NOAA level 2 algorithm developments finalized to improve regional weather forecast applications: boundary layer issues, quality control, first guess choices.

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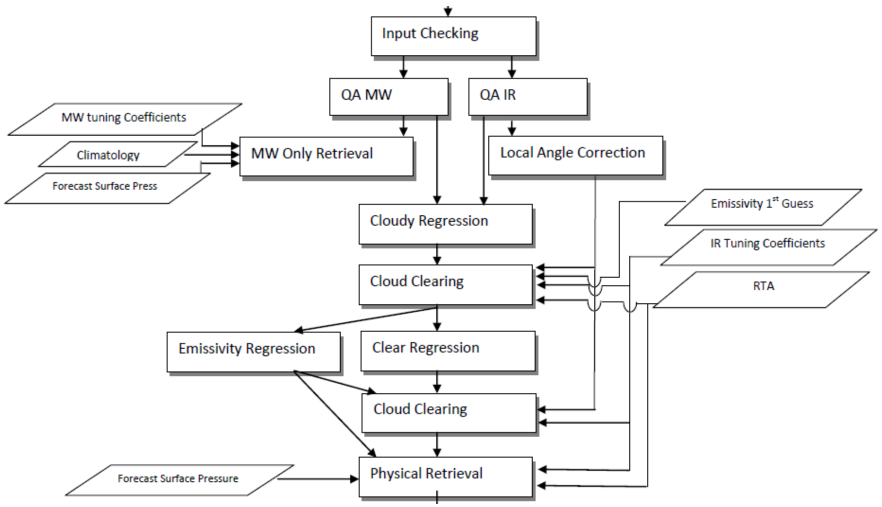
MTG IRS MAG
Brussels, 2018-11-08

NUCAPS:
<u>N</u>OAA <u>U</u>nique <u>C</u>ombined <u>A</u>tmospheric <u>P</u>rocessing <u>S</u>ystem



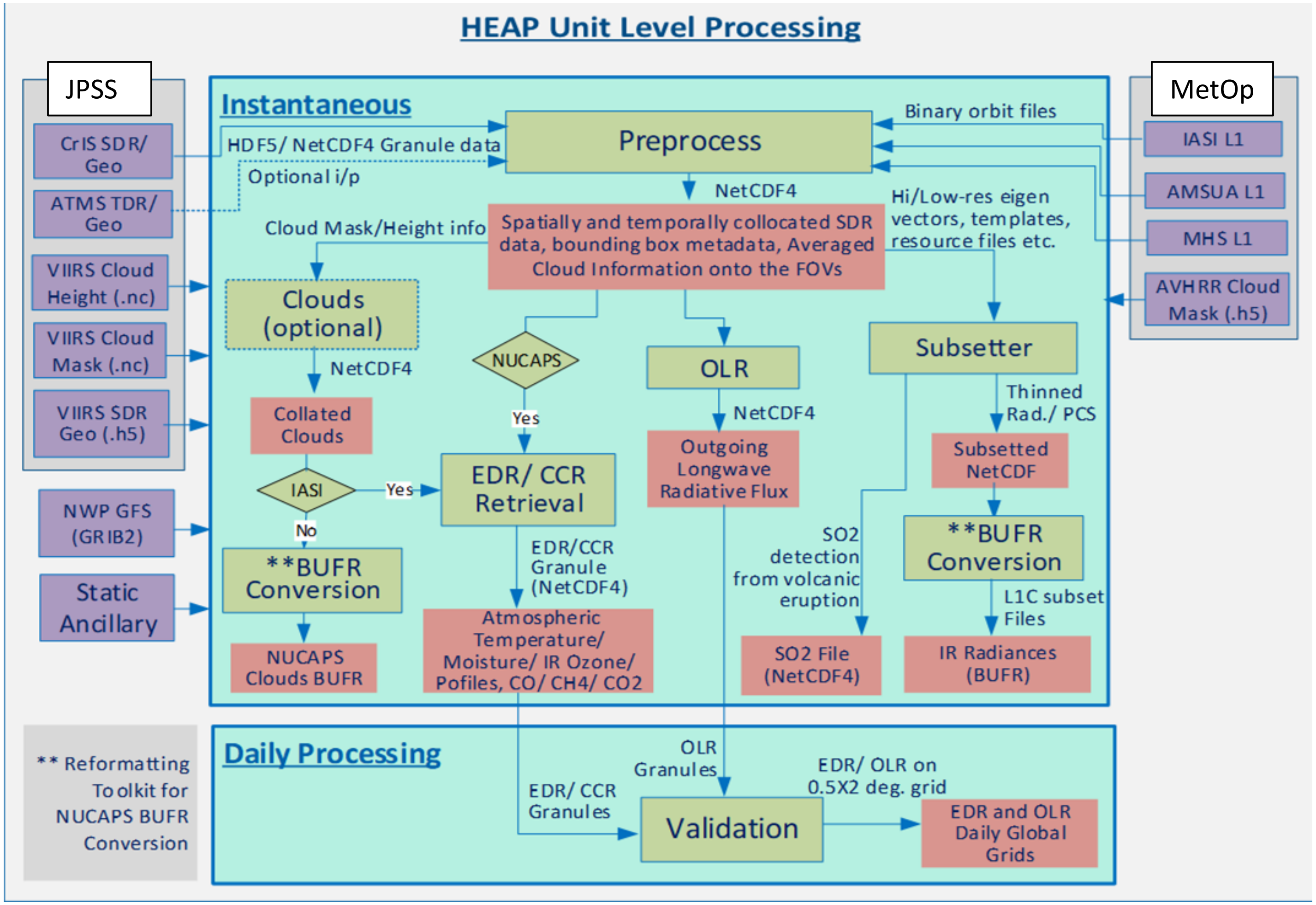
1.MW	Surface classification, temperature, water vapor (P. Rosenkranz, 2003)
2.CC	Cloud Clearing (M. Chahine, 1974, B. Smith, 1968)
3.FG	Statistical Regression of T, WV (M. Goldberg, 2003)
4.MW +IR	Sequential OE, Linearized, Weighted, Regularized Least Squared Minimization (Susskind et el., 2003)

Summary of current NUCAPS operational retrieval products

gas	Range (cm^{-1})	Precision	d.o.f.	Interfering Gases
T	650-800 2375-2395	1K/km	6-10	H2O,O3,N2O emissivity
H_2O	1200-1600	15%	4-6	CH4, HNO3, T(p)
O_3	1025-1050	10%	1+	H2O,emissivity
CO	2080-2200	15%	≈ 1	H2O,N2O
CH_4	1250-1370	1.5%	≈ 1	H2O,HNO3,N2O
CO_2	680-795 2375-2395	0.5%	≈ 1	H2O,O3 T(p)
Volcanic SO_2	1340-1380	50% ??	< 1	H2O,HNO3
HNO_3	860-920 1320-1330	50% ??	< 1	emissivity H2O,CH4,N2O
N_2O	1250-1315 2180-2250	5% ??	< 1	H2O H2O,CO

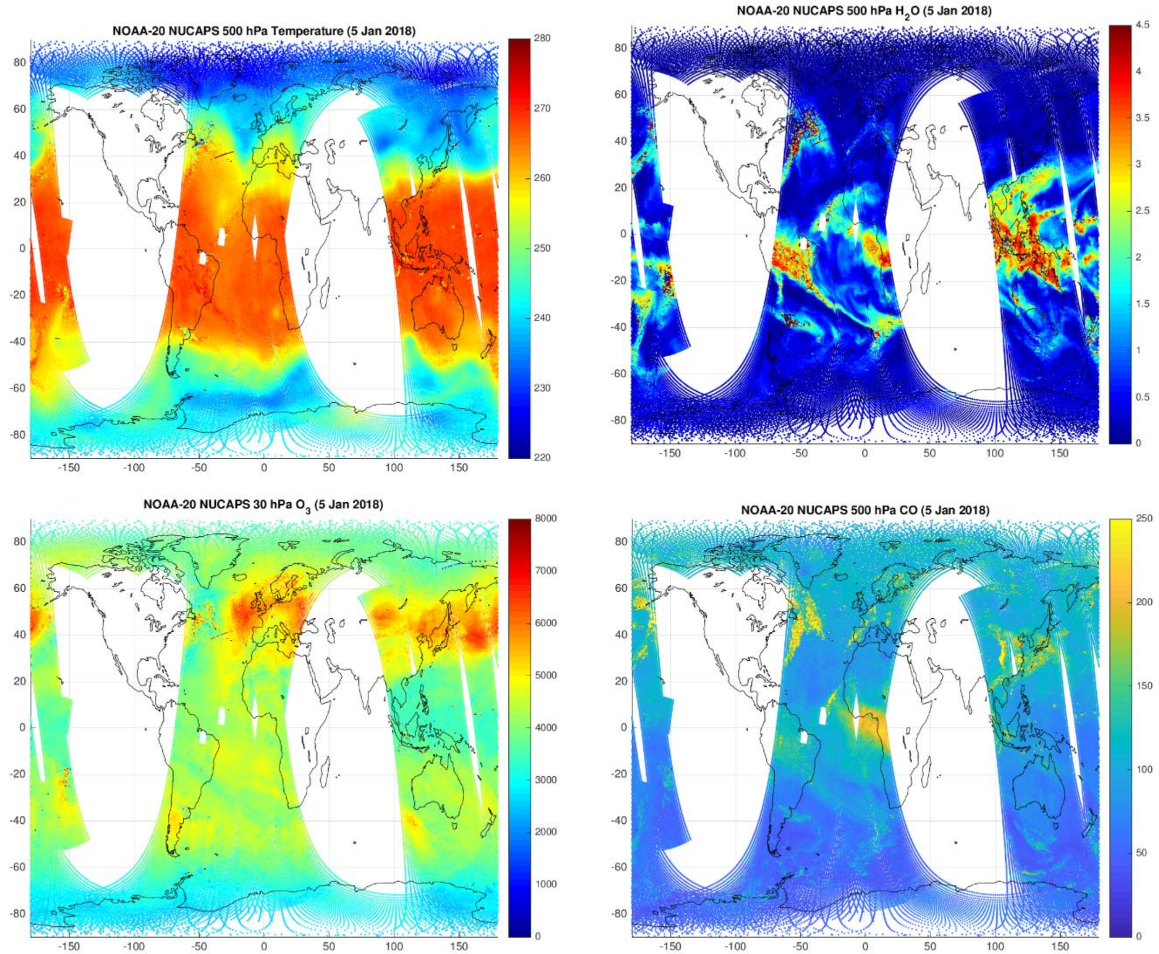
http://www.class.ngdc.noaa.gov
https://www.ospo.noaa.gov/Products/atmosphere/soundings/nucaps/
https://www.ospo.noaa.gov/Products/atmosphere/soundings/iasi/
https://www.star.nesdis.noaa.gov/jpss/mapper

April 4th, 2018:
NUCAPS is implemented in the Hyperspectral Enterprise Algorithm Package (HEAP): multiple instruments, one executable, one machine



January 5th, 2018: NUCAPS NOAA-20 First Light Results

CrIS signal processors and detectors powered up on **January 4th, 2018 at 23:47 UTC**.
First Light NUCAPS NOAA-20 results were generated on **January 5th, at 21:00 UTC**.



