Validated Stage 1 Science Maturity Review for Soundings

Science Review:	*January 8, 2014*	*Page2*
Delta Review:	*September 3, 2014*	*Page 137*

Justification for NUCAPS / CrIMSS EDR Stage-1 Maturity
Jan. 8, 2014
NCWCP

Tony Reale, CrIMSS EDR Validation and Algorithm Lead

Richard Cember, CrIMSS EDR JAM

Significant inputs were made from the entire CrIMSS EDR Algorithm and Validation Team Members.

OUTLINE

- **Team Members**
- **Project Goals**
- **Activities / Achievements**
- **Validation Results**
- **Summary**

TEAM MEMBERS

Lead for Activity	Organization	Task
Tony Reale	NOAA/NESDIS/STAR	CrIS/ATMS EDR Cal/val and Alg Dev (Divakarla, Xiong, Nalli, Iturbide, Tan) … IMSG
Tony Reale	NOAA/NESDIS/STAR	NPROVS/NPROVS+ (Sun, Pettey, Brown, Tilley …) IMSG
Ralph Ferraro	NOAA/NESDIS/STAR	Precipitation Flag

Lead for Activity	Organization	Task
Xu Liu	NASA/LaRC	CrIMSS EDR Algorithm Validation (Kizer)
Hank Revercomb	SSEC	AVMP/AVTP validation (Knuteson)
Dave Tobin	SSEC	ARM-RAOBS at NWP, SGP, NSA
Larrabee Strow	UMBC	OSS validation and comparisons to SARTA

TEAM MEMBERS

Lead for Activity	Organization	Task
Tony Reale	JPSS /ARM/ PNNL	VAISALA RS 92 Dedicated RAOB @ ARM (Nalli, Tobin, Mather …) IMSG/CIMSS/ARM

TEAM MEMBERS

(never funded)

SDR/EDR	Lead for Activity	Organization	Task
ATMS SDR, CrIS SDR, CrIMSS EDR	Degui Gu / Denise Hagan / Xia-Lin Ma	NGAS	EDR /SDR Validation, code integration
ATMS TDR/SDR	Sid Boukabara	NOAA/STAR	MiRS EDR
CrIMSS EDR	Lars Peter Riishojgaard	JCSDA	NCEP analysis
CrIMSS SDR	Steven Beck	Aerospace Corp.	RAOB,LIDAR
CrIMSS SDR	Steven English	UKMET	UKMET analysis
AVTP/AVMP	Lee, Fishbein, Freidman …	NASA/JPL	Sounder PEATE
CrIMSS SDR	Ben Rustin	NRL	NOGAPS/NAVDAS
Eric Maddy	STC	NUCAPS EDR Development and Validation	

****

A. Gambacorta …	IMSG	NUCAPS EDR Development and Validation

PROJECT GOALS

- **Algorithm Development**
  a) **Finalize / Transition CrIMSS to NUCAPS**
  b) **Troubleshoot and Upgrade NUCAPS**
  c) **NOAA compatible algorithm; AIRS, IASI, CrIS**
  d) **Product uncertainty**

- **EDR Validation**
  a) **NPROVS** *(conv RAOB, legacy SAT, NWP…)*
  b) **NPROVS +** *(ref/ded RAOB, legacy sat, ground, SSE … SDR, re-retrieval … algorithm development)*
  c) **leverage existing CrIMSS / NUCAPS** *(focus day, dedicated RAOB, SSE …)*

ALGORITHM DEVELOPMENT

- **Objectives:**
  a) **Finalize / Transition CrIMSS to NUCAPS**
  b) **Troubleshoot and Upgrade NUCAPS**
  c) ***NOAA compatible algorithm; AIRS, IASI, CrIS***
  d) ***Entice users***

- **Methods:**
  a) **Merging of CrIMSS (IDPS) with NUCAPS (NDE) Programs**
  b) **Leverage Project Legacy, NPROVS and NPROVS+ Validation Capabilities**
  c) ***tbd …***
  d) ***Product Uncertainty …***

WHY SOUNDING EDR

- Product of Prime Interest for Weather / Climate
- ***Demonstration of Complete Sensor Capability***
- Legacy
- RT Model Validation
- Users (NWS, Research …)

Users of CrIMSS EDR

In reality, Sounding EDR has (very) limited user base

- NOAA-TOAST product considering use of CrIMSS O3-IP (within NDE)
- **AWIPS has decided to use the NOAA-Unique CrIS/ATMS Processing System (NUCAPS) products**
  - **Desire 100 level product**
  - **Desire continuity with IASI product EDR formats**
  - **Desire rapid R2O environment**
    - **NUCAPS had a successful Alg. Readiness Review on Jan. 14, ready for operations**
    - **Product will be available to users from CLASS in summer 2013**
- CrIMSS-EDR is a baseline operational product
  - Physical-only 1DVAR approach is unique for hyperspectral IR
  - Can explore capabilities for NWP applications.
    - Retrievals are a "test-bed" for exploitation of CrIS radiances.
    - These capabilities are usually imbedded directly into NWP
  - Other developers use it as a "standard" to explore trade-offs in methodologies
- Historically, the users of these kinds of products are varied (e.g., climate, air-quality, process studies, etc.)
  - Users tend to be access data as needed for their study, not a 24/7 user.
  - AIRS EDR products are used in ~30-40 publications/year in recent years.
  - AIRS project has identified 100's of unique users of it's EDR standard and support products; however, it is not clear how much volume of data they use.
  - NASA/AIRS team reprocesses the entire Aqua/AIRS dataset at maturity level transitions (v3 beta, v4 provisional, v5 stage.1, v6 stage.2, etc.) → could attract users.

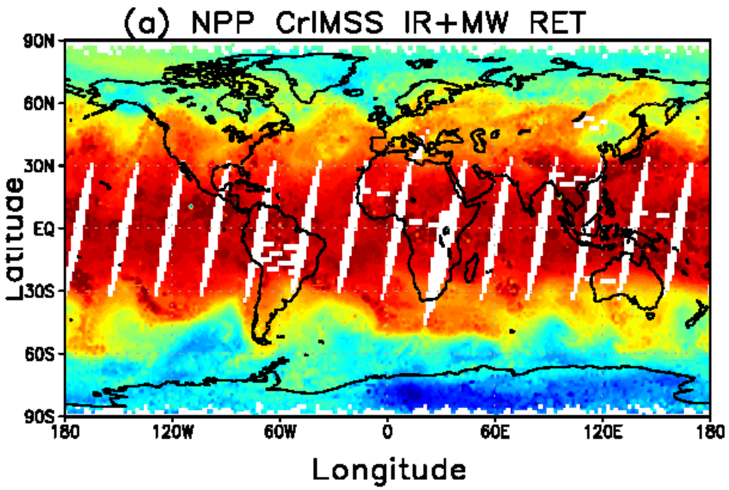
Overview of EDR Data Products (2/4)

Atmospheric Vertical Temperature Profile (AVTP).

Used for initialization of high-resolution NWP models, atmospheric stability, etc.

Lower tropospheric temperature are no-longer KPPs.

Parameter (**Lev 3; no KPP**)	IORD-II, JPSS-L1RD
AVTP Partly Cloudy, surface - 300 mb	**1.6 K/1-km layer**
AVTP Partly Cloudy, 300 to 30 mb	1.5 K/3-km layer
AVTP Partly Cloudy, 30 mb to 1 mb	1.5 K/5-km layer
AVTP Partly Cloudy, 1 mb to 0.5 mb	3.5 K/5-km layer
AVTP Cloudy, surface to 700 mb	**2.5 K/1-km layer**
AVTP Cloudy, 700 mb to 300 mb	1.5 K/1-km layer
AVTP Cloudy, 300 mb to 30 mb	1.5 K/3-km layer
AVTP Cloudy, 30 mb to 1 mb	1.5 K/5-km layer
AVTP Cloudy, 1 mb to 0.05 mb	3.5 K/5-km layer



Example of AVTP at 500 hPa on May 15, 2012 from the CrIMSS off-line EDR
Results are from the coupled algorithm without QC

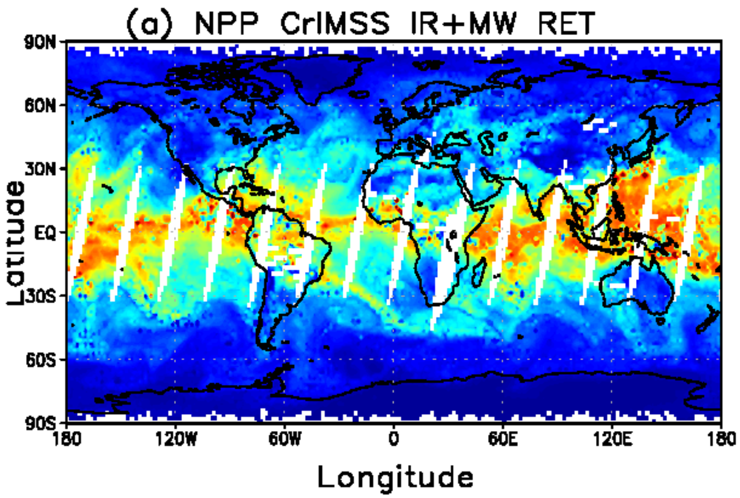
Barnet, Prov

Overview of EDR Data Products (1/4)

Atmospheric Vertical Moisture Profile (AVMP).

Used for initialization of high-resolution NWP models, atmospheric stability, etc.

Lower tropospheric moisture layers are no longer Key Performance Parameters (KPPs) .



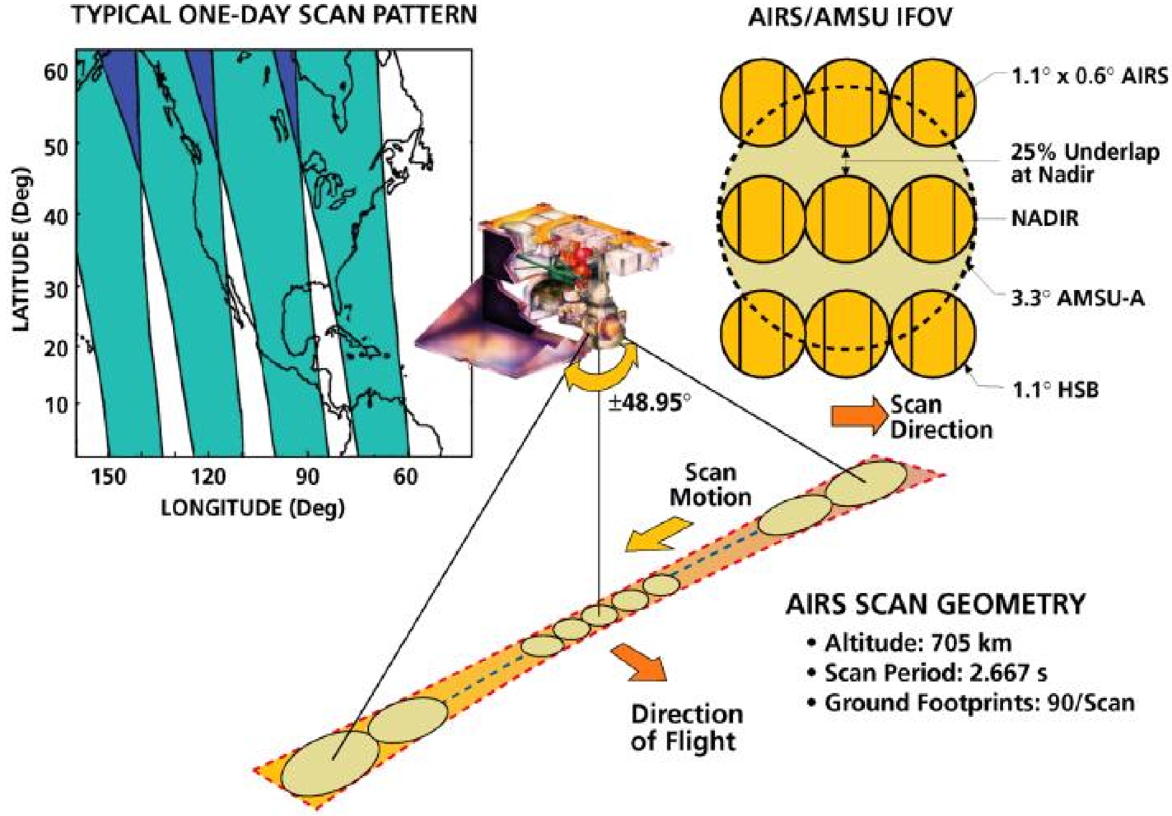
Parameter (KPP(**Lev 3 …)**	IORD-II, JPSS-L1RD
AVMP Partly Cloudy, surface to 600 mb	**Greater of 20% or 0.2 g/kg**
AVMP Partly Cloudy, 600 to 300 mb	Greater of 35% or 0.1 g/kg
AVMP Partly Cloudy, 300 to 100 mb	Greater of 35% or 0.1 g/kg
AVMP Cloudy, surface to 600 mb	**Greater of 20% of 0.2 g/kg**
AVMP Cloudy, 600 mb to 300 mb	Greater of 40% or 0.1 g/kg
AVMP Cloudy, 300 mb to 100 mb	Greater of 40% or 0.1 g/kg

Example of AVMP (shown as total precipitable water) on May 15, 2012 from the CrIMSS off-line EDR

Results are from the coupled algorithm without QC

Overview of EDR Data Products (3/4)

- Sounding is performed on 50 km field of regard (FOR).
- FOR is currently defined by the size of the microwave sounder footprint.
- IASI/AMSU has 4 IR FOV's per FOR
- AIRS/AMSU & CrIS/ATMS have 9 IR FOV's per FOR.
- ATMS is spatially over-sampled and can emulate an AMSU FOV.

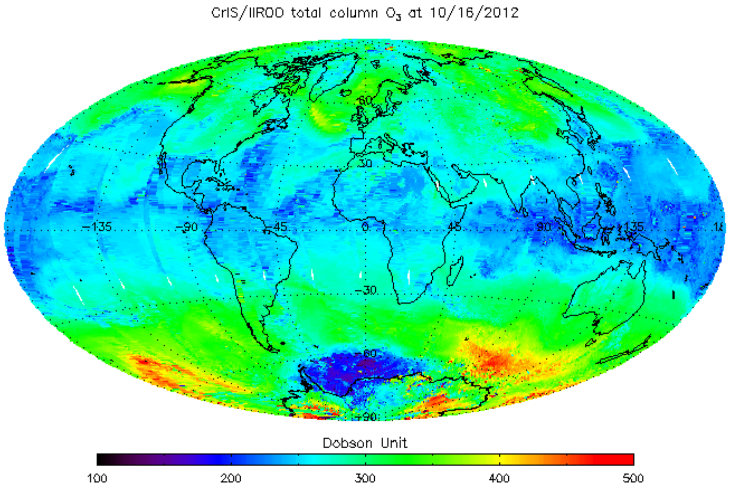


… additional stamp info (500km area centered at RAOB) supports development

Barnet, Prov

Overview of EDR Data Products (4/4)

- Pressure product is a EDR derived product that requires validation.
- Ozone is an intermediate product (IP) used by the OMPS team.
- CO, CH_4 and CO_2 are pre-planned product improvements(P^3I)
  - SOAT has recommended full-resolution RDR's for CrIS SW and MW bands to support these products..



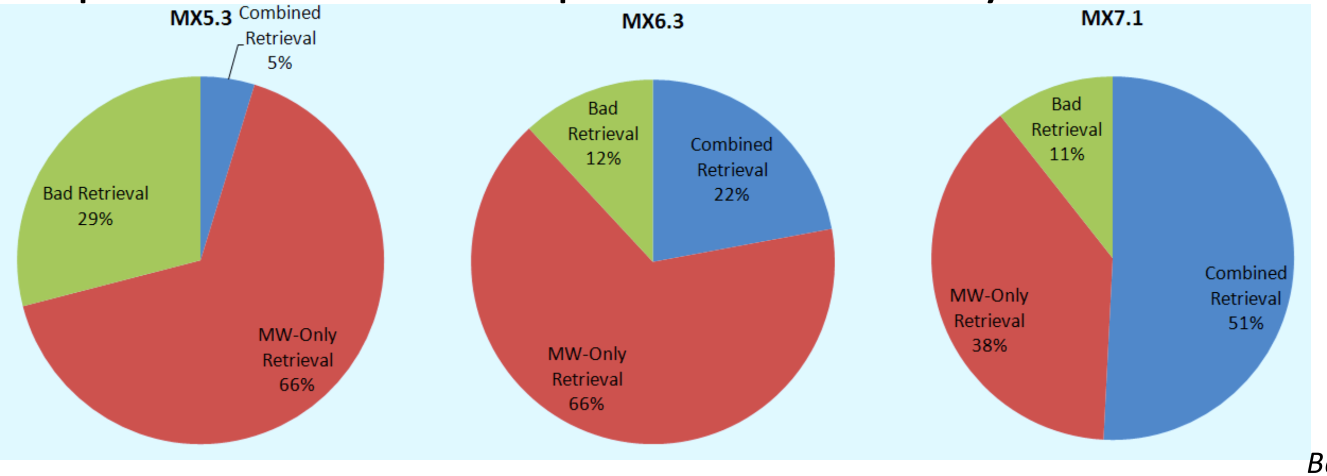
Example of CrIMSS total column ozone IP product (day+night) from CrIS for Oct. 16, 2012.

Parameter (P^3I in Blue)	IORD-II / JPSS-L1RD
Pressure Profile	4 mb threshold, 2 mb goal
Ozone IP	20% precision for ~5 km layers from 4 hPa to 260 hPa
CH_4 (methane) column	1% ± 5% / 1% ± 4% (precison ± accuracy)
CO (carbon monoxide) column	3% ± 5% / 35% ± 25% (precision ± accuracy)

Barnet, Prov

Algorithm Achievements

- Mx5.3, operational since April 1, 2012
  - This is the *beta* maturity system
- Mx6.4 (a.k.a. Mx6.3), operational since Oct. 12, 2012
  - Added empirical bias corrections for ATMS, updated CrIS
- Mx6.6, expected to be operational in Feb. 2012
  - Fixed an indexing bug for non-LTE and ozone channels
  - Significant improvements in daytime yield (from 4% to 50%)
- Mx7.1, expected to be operational in June 2012
  - Improvements in both performance and yield



Barnet, Prov

Algorithm Achievements

The following DRs were completed after MX7.1 (Provisional), and placed in MX8.0.

DR 3193: Typo in NEDN ratio.
Description: Currently the operation code uses a value of 4.246 as the ratio of the clear-radiance differences and the NEDN of the channel. The ATBD calls out a value of 3*sqrt(2) or 4.2426 as the value. The code and ATBD should be consistent. Change all occurrences of 4.246 in the code to 4.2426. (Also, define 4.2426 as a constant, rather than having multiple occurrences of 4.246 in the code.)

DR 7116: Noise Amplification factor coding error
Description: The noise amplification factor was not done correctly when clear skies occur. For clear skies, this value was set to an error (999999) until a partly cloudy or cloudy profile occurred, at which point clear skies kept the last partly cloudy or cloudy value. This sets ccnaf properly to 1/9, which leads to a reported value of 0.333333 in the noise amplification factor.

DR 7119: Cloud Path Mislabel
Description: The definitions for cloudy, partly cloudy, and clear in the QC flags were not consistent with their usage in the code. Clear scenes should not use cloud clearing, partly cloudy scenes should be cloud cleared, and cloudy scenes should not execute the ir+mw portion of the code. The new definition connects clear, partly cloudy, and cloudy scenes to their usage to be consistent.

DR 7197: "Proper Assignment of Quality Control Flags for Combined Microwave and Infrared Retrieval that Terminates Early."
Description: QC flags were not properly assigned when the mw+ir retrieval terminated early. Under specific circumstances, such as overcast skies or high error, the mw+ir retrieval stops. For overcast skies, the QC pass/fail flag for the mw+ir run was based on the prior profile. For high error cases, this high error was intended to automatically fail this flag. However, the error was forgotten when the flag was calculated, resulting in high-error cases with passing QC flags.

Algorithm Achievements

The following DR's were intended for the future MX8.1.
However, they have not yet been implemented in operations:

DR 4068/4069: Precipitation Update
Description: The precipitation algorithm in the original EDR was outdated. This DR replaces the old algorithm with a new algorithm based on MSPPS.

DR 4923: Surface Pressure was not accurate.
Description: The surface pressure ancillary input was corrected for surface elevation once too often, resulting in incorrect surface pressures over land. This was corrected by commenting out the second correction in get_pres.f

DR 7252: Modifications to Ozone and Water Vapor Retrievals
Description: Overcast profiles for water vapor and ozone contained IP data in the mw+ir product that differed from the microwave-only product. This should not be possible, since the combined mw+ir run never occurs so no data can even exist in the first place. The suggested fix is to report mw-only results in the mw+ir product except for ozone, which would be fill. (Ozone product does not exist for mw-only run.)

Algorithm Achievements

The following DR's already exist, but are still being worked on.
Some may need to be re-opened or resubmitted as DRs:

DR 4943: Change IR-ATM-NOISE and IR-NOISE LUTs.
Changes to these LUTs were based in more realistic noise LUTs for the CrIS instrument. However, they appear to be the culprit for introducing larger errors in the 100-200 mb temperatures over the polar regions. These DRs need to be re-addressed to correct the issues in the polar upper atmosphere.

DR 4944: Create new bias LUTs for CrIS and ATMS.
This has been an ongoing DR. Now that the MW SDRs have been modified to account for side lobes, the bias LUT for ATMS needs to be modified. Otherwise, the side lobes are being corrected for twice.

DR 7206: Add emissivity hinge points to improve the ozone product.
Xu Liu has proposed increasing the number of hinge points from 12 to 16. This would require a new LUT and a minor code change increasing the hinge point number to 16. The end result should be an improved ozone product.

DR 7207: Upgrade emissivity (in climatology LUT) to update emissivity values, and stratify by lat/long and month.
Xu Liu has proposed to stratify the emissivity LUT to stratify by categories such as latitude, longitude, and time of year. This would result in a much larger climatology LUT and changes to the code to incorporate the changes. At a minimum, adjust the emissivities to new values.

Algorithm Achievements

These DR's have either been done without our input (Raytheon), have been dropped due to funding (Northrop Grumman) or have otherwise not actively been pursued:

DR 7069: QF flags are incorrect when ATMS is missing.
This was a DR that was pursued by Raytheon. The off-line code at STAR does not run when ATMS data is missing, since the off-line code does not have access to NWP data. The ADL version may still be able to run.

DR 7118: Water vapor supersaturation is too restrictive in the upper atmosphere.
This was being pursued by Xu Liu, but we haven't seen any updates on this particular topic.

DR 7205: Overcast skies can be called clear.
This was being pursued by Northrop Grumman until funding was discontinued. Two suggestions were being considered: rejecting scenes which resulted in drastic changes of the surface temperature, and forcing clear scenes to have a cloud liquid water content of zero prior to the mw+ir run.

DR 7218: ProfDiff (QF value) is incorrect when ATMS is missing.
Again, this is something raised by Raytheon, which the off-line code is not capable of investigating.

Unassigned DR: Fix the calculation of altitude in making the EDR layered product. Suggested by Xu Liu but not pursued at this time.

Unassigned DR: Remove an incorrect calculation of combined IR noise variance when two separate noise values need to be combined (i.e. iatmnoise==1). In MX7.1, this value was hardwired to zero, so this code never gets executed. Therefore, there's no need to change it in operations. It should still be noted that this is a bug and should be removed from the offline code so that iatmnoise==1 runs properly.

Algorithm Achievements

Transition to NUCAPS Underway

PROJECT GOALS

- **Algorithm Development**
  - a) **Finalize / Transition CrIMSS to NUCAPS**
  - b) **Troubleshoot and Upgrade NUCAPS**
  - c) **NOAA compatible algorithm; AIRS, IASI, CrIS**
  - d) **Product uncertainty**

- **EDR Validation**
  - a) **NPROVS** *(conv RAOB, legacy SAT, NWP…)*
  - b) **NPROVS +** *(ref/ded RAOB, legacy sat, ground, SSE … SDR, re-retrieval … algorithm development)*
  - c) **leverage existing CrIMSS / NUCAPS** *(focus day, dedicated RAOB, SSE …)*

EDR VALIDATION

- **Objectives:**
  - Expand the Project EDR Cal / Val (Provisional) Capability … Stage 1, 2, 3
  - Compare NUCAPS vs CrIMSS … etc
    - *Long term (seasonal) … stage 2, 3*
    - Short term (10-day)
    - *deep dive …*

- **Methods:**
  - Compile / analyze “expanded” NPROVS and NPROVS+ Collocation Datasets
  - *Leverage with legacy project validation capability*

EDR VALIDATION

Validated Definition	Artifacts (Deliverables) All Applicable to Stages 1-4
Validated Stage 1: Using a **limited** set of samples, the algorithm output is shown to meet the threshold performance attributes identified in the **JPSS Level 1 Requirements Supplement with the exception of the S-NPP Performance Exclusions**	The list of required artifacts supporting each stage of Validated Maturity are identical: • Algorithm Assessment o Evaluation of algorithm performance to specification requirements o Evaluation of the effect of required algorithm inputs o Error Budget o Quality Flag analysis/validation o Input from key users • Identification of the processing environment o IDPS Build Number and effectivity date o Version of LUT(s) used o Version of PCT(s) used o Description of environment used to achieve particular stage of Validated • Documentation o Current or updated ATBD o Current or updated OAD (algorithm-related redline updates, if applicable) o README file for CLASS o Product User's Guide (Recommended) • User Precautions o Identification of known issues o List of closed Discrepancy Reports between previous maturity milestone and current maturity milestone. o Assessment of outstanding Discrepancy Reports
Validated Stage 2: Using a **moderate** set of samples, the algorithm output is shown to meet the threshold performance attributes identified in the **JPSS Level 1 Requirements Supplement with the exception of the S-NPP Performance Exclusions**	
Validated Stage 3: Using a **large** set of samples representing global conditions over four seasons, the algorithm output is shown to meet the threshold performance attributes identified in the **JPSS Level 1 Requirements Supplement with the exception of the S-NPP Performance Exclusions**	
Validated Stage 4: Using a **large** set of samples representing global conditions over four seasons, the algorithm output is shown to meet or exceed the objective performance attributes identified in the **JPSS Level 1 Requirements Supplement with the exception of the S-NPP Performance Exclusions**	

Stage 1 … meet threshold performance using "limited" samples …

EDR VALIDATION

Atmospheric Vertical Temperature Profile (AVTP) Measurement Uncertainty – Layer Average Temperature Error	
PARAMETER	**THRESHOLD**
AVTP Clear, surface to 300 mb	**1.6 K / 1-km layer**
AVTP Clear, 300 to 30 mb	**1.5 K / 3-km layer**
AVTP Clear, 30 mb to 1 mb	1.5 K / 5-km layer
AVTP Clear, 1 mb to 0.5 mb	3.5 K / 5-km layer
AVTP Cloudy , surface to 700 mb	**2.5 K / 1-km layer**
AVTP Cloudy, 700 mb to 300 mb	**1.5 K / 1-km layer**
AVTP Cloudy, 300 mb to 30 mb	**1.5 K / 3-km layer**
AVTP Cloudy, 30 mb to 1 mb	1.5 K / 5-km layer
AVTP Cloudy, 1 mb to 0.5 mb	3.5 K/ 5-km layer

Clear ... IR+MW

Cloudy ... (MW only)

Atmospheric Vertical Moisture Profile (AVMP) Measurement Uncertainty – 2-km Layer Average Mixing Ratio % Error	
PARAMETER	**THRESHOLD**
AVMP Clear, surface to 600 mb	**Greater of 20%** or 0.2 g/kg **/ 2-km layer**
AVMP Clear, 600 to 300 mb	**Greater of 35%** or 0.1 g/kg / **2-km layer**
AVMP Clear, 300 to 100 mb	Greater of 35% or 0.1 g/kg / 2-km layer
AVMP Cloudy, surface to 600 mb	**Greater of 20%** of 0.2 g/kg **/ 2-km layer**
AVMP Cloudy, 600 mb to 400 mb	**Greater of 40%** or 0.1 g/kg / **2-km layer**
AVMP Cloudy, 400 mb to 100 mb	Greater of 40% or 0.1 g/kg / 2-km layer

Clear ... IR+MW

Cloudy ... (MW only)

(courtesy Nick Nalli)

EDR VALIDATION
(hierarchial … *Nalli et al, JGR 2014)*

Dataset	Sampling	Characteristics
ECMWF/GFS	Global	±3 hour, model errors, select "Focus Days"
NUCAPS EDR	Global, exact match	NOAA Unique using CrIS/ATMS Significant diagnostic capability
AIRS EDR Products	Global, near exact	NOAA Unique / NASA v6 after April 2013; Orbits are aliased, 16d repeat, different instrument
IASI EDR Products	Global, not so exact (except polar)	NOAA Unique, 4 hour orbit difference, different instrument
GPSRO (COSMIC)	Global ~1000 daily; RAOB anchor	Non synchronous; UTLS (T and H20) and Stratosphere (T up to 5mb); tropopause
Op. RAOB	~200 matchup/day	±3 hours, ±100 km, regional w.r.t. op.systems
Dedicated RAOB	~600 matchup/year	Only a handful of locations

CrIMSS EDR cal/val Team has maintained an "off-line" capability to provide reprocessing for these data sets on many systems (e.g., Mx5.3, 6.4, 6.6, 7.1) including individual changes made for each DR

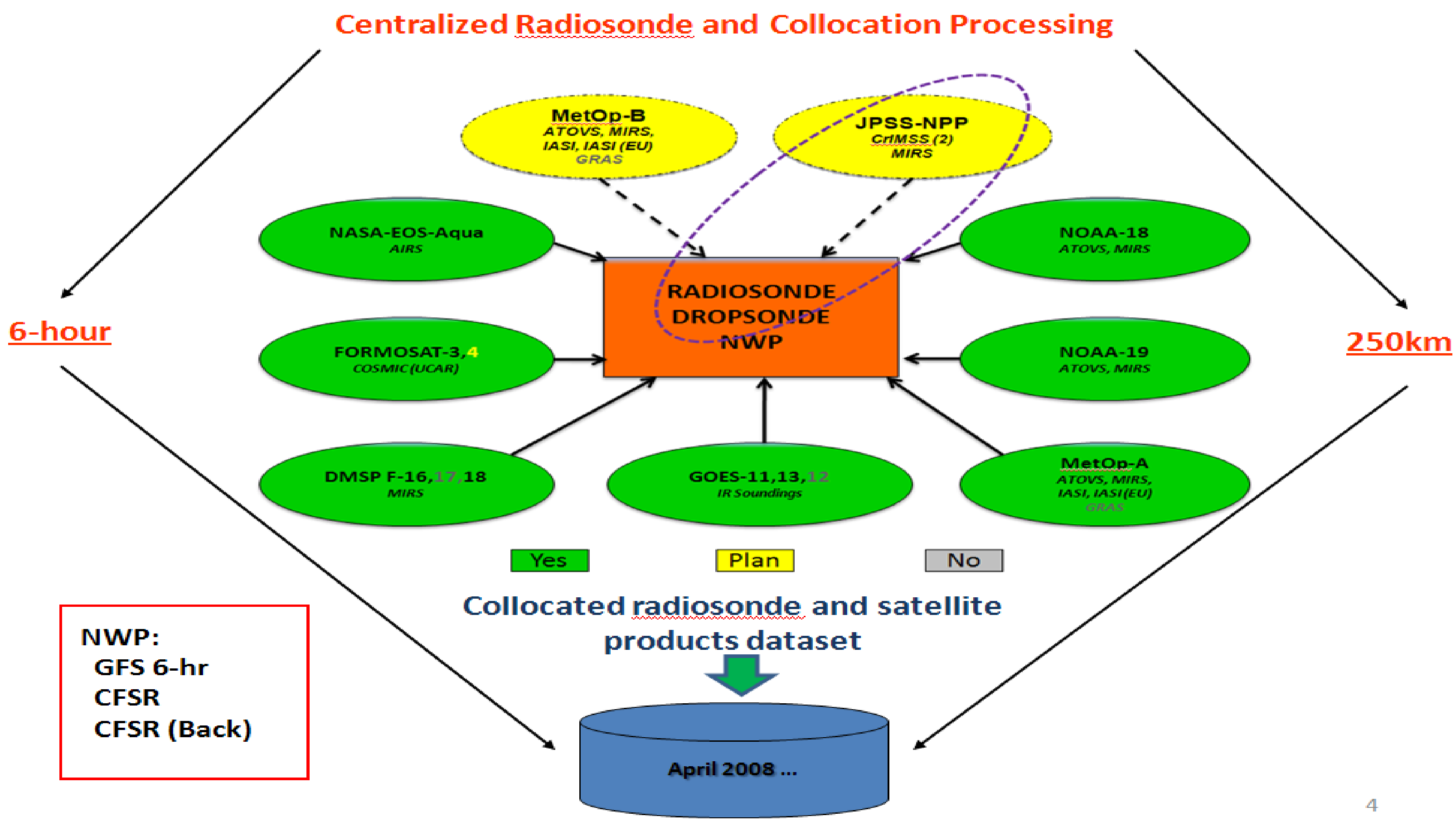
- Allows demonstration of improvements on historical datasets
- Allows maximizing the impact of the investment in "truth" datasets (Barnet, PROV)

EDR Validation

1) NPROVS

conventional RAOB
all legacy sat
large global sample

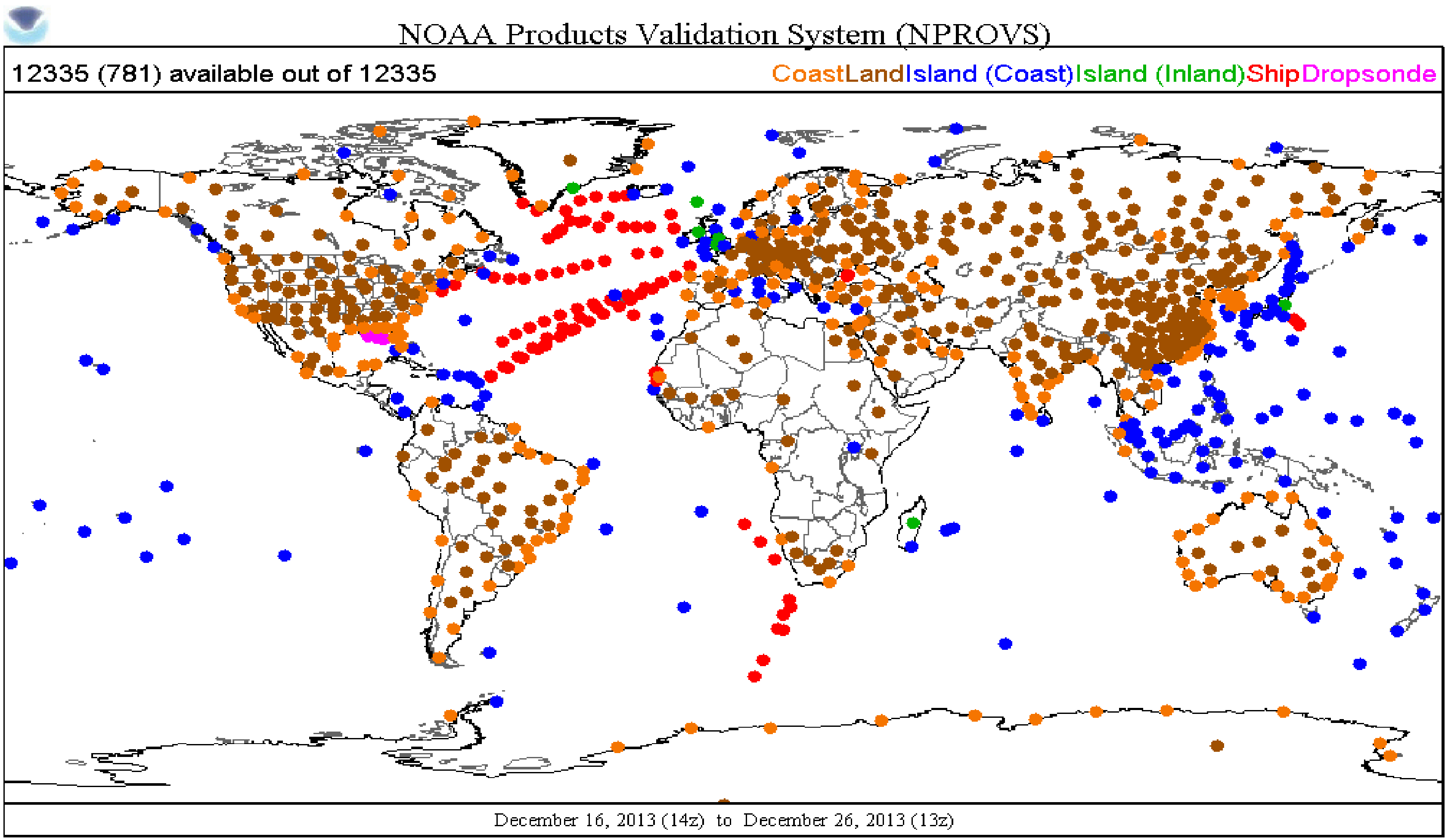
EDR VALIDATION



Conventional RAOB

NOAA Products Validation System (NPROVS)

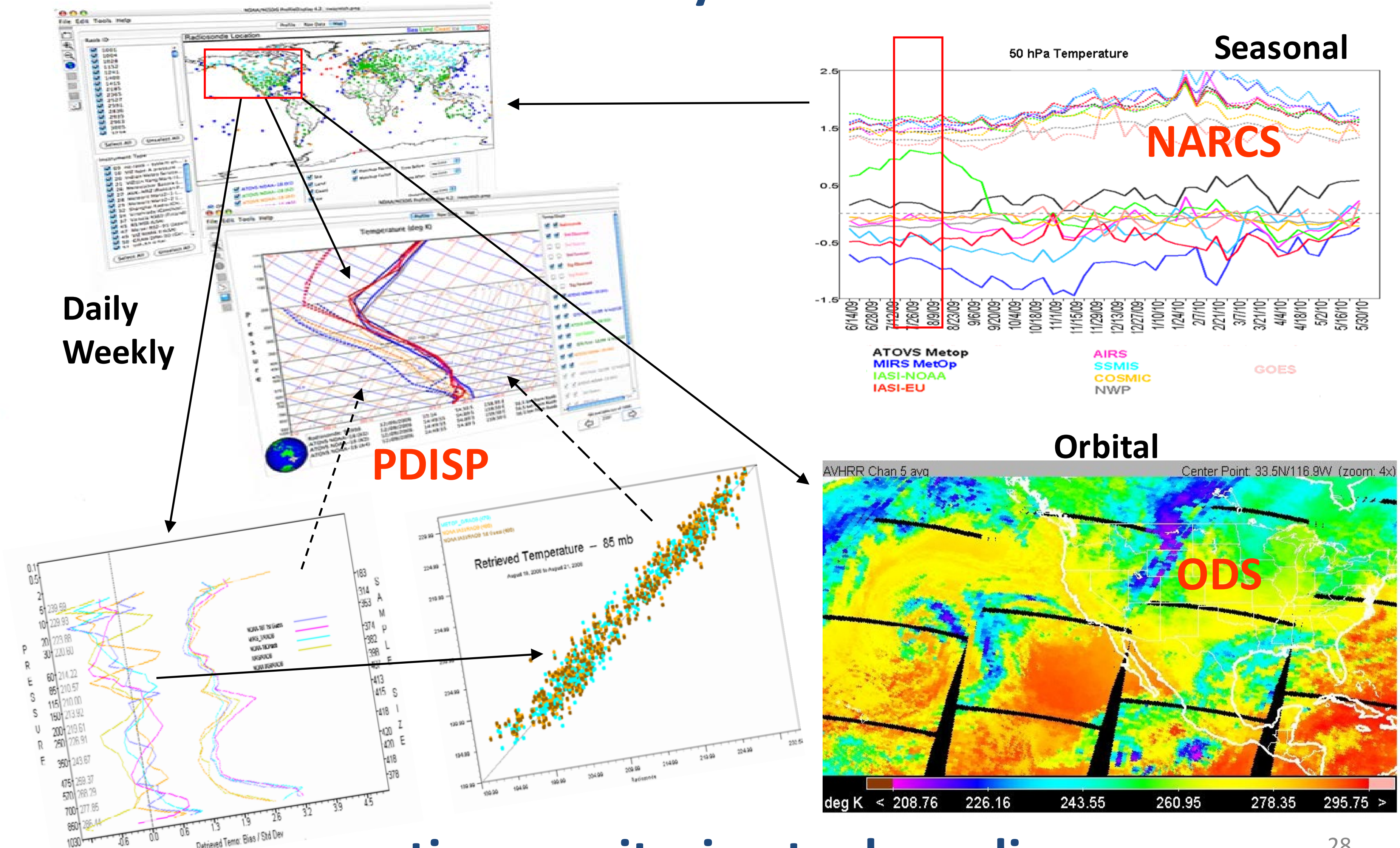
EDR VALIDATION



NPROVS Collocations 12/16 to 12/26 2013 … 12,335

EDR VALIDATION

NPROVS Analytical Interface …



… routine monitoring to deep dive

EDR Validation

2) NPROVS +

Ref/Ded RAOB

select legacy sat

Ground, SSE …

“K” profile analysis

etc

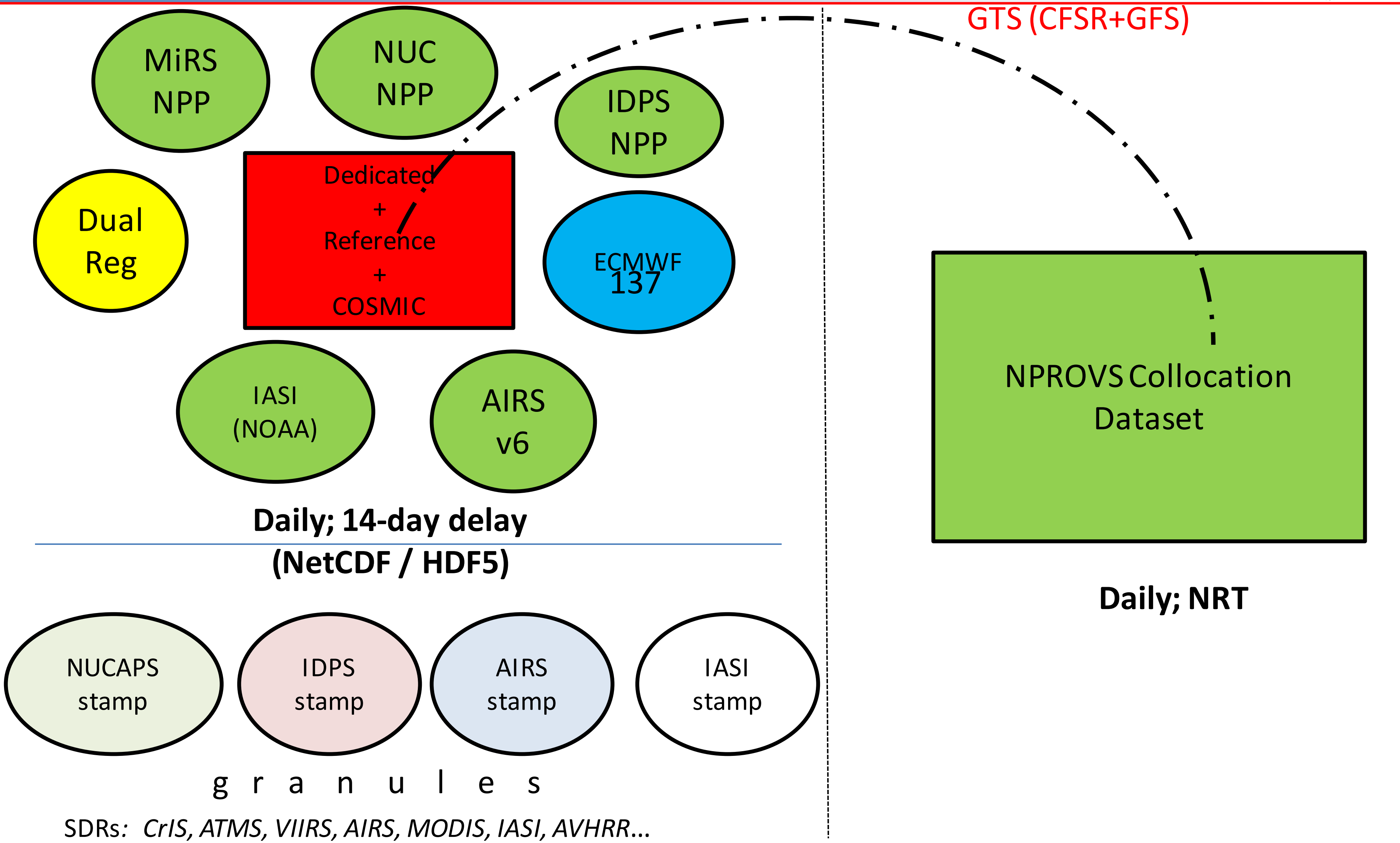
“algorithm development”

