Report on JPSS Soundings EDR (session 6)

Presented by Quanhua (Mark) Liu
On behalf of JPSS Soundings Team

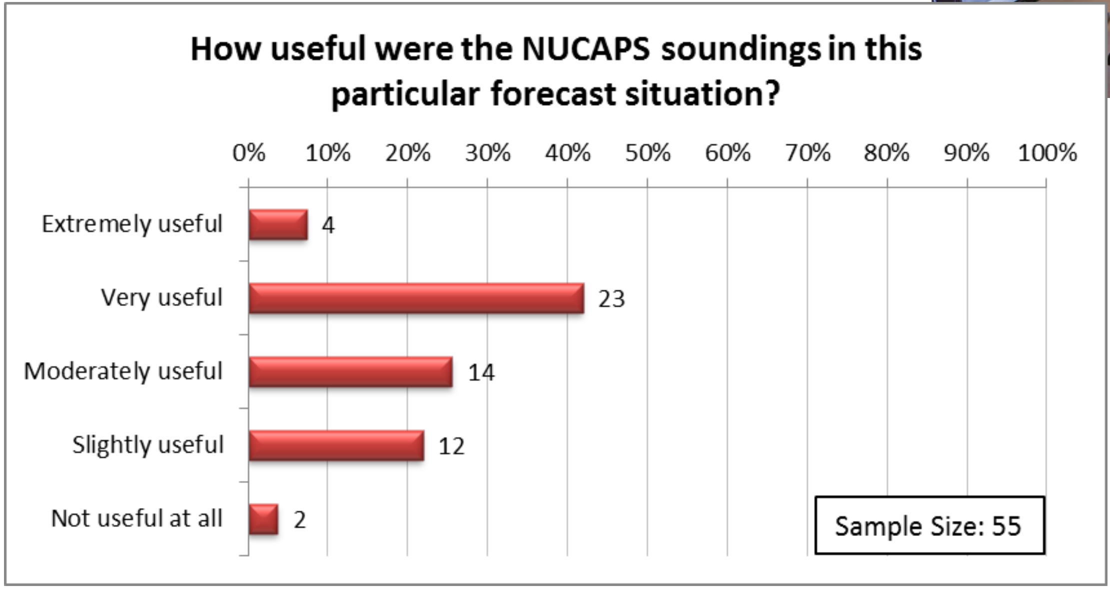
August 12, 2016

NUCAPS Progresses

- NUCAPS has been implemented in AWIPS-II.
- NUCAPS in the Community Satellite Processing Package (CSPP).
- Direct broadcast; latency ~0.5 hour.
- NUCAPS is fully operational for multi-sensors (IASI, CrIS) onboard multi-satellites (SNPP, Metop-A and –B). NUCAPS now stands for NOAA Unique Combined Atmospheric Processing System.
- New channel configuration and tuning for ATMS, MW only retrievals are significantly improved; IR+MW "yield" is increased by 3%.
- NUCAPS is upgraded for CrIS full-spectral data. Experimental test demonstrated similar or slightly better performance for T, q retrievals, much better trace gas EDRs.

How was NUCAPS used in the HWT?

- Assessing the thermodynamic environment…
  - … prior to convective initiation (pre-convective environment)
  - … in the vicinity of ongoing convection
  - … near boundaries
- Comparing with other datasets
  - Water Vapor Imagery
  - Radiosondes
  - NWP



Survey

See presentation of Bill Line

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NUCAPS Future Plan

- J1 Readiness: implementation of new SARTA model, regression coefficients generation, new tuning, testing.
- Improving quality control: find an operationally efficient way to provide averaging kernels and/or error covariances along with tailored products
- Incorporating improvements (e.g., better BL skill, better QC) derived from the research of others (e.g., Bill Smith, Joel Susskind)
- Interactive with users: NUCAPS in AWIPS-II: training & improvements.
- High quality Testbed: Aviation Weather Testbed (AWT); Hazardous Weather Testbed (HWT); Hydrometeorology Testbed (HMT).

MiRS

- MiRS v11 largely improved the performance of MiRS EDRs.
- Problem in MiRS retrieval of snow products for Blizzard 2016 is found.
- MiRS GPM/GMI RR completed and many others.
- Future works

➢ J1 Readiness.

➢ Snow (vegetation correction).

➢ Rainy condition sounding (update a priori constraints)

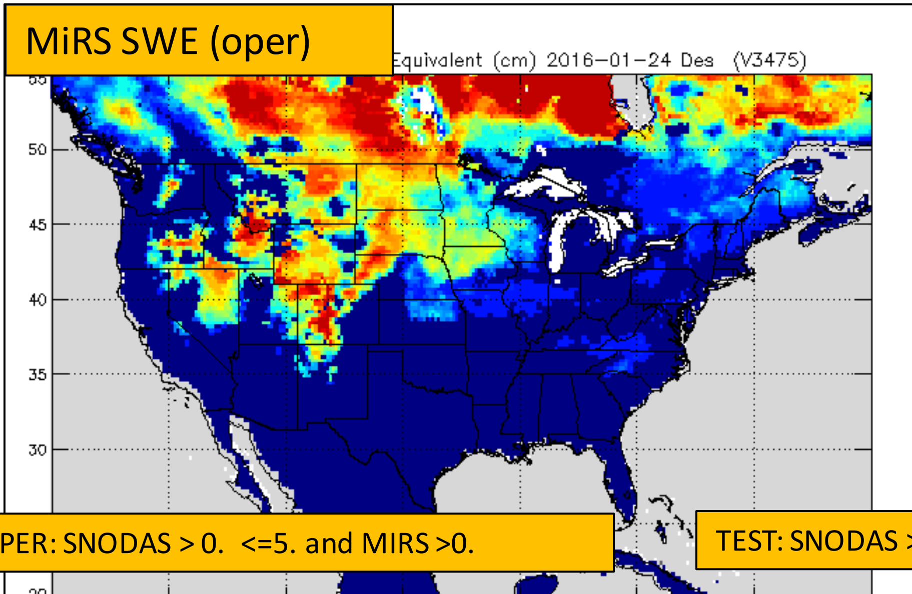
➢ Hydrometeors (improvements to CRTM i.e. scattering, precharacterization of precip type, particle size/shape distribution in CRTM, CLW over land for light rain detection)