NUCAPS: NOAA's Long term Strategy for Hyper Spectral Sounding

Aqua (2002)

MetOp A (2006), B (2012), C (2018)

Suomi NPP (2011)

JPSS 1,2,3,4 (2017 - 2038)

EPS SG (2020, 2040)

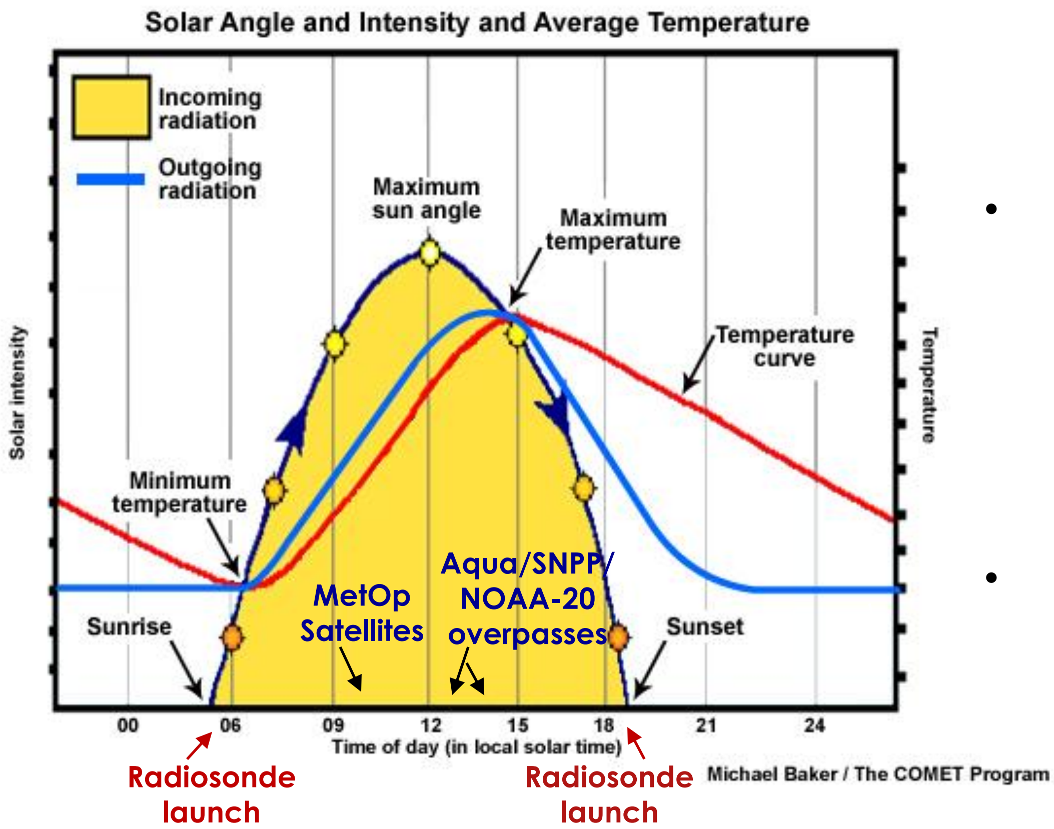
NUCAPS
NOAA **U**nique **C**ombined **A**tmospheric **P**rocessing **S**ystem

CCR, CLD	•National Center Environmental Prediction •Data Assimilation
ST, T, WV	•AWIPS II - https://www.unidata.ucar.edu/software/awips2/ •RealEarth - https://realearth.ssec.wisc.edu/
O3	•TOAST https://www.ospo.noaa.gov/Products/atmosphere/etoast/index.html
CO, CH4, CO2	•IDEA I: https://www.star.nesdis.noaa.gov/smcd/spb/aq/ •Data Assimilation
HNO3, N2O, SO2	•Research products
OLR	•http://www.cpc.ncep.noaa.gov/products/global_precip/html/wpage.cams_opi.html
… HN3	•Future development areas

Advanced Weather Interactive Processing System (AWIPS)

- The **Advanced Weather Interactive Processing System** (AWIPS) is a processing, display and telecommunication system hat is the cornerstone of the US National Weather Service's (NWS) operations.
- AWIPS is a complex network of systems that ingests and integrates meteorological, hydrological, satellite, model and radar data, and also processes and distributes the data to 135 Weather Forecast Offices (WFOs) and River Forecast Centers (RFCs) nationwide.
- Weather forecasters utilize the capabilities of AWIPS to make increasingly accurate weather, water, and climate predictions, and to dispense rapid, highly reliable warnings and advisories.

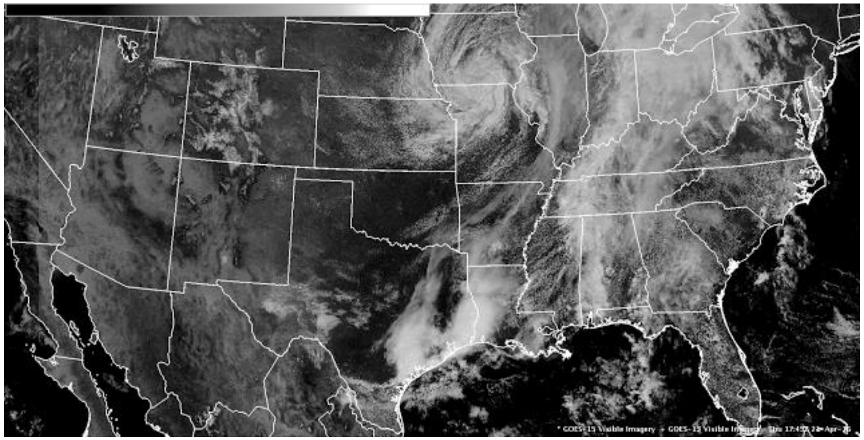
The importance of satellite soundings in regional weather forecasting



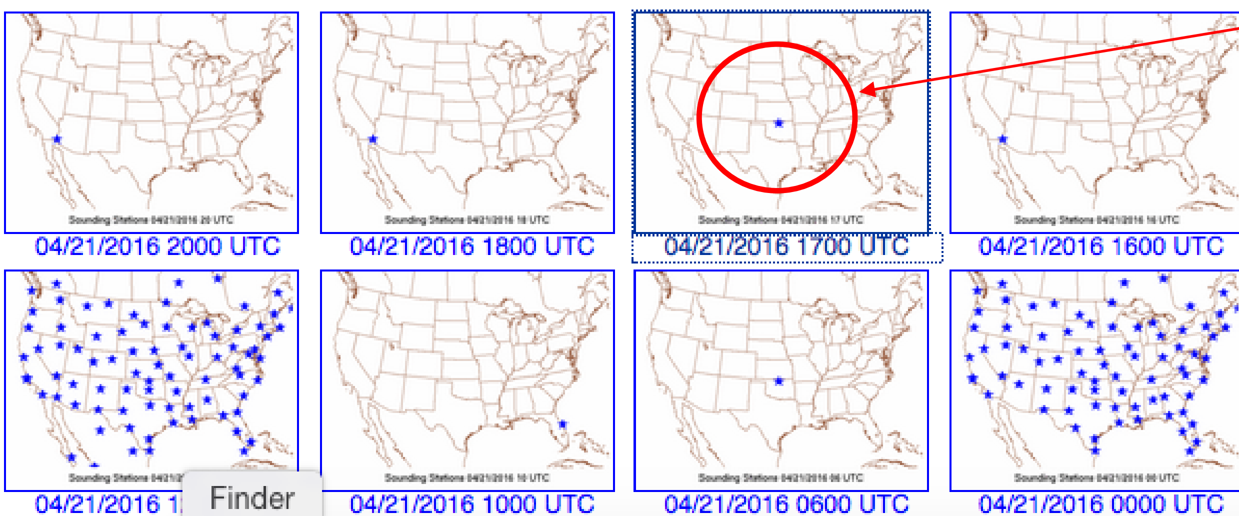
- There is a lack of upper air observations between 6 am (12 UTC) and 6 pm (00 UTC) in the continental United States.
- Satellite soundings can be very important in forecasting for capturing the vertical profile of the atmosphere during daytime heating in between operational radiosonde launches, occurring at 6 am and 6pm central time.
- The combined use of mid-morning (MetOp) and mid-afternoon (JPSS) soundings can prove key in helping forecasting severe convective weather.

