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

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$^4$CIMSS, University of Wisconsin-Madison, USA
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
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  – **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](http://www.woudc.org))
  – **SHADOZ**: Southern Hemisphere Additional Ozonesondes (A. Thompson et al.)


• **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$_2$O/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
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)

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>THRESHOLD</th>
<th>OBJECTIVE</th>
</tr>
</thead>
<tbody>
<tr>
<td>AVTP, Cloud fraction &lt; 50%, surface to 300 hPa</td>
<td>1.6 K / 1-km layer</td>
<td>0.5 K / 1-km layer</td>
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<tr>
<td>AVTP, Cloud fraction &lt; 50%, 300–30 hPa</td>
<td>1.5 K / 3-km layer</td>
<td>0.5 K / 3-km layer</td>
</tr>
<tr>
<td>AVTP, Cloud fraction &lt; 50%, 30–1 hPa</td>
<td>1.5 K / 5-km layer</td>
<td>0.5 K / 5-km layer</td>
</tr>
<tr>
<td>AVTP, Cloud fraction &lt; 50%, 1–0.5 hPa</td>
<td>3.5 K / 5-km layer</td>
<td>0.5 K / 5-km layer</td>
</tr>
<tr>
<td>AVTP, Cloud fraction ≥ 50%, surface to 700 hPa</td>
<td>2.5 K / 1-km layer</td>
<td>0.5 K / 1-km layer</td>
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<td>AVTP, Cloud fraction ≥ 50%, 700–300 hPa</td>
<td>1.5 K / 1-km layer</td>
<td>0.5 K / 1-km layer</td>
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<tr>
<td>AVTP, Cloud fraction ≥ 50%, 300–30 hPa</td>
<td>1.5 K / 3-km layer</td>
<td>0.5 K / 3-km layer</td>
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<tr>
<td>AVTP, Cloud fraction ≥ 50%, 30–1 hPa</td>
<td>1.5 K / 5-km layer</td>
<td>0.5 K / 5-km layer</td>
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<tr>
<td>AVTP, Cloud fraction ≥ 50%, 1–0.5 hPa</td>
<td>3.5 K / 5-km layer</td>
<td>0.5 K / 5-km layer</td>
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</table>

<table>
<thead>
<tr>
<th>PARAMETER</th>
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<th>OBJECTIVE</th>
</tr>
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<tbody>
<tr>
<td>AVMP, Cloud fraction &lt; 50%, surface to 600 hPa</td>
<td>Greater of 20% or 0.2 g kg⁻¹ / 2-km layer</td>
<td>10%</td>
</tr>
<tr>
<td>AVMP, Cloud fraction &lt; 50%, 600–300 hPa</td>
<td>Greater of 35% or 0.1 g kg⁻¹ / 2-km layer</td>
<td>10%</td>
</tr>
<tr>
<td>AVMP, Cloud fraction &lt; 50%, 300–100 hPa</td>
<td>Greater of 35% or 0.1 g kg⁻¹ / 2-km layer</td>
<td>10%</td>
</tr>
<tr>
<td>AVMP, Cloud fraction ≥ 50%, surface to 600 hPa</td>
<td>Greater of 20% or 0.2 g kg⁻¹ / 2-km layer</td>
<td>10%</td>
</tr>
<tr>
<td>AVMP, Cloud fraction ≥ 50%, 600–400 hPa</td>
<td>Greater of 40% or 0.1 g kg⁻¹ / 2-km layer</td>
<td>10%</td>
</tr>
<tr>
<td>AVMP, Cloud fraction ≥ 50%, 400–100 hPa</td>
<td>Greater of 40% or 0.1 g kg⁻¹ / 2-km layer</td>
<td>NS</td>
</tr>
</tbody>
</table>

“Clear to Partly-Cloudy”
(Cloud Fraction < 50%)

IR retrieval

“Cloudy”
(Cloud Fraction >= 50%)