➢ Air mass-dependent bias corrections

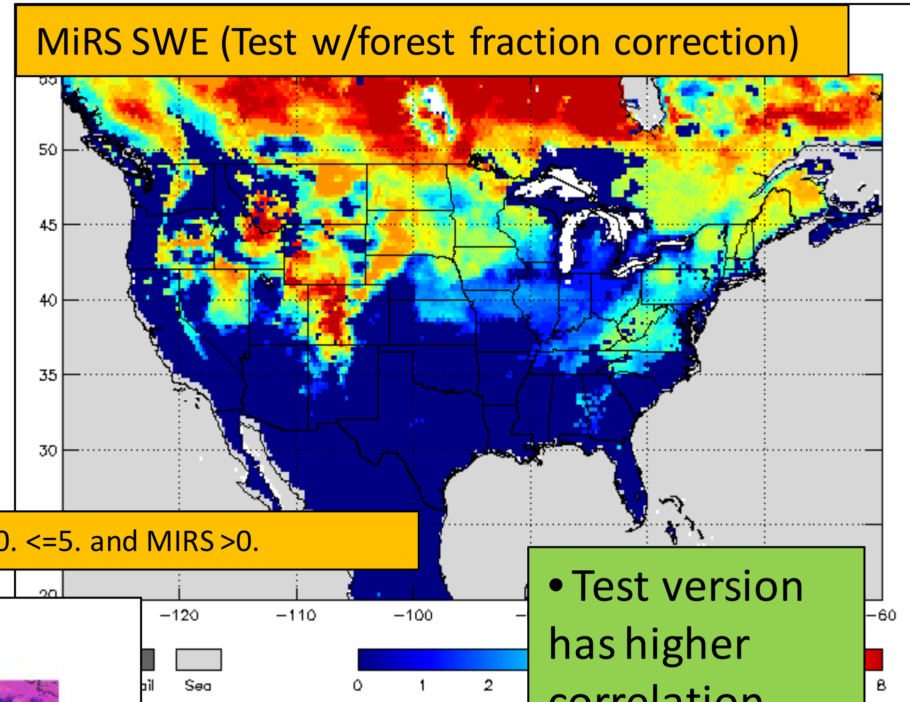
➢ Stakeholders/user needs…

Snow Water Equivalent: Potential Improvements
Case 1, 2016-01-24

MiRS SWE (oper)

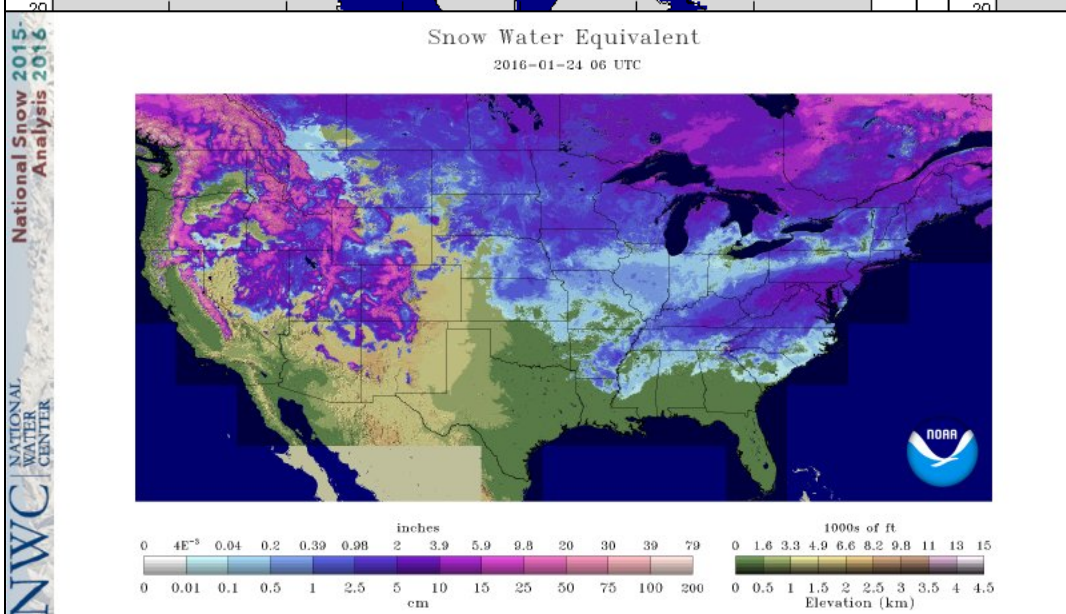


MiRS SWE (Test w/forest fraction correction)



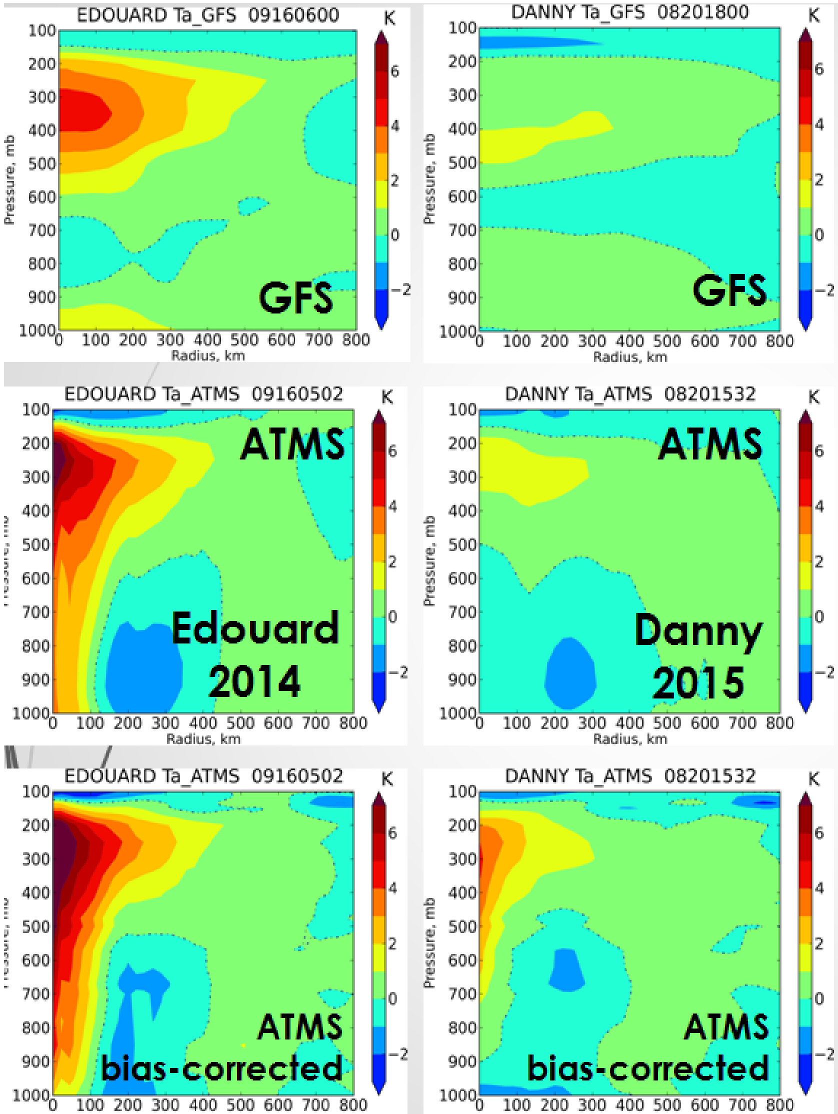
OPER: SNODAS > 0. <=5. and MIRS >0.

