NOAA Unique CrIS ATMS Processing System (NUCAPS)

Quanhua (Mark) Liu, Chris Barnet, Antonia Gambacorta, Nick Nalli, Xiaozhen Xiong, Chanyyi Tan, Flavio Iturbide-Sanchez, Tony Reale, Walter Wolf, and Mitch Goldberg

NASA Sounder Science Team Meeting, Greenbelt Maryland
September 30, 2014
Outline

• NUCAPS Objectives
• Product Requirements
• Retrieval System
• Cloud-Clearing Radiance
• NUCAPS Products
• NUCAPS Products’ Validation
• Conclusion
• Path Forward
NUCAPS Objectives

- Apodize and subset the CrIS SDR’s to produce thinned radiance datasets for use by NWP and satellite products
- Provide CrIS/ATMS NOAA Unique products within three hours of observation
- Cloud Cleared Radiances
- NOAA Unique Trace Gas Products
- Collocated CrIS/VIIRS-cloud datasets
- Provide NUCAPS Products to CLASS for sounding community
- Provide a subset of NUCAPS Products to Advanced Weather Interactive Processing System (AWIPS)
## Temperature Profile Requirements

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Threshold</th>
<th>Objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geographic coverage</td>
<td>90% every 18 hours</td>
<td>&gt; 90%</td>
</tr>
<tr>
<td>Vertical Coverage</td>
<td>Surface to 0.5 mb</td>
<td>Surface to 0.5 mb</td>
</tr>
<tr>
<td>Vertical Cell Size</td>
<td>0.2 ~50 mb</td>
<td>0.1 ~ 10 mb</td>
</tr>
<tr>
<td>Horizontal Cell Size</td>
<td>50 km at nadir</td>
<td>1 km at nadir</td>
</tr>
<tr>
<td>Mapping Uncertainty</td>
<td>5 km</td>
<td>0.5 km</td>
</tr>
</tbody>
</table>

### Measurement Range

<table>
<thead>
<tr>
<th>Cloud</th>
<th>Surface to 300 mb</th>
<th>300 to 30 mb</th>
<th>30 to 1 mb</th>
<th>1 to 0.5 mb</th>
<th>Cloud &gt;= 50%: Surface to 700mb</th>
<th>700 to 300 mb</th>
<th>300 to 30 mb</th>
<th>30 to 1 mb</th>
<th>1 to 0.5 mb</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.6 K per km layer</td>
<td>1.5 K per 3 km layer</td>
<td>1.5 K per 5 km layer</td>
<td>3.5 K per 5 km layer</td>
<td>2.5 K per km layer</td>
<td>1.5 K per km layer</td>
<td>1.5 K per 3 km layer</td>
<td>1.5 K per 5 km layer</td>
<td>3.5 K per 5 km layer</td>
</tr>
<tr>
<td></td>
<td>0.5 K per km layer</td>
<td>0.5 K per 3 km layer</td>
<td>0.5 K per 5 km layer</td>
<td>0.5 K per 5 km layer</td>
<td>0.5 K per km layer</td>
<td>0.5 K per km layer</td>
<td>0.5 K per 3 km layer</td>
<td>0.5 K per 5 km layer</td>
<td>0.5 K per 5 km layer</td>
</tr>
<tr>
<td>Attribute</td>
<td>Threshold</td>
<td>Objective</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-------------------------------</td>
<td>--------------------------------</td>
<td>------------------</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Geographic coverage</td>
<td>90% every 18 hours</td>
<td>3 hrs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vertical Coverage</td>
<td>Surface to 0.5 mb</td>
<td>Surface to 0.5 mb</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vertical Cell Size</td>
<td>20 ~50 mb</td>
<td>5 ~ 10 mb</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Horizontal Cell Size</td>
<td>50 km at nadir</td>
<td>1 km at nadir</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mapping Uncertainty</td>
<td>5 km</td>
<td>0.5 km</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Measurement Range</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Measurement Uncertainty</td>
<td>Expressed as a percent of average ratio in 2 km layers</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cloud &lt; 50%: Surface to 600 mb</td>
<td>Greater of 20% or 0.2 g/kg</td>
<td>10%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>600 to 300 mb</td>
<td>Greater of 35% or 0.1 g/kg</td>
<td>10%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>300 to 100 mb</td>
<td>Greater of 35% or 0.1 g/kg</td>
<td>10%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cloud &gt;= 50%: Surface to 600 mb</td>
<td>Greater of 20% or 0.2 g/kg</td>
<td>10%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>600 to 300 mb</td>
<td>Greater of 40% or 0.1 g/kg</td>
<td>10%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>300 to 100 mb</td>
<td>Greater of 40% or 0.1 g/kg</td>
<td>10%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
# JPSS-1 Requirements