MW-only retrieval

Oct 2017

Nalli et al. – Fall 2017 NSSTM
## JPSS Specification Performance Requirements

**CrIS Trace Gas EDR Uncertainty (O₃, CO, CO₂, CH₄)**

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>THRESHOLD</th>
<th>OBJECTIVE</th>
</tr>
</thead>
<tbody>
<tr>
<td>O₃ (Ozone) Profile Precision, 4–260 hPa (6 statistic layers)</td>
<td>20%</td>
<td>10%</td>
</tr>
<tr>
<td>O₃ (Ozone) Profile Precision, 260 hPa to sfc (1 statistic layer)</td>
<td>20%</td>
<td>10%</td>
</tr>
<tr>
<td>O₃ (Ozone) Profile Accuracy, 4–260 hPa (6 statistic layers)</td>
<td>±10%</td>
<td>±5%</td>
</tr>
<tr>
<td>O₃ (Ozone) Profile Accuracy, 260 hPa to sfc (1 statistic layer)</td>
<td>±10%</td>
<td>±5%</td>
</tr>
<tr>
<td>O₃ (Ozone) Profile Uncertainty, 4–260 hPa (6 statistic layers)</td>
<td>25%</td>
<td>15%</td>
</tr>
<tr>
<td>O₃ (Ozone) Profile Uncertainty, 260 hPa to sfc (1 statistic layer)</td>
<td>25%</td>
<td>15%</td>
</tr>
<tr>
<td>CO (Carbon Monoxide) Total Column Precision</td>
<td>35%, or full res mode 15%</td>
<td>3%</td>
</tr>
<tr>
<td>CO (Carbon Monoxide) Total Column Accuracy</td>
<td>±25%, or full res mode ±5%</td>
<td>±5%</td>
</tr>
<tr>
<td>CO₂ (Carbon Dioxide) Total Column Precision</td>
<td>0.5% (2 ppmv)</td>
<td>1.05 to 1.4 ppmv</td>
</tr>
<tr>
<td>CO₂ (Carbon Dioxide) Total Column Accuracy</td>
<td>±1% (4 ppmv)</td>
<td>NS</td>
</tr>
<tr>
<td>CH₄ (Methane) Total Column Precision</td>
<td>1% (~20 ppbv)</td>
<td>NS</td>
</tr>
<tr>
<td>CH₄ (Methane) Total Column Accuracy</td>
<td>±4% (~80 ppmv)</td>
<td>NS</td>
</tr>
</tbody>
</table>

*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/ncaps/index.html
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)

FOR Collocation Criteria
\( \delta x \leq 75 \text{ km}, -60 < \delta t < 0 \text{ min} \)

Collocations of CrIS/ATMS granules facilitated via NPROVS+ system

From Nalli et al. (2017a)
AVTP Versus RAOB

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

![Graphs showing AVTP versus RAOB statistics](chart.png)

**AVTP RMS**
- IR+MW: 15
- MW-only: 323
- IR+MW broad layer: 1604
- MW-only broad layer: 3449

**AVTP Bias**
- IR+MW: 15
- MW-only: 323
- IR+MW broad layer: 1604
- MW-only broad layer: 3449

**From Nalli et al. (2017a)**

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

AVMP Versus RAOB

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

![Graphs showing AVMP versus RAOB statistics](chart.png)

**AVMP RMS**
- IR+MW: 481
- MW-only: 3797

**AVMP Bias**
- IR+MW: 2354
- MW-only: 3814

**From Nalli et al. (2017a)**
SNPP NUCAPS (NSR v1.5) Dedicated/Reference Ozone Sonde Collocation Sample

Collocated Ozone Sondes for \(O_3\) Profile EDR

- **Dedicated Ozone Sondes**
  - 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

For Collocation Criteria: \(\delta_x \leq 125\) km, \(-240 < \delta_t < +120\) min

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From Nalli et al. (2017b)
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

NUCAPS v1.5 - Focus Day 17–Feb–2015 Zonal Means

From Nalli et al. (2017b)
NUCAPS IR Ozone Profile EDR: Ozone Hole Over Antarctica

NUCAPS observed ozone depletion during SH springtime

From Nalli et al. (2017b)

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SNPP NUCAPS Validation

NUCAPS PHASE 4 V2.0 FSR VALIDATION STATUS
NUCAPS v2.0 FSR IR+MW $T/\text{H}_2\text{O}$ Coarse-Layer Statistics

Global Focus Day 17-Feb-2015

**V1.5 IR+MW**

**V2.0 IR+MW**

AVTP Versus ECMWF

**V1.5 IR+MW**

**V2.0 IR+MW**

AVMP Versus ECMWF

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From Nalli et al. (2017a)

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**V1.5 Yield = 63.4%**

**V2.0 Yield = 88.5%**
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 IR-Only \( T/H_2O \) Coarse-Layer Statistics
Global Focus Day 17-Feb-2015

IR-Only
First Guess

**AVTP Versus ECMWF**

**AVMP Versus ECMWF**

IR-Only Yield = 87.4%
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%

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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

\[ \text{NUCAPS-RAOB Collocations, JPSS Dedicated RAOBs} \]
\[ \delta x = 75 \text{ km}, \delta t = -90 \text{ to } +5 \text{ min} \]

\[ \text{valar_nucaps_offline_v2054_collocation_file_raob_20170629.mat} \]
NUCAPS v2.0 FSR IR+MW $T/H_2O$ Coarse-Layer Statistics Versus JPSS Dedicated RAOBs

IR+MW
MW-Only

AVTP Versus RAOB

IR+MW (n=170)
MW-only (n=390)
IR+MW broad layer
MW-only broad layer

IR+MW
MW-Only

AVMP Versus ECMWF

IR+MW (n=170)
MW-only (n=390)
IR+MW broad layer
MW-only broad layer

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IR+MW Yield = 75.7%

Nalli et al. – Fall 2017 NSSTM
### NUCAPS EDR Maturity Status

#### Slide courtesy of Lihang Zhou, STAR/JPSS

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

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

*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.
Summary and Future Work

- **SNPP NUCAPS NSR (v1.5) T/H$_2$O/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)
THANK YOU! QUESTIONS?
SNPP NUCAPS Validation

EXTRA SLIDES