NUCAPS vs. Observed (RAOB) and Forecast (RAP Model) Soundings

http://goesrhwt.blogspot.com/2016/04/on-large-scale-thursday-afternoon.html

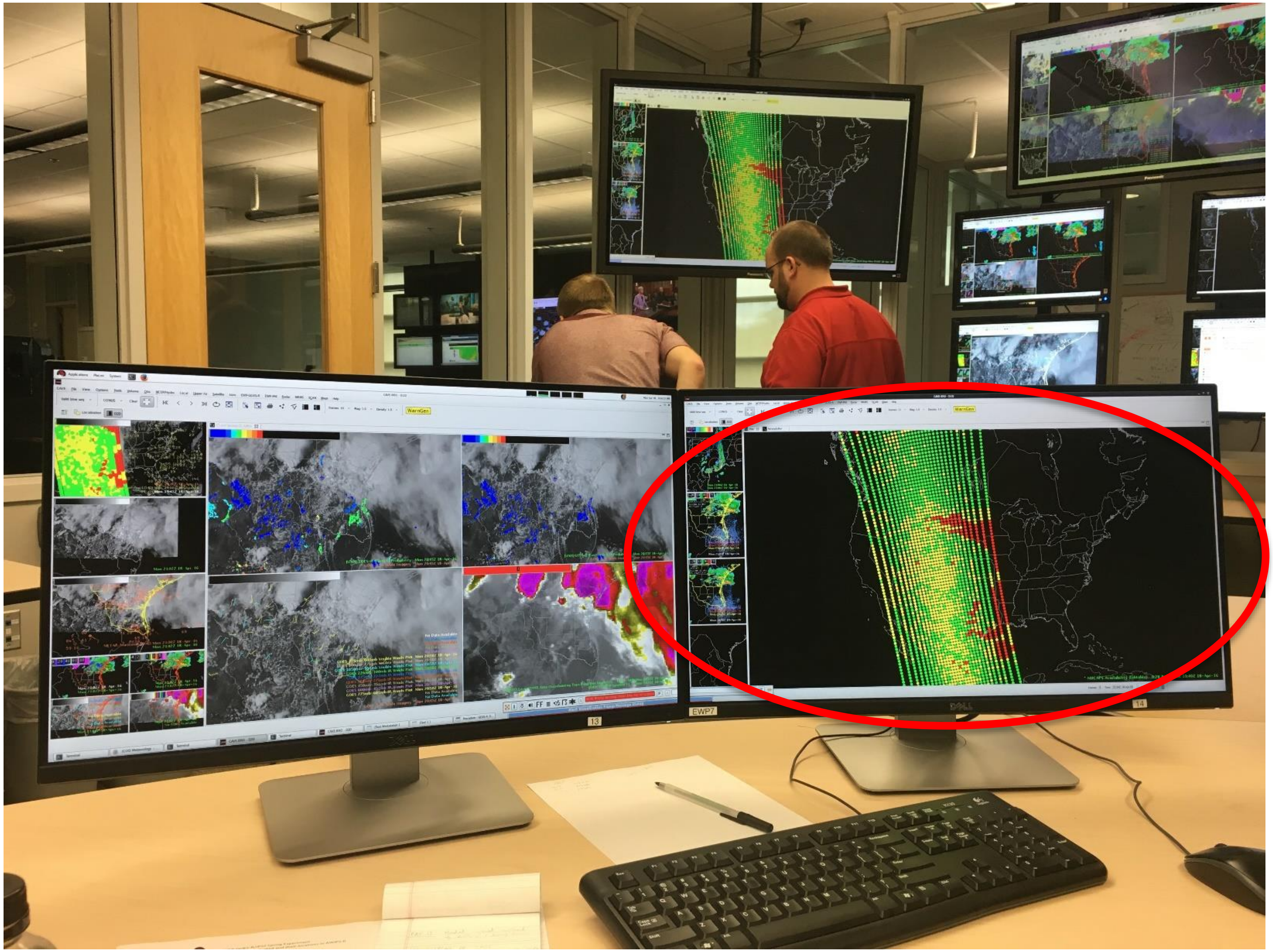


Today - Thursday April 21, 2016



- **Top**: GOES 13 and 15 imagery
- **Bottom**: a snapshot from the Storm Prediction Center Sounding Analysis Page
- At 19Z on Thursday April 21st , a strong upper low pressure system was moving through the upper Mississippi Valley.
- The only RAOB lunched over the central US in the afternoon (17Z) was from the ARM SGP site, Lamont, OK, 37N, 98W.
- NUCAPS soundings from 19Z were the only observations to complement the RAOB sounding and the RAP model.

NUCAPS 19Z acquisition in AWIPS



MW+IR accepted
MW-only accepted
Both rejected

NUCAPS vs. Observed (RAOB) and Forecast (RAP Model) Soundings

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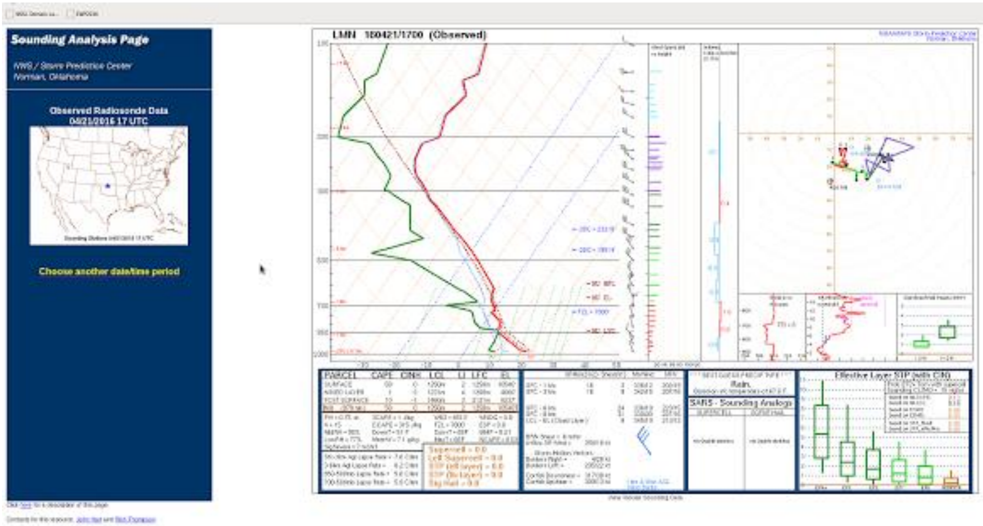

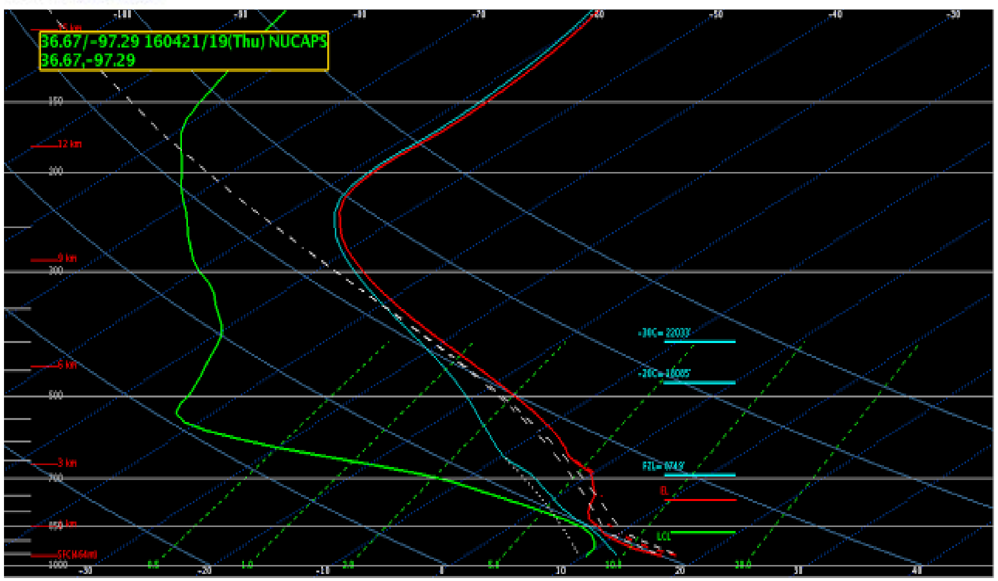

- **Top**: ARM SGP RAOB at 17Z
- **Bottom**: NUCAPS closest accepted at 19Z

- At first glance RAOB and NUCAPS did not agree in the mid level dew point temperature. NUCAPS was showing a dryer layer than the RAOB.

- The feature seemed persistent across a radius of 50km.

- Temporal (17z vs 19z) mismatch seemed to play a role.

- We started looking at additional guidance. Next slide.

