NOAA Unique CrIS ATMS Processing System (NUCAPS)

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NASA Sounder Science Team Meeting, Greenbelt Maryland
September 30, 2014

Outline

- NUCAPS Objectives
- Product Requirements
- Retrieval System
- Cloud-Clearing Radiance
- NUCAPS Products
- NUCAPS Products' Validation
- Conclusion
- Path Forward

NUCAPS Objectives

- Apodize and subset the CrIS SDR's to produce thinned radiance datasets for use by NWP and satellite products
- Provide CrIS/ATMS NOAA Unique products within three hours of observation
- Cloud Cleared Radiances
- NOAA Unique Trace Gas Products
- Collocated CrIS/VIIRS-cloud datasets
- Provide NUCAPS Products to CLASS for sounding community
- Provide a subset of NUCAPS Products to *Advanced Weather Interactive Processing System* (AWIPS)

Temperature Profile Requirements

	Attribute	Threshold	Objective
	Geographic coverage	90% every 18 hours	> 90%
L1RD p43	Vertical Coverage	Surface to 0.5 mb	Surface to 0.5 mb
	Vertical Cell Size	0.2 ~50 mb	0.1 ~ 10 mb
	Horizontal Cell Size	50 km at nadir	1 km at nadir
	Mapping Uncertainty	5 km	0.5 km
	Measurement Range		
	Measurement Uncertainty		
	Cloud < 50%: Surface to 300 mb	1.6 K per km layer	0.5 K per km layer
IR + MW	300 to 30 mb	1.5 K per 3 km layer	0.5 K per 3 km layer
	30 to 1 mb	1.5 K per 5 km layer	0.5 K per 5 km layer
	1 to 0.5 mb	3.5 K per 5 km layer	0.5 K per 5 km layer
	Cloud >= 50%: Surface to 700mb	2.5 K per km layer	0.5 K per km layer
	700 to 300 mb	1.5 K per km layer	0.5 K per km layer
MW only	300 to 30 mb	1.5 K per 3 km layer	0.5 K per 3 km layer
	30 to 1 mb	1.5 K per 5 km layer	0.5 K per 5 km layer
	1 to 0.5 mb	3.5 K per 5 km layer	0.5 K per 5 km layer

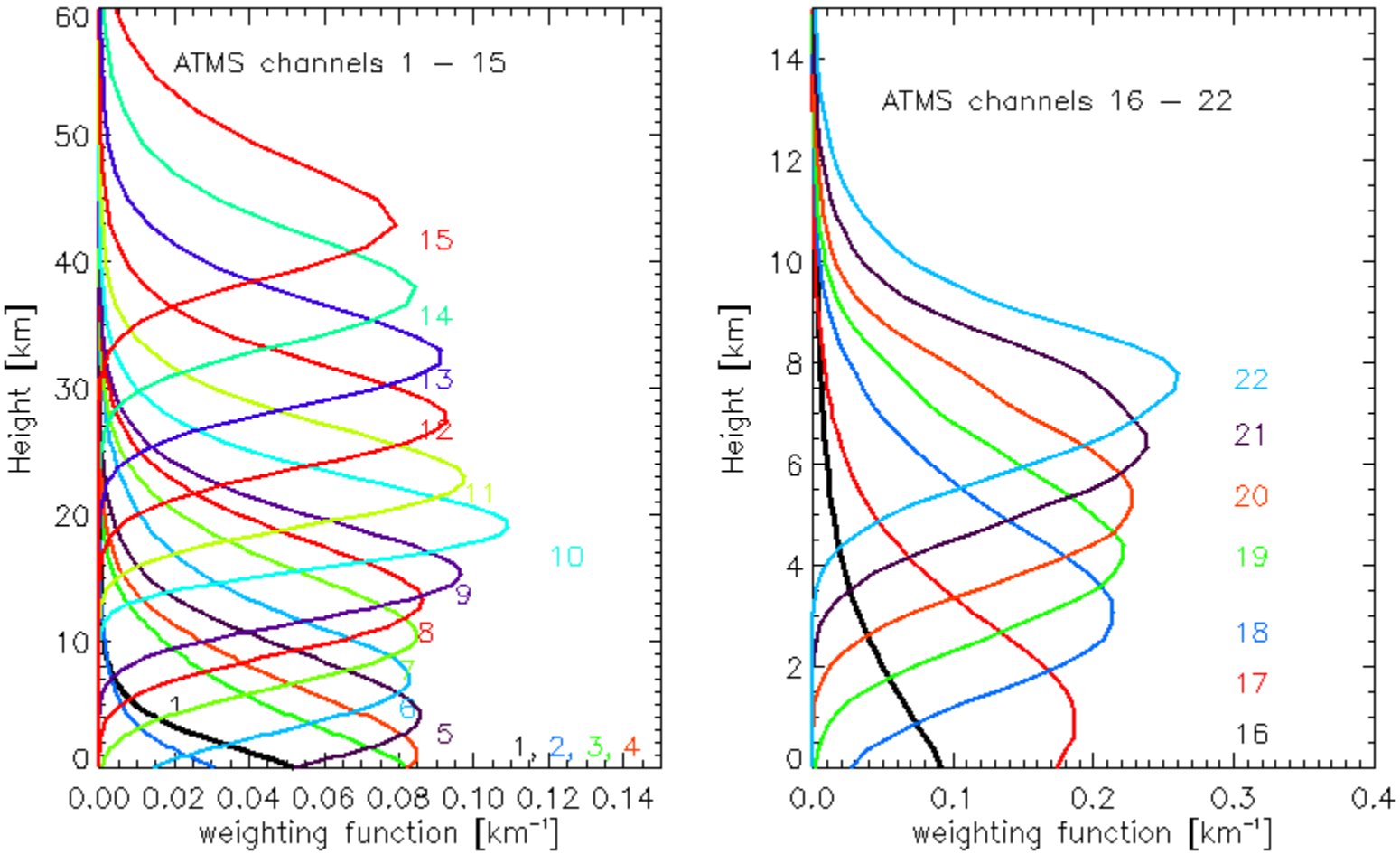
Moisture Profile Requirements

	Attribute	Threshold	Objective
L1RD p41	Geographic coverage	90% every 18 hours	3 hrs
	Vertical Coverage	Surface to 0.5 mb	Surface to 0.5 mb
	Vertical Cell Size	20 ~50 mb	5 ~ 10 mb
	Horizontal Cell Size	50 km at nadir	1 km at nadir
	Mapping Uncertainty	5 km	0.5 km
	Measurement Range		
	Measurement Uncertainty	Expressed as a percent of average ratio in 2 km layers	
IR + MW	Cloud < 50%: Surface to 600 mb	Greater of 20% or 0.2 g/kg	10%
	600 to 300 mb	Greater of 35% or 0.1 g/kg	10%
	300 to 100 mb	Greater of 35% or 0.1 g/kg	10%
	Cloud >= 50%: Surface to 600mb	Greater of 20% or 0.2 g/kg	10%
MW only	600 to 300 mb	Greater of 40% or 0.1 g/kg	10%
	300 to 100 mb	Greater of 40% or 0.1 g/kg	10%

