Status of the NOAA Unique Combined Atmospheric Processing System (NUCAPS)

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Presented by Lihang Zhou

2017 ATOVS Working Group Meeting
Friday, December 1st, 2017
### N as in NUCAPS

<table>
<thead>
<tr>
<th><strong>NOAA</strong></th>
<th>NOAA’s mandate: ensuring state of art inversion methods and highest computational efficiency in order to maximize utilization of large volumes of hyperspectral data for a weather ready nation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Unique</strong></td>
<td>A globally applicable yet mathematically sound (land/ocean, day/night, all season, all sky, TOA-surface) hyperspectral sounding retrieval code</td>
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<tr>
<td><strong>Combined</strong></td>
<td>... that can fully exploit all assets currently available on operational polar sounders: infrared, microwave, visible</td>
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<tr>
<td><strong>Atmospheric</strong></td>
<td>... to generate a full suite of retrieval products: cloud cleared radiances, skin temperature, vertical profiles of temperature, water vapor, O3, CO, CH4, HNO3, N2O, SO2, CO2 (future: NH3)</td>
</tr>
<tr>
<td><strong>Processing</strong></td>
<td>... by the use of a modular design compatible with multiple platforms: Aqua, MetOp, SNPP, JPSS, EPS-SG</td>
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<tr>
<td><strong>System</strong></td>
<td>NUCAPS has been running operationally at NOAA since 2004. It is now in AWIPS II and has been installed in CSPP DB.</td>
</tr>
</tbody>
</table>
NOAA Long term strategy of hyperspectral sounding

Aqua (2002)  
Suomi NPP (2011)  
JPSS 1, 2, 3, 4 (2017 - 2025)  
EPS SG (2020, 2040)  
NUCAPS

Pre-Processor  
Same exact executable  
Same underlying Spectroscopy  
Same look up table methodology for all platforms
November 18th 2017: JPSS 1 successfully launched!

https://www.youtube.com/watch?v=WZITzp2on9w
NUCAPS Retrieval Algorithm Flow Chart

- **I. A microwave retrieval module** which computes Temperature, water vapor and cloud liquid water (Rosenkranz, 2000)
- **II. A fast eigenvector regression** retrieval that is trained against ECMWF and all sky radiances which computes temperature and water vapor (Goldberg et al., 2003)
- **III. A cloud clearing module** (Chahine, 1974)
- **IV. A second fast eigenvector regression** retrieval that is trained against ECMWF analysis and cloud cleared radiances
- **V. The final infrared physical retrieval** based on a regularized iterated least square minimization: temperature, water vapor, trace gases (O3, CO, CH4, CO2, SO2, HNO3, N2O) (Susskind, Barnet, Blaisdell, 2003)
NUCAPS Acceptance Yield Upon Cloud Clearing

NUCAPS global yield = 83 %
The Cross-Track Infrared Sounder (CrIS) is a Fourier spectrometer covering the longwave (655-1095 cm$^{-1}$, “LW”), midwave (1210-1750 cm$^{-1}$, “MW”), and shortwave (2155-2550 cm$^{-1}$, “SW”) infrared spectral regions.

**Past operations (NUCAPS Phase 1-3):**
- Maximum geometrical path $L$ of 0.8 cm (LW), 0.4 cm (MW) and 0.2 cm (SW)
- Nyquist spectral sampling ($1/2L$): 0.625 cm$^{-1}$, 1.25 cm$^{-1}$ and 2.5 cm$^{-1}$

**Operational in August 2017 (NUCAPS Phase 4):**
- Maximum geometrical path $L$ of 0.8 cm in all three bands
- Nyquist spectral sampling ($1/2L$): 0.625 cm$^{-1}$ in all three bands
**NUCAPS FSR Operational CrIS channel selection (610 channels)**

<table>
<thead>
<tr>
<th>EDR</th>
<th>#chns</th>
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</thead>
<tbody>
<tr>
<td>Temp</td>
<td>116</td>
</tr>
<tr>
<td>Surf</td>
<td>136 (62)</td>
</tr>
<tr>
<td>HO2</td>
<td>123 (62)</td>
</tr>
<tr>
<td>O3</td>
<td>77</td>
</tr>
<tr>
<td>CO</td>
<td>52</td>
</tr>
<tr>
<td>CH4</td>
<td>84</td>
</tr>
<tr>
<td>N2O</td>
<td>21</td>
</tr>
<tr>
<td>SO2</td>
<td>31</td>
</tr>
<tr>
<td>HNO3</td>
<td>30</td>
</tr>
<tr>
<td>CO2 (Temp)</td>
<td>50 (T LW)</td>
</tr>
</tbody>
</table>