NUCAPS vs. Observed (RAOB) and Forecast (RAP Model) Soundings

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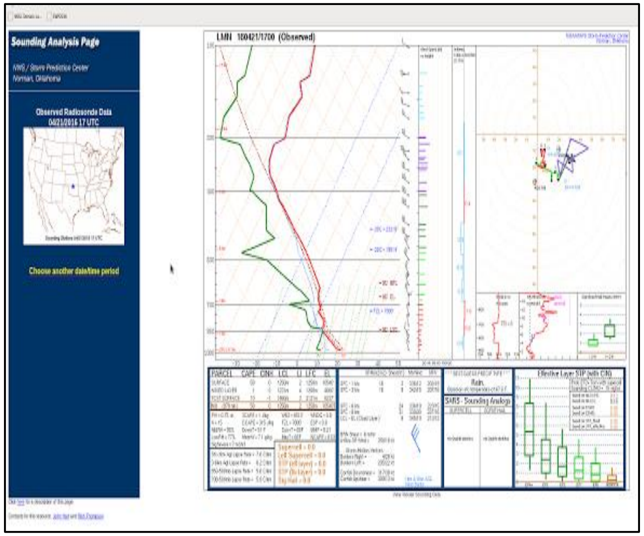
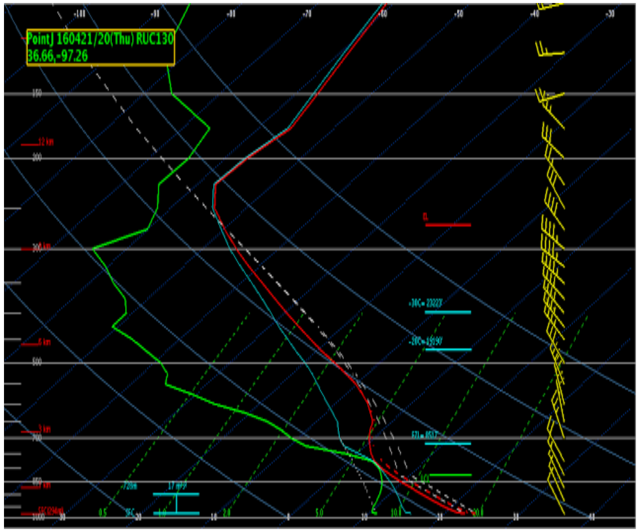
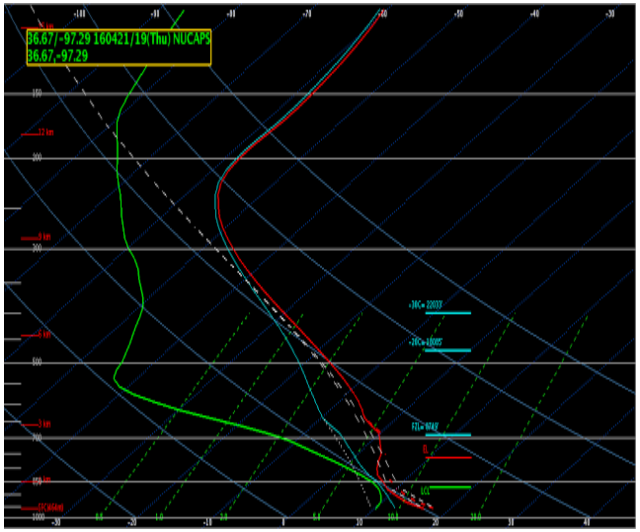
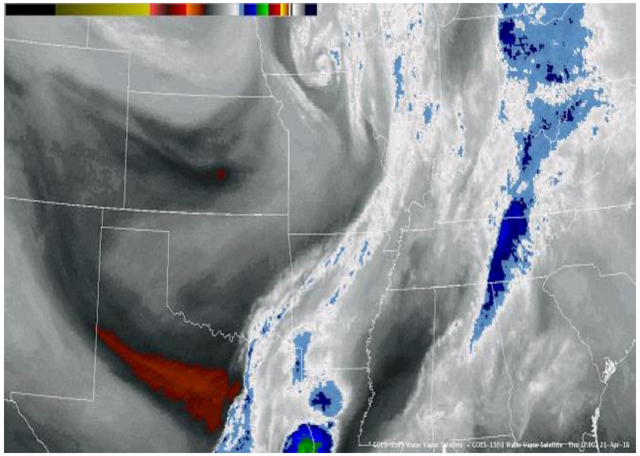








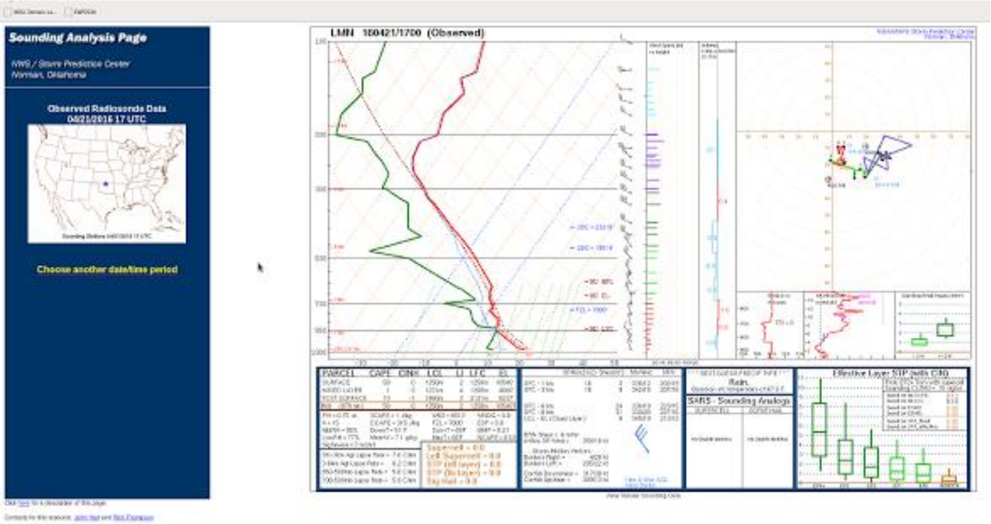
- **Top Left**: ARM SGP RAOB at 17Z
- **Bottom Left** : NUCAPS closest accepted at 19Z
- **Top Right**: RAP model at 20z
- **Bottom Right**: GOES 13 & 15 water vapor plan view from 17z to 20z.

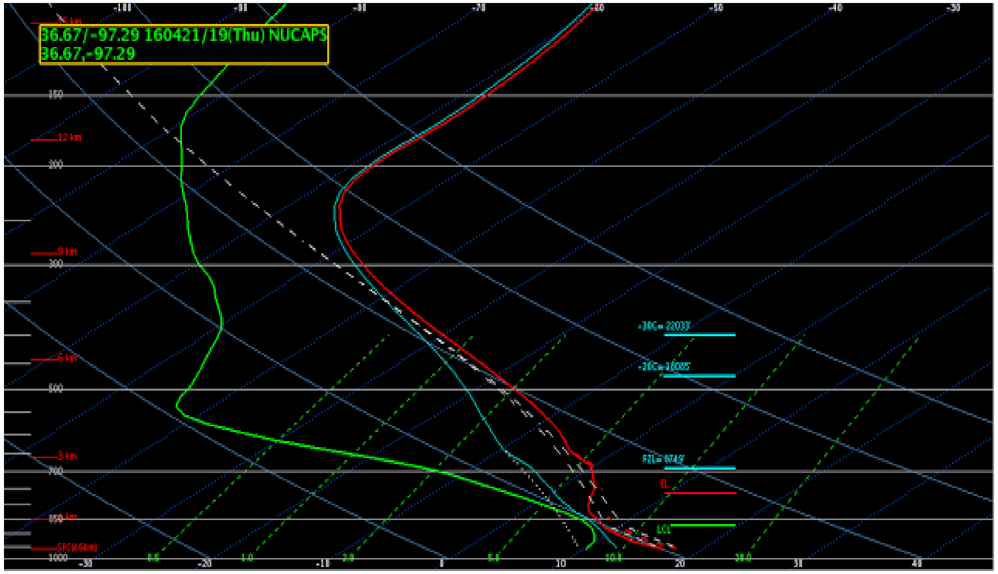
- GOES water vapor imagery showed an influx of dry air sinking south across the Central Plains through the early afternoon hours.

- This explained the drier feature captured by NUCAPS at 19Z and also confirmed by the RAP model at 20Z.

NUCAPS vs. Observed (RAOB) and Forecast (RAP Model) Soundings

http://goesrhwt.blogspot.com/2016/04/on-large-scale-thursday-afternoon.html



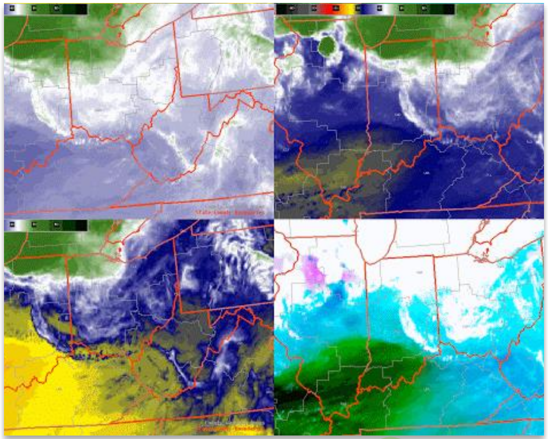


- **Top**: ARM SGP RAOB at 17Z
- **Bottom**: NUCAPS closest accepted at 19Z

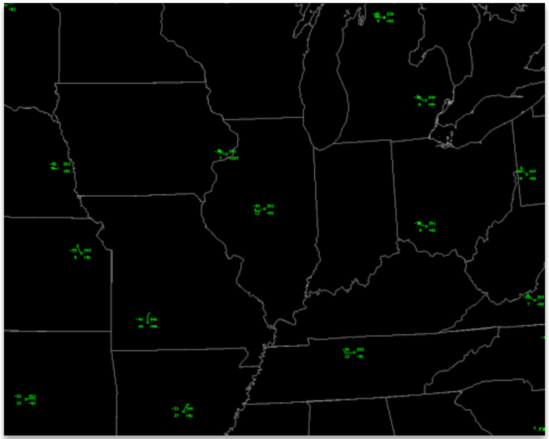
- The NUCAPS sounding also accurately sensed an increase in moisture near the 850 hPa level which per the visible satellite image above, was very likely the flat fair CU field seen on visible satellite imagery above.