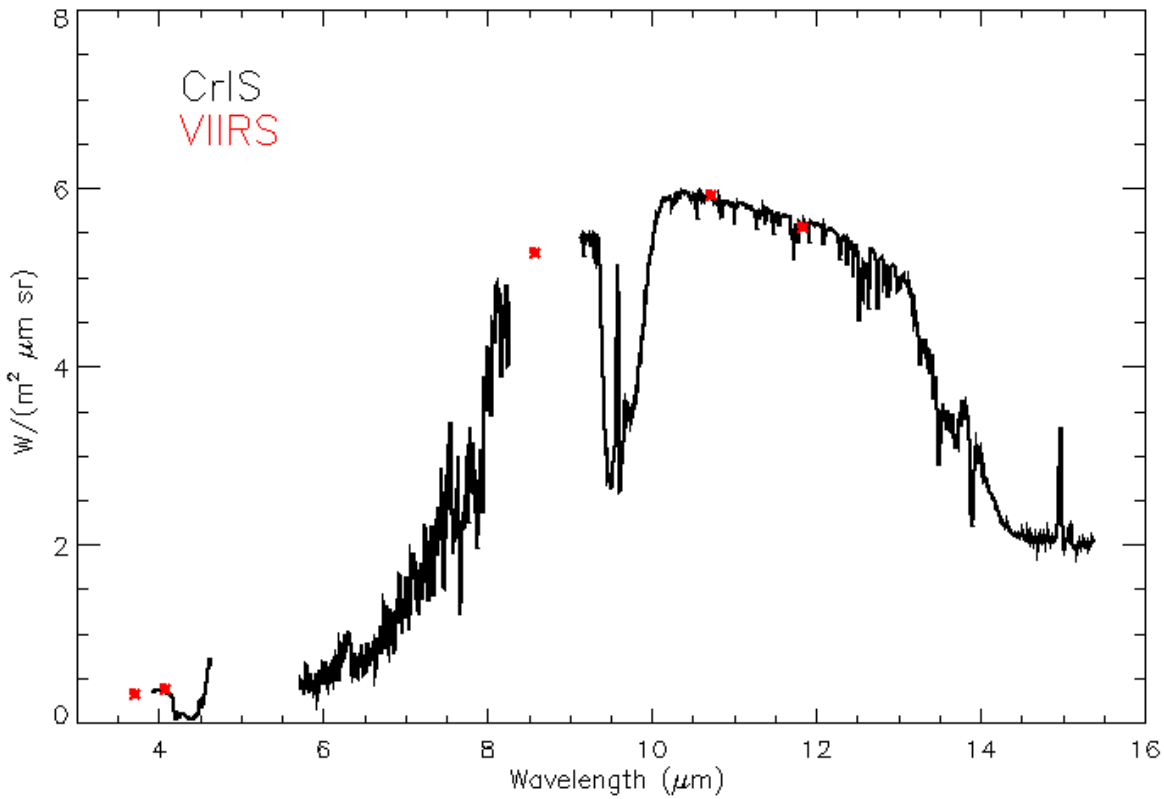
JPSS-1 Requirements

EDR Attribute	CO	CO_2	CH_4
Vertical Coverage	Total Column	Total Column	Total Column
Horizontal Resolution	100 km	100 km	100 km
Mapping Uncertainty, 3 sigma	25 km	25 km	25 km
Measurement Range	0 – 200 ppbv	300 – 500 ppmv	1100 – 2250 ppbv
Measurement Precision	35%	0.5% (2 ppmv)	1% (~20 ppbv)
Measurement Accuracy	±25%	±1% (4 ppmv)	±4% (~80 ppbv)
Refresh	24 h	24 h	24 h
Note			

ATMS Weighting Function



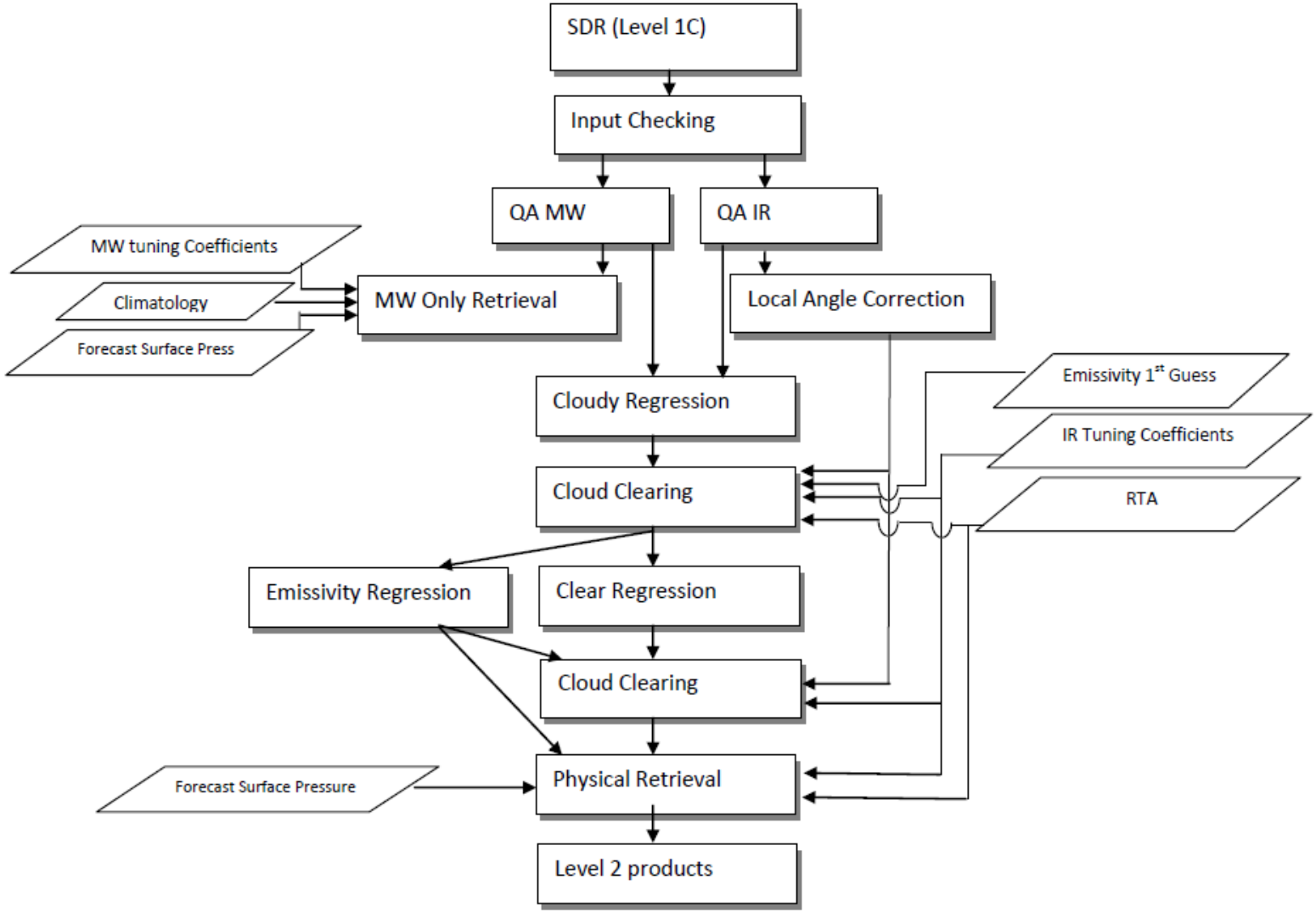
CrIS and ATMS SDR Data



SDR	Number of channels
ATMS	22, temperature/water vapor
CrIS	399 in total
window	24
temperature	87
water vapor	62
ozone	53
CO	27
N2O	24
HNO3	28
CH4	54
SO2	24
CO2	53