TEST: SNODAS > 0. <=5. and MIRS >0.



- Test version has higher correlation, smaller StDv, and regression fit has slope closer to 1
- Note increase in Npts with SWE> 0 in Test version

Three of CIRA's Applications use ATMS-MIRS data: Galina Chirokova



Vertical T cross-section in TCs

- **GFS:** underestimated warm core
- **ATMS:** usually best available warm core representation
- **Bias-Corrected ATMS:**
  - More pronounced warm anomaly at 250 hPa
  - Warm anomaly extends further to the surface

1) **CIRA Operational Microwave TC Intensity and Structure Estimates**: **utilize better ATMS T near TC center.**

2) **Moisture Flux Application**: **utilize better ATMS moisture**, possibly blend it with GFS moisture at lower levels

3) **Detecting Warm Core Changes** during rapid intensification (RI) events: **use unique information provided by ATMS about the TC warm core**

Status of the NOAA Unique Combined Atmospheric Processing System (NUCAPS): algorithm upgrades and lessons learned after 5 years in orbit

Antonia Gambacorta (1), Chris Barnet (1), Nadia Smith (1), Jonathan Smith (1), Walter Wolf (2), Tom King (2), Michael Wilson (2), Letitia Suillard (2), Mark Liu (2), Tony Reale (2), Nick Nalli (2), Bomin San (2), Kexin Zhang (2), Changyi Tan (2), Flavio Iturbide-Sanchez (2), Xiaozhen Xiong (2), Mitch Goldberg (3)

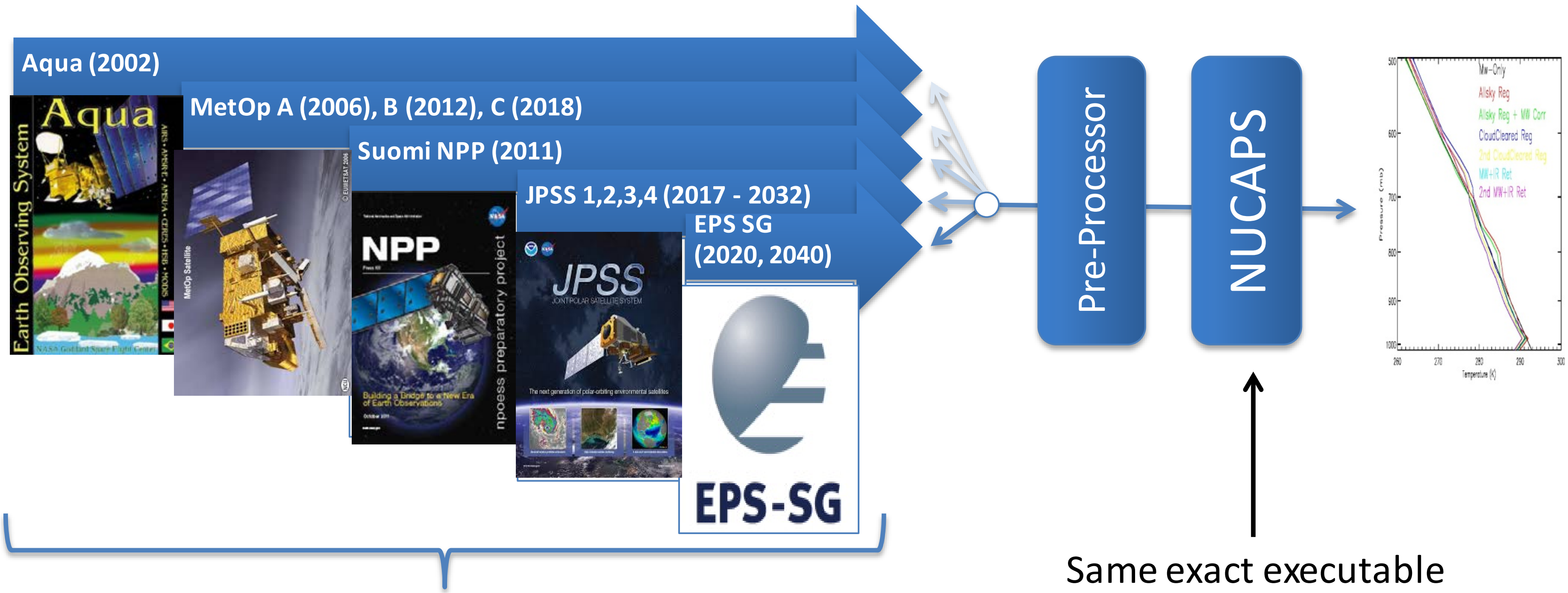
3rd JPSS Annual Meeting
August 10, 2016

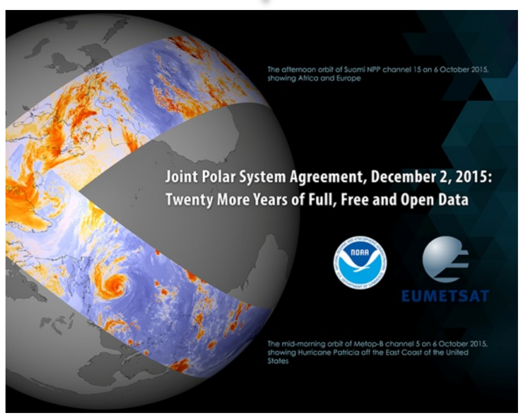
1. Science and Technology Corporation, STC
2. NOAA NESDIS STAR
3. NOAA JPSS Project Scientist

Introduction

- The **NOAA Unique Combined Atmospheric Processing System (NUCAPS)** is the NOAA operational algorithm to retrieve temperature, water vapor and trace gases from IR hyper spectral sounders (AIRS, CrIS, IASI) in combination with microwave (AMSU, MHS, ATMS) and visible (MODIS, AVHRR, VIIRS) instruments .
- NOAA/NESDIS/STAR has been operationally running NUCAPS since 2003 and distributing its products in near real time (~2 hour latency) to the science community through CLASS.
- On September 3rd 2014, NUCAPS passed stage 1 at the JPSS validation review.
- NUCAPS has been implemented in AWIPS-II.
- Full implementation of NUCAPS in the Community Satellite Processing Package (CSPP) was completed in Dec. 2014 and went operational in February 2015. Direct broadcast latency is ~ 0.5 hour.
- **Focus of this talk:** an overview of the status of the algorithm, lessons learned in the past years and the path forward.

The history of the NOAA Unique Combined Atmospheric Processing System (NUCAPS)





Same exact executable
Same underlying Spectroscopy
Same look up table methodology
for all platforms

Philosophy of NUCAPS

- **The challenge**: high computationally efficiency and sophisticated inversion methods to maximize utilization of large volumes of data for real time weather and long-term climate applications

- **Philosophy of NUCAPS**: developing a mathematically sound and globally applicable (land/ocean, day/night, all season, all sky, TOA-surface) retrieval product that can fully exploit all available satellite assets (infrared, microwave, visible). These are among the essential metrics defining a modern, physical and independent data record of atmospheric variables, suitable for both weather and climate applications.

