Evaluation of NUCAPS within high impact mesoscale events: overview of the CalWater 2015 field campaign.

Chris Barnet, Antonia Gambacorta, and Mitch Goldberg

STAR/JPSS Annual Meeting
Thursday, Aug. 26, 2015
Discussion Points

• A few additional comments about the NOAA-Unique CrIS/ATMS Processing System (NUCAPS)

• NOAA Sounding Initiative Activities
  1. CalWater 2 Campaign, Jan/Feb 2015
  2. Cold Air Aloft Initiative
  3. AWIPS-II Implementation and Training
  4. Hazardous Weather 2015 Spring Experiment
  5. Trace Gas Product Evaluation

• Future Plans
Availability of NUCAPS (with latency)

• Apr. 18, 2014 NUCAPS operational at OSPO
  – Via DDS subscription in near real time (≤ 3h)
  – Via CLASS interactive webpage (~ 6h)
  – Via CLASS ftp site (~48h)

• Sep. 2014 AWIPS-II implementation begins
  – NUCAPS T(p) and H2O(p) products can be displayed as skew-T and manipulated (≤ 3h)

• Feb. 24, 2015 NUCAPS operational at CSPP direct broadcast stations
  – Much better latency (~30 minute)
  – CSPP = Community Satellite Processing Package
  – Support field campaigns and science evaluations

• Reprocessing of full mission CrIS+ATMS SDRs and NUCAPS at Univ. Wisconsin (JPSS funded)
  – V1.0 completed in Aug. 2015
  – V1.5 will be run in near future (Oct. timeframe) and available via CLASS
Why Study Retrievals?

- Data assimilation (DA) ingests many instruments
  - Microwave (e.g., ATMS) is easier (more linear) to assimilate
  - Infrared (e.g., CrIS) is under-utilized in all NWP models
    - Avoid clouds, so must sub-sample FOVs and channels
  - Therefore, CrIS/ATMS obs. are sparse and have low weight w.r.t. model
    - Assumes obs. will nudge model in the right direction over many cycles
- Retrievals operate on single satellite field of regard
  - Can afford to do detailed calculations
    - More channels, including trace gas state and covariance
    - Off-diagonal covariance can be used
  - CrIS+ATMS can provide soundings in ~70% of scenes
    - Use of cloud clearing significantly increases the number of scenes and the number of channels used
      - Cloudy scenes are more likely to include interesting weather
  - Many lessons learned can be incorporated into global models
- But there are other applications where profiles have value.
NOAA/JPSS Application Team
Initiatives for Sounding

• Sounding applications team
  – Primary goal is to promote new applications.
  – Secondary goal is to encourage interaction between developers and users to tailor NUCAPS to applications

• We currently have 5 active initiatives for sounding
  1. Hydrometeorology Testbed (HMT): Atmospheric Rivers
  2. Aviation Weather Testbed (AWT): Cold Air Aloft
  3. AWIPS-II NUCAPS and training module & improvements
  4. Hazardous Weather Testbed (HWT): Convective Initiation
  5. NUCAPS Trace Gas Product Evaluation
Initiative #1 / 5

Hydrometeorology Testbed: CalWater-2015

POCs: Chris Barnet (JPSS) & Ryan Spackman (NOAA/ESRL/PSD)
Science focus of this campaign is to improve forecasting of Atmospheric Rivers (ARs)

- CalWater 2 white paper is at [http://esrl.noaa.gov/psd/calwater](http://esrl.noaa.gov/psd/calwater)
  PI is Marty Ralph, Scripps

- Coordinated with DOE ACAPEX (ARM Cloud Aerosol Precipitation Experiment)
  PI is L. Ruby Leung, DOE
Understanding Atmospheric Rivers (ARs) has national and societal value

- ARs are narrow filaments of enhanced WV transport
  - responsible for $\approx 90\%$ of mid-latitude transport (Zhu 1998 MWR)
  - $75\%$ is below 2.25 km altitude

30-50% of annual precipitation on USA west coast is associated with ARs

- Typically within a few extreme precipitation events
  - Jan. 6-8, 2009 a strong event damaged the Hansen Dam (White 2012 BAMS)
  - Warm moist conditions in ARs can accelerate snowmelt

- Northwest USA snowfall tends to come in a few powerful winter ARs
  - Winter snowpack provides 70-90% of water supply for western USA

- AR events end $\sim 40\%$ of Northern California droughts (Dettinger 2013 J.Hydro.)