<table>
<thead>
<tr>
<th>EDR Attribute</th>
<th>CO</th>
<th>CO₂</th>
<th>CH₄</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertical Coverage</td>
<td>Total Column</td>
<td>Total Column</td>
<td>Total Column</td>
</tr>
<tr>
<td>Horizontal Resolution</td>
<td>100 km</td>
<td>100 km</td>
<td>100 km</td>
</tr>
<tr>
<td>Mapping Uncertainty, 3 sigma</td>
<td>25 km</td>
<td>25 km</td>
<td>25 km</td>
</tr>
<tr>
<td>Measurement Range</td>
<td>0 – 200 ppbv</td>
<td>300 – 500 ppmv</td>
<td>1100 – 2250 ppbv</td>
</tr>
<tr>
<td>Measurement Precision</td>
<td>35%</td>
<td>0.5% (2 ppmv)</td>
<td>1% (~20 ppbv)</td>
</tr>
<tr>
<td>Measurement Accuracy</td>
<td>±25%</td>
<td>±1% (4 ppmv)</td>
<td>±4% (~80 ppbv)</td>
</tr>
<tr>
<td>Refresh</td>
<td>24 h</td>
<td>24 h</td>
<td>24 h</td>
</tr>
</tbody>
</table>

Note
CrIS and ATMS SDR Data

CrIS/ATMS SDR are used in the retrieval.
Cloud coverage = 57%

Data from Haibing Sun
CCR (CF< 80%)

Using cloud-clearing radiance, IR retrieval data increases from 3.3% to 59.3%.
NUCAPS Sounding Products Available at NOAA CLASS and to AWIPS-II

- Atmospheric Vertical Temperature Profile
- Atmospheric Vertical Moisture Profile
- Infrared Ozone Profile
- (requirement: total column)
- Vertical CO Profile
- Vertical CO₂ Profile
- Vertical CH₄ Profile
- Outgoing Longwave Radiation (OLR)
- Vertical HNO₃ Profile
- Vertical N₂O Profile
- Vertical SO₂ Profile
- A flag indicating the presence of dust and volcanic emissions
- Cloud-Cleared Radiances

Many others such as Stability
**Validation Methodology, NPROVS and VALAR**

**Numerical Model (e.g., ECMWF, NCEP/GFS)**

*Global Comparisons*

Large, global samples acquired from Focus Days
Useful for early sanity checks, bias tuning and regression
However, not independent truth data

**Satellite EDR (e.g., CrIS, AIRS, ATOVS, COSMIC)**

*Intercomparisons*

Global samples acquired from Focus Days (e.g., CrIS/ATMS)
Consistency checks; merits of different retrieval algorithms
However, IR sounders have similar error characteristics;
must take rigorous account of averaging kernels of both systems (e.g., Rodgers and Connor, 2003)

**Conventional RAOB Matchup Assessments**

Conventional WMO/GTS operational sondes launched ~2/day for NWP (e.g., NPROVS)
Useful for representation of global zones and long-term monitoring
Large statistical samples acquired after a couple months’ accumulation
Limitations:
- Skewed distribution toward NH-continental sites
- Significant mismatch errors, potentially systematic at individual sites
- Non-uniform, less-accurate and poorly characterized radiosonde types used in data sample

**Dedicated/Reference RAOB Matchup Assessments**

Dedicated for the purpose of satellite validation
Well-specified error characteristics and optimal accuracy
Minimal mismatch errors
Include atmospheric state “best estimates” or “merged soundings”
Reference sondes: CFH, corrected RS92, Vaisala RR01 under Development
Traceable measurement
Detailed performance specification and regional Characterization
Limitation: Small sample sizes and geographic coverage
E.g., ARM sites (e.g., Tobin et al., 2006), GRUAN sites, NOAA AEROSE

**Intensive Field Campaign Dissections**

Include dedicated RAOBs, especially those not assimilated into NWP models
Include ancillary datasets (e.g., ozonesondes, lidar, M-AERI, MWR, sunphotometer, etc.)
Ideally include funded aircraft campaign using aircraft IR sounder (e.g., NAST-I, S-HIS) underflights
Detailed performance specification; state specification; SDR cal/val; EDR “dissections”
E.g., AEROSE, JAIVEX, WAVES, AWEX-G, EAQUATE, CalWater-2

