# Status of the NOAA Unique CrIS ATMS Processing System (NUCAPS): algorithm development and lessons learned from recent field campaigns

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American Meteorological Society Annual Meeting, New Orleans, 2016
Session 5: Leveraging the success of Suomi NPP: instruments, science algorithms, data access and education outreach

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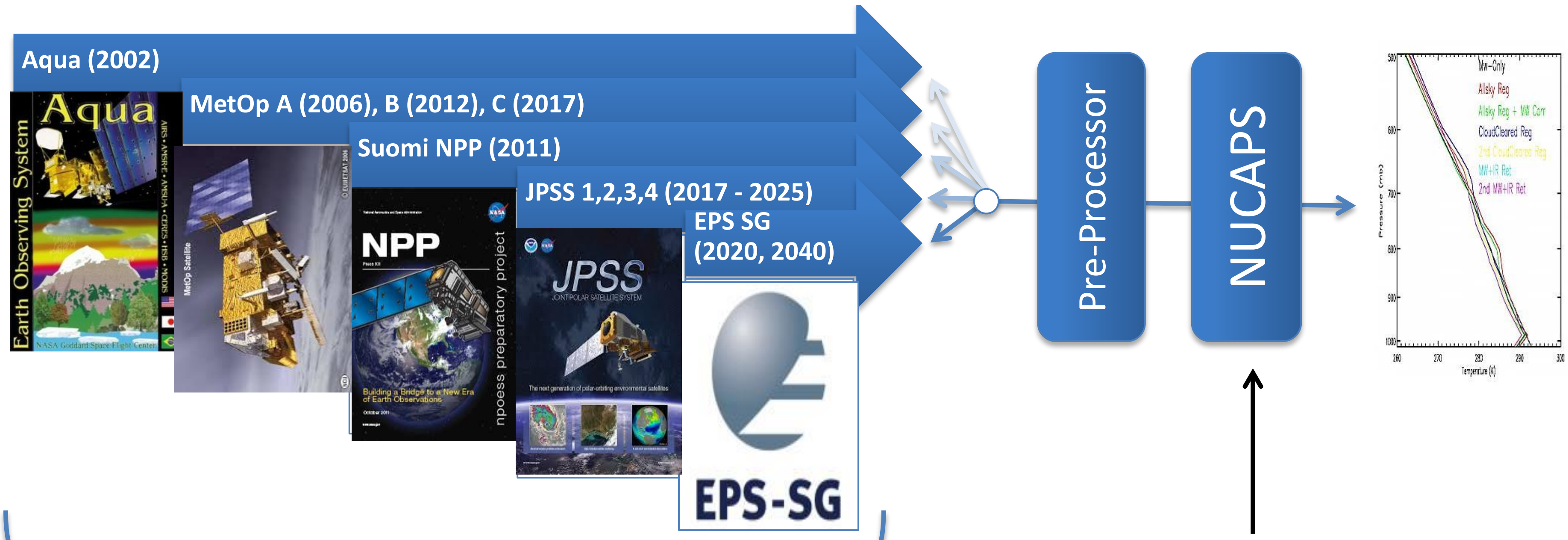
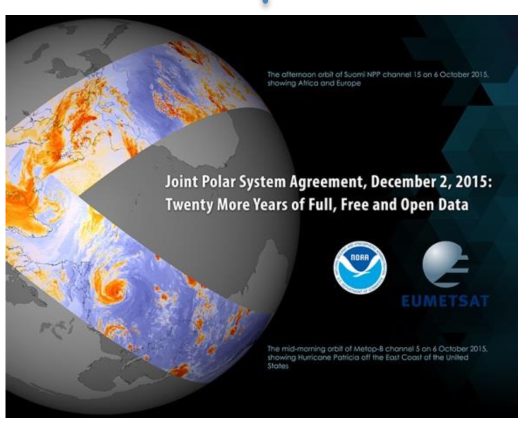
# Introduction

- The **NOAA Unique CrIS/ATMS Processing System (NUCAPS)** is the NOAA operational algorithm to retrieve temperature, water vapor and trace gases from the NPP CrIS and ATMS instruments.
- NOAA/NESDIS/STAR has been operationally running NUCAPS since 2013 and distributing its products in near real time (~3 hour latency) to the science community through CLASS.
- On September 3$^{rd}$ 2014, NUCAPS passed stage 1 at the JPSS validation review.
- NUCAPS has been implemented in AWIPS-II.
- NUCAPS is now running on Univ. of Wisconsin’s PEATE (Product Evaluation and Algorithm Test Element) test machine
- 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 ~ 1 hour.
- **Focus of this talk:** an overview of the status of the algorithm 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

# What's unique about NUCAPS?

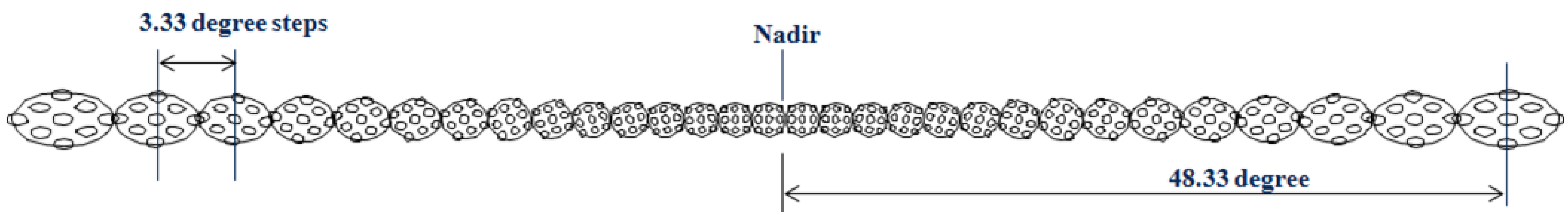
- **NOAA operational algorithm heritage of the AIRS Science Team code**, with additional unique components
- **Designed, from the beginning, to be product-centric** rather than sensor-centric (NPP Science Team priority recommendation)
  - AIRS/AMSU, IASI/AMSU/MHS, and CrIS/ATMS are processed with literally the same NUCAPS code.
  - Extremely fast compared to other approaches (1 CPU for CrIS/ATMS)
  - Same underlying spectroscopy (as best as we could do)
  - Instrument agnostic: specific items are file-driven, not hardwire
  - 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)