- Large ARs transport 13-26 km$^3$/day, $\sim 7.5$-$15$ times the average discharge of the Mississippi River (Ralph 2011 Eos)
CalWater-2015 was topic in recent JPSS focus article

- In JPSS Quarterly Newsletter (Issue 2, Apr-June 2015)
NUCAPS sees domain of the entire field campaign (backup)

- NUCAPS 2200 km wide "scanset" is acquired in 8 seconds
- 30 retrievals with spatial resolution of ~50 km at nadir and ~70x134 km at edges of scan
- In many cases these retrievals reveal structures many hours in advance of a model analysis (i.e., CrIS/ATMS have not been ingested)
- Differences shown at in lower panels could be due to retrieval errors or GFS errors
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NUCAPS Microwave RH Retrieval cross section along scanset shown as black-line in top left figure. Insensitive to non-precipitating clouds

NUCAPS Microwave + Infrared RH retrieval along same scanset. More sensitive to clouds but higher vertical resolution
• Campaign began Jan. 12
• Jan. 12 to Feb. 12 we used Corvallis Oregon DB data
  – Processing with NUCAPS science code
  – Provided forecasters the Pacific west coast overpass (10:00 UT ≅ 2 am PST = 5 am EST) in real time
    • Considered in 7 am PST flight planning meeting
  – Provided 22:00 UT (14:00 PST = 5 pm EST) overpass while field campaign aircraft were in the air
• Feb. 14, 2015 we used Univ. of Hawaii DB data
  – Field campaign is winding down
    • G-IV ferried to Hawaii
    • R.H. Brown departed 2/13
    • NOAA P-3 departed 2/15
  – Provided forecasters the Hawaii overpass in real time (24 UT) while G-IV was in the air.
What JPSS program gained from CalWater 2015

• CalWater-2015 was an opportunity for NUCAPS product validation
  – Over 435 dropsondes were acquired
  – Test NUCAPS in extreme weather that is of national and societal interest

• As algorithm developers, we need these kinds of scenes to improve the retrieval skill and tailor the quality control.
  – Can test experimental versions of NUCAPS
  – Gain the expertise of the entire CalWater science team to characterize the underlying science and meteorology.
  – Other \textit{in-situ} measurements (CO, O$_3$, CO$_2$, aerosols) will help the NPP validation,
  – Demonstrate the value and shortcomings of NUCAPS in the field

<table>
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<tr>
<th>Date</th>
<th>G-IV</th>
<th>P-3</th>
</tr>
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<tbody>
<tr>
<td>1/15</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>1/17</td>
<td>29</td>
<td></td>
</tr>
<tr>
<td>1/22</td>
<td>13</td>
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<td>1/27</td>
<td>22</td>
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<tr>
<td>1/31</td>
<td>24</td>
<td></td>
</tr>
<tr>
<td>2/5</td>
<td>35</td>
<td></td>
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<tr>
<td>2/6</td>
<td>30</td>
<td>7</td>
</tr>
<tr>
<td>2/7</td>
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<tr>
<td>2/9</td>
<td>35</td>
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<td>2/19</td>
<td>37</td>
<td></td>
</tr>
<tr>
<td>2/20</td>
<td>35</td>
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<td>2/24</td>
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<tr>
<td>total</td>
<td>365</td>
<td>78</td>
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</tbody>
</table>
Example of Feb. 6 dropsondes

