2017 JPSS Annual Meeting
NUCAPS Session Opening Remarks

Chairs:

Antonia Gambacorta, Nick Nalli, Tony Reale

Topics of this session

Part I: Focus on the latest upgrades of the NOAA Unique Combined Atmospheric Processing System (NUCAPS)
Co-chair: N. Nalli

ATMS block 2 upgrades

1. MIT Rapid Transmittance Algorithm (RTA)
2. ATMS block 2 RTA bias tuning
3. ATMS block 2 RTA standard deviation error

CrIS Full Spectral Resolution (FSR) upgrades

1. CrIS FSR SARTA Rapid Transmittance Algorithm (RTA) (Larrabee Strow's talk Thu. h10:10 – 10:30)
2. CrIS FSR RTA bias tuning
3. CrIS FSR RTA standard deviation error
4. CrIS FSR NEDT file
5. CrIS FSR channel selection
6. CrIS FSR regression LUTs:
    a. Eigenvector file
    b. All sky regression coefficient file
    c. Cloud cleared radiance regression file

Topics of this session

Part II: A detailed validation assessment to prove that performance requirements are met

Co-chairs: Nick Nalli, T. Reale

- Global focus days
- Dedicated in situ measurements
- NPROVS routine in situ measurements
- Today’s focus is on temperature and water vapor
- Tomorrow’s focus is on atmospheric gases
- New results from single FOV retrieval experiments

Topics of this session

Part III: JPSS Proving Ground and Risk Reduction initiatives

Co-chair: A. Gambacorta

Goal: to demonstrate NUCAPS capabilities under weather regimes of societal value and develop real time users applications

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

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

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) (To be discussed tomorrow, in the trace gas session)

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

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

Antonia Gambacorta [(1)], Nick Nalli [(2)], Flavio Iturbide-Sanchez[(2)], Changyi Tan[(2)], Kexin Zhang[(2)], Xiaozhen Xiong[(2)], Bomin Sun[(2)], Mike Wilson[(2)], Tish Suillard[(2)], Tom King[(2)]

With contributions from:
Chris Barnet[(1)], Tony Reale[(3)], Mark Liu[(3)], Larrabee Strow[(4)], Lihang Zhou[(3)], AK Sharma[(3)], Walter Wolf[(3)], Mitch Goldberg[(5)]

2017 JPSS Annual Meeting – NUCAPS Session

[1]STC; [2] IMSG; [3] NOAA/NESDIS/STAR; [4]UMBC; [5]NOAA JPSS

Outline of this talk

- I. Introduction on the NUCAPS system
- II. Overview of the NUCAPS Full Spectral Resolution (FSR) upgrades
- III. Current activities and future directions

N as in NUCAPS

NOAA	NOAA's mandate: ensuring highest computational efficiency and state of art inversion methods to maximize utilization of large volumes of data for a weather ready nation
Unique	A mathematically sound, globally applicable (land/ocean, day/night, all season, all sky, TOA-surface) hyperspectral retrieval code
Combined	… that can fully exploit all available satellite assets: infrared, microwave, visible
Atmospheric	… 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: HN3)
Processing	… by the use of a modular design compatible with multiple platforms: Aqua, MetOp, SNPP, JPSS, EPS-SG
System	NUCAPS has been running operationally at NOAA since 2004. it is now in AWIPS II. It has been installed in CSPP DB.

Nominal vs Full Spectral Resolution CrIS

- **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}

- **Experimental since 2013 – 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

Overview of NUCAPS Phase 4 CrIS FSR and ATMS block 2 LUT updates

ATMS block 2 upgrades

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CrIS Full Spectral Resolution (FSR) upgrades

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Changyi Tan's poster (Tue. 5-7:30pm)

4. CrIS FSR NEDT file
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   a. Eigenvector file
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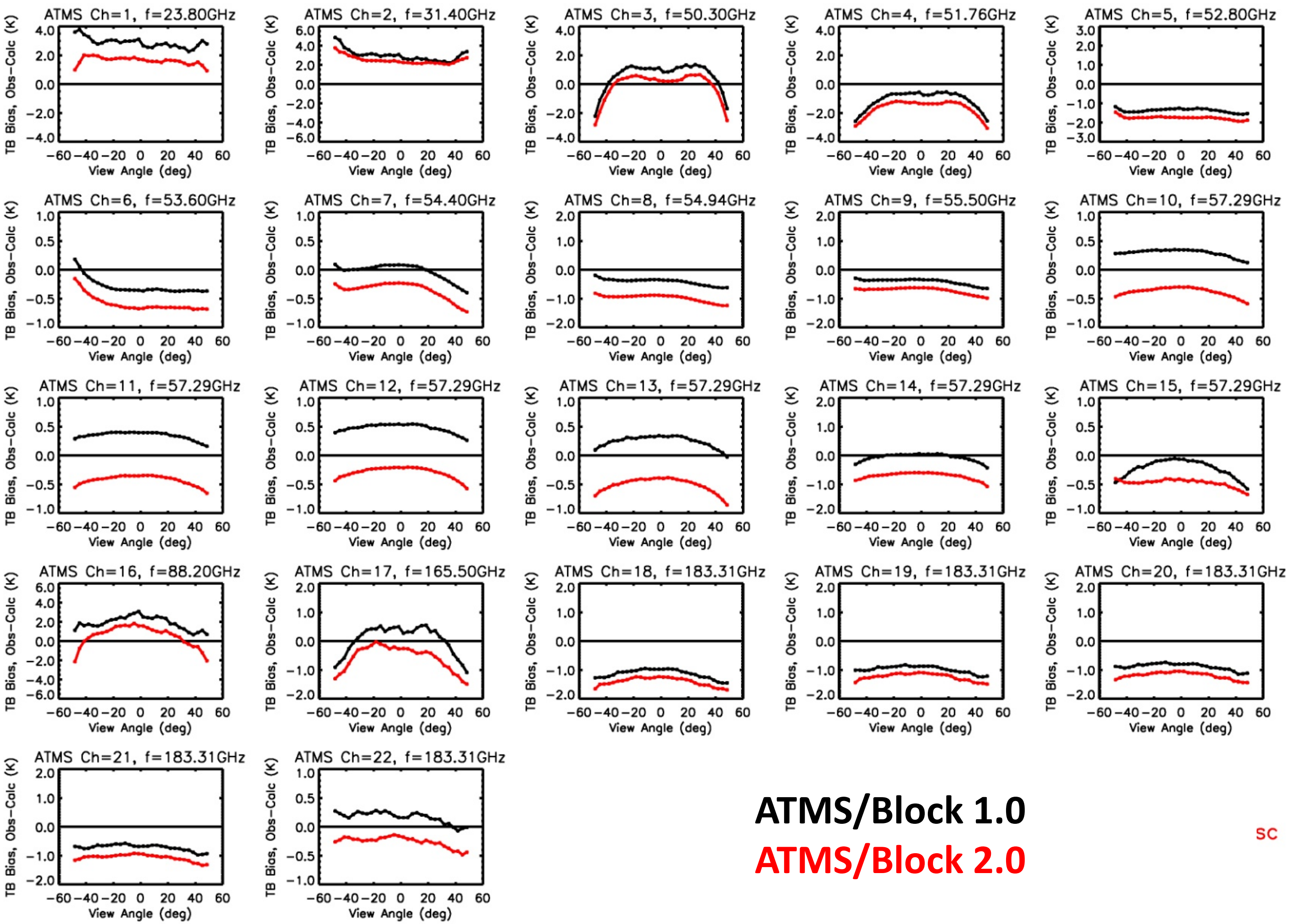
Kexin Zhang's poster (Tue. 5-7:30pm)