# What's unique about NUCAPS?

- **Designed to use all available sounding instruments.**
  - Climatological startup. Only ancillary information used is surface pressure from GFS model
  - Microwave radiances used in microwave-only physical retrieval, "allsky" regression solution, "cloud cleared" regression and downstream physical T(p) and q(p) steps.
- **Utilizes the high-information content of the hyper-spectral infrared – both radiances and physics.**
  - Sequential physical algorithm allows for a robust and stable system with minimal prior information
  - Utilizes forward model derivatives to help constrain the solution
  - Error from previous steps are mapped into an error estimate from interfering parameters
  - All channels used in linear regression first guesses.
- **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 algorithm

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

- We use a cluster of 9 infrared footprints and co-located microwave 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
  - Simple concept: a small number of parameters can remove cloud contamination from thousands of channels.
  - Does not require a model of clouds and is not sensitive to cloud spectral structure
  - Works with complex cloud systems (multiple level of different cloud types).
  - Error introduced by cloud clearing is formally built into the measurement error covariance matrix

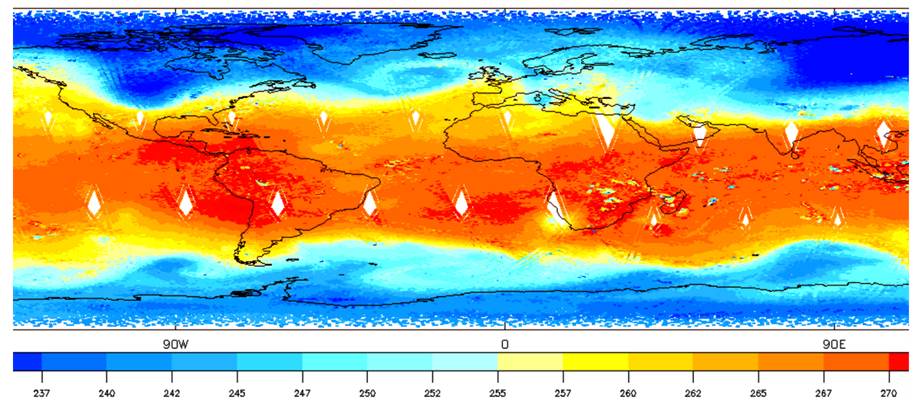


# NUCAPS operational retrieval products

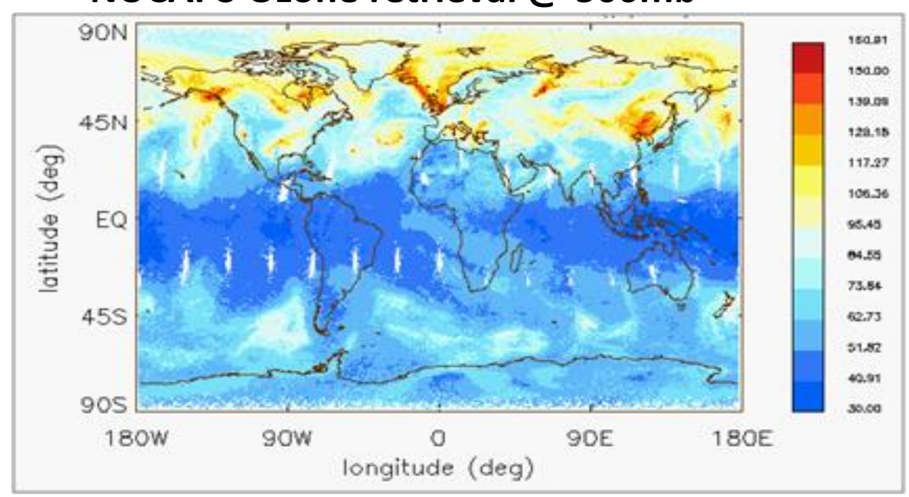
## Retrieval Products

| | |
|---|---|
| Cloud Cleared Radiances | 660-750 cm-1<br>2200-2400 cm-1 |
| Cloud fraction and Top Pressure | 660-750 cm-1 |
| Surface temperature | window |
| Temperature | 660-750 cm-1<br>2200-2400 cm-1 |
| Water Vapor | 780 – 1090 cm-1<br>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<br>2190-2240cm-1 |
| HNO3 | 760-1320cm-1 |
| SO2 | 1343-1383cm-1 |