- NOAA G-IV did a saw-tooth pattern across the AR
  - NPP Overpass occurred between sondes #19 and #20
  - Capture pre-AR, AR, and post-AR regimes on 4 crossings
  - Pre-AR is relatively warm and dry
  - AR is wet, cloudy, warm, and most likely raining
  - Post-AR is wet and cooler

- NOAA P-3 was flying at 800 mb
  - Sampling same region as G-IV
  - ~4 hours later
wide range of pre-AR, AR, and post-AR conditions

Pre-AR: #8, 9, 20, 21, 22

AR: #10, 19

Post-AR: #13, 27, 28, 29, 30
Dropsonde and retrieval cross section along flight

Transect 1  Transect 2  Transect 3  Transect 4

Regression first guess

MW+IR retrieval

Micro-wave only
Summary of CalWater-2015

• We demonstrated the value of NUCAPS soundings in defining crucial moisture structure (position, water vapor content, amplitude) in the vicinity of sparsely sampled but high impact mesoscale events.
  – Low latency (direct broadcast) access is valuable for field campaign logistical support and understanding context of in-situ data
  – Synergistic validation yields a large sample of in-situ data (~150 RS-92 radiosonde and ~450 dropsondes from CalWater-2015 alone) in regimes that are traditionally difficult to validate

• Ongoing and future work:
  – We are using these dropsondes to improve performance (better radiance bias tuning, first guess, etc.)
    • Retrieval can be re-run with proposed changes and compared to original retrieval and in-situ data before promoting to operations
  – Will publish an analysis of NUCAPS capabilities in AR environments
Initiative #2 / 5

Aviation Weather Testbed: Cold Air Aloft

POC: Brad Zavodsky (NASA/SPoRT), Kristine Nelson (NWS/AR/ARS/CWSU/ANCHORAGE AK)
In Alaska, forecasters must rely on analysis and model fields and limited radiosonde observations (~4/day) to determine the 3D extent of the cold air aloft

- Airline fuel begins to freeze below -65 degC, need to issue pilot advisories
- Forecasters need to know spatial and vertical location of “bubble” of cold air aloft

- Anchorage Flight Information Area (FIR) encompasses 2.4 square million miles
- Anchorage Airport was ranked 3rd worldwide for throughput cargo (90% of China to USA) and 1st in the USA for cargo poundage (5.9 Billion lbs)
Daily Cold Air Loft frequency of occurrence at 190 mbar

Analysis and graphics by C. Francoeur, STC

Used AIRS Level.2 Support Product

Counted occurrences of $T(190\text{mb}) \leq -65\degree \text{C}$ in a 1x1 deg grid

Anchorage Center Weather Service Unit (CWSU) issues warnings on Nov. 11th to 14th
Daily Cold Air Loft frequency of occurrence (backup)

Used AIRS Level.2 Support Product

Counted occurrences of $T(190\text{mb}) \leq -65\,$degC in a 1x1 deg grid

Anchorage Center Weather Service Unit (CWSU) issues warnings on Nov. 11th to 14th

Analysis and graphics by C. Francoeur, STC
Summary of Aviation Weather initiative

• CrIS/ATMS easily sees the cold air aloft in our cross-sections and skew-T plots
  – Product has +/- 4 K differences f/GFS and is smoother
    • Vertical location is different
  – Goal is to work with Alaska AWT/CWSU to develop better visualization of cold air aloft and to evaluate Suomi-NPP soundings in this context.

• GFS ingests CrIS and ATMS, is it good enough?
  – At 200 mbar many CrIS channels are used
  – Real time NUCAPS (8, 9.5, 11 and 20, 21.5, 23 Z) adds information between the model analysis times (0, 6, 12, 18Z) and gives forecaster more confidence
Initiative # 3 / 5

AWIPS-II NUCAPS training module & AWIPS improvements

POCs: Brian Motta (NWS), Scott Lindstrom (CIMSS)
Articulate Presenter modules are available at:
- V1: https://www.youtube.com/watch?v=91ORWNreXLI
- V2: https://www.youtube.com/watch?v=U-w6EBnOzb0