MW RTA Bias Correction: ATMS/TDR Block 1.0 vs Block 2.0



CrIS Full Spectral Resolution (FSR) SARTA Rapid Transmittance Algorithm (RTA)

Upgrades in the CrIS FSR SARTA RTA (L. Strow's talk in the trace gas session)

- CrIS high-resolution ILS
- HITRAN 2012 (vs 2008 in original CrIS RTA)
- LBLRTM Line Mixing for CO_2 and CH_4, H_2O continuum
- UMBC line-by-line for water vapor
- Improved reflected thermal component for high secant angles
- Tested on 750+ profiles (from ECMWF selected subset), regressed on 49 profiles
- Error covariance estimates available from 750+ profile testing

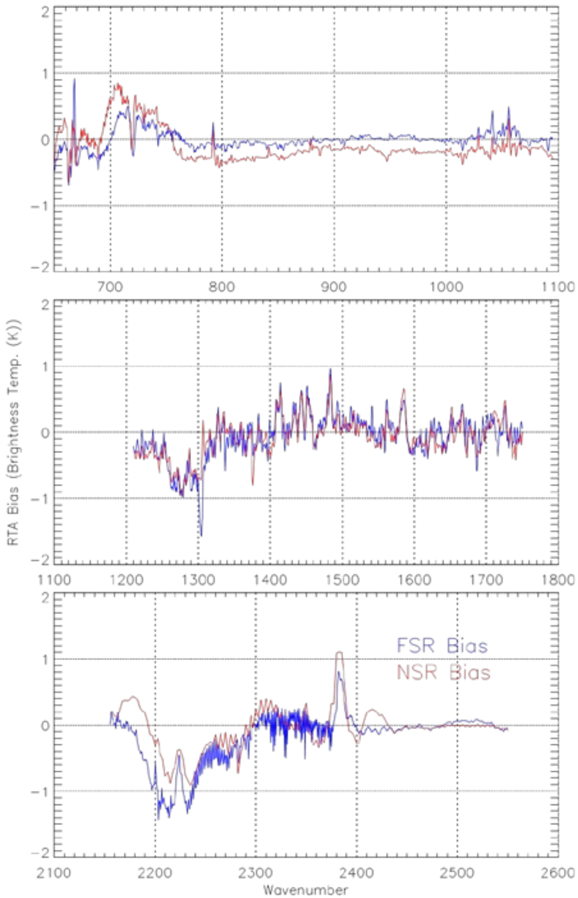
CrIS FSR SARTA bias tuning and sdev

Bias

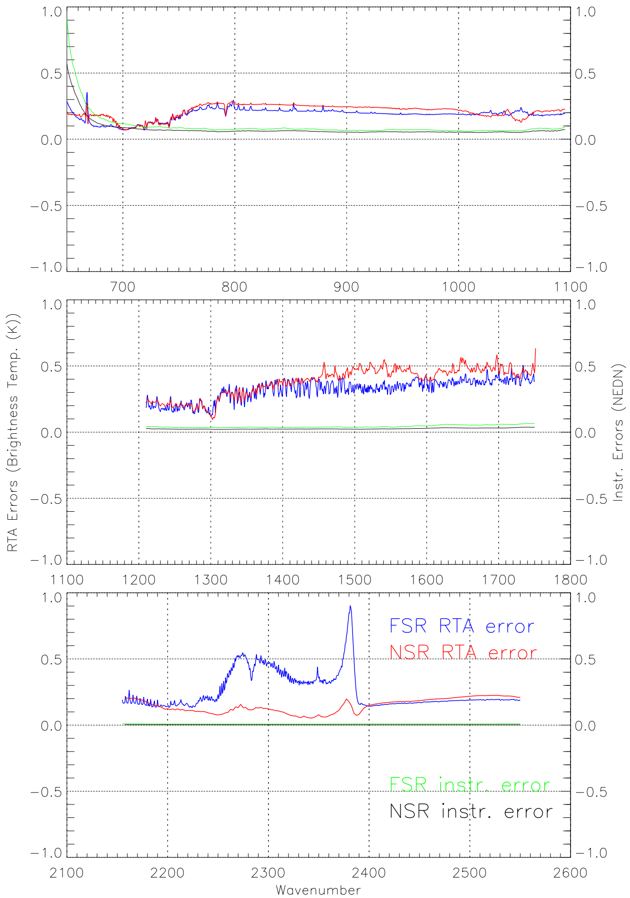
FSR LW window benefited from VIIRS cloud filtering

Water vapor region stays consistent

SW band appears better behaved



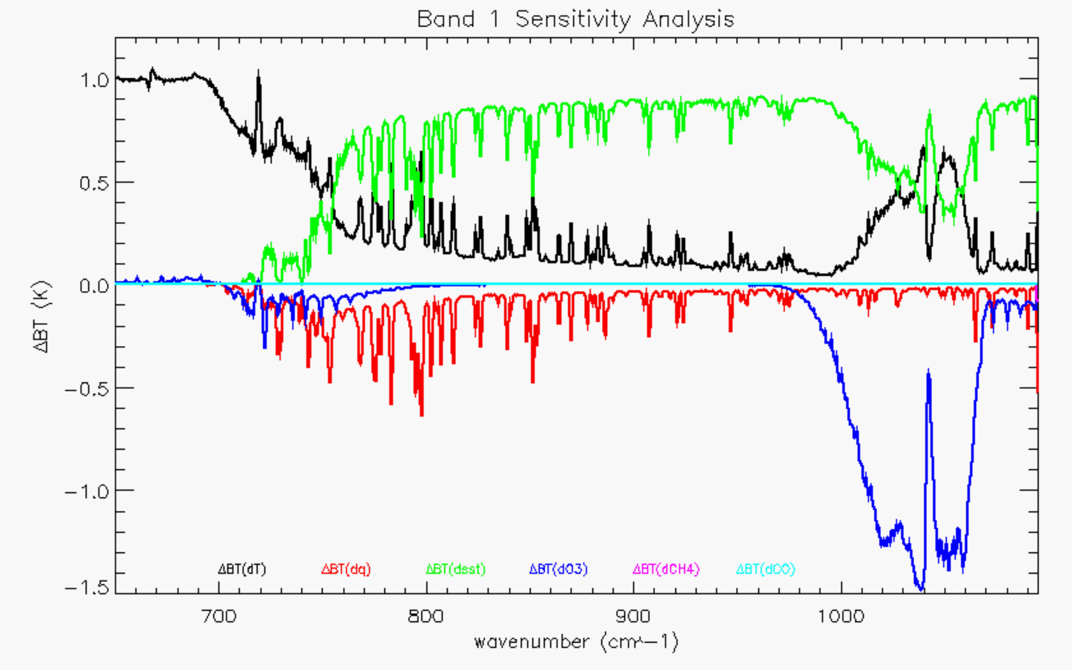
Standard deviation



Original NSR st dev was divided by two to account for errors in the truth.