Validation Data Sets

Qualitative Analysis
Product of global distribution

Quantitative Analysis
a. Aerosols and Ocean Science Expeditions (AEROSE)
b. ECMWF Global Analysis
c. Dedicated radiosondes

NUCAPS Products
Black indicate where IR+MW and MW-only failed qc ...
Dedicated and GRUAN Reference RAOB

**JPSS S-NPP Dedicated**

**S-NPP CrImSS EDR ICV Dedicated RAOB Sites (Year 1)**

**S-NPP CrImSS EDR ICV Dedicated RAOB Sites (Year 2)**

**GRUAN Reference Sites (NPROVS+ Collocation)**

**GRUAN RAOB Sites for Sounder EDR ICV**

---

<table>
<thead>
<tr>
<th>Location</th>
<th>BEL</th>
<th>BOU</th>
<th>CAB</th>
<th>DAR</th>
<th>ENA</th>
<th>ERK</th>
<th>GAN</th>
<th>HIH</th>
<th>LAU</th>
<th>LIN</th>
<th>MAN</th>
<th>NAU</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lat (deg)</td>
<td>39.05</td>
<td>39.95</td>
<td>52.1</td>
<td>-12.475</td>
<td>39.05</td>
<td>79.98</td>
<td>-0.69</td>
<td>19.72</td>
<td>-45.04</td>
<td>52.22</td>
<td>-2.06</td>
<td>-0.52</td>
</tr>
<tr>
<td>Lon (deg)</td>
<td>-76.88</td>
<td>-105.2</td>
<td>5.18</td>
<td>130.83</td>
<td>-28.03</td>
<td>-85.93</td>
<td>73.15</td>
<td>-155.05</td>
<td>169.68</td>
<td>14.12</td>
<td>147.43</td>
<td>166.92</td>
</tr>
</tbody>
</table>

---

<table>
<thead>
<tr>
<th>Location</th>
<th>NSA</th>
<th>NYA</th>
<th>OUA</th>
<th>PAY</th>
<th>POT</th>
<th>REU</th>
<th>SRC</th>
<th>SGP</th>
<th>SOD</th>
<th>TAT</th>
<th>TMF</th>
<th>XIL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lat (deg)</td>
<td>71.32</td>
<td>78.92</td>
<td>12.4</td>
<td>46.81</td>
<td>40.6</td>
<td>-21.08</td>
<td>-0.9</td>
<td>36.61</td>
<td>67.37</td>
<td>36.06</td>
<td>34.39</td>
<td>43.95</td>
</tr>
<tr>
<td>Lon (deg)</td>
<td>-156.6</td>
<td>11.92</td>
<td>-1.5</td>
<td>6.95</td>
<td>15.72</td>
<td>55.38</td>
<td>-89.6</td>
<td>-97.49</td>
<td>26.63</td>
<td>140.1</td>
<td>-117.7</td>
<td>116.12</td>
</tr>
</tbody>
</table>
2013 AEROSE State Parameters

\( P(z), T(p), H_2O(p), O_3(p), T_s, u_s, v_s, \text{AOD} \)

AEROSE-2013b Surface State Parameters at Ozoneonde Launch Locations

Surface Temperatures

Balloon Burst Pressures

Surface Pressures

Microtops Sunphotometer AOD

Microtops Angstrom Exponent

Ozoonesonde Launch Locations and Surface Winds

Temperature plot showing data from 11/17 to 12/07 for different locations and conditions.

Pressure graphs showing changes over time for different pressures.

A map showing ozoonesonde locations with surface wind vectors.
Offline IR + MW

MOD = ECMWF

VALAR Site Accepted Matchups ($\delta x \leq 75$ km)

Standard tropical water vapor profile

Temperature

Moisture

AVTP RMS ($n = 249$)

AVMP RMS ($n = 249$)

AVTP Bias ($n = 249$)

AVMP Bias ($n = 249$)
Offline MW-Only (MIT)

MOD=ECMWF

VALAR Site Accepted Matchups ($\delta x \leq 75$ km)

Temperature

Moisture

Standard tropical water vapor profile

AVTP RMS ($n_{jx}=249$)

AVMP RMS ($n_{jx}=249$)

AVTP Bias ($n_{jx}=249$)