**NUCAPS Temperature retrieval @ 500mb**

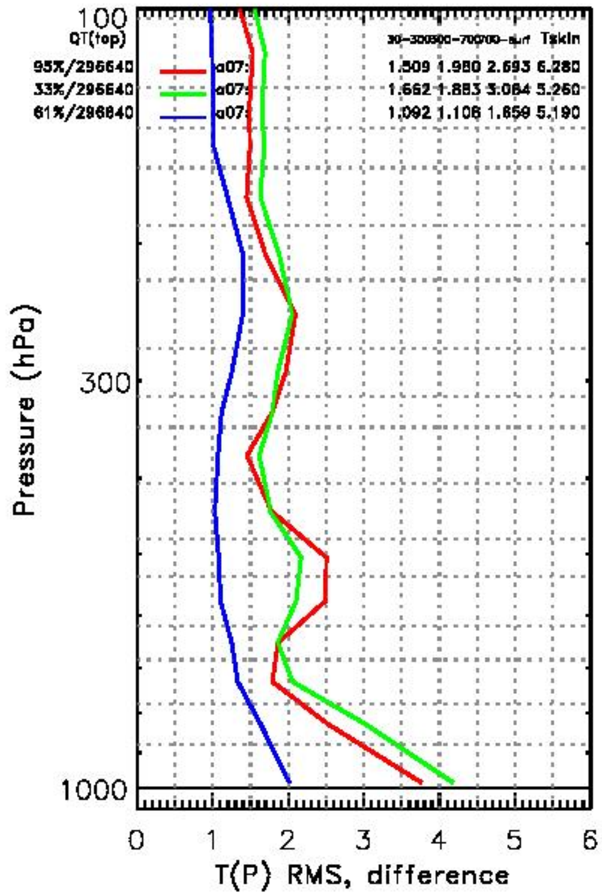



**NUCAPS Ozone retrieval @ 500mb**

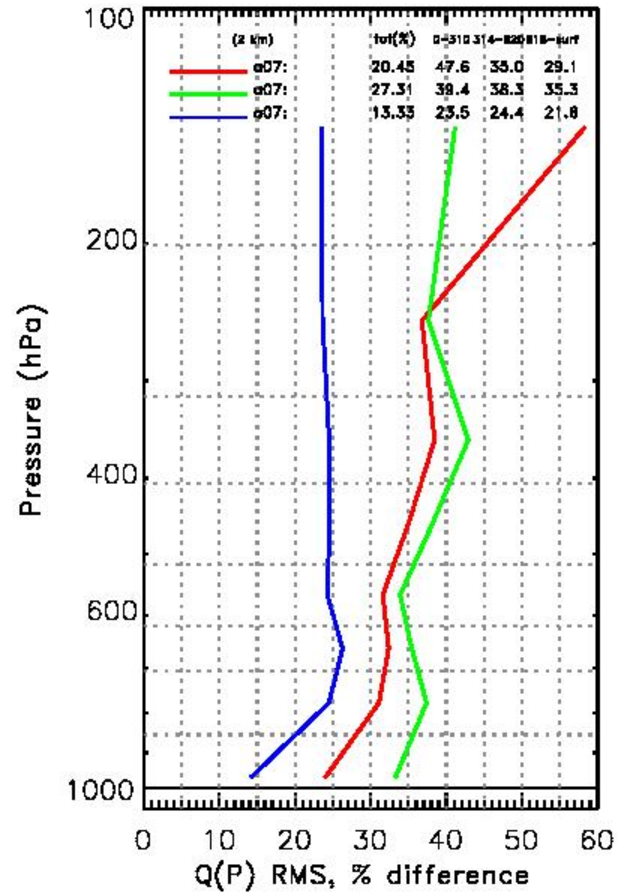


# Global Performance (RMS)

Temperature RMS



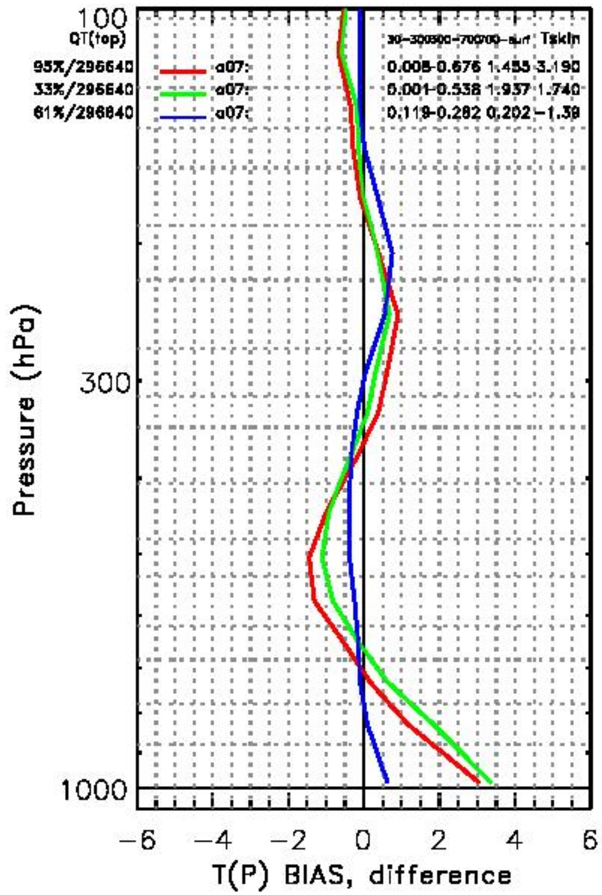

Water vapor RMS



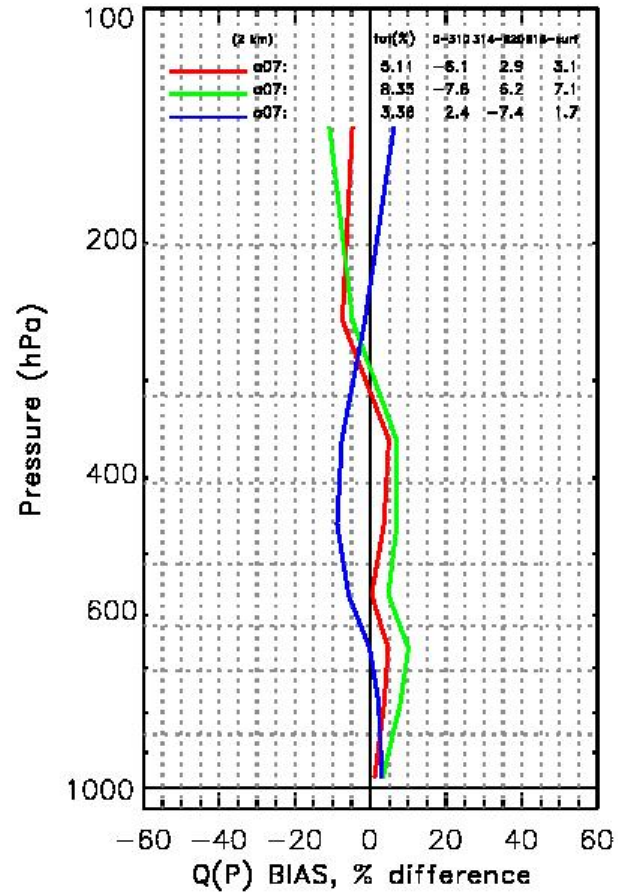

NUCAPS MW ONLY (95%) NUCAPS MW+IR (61%) NUCAPS MW ONLY (rejected by IR, 34%)