In the improved training methodology, this division is not needed any longer

CrIS FSR Channel Selection



Perturbation Applied

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

Brightness temperature difference (ΔBT) terms represent the sensitivity of each channel to a given perturbation species and are indicative of the degree of *"spectral purity"* of each channel.

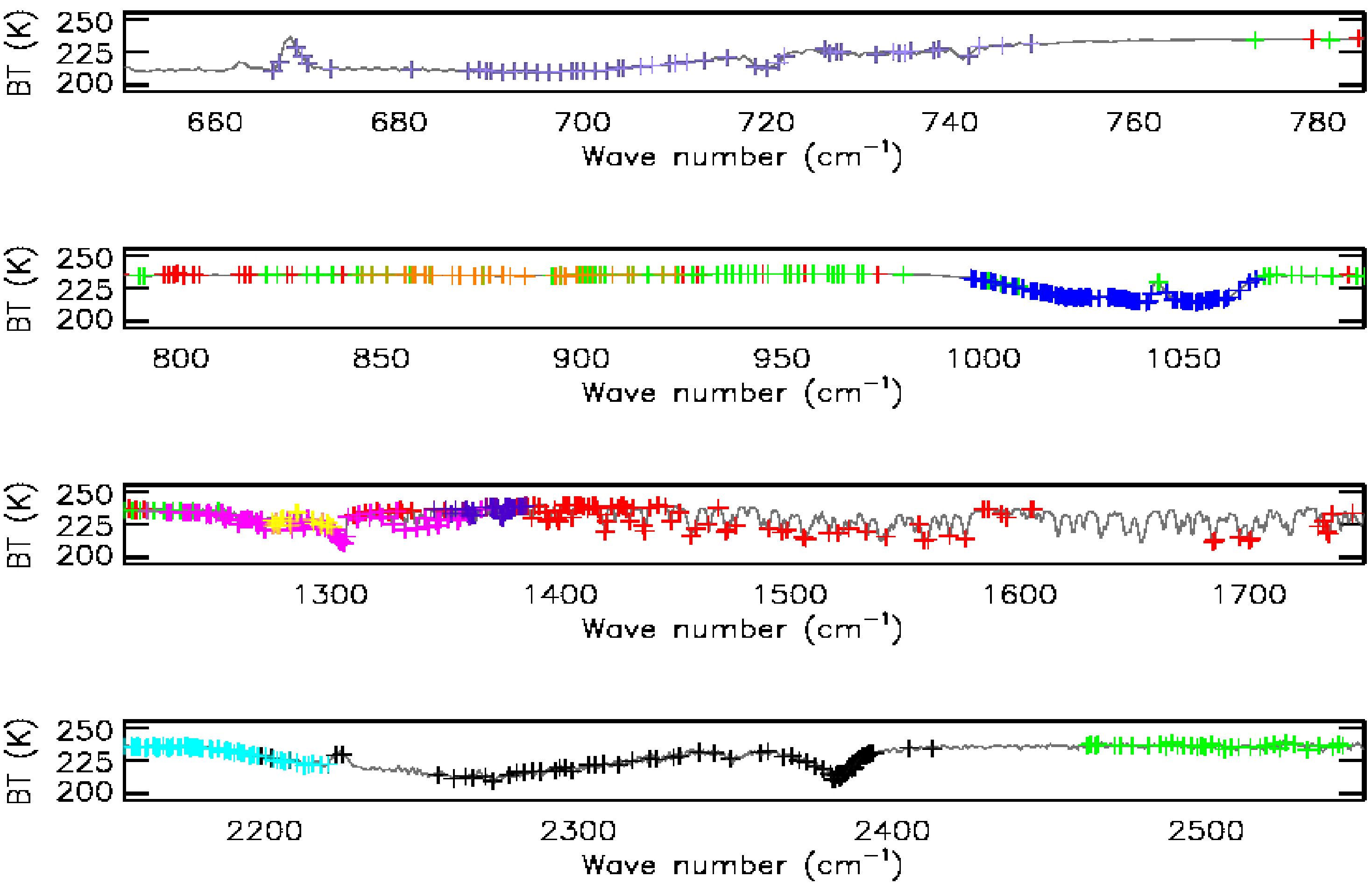
•For each atmospheric species, we select channels with:

- **the highest degree of spectral purity** (the highest sensitivity to the species of interest and the lowest sensitivity to all other interfering species).
- **the lowest noise sources** (NEDT, calibration & apodization corr., RTA errors)
- **unique spectral features** (to capture atmospheric variability, maximize vertical resolution)