AVMP Bias ($n_{jx}=249$)

t al. - STAR VALAR
# Error Budget for Temperature Profile

<table>
<thead>
<tr>
<th>Attribute Analyzed</th>
<th>L1RD Threshold</th>
<th>Analysis/Validation Result</th>
<th>Error Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geographic coverage</td>
<td>90% every 18 hours</td>
<td>&gt; 90%</td>
<td></td>
</tr>
<tr>
<td>Vertical Coverage</td>
<td>Surface to 0.5 mb</td>
<td>Surface to 0.016 mb</td>
<td></td>
</tr>
<tr>
<td>Vertical Cell Size</td>
<td>0.2 ~50 mb</td>
<td>0.2 ~ 30 mb</td>
<td></td>
</tr>
<tr>
<td>Horizontal Cell Size</td>
<td>50 km at nadir</td>
<td>50 km at nadir</td>
<td></td>
</tr>
<tr>
<td>Mapping Uncertainty</td>
<td>5 km</td>
<td>5 km</td>
<td></td>
</tr>
<tr>
<td>Measurement Range</td>
<td>Propose 150 ~ 400 K</td>
<td>200 ~ 310 K</td>
<td></td>
</tr>
<tr>
<td>Cloud &lt; 50%: Surface to 300 mb</td>
<td>1.6 K per km layer</td>
<td>1.34 K per km layer</td>
<td></td>
</tr>
<tr>
<td>300 to 30 mb</td>
<td>1.5 K per 3 km layer</td>
<td>1.04 K per 3 km layer</td>
<td></td>
</tr>
<tr>
<td>30 to 1 mb</td>
<td>1.5 K per 5 km layer</td>
<td>1.04 K per 5 km layer</td>
<td></td>
</tr>
<tr>
<td>1 to 0.5 mb</td>
<td>3.5 K per 5 km layer</td>
<td>1.04 K per 5 km layer</td>
<td></td>
</tr>
<tr>
<td>Cloud &gt;= 50%: Surface to 700mb</td>
<td>2.5 K per km layer</td>
<td>2.68 K per km layer</td>
<td></td>
</tr>
<tr>
<td>700 to 300 mb</td>
<td>1.5 K per km layer</td>
<td>1.88 K per km layer</td>
<td></td>
</tr>
<tr>
<td>300 to 30 mb</td>
<td>1.5 K per 3 km layer</td>
<td>1.88 K per 3 km layer</td>
<td></td>
</tr>
<tr>
<td>30 to 1 mb</td>
<td>1.5 K per 5 km layer</td>
<td>1.88 K per 5 km layer</td>
<td></td>
</tr>
<tr>
<td>1 to 0.5 mb</td>
<td>3.5 K per 5 km layer</td>
<td>1.88 K per 5 km layer</td>
<td></td>
</tr>
</tbody>
</table>
## Error Budget for Moisture Profile

<table>
<thead>
<tr>
<th>Attribute Analyzed</th>
<th>L1RD Threshold</th>
<th>Analysis/Validation Result</th>
<th>Error Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geographic coverage</td>
<td>90% every 18 hours</td>
<td>&gt; 90%</td>
<td></td>
</tr>
<tr>
<td>Vertical Coverage</td>
<td>Surface to 0.5 mb</td>
<td>Surface to 0.016 mb</td>
<td></td>
</tr>
<tr>
<td>Vertical Cell Size</td>
<td>0.2 ~ 50 mb</td>
<td>0.2 ~ 30 mb</td>
<td></td>
</tr>
<tr>
<td>Horizontal Cell Size</td>
<td>50 km at nadir</td>
<td>50 km at nadir</td>
<td></td>
</tr>
<tr>
<td>Mapping Uncertainty</td>
<td>5 km</td>
<td>5 km</td>
<td></td>
</tr>
<tr>
<td>Cloud &lt; 50%: Surface to 600 mb</td>
<td>Greater of 20% or 0.2 g/kg</td>
<td>19.8%</td>
<td></td>
</tr>
<tr>
<td>600 to 300 mb</td>
<td>Greater of 35% or 0.1 g/kg</td>
<td>23.3%</td>
<td></td>
</tr>
<tr>
<td>300 to 100 mb</td>
<td>Greater of 35% or 0.1 g/kg</td>
<td>23.3%</td>
<td></td>
</tr>
<tr>
<td>Cloud &gt;= 50%: Surface to 600 mb</td>
<td>Greater of 20% or 0.2 g/kg</td>
<td>23.6%</td>
<td></td>
</tr>
<tr>
<td>600 to 400 mb</td>
<td>Greater of 40% or 0.1 g/kg</td>
<td>32.2%</td>
<td></td>
</tr>
<tr>
<td>400 to 100 mb</td>
<td>Greater of 40% or 0.1 g/kg</td>
<td>32.2%</td>
<td></td>
</tr>
</tbody>
</table>
VALIDATION SUMMARY