- **Recommendation on quality control:** *"I think the best area to target for QC would be the 850-500 hPa layer as this is the area where capping inversions are commonplace. Knowledge on the strength of a capping inversion is crucial in the severe weather forecasting environment and NUCAPS soundings can provide added value in the near-term convective forecasting environment."*

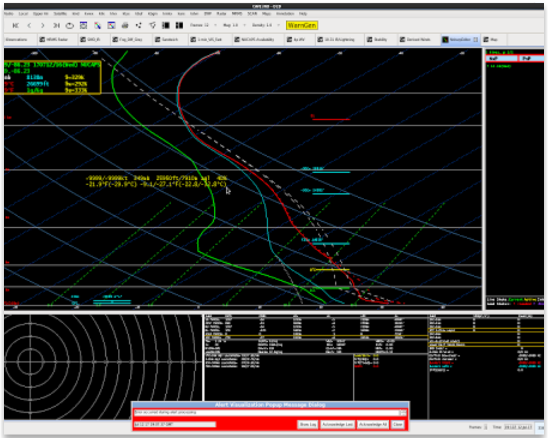
The usefulness of MetOp soundings



GOES-16 12Z water vapor bands over Indiana at 12Z



No RAOB sounding as of 12Z

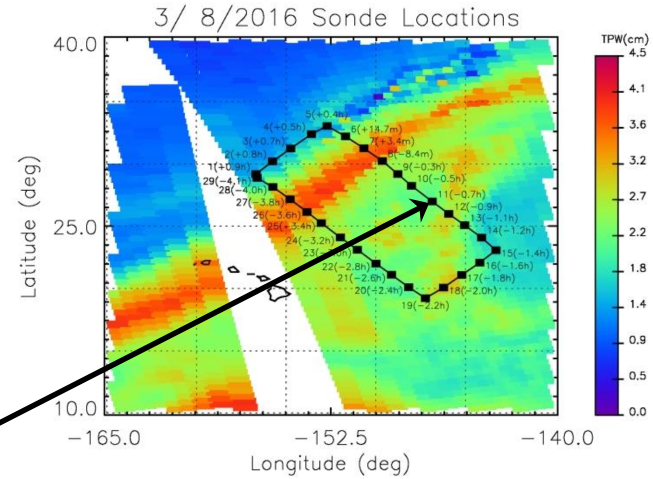


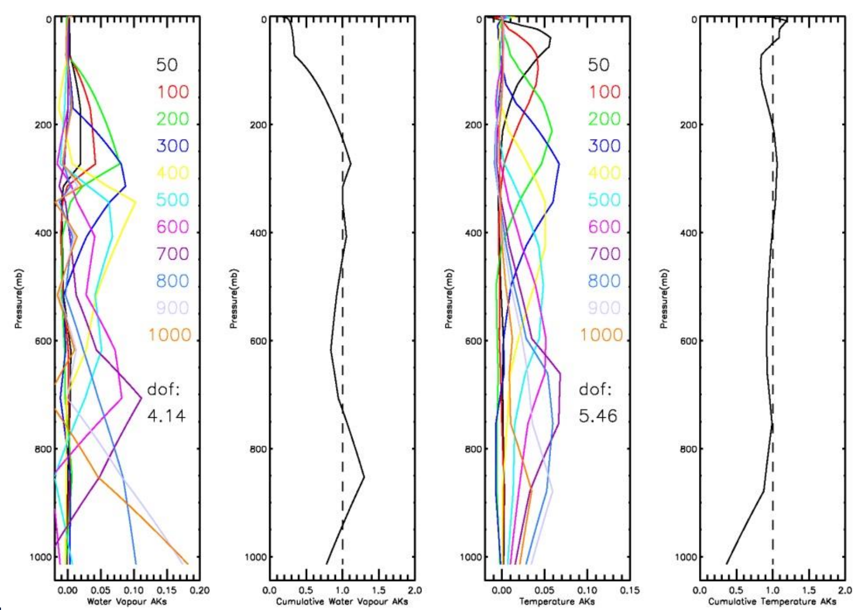
1623Z MetOp A overpass close to Indianapolis

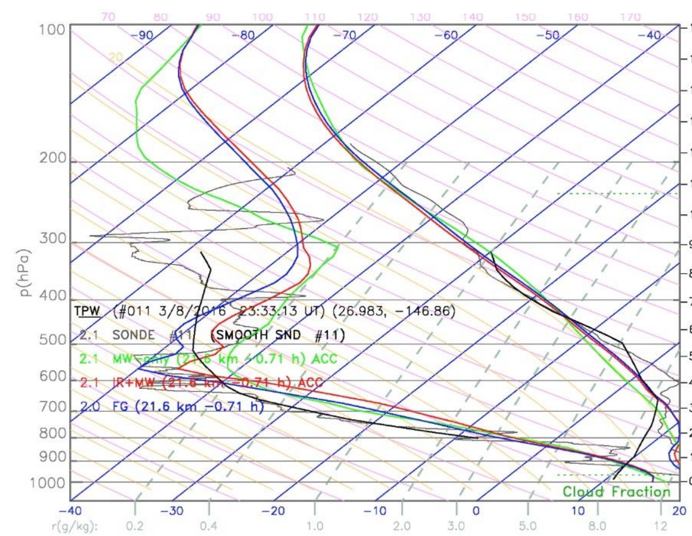
- "Taking a look at the MetOp A sounding pass at 1623Z near Indianapolis showed some usefulness in showing the destabilization occurring south of the warm front in central Indiana. The surface temperature was in line with the expected temperature at that time and the surface moisture was just a few degrees too dry on the dewpoint. Otherwise, it came fairly close to surface conditions. Also, seemed to capture the dry mid/upper levels fairly well as indicated by the 6.19, 6.95, and 7.34um water vapor channels."
- "This sounding pass came in a pre-convective environment and I found the timing to be more beneficial with the pass around midday. This allowed to see the freezing level height and equilibrium level. **With no sounding available in central Indiana in this area, the data came to be useful."**
- "**Overall, I could actually see some usefulness in this earlier day pass from the MetopA.**"
- ISU 2004, Wednesday July 12, 2017.
- http://goesrhwt.blogspot.com/2017/07/taking-look-at-metop-sounding-pass-at.html

El Nino Rapid Response Campaign Mar. 8, 2016

- Relatively cloud-free with upper level dry layer and moist BL
- AK's have near surface sensitivity
- Retrieval captures the dry layer aloft and marine T(p) inversion

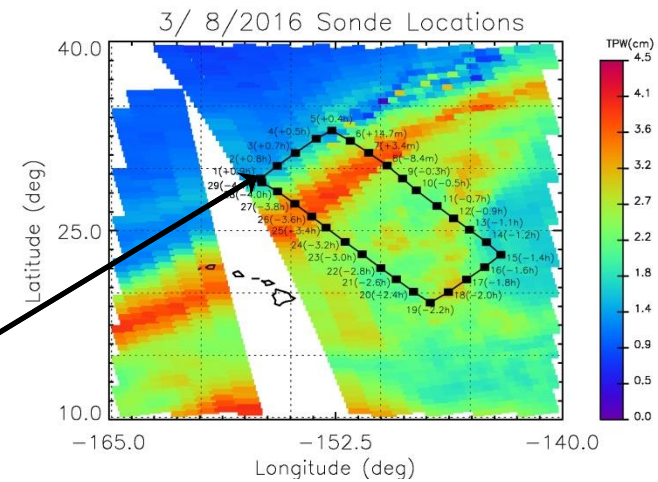


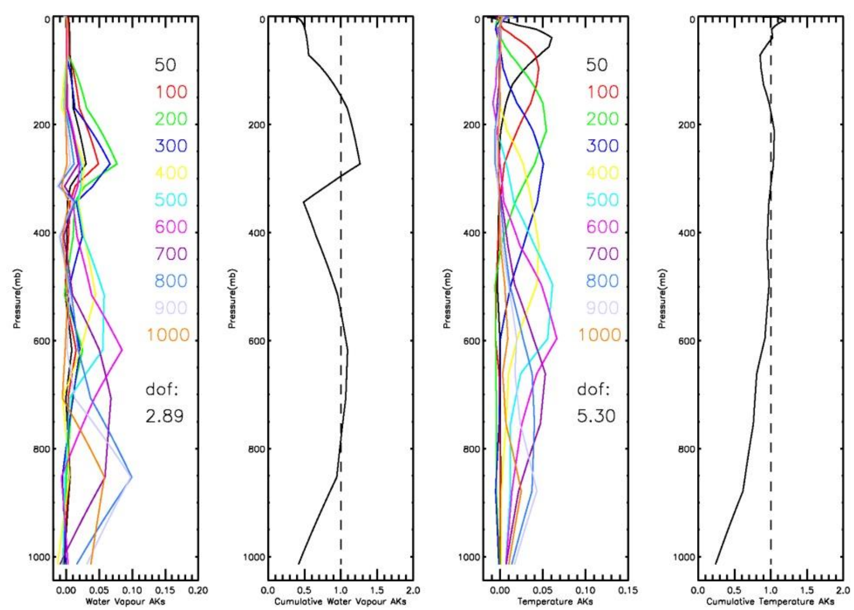


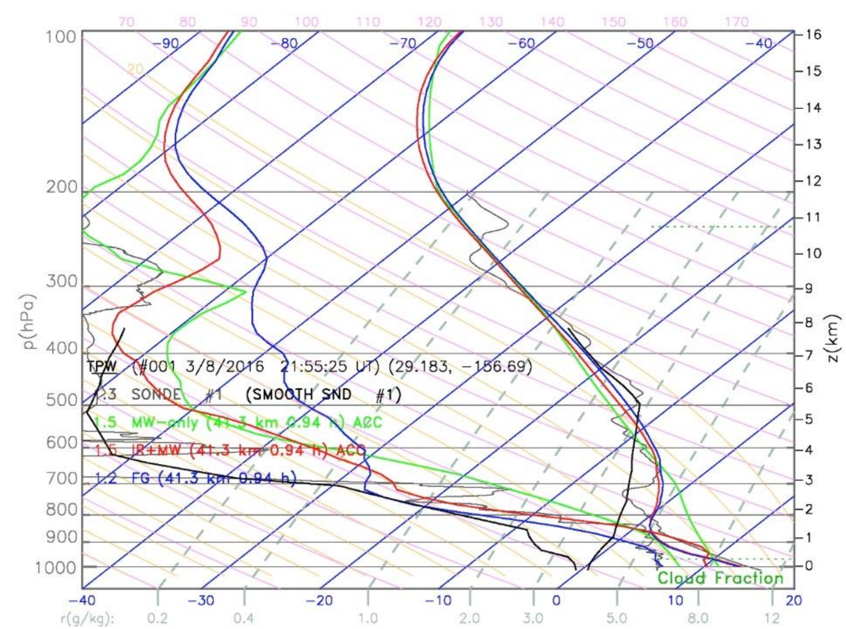


El Nino Rapid Response Campaign Mar. 8, 2016

- Relatively cool and dry, cloud free with upper level dry layer
- AK's have near surface sensitivity
- First guess q(p) too moist, but the physical recovers well where we have skill (300-500 mb) but overshoots near surface for T & T_{dew}