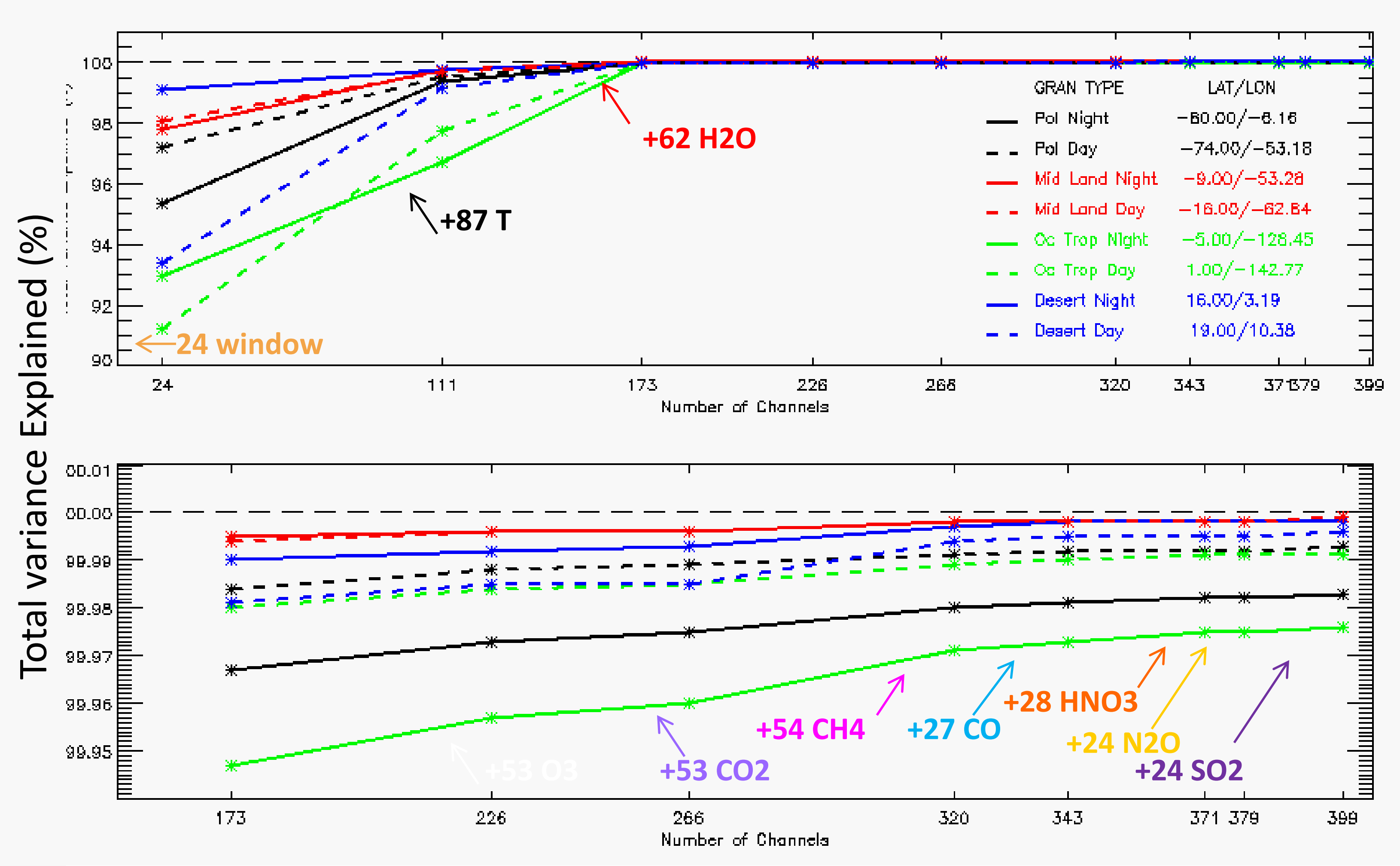
REF: A. Gambacorta and C. Barnet., Methodology and information content of the NOAA NESDIS operational channel selection for the Cross-Track Infrared Sounder (CrIS), IEEE, Vol. 51, Issue 6, 2013

NUCAPS Operational FSR CrIS channel selection (610 channels)

EDR	#chns
Temp	116
Surf	136 (62)
HO2	123 (62)
O3	77
CO	52
CH4	84
N2O	21
SO2	31
HNO3	30
CO2	50 (T LW)



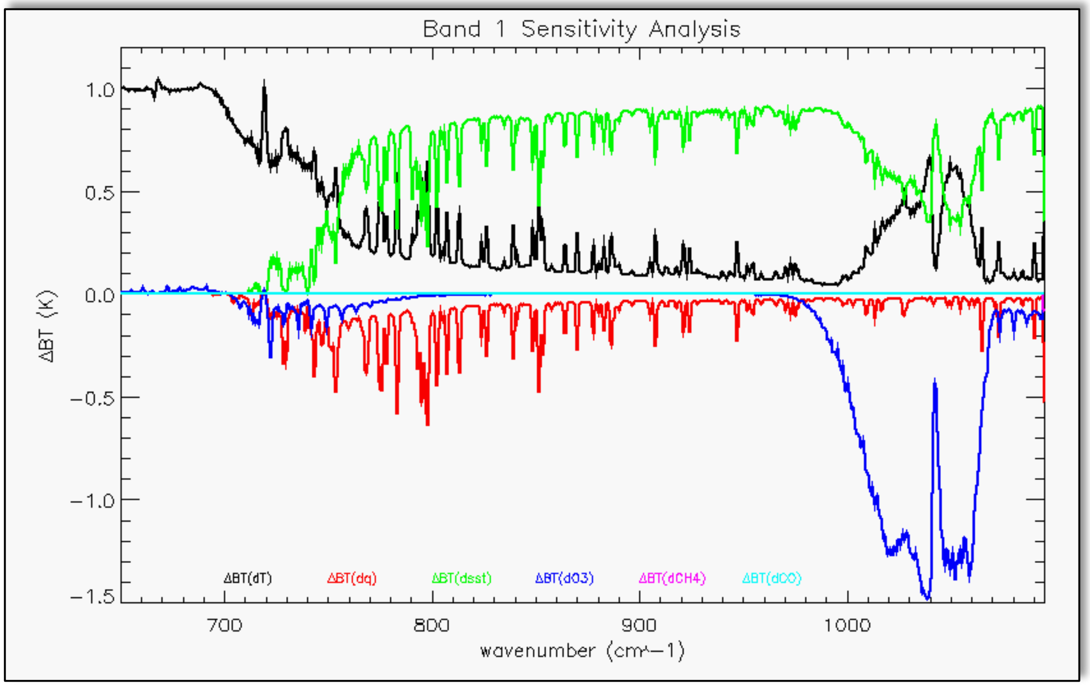
Total Variance Explained



• The full list of 399 selected channels explains ~99.9% of the total atmospheric variance, consistently across all geophysical regimes.

• The first 173 channels (window, temperature and water vapor channels) alone explain ~ 99% of the total atmospheric variance. REF: Gambacorta et al., IEEE, 2013

NUCAPS: a sequential, iterated, linearized, regularized square fit



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

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

$$\varepsilon_n = NEDT_n + \delta R_{CCR} + \delta RTA_n + \sum_{j \neq i} K^j \delta X^j$$