# Global Performance (BIAS)

## Temperature RMS




## Water vapor RMS



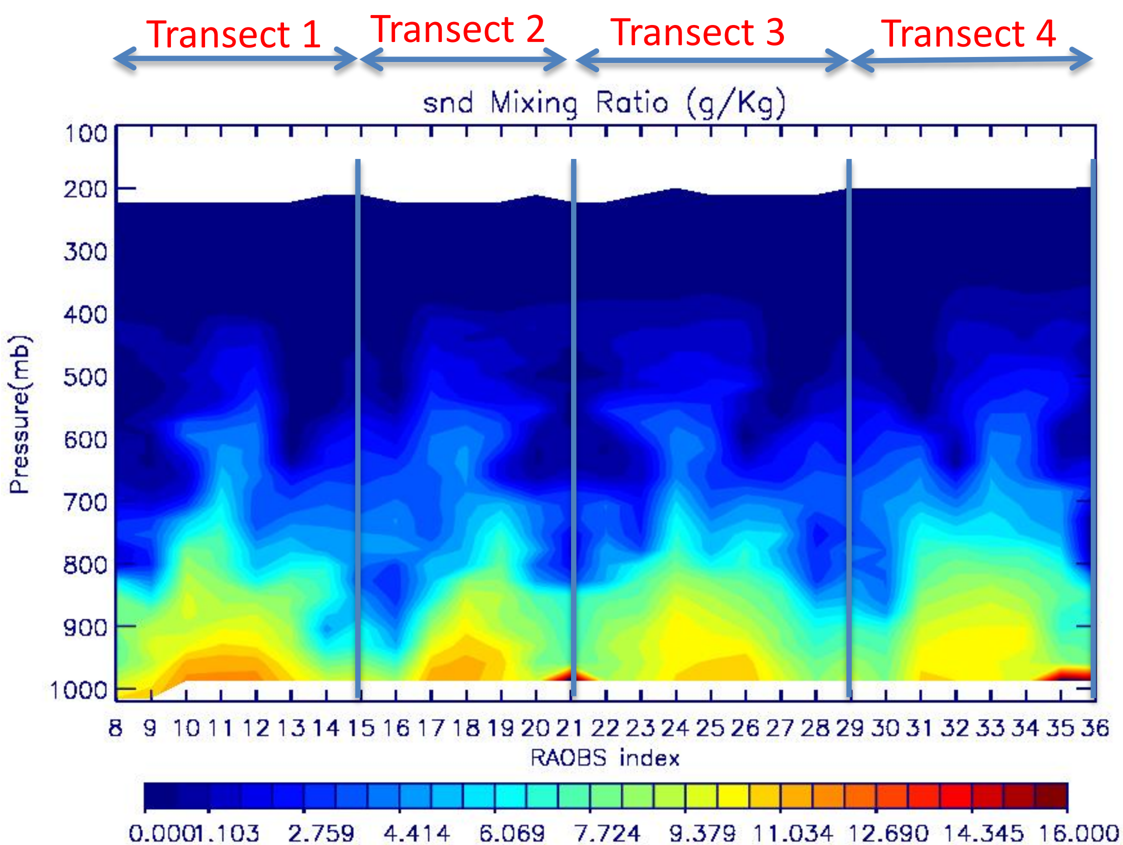

**NUCAPS MW ONLY (95%)** **NUCAPS MW+IR (61%)** **NUCAPS MW ONLY (rejected by IR, 34%)**

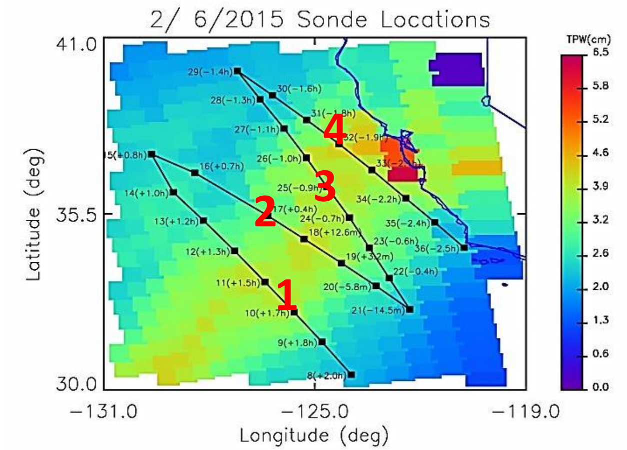
# How can NUCAPS add value to the forecast of societally relevant weather events?

- 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
- Our current initiatives:
  - Cold Air Aloft
  - Atmospheric rivers (CalWater 2015)
  - Hazardous Weather events (HWT Experiment 2015)
  - El Nino anomaly (El Nino Rapid Response Initiative 2016)