**Graphs**

1. **Temperature (Temp)**
   - Wave number (cm\(^{-1}\))
   - Channels: 116

2. **Surface (Surf)**
   - Wave number (cm\(^{-1}\))
   - Channels: 136 (62)

3. **HO2**
   - Wave number (cm\(^{-1}\))
   - Channels: 123 (62)

4. **O3**
   - Wave number (cm\(^{-1}\))
   - Channels: 77

5. **CO**
   - Wave number (cm\(^{-1}\))
   - Channels: 52

6. **CH4**
   - Wave number (cm\(^{-1}\))
   - Channels: 84

7. **N2O**
   - Wave number (cm\(^{-1}\))
   - Channels: 21

8. **SO2**
   - Wave number (cm\(^{-1}\))
   - Channels: 31

9. **HNO3**
   - Wave number (cm\(^{-1}\))
   - Channels: 30

10. **CO2 (Temp)**
    - Wave number (cm\(^{-1}\))
    - Channels: 50 (T LW)

**Reference:**

A. Gambacorta and C. Barnet., *Methodology and information content of the NOAA NESDIS operational channel selection for the Cross-Track Infrared Sounder (CrIS)*, IEEE, Vol. 51, Issue 6, 2013
Channels chosen:
- LW Temp/CO₂ 125
- Surface (LW+SW) 139
- O₃ 19
- H₂O 108
- SW Temp 24
- SO₂ 5
- CO 5
- CH₄ 6

- All band 1 channels in the previous 399 subset (as band 1 has not changed when going to FSR) except those designated as sensitive to HNO₃ and HCl.
- All channels between channels 50 and 200 (i.e., total coverage for the 15μm CO₂ band tropospheric sounding channels)
- 48 channels in the band head of the 4.3μm CO₂ band (this band has the sharpest CO₂ Jacobians in the spectrum).
- A very reduced number of channels sensitive to trace gases (less of a priority for NWP).
Global Statistics:
MW-only, First guess and MW+IR (RMS)

Results are based on 2 Focus Days
NUCAPS IR-Only characterization: RMS

All-Sky v2.0.5.4
FG v2.0.5.4
IR-Only v2.0.5.4
(Yield=85%)

Results are based on 2 Focus Days
Sensitivity Analysis to 1% CO perturbation

2.5 cm\(^{-1}\) (CrIS NSR) 0.625 cm\(^{-1}\) (CrIS FSR) 0.25 cm\(^{-1}\) (IASI)

Total Carbon Column Observing Network (TCCON)  
17 Feb 2015 and 17 Jul 2015 Focus Days

TCCON Stations (17-Feb-15 17-Jul-15 Focus Days)

TCCON (Wunch et al. 2011)
NUCAPS vs TCCON Histograms
17 Feb 2015 and 17 Jul 2015 Focus Days

All FOR within threshold radius (100 km)

Time window (±6 hours) versus mean TCCON

NUCAPS v2.0.5.4 acc (17-Feb-15 17-Jul-15)

<table>
<thead>
<tr>
<th>Trace Gas</th>
<th>EDR</th>
<th>TCCON Baseline One Focus Day N = 151</th>
<th>TCCON Baseline Two Focus Days N = 128</th>
<th>AIRS Baseline One Focus Day N = O(100,000)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO</td>
<td></td>
<td>+2.1 (15.0) 12.9 (15.0) 13.1 6.0 (15.0) 8.0 (15.0) 10.0</td>
<td>+3.0 3.3 (15.0) 9.2 (15.0) 8.9 (15.0) 9.7 (15.0) 9.5 (15.0)</td>
<td></td>
</tr>
<tr>
<td>CO₂</td>
<td></td>
<td>-0.3 (11.0) 0.6 (0.5) 0.7 0.5 (11.0) 0.6 (0.5) 0.8</td>
<td>+0.2 0.1 (11.0) 0.9 (11.0) 0.9 (11.0) 1.0 (11.0) 0.9 (11.0)</td>
<td></td>
</tr>
<tr>
<td>CH₄</td>
<td></td>
<td>-3.0 (14.0) 4.4 (1.0) 5.3 -1.1 (8.0) 2.6 (1.0) 2.9</td>
<td>+0.6 0.8 (14.0) 1.7 (1.0) 1.6 (1.0) 1.8 (1.0) 1.8 (1.0)</td>
<td></td>
</tr>
</tbody>
</table>
DATA FUSION: NUCAPS + NOAA MADIS Surface Observations
Surface-Based Convective Available Potential Energy (SB-CAPE)

- Experimental near-real time product developed at UW-CIMSS by Callyn Bloch, now at NOAA/NESDIS/STAR.
- Substitutes NUCAPS surface T, T_dew with NOAA MADIS surface observations to compute CAPE.
- SSEC Real-Earth updates automatically for DB overpasses with CSPP NUCAPS EDRs.