NUCAPS was installed without QC
- QC exists in NUCAPS file ingested by AWIPS
- DR submitted to fix the problem

Recent upgrades to AWIPS-II causes NUCAPS data to be deleted
- WFO installed patch until problem can be fixed

Improved Visualization
- Plan View displays
Initiative #4 / 5

Hazardous Weather Testbed: 2015 Spring Experiment

Will be discussed in next 2 presentations by the POCs: Bill Line (OU/CIMMS & NOAA/NWS/SPC) and Dan Nietfeld (SOO at Omaha WFO)
Initiative #5 / 5

NUCAPS Trace Gas Product Evaluation

POCs: Greg Frost (NOAA/ESRL/GSD), Brad Pierce (NOAA/STAR)
NUCAPS Trace Gas Product Evaluation

• This initiative is based on two recent JPSS funded proposals.

  1. Greg Frost: “Understanding emissions and tropospheric chemistry using NUCAPS and VIIRS”
  2. Brad Pierce: “High Resolution Trajectory-Based Smoke Forecasts using VIIRS Aerosol Optical Depth and NUCAPS Carbon Monoxide Retrievals “

• Using modeling and in-situ aircraft observations
  – Models are used to interpolate the sparse field observations to the satellite temporal, spatial, and vertical sampling characteristics
NUCAPS Trace Gas Product Evaluation

• We selected two field campaigns for initial study
  – Senex: http://www.esrl.noaa.gov/csd/projects/senex
    • Senex ≡ Southeast Nexus, Summer 2013, SE USA
    • Look at methane emissions associated with fires.
  – Songex: http://esrl.noaa.gov/csd/projects/songnex/
    • Songex ≡ Shale Oil and Natural Gas Nexus, Spring 2014, Western USA
    • Will begin with NUCAPS Carbon Monoxide product
      – Requires full spectral resolution CrIS data
      – Will use experimental version of NUCAPS
    • Also look at methane emissions from oil and gas
Future Plans for NUCAPS and The Path Forward
Future Plans
The way forward

• Improve AWIPS implementation
  – Better training
  – Automate profile modification (funded, Dan Lindsey)
  – Spatial and/or cross-section visualization

• Metop-A & B retrievals into AWIPS-II
  – Same as NUCAPS, but 4 hours earlier
  – NOAA/STAR can provide file now.
  – Need user request to make it happen within AWIPS.

• Metop-A & B retrievals into CSPP direct broadcast
  – In work, should be operational in early 2016
Constellation of satellites allows more observations between 0Z & 12Z RAOBS

NPP/J-1 will be phased similar to Metop-A/B approx. 6 months after launch of J-1

If we included NOAA AMSU/HIRS there would be even more soundings

These are overpasses with satellite elevation > 32 deg (all FOR’s)
Also looking for ways to take lessons learned back to NWS

• Much of the NUCAPS retrieval skill comes from use of cloud cleared radiances
  – Jun Li (CIMSS) is doing a study of using NUCAPS cloud cleared radiances within a NWP regional model
    • WRF model
    • focused on H. Sandy (2012) and Typhoon Haiyan (2013)

• Emily Berndt (SPoRT) will investigate the use of NUCAPS T(p), q(p), and O3(p) to study extratropical transition of hurricanes
  – create an enhanced stratospheric depth product
  – conduct a product demonstration and assessment with the NHC, WPC, OPC forecasters
QUESTIONS?
Acronyms