What's unique about NUCAPS?

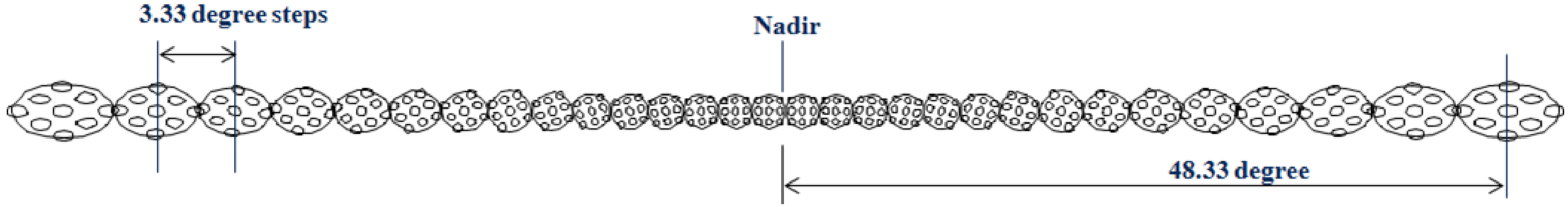
- **NOAA operational algorithm heritage of the AIRS Science Team code**, with additional unique components
- **Designed, from the beginning, to be product-centric** rather than sensor-centric (NPP Science Team priority recommendation)
  - AIRS/AMSU, IASI/AMSU/MHS, and CrIS/ATMS are processed with literally the same NUCAPS code.
  - Same underlying spectroscopy and look up table methodology
  - Instrument agnostic: specific items are file-driven, not hardwired
  - Extremely fast compared to other approaches (1 CPU for CrIS/ATMS)
  - Code is backward and forward (as much as possible) compatible.
  - Retrieval components are programmable via namelists (can quickly compare retrieval enhancements and/or methodologies).
  - Operational code is a "filtered" version of the science code.
  - Capable of processing CrIS full-resolution spectra (Gambacorta 2013 IEEE GRSL);
- **Uses an open framework** (NPP Science Team priority recommendation)
  - other researchers can link other algorithms for the core products and new algorithms for ancillary products (e.g., cloud microphysical products, trace gases, etc.).
- **Could add new products**
  - Ammonia, Formic Acid (HCOOH), and Peroxyacetyl Nitrate (PAN), etc.

What's unique about NUCAPS?

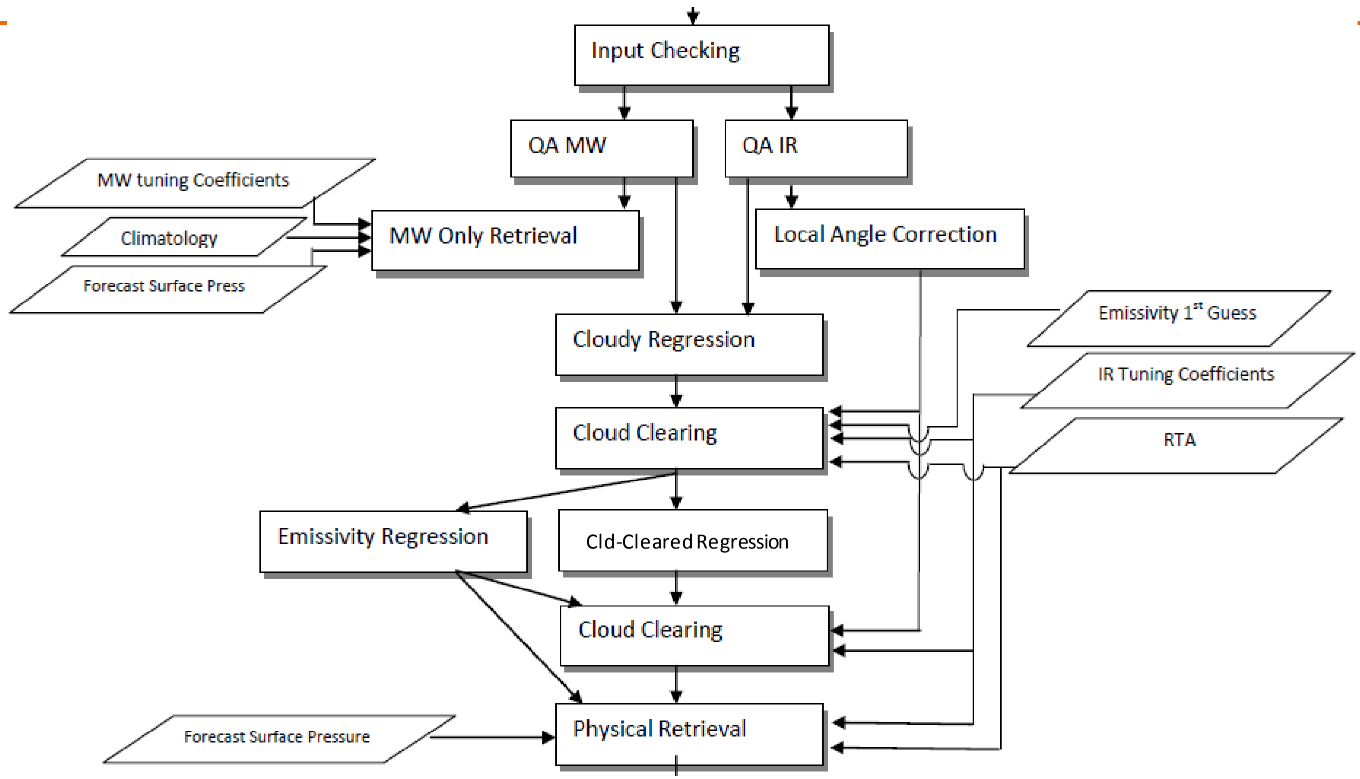
- **Designed to use all available sounding instruments.**
  - Microwave radiances used in microwave-only physical retrieval, "allsky" regression solution, "cloud cleared" regression and downstream physical T(p) and q(p) steps.
  - Visible radiances used to improve cloud clearing
- **Utilizes the high-information content of the hyper-spectral infrared – both radiances and physics.**
  - Climatological startup. Only ancillary information used is surface pressure from GFS model
  - Sequential physical algorithm allows for a robust and stable system with minimal geophysical a priori dependence
  - Utilizes forward model derivatives as spectral constraint to help stabilize the solution
  - Error from previous steps are mapped into an error estimate from interfering parameters
- **Utilizes cloud clearing**
  - Goal is to sound as close to the surface as possible
  - Sacrifices spatial resolution to achieve global coverage: no clear sky biases
  - Allows graceful degradation with decreased information content
  - Avoids ad hoc switches between clear sky only and cloudy sky single FOV algorithms

Goal of NUCAPS is to sound as close to the surface as possible

- We use a cluster of 9 infrared footprints to eliminate the effects of clouds
  - Cloud clearing sacrifices spatial resolution for coverage
  - Cloud clearing works in ~70% of cases (~225,000 / 324,000 per day)
  - Removes the difficulty of separating clouds from temperature and water vapor, typical of simultaneous cloudy retrievals
  - Works with complex cloud systems (multiple level of different cloud types).
  - Simple concept: a small number of parameters can remove cloud contamination from thousands of channels.
  - Does not require knowledge of cloud microphysics, nor cloud a priori.
  - Error introduced by cloud clearing is formally built into the measurement error covariance matrix and propagated through downstream retrieval error steps.