• NUCAPS MW+IR
  – meets requirements globally vs ECMWF
  – meets requirements over ocean vs ECMWF
  – Close to meet requirements globally and over selected areas vs Dedicated RAOBs

• NUCAPS MW – Only
  – NUCAPS MW Only close to meet requirements globally vs ECMWF
  – NUCAPS MW only close to meet requirements over ocean vs ECMWF
  – meets requirements over tropical western pacific dedicated RAOBs

• Present issues in the validation truth:
  – Residual temporal and spatial mismatch between retrievals and model: ECMWF mismatch is +/- 1.5 hour and +/- 0.25 deg and we use both forecast and analysis depending on UT time.
  – Uncertainty in the ECMWF model
    • Residual temporal and spatial mismatch (75km) between retrievals and RAOBs considerably affects water vapor statistics (up to 10% due to 50km mismatch, especially in the UTH due to RAOB drift)
    • Uncertainty in the RAOBs (supersaturation, calibration uncertainty)

• Ongoing activity:
  – We are aware that there is a need for updating the look up tables for both the MW-Only and MW+IR retrieval:
    • A priori, First guess, radiance bias correction
Support CrIS SDR

- **Full Spectral Requirement**
  - CrIS full spectral data are required for trace gas retrievals.

- **ILS**
  - Inhomogeneity effect on CrIS spectral shift is < 3 ppm, smaller than noise.

- **Discard one FOV for direct full-spectral CrIS broadcast**
  - The corner FOV 7 should provide a slight better contrast, but the large noise of FOV 7 degrades the use. Our recommendation is to discard FOV 7 instead of FOV 4 for NPP CrIS full spectral data direct broadcast.
Sensitivity Analysis to 1% CO perturbation

- Only when switched to high spectral resolution, CrIS spectrum (red curve, bottom part) shows the distinctive signature of CO absorption (red and black curve, top figure).
- Blue cross symbols: CO high resolution channel selection.

NeDT depends strongly on scene temperature.

Courtesy of X. Jin, Y. Chen, L. Wang
Conclusion

• **NUCAPS Validation Results Summary**
  
  – NUCAPS IR+MW AVTP and AVMP EDRs are demonstrated to meet the threshold requirements (on the coarse coarse-layers) as follows:
    
    • Ocean and land versus global ECWMF model
    • Tropical marine regions (ship and island) versus high-quality dedicated RAOBs (e.g., AEROSE, TWP and PMRF)

  – NUCAPS MW-only (MIT algorithm) EDRs are demonstrated to be close to meeting the threshold requirements for the same data samples.

  – NUCAPS AVTP and AVMP EDRs are publicly available on the NOAA CLASS. NUCAPS products are available from AWIPS II and forecasters have started to use the product.
Path Forward

1) Make quality flag simple
2) Improve MW only performance
3) Update IR+MW surface emissivity tables
4) Standardize retrieval code
5) Unified Hyperspectral Sensors’ Sounding System
6) CrIS full spectral channel selection for NWP and NUCAPS
7) CrIS Full Spectral Data in Sounding System
8) Trace Gas (CO, CO₂, and CH₄) Algorithm Tuning, Validation, and Verification
9) Single FOV Retrieval
Presentations

Xiaozhen (Shawn) Xiong NOAA
Atmospheric CH4 and N2O from Thermal Infrared Sounders: Retrieval, Validation and Monitoring of their Increase Trends at 1:00 PM, session 6

Antonia Gambacorta NOAA
The NOAA operational hyper spectral retrieval system: algorithm description and inter-consistency among the AIRS/AMSU, IASI/AMSU/MHS and CrIS/ATMS systems at 4:45 PM, session 7

Tony Reale
NOAA Comparison of IASI, NUCAPS and AIRS V6 Soundings Using the NOAA Products Validation System at 5:00 PM

Nicholas Nalli
NOAA Validation of the NOAA Unique CrIS/ATMS Processing System (NUCAPS) Operational Retrieval Products at 5:15 PM

Xu Liu
LARC Single Field of View Cloudy Retrieval using Combined IR and MW Sounder Data at 9:40 AM, session 8

Chris Barnet NOAA
The development and validation of the Community Hyper-Spectral Infrared Microwave Earth Retrieval Algorithm (CHIMERA): the path Forward, at 10:30 AM