SDR

Re-retrieval

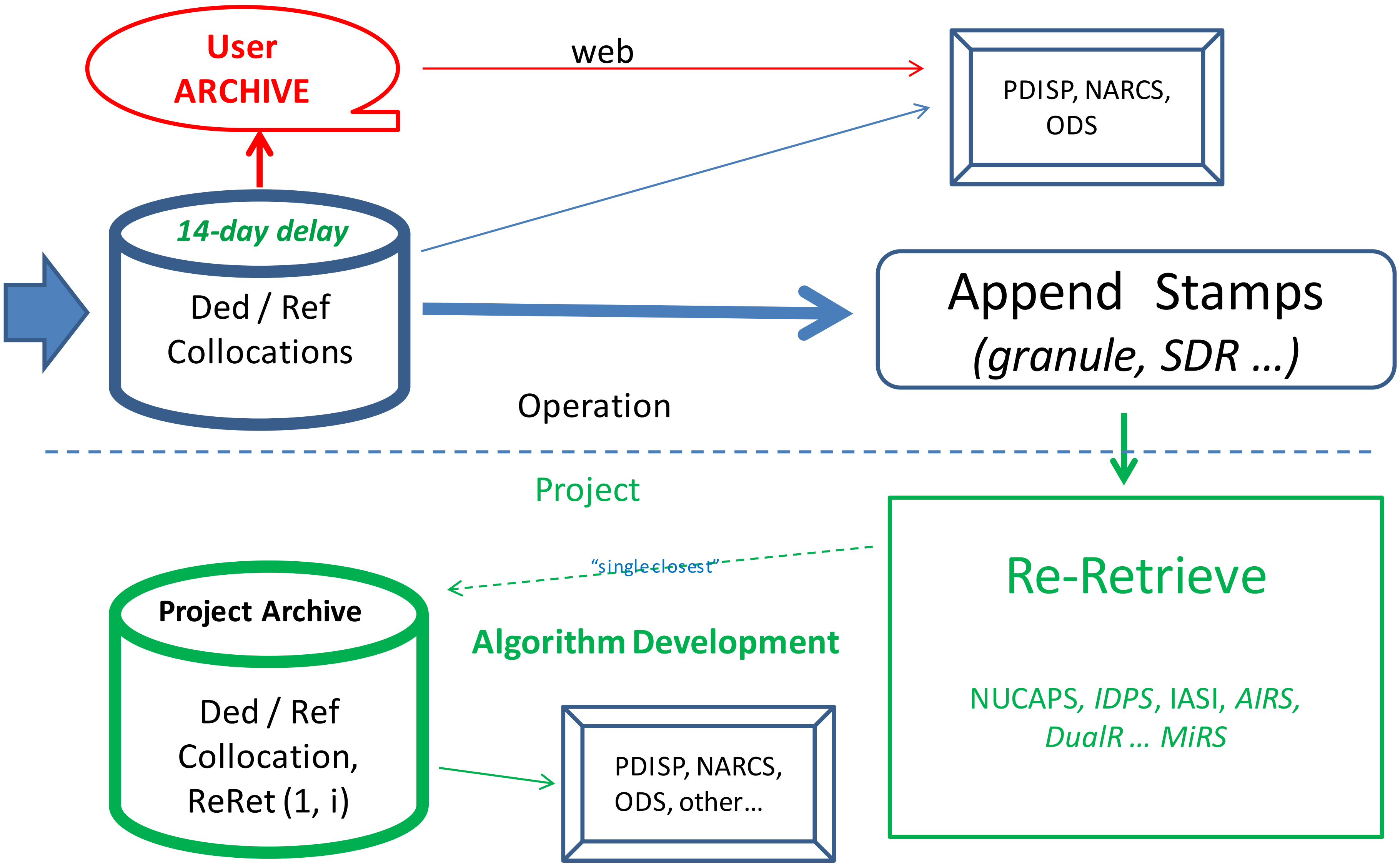
etc …

EDR Validation



NPROVS+

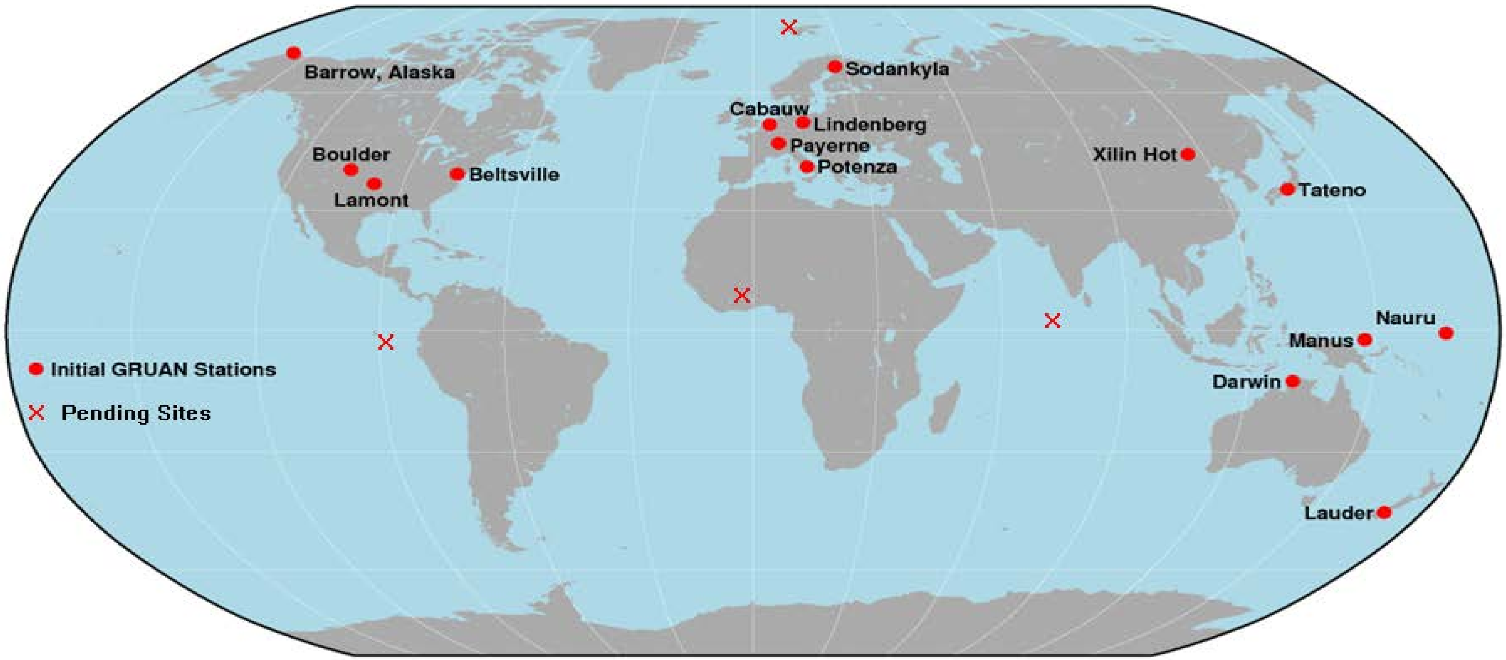
EDR Validation



NPROVS+ … unified validation and development

EDR Validation

GCOS "Reference" Upper AIR Network (GRUAN)



GRUAN 6th International Coordination Meeting (ICM-6) March 10-14, GreenBelt, Hilton

… special Tuesday session on satellite synergies

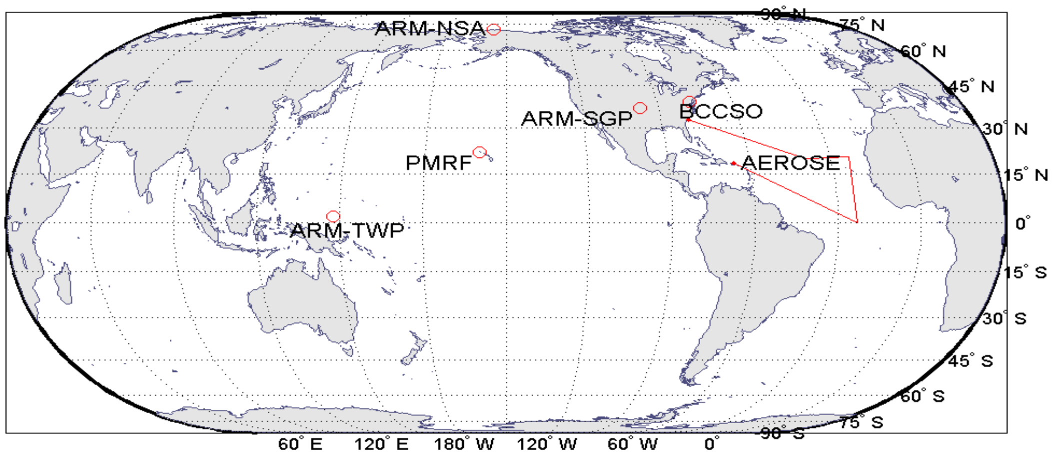
… sites provide reference radiosonde (RS92) plus ancillary ground (lidar, MWR, FTIR …) observations, adherence to best measurement practices GRUAN Manual and Measurement Guideline documents) including specification of "**Measurement Uncertainty**" with plans for up to 40 sites (5+ years)

EDR Validation

Dedicated S-NPP RS92 RAOB funded by JPSS CrIMSS Project

	ARM-TWP	ARM-SGP	ARM-NSA		ARM-TWP	ARM-SGP	ARM-NSA	PMRF	BCCSO	NOAA AEROSE
Location	Manus Island, Papua New Guinea	Ponca City, Oklahoma, USA	Barrow, Alaska, USA	Location	Manus Island, Papua New Guinea	Ponca City, Oklahoma, USA	Barrow, Alaska, USA	Kauai, Hawaii, USA	Beltsville, Maryland, USA	Tropical North Atlantic Ocean
Regime	Tropical Pacific Warm Pool, Island	Midlatitude Continent, Rural	Polar Continent	Regime	Tropical Pacific Warm Pool, Island	Midlatitude Continent, Rural	Polar Continent	Tropical Pacific, Island	Midlatitude Continent, Urban	Tropical Atlantic, Ship
Planned N	90	180	180	Planned N	90	180	180	40	—	≈ 60–120
Launched n_1	**42**	**92**	**93**	Launched n_1	**42**	**92**	**93**	**40**	**23**	**2**
Launched n_2	—	**88**	**90**	Launched n_2	—	**88**	**90**	—	—	**0**
Time Frame	Aug–present	Jul–present	Jul–present	Time Frame	Aug–present	Jul–present	Jul–present	May, Sep	Jun–Jul, Sep–present	Jan–Feb 2013

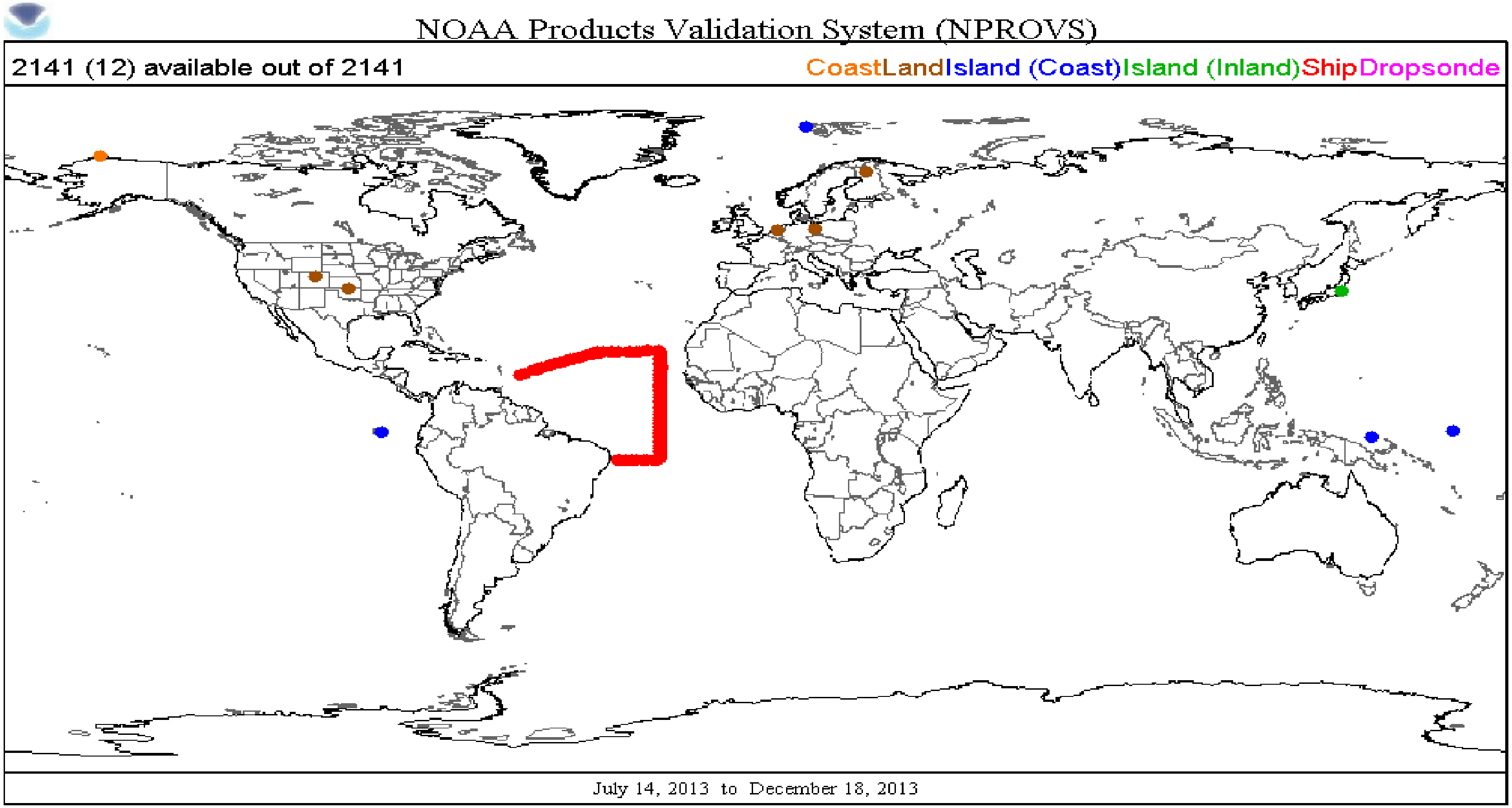
NPP CrIMSS EDR ICV Dedicated RAOB Sites



… ongoing re-structure of ARM scheduling to provide "sustained" year round coverage

EDR Validation

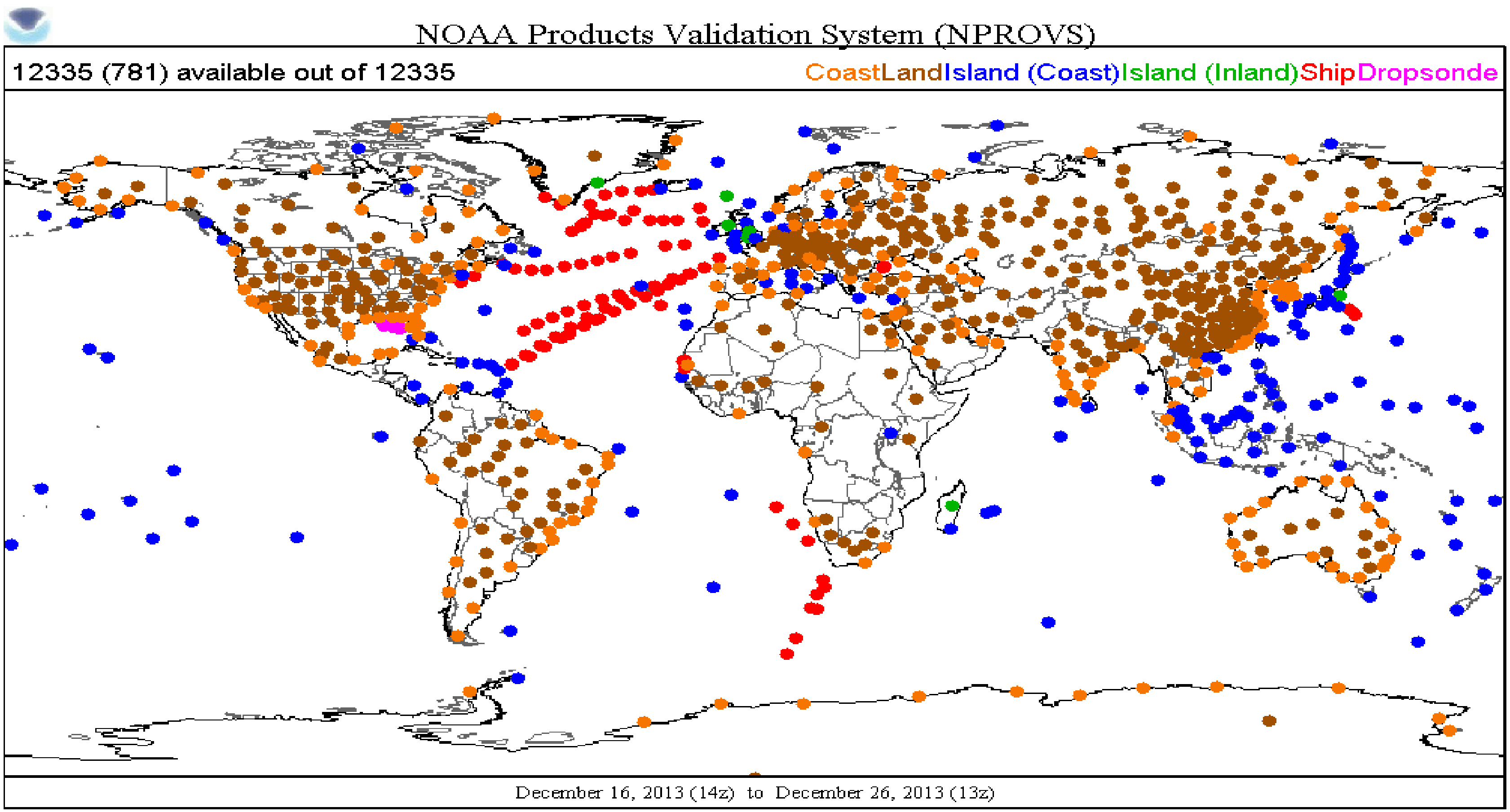
NPROVS+



2050 collocations (350 Dedicated, 1700 GRUAN) … 5mos

EDR Validation

NPROVS



12,335 Collocations 12/16 to 12/26 2013 … 10-days

Preview Results

CrIMSS IDPS Mx7.1 Problem

EDR Validation

IDPS MX 6.3 vs. MX 7.1 Yield Analysis

MX6.3	02/22	02/23	02/24	02/25	4 days	**(10 day)**
– IR+MW	20%	17%	18%	23%	19%	**20%**
– MW-only	61%	63%	64%	59%	61%	**62%**
– Poor	19%	21%	18%	19%	20%	**18%**

MX6.6	03/02	03/03	03/04	03/05	4 days	**(10 day)**
– IR+MW	35%	37%	37%	34%	36%	**34%**
– MW-only	50%	47%	44%	50%	47%	**51%**
– Poor	16%	16%	19%	16%	17%	**15%**

MX7.1	**J U L Y**
- IR+MW	**50.6**
- MW-only	**38.9**
- Poor	**10.4**

EDR Validation

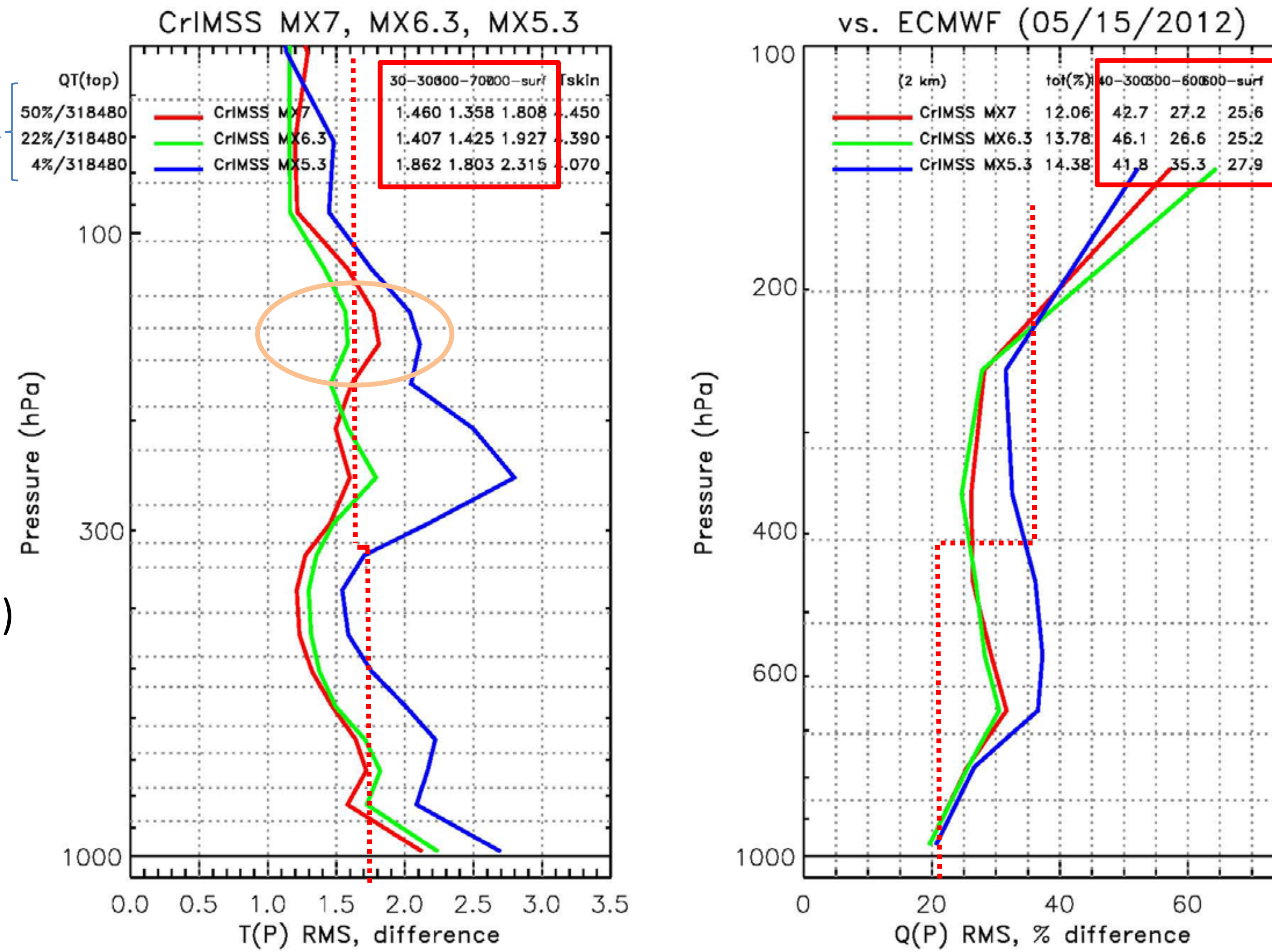
Provisional Maturity Evaluation (Focus Day) for May 15, 2012

Yield has increased from 4% (Mx5.3) to 50% (Mx7.1)

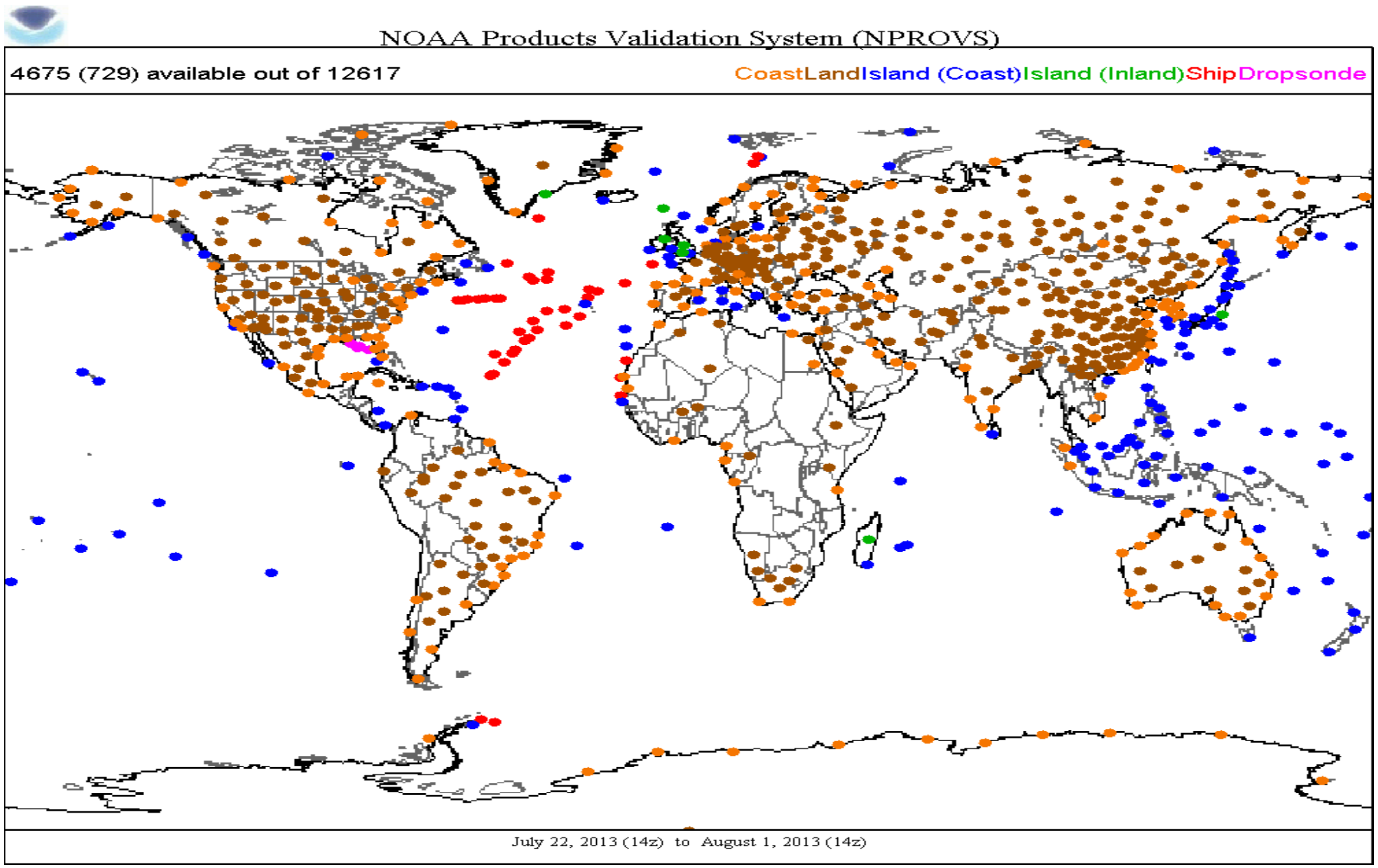
Results are shown w.r.t. ECMWF

Specifications shown as dotted red line (only relevant for GLOBAL RMS) and numerical (red boxes)

Performance has improved with IDPS version (will be summarized in table later)

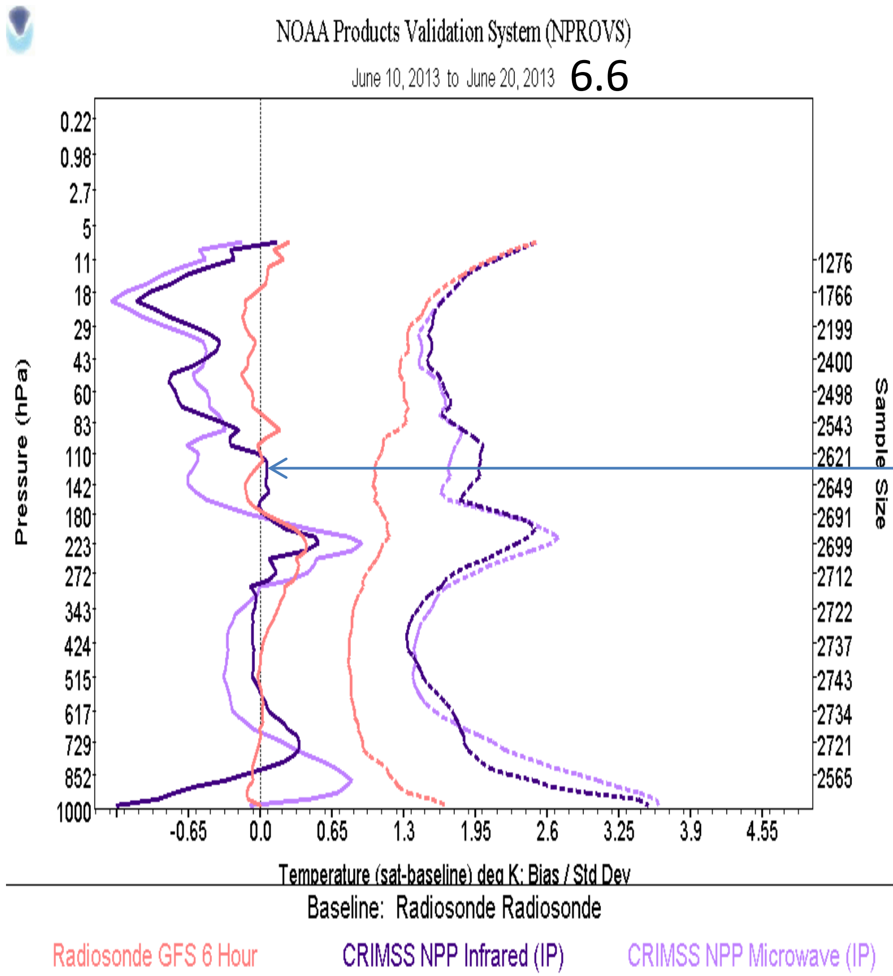


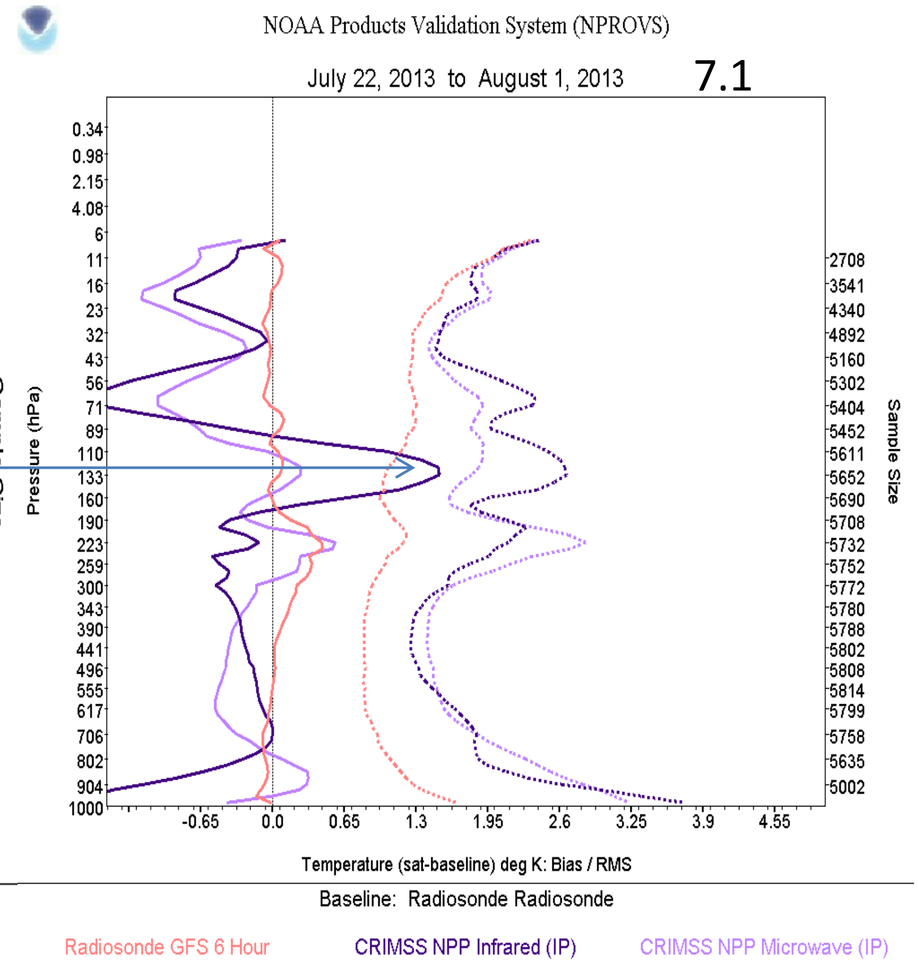
EDR Validation



Collocations containing (IR+MW) EDR from CrIMSS and NUCAPS which passed QC (4675/12617 … 37%)