CrIS/ATMS SDR are used in the retrieval

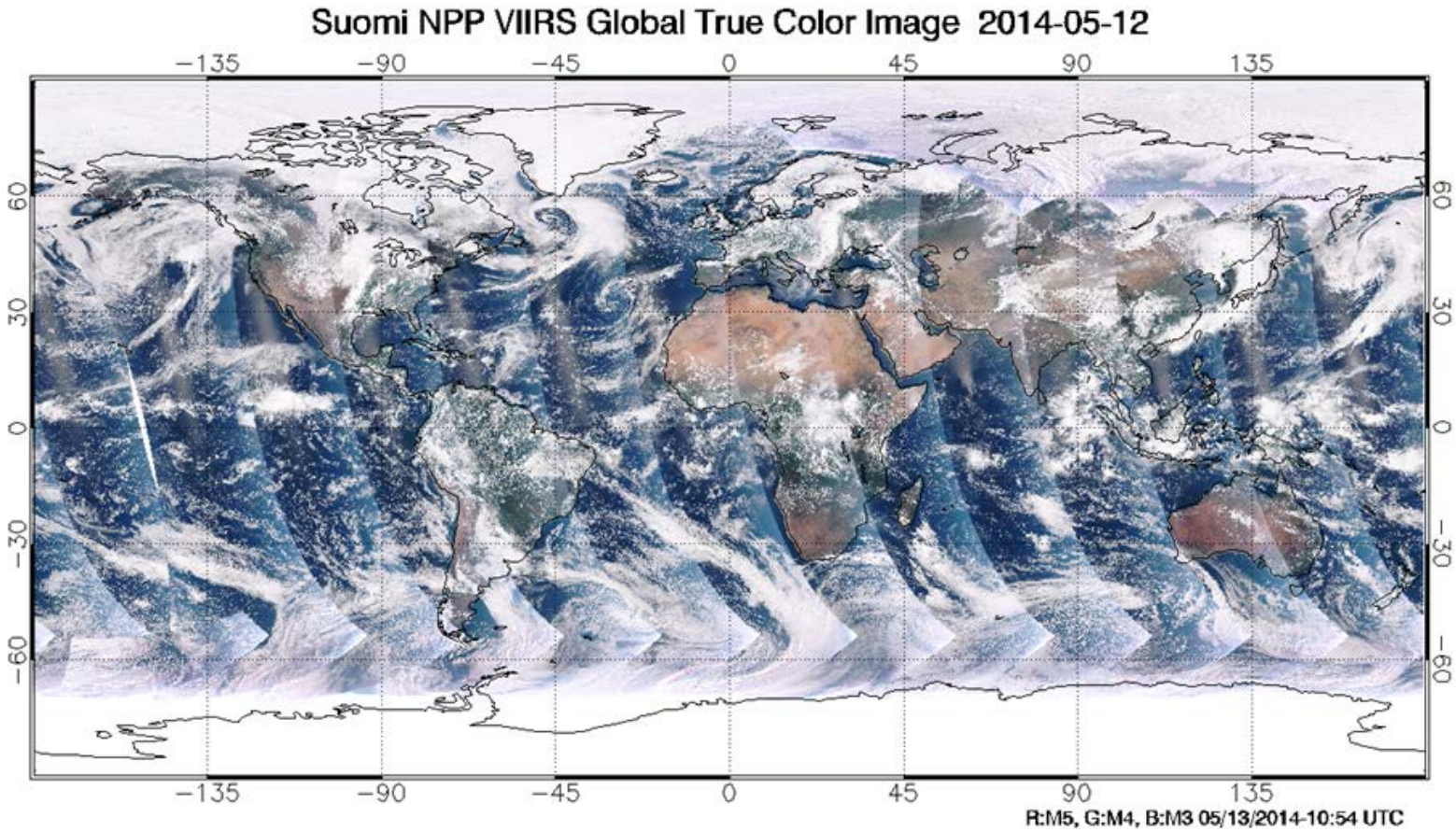
NOAA Unique CrIS/ATMS Processing System (NUCAPS) Retrieval System



Antonia Gambacorta and Chris Barnet, 2012: 10.1109/TGRS.2012.2220369.

Cloud Coverage, May 12, 2014

from STAR ICVS



FOV

Clear	1-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-99	100%
8.61	13.92	6.16	5.67	4.52	3.94	3.68	3.80	4.32	8.66	18.28	18.44

Cloud coverage = 57%

FOR

Clear	1-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-99	100%
3.30	13.78	7.16	6.78	5.86	5.47	5.33	5.43	6.14	8.52	21.99	10.24

Data from Haibing Sun

CCR (CF< 80%)

Using cloud-clearing radiance, IR retrieval data increases from 3.3% to 59.3%.

NUCAPS Sounding Products Available at NOAA CLASS and to AWIPS-II

- Atmospheric Vertical Temperature Profile
- Atmospheric Vertical Moisture Profile
- Infrared Ozone Profile

- (requirement: total column)
- Vertical CO Profile
- Vertical CO_2 Profile
- Vertical CH_4 Profile
- Outgoing Longwave Radiation (OLR)

- Vertical HNO_3 Profile
- Vertical N_2O Profile
- Vertical SO_2 Profile
- A flag indicating the presence of dust and volcanic emissions
- Cloud-Cleared Radiances

Many others such as Stability

Validation Methodology, NPROVS and VALAR

Numerical Model (e.g., ECMWF, NCEP/GFS) Global *Comparisons*

Large, global samples acquired from Focus Days
Useful for early sanity checks, bias tuning and regression
However, not independent truth data

Satellite EDR (e.g., CrIS, AIRS, ATOVS, COSMIC) *Intercomparisons*

Global samples acquired from Focus Days (e.g., CrIS/ATMS)
Consistency checks; merits of different retrieval algorithms
However, IR sounders have similar error characteristics; must take rigorous account of averaging kernels of both systems (e.g., *Rodgers and Connor,* 2003)

Conventional RAOB Matchup *Assessments*

Conventional WMO/GTS operational sondes launched ~2/day for NWP (e.g., NPROVS)
Useful for representation of global zones and long-term monitoring
Large statistical samples acquired after a couple months' accumulation
Limitations:

- Skewed distribution toward NH-continental sites
- Significant mismatch errors, potentially systematic at individual sites
- Non-uniform, less-accurate and poorly characterized
- radiosonde types used in data sample

Dedicated/Reference RAOB Matchup *Assessments*

Dedicated for the purpose of satellite validation
Well-specified error characteristics and optimal accuracy
Minimal mismatch errors
Include atmospheric state "best estimates" or "merged soundings"
Reference sondes: CFH, corrected RS92, Vaisala RR01 under Development
Traceable measurement
Detailed performance specification and regional Characterization
Limitation: Small sample sizes and geographic coverage
E.g., ARM sites (e.g., *Tobin et al.,* 2006), GRUAN sites, NOAA AEROSE

Intensive Field Campaign *Dissections*

Include dedicated RAOBs, especially those *not* assimilated nto NWP models
Include ancillary datasets (e.g., ozonesondes, lidar, M-AERI, MWR, sunphotometer, etc.)
Ideally include funded aircraft campaign using aircraft IR sounder (e.g., NAST-I, S-HIS) underflights
Detailed performance specification; state specification; SDR cal/val; EDR "dissections"
E.g., AEROSE, JAIVEX, WAVES, AWEX-G, EAQUATE, CalWater-2

Nalli et al., 2013: JGR; Divakarla, et al., 2014: JGR-Atmosphere.