- AIRS = Atmospheric Infrared Sounder
- AMSU = Advanced Microwave Sounding Unit
- AR = Atmospheric River
- ATMS = Advanced Technology Microwave Sounder
- AVHRR = Advanced Very High Resolution Radiometer
- AWIPS = Advanced Weather Interactive Processing System
- AWT = Aviation Weather Testbed
- CrIS = Cross-track Infrared Sounder
- CIMMS = Cooperative Institute for Mesoscale Meteorological Studies
- CIMSS = Cooperative Institute for Meteorological Satellite Studies
- CSPP = (CIMSS) Community Satellite Processing Package
- CWA = (NWS) County Warning Area
- CWUS = (FAA) Center Weather Service Unit
- EUMETSAT = EUropean organization for exploitation of METeorological SATellites
- FOV/FOR = Field Of View/Regard
- GFS = (NCEP) Global Forecast System
- GSFC = (NASA) Goddard Space Flight Center
- HMT = Hydrometeorology Testbed
- HSB = Humidity Sounder Brazil
- HWT = Hazardous Weather Testbed
- IASI = Infrared Atmospheric Sounding Interferometer
- JPSS = Joint Polar Satellite System
- METOP = METeorological Observing Platform
- MHS = Microwave Humidity Sensor
- MODIS = MODerate resolution Imaging Spectroradiometer
- NASA = National Aeronautics and Space Administration
- NCEP = National Centers for Environmental Prediction
- NESDIS = National Environmental Satellite, Data, and Information Service
- NHC = (NCEP) National Hurricane Center
- NOAA = National Oceanographic and Atmospheric Administration
- NPP = National Polar-orbiting Partnership
- NWP = Numerical Weather Prediction
- NWS = National Weather Service
- NUCAPS = NOAA Unique CrIS/ATMS Processing System
- OPC = (NCEP) Ocean Prediction Center
- OSPO = (NESDIS) Office of Satellite and Product Operations
- SPC = (NCEP) Storm Prediction Center
- SPORT = (NASA) Short-term Prediction and Research Transition Center
- STAR = (NESDIS) SaTellite Applications and Research
- STC = Science and Technology Corporation
- UMBC = University of Maryland, Baltimore County
- VIIRS = Visible Infrared Imaging Radiometer Suite
- WFO = (NWS) Weather Forecast Office
- WPC = (NCEP) Weather Prediction Center
### Summary of products from NUCAPS (and AWIPS-II)

<table>
<thead>
<tr>
<th>gas</th>
<th>Precision</th>
<th>d.o.f.</th>
<th>Interfering Parameters</th>
<th>Sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Temperature Profile, T(p), SST, LST</strong></td>
<td>1.5K/km</td>
<td>6-10</td>
<td>Emissivity, H₂O, O₃, N₂O</td>
<td>surface to ~1 mb</td>
</tr>
<tr>
<td><strong>Water Profile, H₂O(p)</strong></td>
<td>15%</td>
<td>4-6</td>
<td>CH₄, HNO₃</td>
<td>surface to ~300 mb</td>
</tr>
<tr>
<td>Cloud Top Pressure</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cloud fraction</td>
<td>25 mbar,</td>
<td>2</td>
<td>CO₂, H₂O</td>
<td>surface to tropopause</td>
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<td></td>
<td>1.5K, 5%</td>
<td>18</td>
<td></td>
<td></td>
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<tr>
<td>Ozone, O₃</td>
<td>10%</td>
<td>1+</td>
<td>H₂O, emissivity</td>
<td>Lower stratosphere</td>
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<tr>
<td>Carbon Monoxide, CO</td>
<td>15%</td>
<td>≈ 1</td>
<td>H₂O, N₂O</td>
<td>Mid-troposphere</td>
</tr>
<tr>
<td>Methane, CH₄</td>
<td>1.5%</td>
<td>≈ 1</td>
<td>H₂O, HNO₃, N₂O</td>
<td>Mid-troposphere</td>
</tr>
<tr>
<td>Carbon Dioxide, CO₂</td>
<td>0.5%</td>
<td>≈ 1</td>
<td>H₂O, O₃, T(p)</td>
<td>Mid-troposphere</td>
</tr>
<tr>
<td>Sulfur Dioxide, SO₂</td>
<td>≈ 50%</td>
<td>&lt; 1</td>
<td>H₂O, HNO₃</td>
<td>Volcanic flag</td>
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<tr>
<td>Nitric Acid, HNO₃</td>
<td>≈ 50%</td>
<td>&lt; 1</td>
<td>emissivity H₂O, CH₄, N₂O</td>
<td>Upper troposphere</td>
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<tr>
<td>Nitrous Oxide, N₂O</td>
<td>≈ 5%</td>
<td>&lt; 1</td>
<td>H₂O, CO</td>
<td>Mid-troposphere</td>
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## NUCAPS Retrieval File Variables for AWIPS