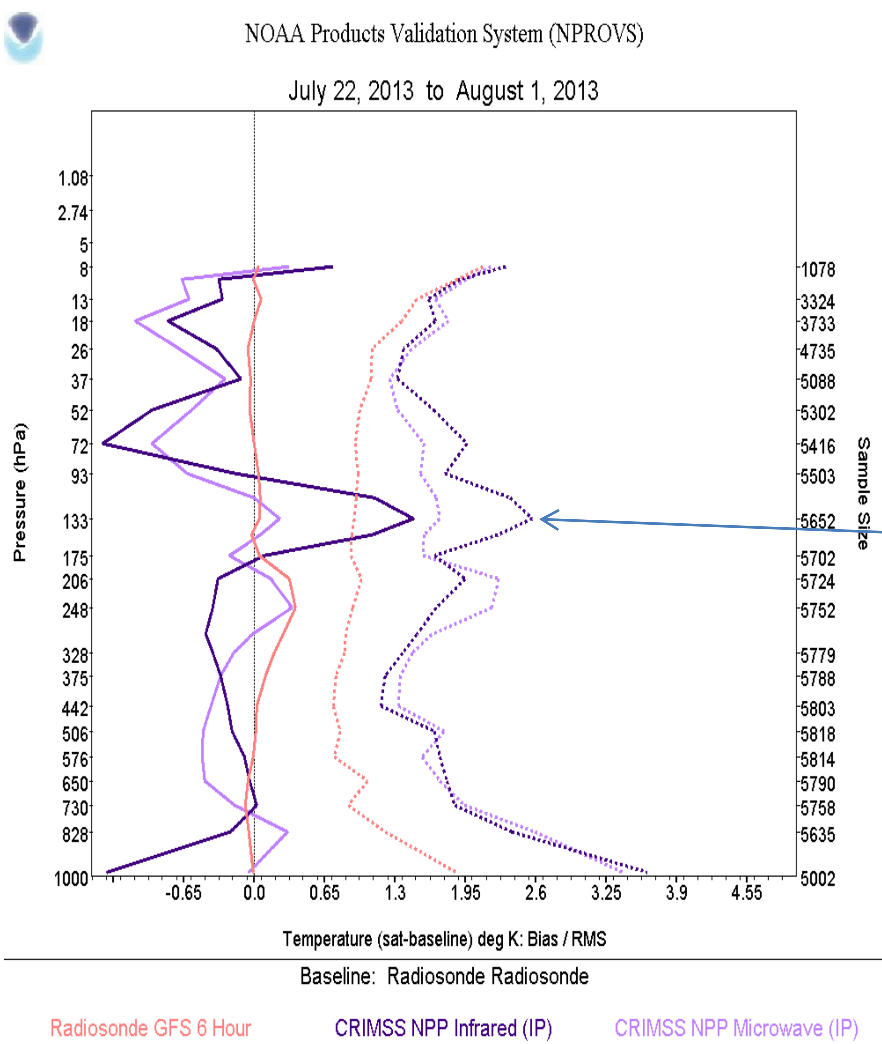
EDR Validation



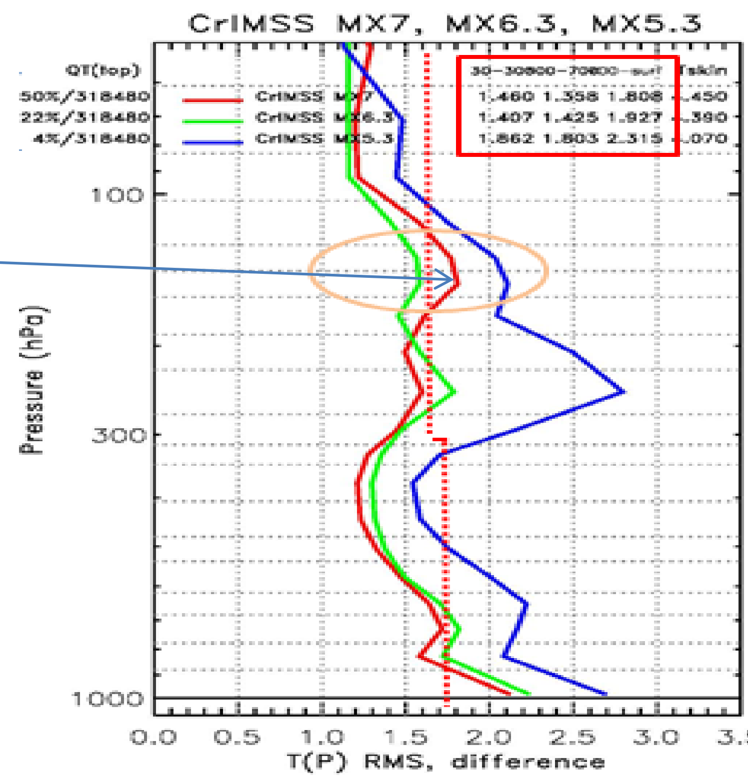


IR + MW pass

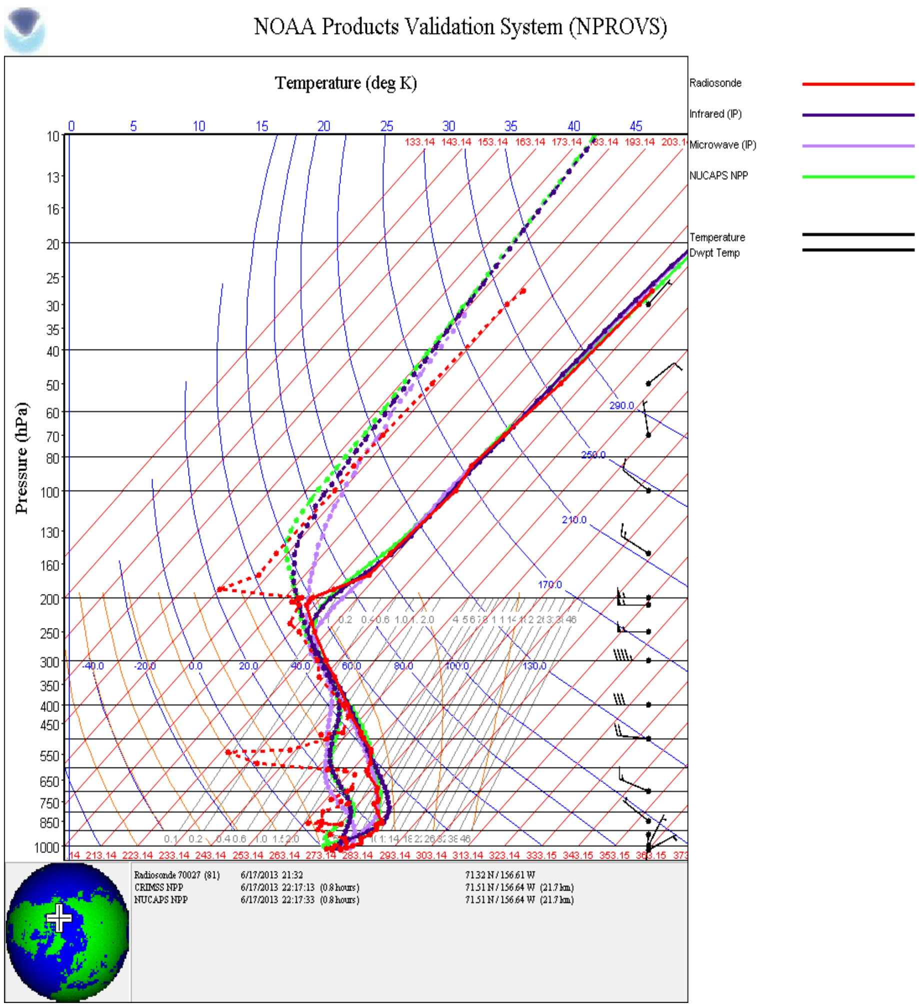
EDR Validation

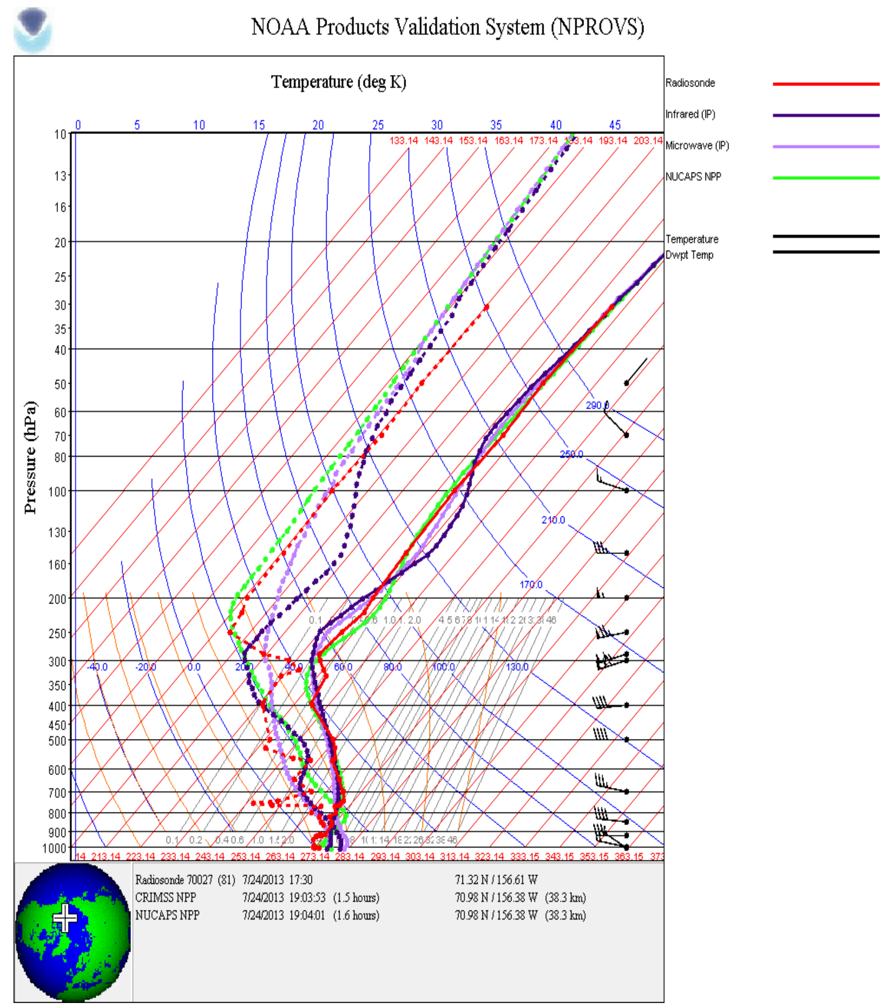


Focus day 5-15-12



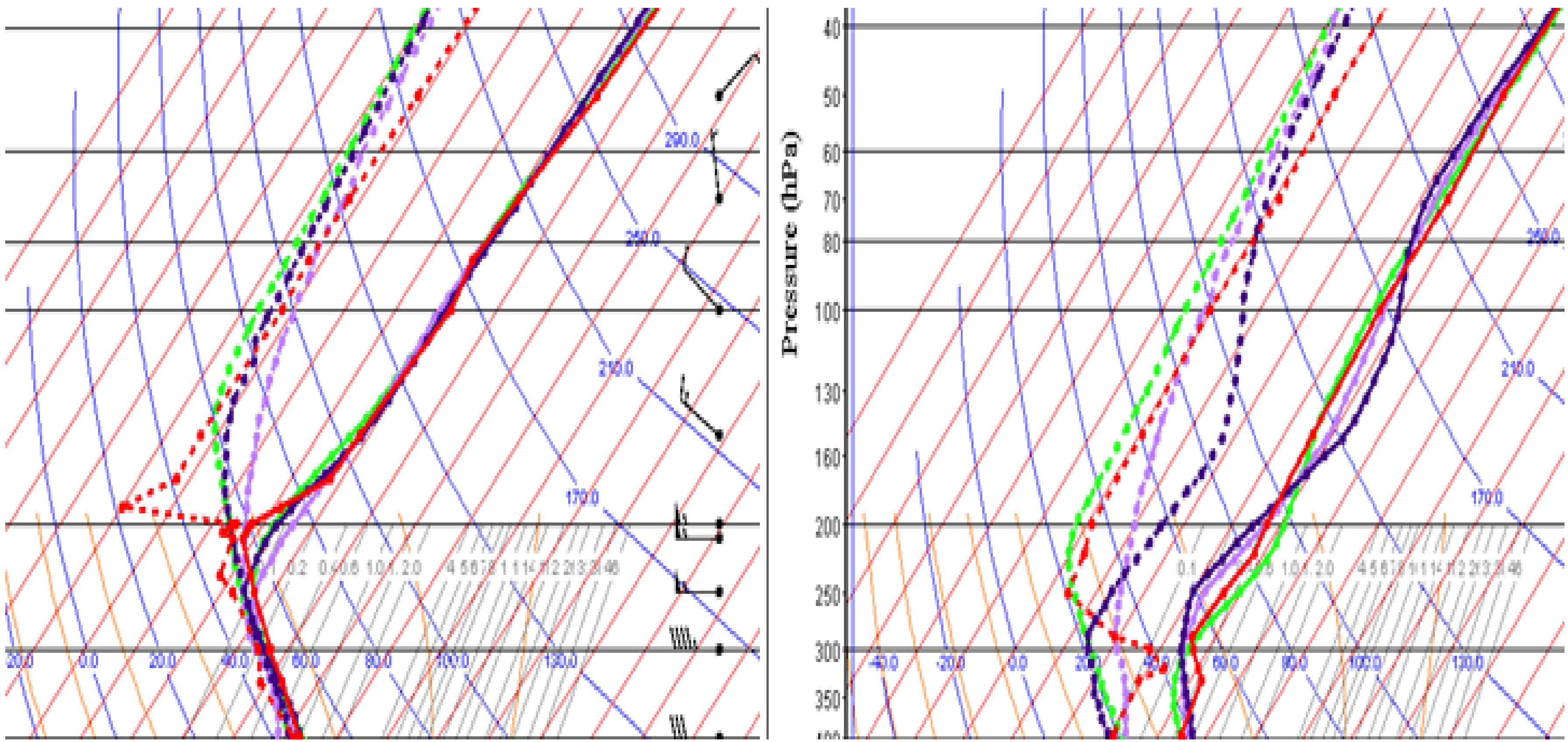
EDR Validation





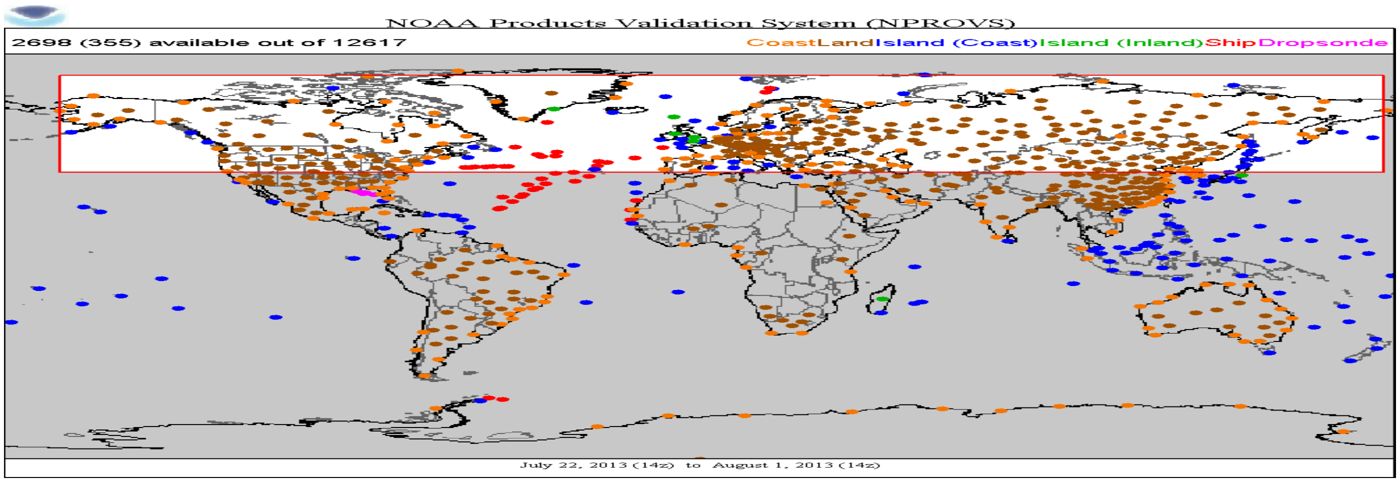
P D I S P

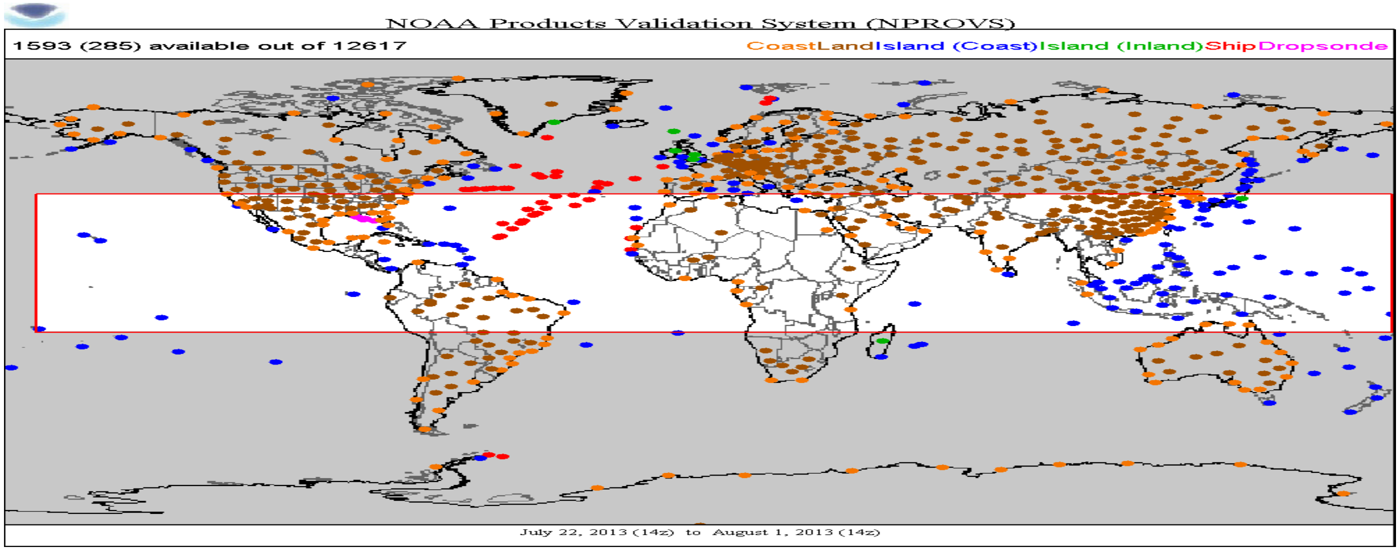
EDR Validation



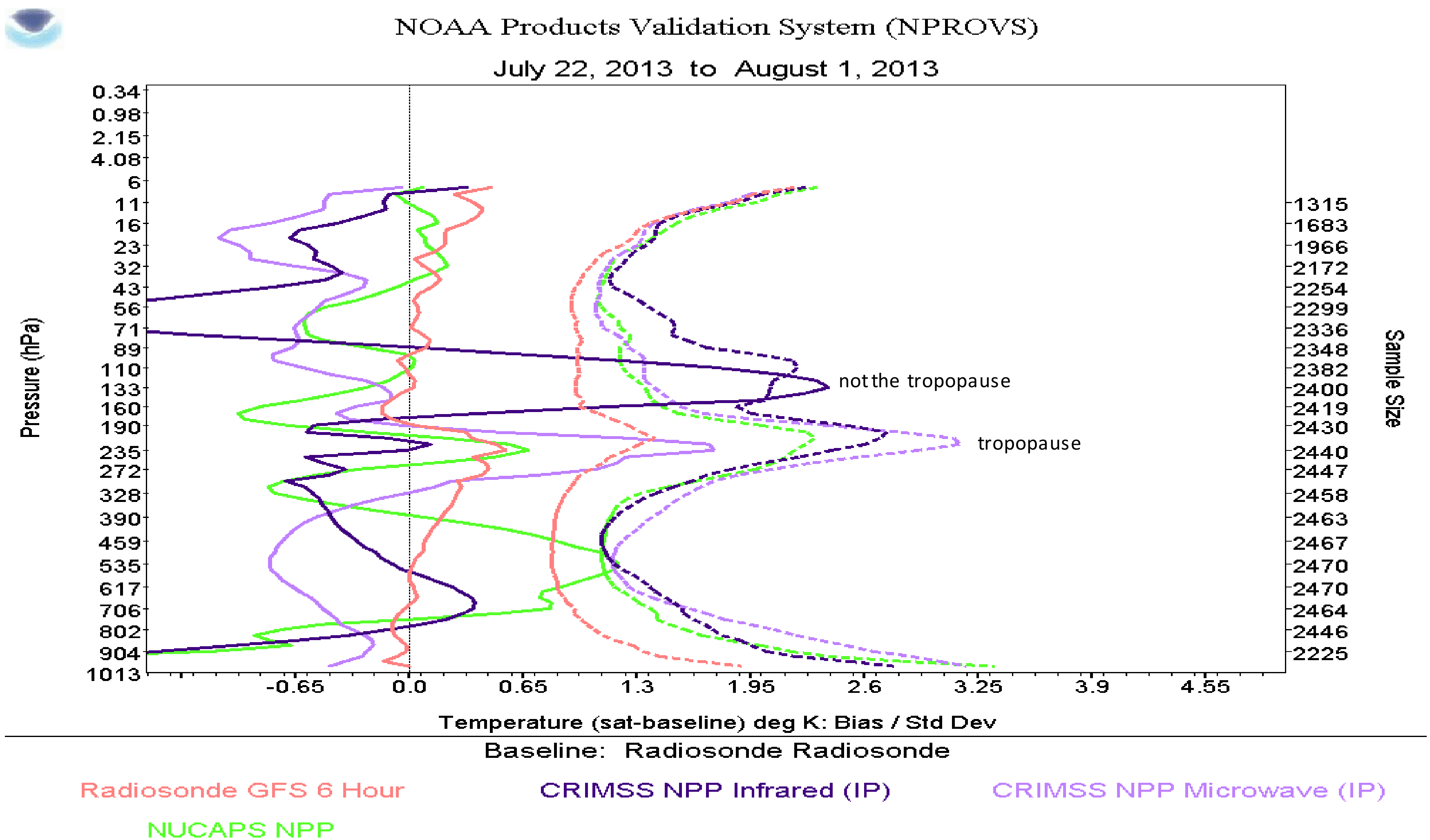
NUCAPS (IR+MW) IDPS (IR + MW) IDPS (MW)

EDR Validation



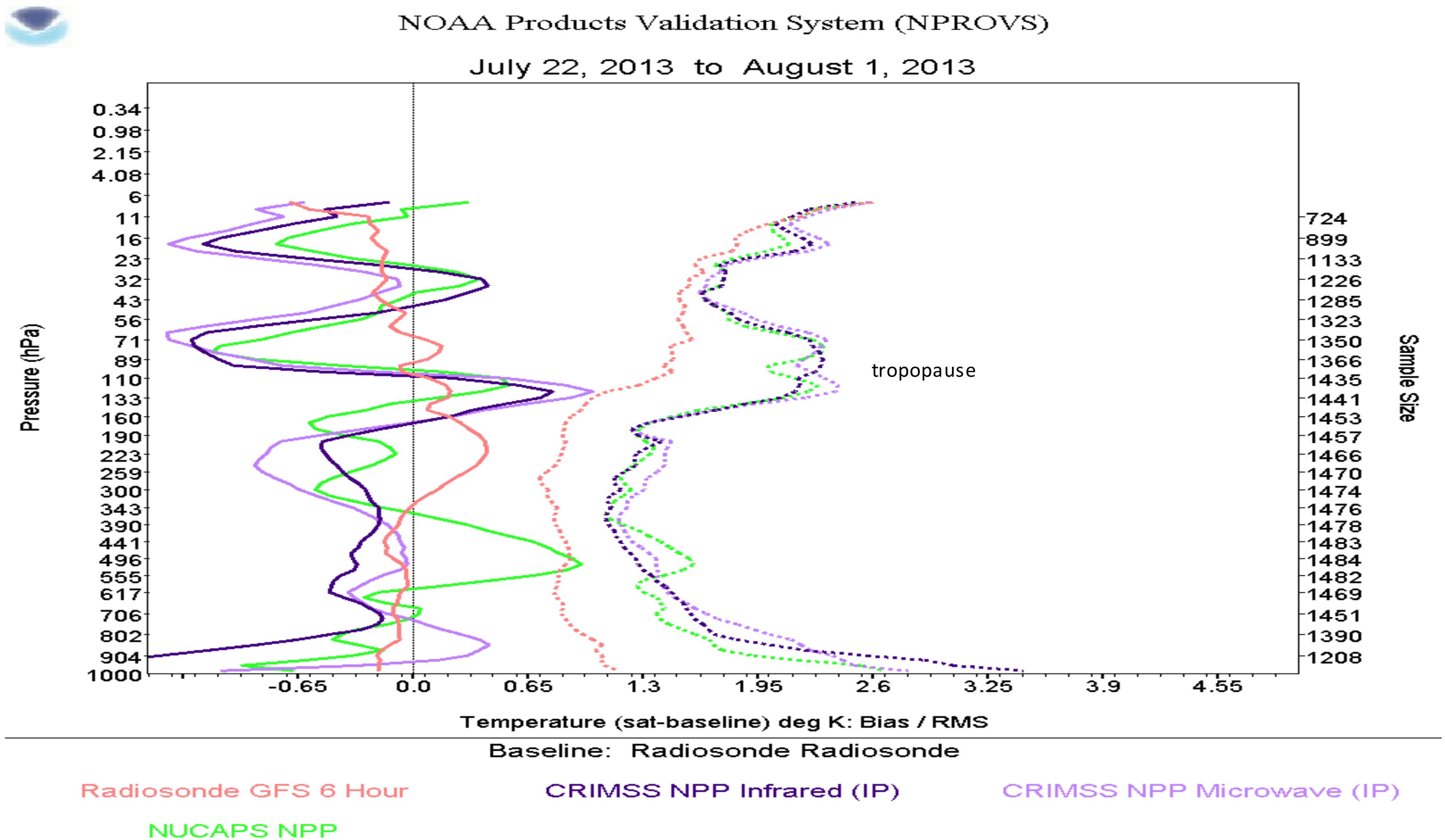


EDR Validation



90N - 50N

EDR Validation



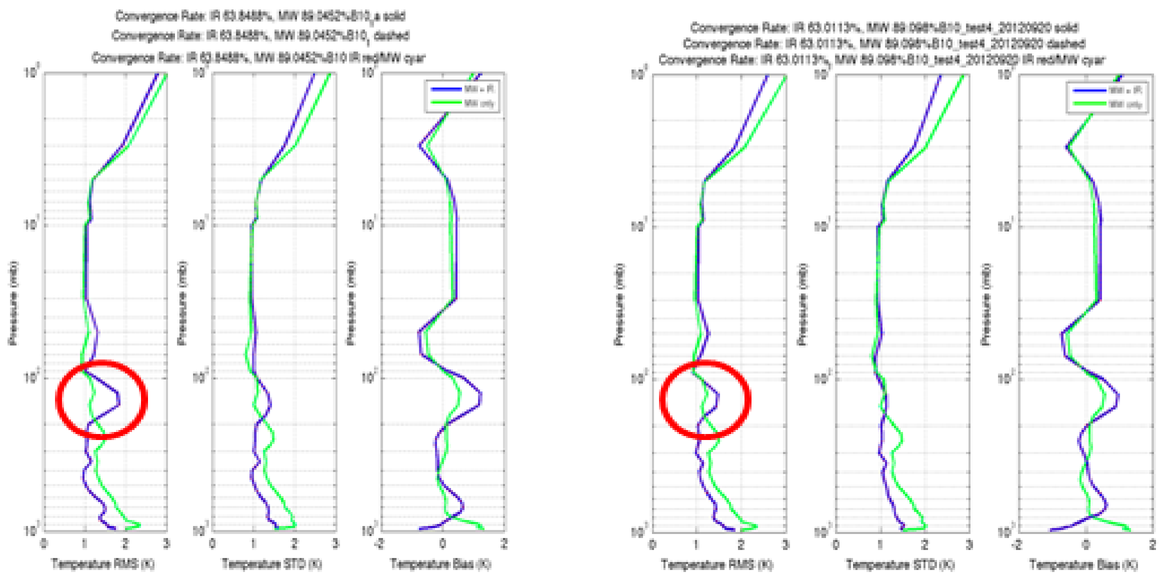
30N to 30S

EDR Validation

… resulting investigations by
Xu Liu / S. Kizer
NASA Langley Research Center
(NARC)

EDR Validation

– CrIMSS IDPS algorithm development identifies possible root cause for polar region stratospheric temperature sounding anomaly identified in IDPS version 7.1



– The above results provide plots comparing initial corrective actions to IDPS v7.1 with respect to stratospheric temperature anomaly
– The 3 left panels show the current method and the right panels the initial corrective approach; respective RMS, standard deviation and bias differences vs ECMWF for focus day 5-15-12 are shown
– The stratospheric anomaly illustrated by the RMS bump in the lower stratosphere is seen to decrease using the corrective approach
– The corrective approach reduces the problem but does not resolve it; work continues

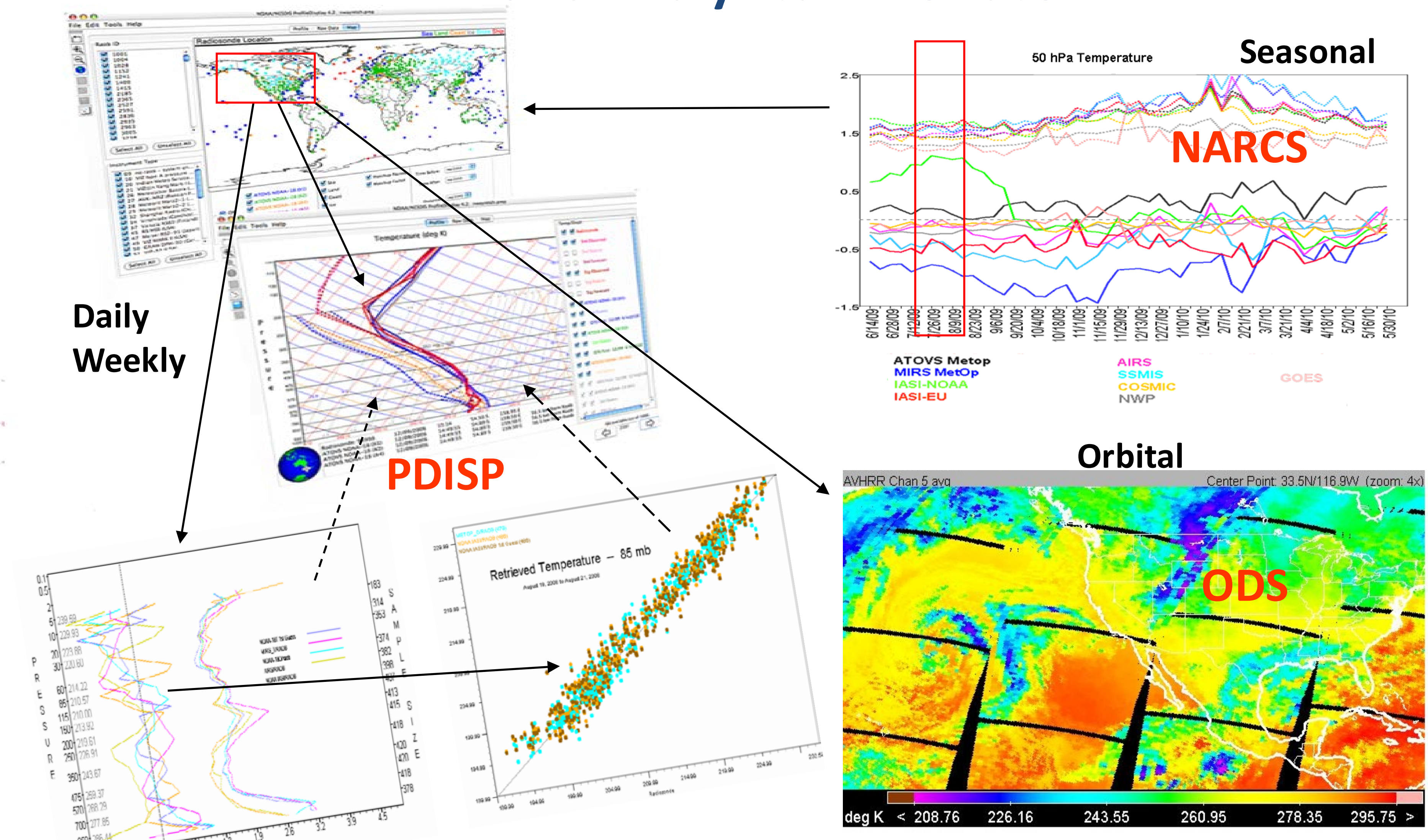
courtesy NARC … tbc

OUTLINE

- **Team Members**
- **Project Goals**
- **Activities / Achievements**
- **Validation Results**
- **Summary**

EDR Validation Results

NPROVS Analytical Interface …



… routine monitoring to deep dive

EDR Validation Results

Validation Results

- NARCS
- PDISP
- *ODS*

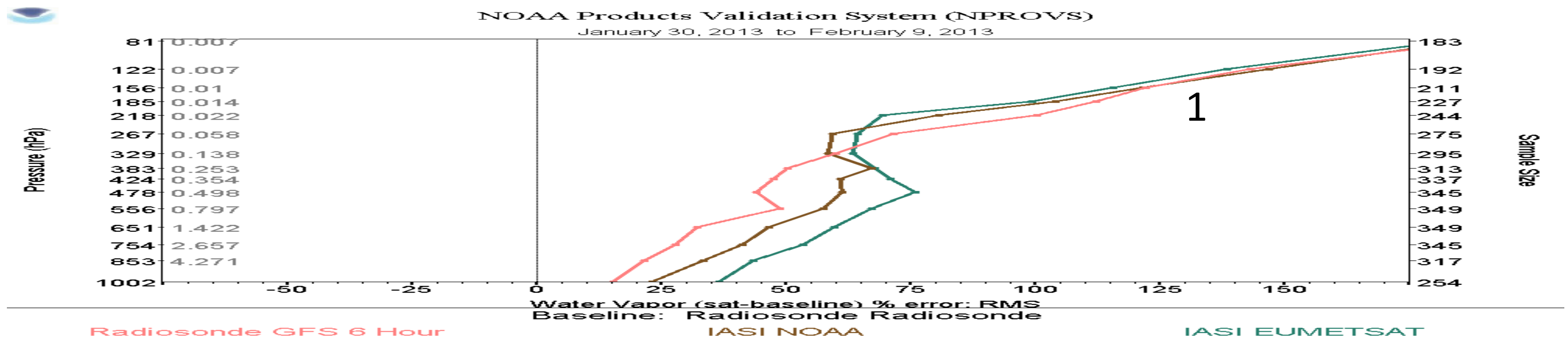
EDR Validation Results

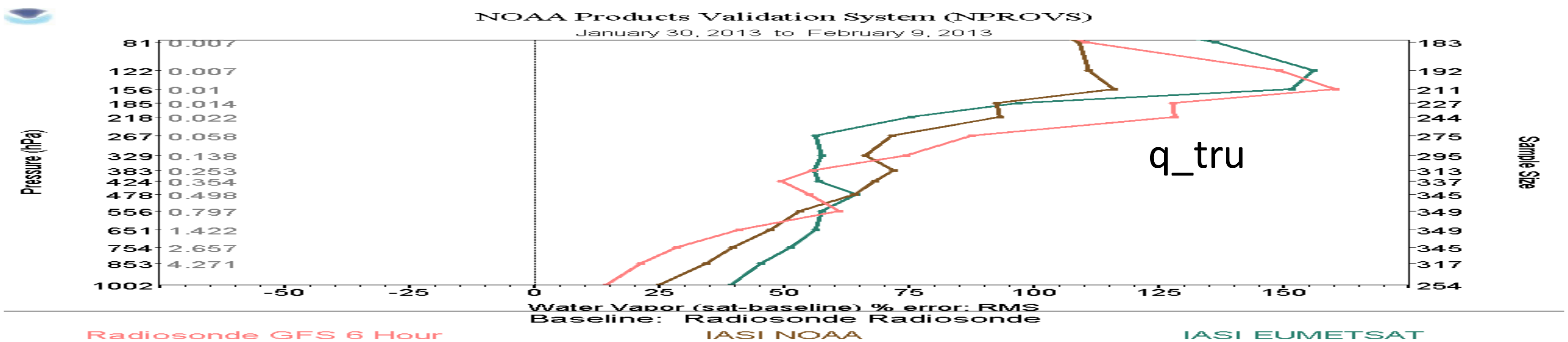
H20 Vapor Fraction Statistics Weighting

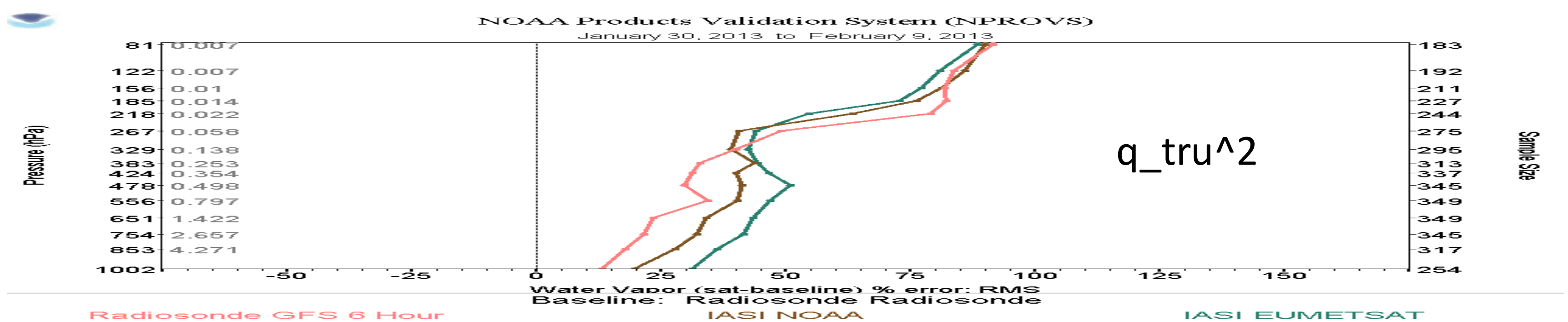
- Ran an experiment in which 3 weights were used
  - W1 = 1 … ***NARCS***
  - W2 = q_tru
  - ***W3 = (q_tru)^2 … PDISP***
  - There is no change in the profiles themselves
  - Only difference are in the statistic itself
- Level-1 requirements document is sufficiently vague
  - Historically, these requirements were derived from the w=q_tru^2 weighting for RMS from AIRS simulation experiments.

EDR Validation Results

H20 Vapor Fraction Statistics Weighting







EDR Validation Results

N A R C S

Cheat Sheet

SAT-minus-RAOB per level:

- T (K) @ levels (101)
- H20 vapor fraction (%) … SAT-minus-RAOB / Mean RAOB for H20 vapor mixing ratio (g/kg) weighted by ***(1)***
- "Independent" samples which passed respective qc for given system (respective qc yield optimal per system, thus samples differ)
- NPROVS (conventional RAOB) collocations
- IR+MW only (except MiRS)

EDR Validation Results

Atmospheric Vertical Temperature Profile (AVTP) Measurement Uncertainty – Layer Average Temperature Error	
PARAMETER	**THRESHOLD**
AVTP Clear, surface to 300 mb	**1.6 K / 1-km layer**
AVTP Clear, 300 to 30 mb	**1.5 K / 3-km layer**
AVTP Clear, 30 mb to 1 mb	1.5 K / 5-km layer
AVTP Clear, 1 mb to 0.5 mb	3.5 K / 5-km layer
AVTP Cloudy , surface to 700 mb	**2.5 K / 1-km layer**
AVTP Cloudy, 700 mb to 300 mb	**1.5 K / 1-km layer**
AVTP Cloudy, 300 mb to 30 mb	**1.5 K / 3-km layer**
AVTP Cloudy, 30 mb to 1 mb	1.5 K / 5-km layer
AVTP Cloudy, 1 mb to 0.5 mb	3.5 K/ 5-km layer

Clear … IR+MW

Cloudy … (MW only)

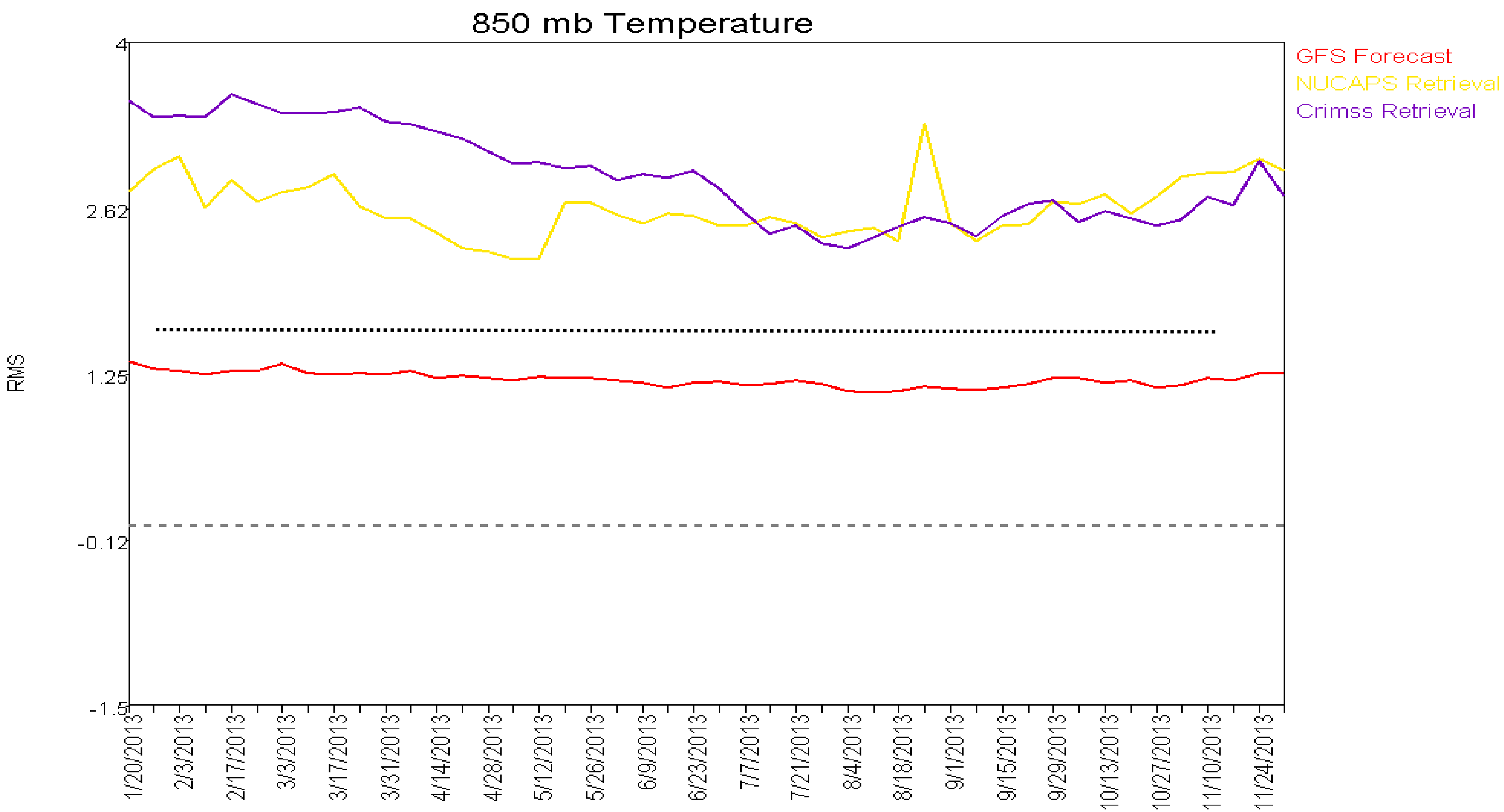
Atmospheric Vertical Moisture Profile (AVMP) Measurement Uncertainty – 2-km Layer Average Mixing Ratio % Error	
PARAMETER	**THRESHOLD**
AVMP Clear, surface to 600 mb	**Greater of 20%** or 0.2 g/kg **/ 2-km layer**
AVMP Clear, 600 to 300 mb	**Greater of 35%** or 0.1 g/kg / **2-km layer**
AVMP Clear, 300 to 100 mb	Greater of 35% or 0.1 g/kg / 2-km layer
AVMP Cloudy, surface to 600 mb	**Greater of 20%** of 0.2 g/kg **/ 2-km layer**
AVMP Cloudy, 600 mb to 400 mb	**Greater of 40%** or 0.1 g/kg / **2-km layer**
AVMP Cloudy, 400 mb to 100 mb	Greater of 40% or 0.1 g/kg / 2-km layer

Clear … IR+MW

Cloudy … (MW only)

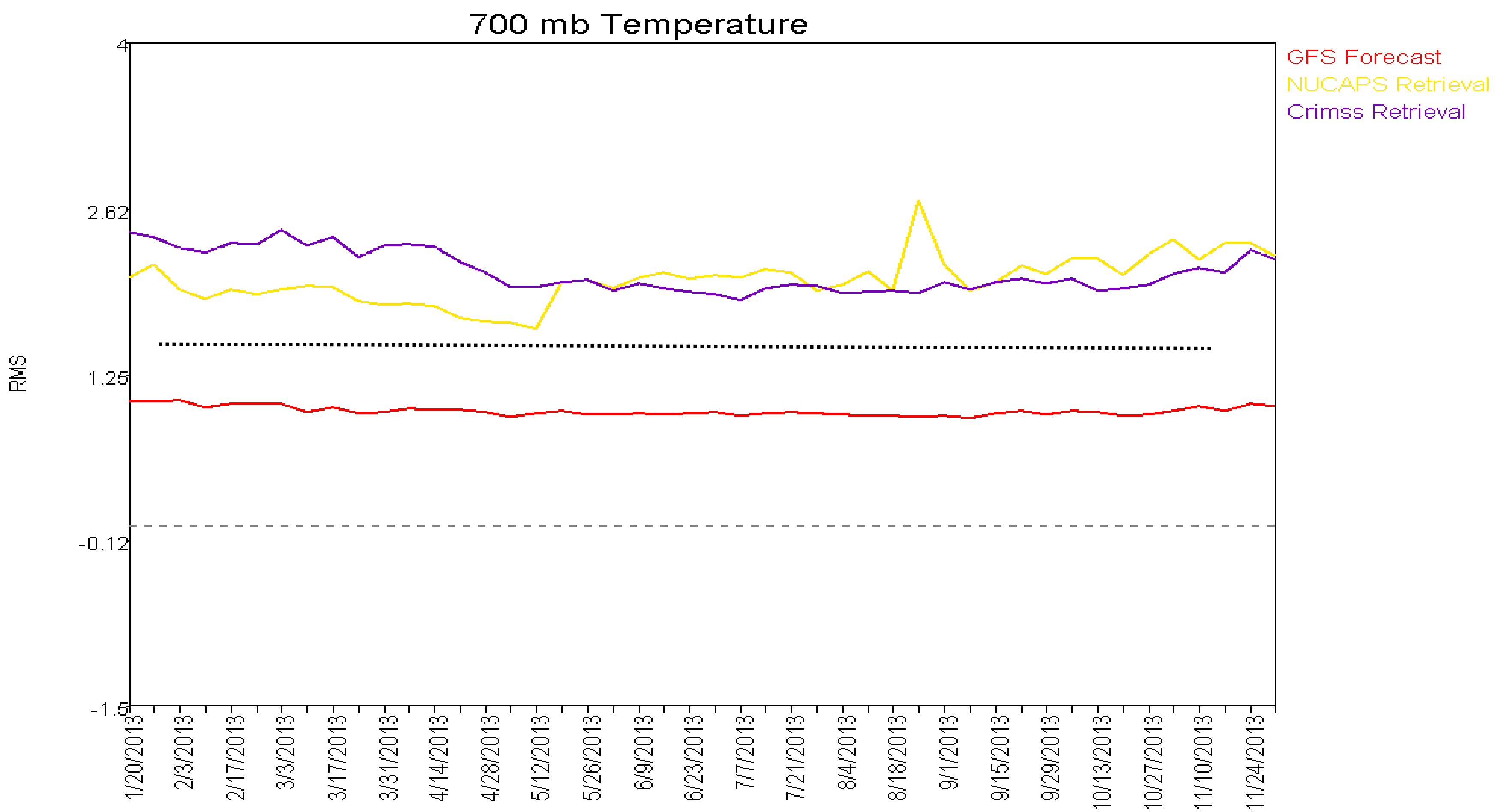
(courtesy Nick Nalli)