**Joint Session 9:** Satellite testbeds and proving ground activities

# Radiosonde measurements from CalWater 2015 February 6th test case



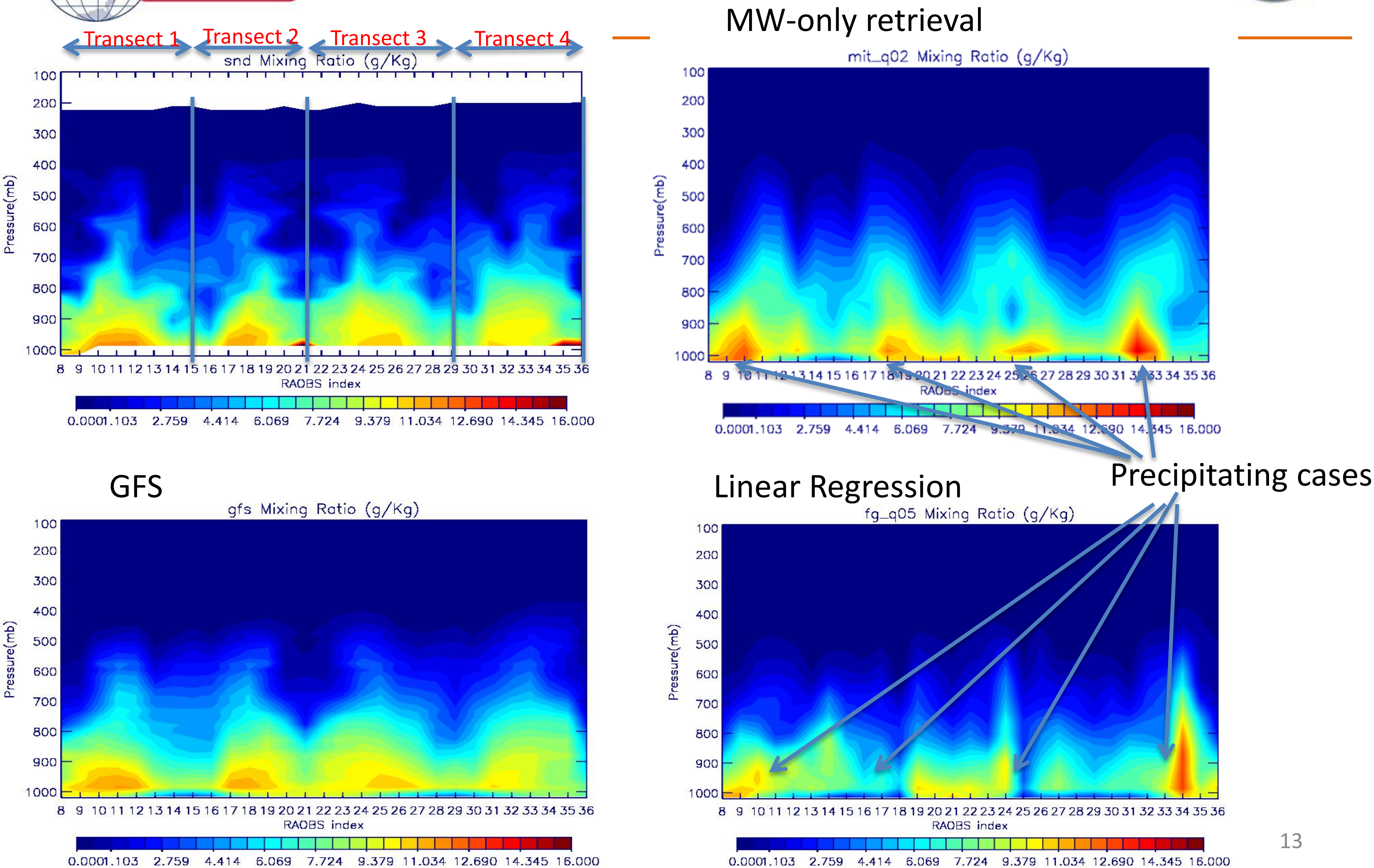

- ~ 4 hours flight with 4 transects across the river capturing pre, in and post river environment as the river quickly approaches the US West coast
- Good spatial and temporal matching with NPP (drop sonde location 19 is ~ 3.2 minutes ahead of over pass

# 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



# 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.

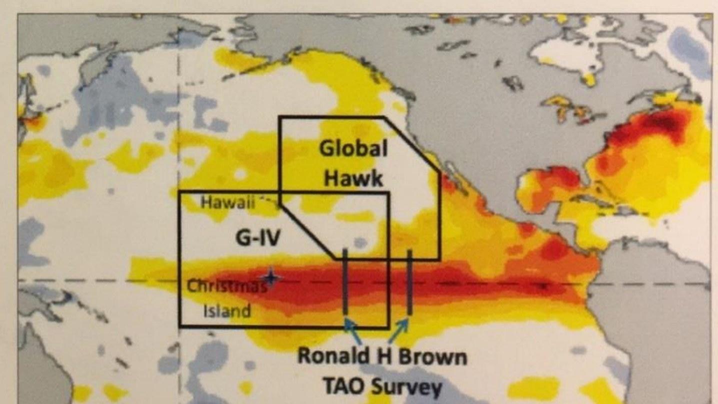
# El Nino Rapid Response Initiative
# January – March 2016


## NOAA El Niño Rapid Response Field Campaign

### January–March 2016

The current major El Niño presents an unprecedented scientific opportunity to accelerate advances in understanding and predictions of an extreme climate event and its impacts through research conducted *while the event is ongoing*.

- NOAA scientists are set to launch a land, sea, and airborne research effort to better **observe** and document the responses to the current strong El Niño.
- Intensive observations gathered in the tropical Pacific will provide a foundation to better **understand** how El Niño influences U.S. weather.
- The results will help scientists to better **predict** how climate phenomena like El Niño influence weather and climate extremes and their impacts.