Validation Data Sets

Qualitative Analysis

Product of global distribution

Quantitative Analysis

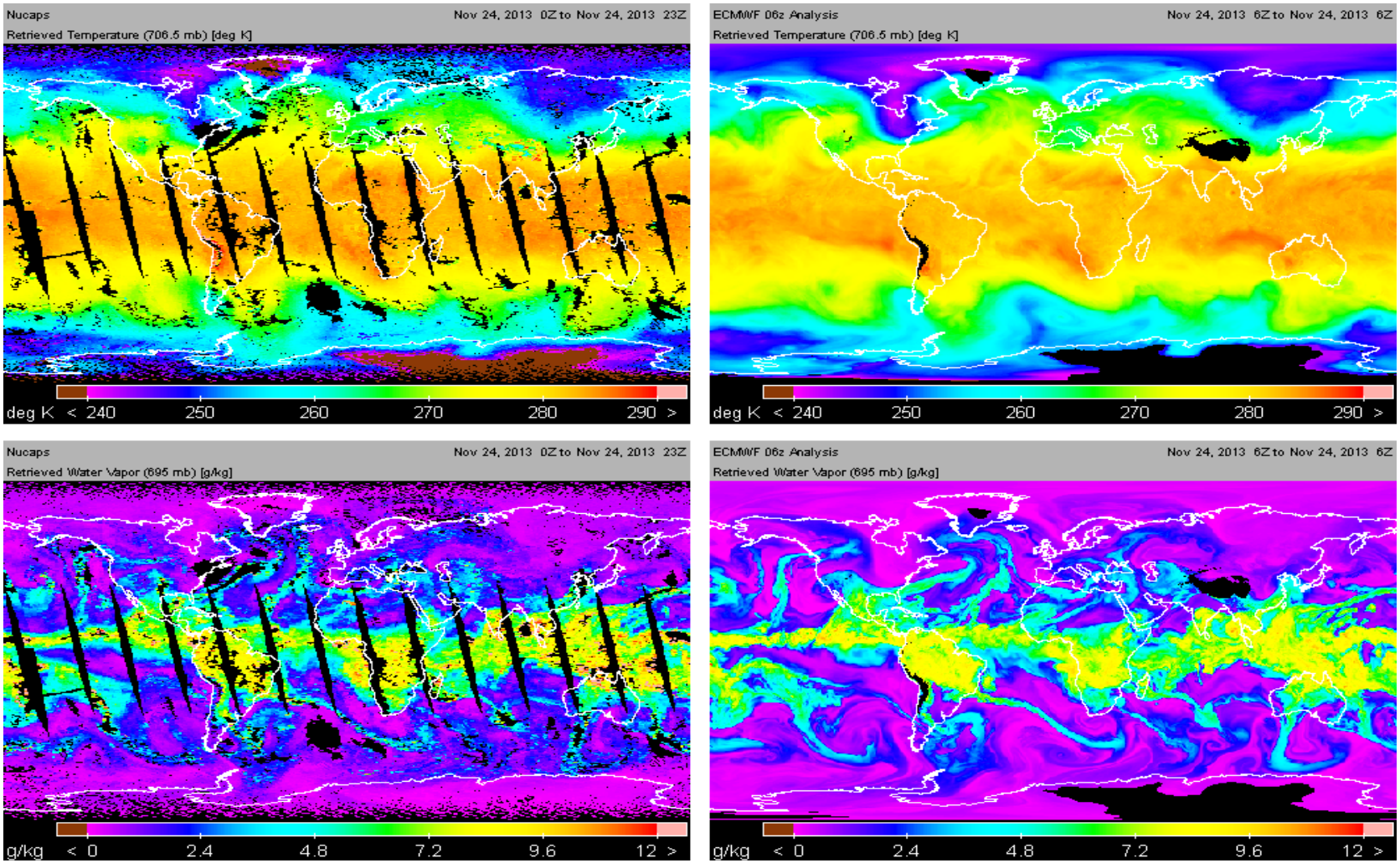
a. Aerosols and Ocean Science Expeditions (AEROSE)

b. ECMWF Global Analysis

c. Dedicated radiosondes

NUCAPS Products

NUCAPS vs ECMWF, T and H_2O

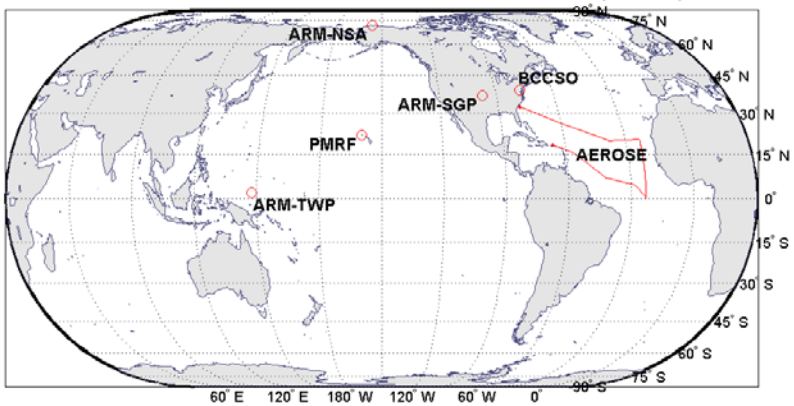


Black indicate where IR+MW and MW-only failed qc …

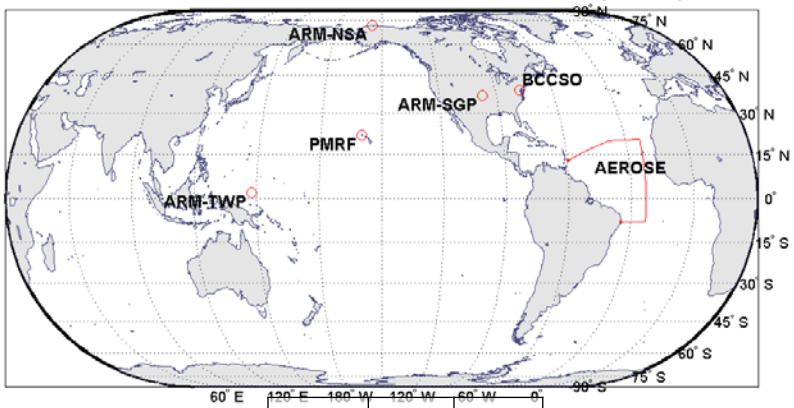
Dedicated and GRUAN Reference RAOB

JPSS S-NPP Dedicated

S-NPP CrIMSS EDR ICV Dedicated RAOB Sites (Year 1)



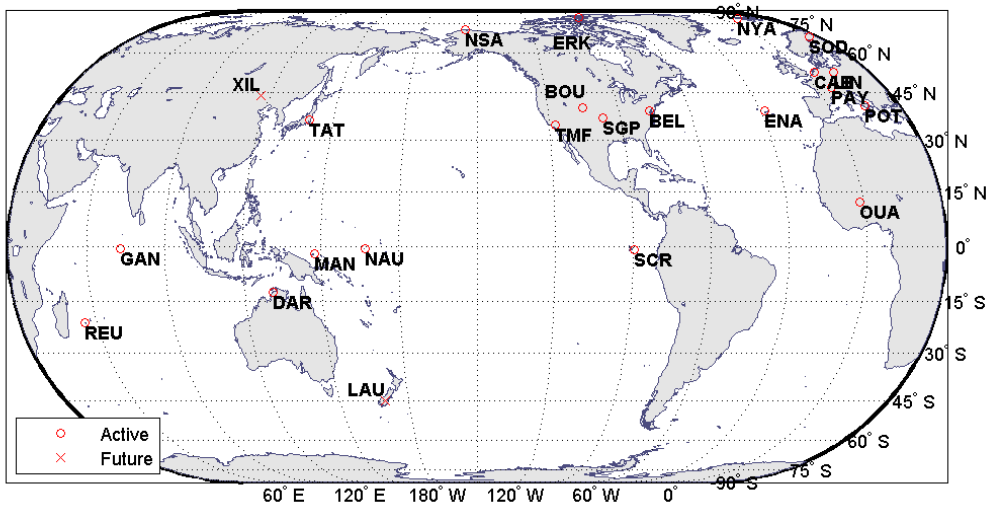
S-NPP CrIMSS EDR ICV Dedicated RAOB Sites (Year 2)