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

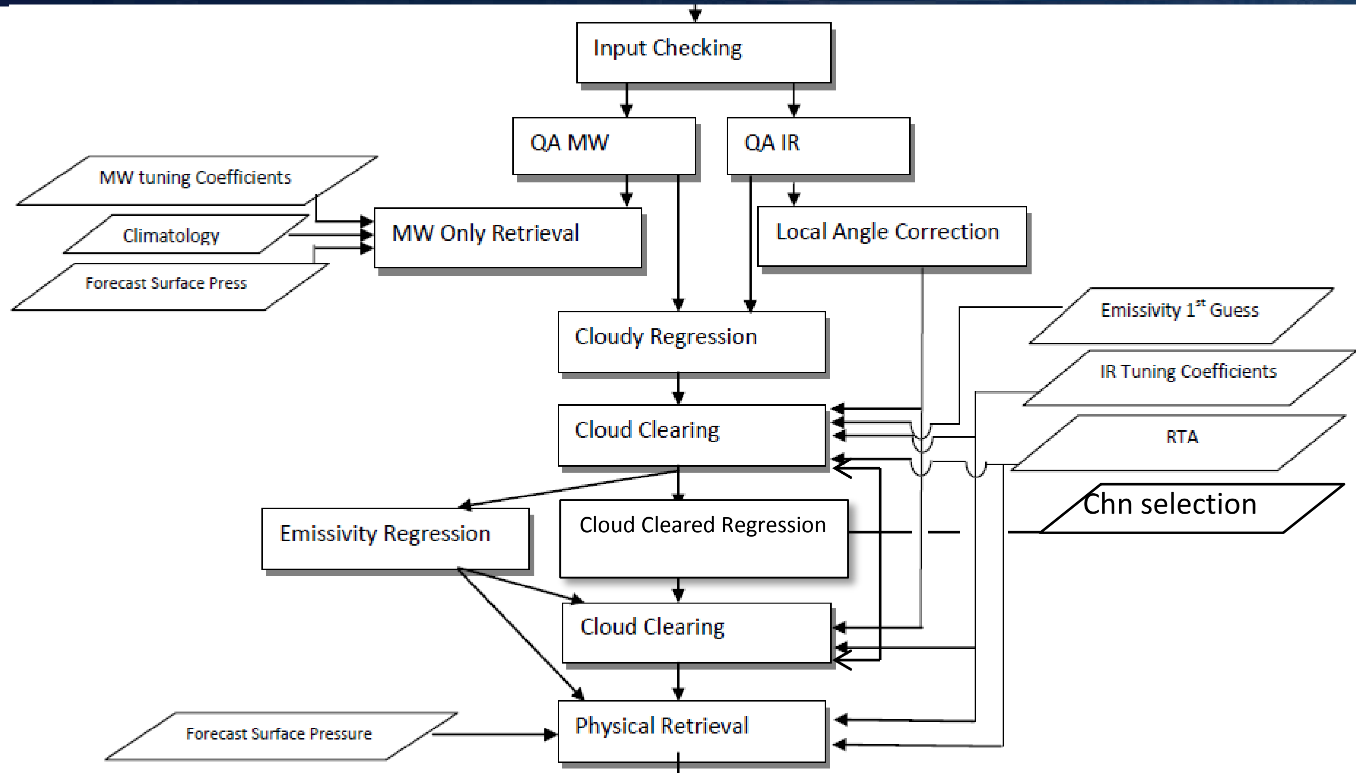
Clouds, clouds, everywhere

- **How does Cloud Clearing work?**
  - Utilizes a cluster of 9 FOVs and a subset of temperature sensitive channels to extrapolate the radiance signal that the instrument would see if there were no clouds.
  - Basic assumption: clouds are solely responsible for the variance in the cluster of FOVs. Works best over ocean, worse over land.
  - Sacrifices spatial resolution (9 FOV ~ 45km) to achieve global coverage: ~80% yield vs 5% clear scenes
- **Why Cloud Clearing?**
  - Goal is to retrieve TOA – Surface profiles.
  - Clouds radiative effects and geophysical correlation with other atmospheric parameters are highly non-linear.
  - Cloud geophysical a priori and spectral constraints are highly uncertain.
  - 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. 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 and propagated through downstream retrieval error steps
  - Proper error characterization and propagation allows graceful degradation toward the microwave information with decreased information content
- **Can we still retrieve cloud parameters?**
  - Yes, cloud parameters are retrieved from Cloudy Obs – Calc LSQ minimization in the post-processing
- **Are there alternatives?**
  - Single FOV cloud clearing by the additional use of visible instruments.
    - See Jim Jung’s talk, Monday 2018-08-14, “Advanced Application Session, h13:00 – 13:15”
  - Single FOV all sky retrievals by the use of cloudy forward models and geophysical a priori
    - See Xu Liu’s talk today, “NUCAPS Session”, h 10:15 – 10:30”
    - See Larrabee Strow’s talk tomorrow, “Trace Gas Session”, h10:10 – 10:30

NUCAPS a priori choices

- NUCAPS is currently using a statistical operator (linear regression) as a priori
- Pro's:
  - Does not require a radiative transfer model for training or application.
  - Application of eigenvector & regression coefficients is VERY fast and for hyper-spectral instruments it is very accurate
  - 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.
  - Since clouds are identified as unique eigenvectors, a properly trained regression tends to "see through" clouds.
- Con's:
  - Training requires a large number of co-located "truth" scenes.
  - Statistical operators inherently lack in computation of formal error estimates. They do not obey any convergence criteria. Ad hoc QC methods need to be introduced.
  - Statistical operators build 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. They can introduce sub-resolved structures in the retrieval
- We have started exploring the possibility of a new a priori in the form of a climatology based on MERRA-2 reanalysis.

NUCAPS Retrieval Algorithm Flow Chart



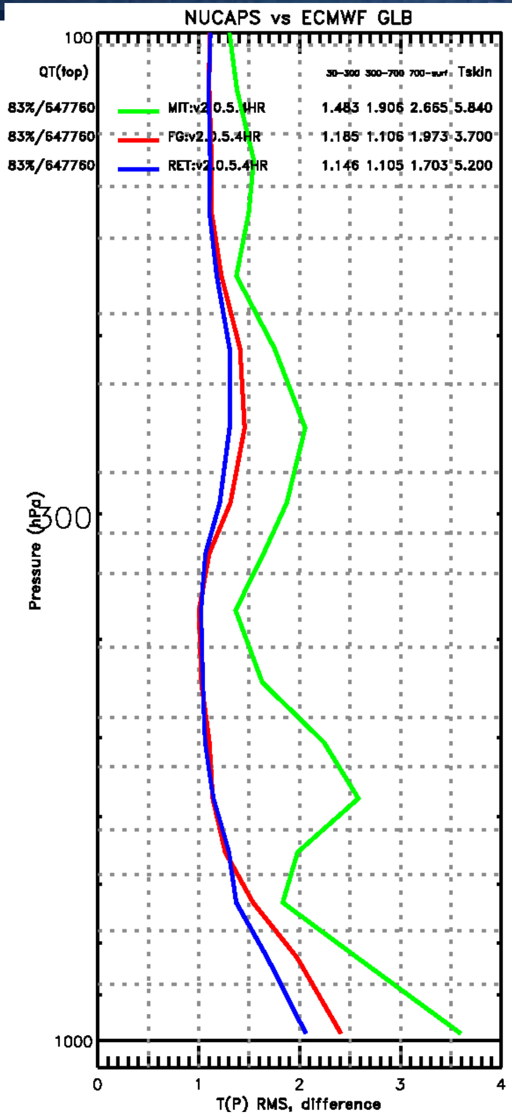
- **I. A microwave retrieval module** which computes Temperature, water vapor and cloud liquid water (Rosenkranz, 2000)
- **II. A fast eigenvector regression** retrieval that is trained against ECMWF and all sky radiances which computes temperature and water vapor (Goldberg et al., 2003)
- **III. A cloud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