NUCAPS Flow Chart



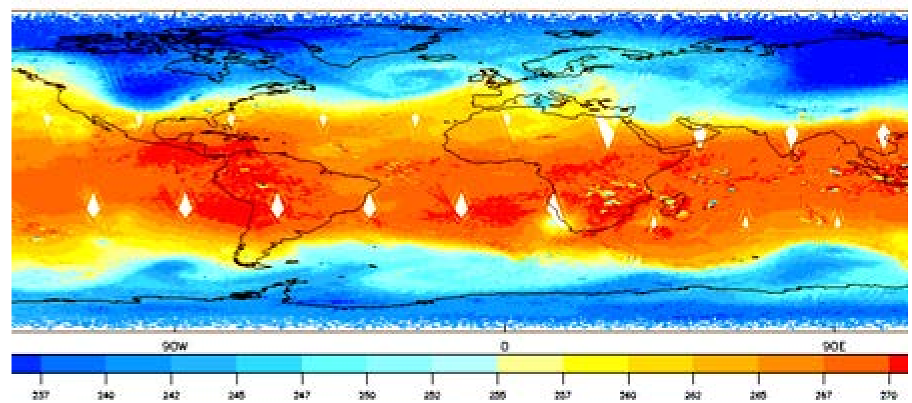
- **I. A microwave retrieval module** which computes Temperature, water vapor and cloud liquid water (Rosenkranz, 2000)
- **II. A fast eigenvector regression** retrieval that is trained against ECMWF and all sky radiances which computes temperature and water vapor (Goldberg et al., 2003)
- **III. A cloud 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 operational retrieval products

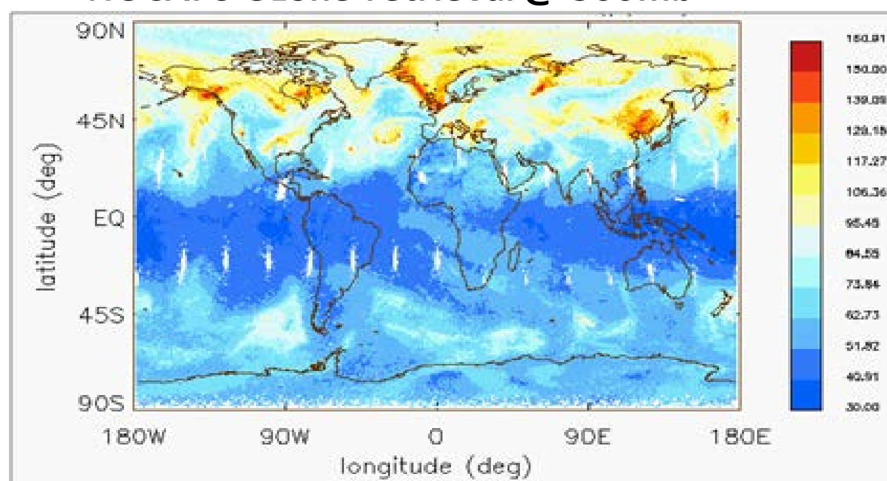
Retrieval Products

Cloud Cleared Radiances	**660-750 cm-1 2200-2400 cm-1**
Cloud fraction and Top Pressure	**660-750 cm-1**
Surface temperature	**window**
Temperature	**660-750 cm-1 2200-2400 cm-1**
Water Vapor	**780 – 1090 cm-1 1200-1750 cm-1**
O3	**990 – 1070 cm-1**
CO	**2155 – 2220 cm-1**
CH4	**1220-1350 cm-1**
CO2	**660-760 cm-1**
N2O	**1290-1300cm-1 2190-2240cm-1**
HNO3	**760-1320cm-1**
SO2	**1343-1383cm-1**

NUCAPS Temperature retrieval @ 500mb



NUCAPS Ozone retrieval @ 500mb



One year has gone by…

- A team effort between NOAA/STAR, NPP Science Team and NOAA JPSS:
  - A fully functional NUCAPS MW-only retrieval module, consistent across AMSU/MHS and ATMS
  - A fully functional NUCAPS in CrIS high resolution mode
    - NUCAPS Phase IV CDR held on February 4, 2016
    - NUCAPS high resolution first guess modules
    - NUCAPS high resolution channel selection
    - NUCAPS high resolution RTA model and bias correction
    - Delivery expected in late 2016.
  - A fully functional capability of NUCAPS in IR-only mode

Global RMS Performance of NUCAPS

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Temperature RMS   Water vapor RMS

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NUCAPS MW ONLY (95%) NUCAPS MW+IR (70%) NUCAPS MW ONLY (rejected by IR, 30%)

Global Performance (BIAS)

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Temperature RMS

Water vapor RMS

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NUCAPS MW ONLY (95%) NUCAPS MW+IR (70%) NUCAPS MW ONLY (rejected by IR, 30%)

A busy list of JPSS funded initiatives to demonstrate NUCAPS application capabilities