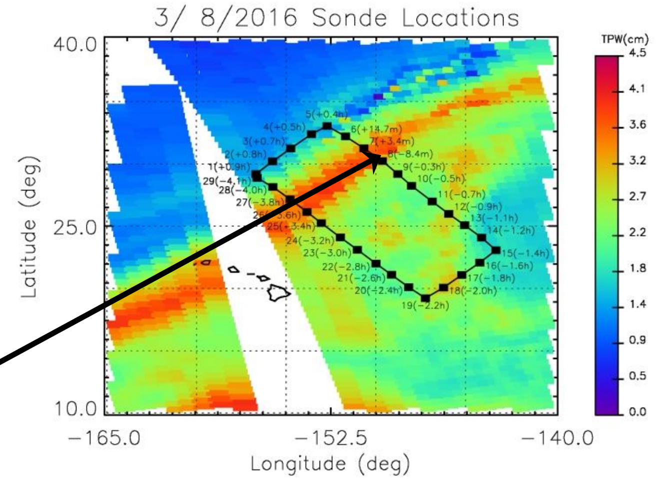


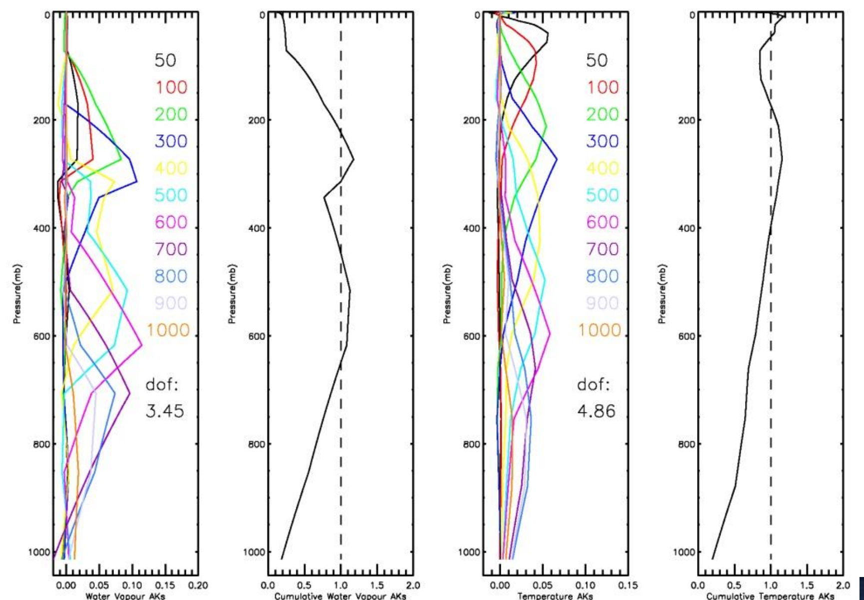


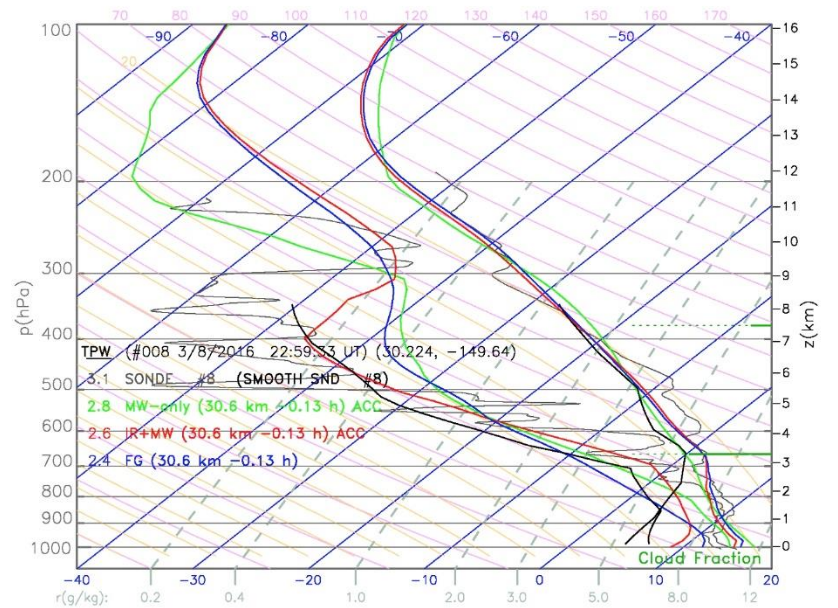


El Nino Rapid Response Campaign Mar. 8, 2016

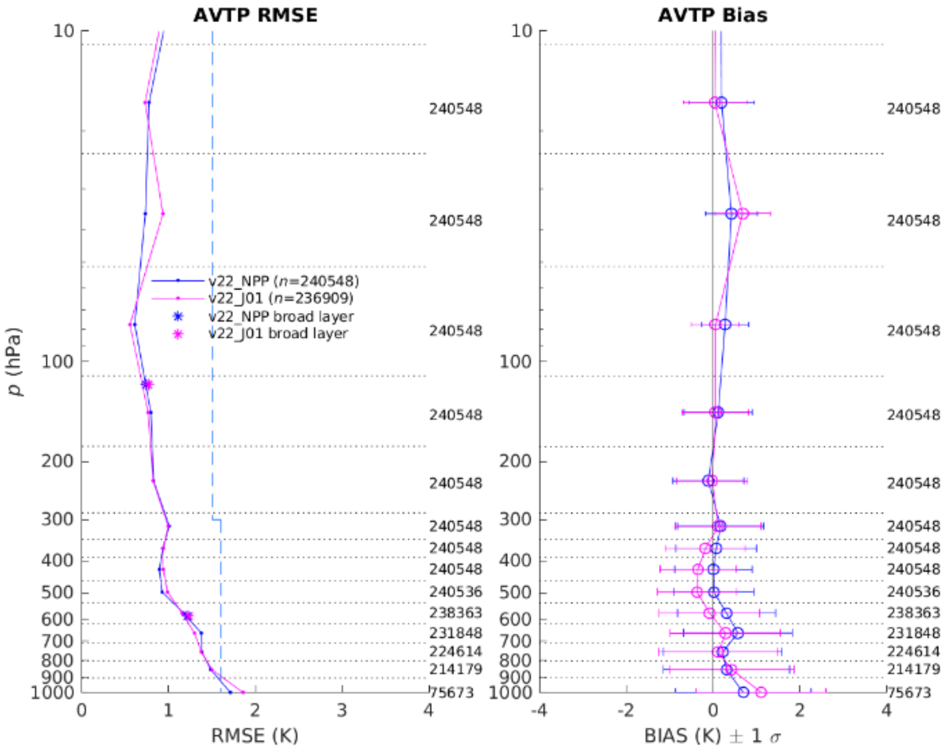
- Very moist with both upper level (~15%) and lower level clouds (~60%)
- AK's do not show lower troposphere sensitivity
- Physical retrieval recovers well from a too moist first guess at ~400mb.







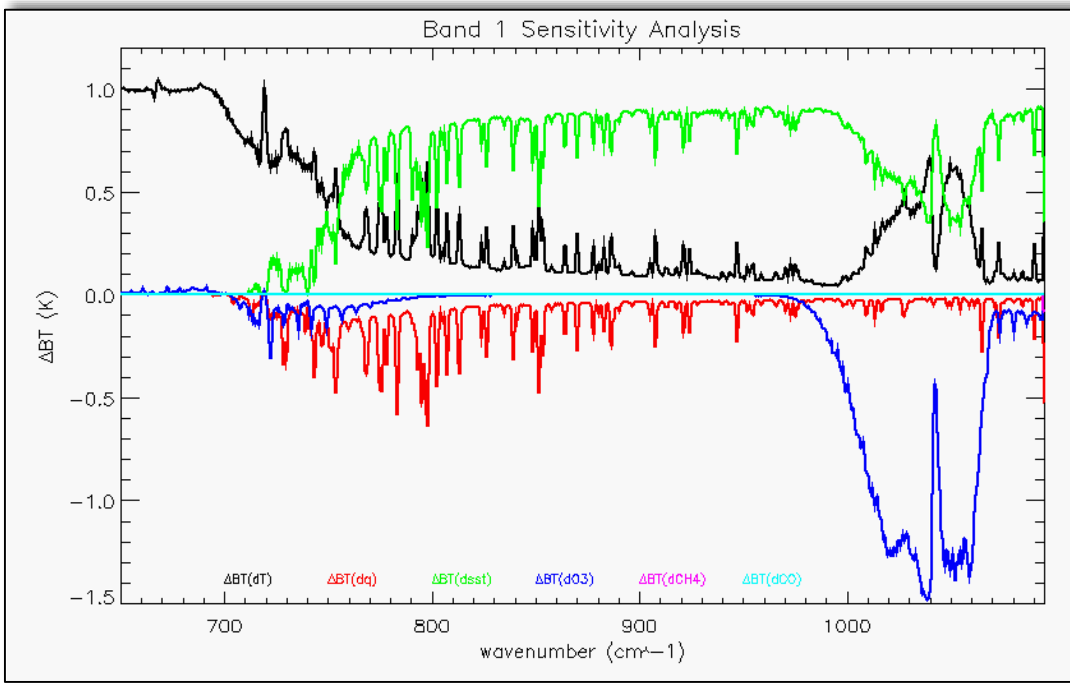
How do we improve the retrieval skill in the BL?