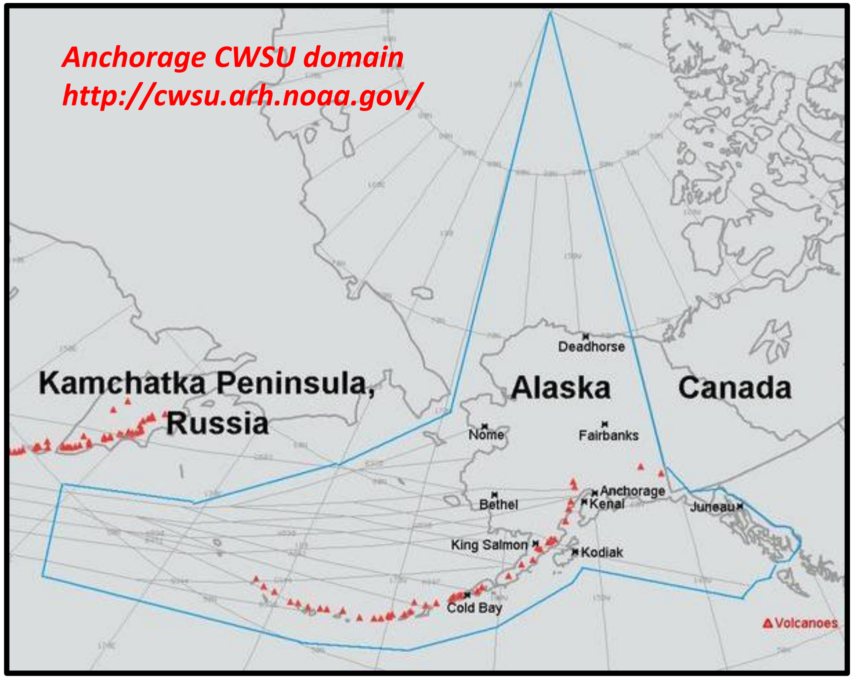
# Summary and the path forward

- The NOAA Unique CrIS/ATMS Processing System (NUCAPS) is the NOAA operational algorithm to retrieve temperature, water vapor and trace gases from the NPP CrIS and ATMS instruments.
- April 2013: NUCAPS is operational at NOAA/NESDIS/STAR
- September 3rd 2014: NUCAPS passes stage 1 at the JPSS validation review.
- February 2015: NUCAPS is operationally implemented in the Community Satellite Processing Package (CSPP) direct broadcast
- December 2015: NUCAPS, with QC flags, is fully operational in AWIPS II.
- **January 2016:** NUCAPS with CrIS in full spectral resolution mode Critical Design Review
- **2016:**
  - Implementation of the IASI system in AWIPS II and Direct broadcast.
  - El Nino Rapid Response Initiative (January – March 2016)
  - HWT Experiment 2016
  - Tropical cyclone initiatives

# BACK UP SLIDES

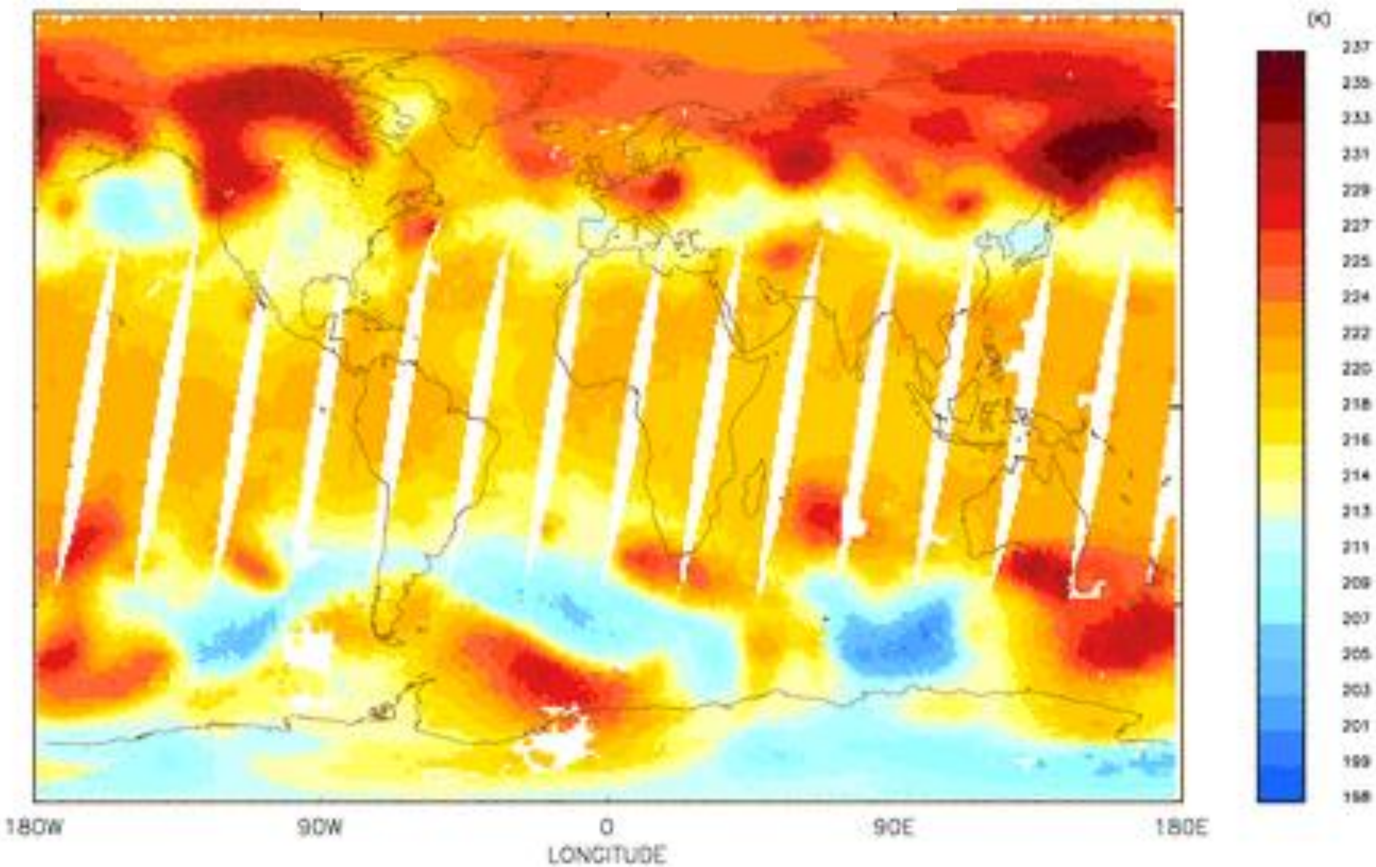
# Cold Air Aloft (CAA) Initiative

- Cold Air Aloft (-65°C and below) is potentially hazardous to aircrafts due to the threat of fuel freezing at these extreme temperatures
- When these events occur, the Anchorage Alaska Center Weather Service Unit (CWSU) provides Meteorological Impact Statements (MIS) to Air Traffic Controllers to re-direct flights around Cold Air Aloft events.