EDR Validation Results



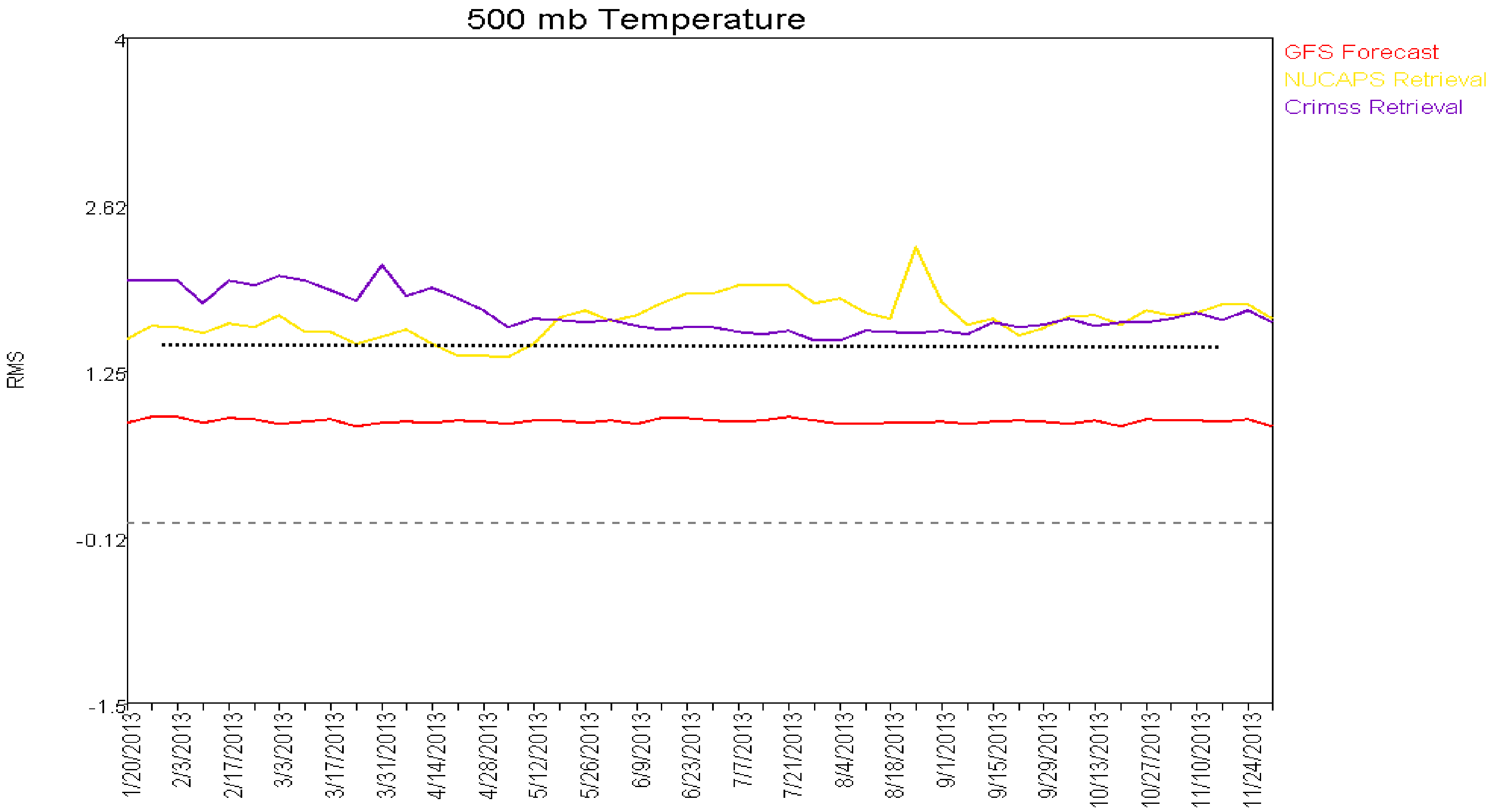
NARCS 12 months 2013

EDR Validation Results



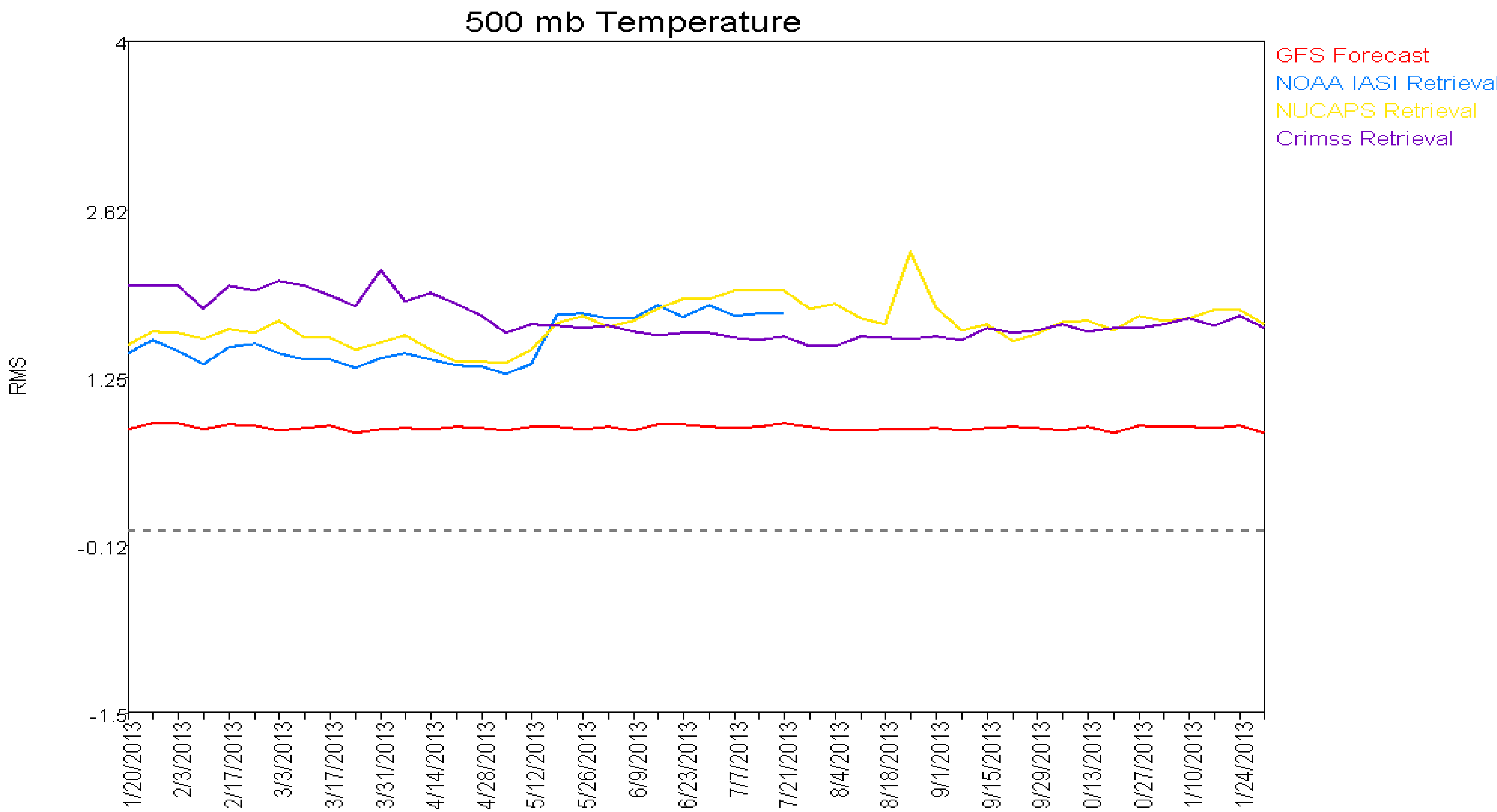
NARCS 12 months 2013

EDR Validation Results



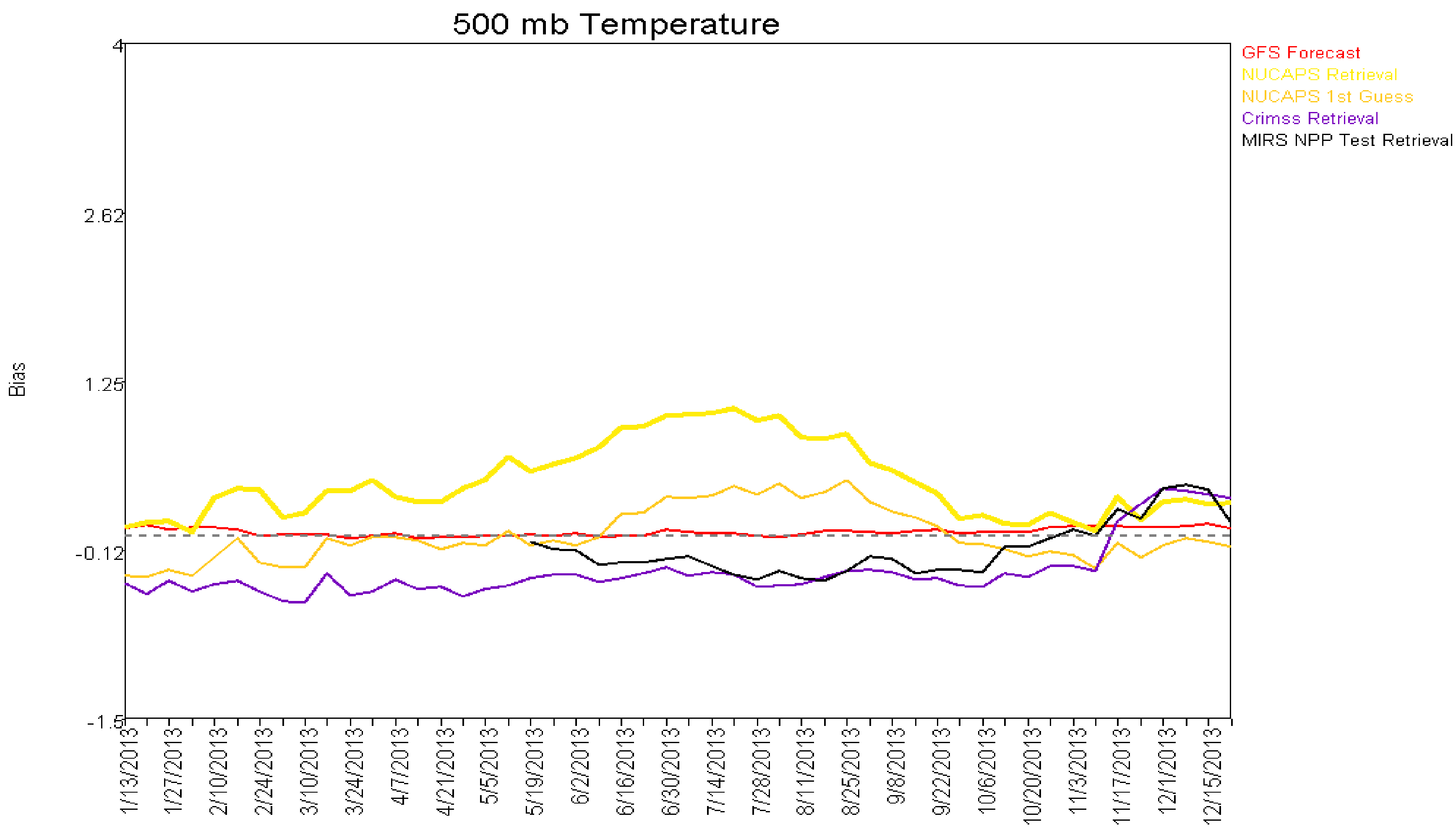
NARCS 12 months 2013

EDR Validation Results



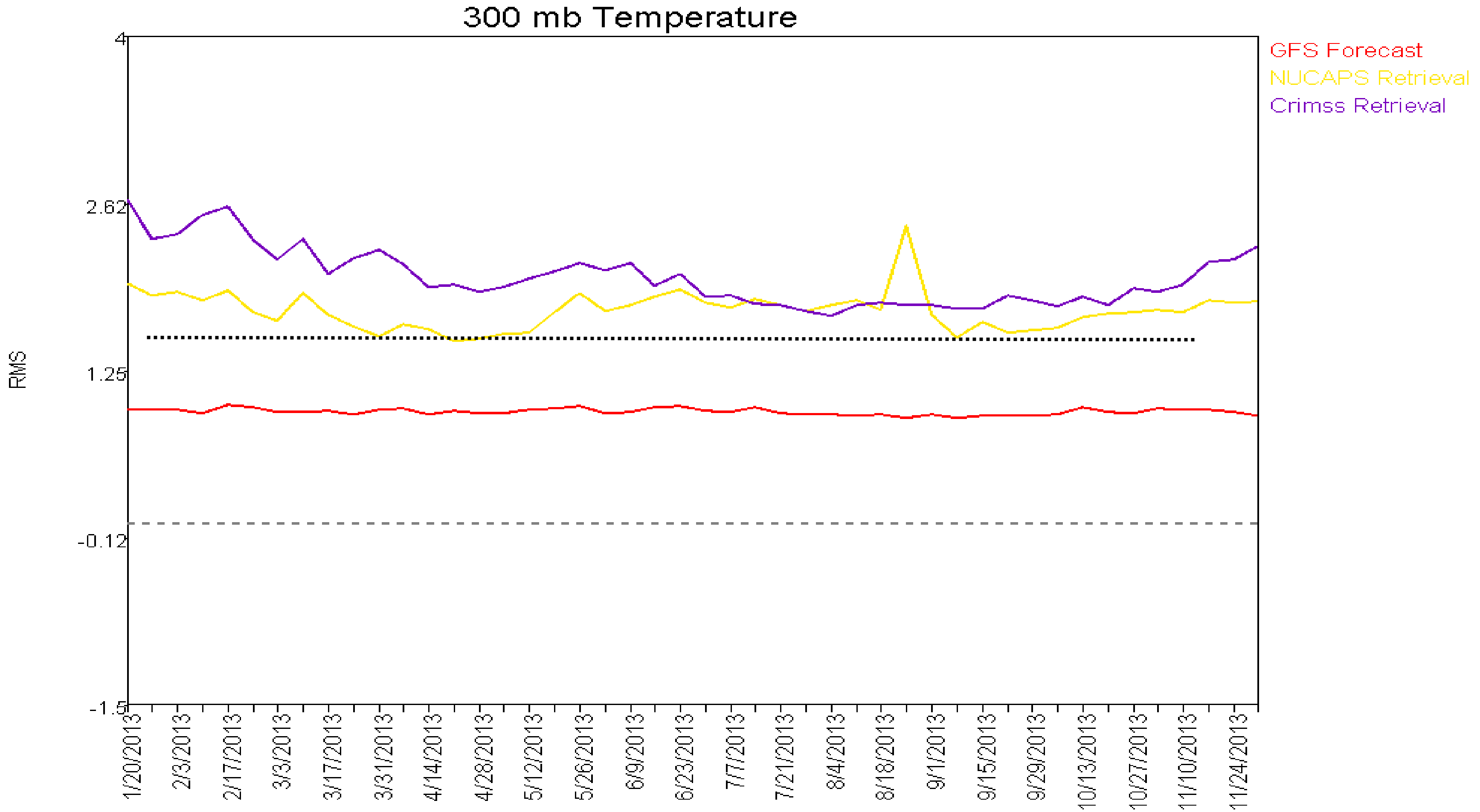
NARCS 12 months 2013

EDR Validation Results



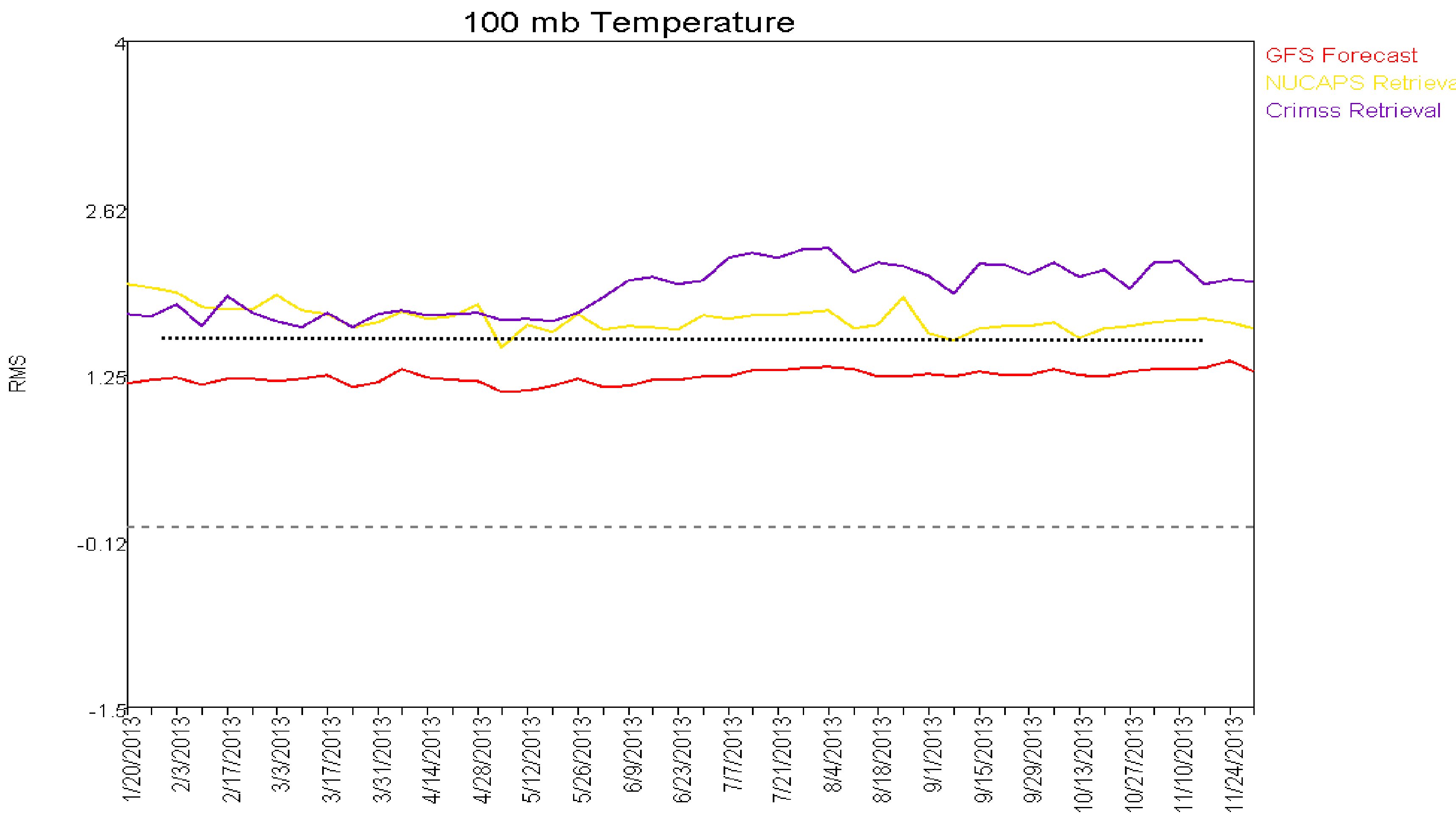
NARCS 12 months 2013

EDR Validation Results



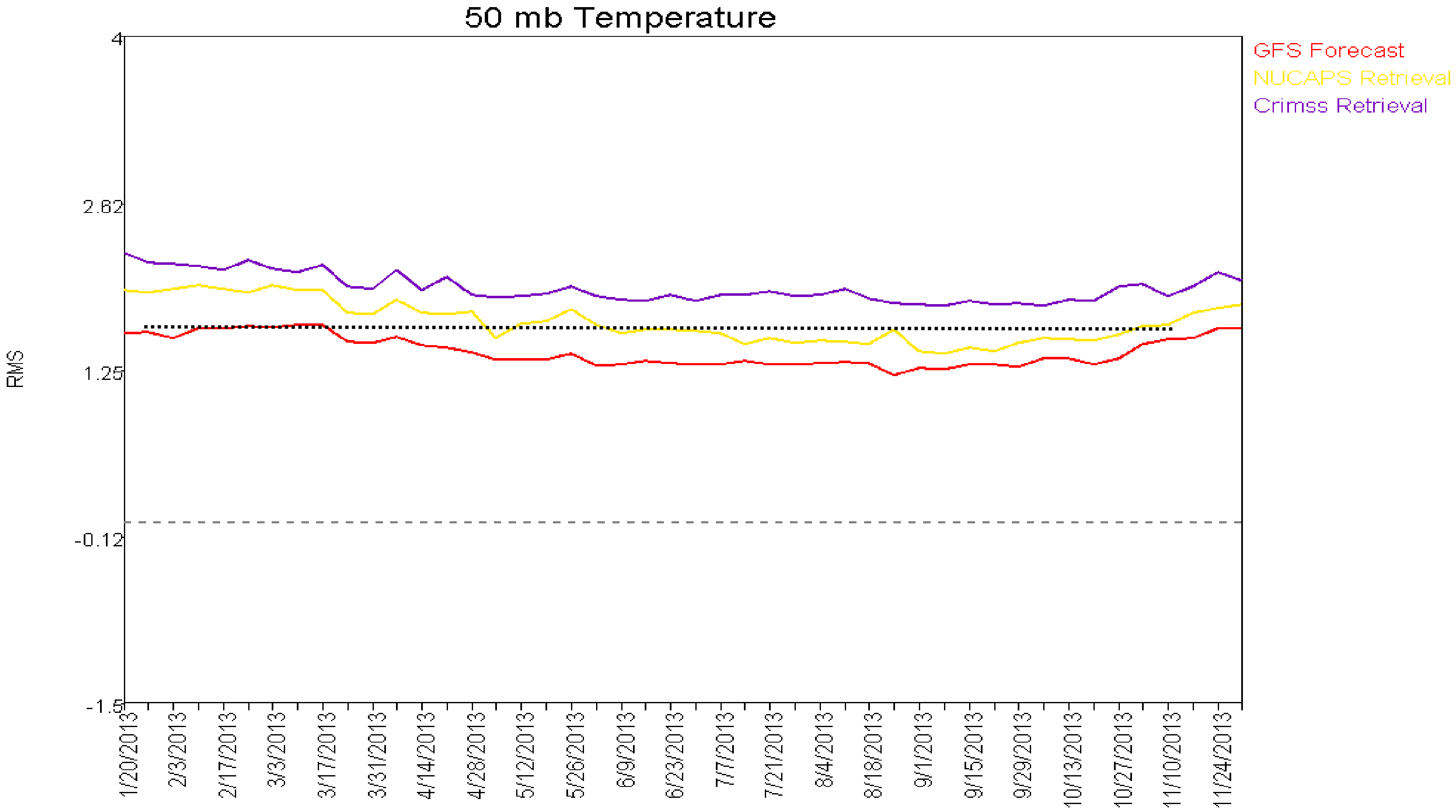
NARCS 12 months 2013

EDR Validation Results



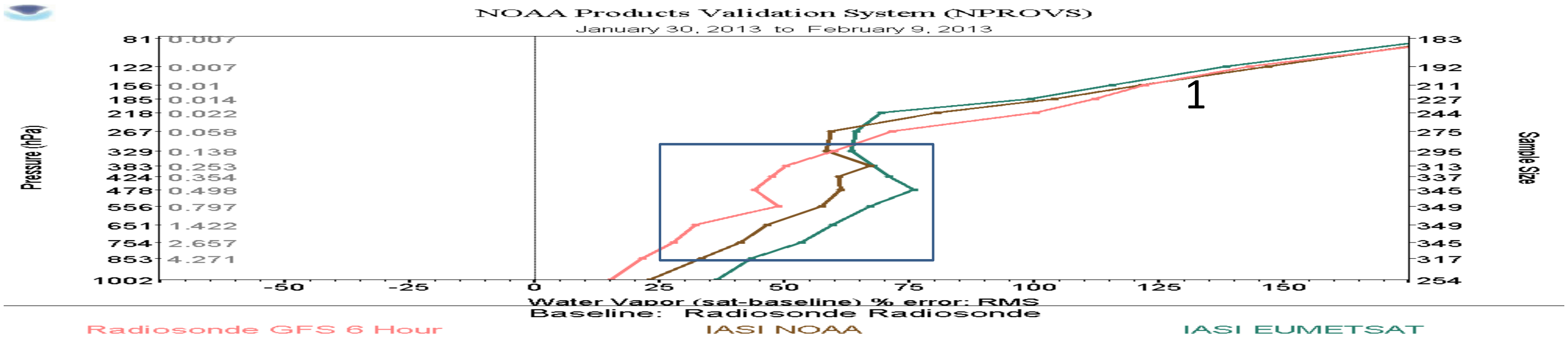
NARCS 12 months 2013

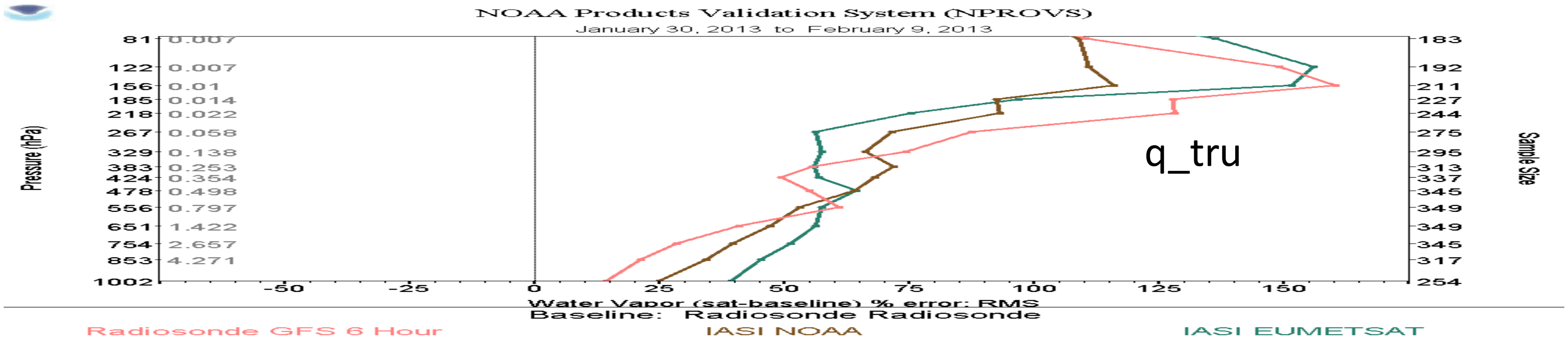
EDR Validation Results

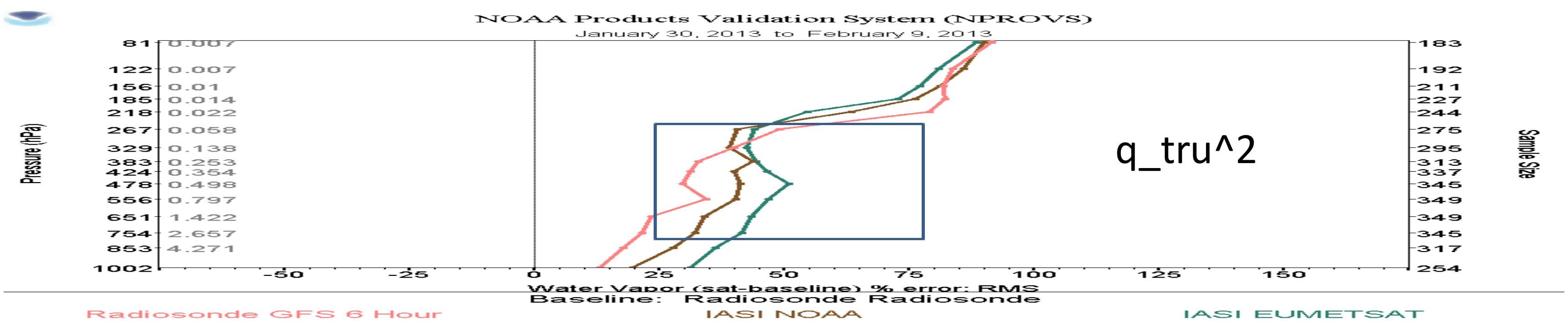


NARCS 12 months 2013

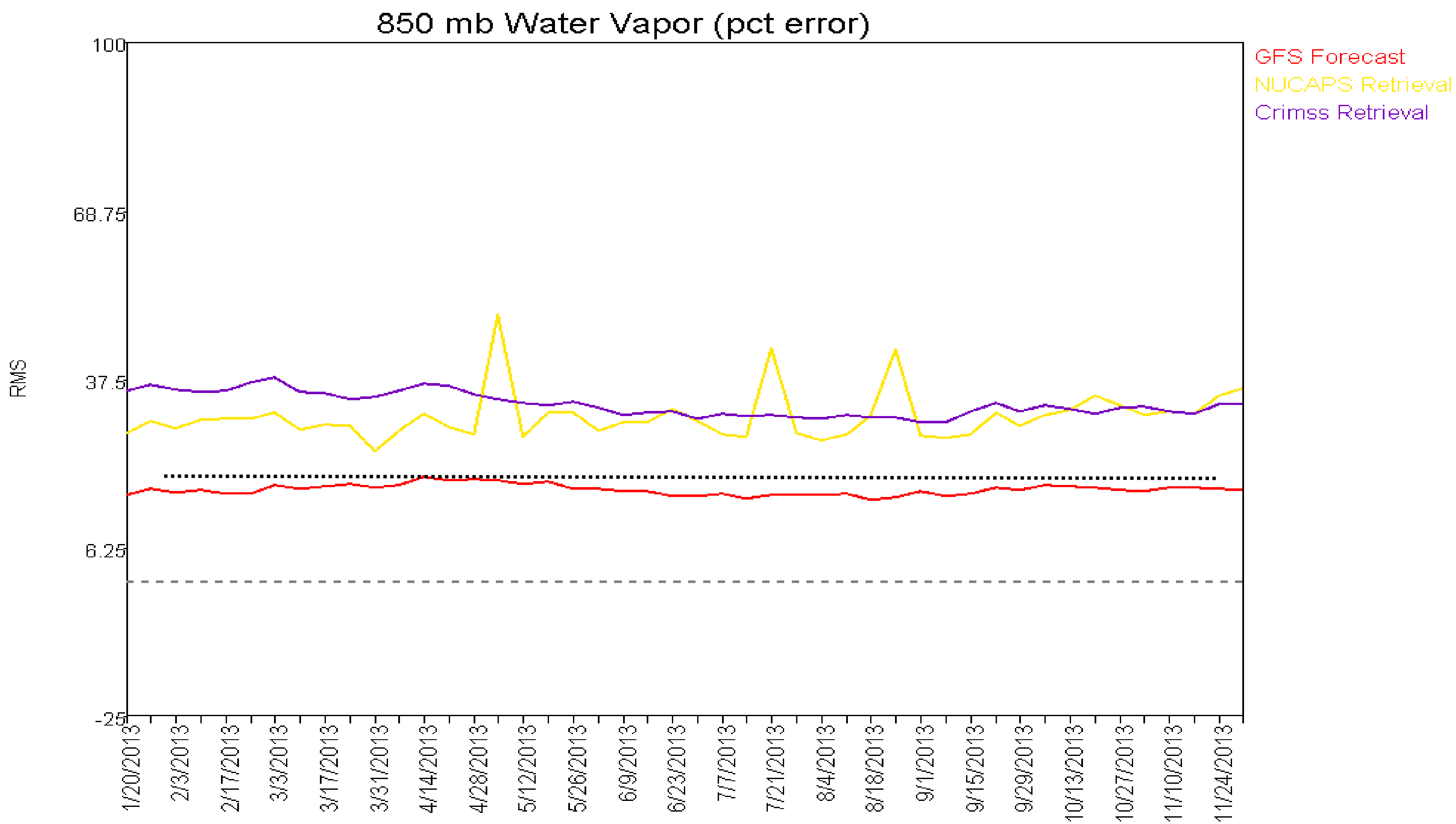
EDR Validation Results





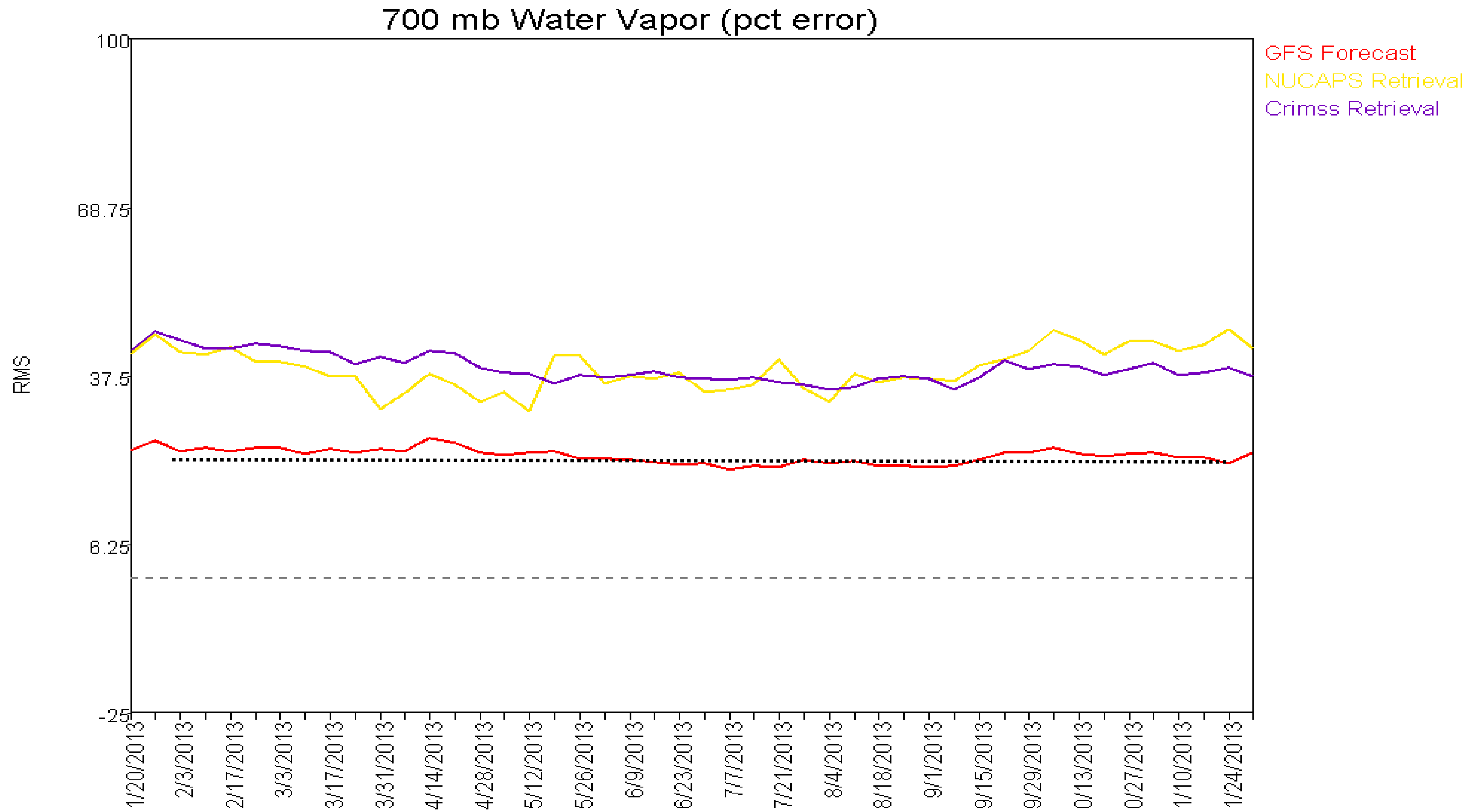


EDR Validation Results



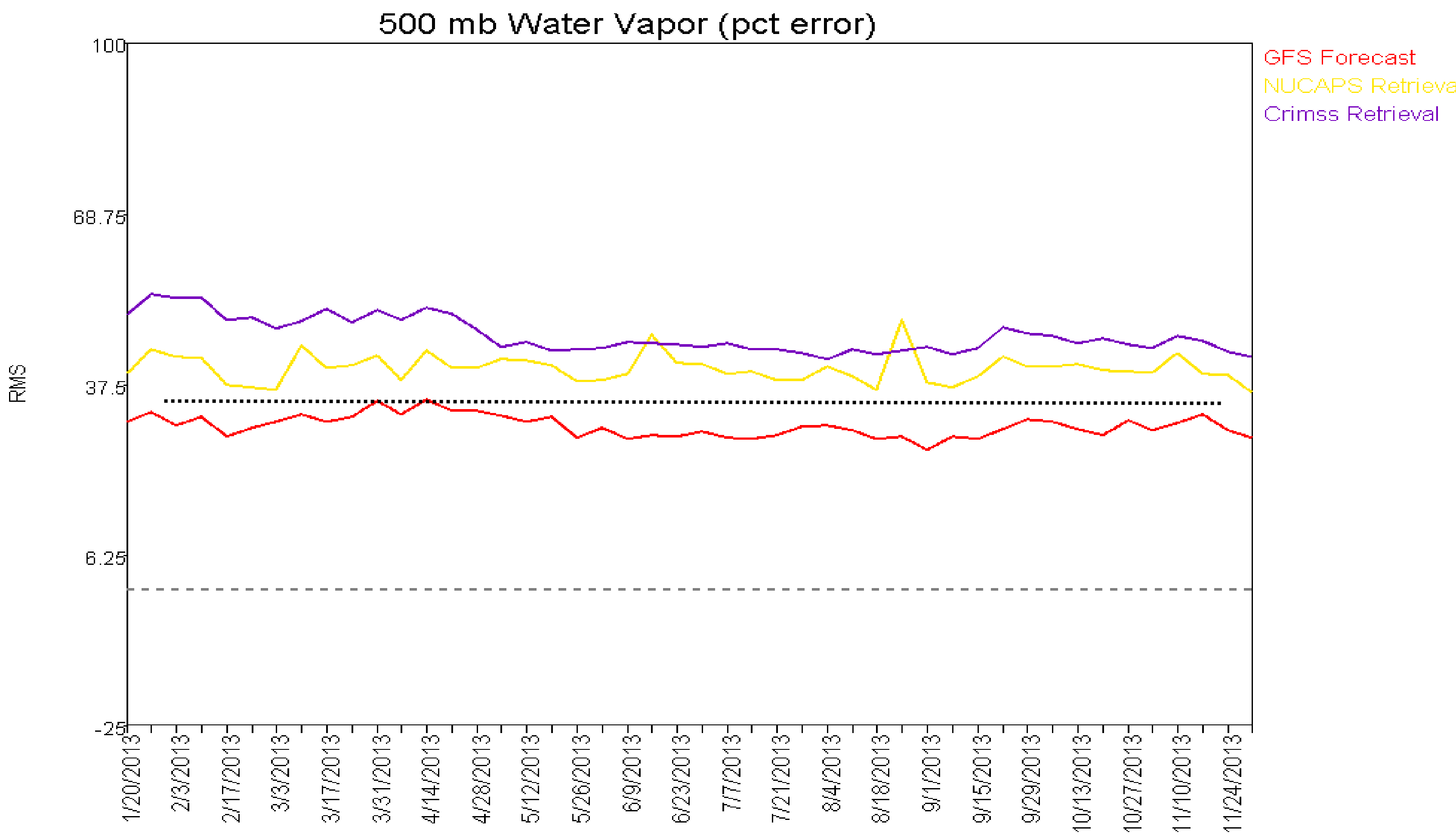
NARCS 12 months 2013

EDR Validation Results



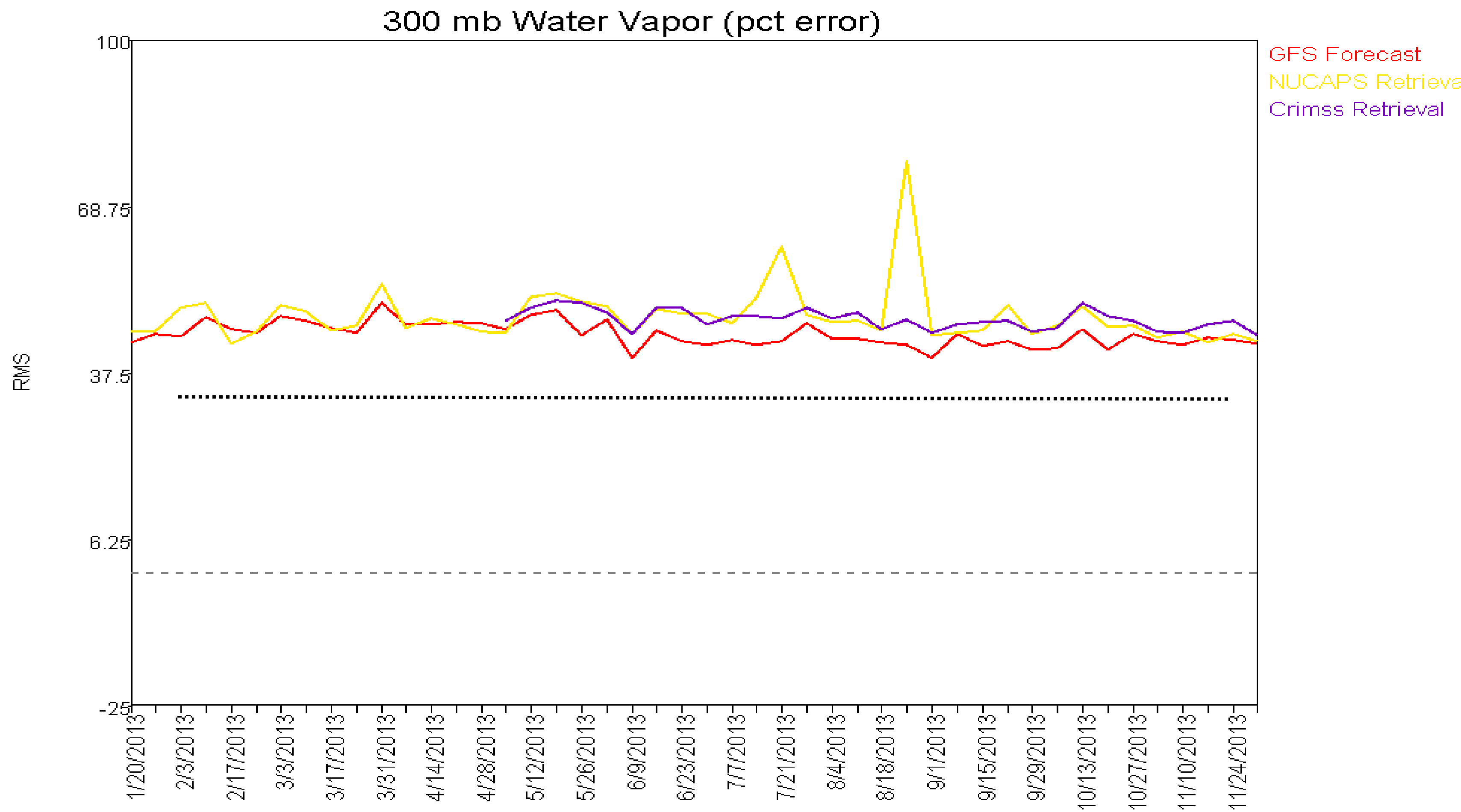
NARCS 12 months 2013

EDR Validation Results



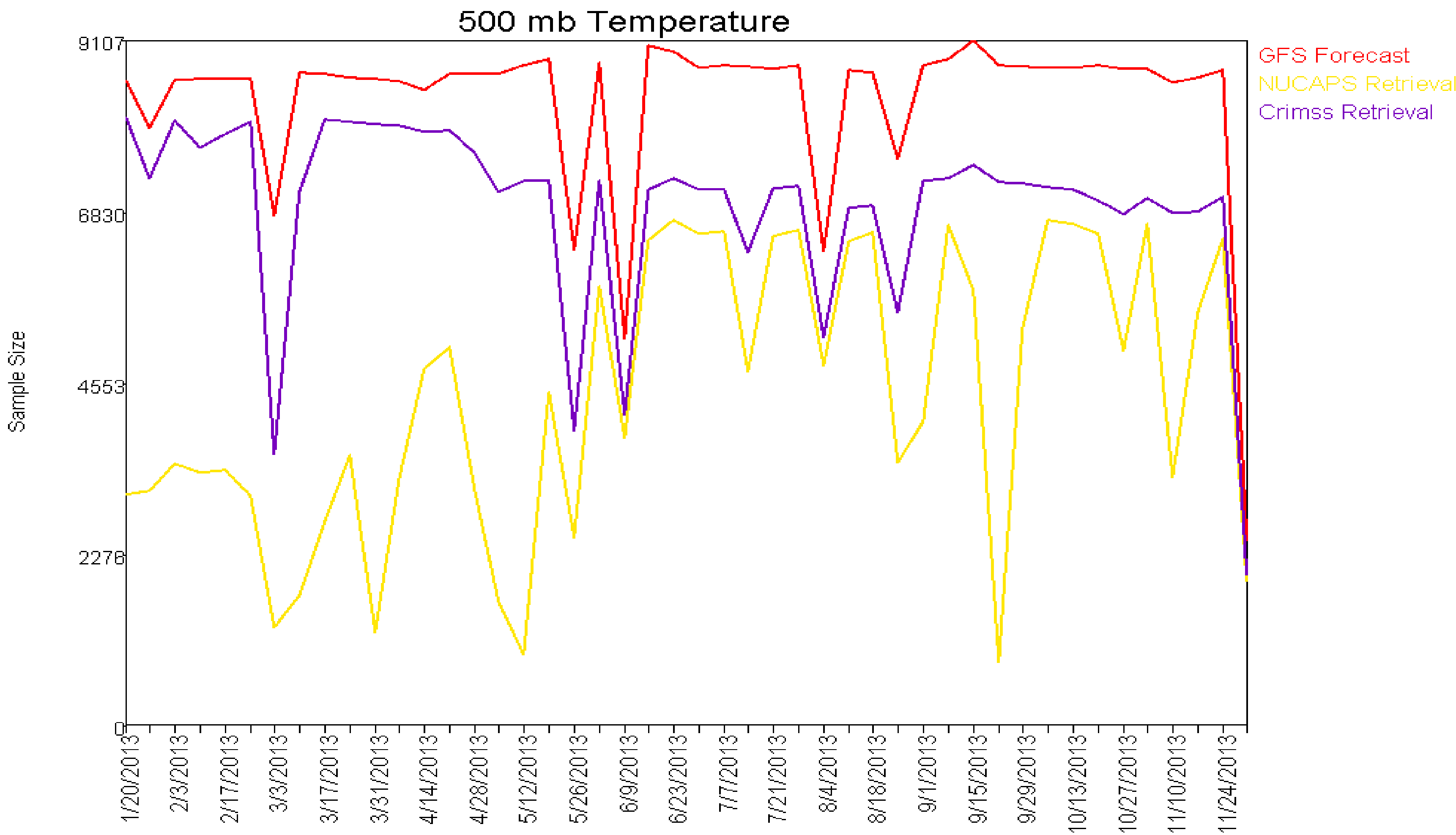
NARCS 12 months 2013

EDR Validation Results



NARCS 12 months 2013

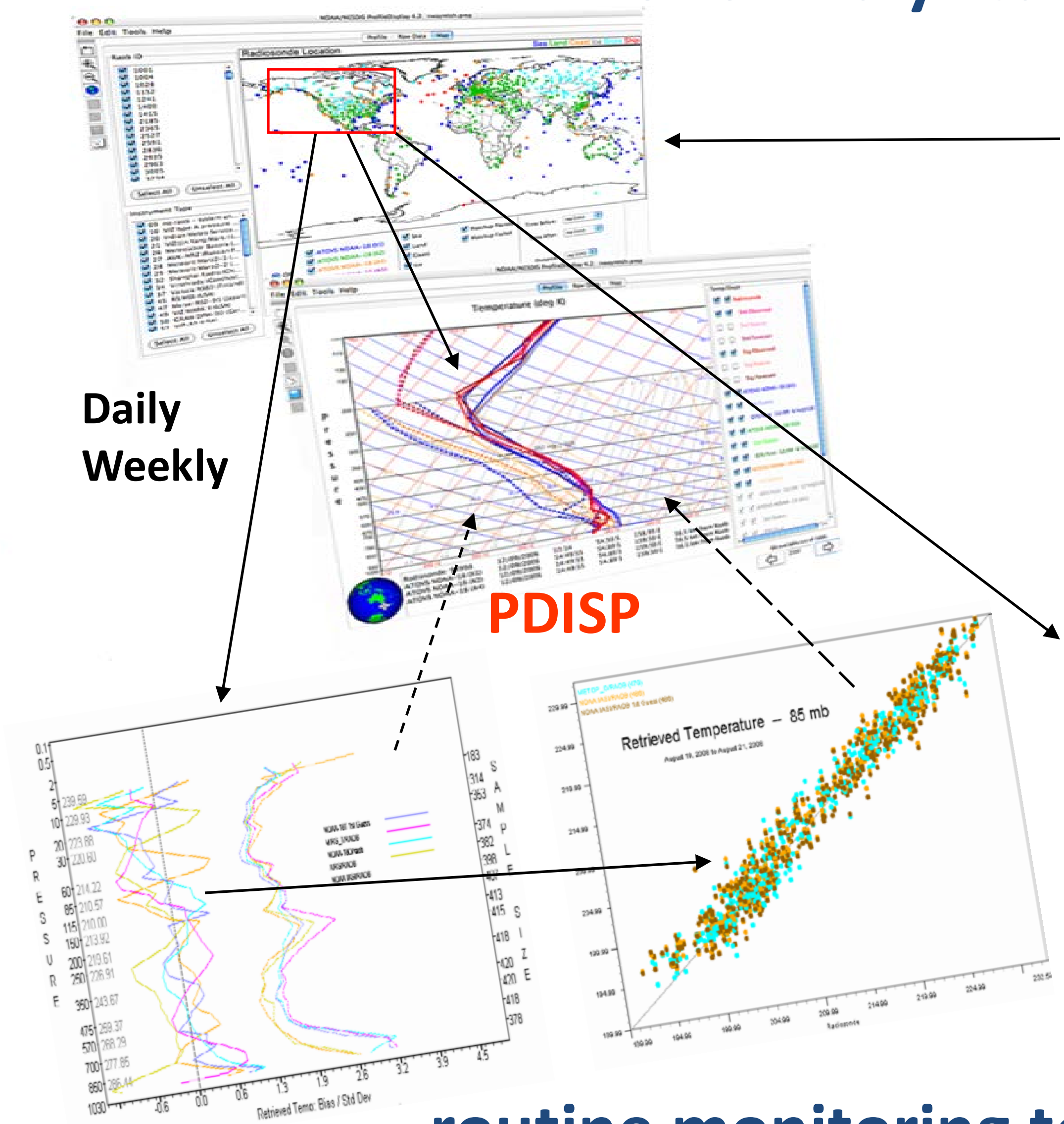
EDR Validation Results

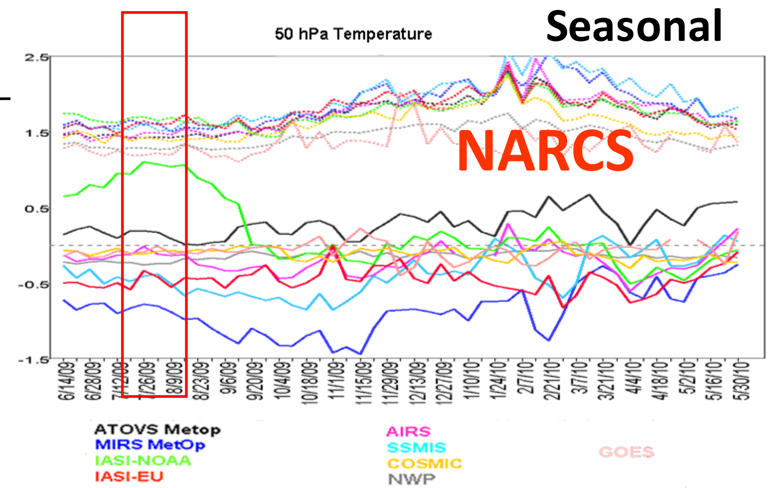


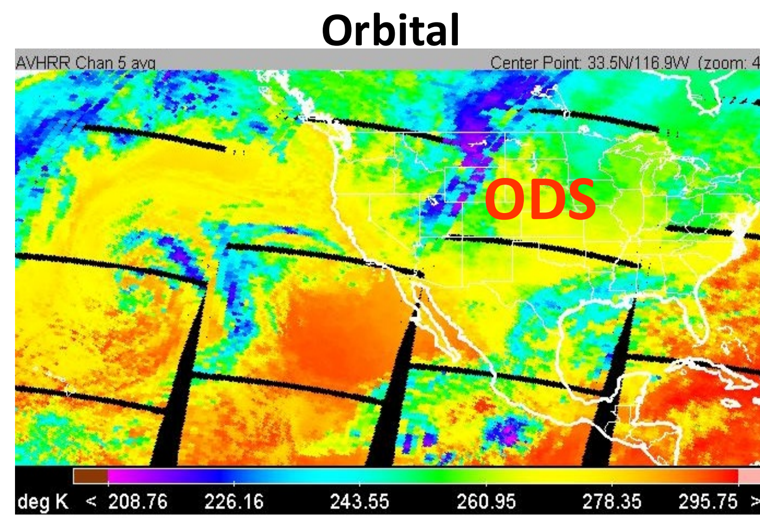
NARCS 12 months 2013

EDR Validation Results

NPROVS Analytical Interface …







… routine monitoring to deep dive

EDR Validation Results

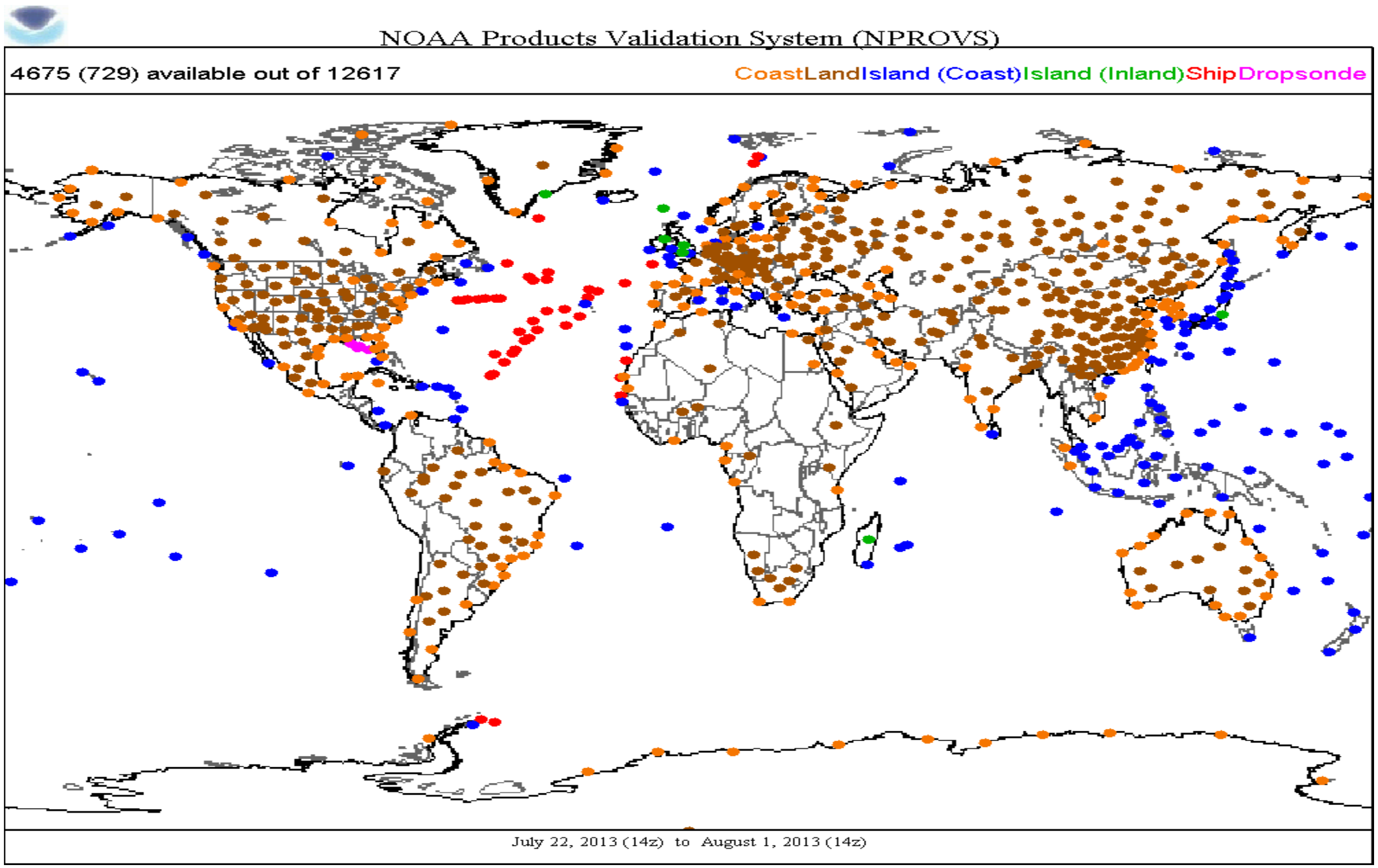
P D I S P

Cheat Sheet

SAT-minus-RAOB per level:

- T (K) @ 1km/2km layers
- H20 vapor fraction (%) … SAT-minus-RAOB / Mean RAOB … ***(q_tru)^2***