I. **Aviation Weather Testbed (AWT)**: Cold Air Aloft

II. **NUCAPS in AWIPS-II**: training & improvements

III. **Hazardous Weather Testbed (HWT)**: Convective Initiation

IV. **Hydrometeorology Testbed (HMT)**: Pacific field campaigns (2014, 2015 CalWater & 2016 ENRR)

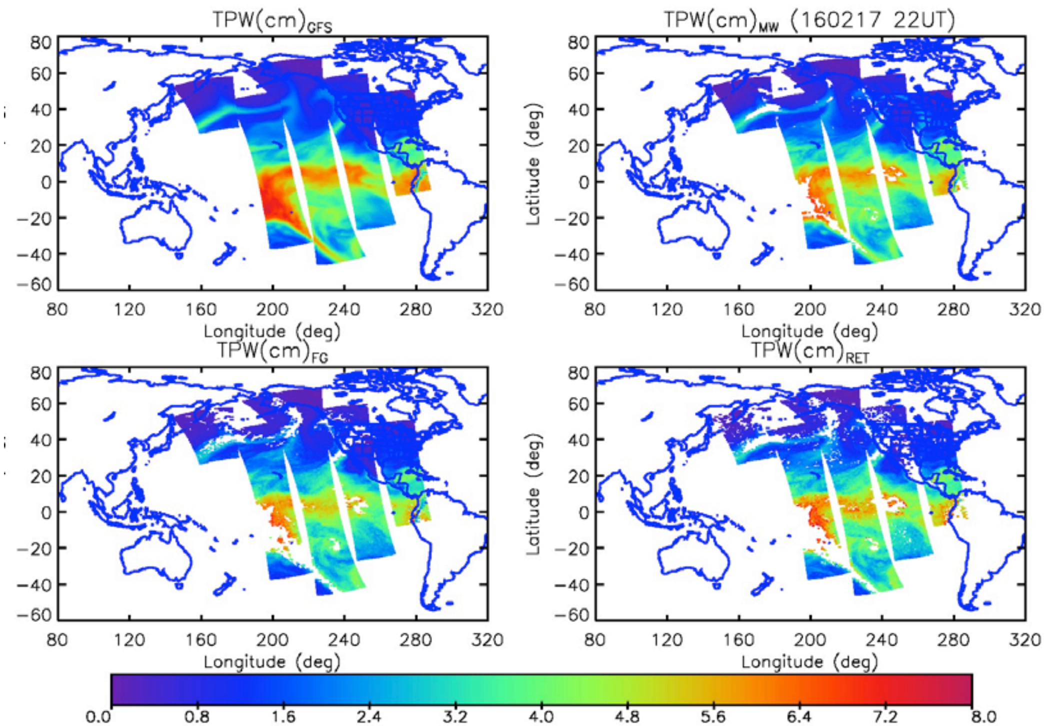
V. **Carbon Monoxide and Methane product evaluation** (NESDIS/STAR & OAR/ESRL/CSD)

VI. **Use of NUCAPS Ozone in hurricane extratropical transition applications**

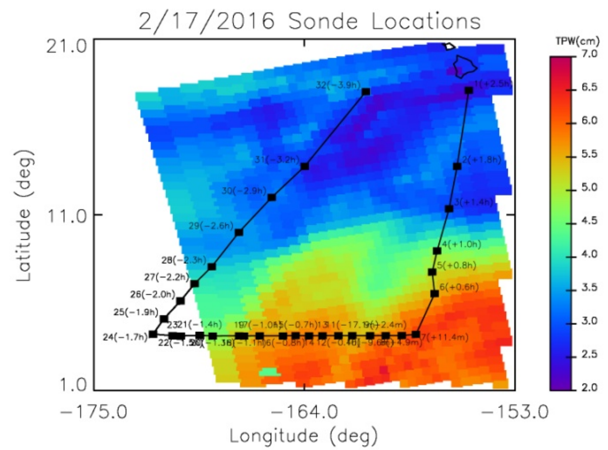
How can NUCAPS add value to the forecast of societally relevant weather events?

- Our goal is to demonstrate NUCAPS soundings capability in capturing high impact mesoscale phenomena over otherwise poorly sampled regions.
- NUCAPS implementation into CSPP direct broadcast enables unprecedented low latency data distribution, suitable for decision aid applications.
- Primary goal is to promote user applications.
- Intensive field campaign data are incredibly valuable for algorithm validation
  - Synergistic initiatives yield a large sample of in-situ data (~450 dropsondes and 175 radiosondes from CalWater-15 alone)
  - NUCAPS is a test-bed to study new methodologies

Assessing and improving NUCAPS sounding capability during high impact weather events: a test case from the 2016 El Nino Rapid Response Campaign



A snapshot of the full region



A close up figure over the flight path

➢Satellite data can provide near real time (~0.5 hour), 3D context to a high impact weather event

El Nino Rapid Response Campaign
February 17, 2016

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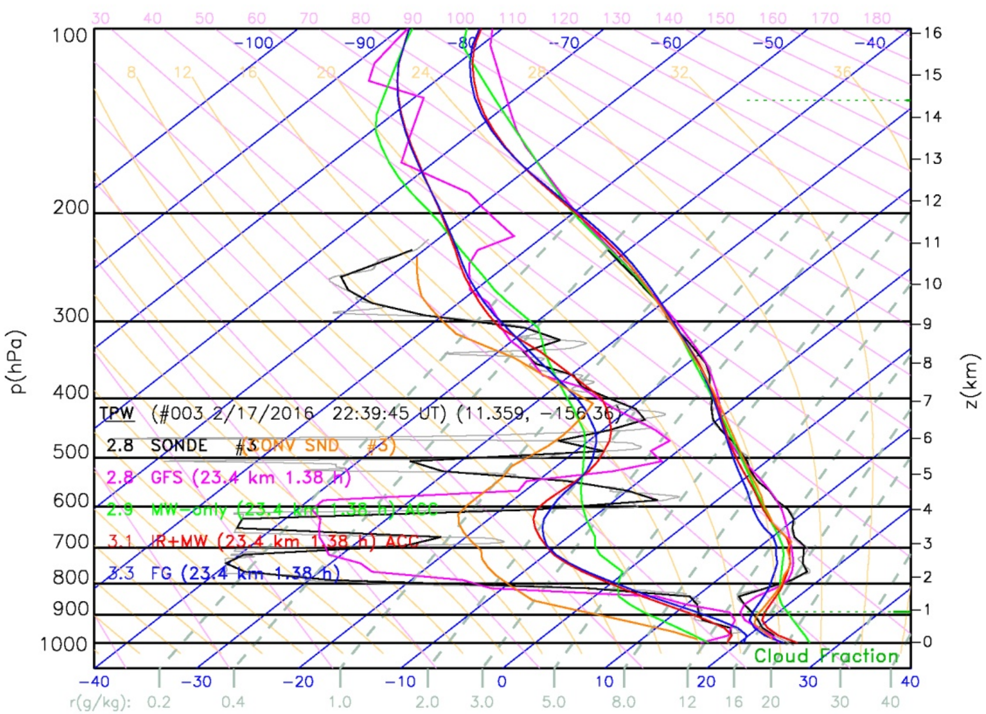

Orginal Sonde, AK-conv. Sonde, GFS, MW-only, MW+IR, FG

- We are building a diagnostic capability to assess NUCAPS performance under high impact weather events. This will enable a more intelligent use of NUCAPS products and ultimately serve to make improvements on the algorithm.

