NUCAPS
    - **Recent NUCAPS upgrades have focused on upgrades/optimizations of the CO trace gas EDR product**
    - **Preliminary validation** versus AIRS, TCCON and ATom truth datasets show the products are close to meeting JPSS requirements

- **Future Work**
  - **Ongoing NUCAPS development, Cal/Val and Long-Term Monitoring**
    - **Continue v2.x algorithm optimizations**
    - **NUCAPS Trace Gas Validated Maturity Review**
      - **Utilize field campaign datasets (viz., ATom)**
      - **Upgrades/optimizations for CH_4 and CO_2 products**
    - **NOAA-20 NUCAPS validation**
      - Continue support of dedicated RAOBs (including **ARM, RIVAL, AEROSE**)
      - **Next AEROSE campaign is scheduled for Feb-Mar 2019**
  - **Other Related Work**
    - **Apply averaging kernels** in NUCAPS error analyses, including carbon trace gases and ozone profile EDRs
    - 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**)

NUCAPS Validation

THANK YOU! QUESTIONS?

NUCAPS Validation

EXTRA SLIDES