- "Common" samples which passed respective qc for given system
- IR+MW and MW-only
- Terrain / time window segregations

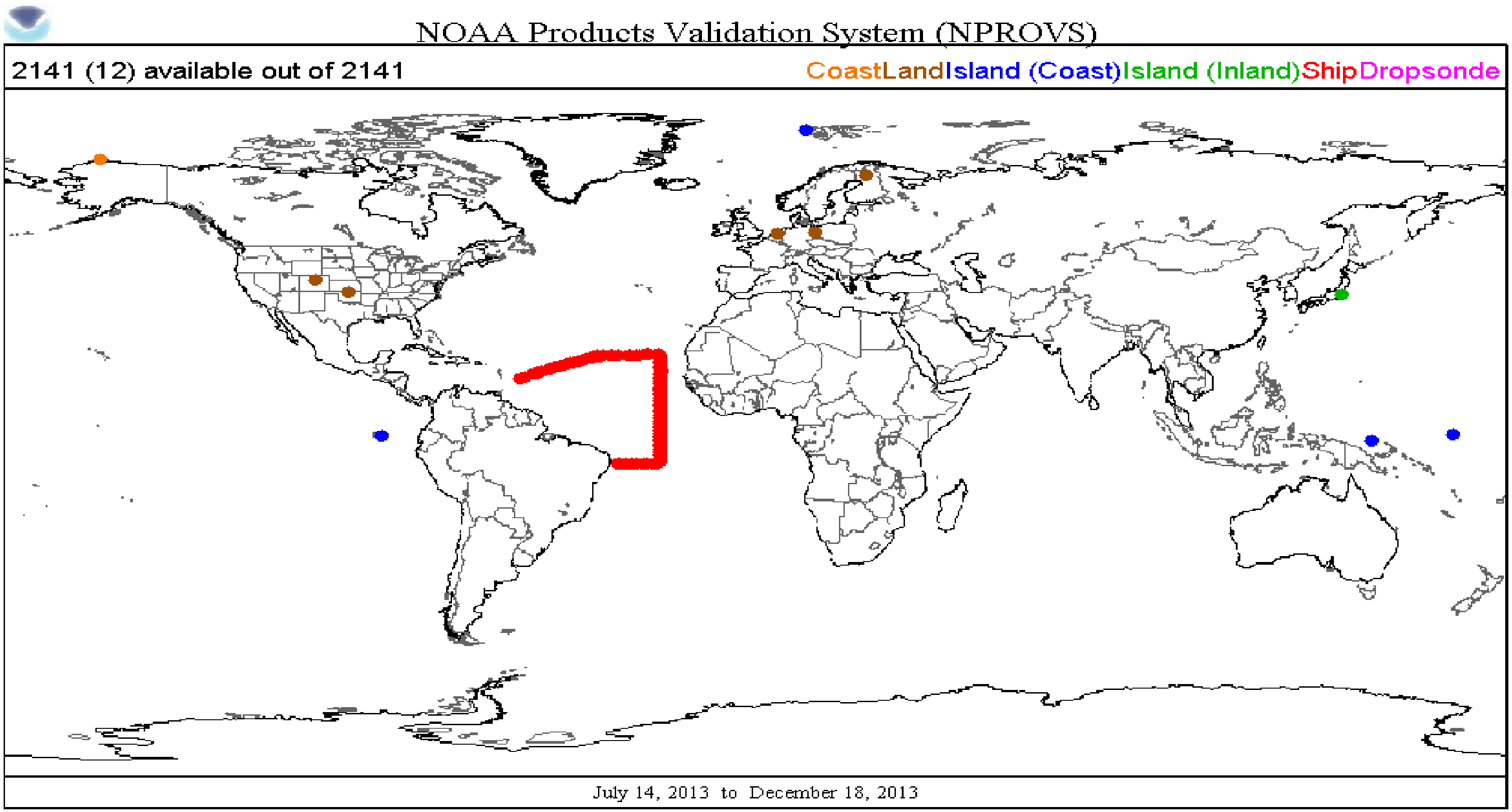
EDR Validation Results



Collocations containing (IR+MW) EDR from CrIMSS and NUCAPS which passed QC (4675/12617 … 37%)

EDR Validation

NPROVS+



2050 collocations (350 Dedicated, 1700 GRUAN) … 5mos

EDR Validation Results

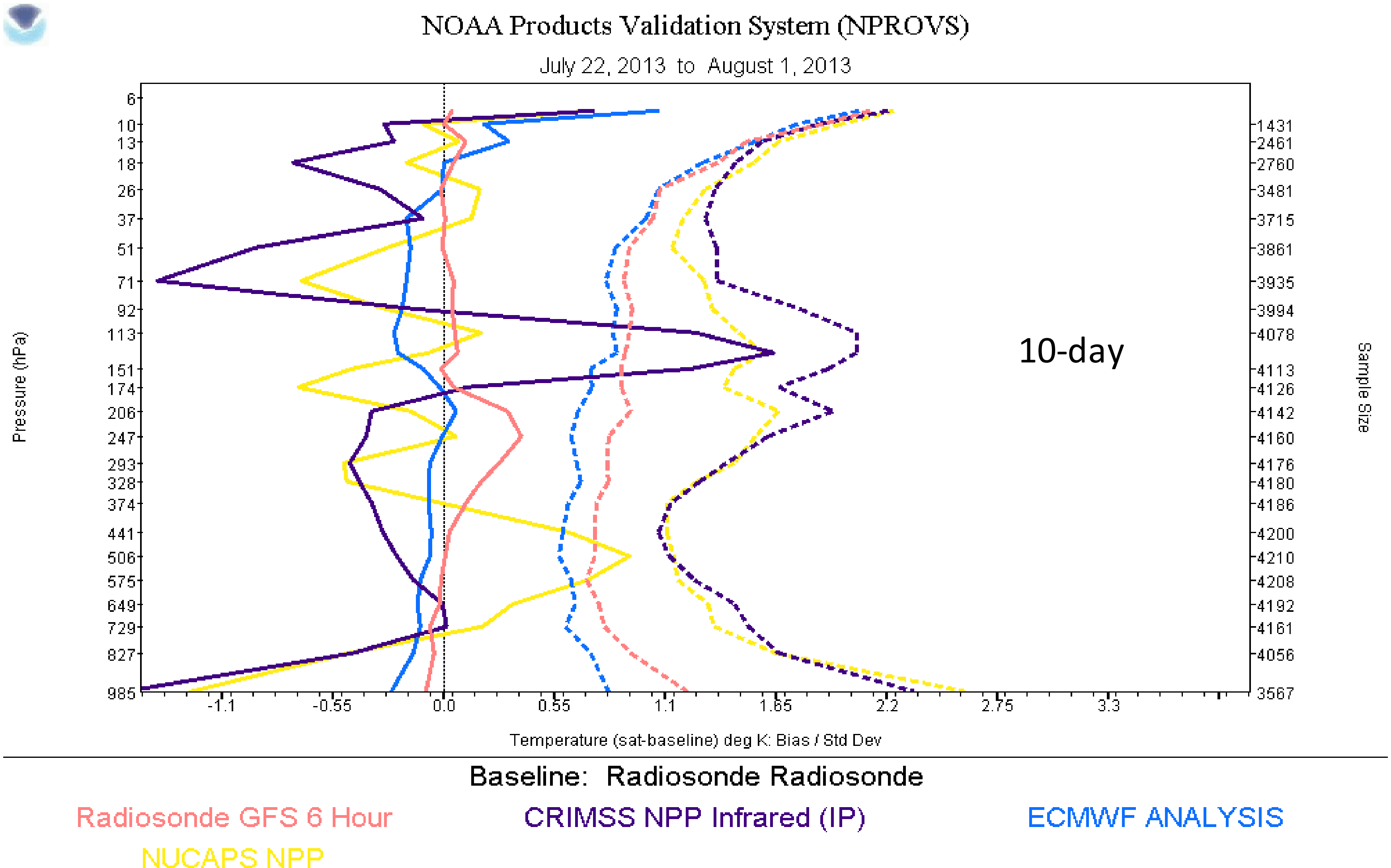
PDISP

Part 1

a) **IR+MW Only:**
NPROVS vs NPROVS+
Summer vs Fall

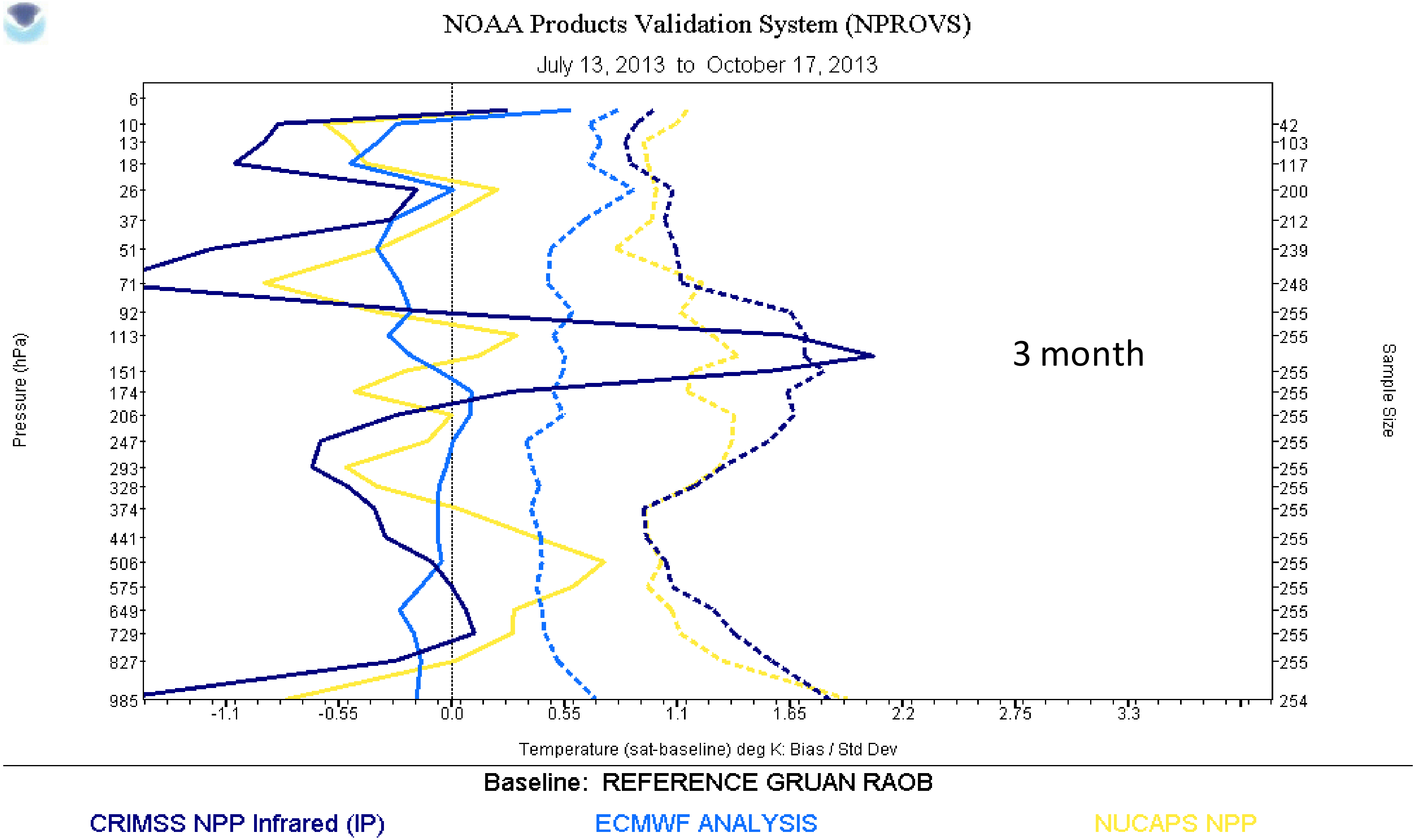
b) **MW only**

EDR Validation Results



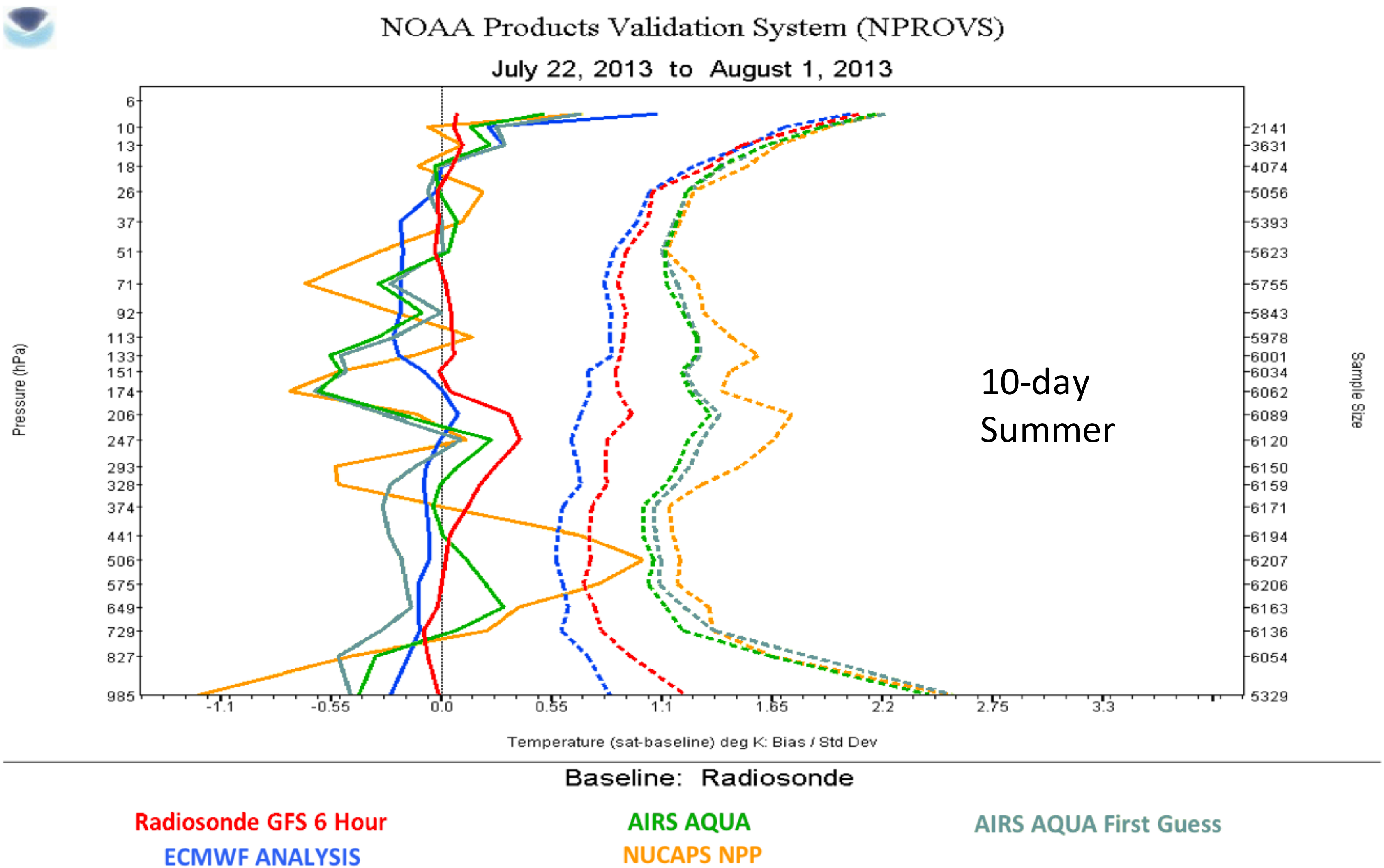
NPROVS PDISP

EDR Validation Results



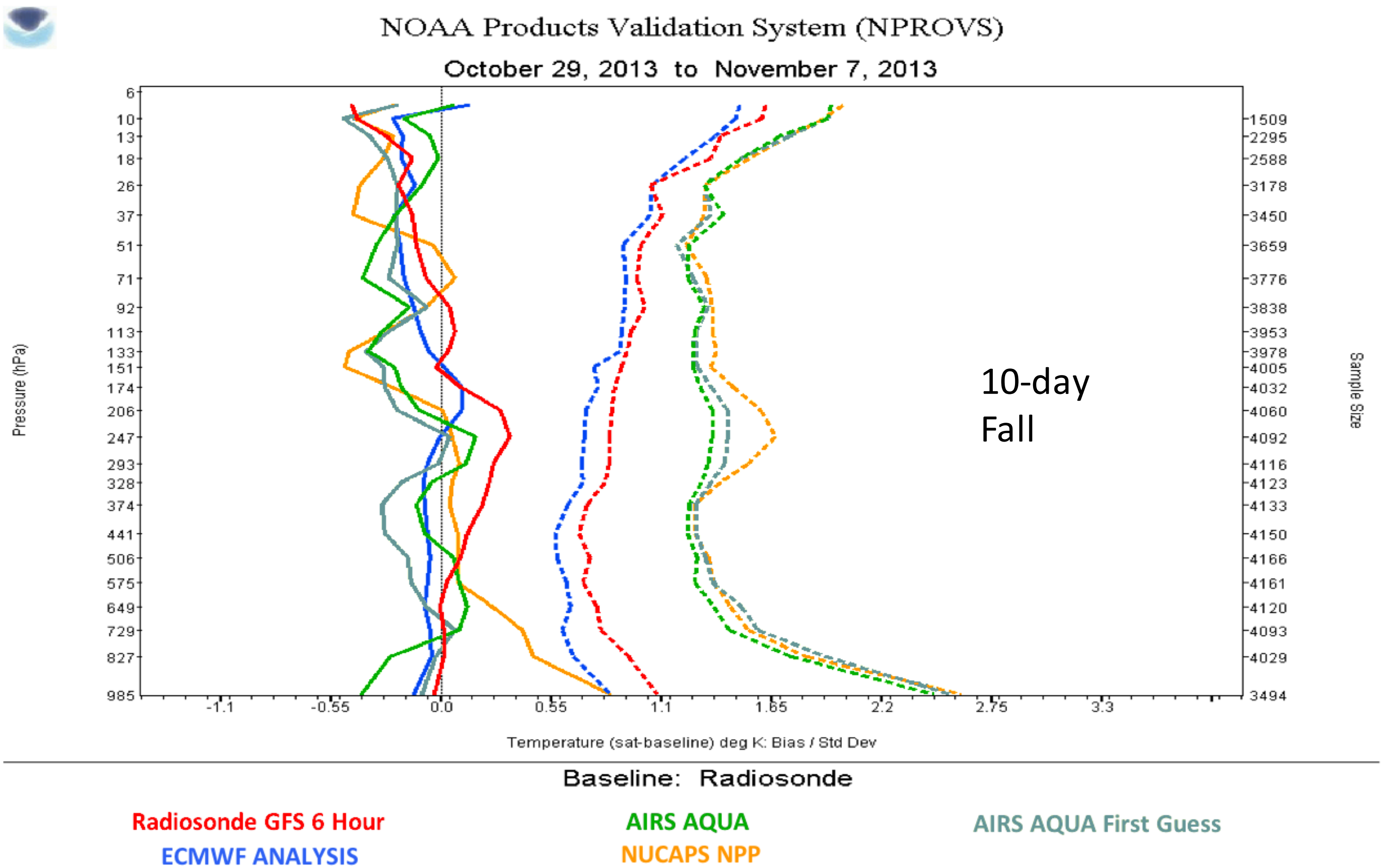
NPROVS+ PDISP

EDR Validation Results



NPROVS PDISP

EDR Validation Results

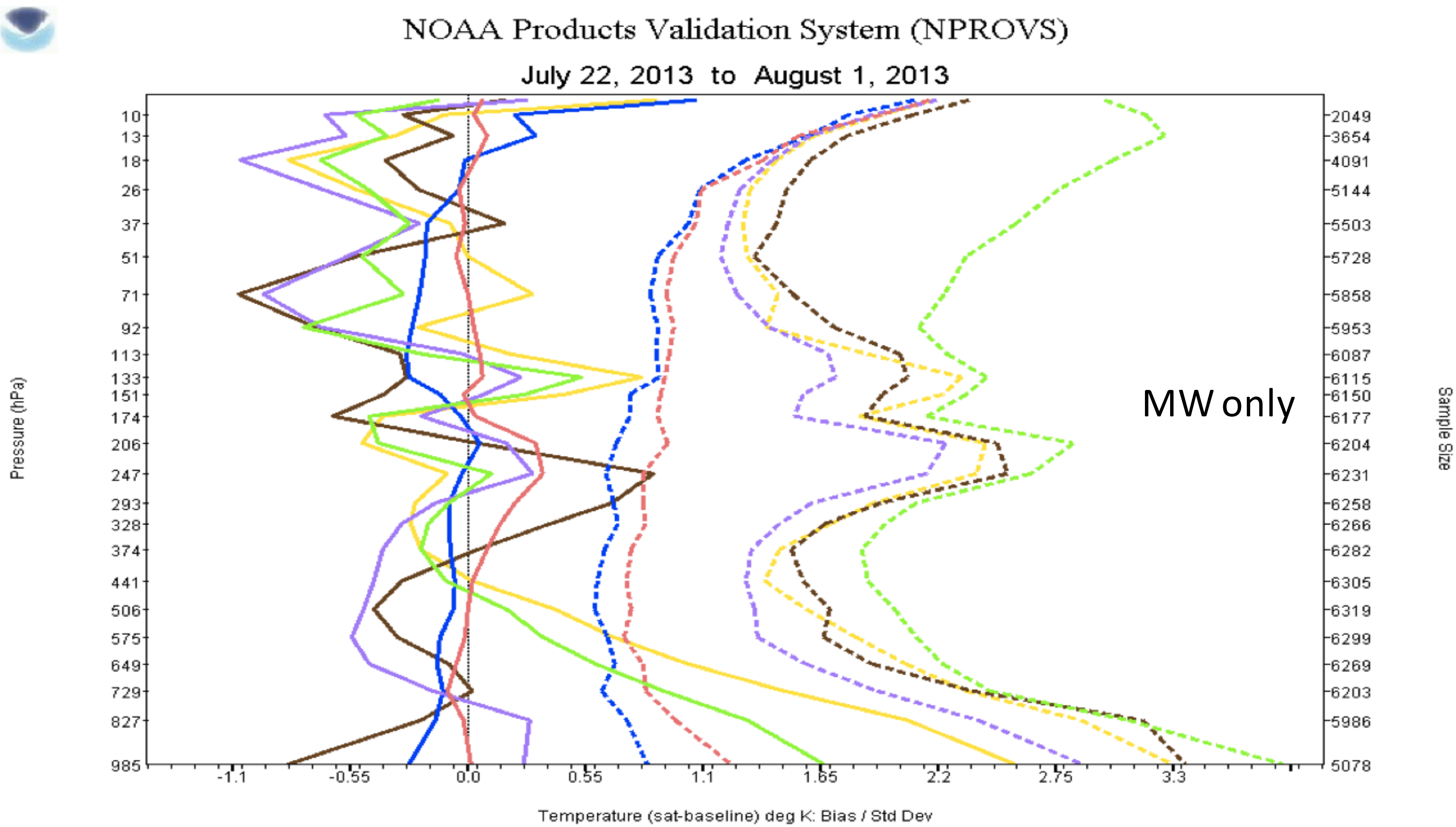


NPROVS

EDR Validation Results

MW only Pass
(the so called “cloudy”)

EDR Validation Results

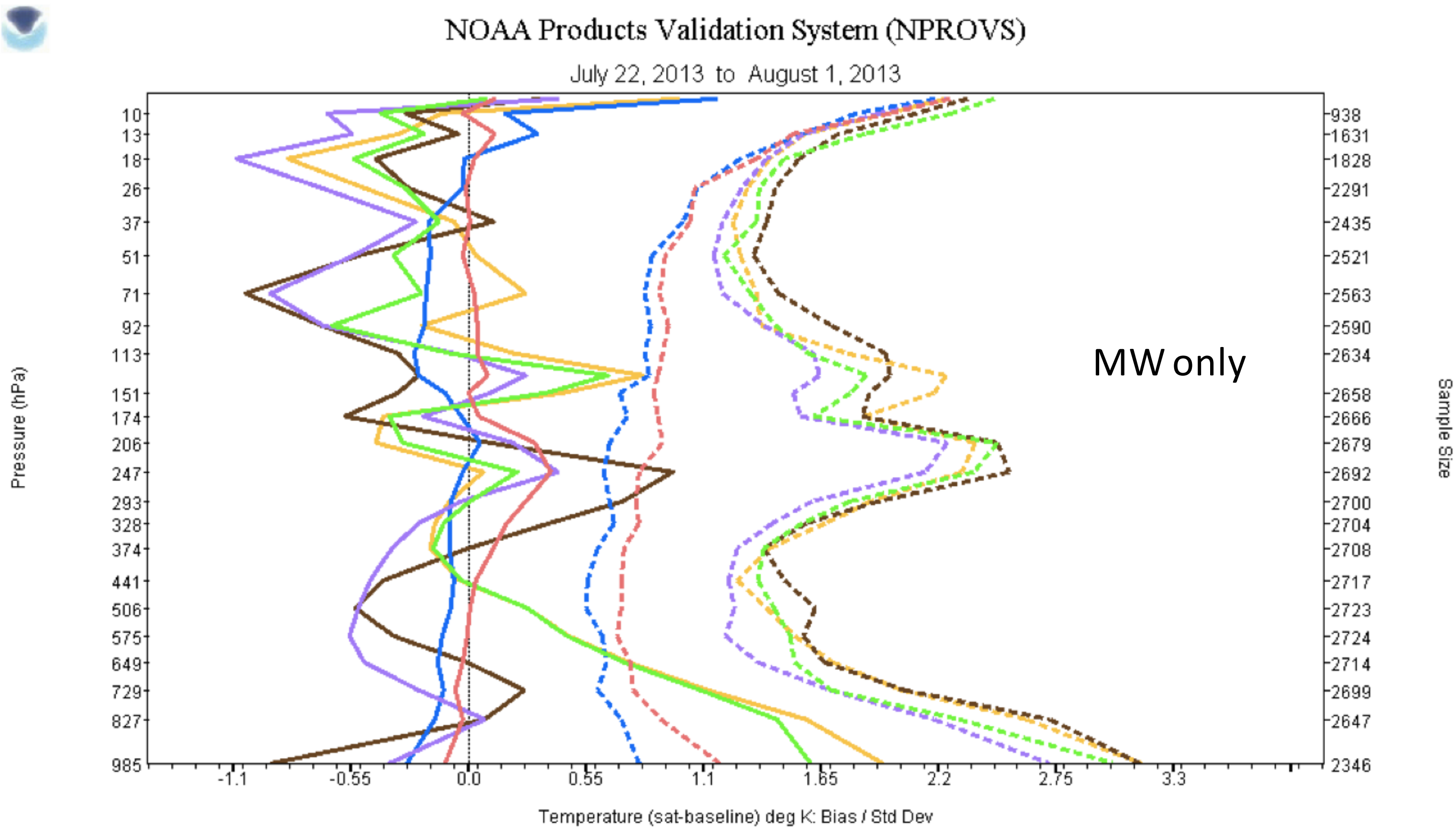


Baseline: Radiosonde

Radiosonde GFS 6 Hour
ECMWF ANALYSIS
IASI NOAA MIT
MIRS NPP
CRIMSS NPP Microwave (IP)
NUCAPS NPP MIT

MW only Pass QC

EDR Validation Results

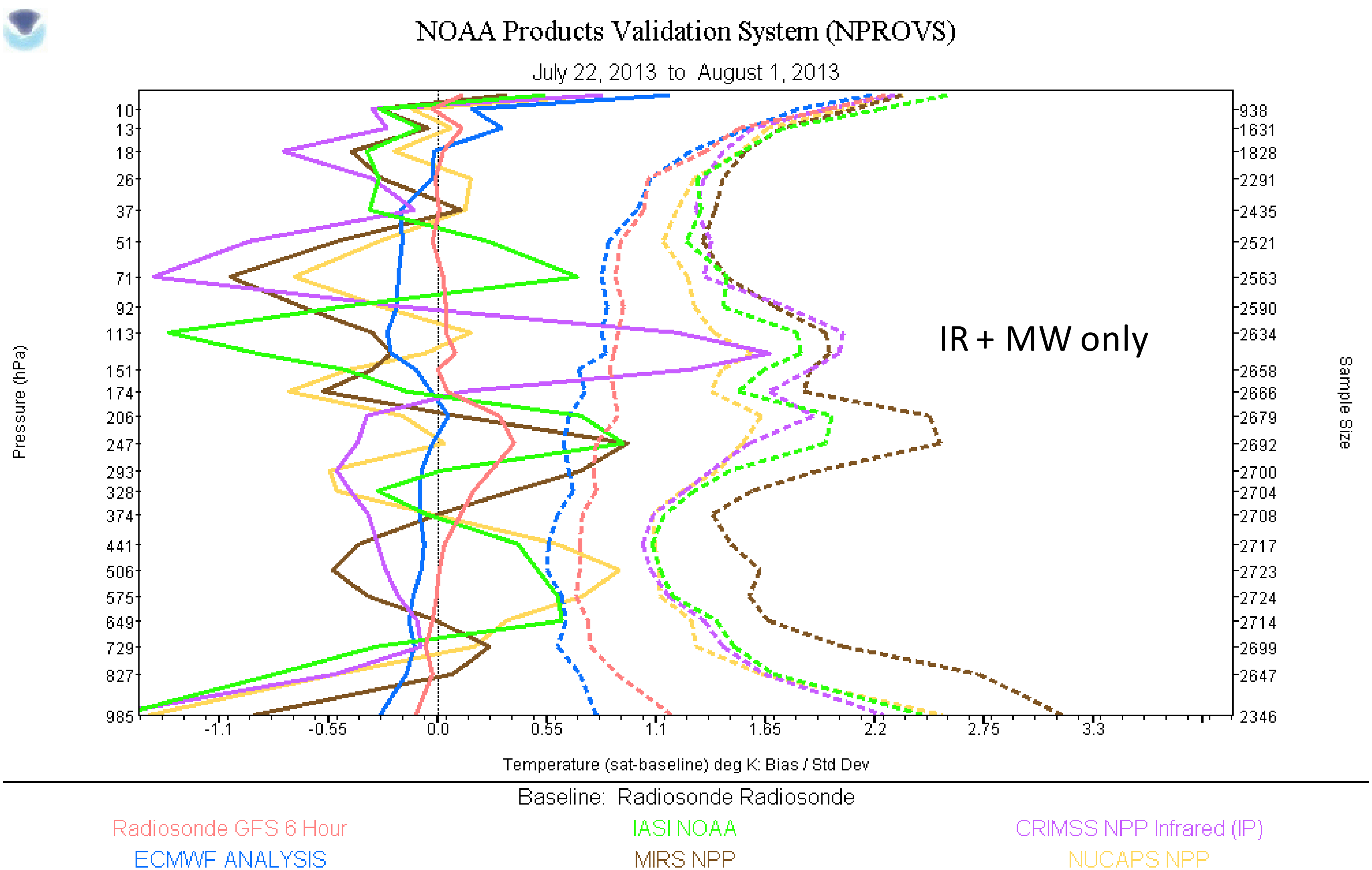


Baseline: Radiosonde

Radiosonde GFS 6 Hour
ECMWF ANALYSIS
IASI NOAA MIT
MIRS NPP
CRIMSS NPP Microwave (IP)
NUCAPS NPP MIT

IR + MW only Pass QC

EDR Validation Results



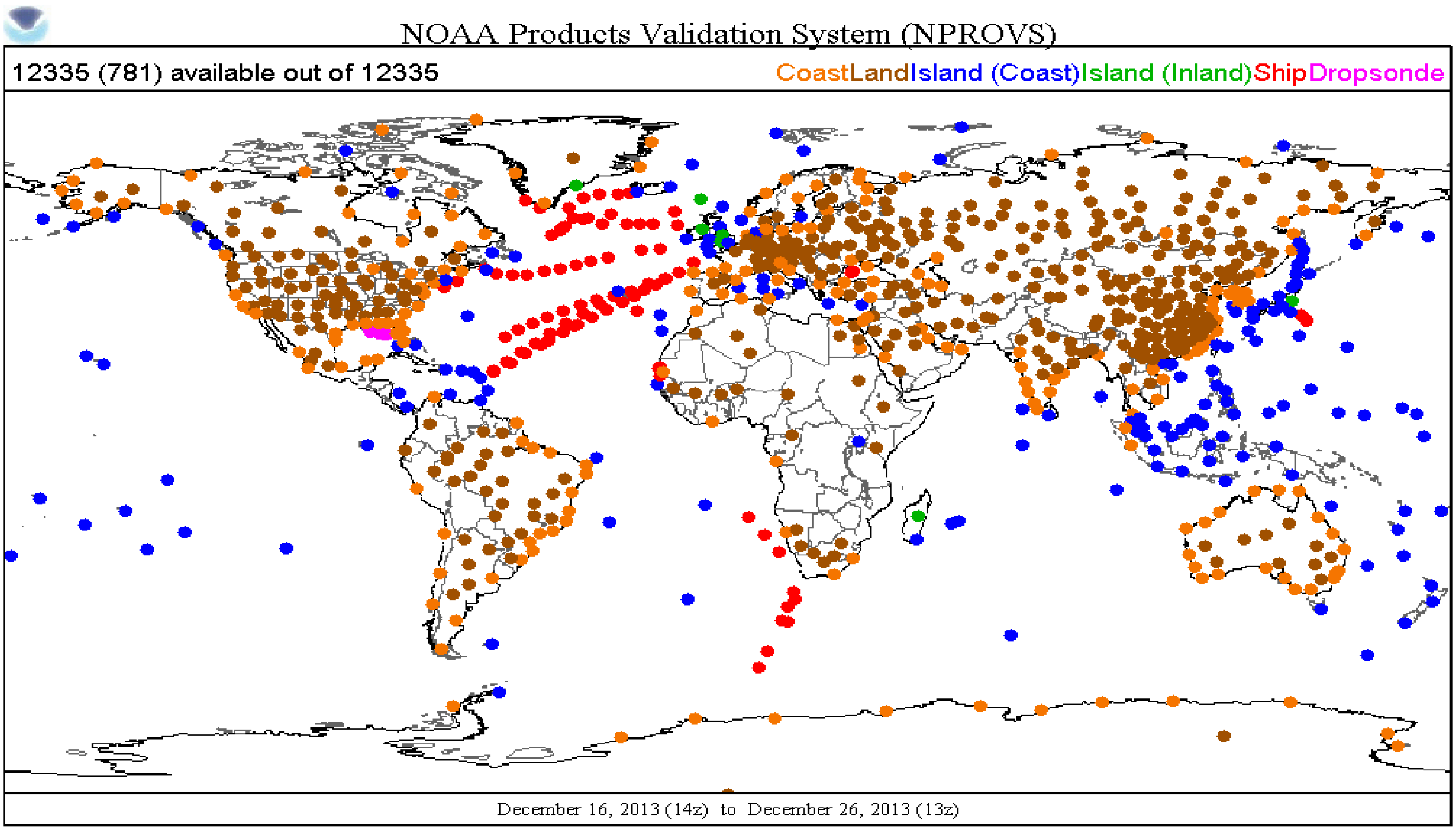
IR + MW only Pass QC

EDR Validation Results

Part 2

NPROVS
Dec 16-26
2013

EDR Validation Results



NPROVS Collocations 12/16 to 12/26 2013 … 12,335

EDR Validation Results

IASI (11,180)	(December)
– IR+MW	43%
– MW-only	54%
– Poor	02%

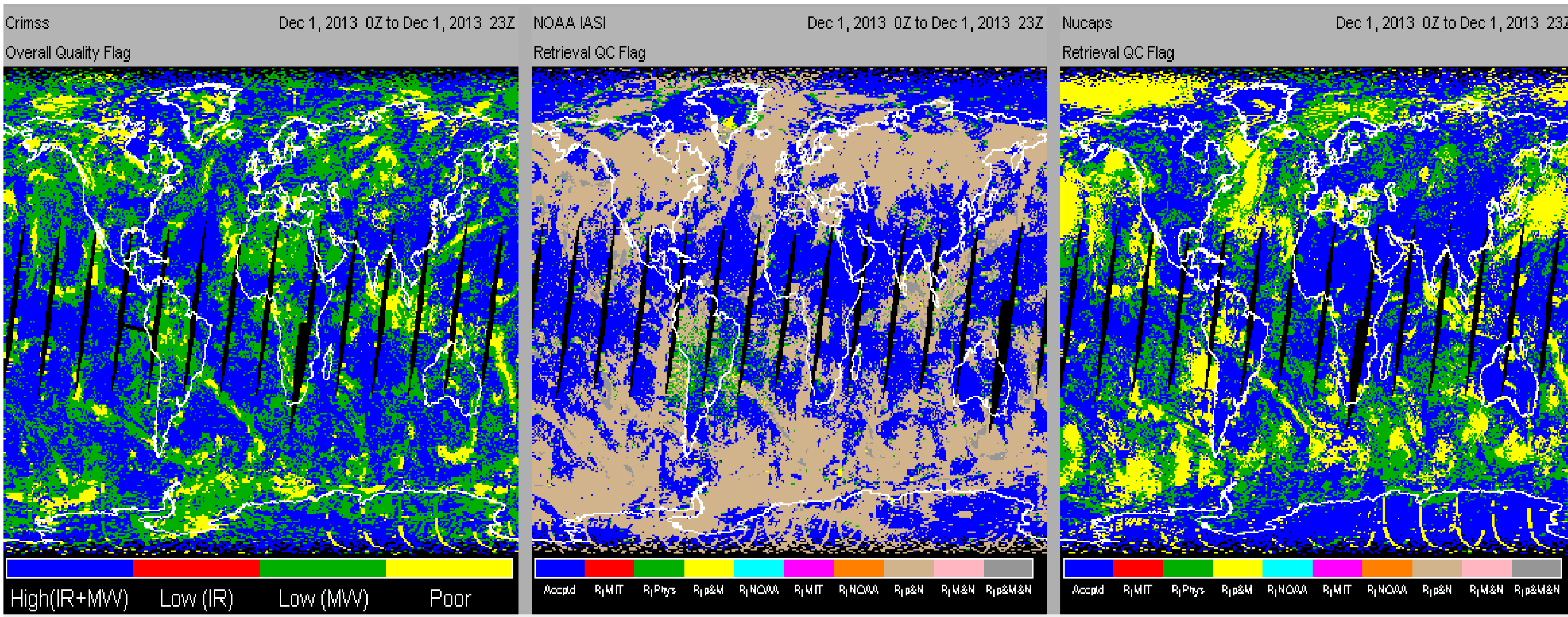
NUCAPS (11,355)	
– IR+MW	57%
– MW-only	21%
– Poor	22%