Now also a smart phone app: “SSEC – RealEarth”!
The 2017 intense hurricane season

September 8th, 2017
• NUCAPS combines MW and IR measurements to retrieve the atmospheric state.
• Rejection occurs under precipitation (MW only QC) and overcast scenes (IR QC).
Exploring an innovative data fusion product: MW+IR and MW-only

- Using accepted NUCAPS MW+IR retrievals & NUCAPS MW only retrievals when MW+IR retrievals fail.
- Composite yield increases to ~95%
- Validation is underway. Challenges: ensure stability when transitioning from MW+IR to MW-only retrievals.
“We are expecting a 15 feet storm surge, wherever hurricane Irma makes landfall. I am glad that this year the US and the European models are in agreement. This means that the investment made in the aftermath of hurricane Sandy in 2012 is paying off. We will soon start preparing for the evacuation of the state of Florida”.

Everglades National Park Visitors Center, September 1st, 2017
Thank you! Questions?
S-NPP/J1 SDR/EDR Products and Maturity

<table>
<thead>
<tr>
<th>JPSS Instruments</th>
<th>Measurements</th>
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<tbody>
<tr>
<td>ATMS - Advanced Technology</td>
<td>ATMS and CrIS together provide high vertical resolution temperature and water vapor information needed to maintain and improve forecast skill out to 5 to 7 days in advance for extreme weather events, including hurricanes and severe weather outbreaks</td>
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<tr>
<td>Microwave Sounder</td>
<td></td>
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<tr>
<td>CrIS - Cross-track Infrared</td>
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<tr>
<td>Sounder</td>
<td></td>
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<tr>
<td>VIIRS – Visible Infrared</td>
<td>VIIRS provides many critical imagery products including snow/ice cover, clouds, fog, aerosols, fire, smoke plumes, vegetation health, phytoplankton abundance/chlorophyll</td>
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<tr>
<td>Radiometer Suite</td>
<td></td>
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<tr>
<td>OMPS - Ozone Mapping and</td>
<td>Ozone spectrometers for monitoring ozone hole and recovery of stratospheric ozone and for UV index forecasts</td>
</tr>
<tr>
<td>Profiler Suite</td>
<td></td>
</tr>
<tr>
<td>CERES - Clouds and the Earth’s</td>
<td>Scanning radiometer which supports studies of Earth Radiation Budget (ERB)</td>
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<tr>
<td>Radiant Energy System</td>
<td></td>
</tr>
</tbody>
</table>

**JPSS Program Data Products**

- **VIIRS (28 EDRs)**
  - EDRs: Active Fires, Aerosol Detection, Aerosol Optical Depth, Aerosol Particle Size, Albedo (Surface), Annual Surface Type, Cloud Height (Top and Base), Cloud Coverage Layers, Cloud Mask, Cloud Optical Depth (DF), Cloud Particle Size Distribution, Cloud Phase, Cloud Top Pressure, Cloud Top Temperature
  - Tools: Green Vegetation Fraction, Ice Cloud Fraction, Ice Cloud Top Temperature, Ocean Color/Chlorophyll, Polar Winds, Sea Surface Temperature, Sea Ice Temperature, Snow Cover (Binary Fraction), Surface Reflectance, Volcanic Ash Detection & Height

- **OMPS-Nadir (2 EDRs)**
  - EDRs: Ozone Total Column, Ozone Nadir Profile

- **OMPS- Limb**
  - EDRs: Temperature, Total Precipitable Water, Moisture Profile

- **AMSR2 (11 EDRs)**
  - EDRs: Cloud Liquid Water, Snow Cover, Snow Water Equivalent, Precipitation Type/Rate, Soil Moisture, Sea Ice Characterization, Sea Surface Temperature, Surface Type, Total Precipitable Water, Sea Surface Wind Speed

- **CERES/RBI (AP)**
  - EDRs: Radiation Budget

- **CrIS (5 EDRs)**
  - EDRs: Carbon Dioxide ECL, Carbon Monoxide ECL, Infrared Ozone Profile, Outgoing Longwave Radiation

- **CrIS/ATMS (2 EDRs)**
  - EDRs: Atmospheric Vertical Temperature Profile, Atmospheric Vertical Moisture Profile

- **ATMS (11 EDRs)**
  - EDRs: Cloud Liquid Water, Ice Concentration, Snow Cover, Snow Water Equivalent, Temperature Profile, Total Precipitable Water, Moisture Profile

**KEY**

- **AP** Application Packet
- **ASD** Application Process Identifier Sorted Data
- **RDR** Raw Data Record
- **SDR** Sensor Data Record
- **TDR** Temperature Data Record
- **EDR** Environmental Data Record
- **O** Products with Key Performance Parameters
- **P** Mission Unique Data Products

Data available through PDA, CLASS, and Direct Readout