RAOB Site	Lat (deg)	Lon (deg)
ARM-SGP	36.6	-97.5
ARM-NSA	71.3	-156.6
ARM-TWP	2.06	147.43
PMRF	22.05	-159.78
BCCS	39.05	-76.88
AEROSE	Tropical Ocean	

GRUAN Reference Sites (NPROVS+ Collocation)

GRUAN RAOB Sites for Sounder EDR ICV

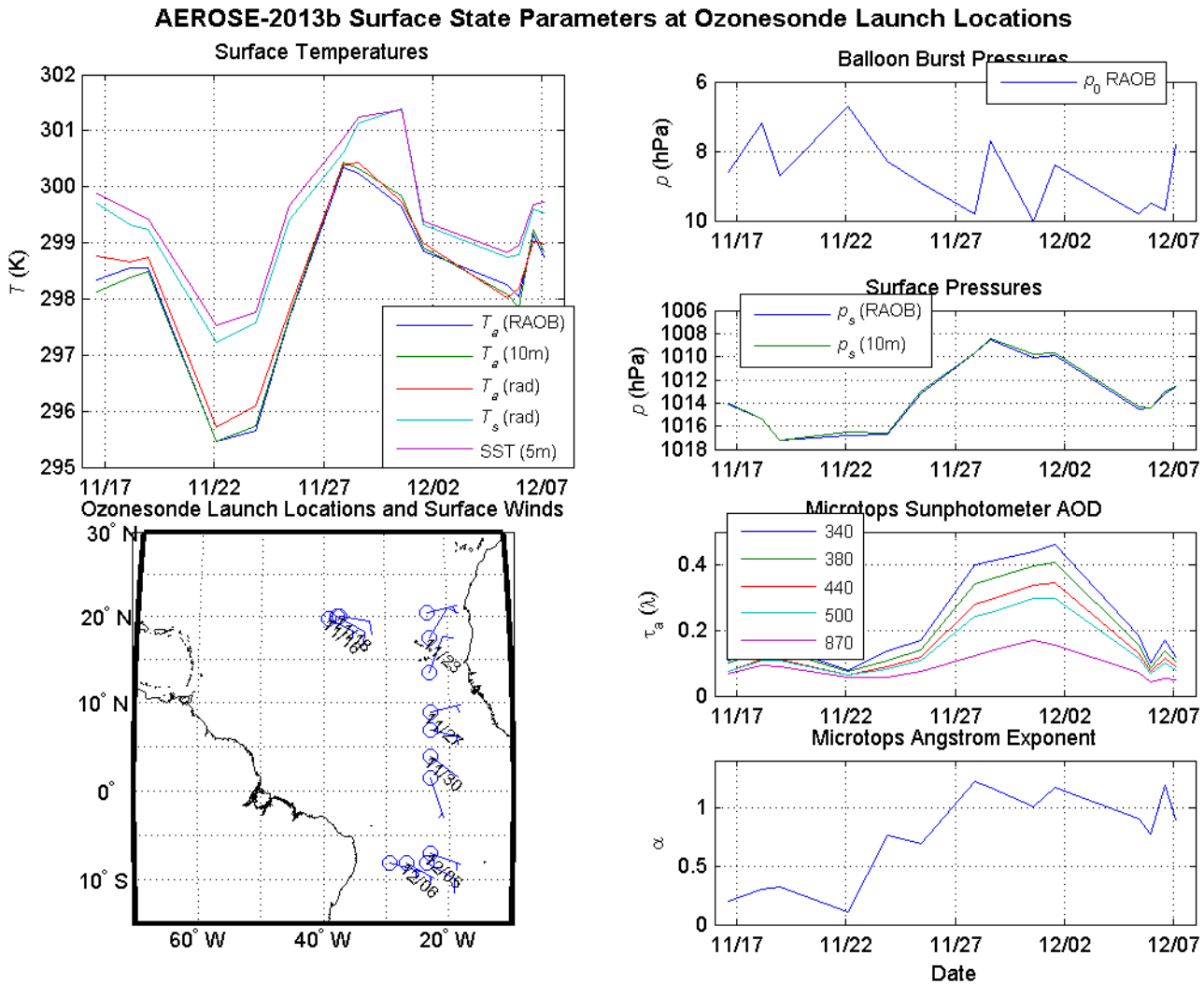


Location	BEL	BOU	CAB	DAR	ENA	ERK	GAN	HIH	LAU	LIN	MAN	NAU
Lat (deg)	39.05	39.95	52.1	-12.475	39.05	79.98	-0.69	19.72	-45.04	52.22	-2.06	-0.52
Lon(deg)	-76.88	-105.2	5.18	130.83	-28.03	-85.93	73.15	-155.05	169.68	14.12	147.43	166.92

Location	NSA	NYA	OUA	PAY	POT	REU	SRC	SGP	SOD	TAT	TMF	XIL
Lat (deg)	71.32	78.92	12.4	46.81	40.6	-21.08	-0.9	36.61	67.37	36.06	34.39	43.95
Lon(deg)	-156.6	11.92	-1.5	6.95	15.72	55.38	-89.6	-97.49	26.63	140.1	-117.7	116.12