MX7.1 (11,347)		(July)
- IR+MW	43%	(50.6)
- MW-only	40%	(38.9)
- Poor	17%	(10.4)

Yield Analysis

NPROVS Collocations 12/16 to 12/26 2013 … 12,335

EDR Validation Results



ODS indicates inconsistencies in the way we are “interpreting” IASI qc

NPROVS Collocations do not reflect oceanic yields …

EDR Validation Results

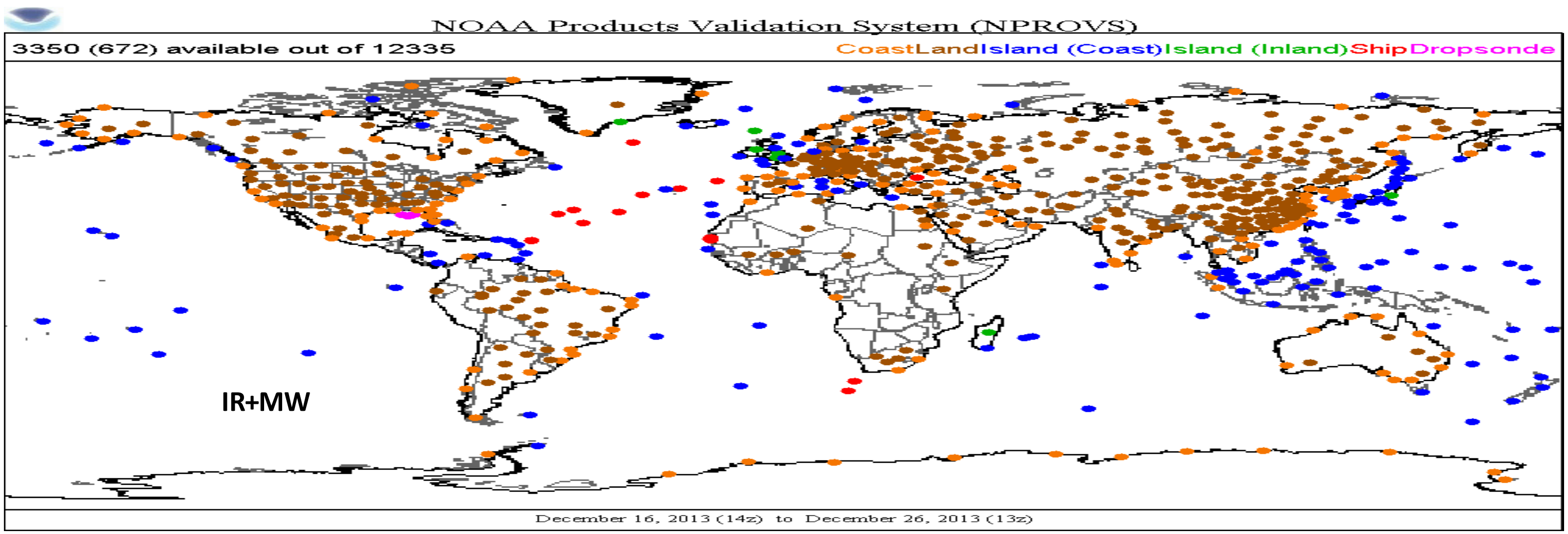
IR + MW Pass QC:

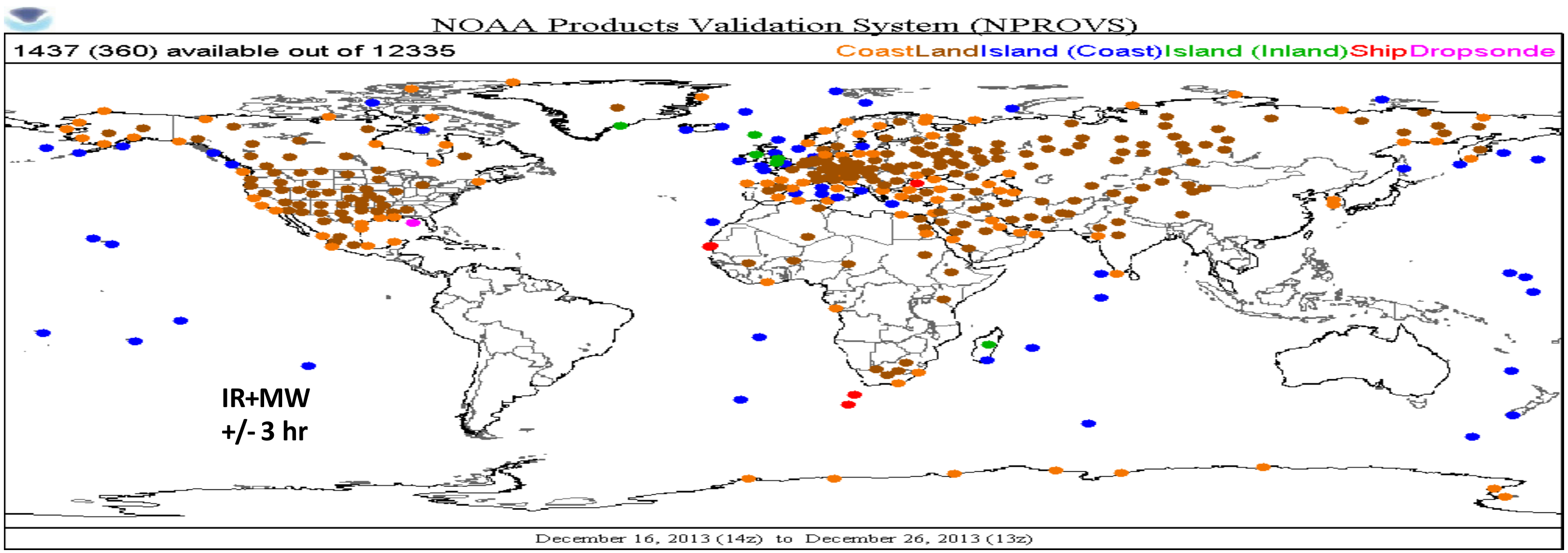
a) All Terrain … (3000 / 12000)

b) All Terrain, +/- 3 hr / 100km … (1000)

c) Maritime, +/- 3hr / 100km … (150)

EDR Validation Results





EDR Validation Results

Atmospheric Vertical Temperature Profile (AVTP) Measurement Uncertainty – Layer Average Temperature Error	
PARAMETER	**THRESHOLD**
AVTP Clear, surface to 300 mb	**1.6 K / 1-km layer**
AVTP Clear, 300 to 30 mb	**1.5 K / 3-km layer**
AVTP Clear, 30 mb to 1 mb	1.5 K / 5-km layer
AVTP Clear, 1 mb to 0.5 mb	3.5 K / 5-km layer
AVTP Cloudy , surface to 700 mb	**2.5 K / 1-km layer**
AVTP Cloudy, 700 mb to 300 mb	**1.5 K / 1-km layer**
AVTP Cloudy, 300 mb to 30 mb	**1.5 K / 3-km layer**
AVTP Cloudy, 30 mb to 1 mb	1.5 K / 5-km layer
AVTP Cloudy, 1 mb to 0.5 mb	3.5 K/ 5-km layer

Clear ... IR+MW

Cloudy ... (MW only)

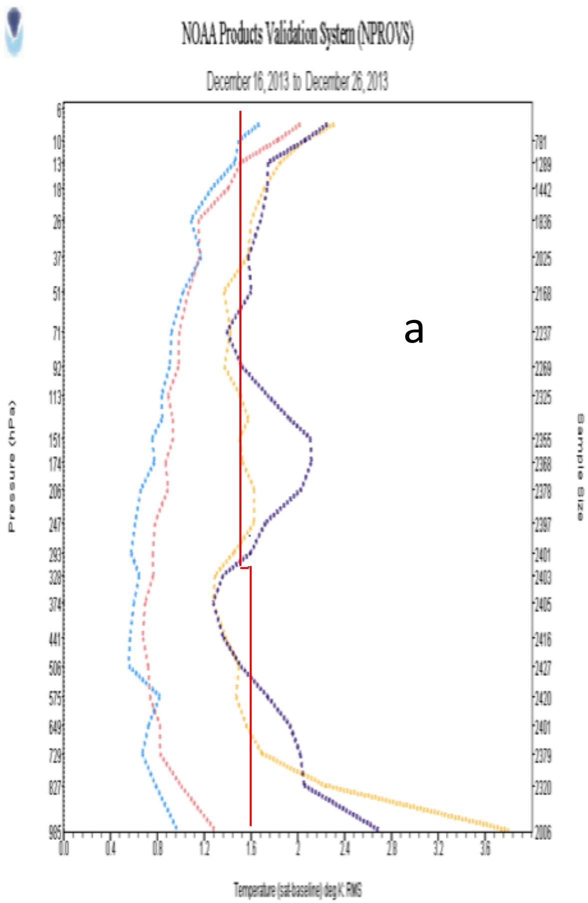
Atmospheric Vertical Moisture Profile (AVMP) Measurement Uncertainty – 2-km Layer Average Mixing Ratio % Error	
PARAMETER	**THRESHOLD**
AVMP Clear, surface to 600 mb	**Greater of 20%** or 0.2 g/kg **/ 2-km layer**
AVMP Clear, 600 to 300 mb	**Greater of 35%** or 0.1 g/kg / **2-km layer**
AVMP Clear, 300 to 100 mb	Greater of 35% or 0.1 g/kg / 2-km layer
AVMP Cloudy, surface to 600 mb	**Greater of 20%** of 0.2 g/kg **/ 2-km layer**
AVMP Cloudy, 600 mb to 400 mb	**Greater of 40%** or 0.1 g/kg / **2-km layer**
AVMP Cloudy, 400 mb to 100 mb	Greater of 40% or 0.1 g/kg / 2-km layer

Clear ... IR+MW

Cloudy ... (MW only)

(courtesy Nick Nalli)

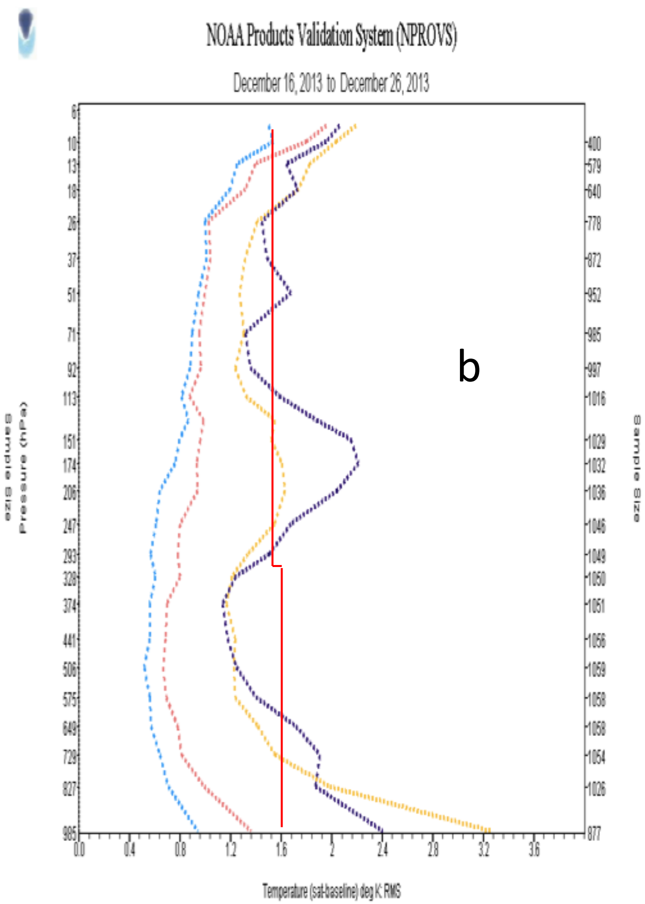
EDR Validation Results



Baseline: Radiosonde

Radiosonde GFS 6 Hour | NUCAPS NPP

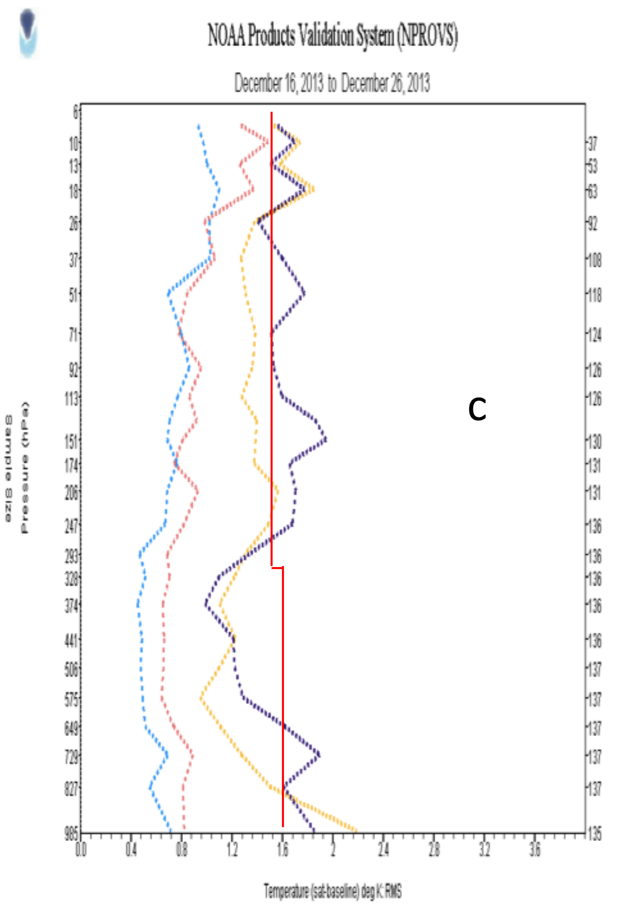
CRIMSS NPP Infrared (IP) | ECMWF ANALYSIS



Baseline: Radiosonde

Radiosonde GFS 6 Hour | NUCAPS NPP

CRIMSS NPP Infrared (IP) | ECMWF ANALYSIS

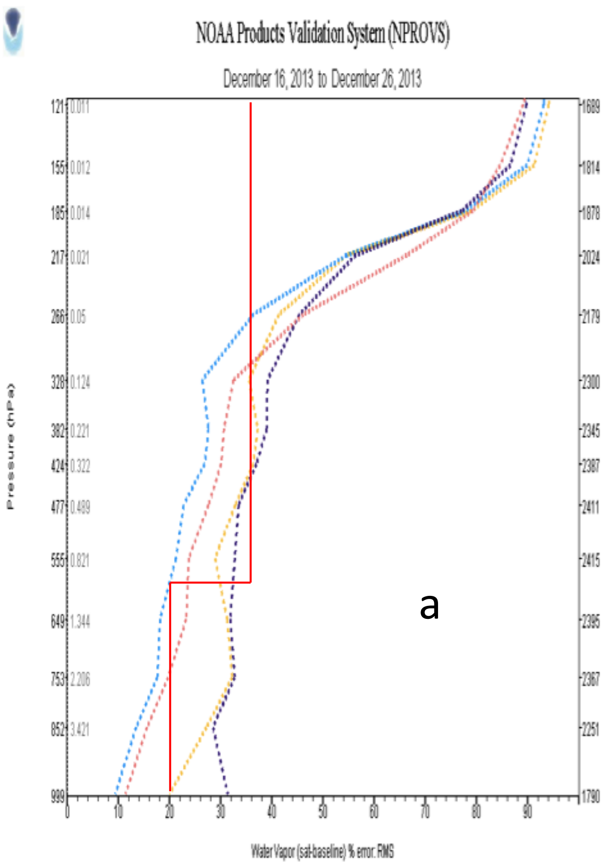


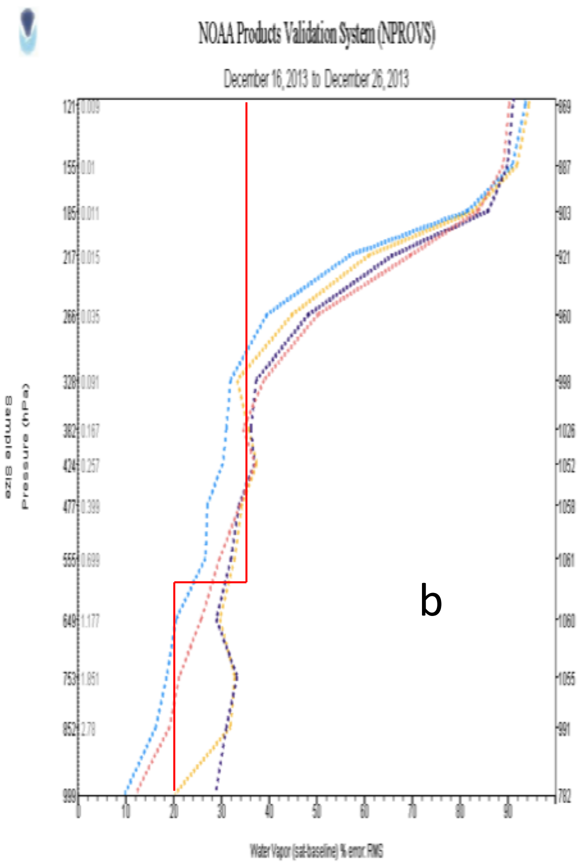
Baseline: Radiosonde

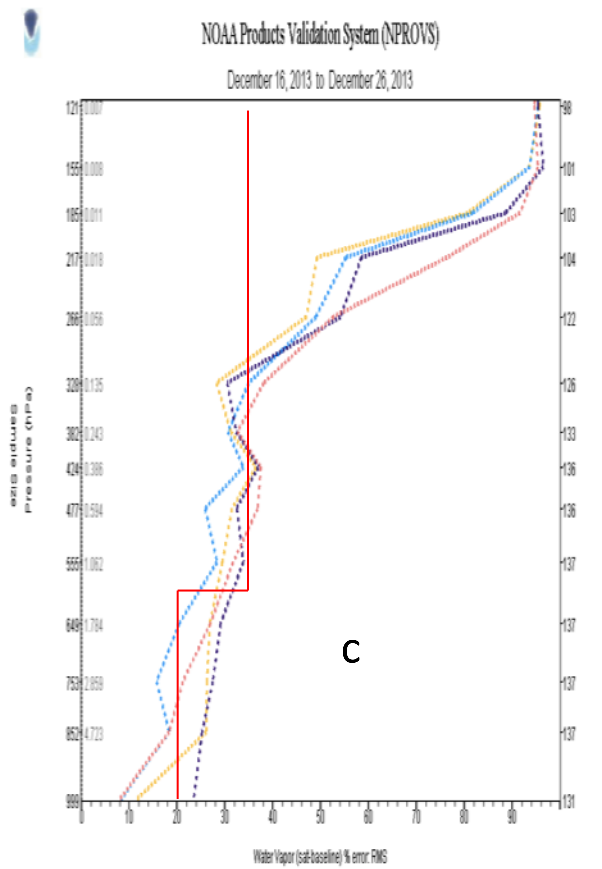
Radiosonde GFS 6 Hour | NUCAPS NPP

CRIMSS NPP Infrared (IP) | ECMWF ANALYSIS

EDR Validation Results







Baseline: Radiosonde

Radiosonde GFS 6 Hour — NUCAPS NPP

CRIMSS NPP Infrared (IP) — ECMWF ANALYSIS

Baseline: Radiosonde

Radiosonde GFS 6 Hour — NUCAPS NPP

CRIMSS NPP Infrared (IP) — ECMWF ANALYSIS

Baseline: Radiosonde

Radiosonde GFS 6 Hour — NUCAPS NPP

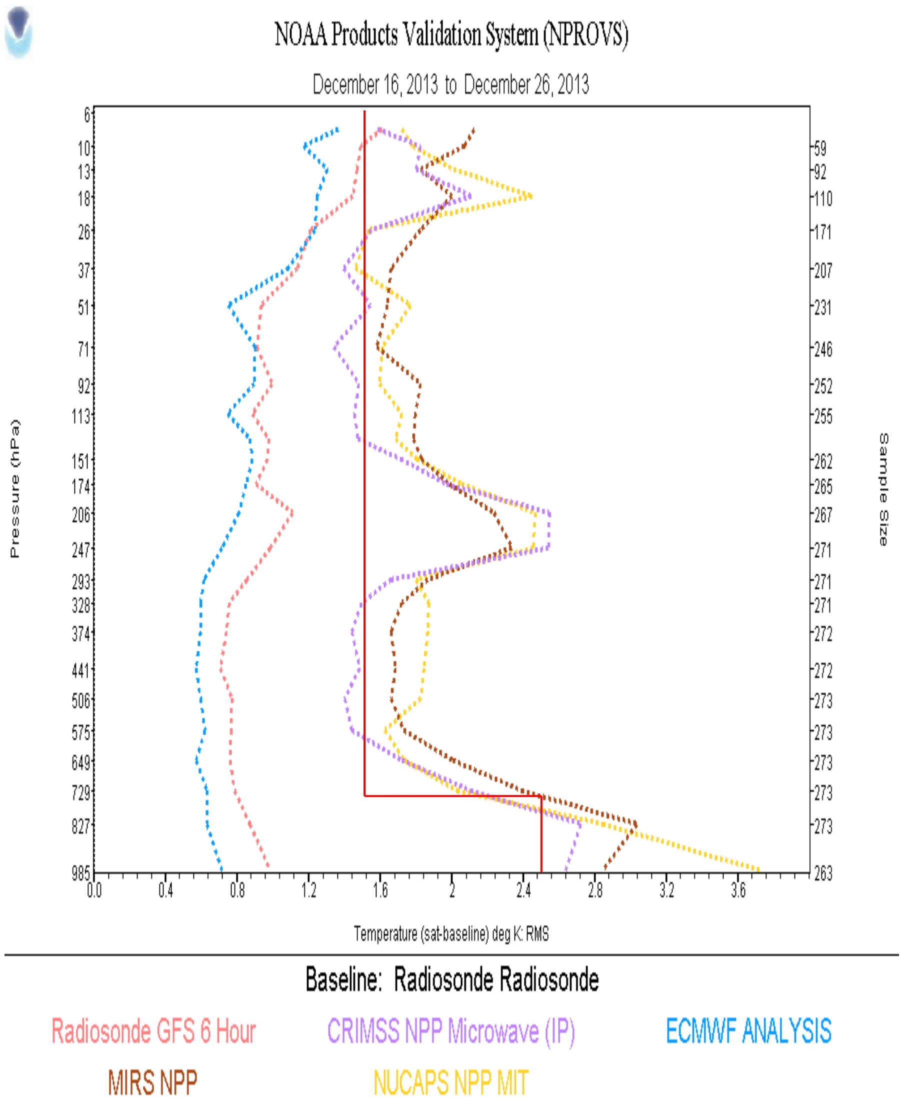
CRIMSS NPP Infrared (IP) — ECMWF ANALYSIS

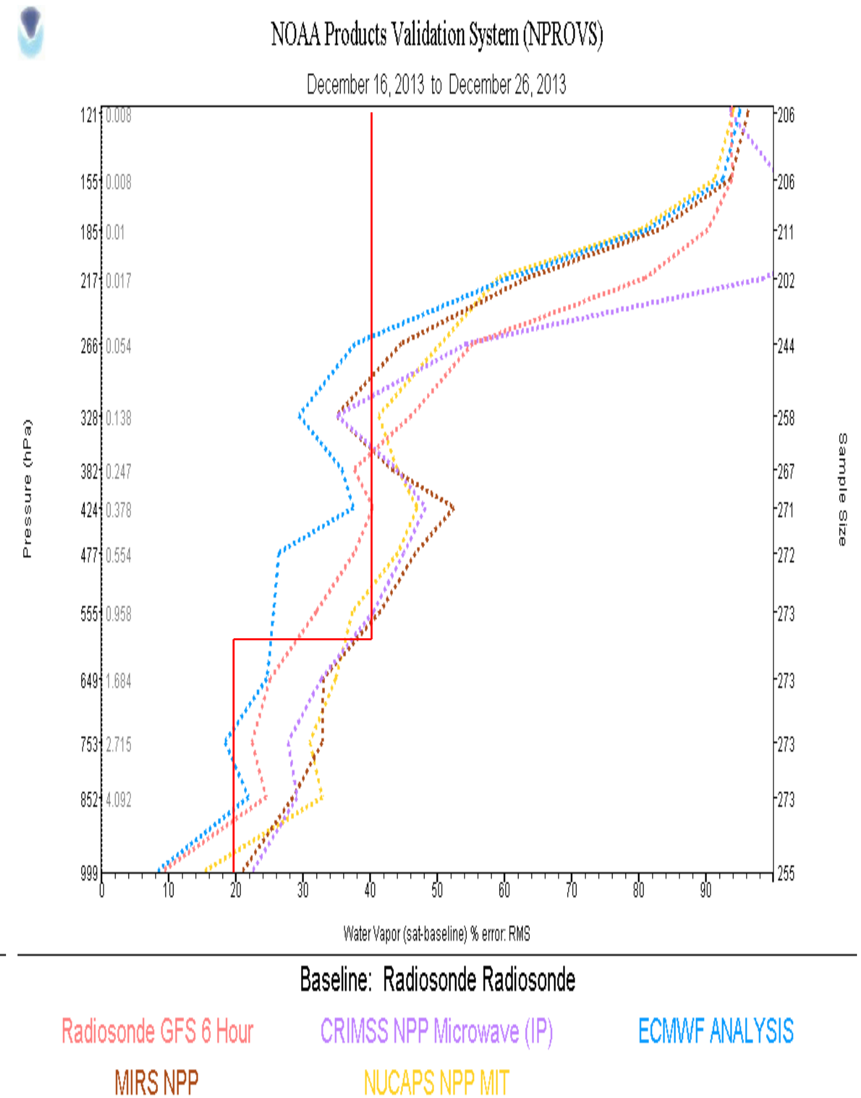
EDR Validation Results

MW Pass QC:

a) Maritime, +/- 3hr / 100km … (250)

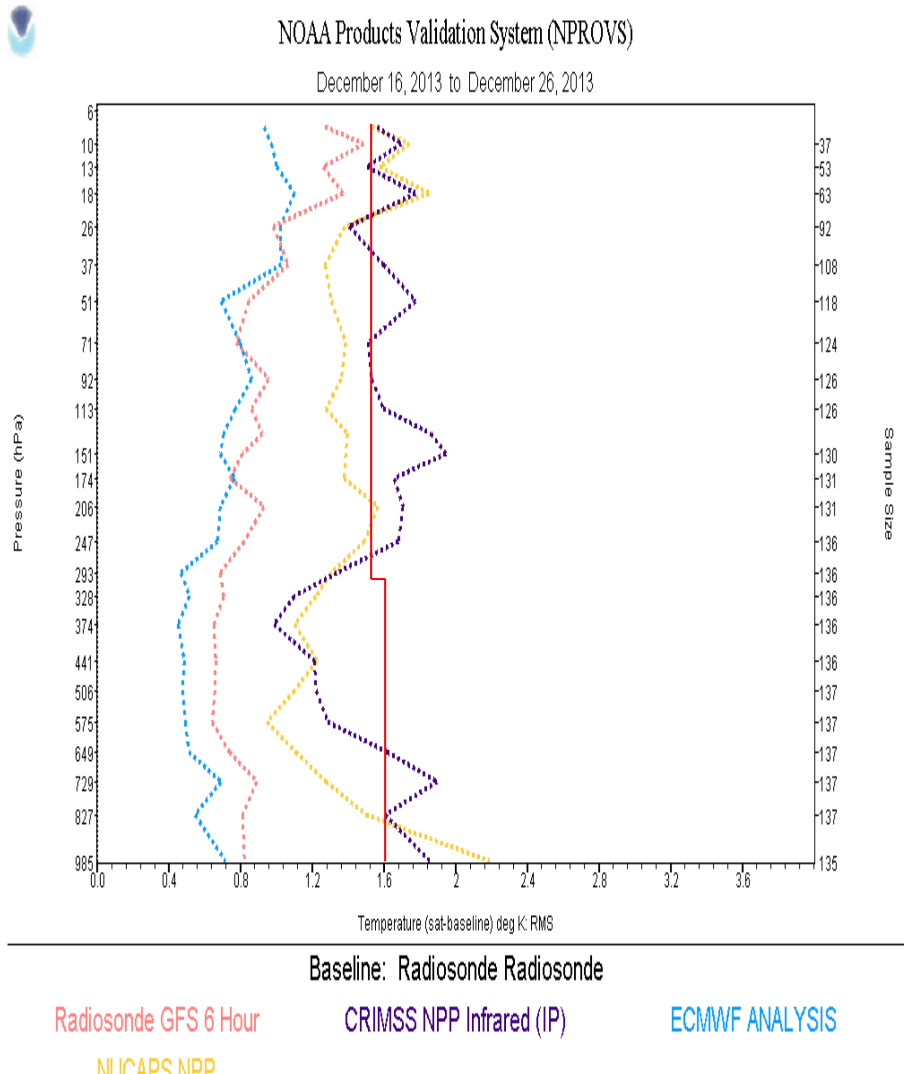
EDR Validation Results

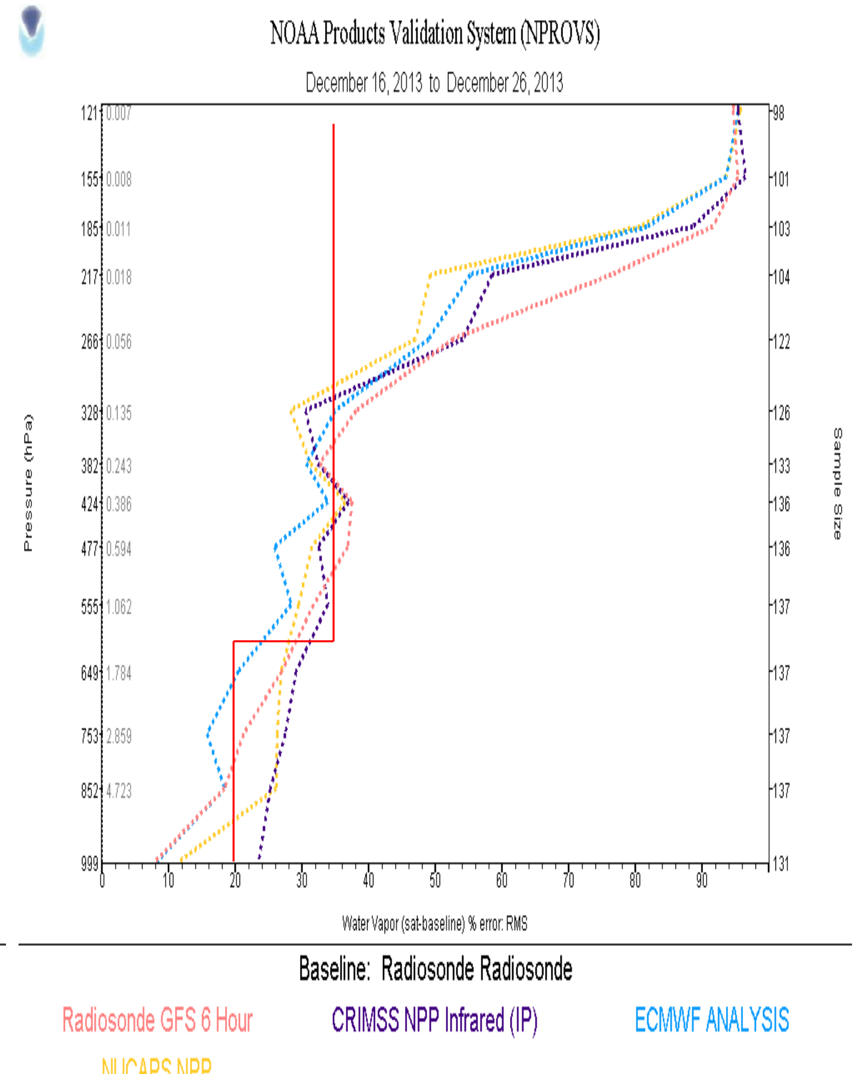




MW Only pass QC

EDR Validation Results





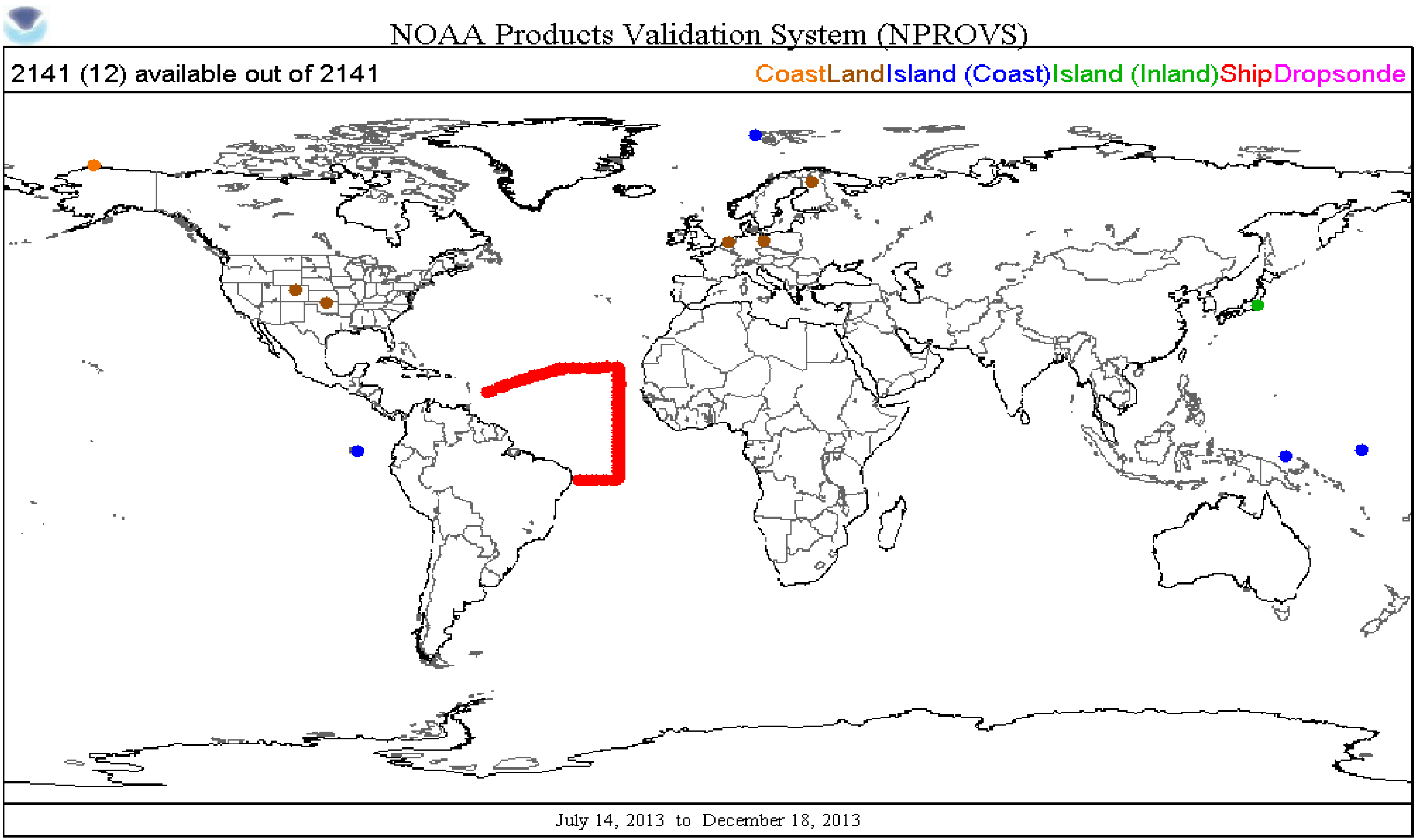
IR + MW pass QC)