- **Blue:** NUCAPS SNPP operational
  - **Magenta:** NUCAPS N-20

- Due to spectral opacity, especially in presence of clouds, IR satellite radiance measurements typically lack in information content associated to the boundary layer. This aspect contributes to the ill-posed nature of satellite remote sensing.
- Finding an accurate and stable geophysical constraint to anchor the solution can be problematic, particularly over land, where surface emissivity is highly variable.
- As a result, the validation of the retrieved atmospheric profiles along the vertical pressure column, shows an increased uncertainty and bias in the boundary layer.
- **Question**: how do we improve the retrieval skill in the BL?

Once upon a time a Linearized Square fit



SST	1K
T	1K
H2O	10%
O3	10%
CH4	2%
CO	1%

$$\Delta R_n = K^i_{n,L}\,\Delta X^i_{n,L} + \varepsilon_n$$

$$\varepsilon_n = NEDT_n + dR_{CCR} + dRTA_n + \sum_{j \neq i} K^j dX^j$$

$$X_L = X^a_L + \left[K^T_{L,n} \cdot S^{-1}_{\epsilon\, n,n} \cdot K_{n,L} + S^{-1}_{a\, L,L}\right]^{-1} \cdot K^T_{L,n} \cdot S^{-1}_{\epsilon\, n,n} \cdot \left(R_n - K_{n,L} \cdot X^a_L\right) \pm dX$$

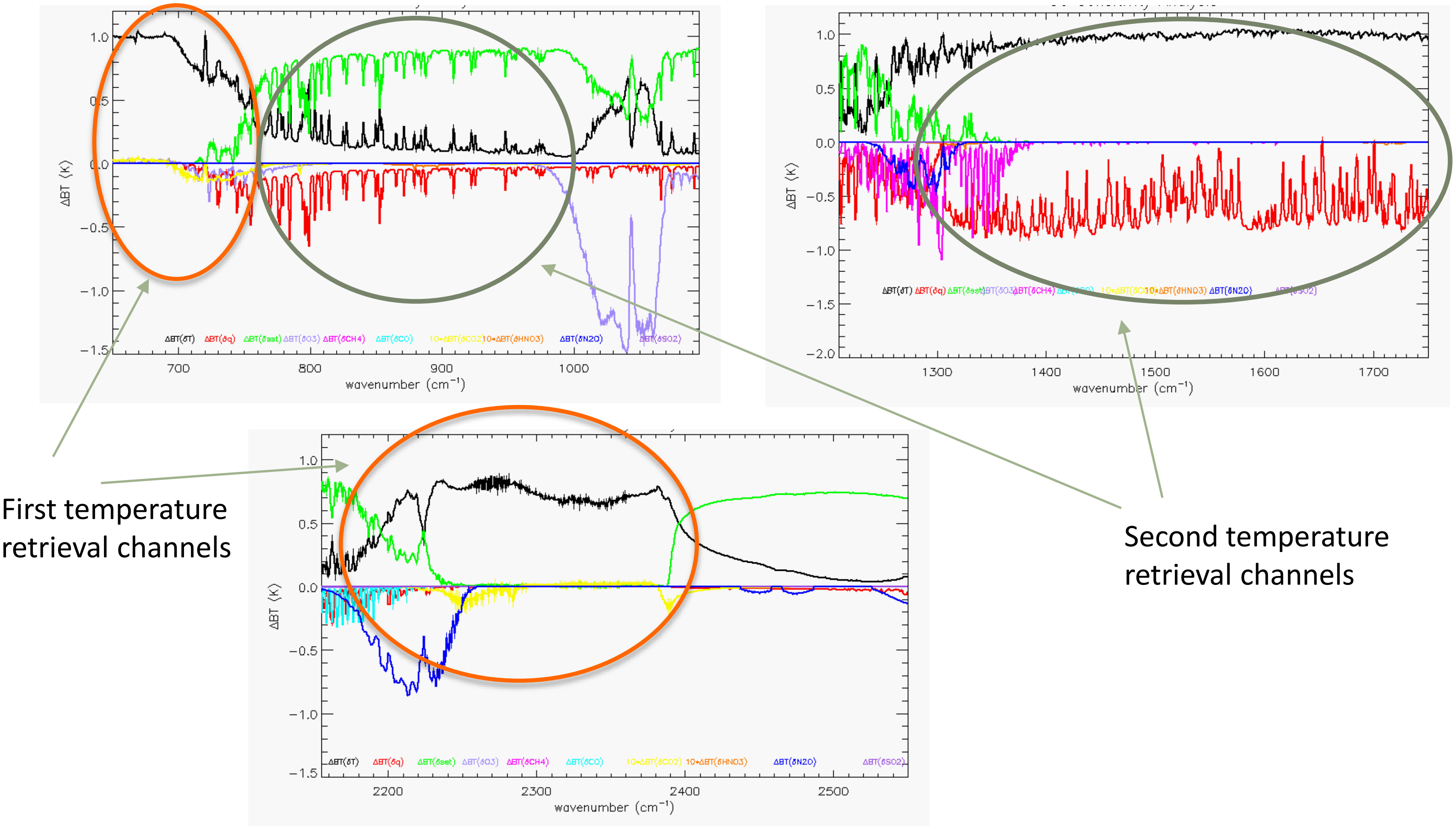
How do we improve linearization?
How do we maximize the use of information content?

Simultaneous (1) vs sequential (2) solutions

- (1) Retrieval algorithms attempting to simultaneously solve for multiple unknown variables are generally called *simultaneous retrieval algorithms*.
  - Computationally expensive: solves for multi-dimensional (generally hundred layers), multi-variables (clouds, temperature, constituents) retrieval solutions; using a large number of channels (hundreds to thousands); performing repeated iterations.
  - Frequent simplification taken: reduced retrieval vector state; diagonalization of the sensitivity matrix
  - Problems: Strong dependence on the geophysical a priori term. Need for an accurate global multi species a priori and error covariance (must be Gaussian). Risk to over-constrain the solution.

- (2) Each step aims at solving for one individual species at the time, *sequentially*, while assuming that all other active species stay constant.
  - The error resulting from this assumption is computed from spectral sensitivity analysis and formally factored in the retrieval equation in the form of a measurement error.
  - Computationally efficient: The dimension of the problem is lowered to the dimension of the individual retrieval steps.
  - It removes the need for a finely tailored geophysical a priori
  - A three step strategy for boundary layer remote sensing:
    - a) First retrieve temperature while keeping water vapor constant, use water vapor interference as a noise source;
    - b) then retrieve water vapor while keeping temperature constant, using temperature interference as a noise source;
    - c) add water vapor channels to the temperature channel list and re-retrieve temperature while keeping water vapor constant and use water vapor interference as a noise source;

Spectral sensitivity in the IR domain



A. Gambacorta & C. Barnet, Methodology and Information Content of the NOAA NESDIS Operational Channel Selection for the Cross-Track Infrared Sounder (CrIS), IEEE TRANSACTIONS ON GEOSCIENCE AND REMOTE SENSING, VOL. 51, NO. 6, JUNE 2013

What makes a good geophysical a priori?

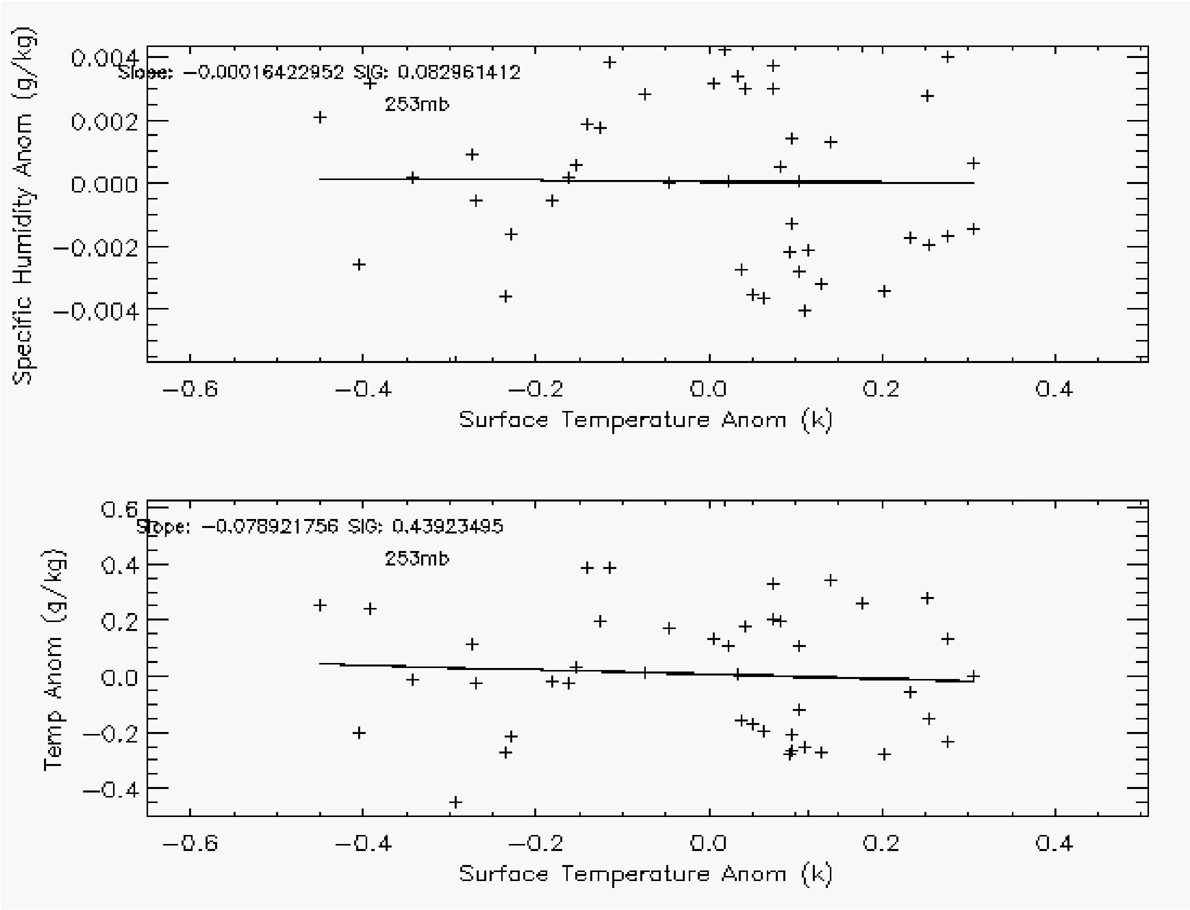
- To describe the variance and co-variance of the *full* geophysical state (T, SST, q, trace gases), you need a regional and highly tailored a priori.