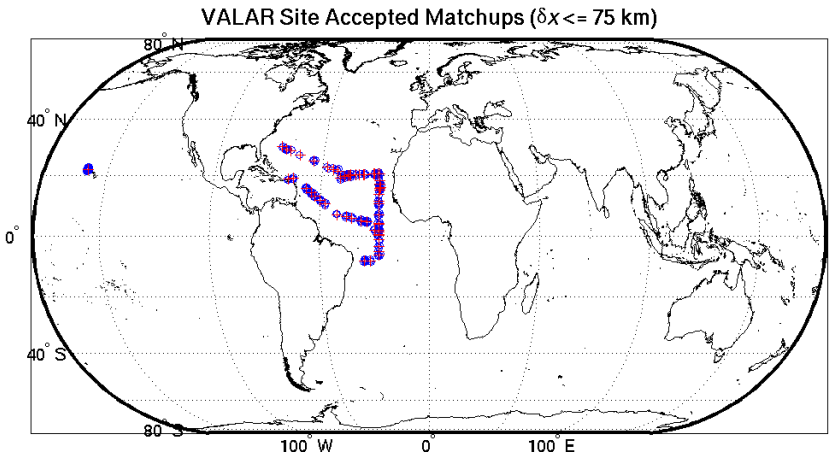
2013 AEROSE State Parameters

$P(z)$, $T(p)$, $H_2O(p)$, $O_3(p)$, T_s, u_s, v_s, AOD

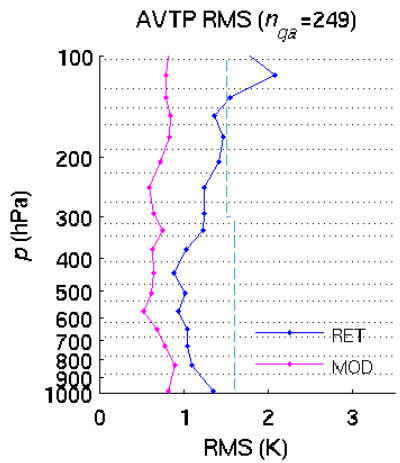


Offline IR + MW

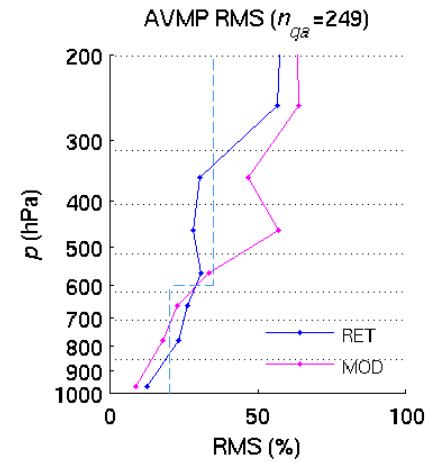
MOD=ECMWF



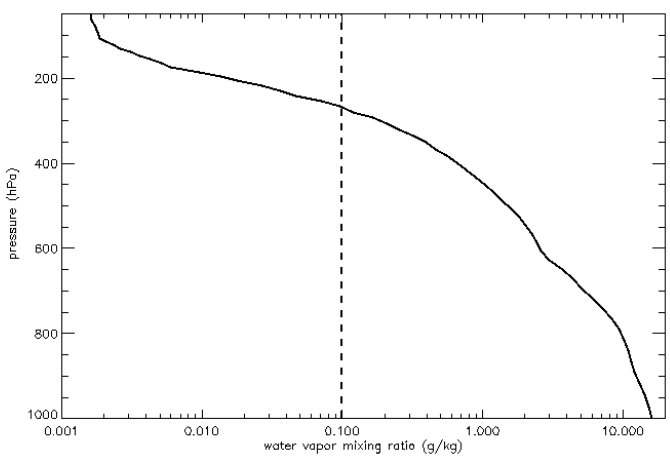
Temperature

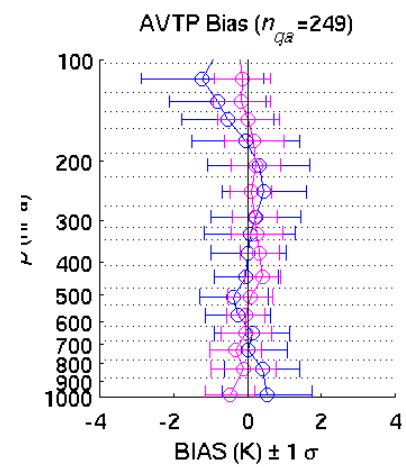


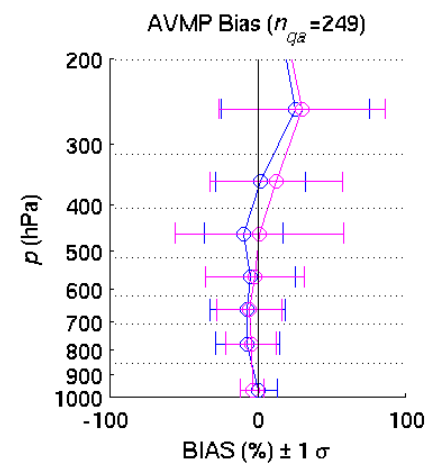
Moisture



Standard tropical water vapor profile

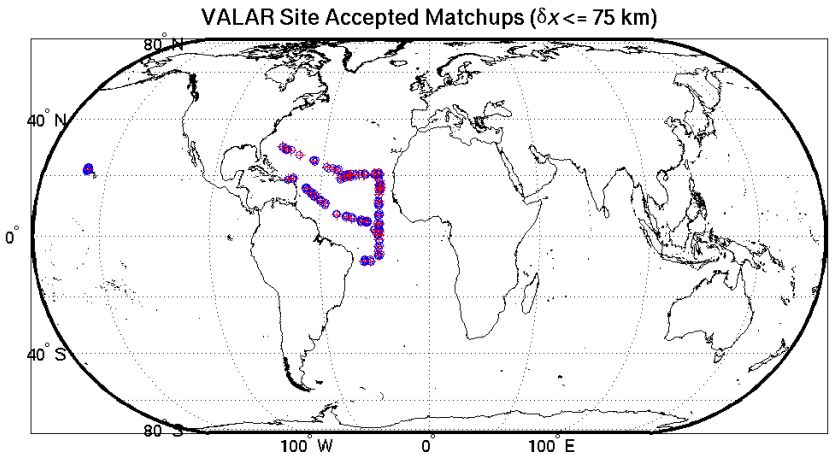




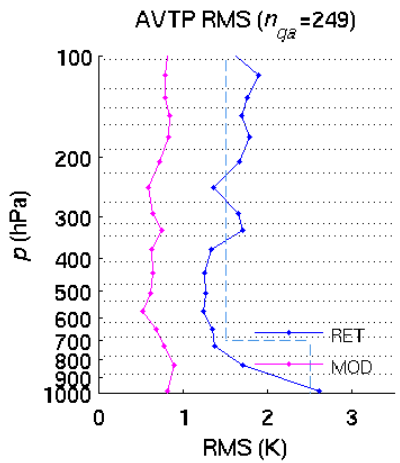


Offline MW-Only (MIT)