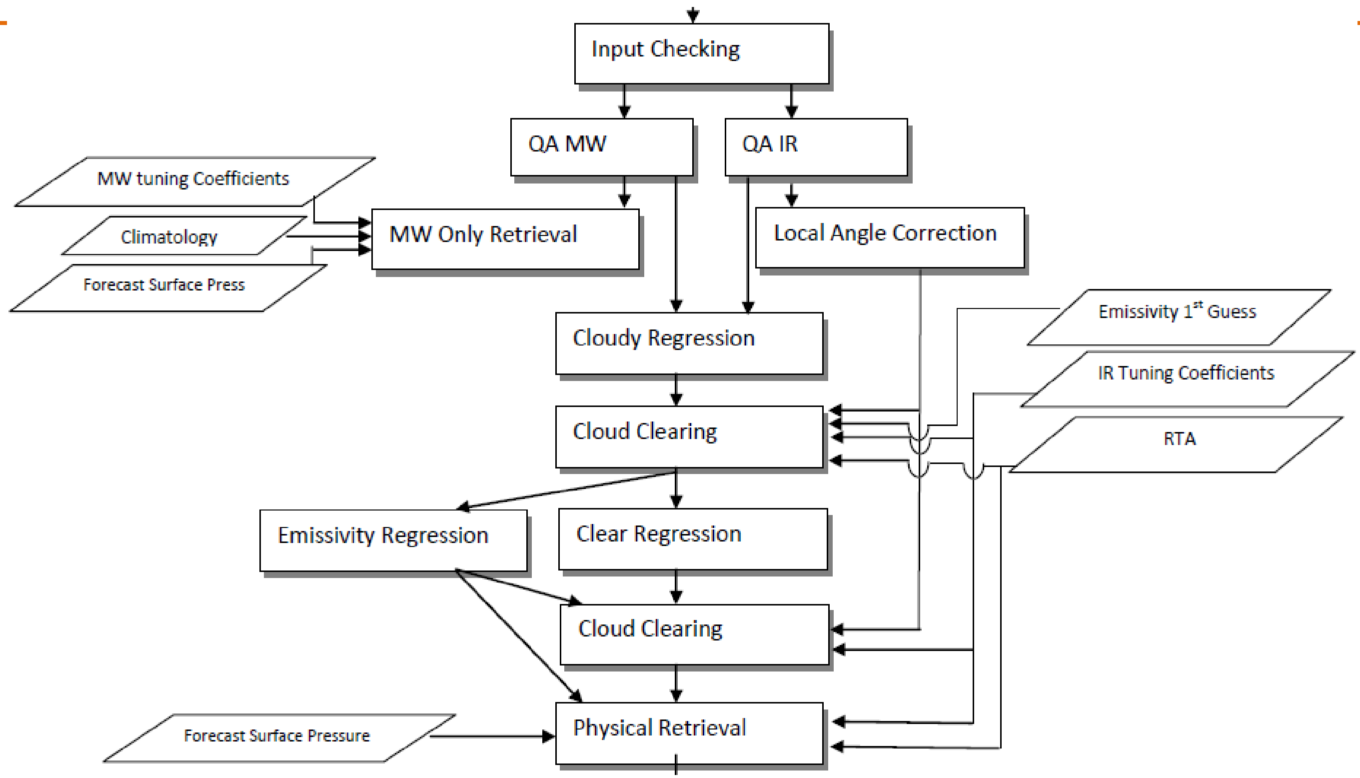

- In data sparse regions like Alaska, forecasters can only rely on model fields and limited radiosonde observations.
- Use of direct broadcast satellite observations provides an opportunity for forecasters to observe the 3D extent of the Cold Air Aloft in real-time, where conventional observations are lacking.
- Forecasters at the CWSU have expressed the need for an observational product from satellites that can be used to improve confidence in the model output.

# Daily temperature maps at 200mb 2014/07/01 – 2014/10/05




CAA events

# 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 CrIS 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 CrIS 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)

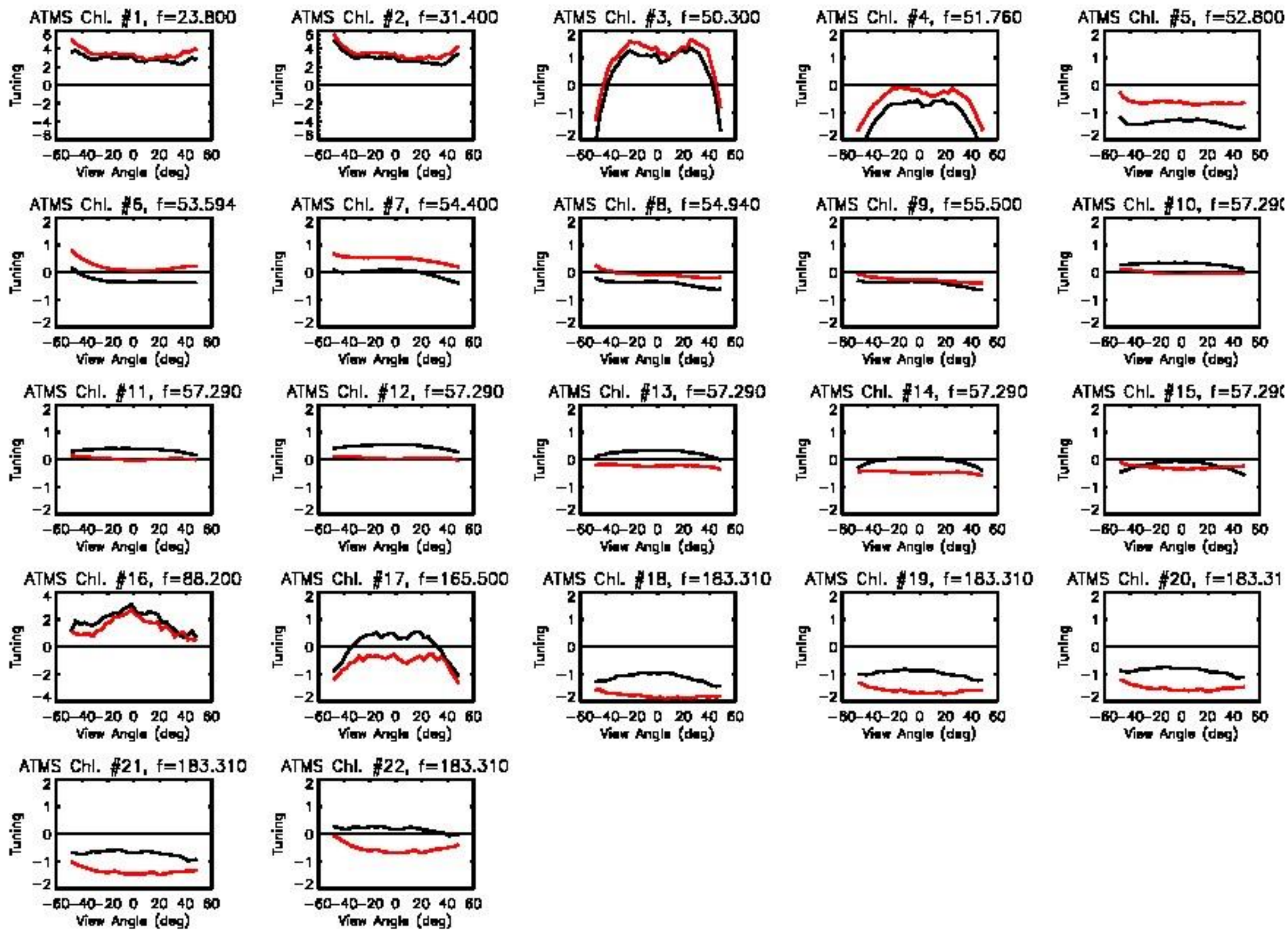
# Simultaneous vs sequential OE approach