Summary of current NUCAPS retrieval products

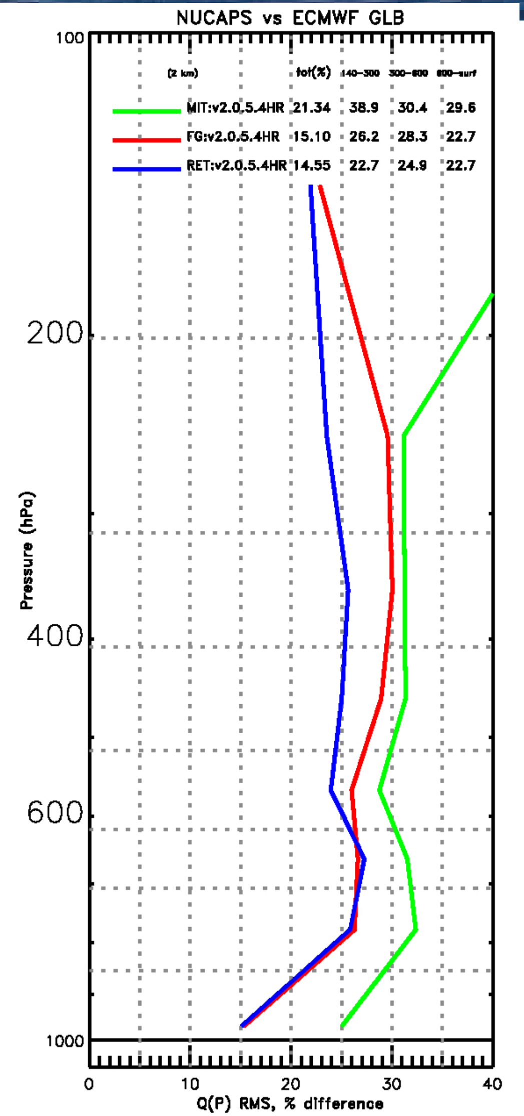
gas	Range (cm^{-1})	Precision	d.o.f.	Interfering Gases
T	650-800 2375-2395	1K/km	6-10	H2O,O3,N2O emissivity
H_2O	1200-1600	15%	4-6	CH4, HNO3
O_3	1025-1050	10%	1+	H2O,emissivity
CO	2080-2200	15%	≈ 1	H2O,N2O
CH_4	1250-1370	1.5%	≈ 1	H2O,HNO3,N2O
CO_2	680-795 2375-2395	0.5%	≈ 1	H2O,O3 T(p)
Volcanic SO_2	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
$CFCl_3$ (F11)	*830-860*	*20%*	*-*	*emissivity*
CF_2Cl (F12)	*900-940*	*20%*	*-*	*emissivity*
CCl_4	*790-805*	*50%*	*-*	*emissivity*

Potential additions

Global Performance Summary: MW-only, First guess and MW+IR (RMS)