- As the a priori becomes more specific (both in time and space), the a priori covariance and variance terms start to decrease.

- This inherently corresponds to an increase in the relative weight of the a priori and a tendency in the solution to **preserve the a priori shape**, while decreasing the weight of the measurement.

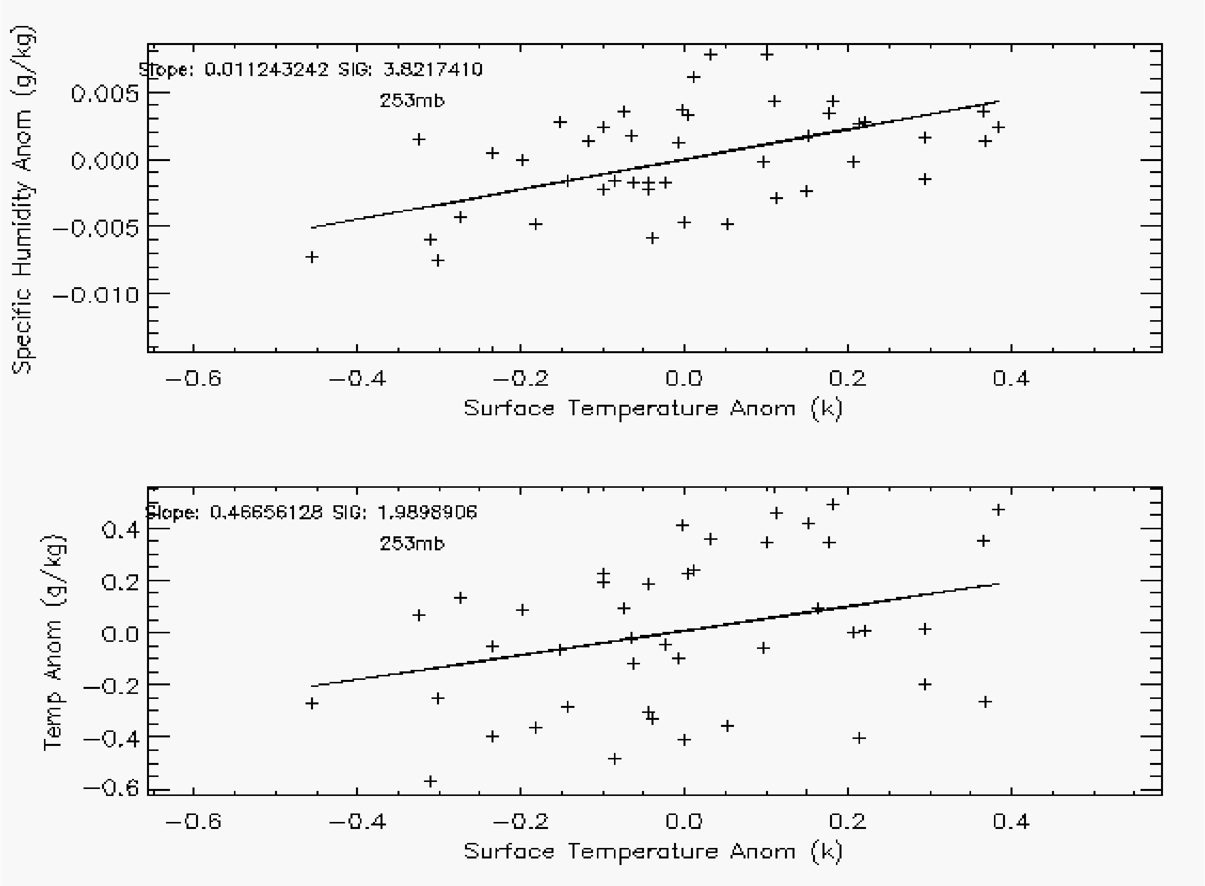
- Also, constraining the solution to a finely structured a priori, (vertically, spatially and temporally) may **introduce discontinuities and sub-resolved structures** in regions of the retrieval solution where the measurement has no information content.

The non linear nature of *nature* and its impact on the geophysical a priori term



Scatter plots of monthly mean anomalies averaged over **[-30, 30]** degree latitude

The non linear nature of *nature* and its impact on the geophysical a priori term



Scatter plots of monthly mean anomalies averaged over **[-5, 5]** degree latitude

The *a priori* dilemma

NUCAPS

	Mw-only	Climatology	Stat Methods	Re-analysis & forecast
Spatial Structure	significant	minimal	Significant	significant
Weather of today	YES	NO	YES	YES
Vertical structure	NO	NO	YES	YES
Speed of convergence	Fast (if accurate)	Slow	Fast (if accurate)	Fast (if accurate)
Error Estimate	YES	YES	NO	YES
Data Independence	YES	YES	YES	NO

- The choice is user-dependent (weather vs climate)
- There are some applications for which model independence is more important, and other applications where the "best answer now" is more important.

A NUCAPS success story: the need for model independence

NUCAPS

RAP MODEL

Real Inversion?

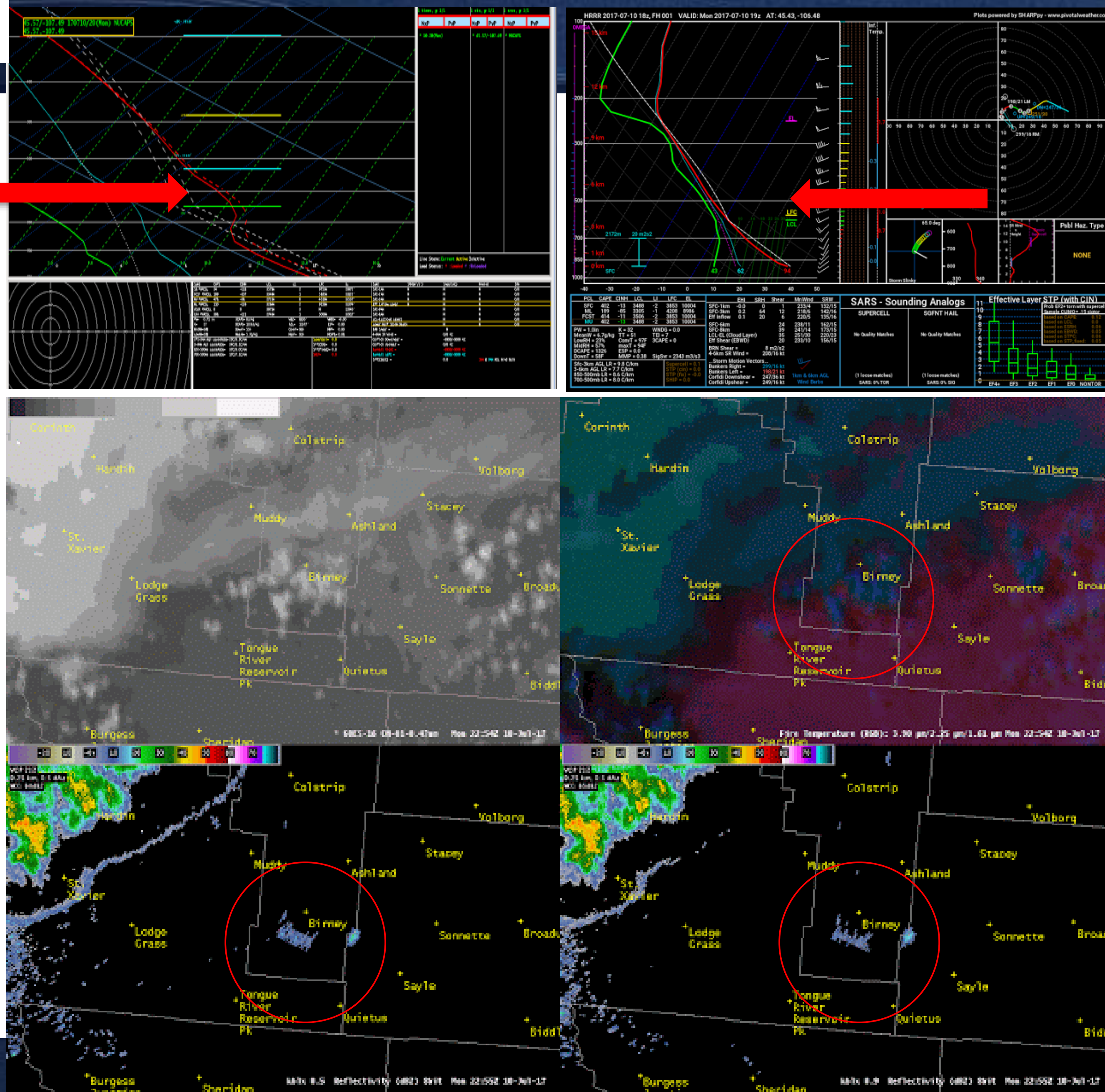
No inversion

GOES 16 Imagery

Fire Temperature (RGB)

Radar Reflectivity

Radar Reflectivity



Coming next

- We'll assess the retrieval inter-consistency of the SNPP, NOAA-20 and MetOp NUCAPS products.
- Future algorithm developments intended to improve BL retrieval products;
    - Ocean and land surface emissivity retrieval
    - Improve quality control of cloud clearing towards improved stability in the product
    - Improve the constraint to avoid unrealistic supersaturation cases in the BL.
- NUCAPS NOAA-20 temperature and water vapor scheduled to become fully operational in Spring 2019.
- NUCAPS MetOp C scheduled to become operational in September 2019.
- NUCAPS "Enterprise" algorithm will run all systems (Spring 2019).