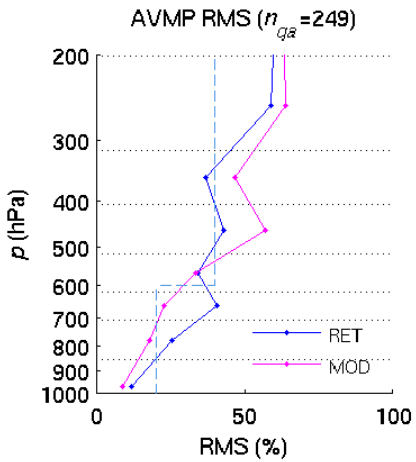
MOD=ECMWF



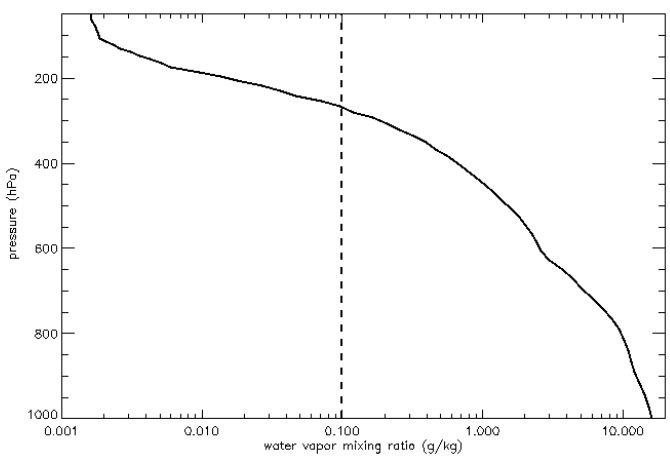
Temperature

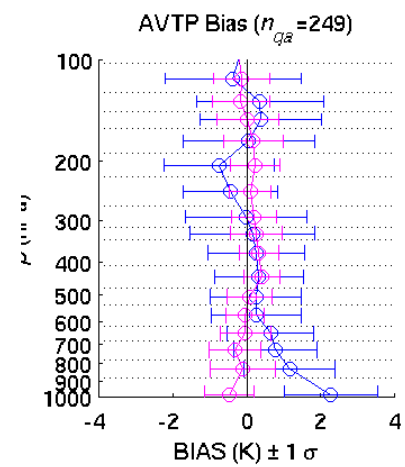


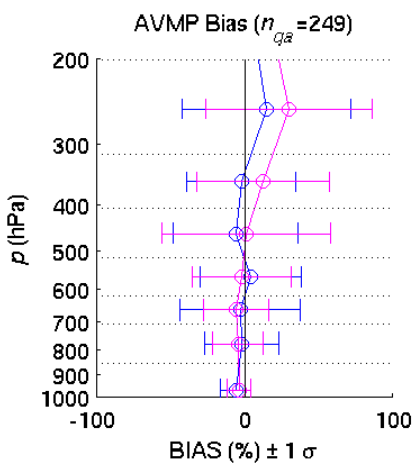
Moisture



Standard tropical water vapor profile







Error Budget for Temperature Profile

	Attribute Analyzed	L1RD Threshold	Analysis/Validation Result	Error Summary
	Geographic coverage	90% every 18 hours	> 90%	
	Vertical Coverage	Surface to 0.5 mb	Surface to 0.016 mb	
	Vertical Cell Size	0.2 ~50 mb	0.2 ~ 30 mb	
	Horizontal Cell Size	50 km at nadir	50 km at nadir	
	Mapping Uncertainty	5 km	5 km	
	Measurement Range	Propose 150 ~ 400 K	200 ~ 310 K	
	Cloud < 50%: Surface to 300 mb	1.6 K per km layer	1.34 K per km layer	
IR + MW	300 to 30 mb	1.5 K per 3 km layer	1.04 K per 3 km layer	
	30 to 1 mb	1.5 K per 5 km layer	1.04 K per 5 km layer	
	1 to 0.5 mb	3.5 K per 5 km layer	1.04 K per 5 km layer	
	Cloud >= 50%: Surface to 700mb	2.5 K per km layer	2.68 K per km layer	
MW only	700 to 300 mb	1.5 K per km layer	1.88 K per km layer	
	300 to 30 mb	1.5 K per 3 km layer	1.88 K per 3 km layer	
	30 to 1 mb	1.5 K per 5 km layer	1.88 K per 5 km layer	
	1 to 0.5 mb	3.5 K per 5 km layer	1.88 K per 5 km layer	

Error Budget for Moisture Profile

	Attribute Analyzed	L1RD Threshold	Analysis/Validation Result	Error Summary
	Geographic coverage	90% every 18 hours	> 90%	
	Vertical Coverage	Surface to 0.5 mb	Surface to 0.016 mb	
	Vertical Cell Size	0.2 ~50 mb	0.2 ~ 30 mb	
	Horizontal Cell Size	50 km at nadir	50 km at nadir	
	Mapping Uncertainty	5 km	5 km	
	Cloud < 50%: Surface to 600 mb	Greater of 20% or 0.2 g/kg	19.8%	
IR + MW	600 to 300 mb	Greater of 35% or 0.1 g/kg	23.3%	
IR + MW	300 to 100 mb	Greater of 35% or 0.1 g/kg	23.3%	
	Cloud >= 50%: Surface to 600mb	Greater of 20% or 0.2 g/kg	23.6%	
MW only	600 to 400 mb	Greater of 40% or 0.1 g/kg	32.2%	
MW only	400 to 100 mb	Greater of 40% or 0.1 g/kg	32.2%	

VALIDATION SUMMARY

- **NUCAPS MW+IR**
  - **meets requirements globally vs ECMWF**
  - **meets requirements over ocean vs ECMWF**
  - **Close to meet requirements globally and over selected areas vs Dedicated RAOBs**

- **NUCAPS MW – Only**
  - **NUCAPS MW Only close to meet requirements globally vs ECMWF**
  - **NUCAPS MW only close to meet requirements over ocean vs ECMWF**
  - **meets requirements over tropical western pacific dedicated RAOBs**

- **Present issues in the validation truth:**
  - Residual temporal and spatial mismatch between retrievals and model: ECMWF mismatch is +/- 1.5 hour and +/- 0.25 deg and we use both forecast and analysis depending on UT time.
  - Uncertainty in the ECMWF model
  - Residual temporal and spatial mismatch (75km) between retrievals and RAOBs considerably affects water vapor statistics (up to 10% due to 50km mismatch, especially in the UTH due to RAOB drift)
  - Uncertainty in the RAOBs (supersaturation, calibration uncertainty)
- **Ongoing activity:**
  - We are aware that there is a need for updating the look up tables for both the MW-Only and MW+IR retrieval:
    - A priori, First guess, radiance bias correction

Support CrIS SDR

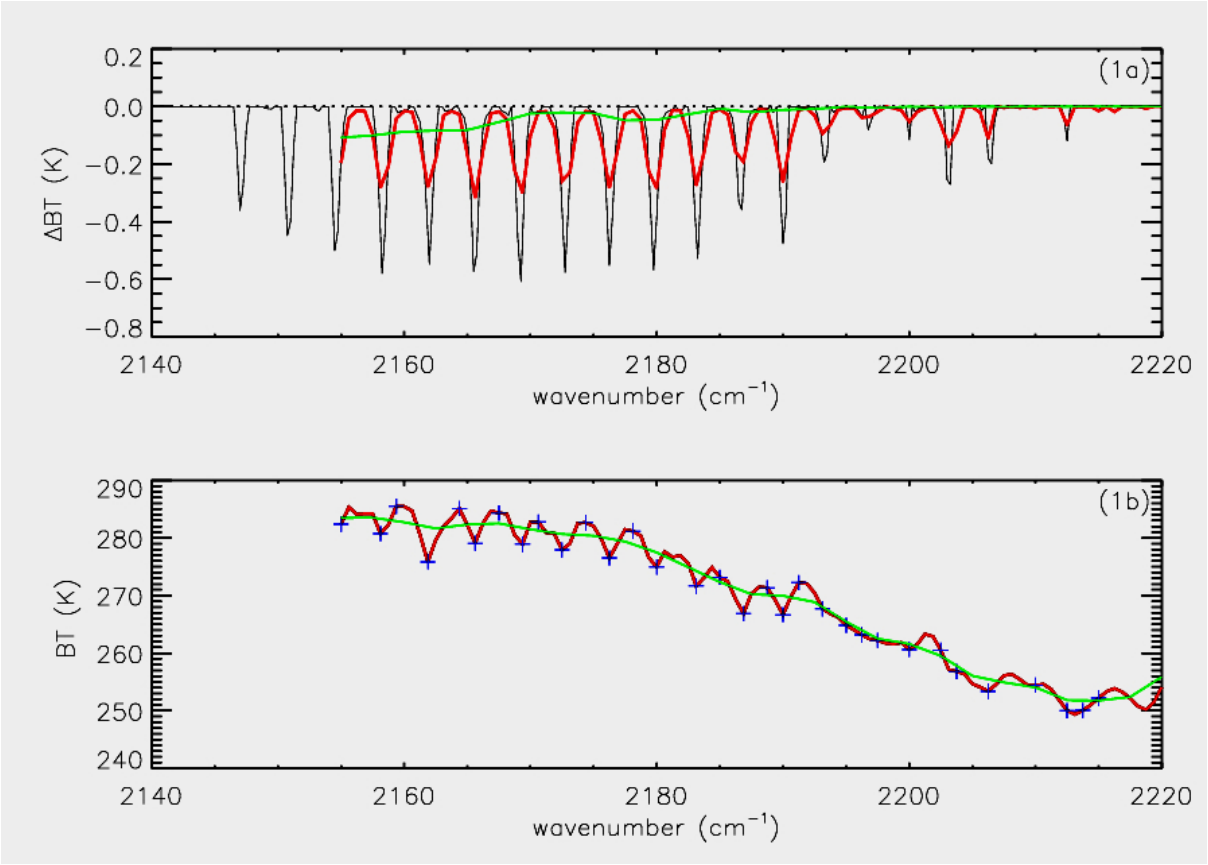
- Full Spectral Requirement
  - CrIS full spectral data are required for trace gas retrievals.

- ILS
  - Inhomogeneity effect on CrIS spectral shift is < 3 ppm, smaller than noise.

- Discard one FOV for direct full-spectral CrIS broadcast
  - The corner FOV 7 should provide a slight better contrast, but the large noise of FOV 7 degrades the use. Our recommendation is to discard FOV 7 instead of FOV 4 for NPP CrIS full spectral data direct broadcast.