Temperature



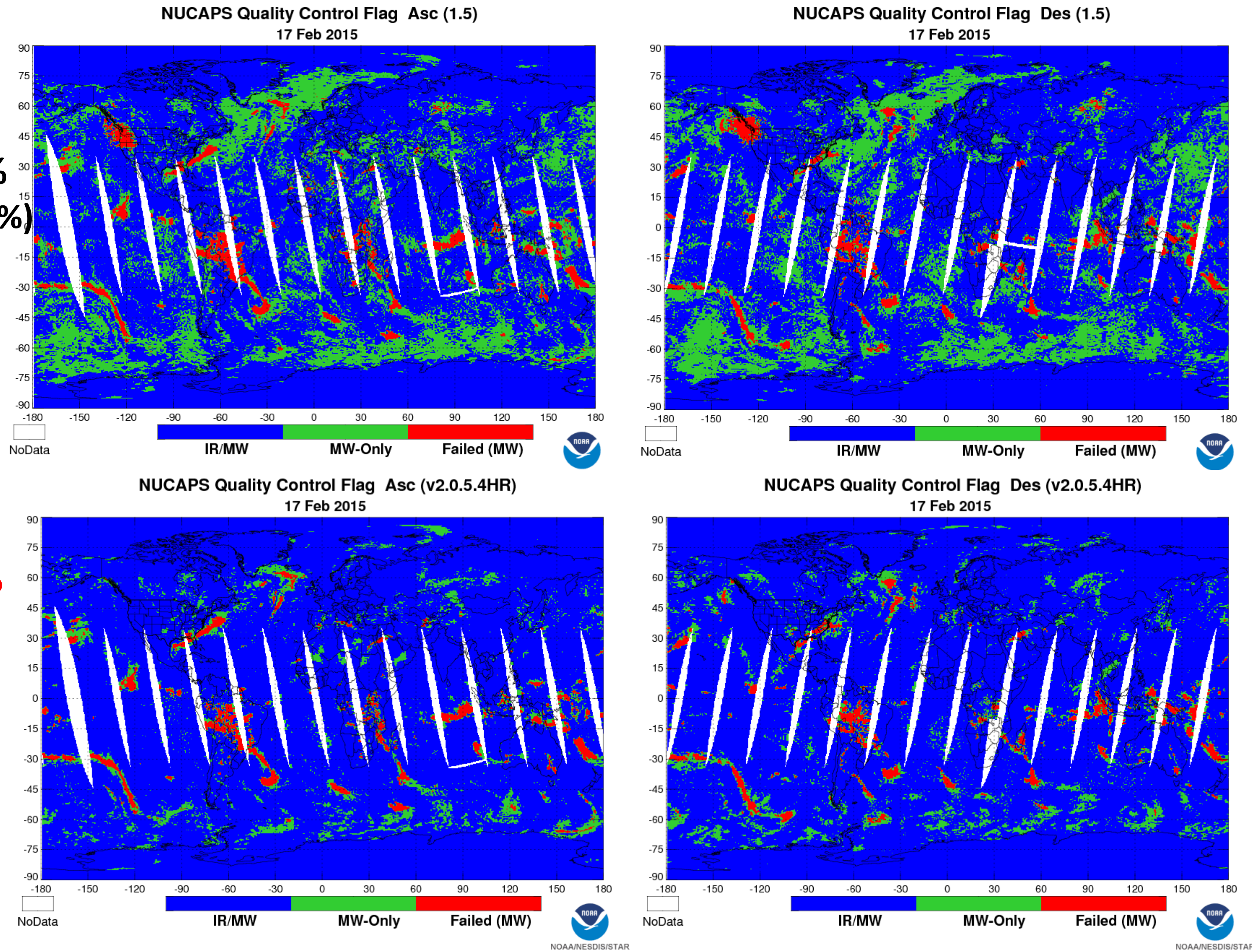
Water Vapor

NUCAPS Operational NSR vs FSR yield

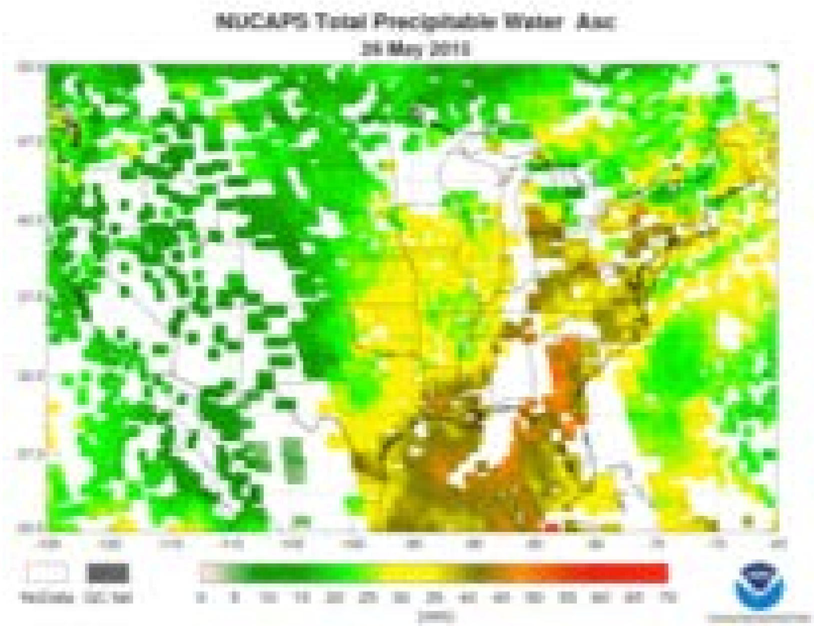
NSR Yield = 63 %

(NSR v1.7 yield = 70%)

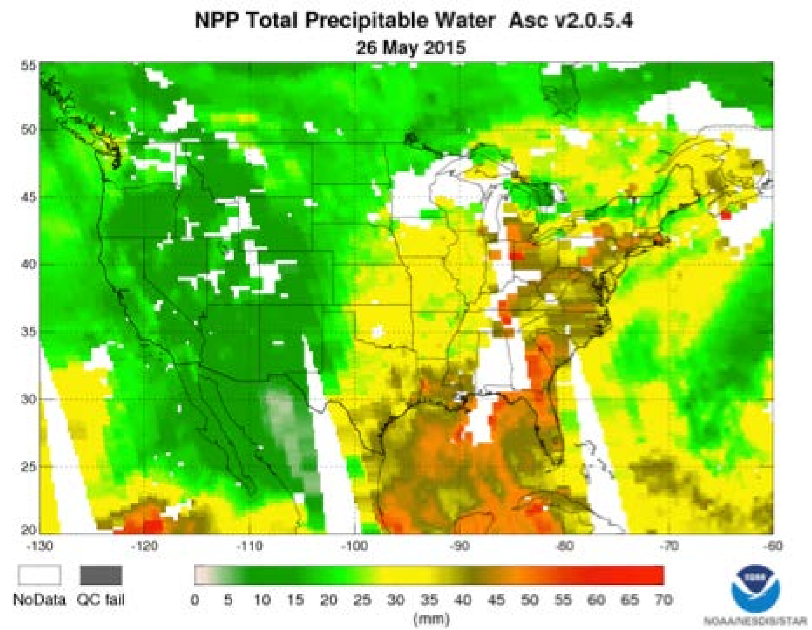
FSR Yield = 83 %



Significance to users applications



Operational NSR NUCAPS



Operational FSR NUCAPS

(S. De Silva's Poster Session, Tuesday 5-7:30pm)

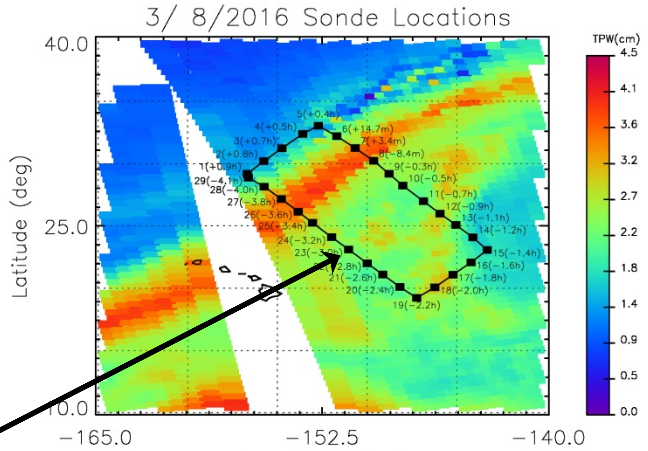
- Increased yield by ~20% enables uniform and more consistent global coverage
- This is essential to fill in the gaps of sparse in situ measurements and makes NUCAPS suitable for users applications.

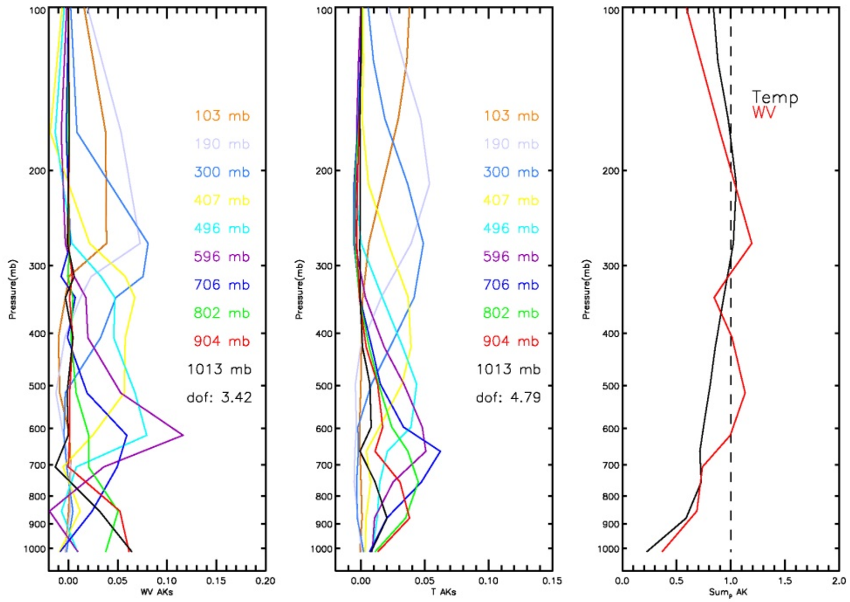
NUCAPS ultimate goal: a weather and climate quality retrieval algorithm