| 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 CO2, H2O, O3, CO, … lines). | Each parameter is derived from the best channels for that parameter (*e.g.,* derive T(p) from CO2 lines, q(p) from H2O 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. |

# 183GHz bias problem

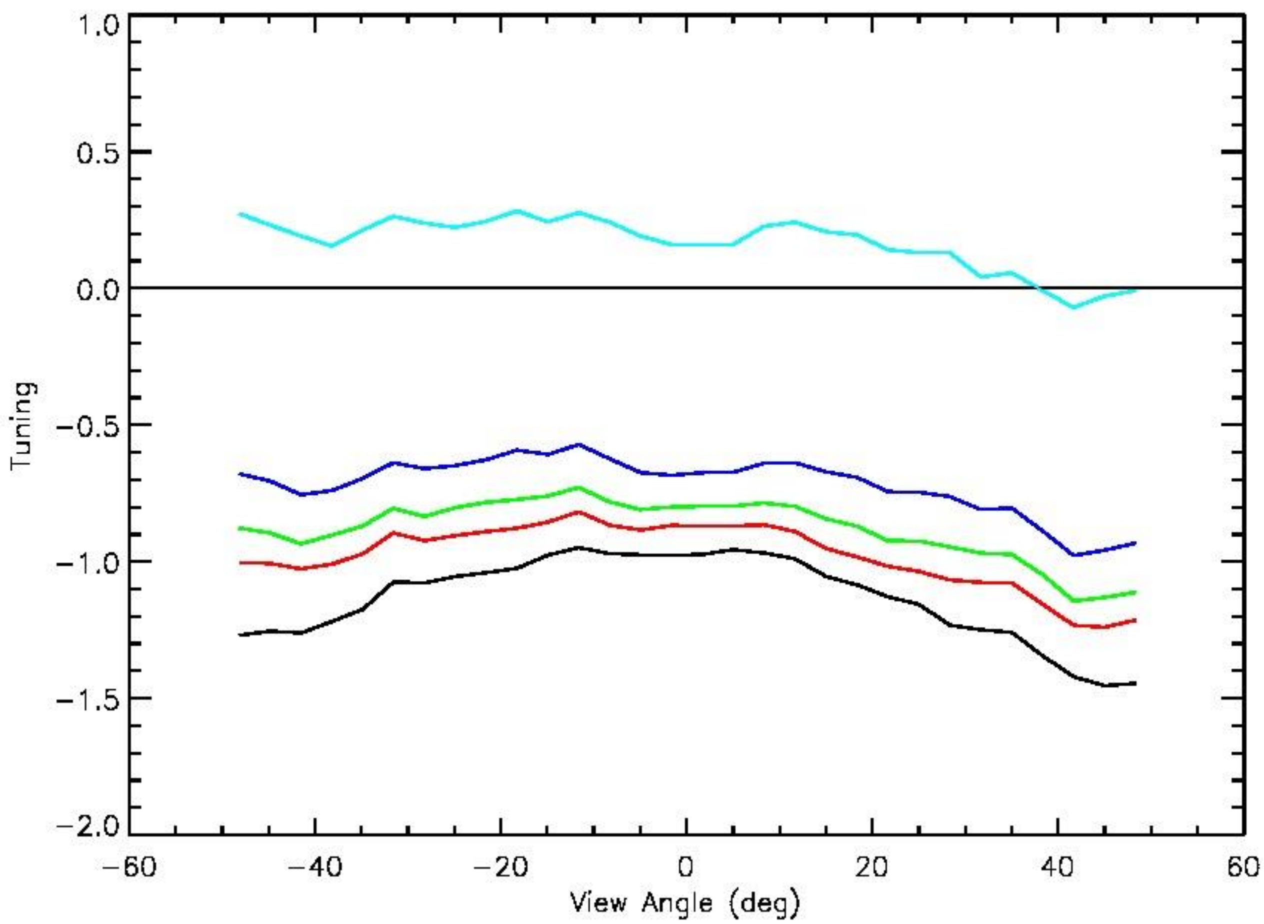
- Ongoing discussion on the sensitivity peak height dependent bias in the 183GHz band
  - OBS-CALC bias computation is observed to increase with lower peaking 183GHz channels
  - Problem is observed across all current forward models and MW instruments (AMSU, SAPHIR, ATMS)
  - Problem is observed on both ATMS TDR and SDR files (next 2 slides)
  - 29-30 June 2015: a dedicated workshop to study the issue. Executive summary available upon request.
  - Possible sources: surface, precipitation contamination, water vapor continuum.
  - We are in contact with Phil Rosenkranz who has an updated forward model with improved water vapor transmittance.

# ATMS tuning
# TDR (black) & SDR (red)



# 183 GHz bias (OBS-CALC): TDR cases

ATMS Chn. 22
ATMS chn. 21
ATMS chn. 20
ATMS chn. 19
ATMS chn. 18



# 183 GHz bias (OBS-CALC): SDR cases

ATMS Chn. 22
ATMS chn. 21
ATMS chn. 20
ATMS chn. 19
ATMS chn. 18