Sensitivity Analysis to 1% CO perturbation

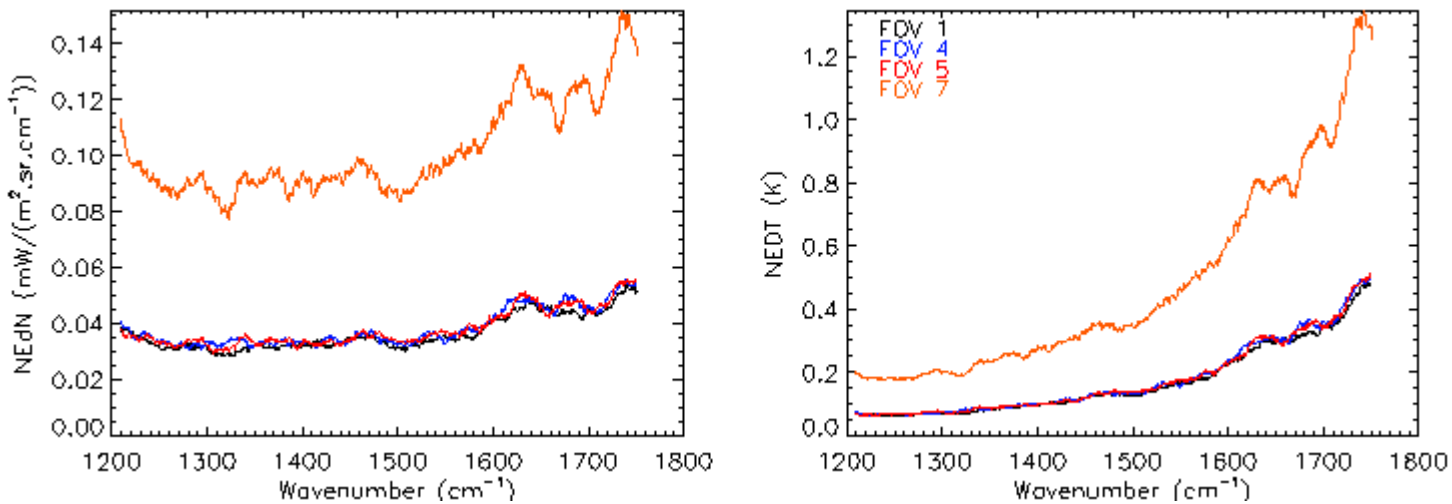
2.5cm^-1 0.625 cm^-1 0.25cm ^-1



Ref: ***Gambacorta et al., IEEE Geoph. And Rem. Sen. Letters, 2014.***

- Only when switched to high spectral resolution, CrIS spectrum (red curve, bottom part) shows the distinctive signature of CO absorption (red and black curve, top figure).
- Blue cross symbols: CO high resolution channel selection.

CrIS MW NEDN FOV in full spectral data



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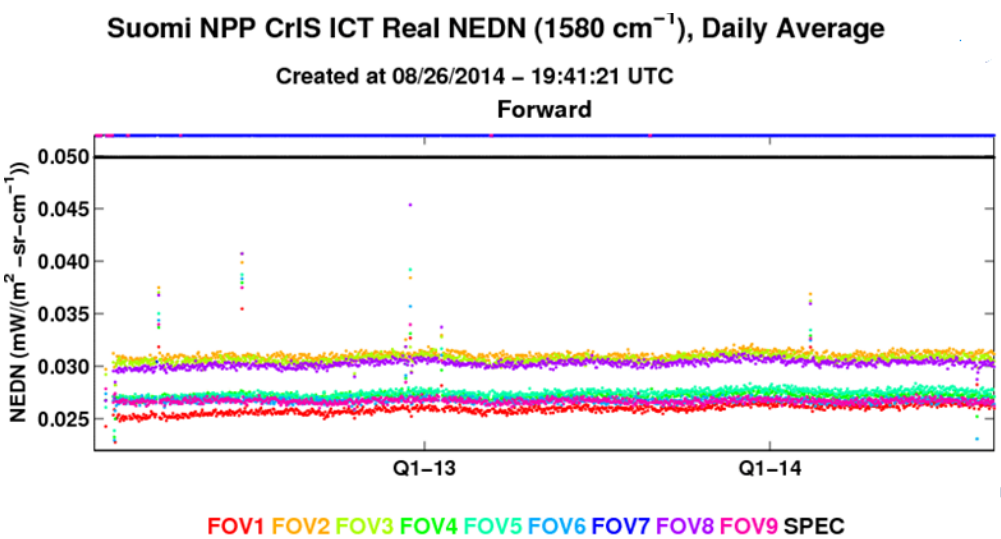

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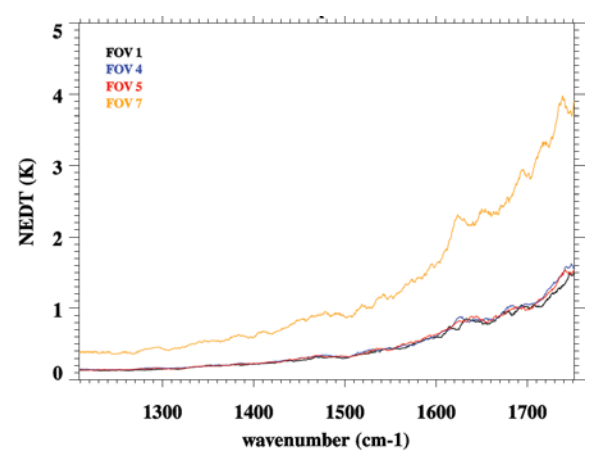

NeDT depends strongly on scene temperature.

Courtesy of X. Jin, Y. Chen, L. Wang

Conclusion

- **NUCAPS Validation Results Summary**
  - NUCAPS IR+MW AVTP and AVMP EDRs are demonstrated to meet the threshold requirements (on the coarse coarse-layers) as follows:
    - Ocean and land versus global ECWMF model
    - Tropical marine regions (ship and island) versus high-quality dedicated RAOBs (e.g., AEROSE, TWP and PMRF)
  - NUCAPS MW-only (MIT algorithm) EDRs are demonstrated to be close to meeting the threshold requirements for the same data samples.
  - NUCAPS AVTP and AVMP EDRs are publicly available on the NOAA CLASS. NUCAPS products are available from AWIPS II and forecasters have started to use the product.

Path Forward

1) Make quality flag simple
2) Improve MW only performance
3) Update IR+MW surface emissivity tables
4) Standardize retrieval code
5) Unified Hyperspectral Sensors' Sounding System
6) CrIS full spectral channel selection for NWP and NUCAPS
7) CrIS Full Spectral Data in Sounding System
8) Trace Gas (CO, CO_2, and CH_4) Algorithm Tuning, Validation, and Verification
9) Single FOV Retrieval

Presentations

Xiaozhen (Shawn) Xiong NOAA
Atmospheric CH4 and N2O from Thermal Infrared Sounders:
Retrieval, Validation and Monitoring of their Increase Trends at 1:00 PM, session 6

Antonia Gambacorta NOAA
The NOAA operational hyper spectral retrieval system: algorithm description and inter-consistency among the AIRS/AMSU,IASI/AMSU/MHS and CrIS/ATMS systems at 4:45 PM, session 7

Tony Reale
NOAA Comparison of IASI, NUCAPS and AIRS V6 Soundings Using the
NOAA Products Validation System at 5:00 PM

Nicholas Nalli
NOAA Validation of the NOAA Unique CrIS/ATMS Processing System
(NUCAPS) Operational Retrieval Products at 5:15 PM

Xu Liu
LARC Single Field of View Cloudy Retrieval using Combined IR and MW
Sounder Data at 9:40 AM, session 8

Chris Barnet NOAA
The development and validation of the Community Hyper-Spectral Infrared Microwave Earth Retrieval Algorithm (CHIMERA): the path Forward, at 10:30 AM