<table>
<thead>
<tr>
<th>Variable</th>
<th>Type</th>
<th>Dim</th>
<th>Description</th>
<th>Units</th>
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<tr>
<td>Dice</td>
<td>Long</td>
<td>120</td>
<td>Field of Regard (FOR) number 1-120</td>
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</tr>
<tr>
<td>Time</td>
<td>Doub</td>
<td>120</td>
<td>UTC Milliseconds since Jan 1, 1970</td>
<td>Millisec</td>
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<tr>
<td>Latitude</td>
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<td>Latitude of the center of the FOR</td>
<td>Degrees</td>
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<td>Instrument view angle</td>
<td>Degrees</td>
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<td>Ascend/Descend</td>
<td>Short</td>
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<td>Ascending /Descending flag (0=Descending, 1=Ascending) for ea FOV</td>
<td>NA</td>
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<tr>
<td>Topography</td>
<td>Float</td>
<td>120</td>
<td>Surface elevation in meters above sea level</td>
<td>m</td>
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<td>Surface_Pressure</td>
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<td>Surface pressure</td>
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<td>Skin_Temperature</td>
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<td>Skin temperature from the final retrieval step</td>
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<td>Quality flag for the retrieval (0=good, non zero = bad)</td>
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<td>Pressure</td>
<td>Float</td>
<td>120,100</td>
<td>Pressure at each of the 100 retrieval levels</td>
<td>mb</td>
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<td>Effective_Pressure</td>
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<td>Temperature</td>
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<td>Temperature from the final retrieval</td>
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</table>
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<table>
<thead>
<tr>
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<th>Type</th>
<th>Dim</th>
<th>Description</th>
<th>Units</th>
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<td>Water vapor mixing ratio from the final retrieval</td>
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<td>ppb</td>
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<td>Ice liquid flag 0=water, 1=ice</td>
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<td>Sulfur Dioxide mixing ratio from the final retrieval</td>
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<td>Stability</td>
<td>Float</td>
<td>120,16</td>
<td>Stability parameters</td>
<td>Varying</td>
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</table>
Simplified Flow Diagram of the AIRS Science Team Algorithm

- Climatological First Guess for all products
- Microwave Physical for $T(p)$, $q(p)$, LIQ($p$), $\varepsilon(f)$
- Initial Cloud Clearing, $\eta_j$, $R_{ccr}$
- Statistical Operator for $T_s$, $\varepsilon(v)$, $T(p)$, $q(p)$
- IR Physical $T_s$, $\varepsilon(v)$, $\rho(v)$
- Improved Cloud Clearing, $\eta_j$, $R_{ccr}$
- IR Physical T($p$)
- IR Physical q($p$)
- IR Physical $O_3(p)$
- Final Cloud Clearing, $\eta_j$, $R_{ccr}$
- IR Physical $T_s$, $\varepsilon(v)$, $\rho(v)$
- IR Physical $T(p)$
- IR Physical CO($p$)
- IR Physical HNO$_3$($p$)
- IR Physical CH$_4$($p$)
- IR Physical CO$_2$($p$)
- IR Physical N$_2$O($p$)

Note: Physical retrieval steps that are repeated always use same startup for that product, but it uses retrieval products and error estimates from all other retrievals.
Constellation of satellites allows more observations between RAOBS

NPP/J-1 will be phased similar to Metop-A/B approx. 6 months after launch of J-1

If we included NOAA AMSU/HIRS there would be even more soundings

These are overpasses with satellite elevation > 45 deg (FOR 4-27)