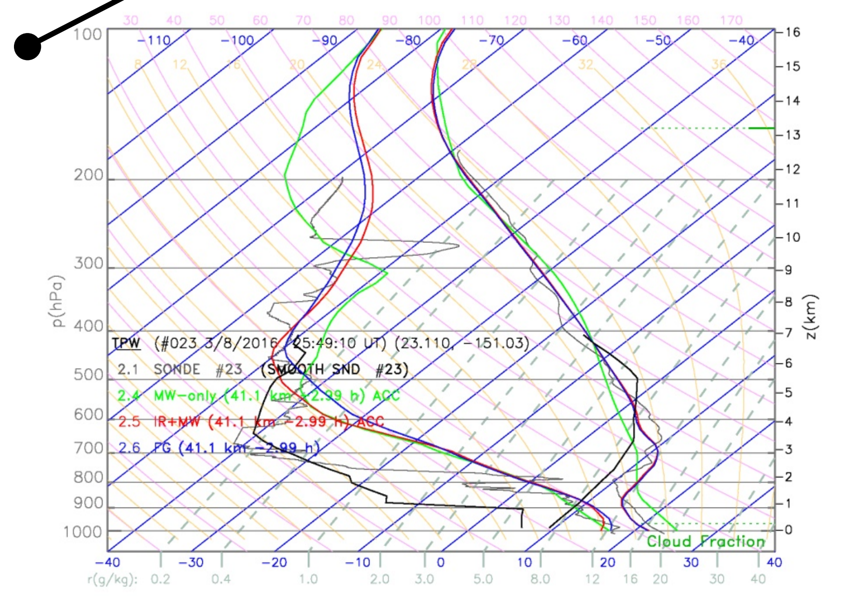
- **Why do we need a weather and climate quality retrieval algorithm?**
  – An independent, all-sky, global environmental data record
    - to add real time context to weather forecasting
    - to study atmospheric variability, feedbacks, trends.
- **Definition of a weather and climate quality algorithm**
  – A retrieval algorithm that can be characterized by explicitly evaluating the functional form of the relationship between the retrieved profile, the true atmosphere, and the various error sources.
- **How do we demonstrate NUCAPS capability to add value to weather forecasting and climate prediction?**
  – What are the dominant sources of NUCAPS uncertainties?
  – How does NUCAPS uncertainty vary by scene types?
  – How does NUCAPS uncertainty vary along the vertical domain?
  – What's NUCAPS effective vertical resolution?

A test case from the 2016 El Nino Rapid Response (ENRR) Campaign Mar. 8, 2016 Sonde #23

- Relatively warm w/ upper level dry layer and moist BL, higher clouds
- AK’s have less T(p) skill below upper cloud
- But retrieval still captures the dry layer aloft, moist BL (mostly from regression) and marine T(p) inversion

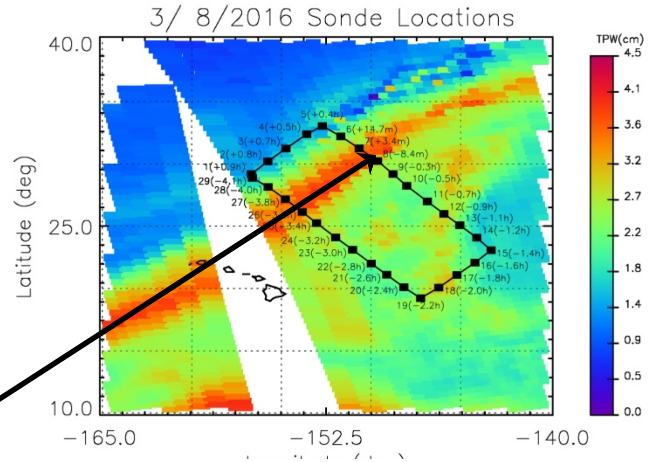


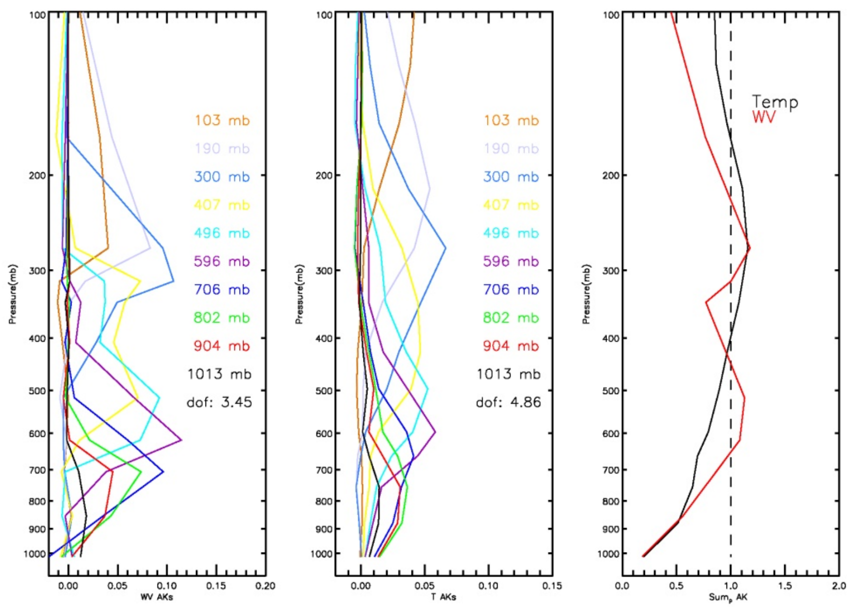


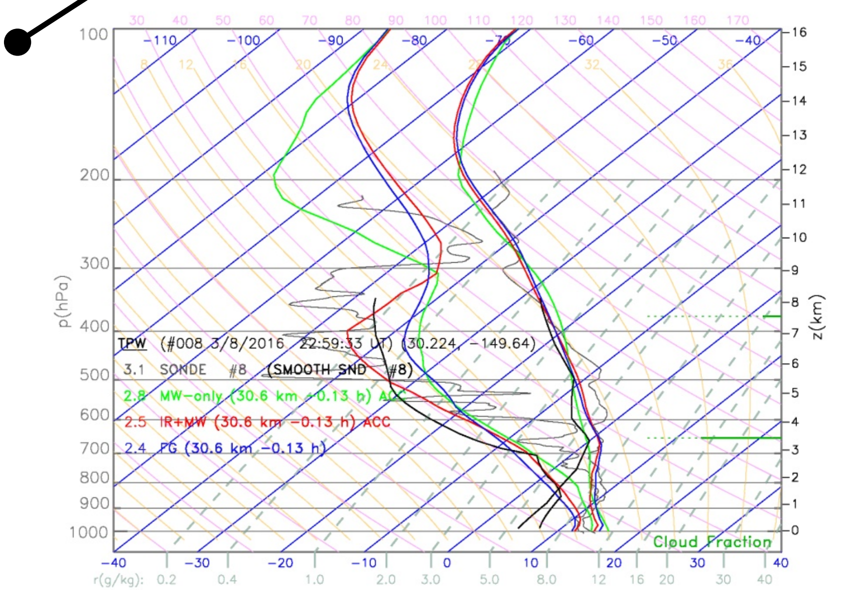


A test case from the 2016 El Nino Rapid Response (ENRR) Campaign Mar. 8, 2016 Sonde #08

- Very moist with both upper level (~15%) and lower level clouds (~60%)
- AK's do not have surface sensitivity. Both regression and physical know we have a lot of water







Coming next…

- Validation, demonstrations, applications
  - A global validation study to demonstrate NUCAPS retrieval skill (F. Iturbide-Sanchez Poster)
  - A detailed validation assessment to prove requirements are met (N. Nalli , T. Reale, L. Borg talks in today's session)
  - A focused list of proving ground and risk reduction initiatives to develop new users applications and provide indirect validation and demonstration of NUCAPS products (B. Sjoberg, B. Zavodski, M. Bowlan, E. Stevens, J. Dostalek talks in the second part of today's session; A. Wheleer and S. De Silva's posters).
- Thank you!