Vertical resolution, information content and departure from first guess as metrics to assess *and improve* retrieval performance

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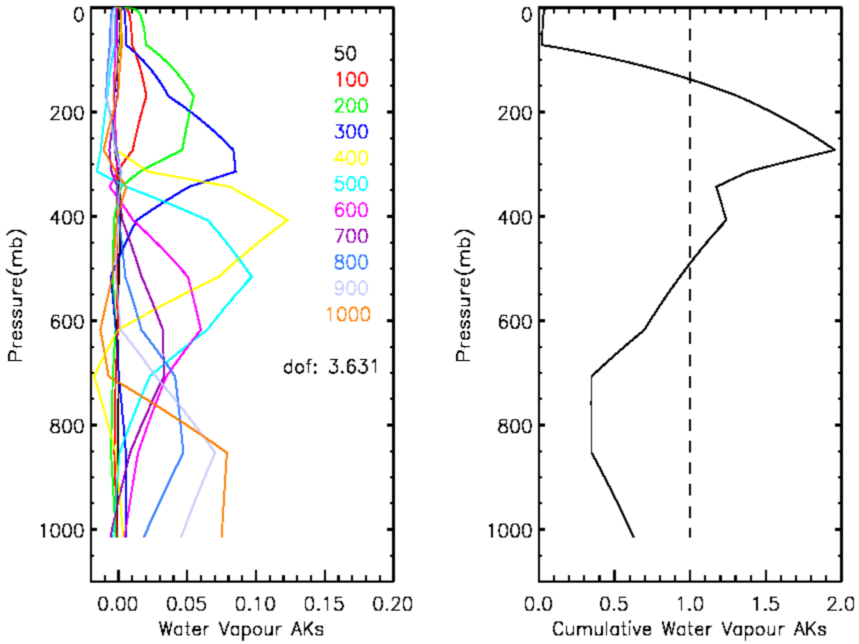

- Averaging Kernels provide insights on NUCAPS effective vertical resolution (broadness of the peaks), information content (magnitude of the peaks) and separation of the contributions to the solution originating from the measurement and from the a-priori.
- They represent a necessary tool for any characterization, validation and proper application of a retrieval product.

El Nino Rapid Response Campaign
February 17, 2016

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- We are building a diagnostic capability to assess NUCAPS performance under high impact weather events. This will enable a more intelligent use of NUCAPS products and ultimately serve to make improvements on the algorithm.
- What's NUCAPS effective vertical resolution and how can we improve it?
- Where do we have and how can we improve information content?
- What are the sources of retrieval error at play?

} Channel selections, A priori, QCs, RTA, CCR, err prop., etc.

Summary & Future Work

- NUCAPS has demonstrated to meet user requirements
- NUCAPS Phase IV expected to become operational this Fall in preparation for J1.
- We now have ground truth and a diagnostic capability to assess NUCAPS performance under high impact weather events for user applications of societal importance.
- This new type of validation approach enables a more intelligent use of NUCAPS products, engages new users, promotes new users requirements, leads to improvements to the retrieval products, justifies transition to operations.

Backup slides

Radiosonde measurements from CalWater 2015 February 6th test case

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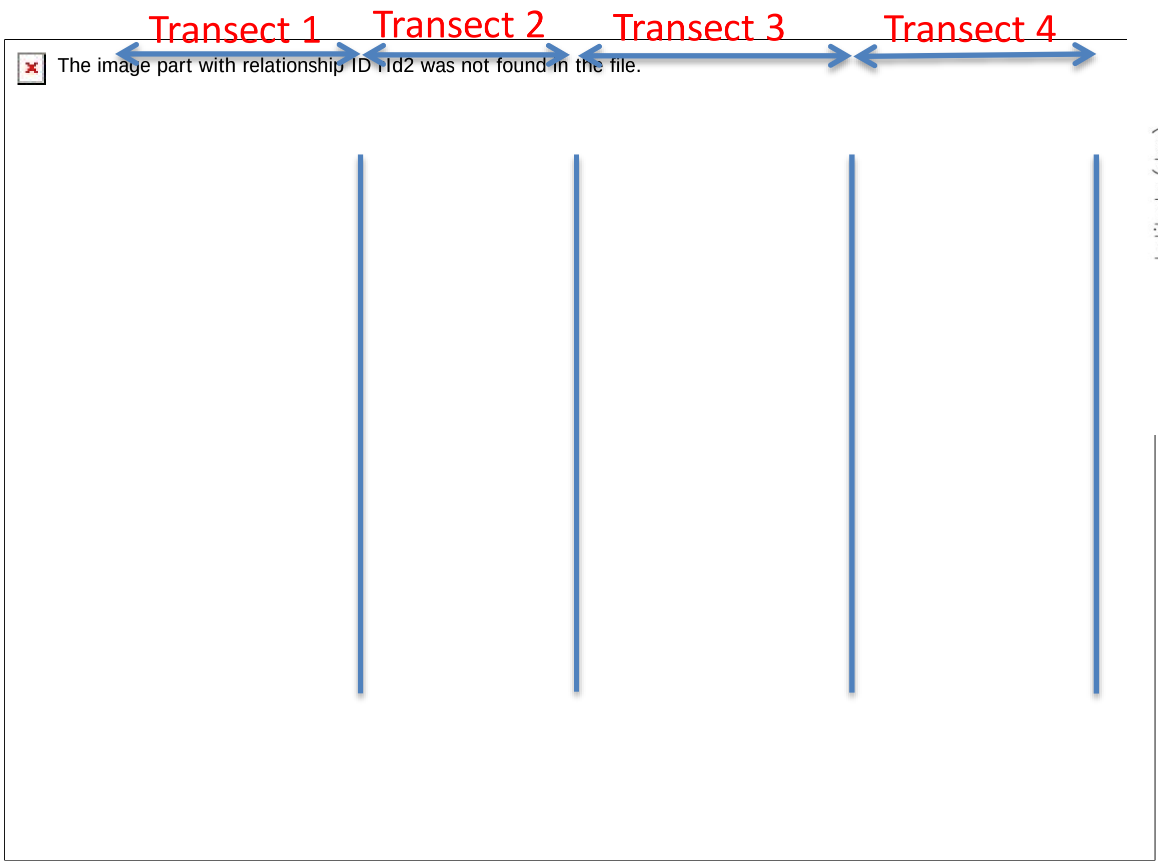

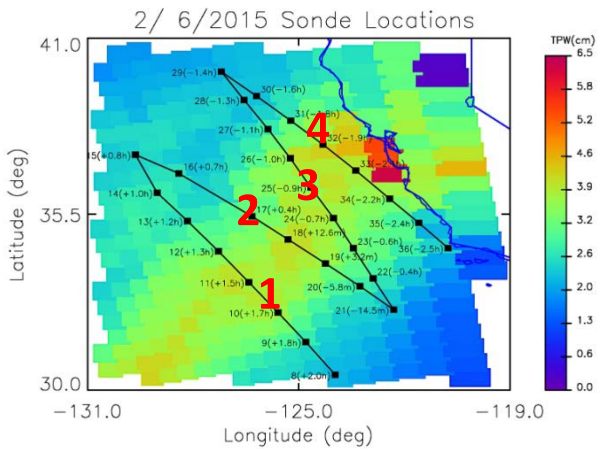

- ~ 4 hours flight with 4 transects across the river capturing pre, in and post river environment as the river quickly approaches the US West coast
- Good spatial and temporal matching with NPP (drop sonde location 19 is ~ 3.2 minutes ahead of over pass

Understanding the role of the a priori and first guess

- NUCAPS is currently using a statistical operator (linear regression) as a priori

Pro' s	Con' s
Does not require a radiative transfer model for training or application.	Training requires a large number of co-located "truth" scenes.
Application of eigenvector & regression coefficients is VERY fast and for hyper-spectral instruments it is very accurate.	The regression operator does not provide any diagnostics or physical interpretation of the answer it provides. It can introduce sub-resolved structures in the retrieval
Since real radiances are used the regression implicitly handles many instrument calibration (e.g., spectral offsets) issues. This is a huge advantage early in a mission.	The regression answer builds in correlations between geophysical parameters. For example, retrieved O_3 in biomass regions might really be a *measurement* of CO with a statistical correlation between CO and O_3.
Since clouds are identified as unique eigenvectors, a properly trained regression tends to "see through" clouds.	Very difficult to assess errors in a regression retrieval without the use of a physical interpretation.

Towards a more stable a-priori and first guess choice

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MW-only retrieval

Transect 1 Transect 2 Transect 3 Transect 4

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GFS

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Linear Regression

Precipitating cases

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Correct choice of a priori and first guess

We have started investigating three possible *a-priori:*

1) climatology built from a decade of ECMWF (this has already been constructed by the AIRS science team and will be tested)

2) ERA-interim; NCEP reanalysis; MERRA.

3) microwave-only retrieval. For CrIS/ATMS this has the potential to be an exceptional *a-priori*. For AIRS/AMSU and IASI/AMSU/MHS it is unlikely that the AMSU information content is sufficient.

Note:

- the retrieval solution is derived on the assumption that both measurement and a priori error statistics are Gaussian. Gaussian behaviour in a priori and first guess statistics must be be verified.
- Need a statistically significant validation ensemble.

El Nino Rapid Response Initiative
January – March 2016

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Simultaneous vs sequential OE approach

Simultaneous OE	Sequential OE
Solve all parameters simultaneously	Solve each state variable (*e.g*., T(p)), separately.
Error covariance includes only instrument model.	Error covariance is computed for all *relevant* state variables that are held fixed in a given step. Retrieval error covariance is propagated between steps.
Each parameter is derived from all channels used (*e.g*., can derive T(p) from CO_2, H_2O, O_3, CO, … lines).	Each parameter is derived from the best channels for that parameter (*e.g.,* derive T(p) from CO_2 lines, q(p) from H_2O lines, etc.)
A-priori must be rather close to solution, since state variable interactions can de-stabilize the solution.	*A-priori* can be simple for hyperspectral.
This method has large state matrices (all parameters) and covariance matrices (all channels used). Inversion of these large matrices is computationally expensive.	State matrices are small (largest is 25 T(p) parameters) and covariance matrices of the channels subsets are quite small. Very fast algorithm. Encourages using more channels.

Global impact of losing MW-only sounding capability (2)

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Temperature RMS | Water vapor RMS

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NUCAPS MW+IR (67%) | **NUCAPS IR ONLY (35%)**

- Losing the MW instrument degrades the global retrieval performance of temperature (water vapor) rms statistics by ~2K (~5%) in the lower troposphere and 1.5K (7%) in the mid troposphere

Impact of losing MW-only sounding capability during extreme events: a case study from May 6, 2015 tornado event in Norman, OK (3)

Temperature RMS | Water vapor RMS

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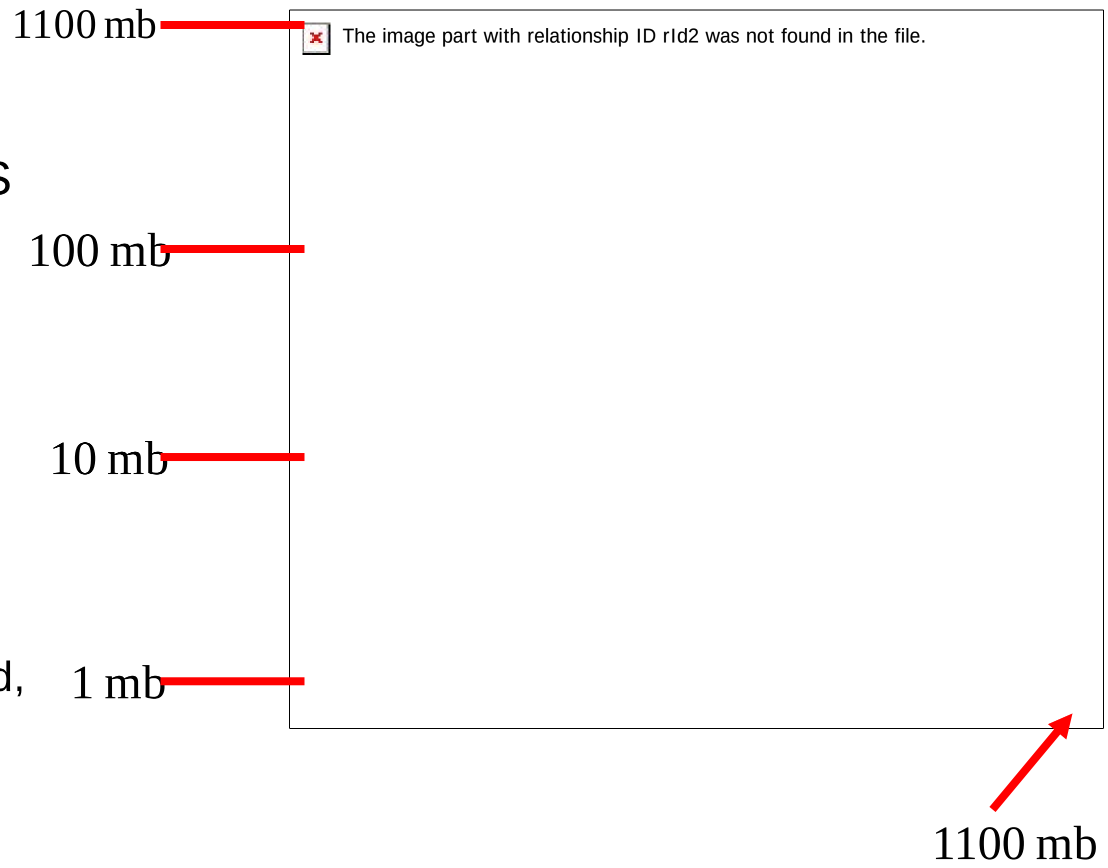
NUCAPS MW+IR (67%) | **NUCAPS IR ONLY (62%)**

- Losing the MW instrument degrades the global retrieval performance of temperature (water vapor) rms statistics by ~2K (~5%) in the lower troposphere and 1.5K (7%) in the mid troposphere

Example of temperature retrieval error covariance

- An example of temperature retrieval correlation (minimum variance method) for the AIRS instrument
- Top of atmosphere radiances (TOA) are used to invert the radiative transfer equation for T(p).
- This results in a correlation that is a vertical oscillatory function.
  - TOA radiances are minimized, but
  - An error in one layer is compensated for in other layer(s).



Therefore, the use of retrieval products requires knowledge of retrieval "averaging kernels" and/or error *covariance* estimates.