EDR Validation Results

Part 3

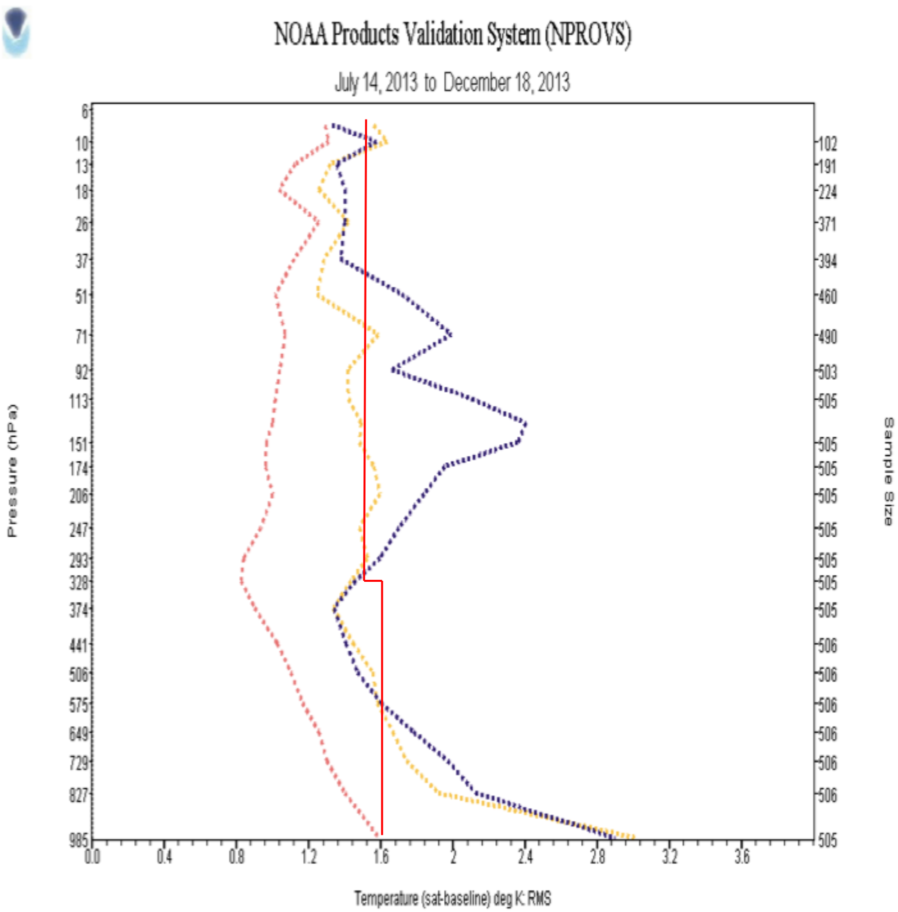
NPROVS +
July 15 to Dec 22
2013

EDR Validation Results



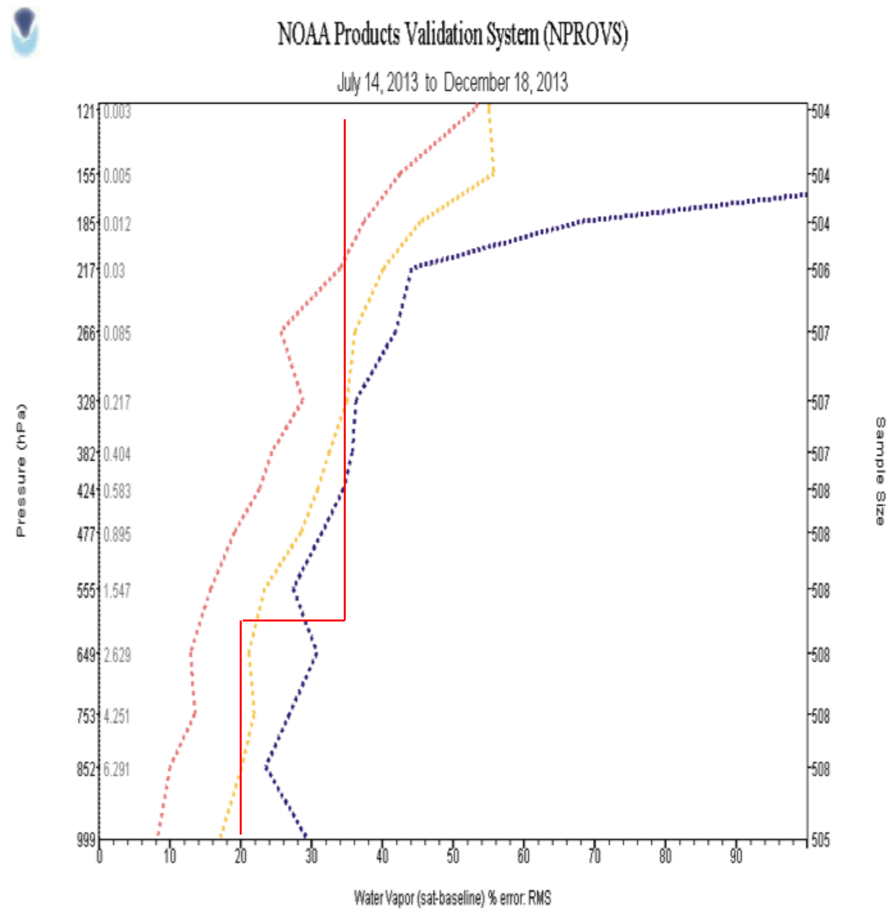
350 Dedicated, 1790 GRUAN

EDR Validation Results



Baseline: REFERENCE SONDE GRUAN RAOB

CRIMSS NPP Infrared (IP) ECMWF ANALYSIS NUCAPS NPP TEST

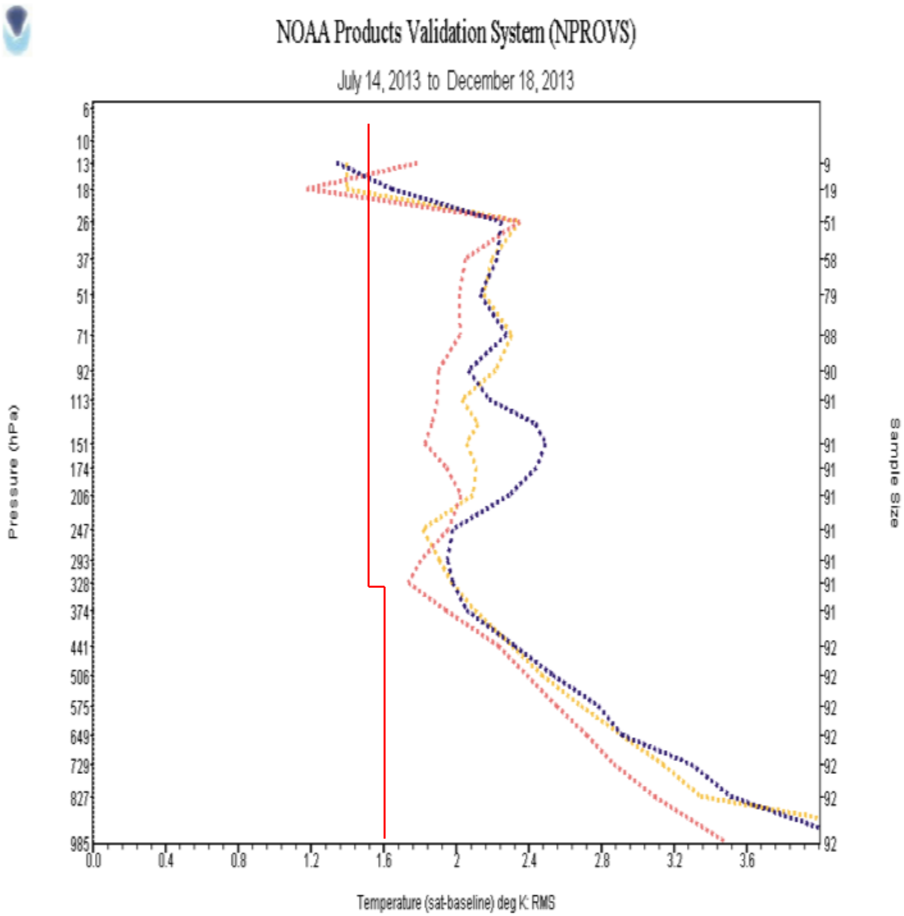


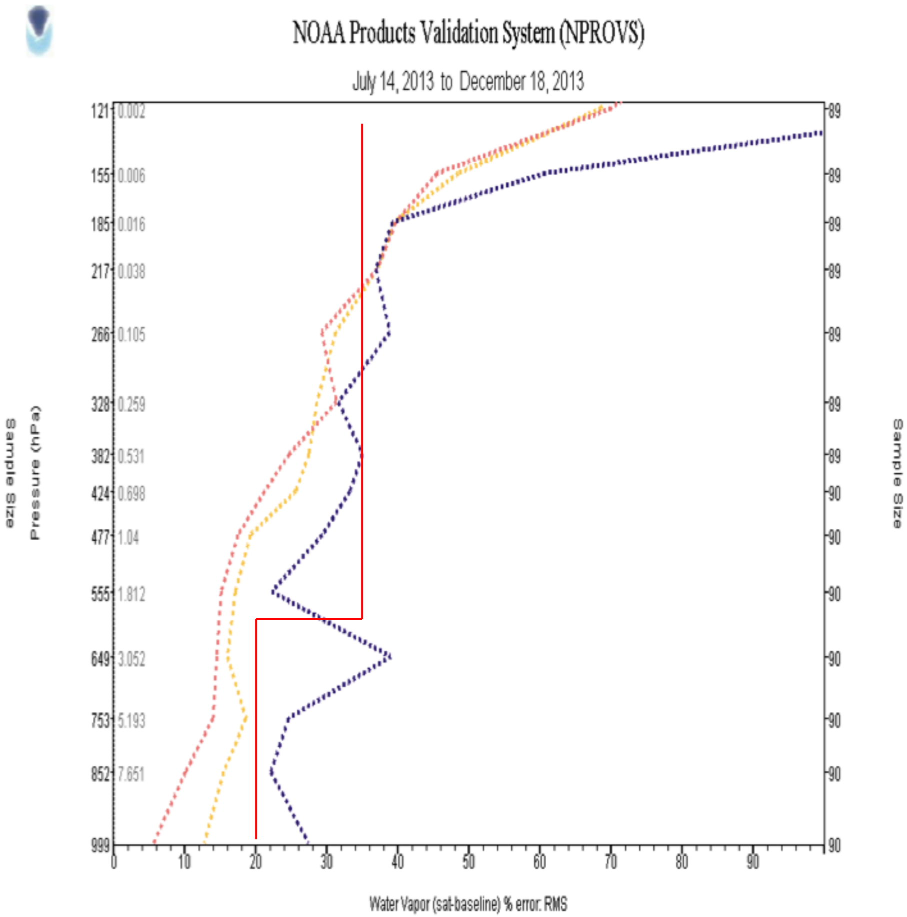
Baseline: REFERENCE SONDE GRUAN RAOB

CRIMSS NPP Infrared (IP) ECMWF ANALYSIS NUCAPS NPP TEST

2141: IR + MW Pass QC … 1080 (NU), 870 (IDPS), 500 (both)

EDR Validation Results





Baseline: REFERENCE SONDE GRUAN RAOB

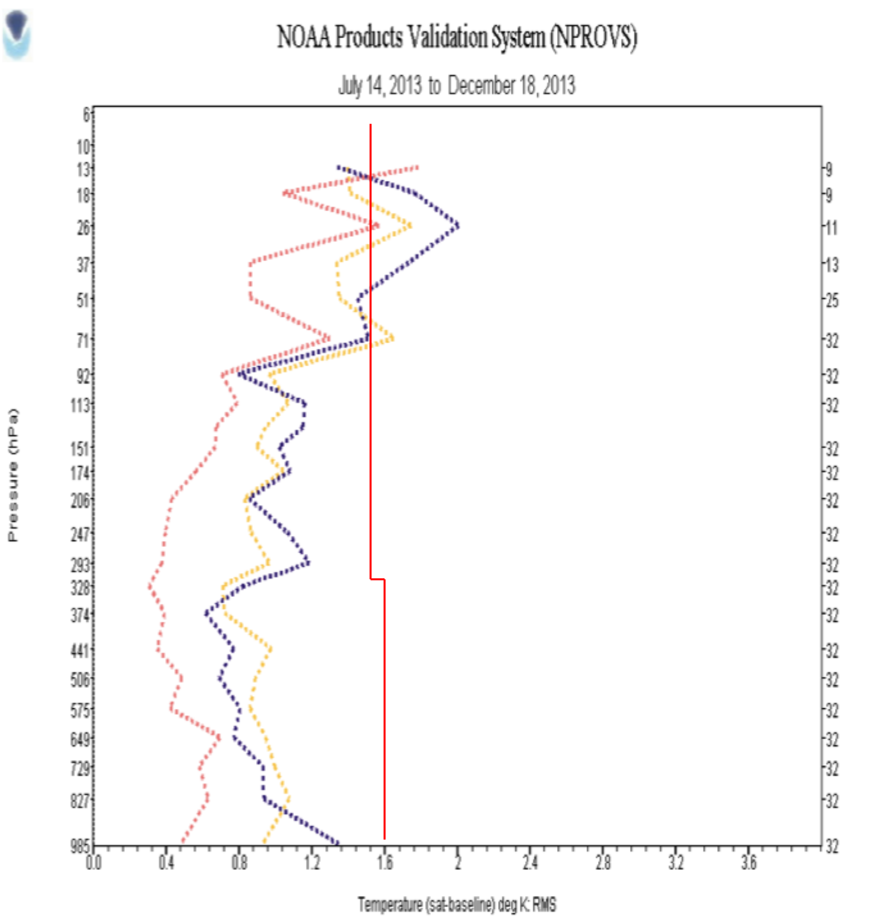
CRIMSS NPP Infrared (IP) **ECMWF ANALYSIS** **NUCAPS NPP TEST**

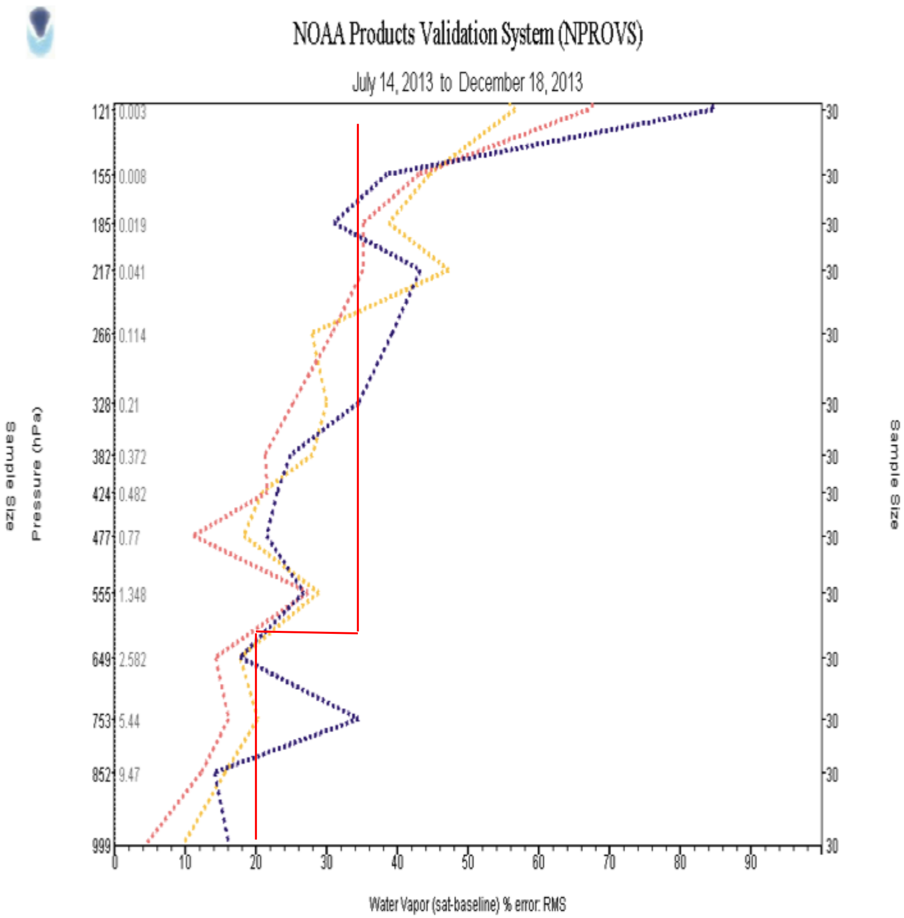
Baseline: REFERENCE SONDE GRUAN RAOB

CRIMSS NPP Infrared (IP) **ECMWF ANALYSIS** **NUCAPS NPP TEST**

IR + MW Pass QC … Dedicated only

EDR Validation Results





Baseline: REFERENCE SONDE GRUAN RAOB

CRIMSS NPP Infrared (IP) **ECMWF ANALYSIS** **NUCAPS NPP TEST**

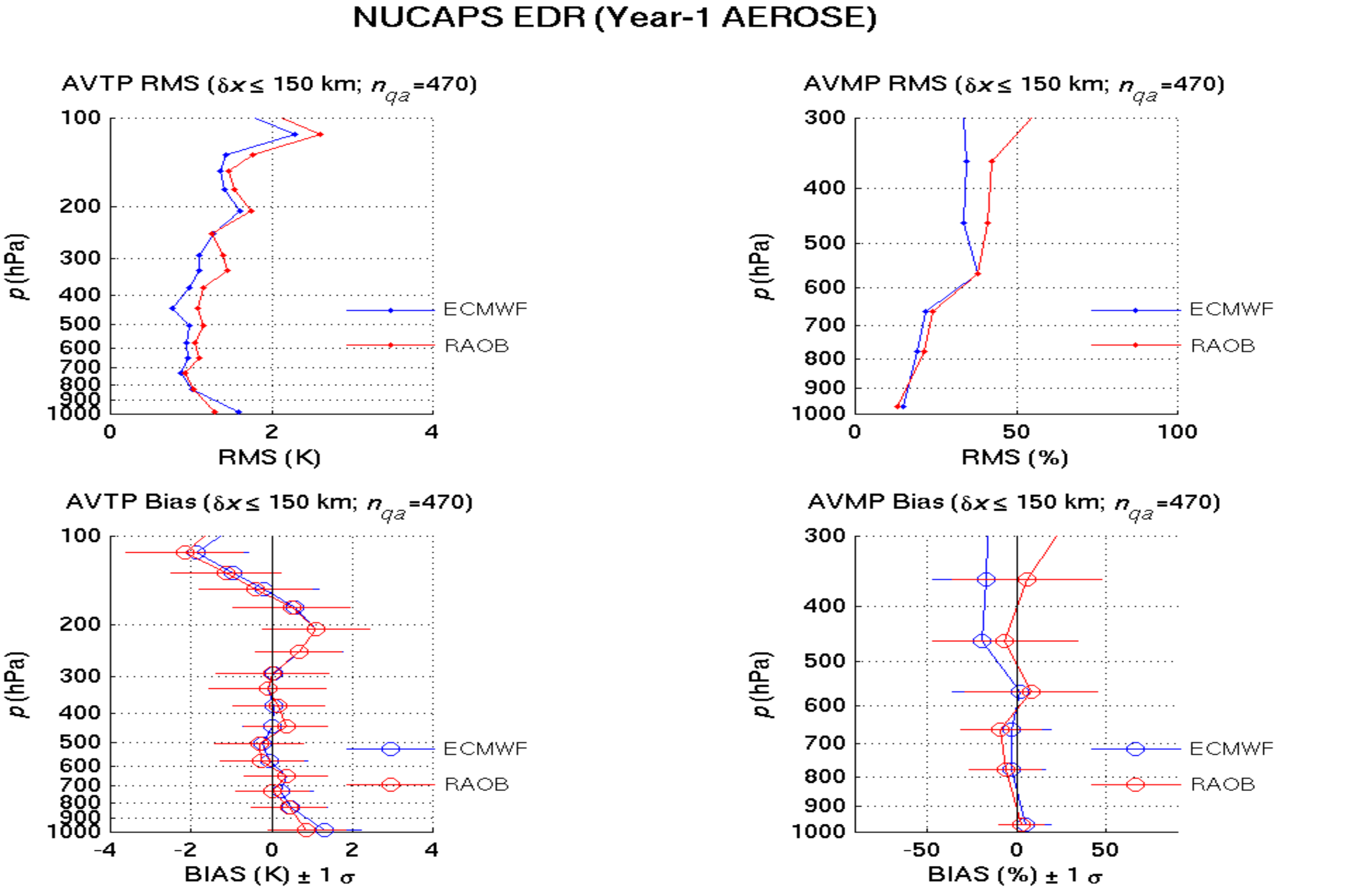
Baseline: REFERENCE SONDE GRUAN RAOB

CRIMSS NPP Infrared (IP) **ECMWF ANALYSIS** **NUCAPS NPP TEST**

IR + MW Pass QC … AEROSE only

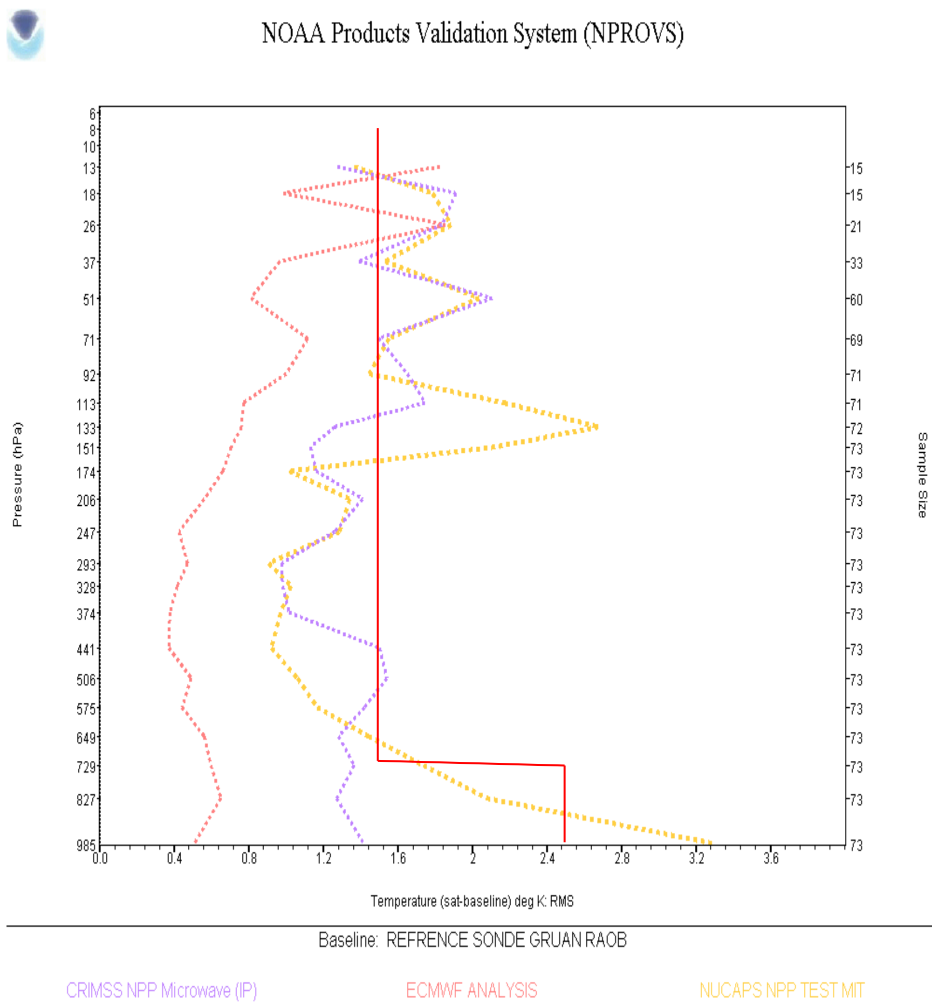
EDR Validation Results

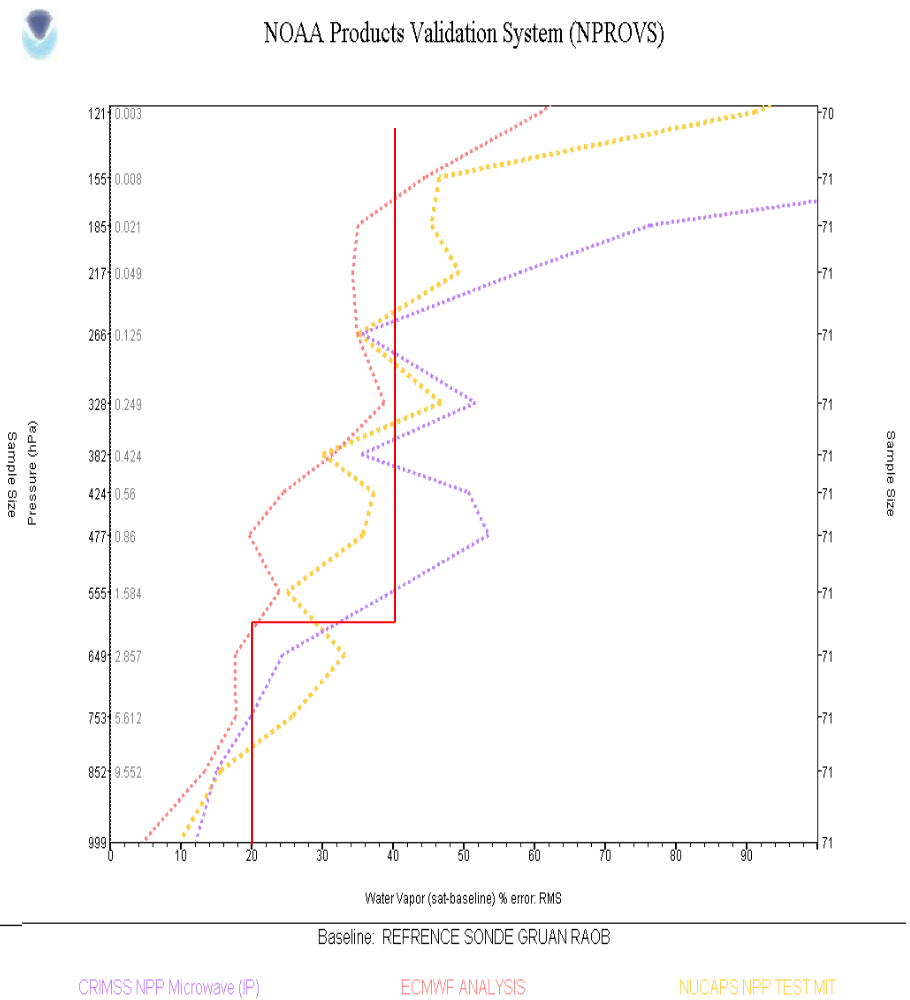
Year 1 AEROSE/NUCAPS Phase 2 Validation Statistics



courtesy Gambacorta et al

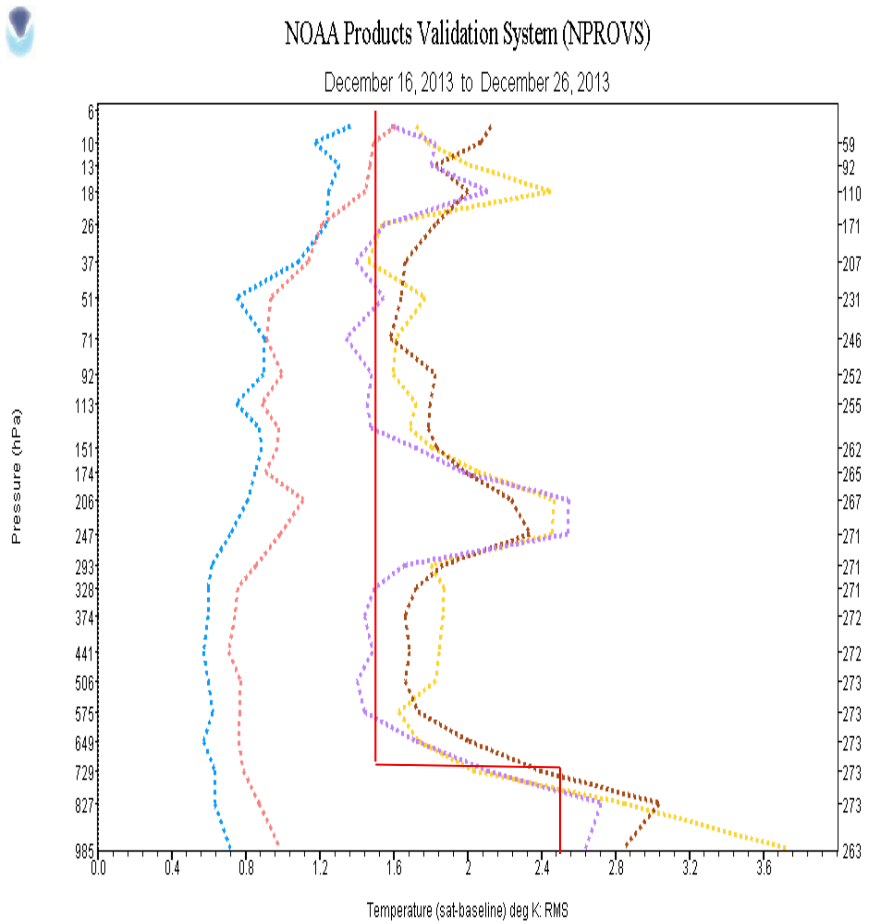
EDR Validation Results

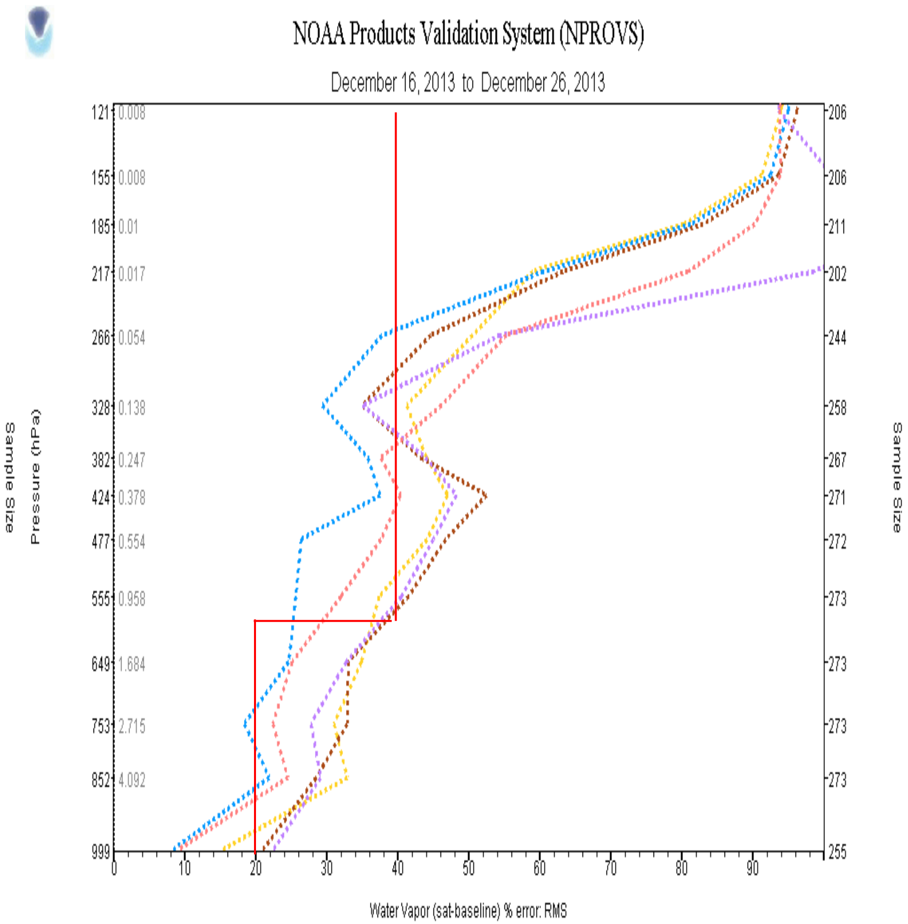




MW only Pass QC … **AEROSE**

EDR Validation Results





Baseline: Radiosonde Radiosonde

Radiosonde GFS 6 Hour CRIMSS NPP Microwave (IP) ECMWF ANALYSIS

MIRS NPP NUCAPS NPP MIT

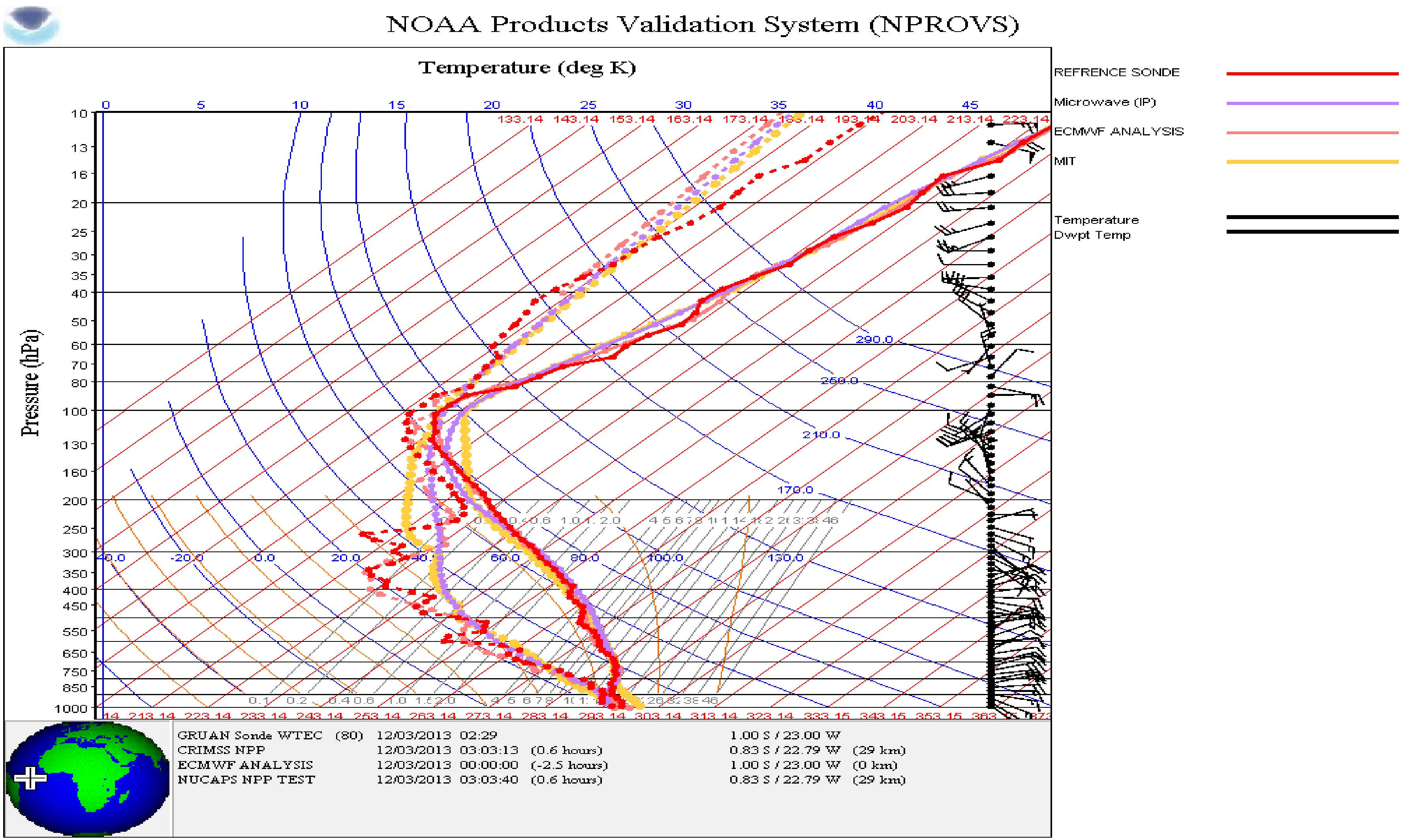
Baseline: Radiosonde Radiosonde

Radiosonde GFS 6 Hour CRIMSS NPP Microwave (IP) ECMWF ANALYSIS

MIRS NPP NUCAPS NPP MIT

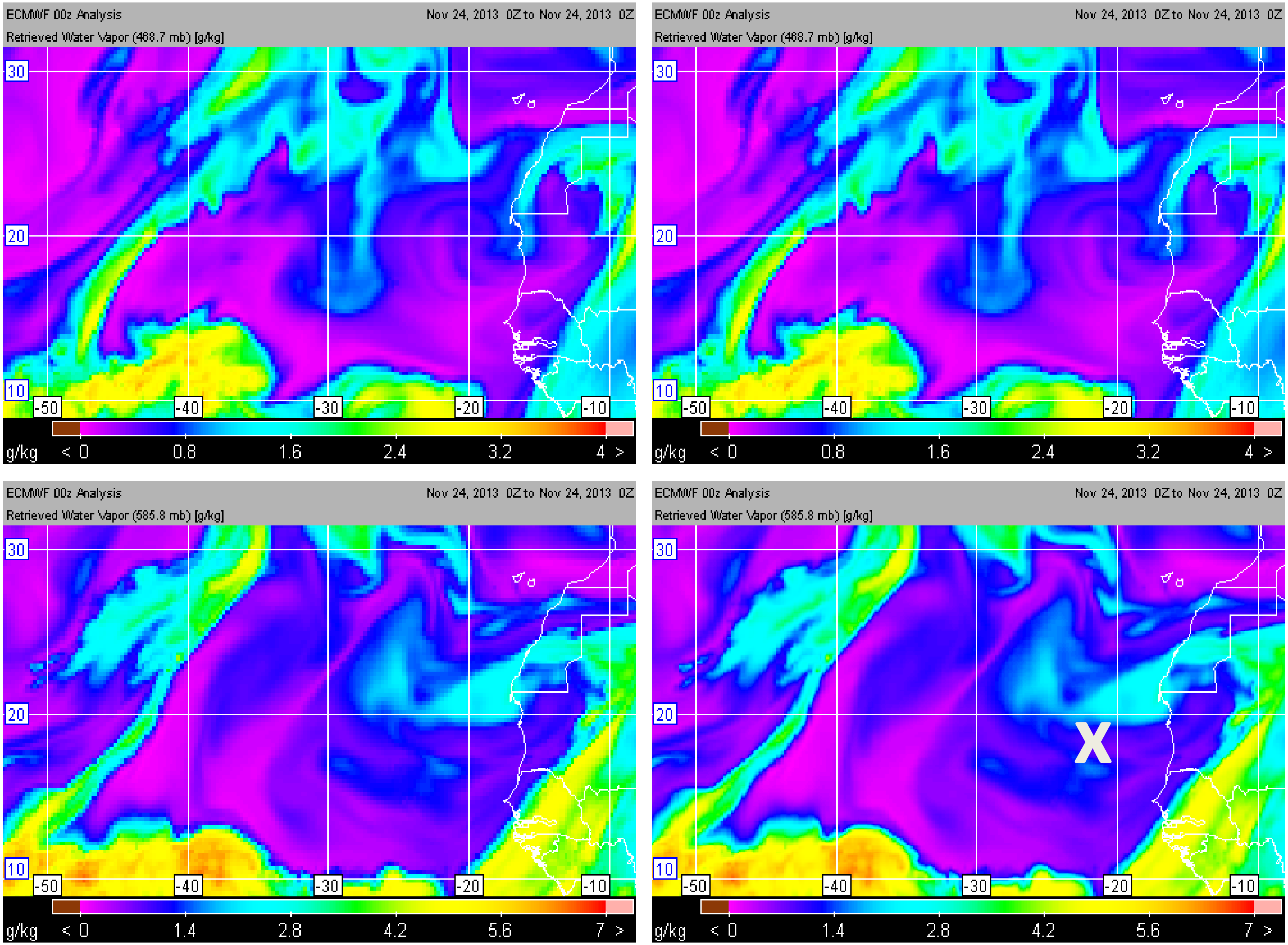
MW Only pass QC , Maritime, +/- 3 hr

EDR Validation Results



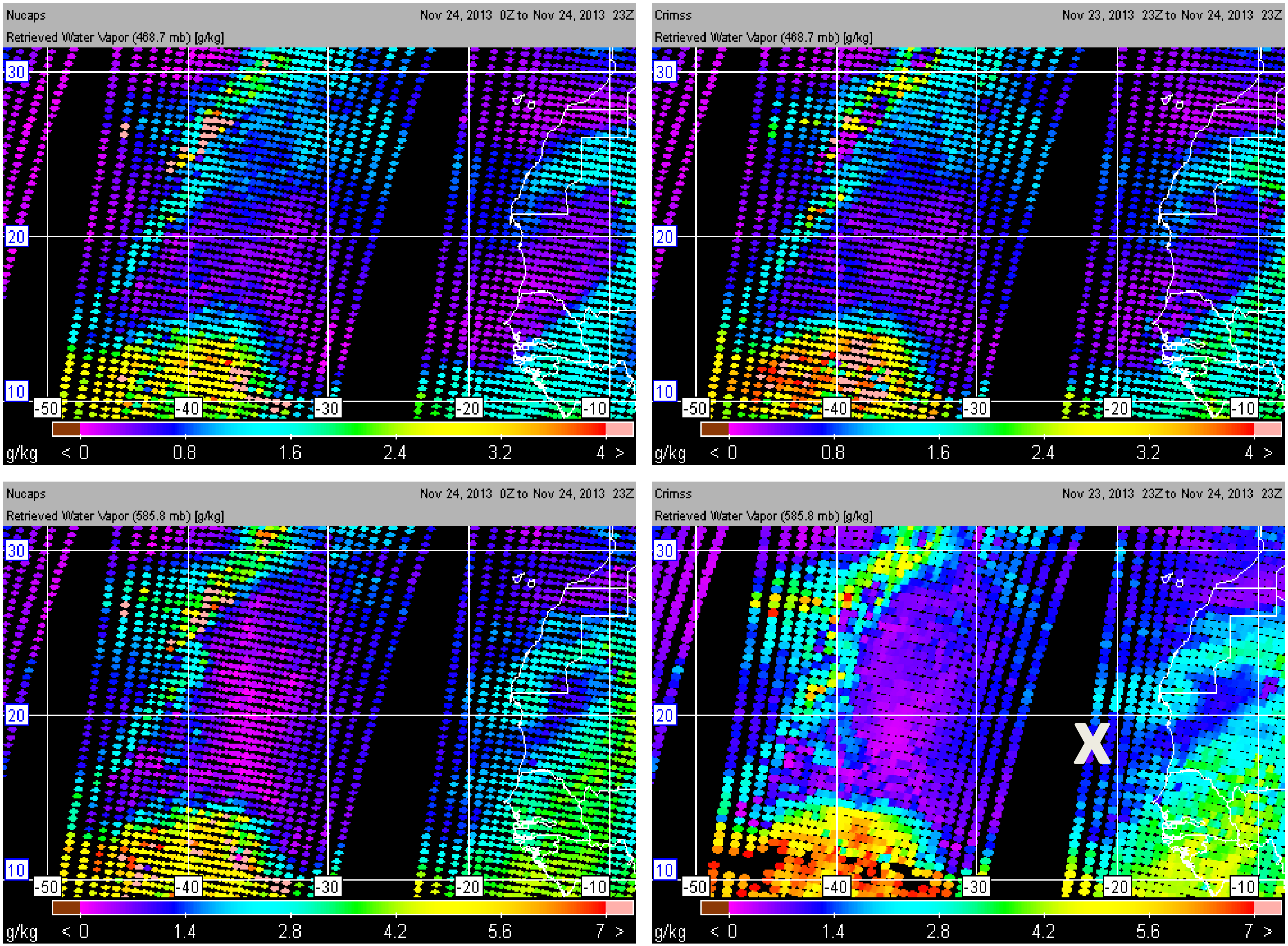
Outlier AEROSE MW only

EDR Validation Results



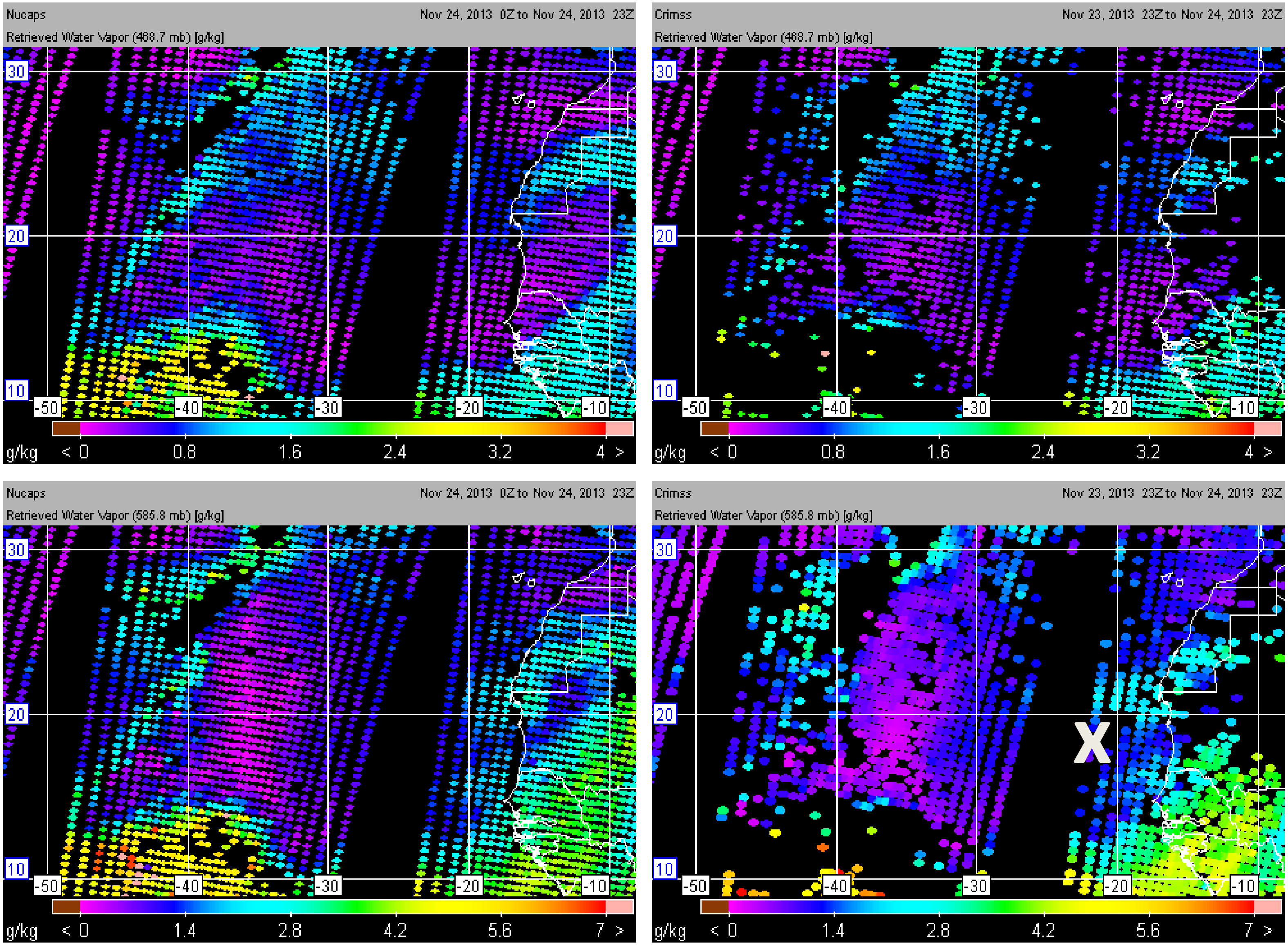
AEROSE

EDR Validation Results



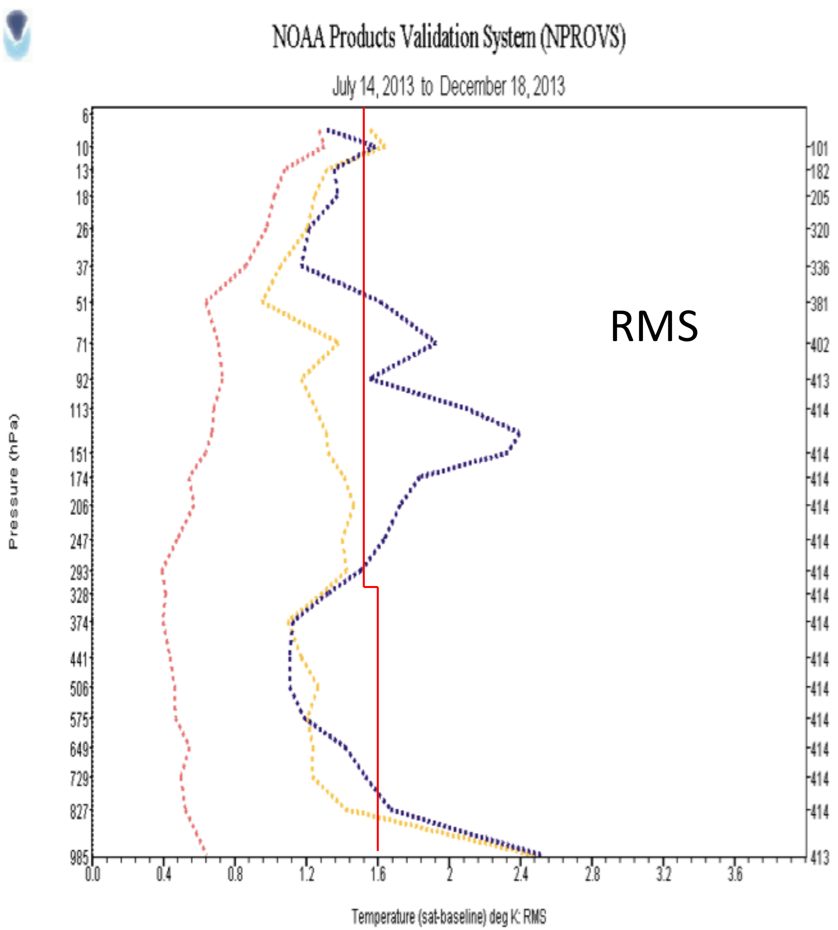
AEROSE

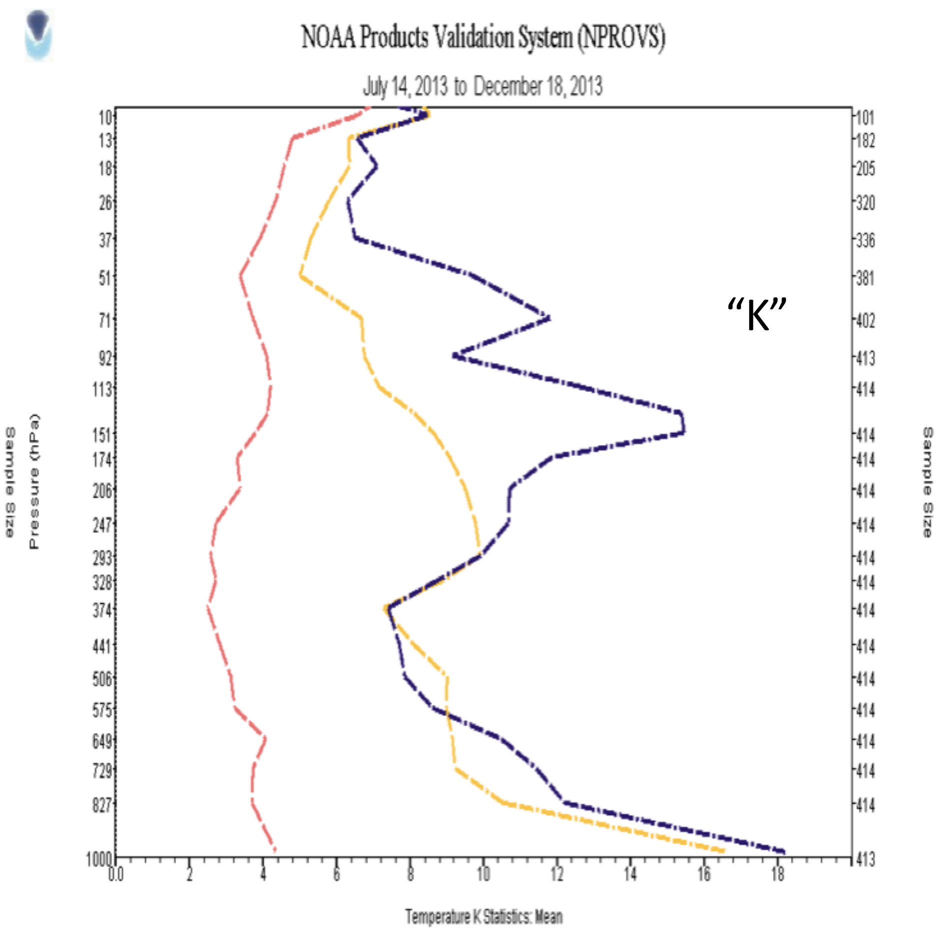
EDR Validation Results



AEROSE

EDR Validation Results





Baseline: REFERENCE SONDE GRUAN RAOB

CRIMSS NPP Infrared (IP) **ECMWF ANALYSIS** **NUCAPS NPP TEST**

Baseline: REFERENCE SONDE GRUAN RAOB

CRIMSS NPP Infrared (IP) **ECMWF ANALYSIS** **NUCAPS NPP TEST**

GRUAN only … Include Uncertainty Estimates … *"K" Profiles*

EDR Validation Results

GRUAN Reference Measurement Principles

Consistency in a Finite Atmospheric Region

Co-location / co-incidence:

Determine the variability (σ) of a variable (m) in time and space from measurement or model

Two observations on different platforms are consistent if

$$\left| m_1 - m_2 \right| < k\sqrt{\sigma^2 + u_1^2 + u_2^2}$$

... at this preliminary stage:

K = ABS(X – GRUAN) / Uncertainty (u1)

where “X” either SAT or NWP

“need uncertainty estimates for EDR”

EDR Validation Results

COSMIC / GRAS
(Stratosphere Reference from Space …)

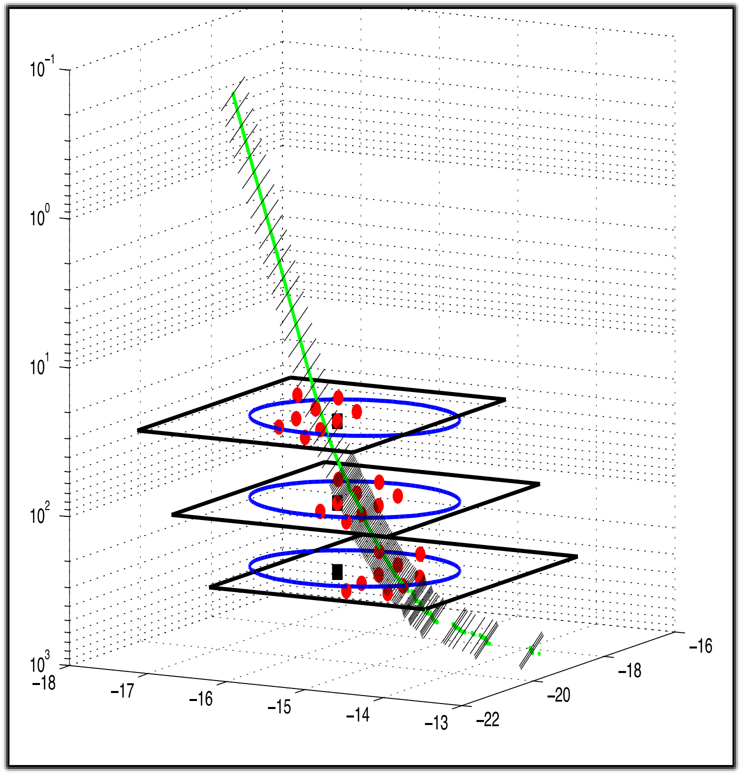
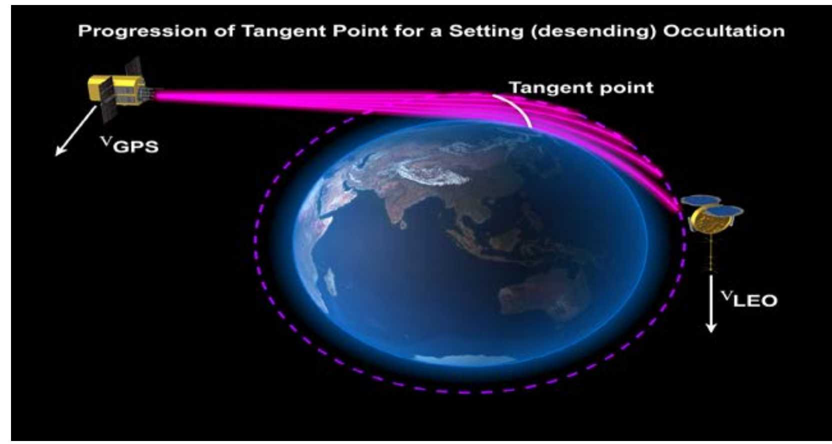
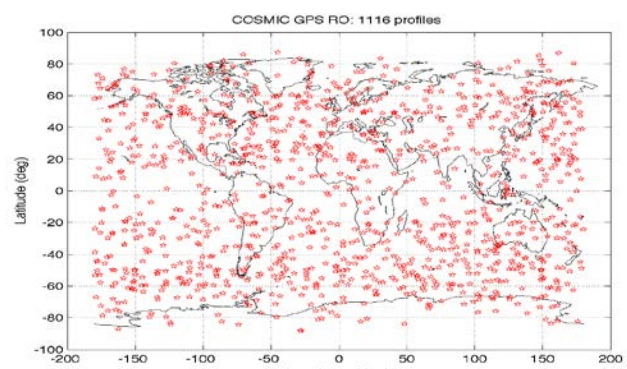


Illustration of the closest (black square), circular (blue circle), and ray path (red dots) methods for a single GPS profile (green) for the circle centered at the GPS RO level of 100 hPa



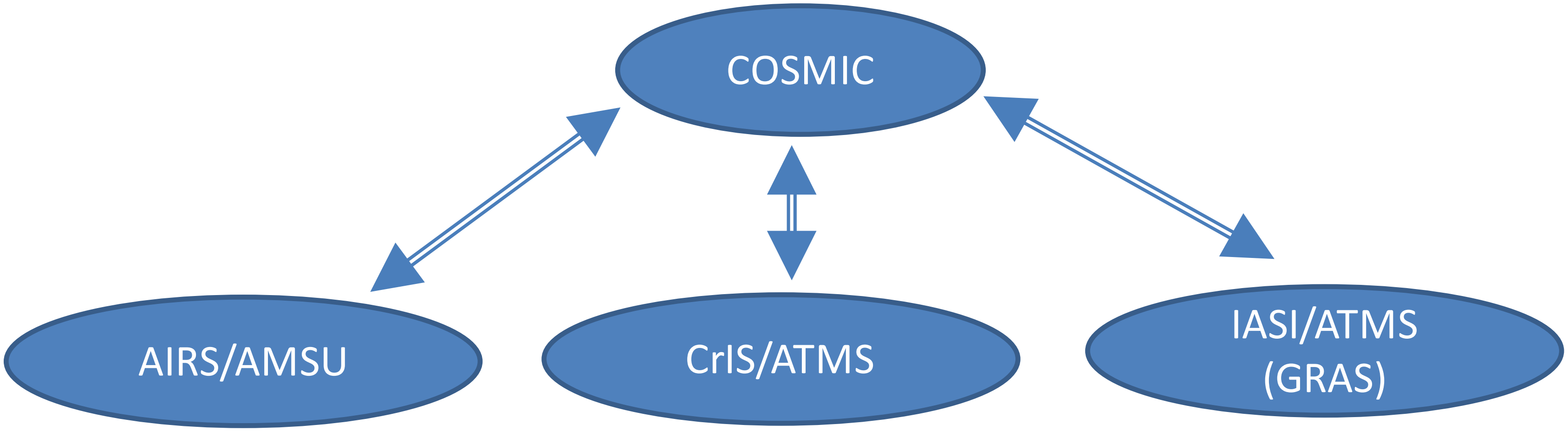
http://www.cosmic.ucar.edu/launch/GPS_RO_cartoon.jpg



One Day of COSMIC Profiles

courtesy Knuteson / Feltz CIMSS

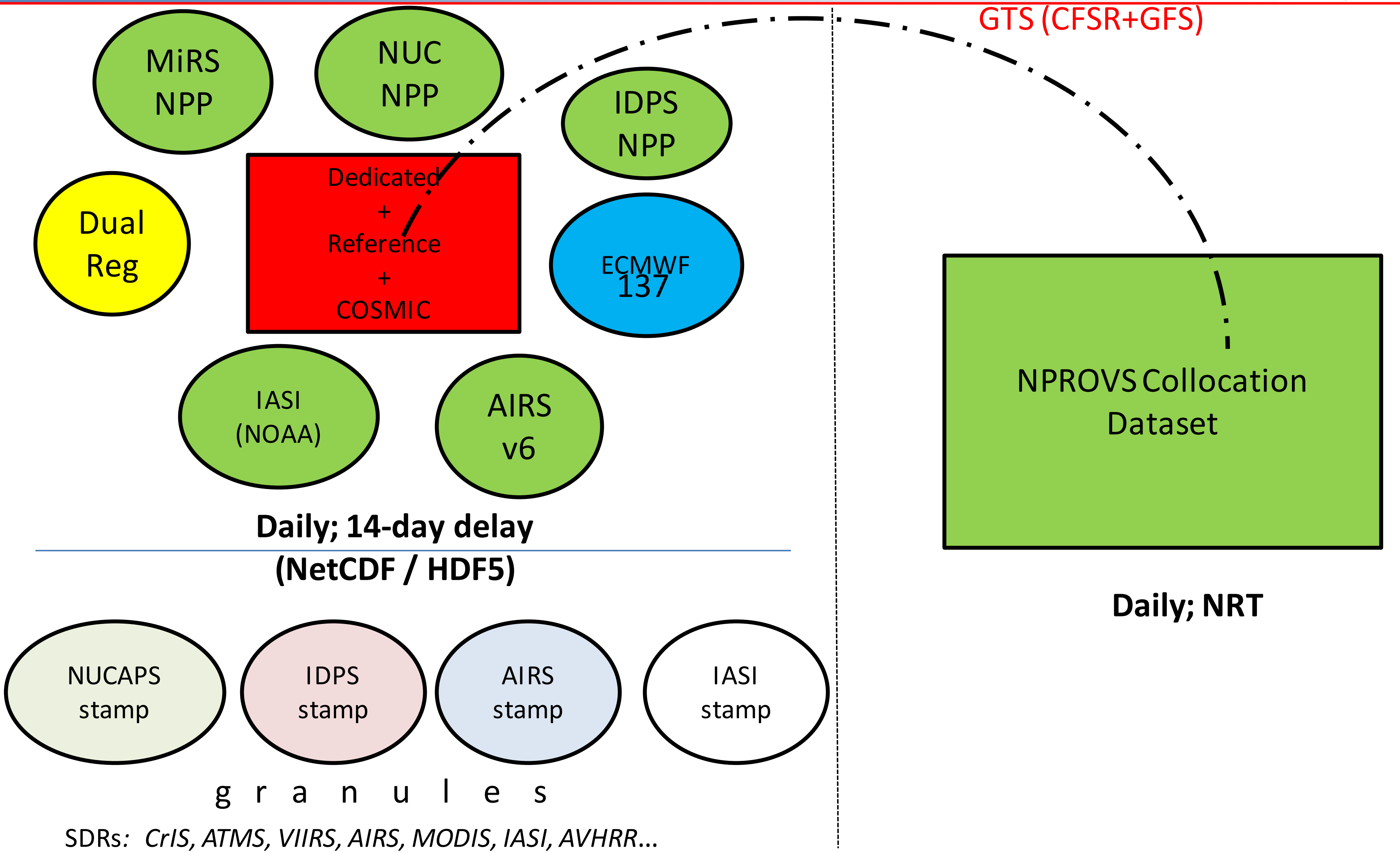
EDR Validation Results



GPSRO Anchored Collocation

- Integrate STAR (Weng, Reale) and CIMSS (Knuteson / Feltz) approaches
- EDR and SDR
- GPS RO provides Reference for EDR, SDR and RTM

EDR Validation Results



… exclusive anchor to Ref / Ded RAOB and GPSRO….

Conclusions on EDR Validation

- Final alignments of NARCS / PDISP wrt product qc flag, sensor combination …
- NUCAPS IR + MW generally better IDPS v7.1; IDPS MW only better in low troposphere for T and about same for H20
- Land: Below 700hPa, T and H20 not meeting spec (both); moisture less erratic. Above 700hPa, NUCAPS T and H20 meet spec for IR+MW but not for MW only … *87-90, 94*
- Maritime: NUCAPS IR+MW T and H20 meet spec (87c, 88c, 96); close for H20. MW only T and H20 close to spec (Yes - AEROSE, No - maritime)
- Indications of seasonal bias in NUCAPS Temp (IR+MW)…
- Yield Concerns: Too many IR+MW land (?) and QC failures over sea (mid-Lat) …
- Overall, NUCAPS satisfies Stage 1 (Stage 2) validation requirements

SUMMARY

- Project Goals and staffing discussed
- Integration and Unification of routine product and algorithm development validation strategies
- NPROVS and NPROVS+
- Seasonal (year) and short term (10-day) validation results presented for NUCAPS vs CrIMSS (v7.1)
- NUCAPS meets requirements for Stage 1 validation; problem areas identified

PATH FORWARD

- Project Lead
- CrIMSS to NUCAPS transition
- Stage 2 (3) Validation in July
- Compatible (AIRS - IASI- CrIS) /ATMS algorithms
- Entice Users … EDR uncertainty estimates, *“K” profile statistics*
- NPROVS (RAOB / COSMIC) collocations basis for revising GFS RAOB Radiation Correction (RADCOR) (Sun, Ballish, Collard, Seidel …)
- COSMIC anchored Satellite EDR/SDR collocations (Knuteson, Weng, Xiong, Sun …)
- Sustained validation against Ref and Ded RAOB (NPROVS+) …
- Publish / Survive !

Publications

Peer Review

Sun, B., A. Reale, S. Schrieder, D.J. Seidel, and B. Ballish: "Toward improved corrections for radiation-induced biases in radiosonde temperature observations". Journal of Geophysical Research, VOL. 118, 1–13, doi:10.1002/jgrd.50369, 2013.

Divakarla, M., C. Barnet, X. Liu, D. Gu, M. Wilson, S. Kizer, X. Xiong, E. Maddy, R. Ferraro, R. Knuteson, D. Hagan, X. Ma, C. Tan, N. Nalli, A. Reale, A. Mollner, W. Yang, A. Gambacorata, M. Feltz, F. Iturbide-Sanchez, B. Sun, and M. Goldberg, 2013 The CrIMSS EDR Algorithm: Characterization, optimization and validation, Accepted for publication in the JGR, Special issue.

Nicholas R. Nalli[1,2,*], Christopher D. Barnet[3], Anthony Reale[4],David Tobin[5],Antonia Gambacorta[1,2],Eric S. Maddy[2,3],Everette Joseph[6],Bomin Sun[1,4],Lori Borg[5], Andrew K. Mollner[7],Vernon R. Morris[6],Xu Liu[8],Murty Divakarla[1,2],Peter J. Minnett[9],Robert O. Knuteson[5],Thomas S. King[1,2],Walter W. Wolf[2] **Validation of satellite sounder environmental data records: Application to the Cross-track Infrared Microwave Sounder Suite** Article first published online: 26 DEC 2013 DOI: 10.1002/2013JD020436

Wang J., T. Hock, S.A. Cohn, C. Martin, N. Potts, A. Reale, B. Sun, and F. Tilley: "Unprecedented upper-air dropsonde observations over Antarctica from the 2010 Concordiasi Experiment: Validation of satellite-derived temperature profiles". Geophysical Research Letters, VOL. 40, 1–6, doi:10.1002/grl.50246, 2013.

Publications

Conference

Hagan, D., D. Gu, X. L. Ma, C. D. Barnet, and M. G. Divakarla, (2013), CrIMSS Single FOV EDR Retrieval, 93rd American Meteorological Society Annual Meeting, Ninth Annual Symposium on Future Operational Environmental Satellite Systems, 6-10 January, 2013, Austin, TX 78701.

Hagan, D., D. Gu, X. L. Ma, C. D. Barnet, and M. G. Divakarla, (2013), Calibration and Validation of the S-NPP Sensor Data Records and Environmental Data Records, 93rd American Meteorological Society Annual Meeting, Ninth Annual Symposium on Future Operational Environmental Satellite Systems, 6-10 January, 2013, Austin, TX 78701.

Wilson, M., C. D. Barnet, M. G. Divakarla, C. Tan, X. Xiong, X. Liu, S. Kizer, D. Gu, N. R. Nalli, A. Gambacorta, and E. Maddy, 2013, A Global Perspective of the Current and Future CrIMSS EDR Algorithm, 93rd American Meteorological Society Annual Meeting, Ninth Annual Symposium on Future Operational Environmental Satellite Systems, 6-10 January, 2013, Austin, TX 78701.

Tan, C., A. Gambacorta, M. G. Divakarla, S. Kizer, E. Maddy, G. Guo, M. Wilson, X. Xiong, X. Liu, and C. D. Barnet, (2013), On Empirical Bias Corrections of NPP CrIMSS OSS Forward Model, 93rd American Meteorological Society Annual Meeting, Ninth Annual Symposium on Future Operational Environmental Satellite Systems, 6-10 January, 2013, Austin, TX 78701.

Kizer, S., X. Liu, C. D. Barnet, M. G. Divakarla, D. Gu, X. L. Ma, D. K. Zhou, A. M. Larar, X. Xiong, G. Guo, A. Gambacorta, M. Wilson, (2013), Suomi NPP CrIMSS EDR Algorithms: Porting and Validation, 93rd American Meteorological Society Annual Meeting, Ninth Annual Symposium on Future Operational Environmental Satellite Systems, 6-10 January, 2013, Austin, TX 78701.

Liu, X., S. Kizer, C. D. Barnet, M. G. Divakarla, N. R. Nalli, D. Gu, D. K. Zhou, A. M. Larar, X. Xiong, A. Gambacorta, M. Wilson, W. J. Blackwell, (2013), NPP/JPSS CrIMSS EDR Algorithm Validation and Tuning, 93rd American Meteorological Society Annual Meeting, Ninth Annual Symposium on Future Operational Environmental Satellite Systems, 6-10 January, 2013, Austin, TX 78701.

Divakarla, M., and C. D. Barnet, X. Liu, S. Kizer, E. Maddy, C. Tan, and M. Wilson, (2013), Evaluation of CrIS/ATMS Proxy Data Generation Algorithms with Observed Radiances and Retrieval, 93rd American Meteorological Society Annual Meeting, Ninth Annual Symposium on Future Operational Environmental Satellite Systems, 6-10 January, 2013, Austin, TX 78701.

Divakarla, M., C. D. Barnet, M. Wilson, X. Xiong, C. Tan, E. Maddy, D. Gu, X. Liu, S. Kizer, A. Gambacorta, N. Nalli, X. Ma, D. Hagan, and M. Goldberg, (2013), Provisional Maturity Assessment of Cross Track Infrared Sounder (CrIS) Temperature and Moisture Profile Products, 93rd American Meteorological Society Annual Meeting, Ninth Annual Symposium on Future Operational Environmental Satellite Systems, 6-10 January, 2013, Austin, TX 78701.

Publications

Conference

Divakarla, M., Chris Barnet, Xu Liu, Degui Gu, Mike Wilson, Susan Kizer, Xiaozhen Xiong, Eric Maddy, Ralph Ferraro, Robert Knuteson, Denise Hagan, Xia-lin Ma, Changyi Tan, Nick Nalli, Andrew Mollner, Wenze Yang, Michelle Feltz, Antonia Gambacorta, Flavio Iturbide-Sanchez,Tony Reale, Bomin Sun, and Mitch Goldberg, (2013), The CrIMSS EDR Algorithm: Provisional Maturity and Beyond, presentation made for the Sounder Science Team Meeting, NASA, JPL, May 21.

Divakarla, M., Chris Barnet, Mike Wilson, Xu Liu, Degui Gu, Tony Reale, Nick Nalli, Xiaozhen Xiong, Changyi Tan, Eric Maddy, Susan Kizer, Xia Ma, Denise Hagan, Andrew Mollner, Antonia Gambacorta, Flavio Iturbide-Sanchez, Bomin Sun, and Mitch Goldberg, (2012), The CrIMSS EDR Algorithm: Optimization and Validation with In-situ Measurements, Model Analysis Fields, and Retrieval Products from Heritage Algorithms, International Geo-Science and Remote Sensing Symposium, IGARSS, July 21-27, Melbourne, Australia.

Planned

Divakarla, M., et al., (2014), Validation of CrIMSS AVTP and AVMP Retrievals with PMRF RAOBs, ECMWF Analysis Fields, and the Retrieval Products from Heritage Algorithms" abstract accepted for presentation in the Tenth Annual Symposium on New Generation Operational Environmental Satellite Systems,AMS 94th Annual Meeting, 2-6 February 2014 in Atlanta, GA.

Divakarla, M., et al., (2014) et al., The CrIMSS EDR Algorithm Assessment: Provisional Maturity and Beyond, abstract accepted for presentation in the Tenth Annual Symposium on New Generation Operational Environmental Satellite Systems,AMS 94th Annual Meeting, 2-6 February 2014 in Atlanta, GA.

Andrew K. Mollner, John E Wessel, Kevin M Gaab, David M Cardoza, Stephen D LaLumondiere, Petras Karuza, William T Lotshaw, Nicholas R. Nalli, Anthony Reale, Antonia Gambacorta, Murty Divakarla, Christopher D. Barnet, Eric S. Maddy,Changyi Tan, Xiaozhen Xiong, Orson Porter, Mid-Pacific Ground-Truth Data for Validation of the CrIMSS Sensor Suite Aboard Suomi-NPP, abstract accepted for AGU, December 2013.

Nalli, N., C. D. Barnet, T. Reale, A. Gambacorta, E. Maddy, B. Sun, E. Joseph, L. A. Borg, A. Mollner, M. Divakarla, X. Liu, R. O. Knuteson, T. King, and W. Wolf, (2013), Validation Methods for Infrared Sounder Environmental Data Records: Application to Suomi NPP, abstract accepted for presentation in the Tenth Annual Symposium on New Generation Operational Environmental Satellite Systems,AMS 94th Annual Meeting, 2-6 February 2014 in Atlanta, GA.

Maddy, E.C., M. Divakarla, N. R. Nalli, C. D. Barnet, T. Reale, A. Gambacorta, and D. M. Goldberg, (2014) Using S-NPP Cal/Val datasets for Aqua/AIRS-V6 and future AIRS/MODIS/AMSU, algorithm development, improvement, and validation, abstract accepted for presentation in the Tenth Annual Symposium on New Generation Operational Environmental Satellite Systems,AMS 94th Annual Meeting, 2-6 February 2014 in Atlanta, GA.

Publications

Planned

Sun, Bomin, A. Reale, M. Pettey, F. Tilley, C. Brown, N. Nalli, A. Gambacorta, and M. G. Divakarla, (2013), Using NPROVS for Evaluation of Suomi NPP Atmospheric Sounding Retrievals against Conventional Radiosonde Observations, abstract accepted for presentation in the Tenth Annual Symposium on New Generation Operational Environmental Satellite Systems,AMS 94th Annual Meeting, 2-6 February 2014 in Atlanta, GA.

***Wenze Yang**, F. Iturbide-Sanchez, R. R. Ferraro, M. Divakarla, and T. Reale, (2014), Evaluation and Improvement of the S-NPP CrIMSS Rain Flag, abstract accepted for presentation in the Tenth Annual Symposium on New Generation Operational Environmental Satellite Systems,AMS 94th Annual Meeting, 2-6 February 2014 in Atlanta, GA.*

Publications

CIMMS Group (SSEC, Madison)

Feltz, M. L., R. O. Knuteson, D. C. Tobin, and H. E. Revercomb, A Methodology for the Validation of Temperature Profiles from Hyperspectral Infrared Sounders Using GPS Radio Occultation: Experience with AIRS and COSMIC, Journal of Geophysical Research: Atmospheres (2014), accepted.

Feltz, M., R. Knuteson and Coauthors, Application of GPS Radio Occultation to the Assessment of Temperature Profile Retrievals from Microwave and Infrared Sounders , Atmos. Meas. Tech. special issue, in preparation (2014).

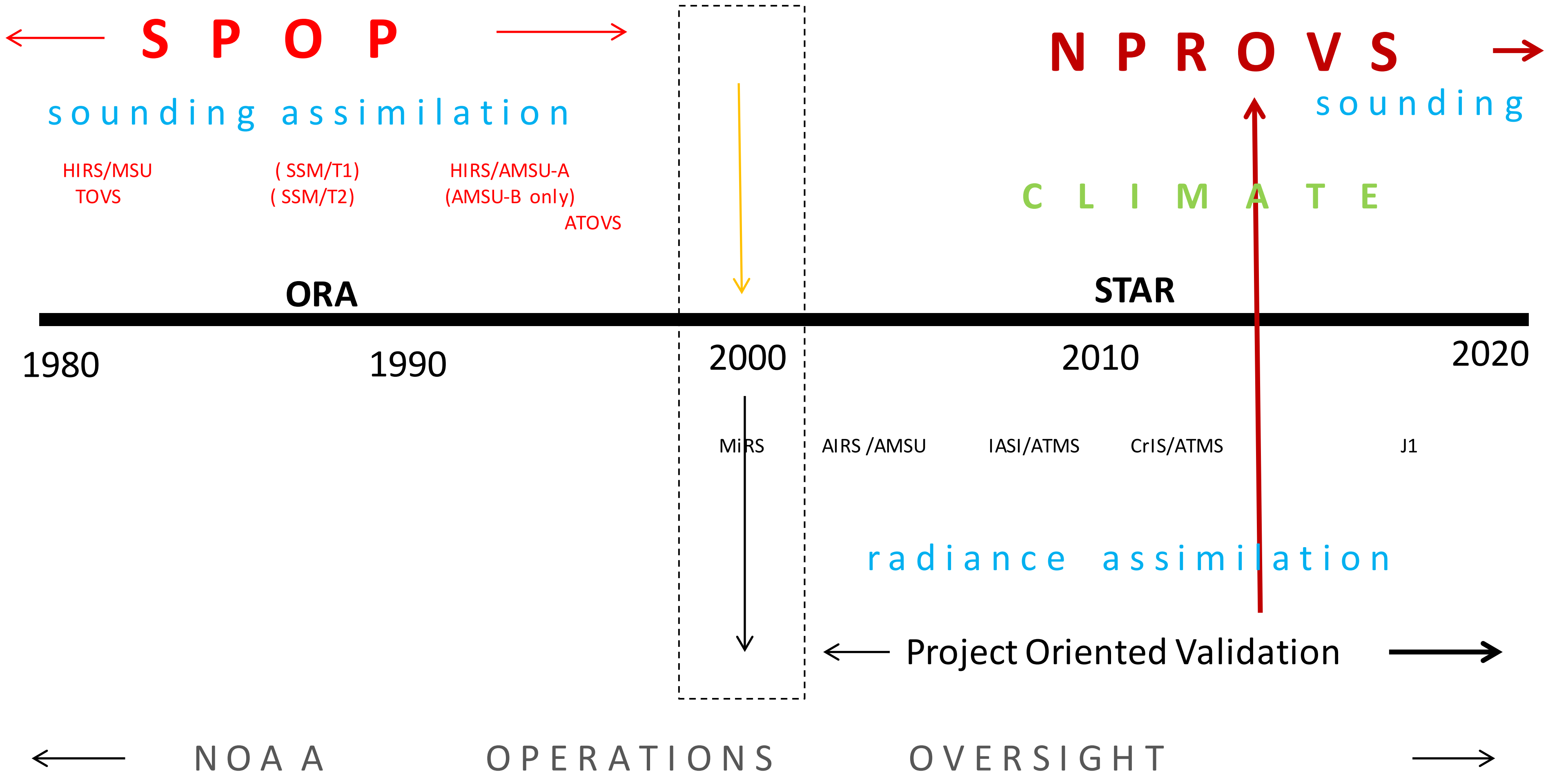
Another graduate student (Jacola Roman) has three publications on water vapor that have been partially supported by this EDR Cal/Val effort. Here are her citations:

Roman, J.A. et al. 2014: Time-To-Detect Trends in Precipitable Water Vapor with Varying Measurement Error. J.Climate (submitted)

Roman, J.A. et al. 2013: Using AIRS to Assess the Precipitable Water Vapor in Global Climate Models (GCMs) with Regional Validation from SuomiNet. AIP Conf. Proc., 1531, 480. doi: http://dx.doi.org/10.1063/1.4804811

Roman, J. A et al. 2012: Assessment of Regional Global Climate Model Water Vapor Bias and Trends Using Precipitable Water Vapor (PWV) Observations from a Network of Global Positioning Satellite (GPS) Receivers in the U.S. Great Plains and Midwest. J.Climate, 25, 5471–5493. doi: http://dx.doi.org/10.1175/JCLI-D-11-00570.1

Brief History NOAA Program for Soundings



Restore Project Independent **N**OAA **PRO**duct O**V**er**S**ight

Discussion on AVMP statistic definition (5/7)
A detailed look at 550 mbar region

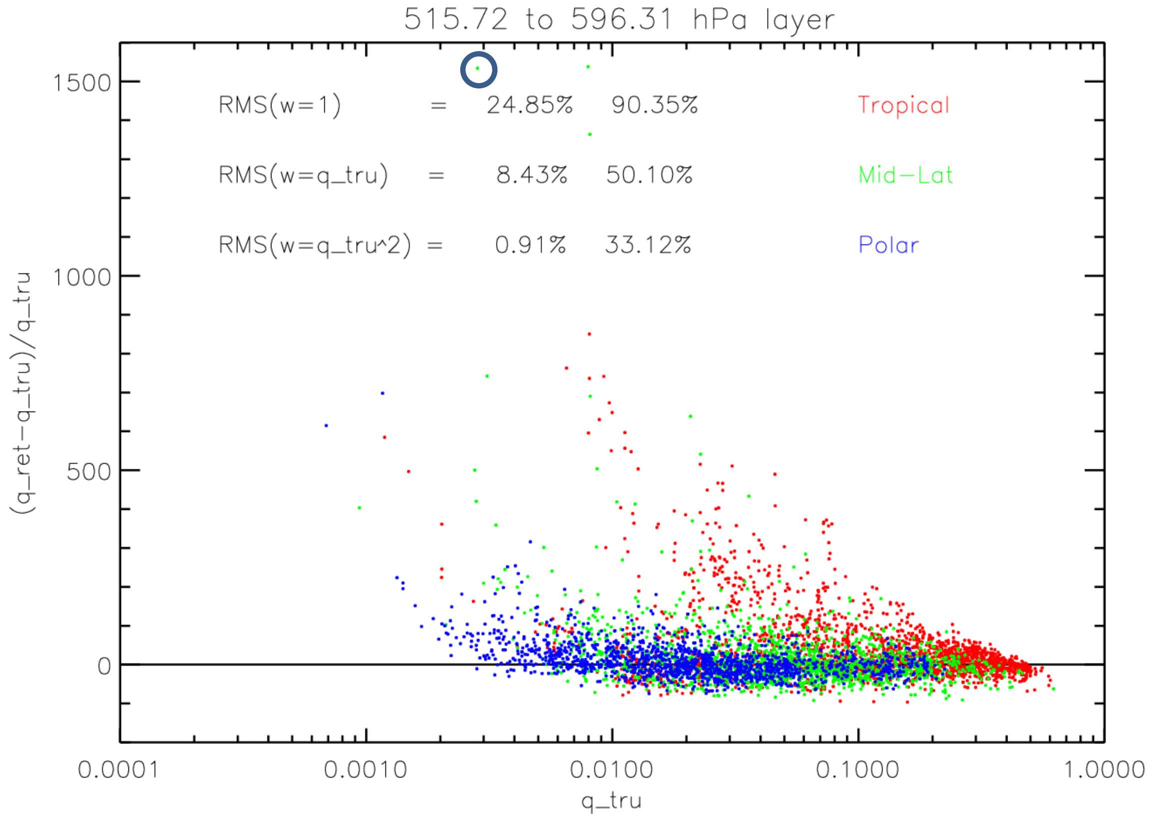
Below is a scatter plot of (g vs q_tru) the individual retrievals for the 515-600 hPa layer. The three colors show cases for tropical (red), mid-latitude (green), and polar (blue).

Also shown is the %bias and %rms statistic for the 3 weighting schemes for the global ensemble.

Circled point will be looked in the next slide

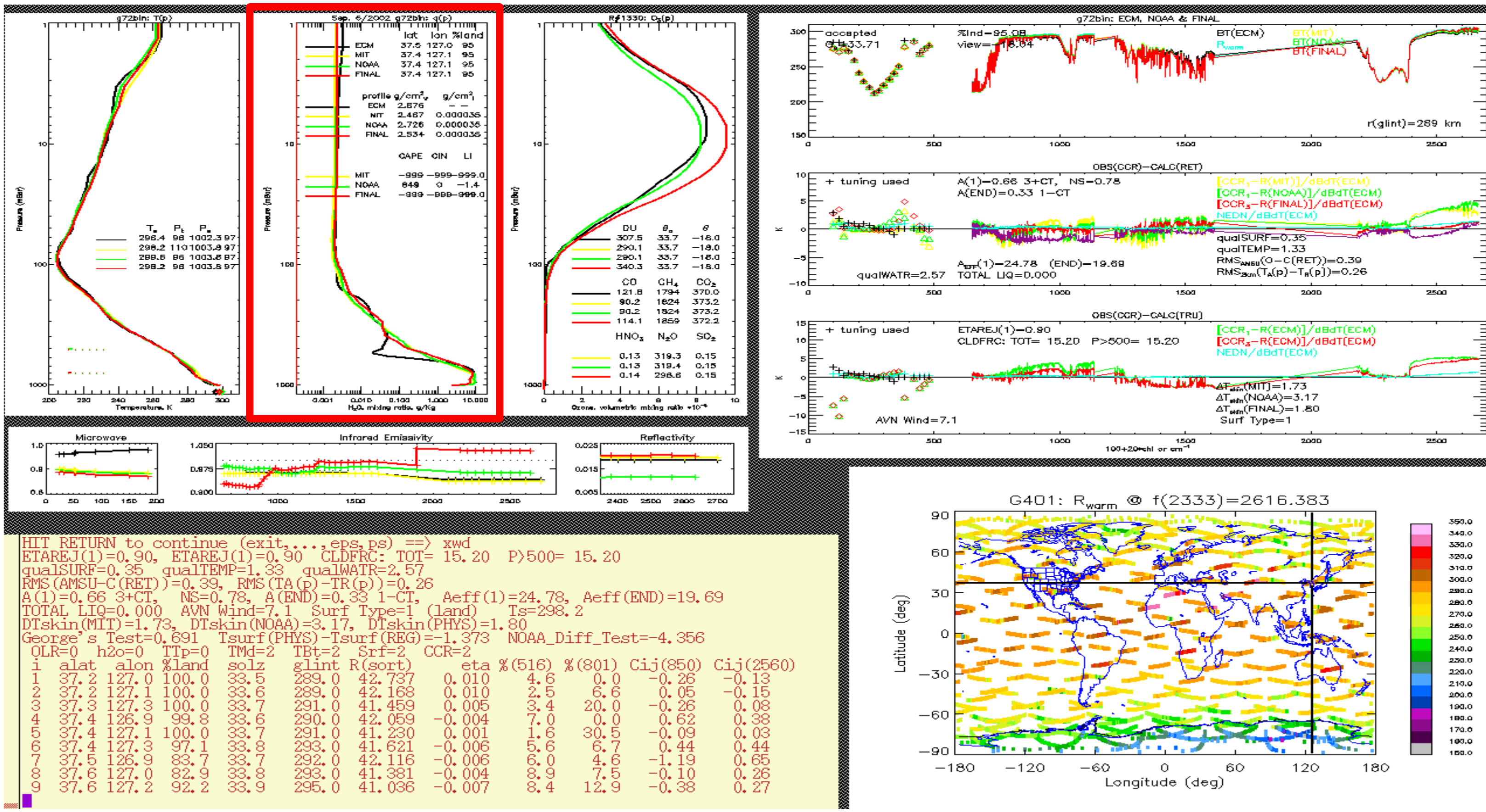
Note that in each latitude band (red, green, blue) there are large outliers, but these outliers and the overall error tends to increase for small q_tru in this layer.

Also, there are more positive outliers (wet retrieval) than there are negative outliers.



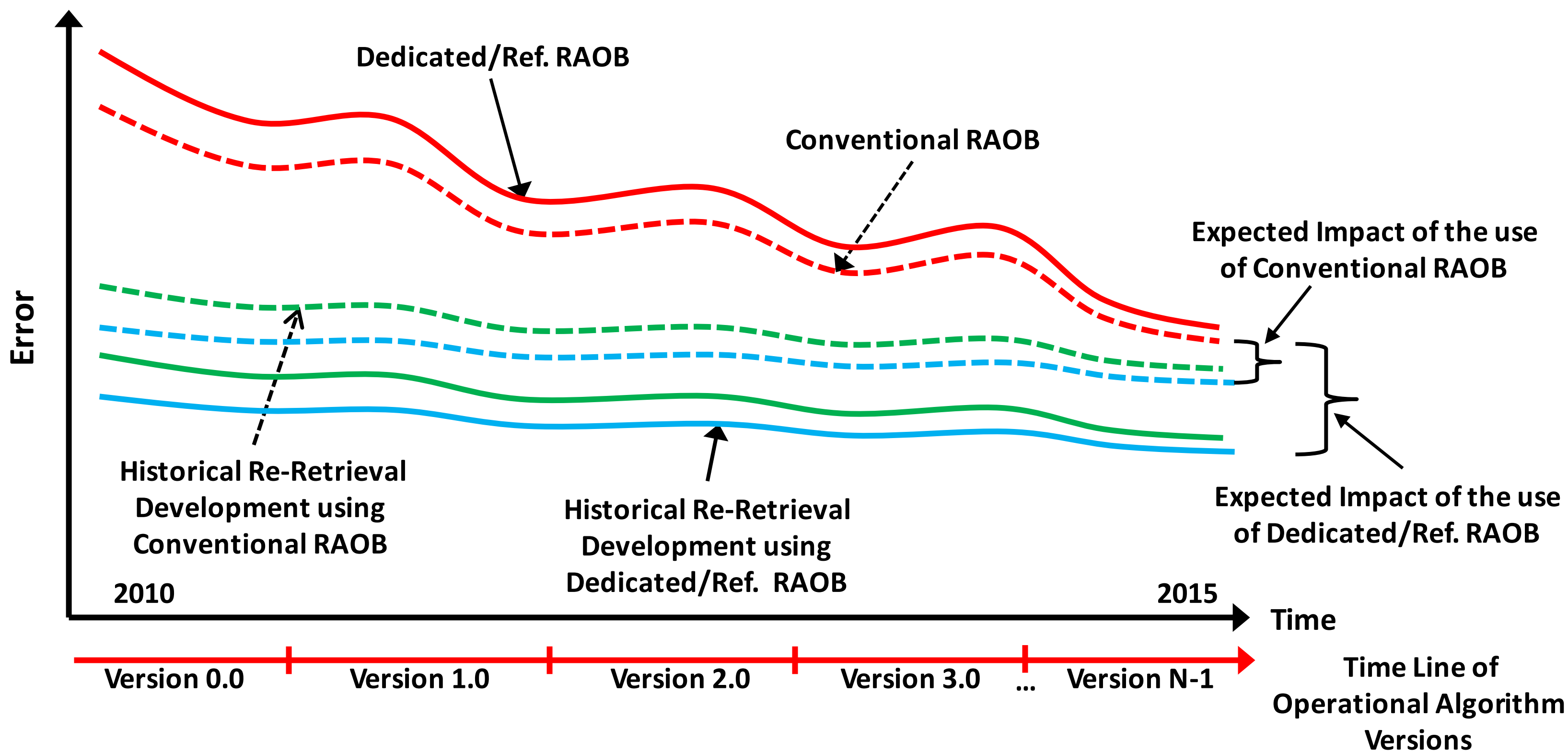
Discussion on AVMP statistic definition (6/7) A detailed look at one case with large error.

Here is a detailed diagnostic for one of the mid-latitude outliers. Lots of info on this plot, but if you look at the 2nd panel in the upper left profile plot (highlighted in red) you will see that ECMWF has a dry layer (NOTE: this is a log scale) that the smooth retrieval doesn't capture – but this is a "good" retrieval. This case is the one in previous plot with g=1533, q_tru=0.0028 g/cm^2 at latitude=37.4 (index = 1330 in granule 401)



EDR Validation

Projected Performance of Operational (Red) and Development (Green and Blue) over Time when compared Against Conventional (dashed) and Ref/Dedicated (solid) RAOB

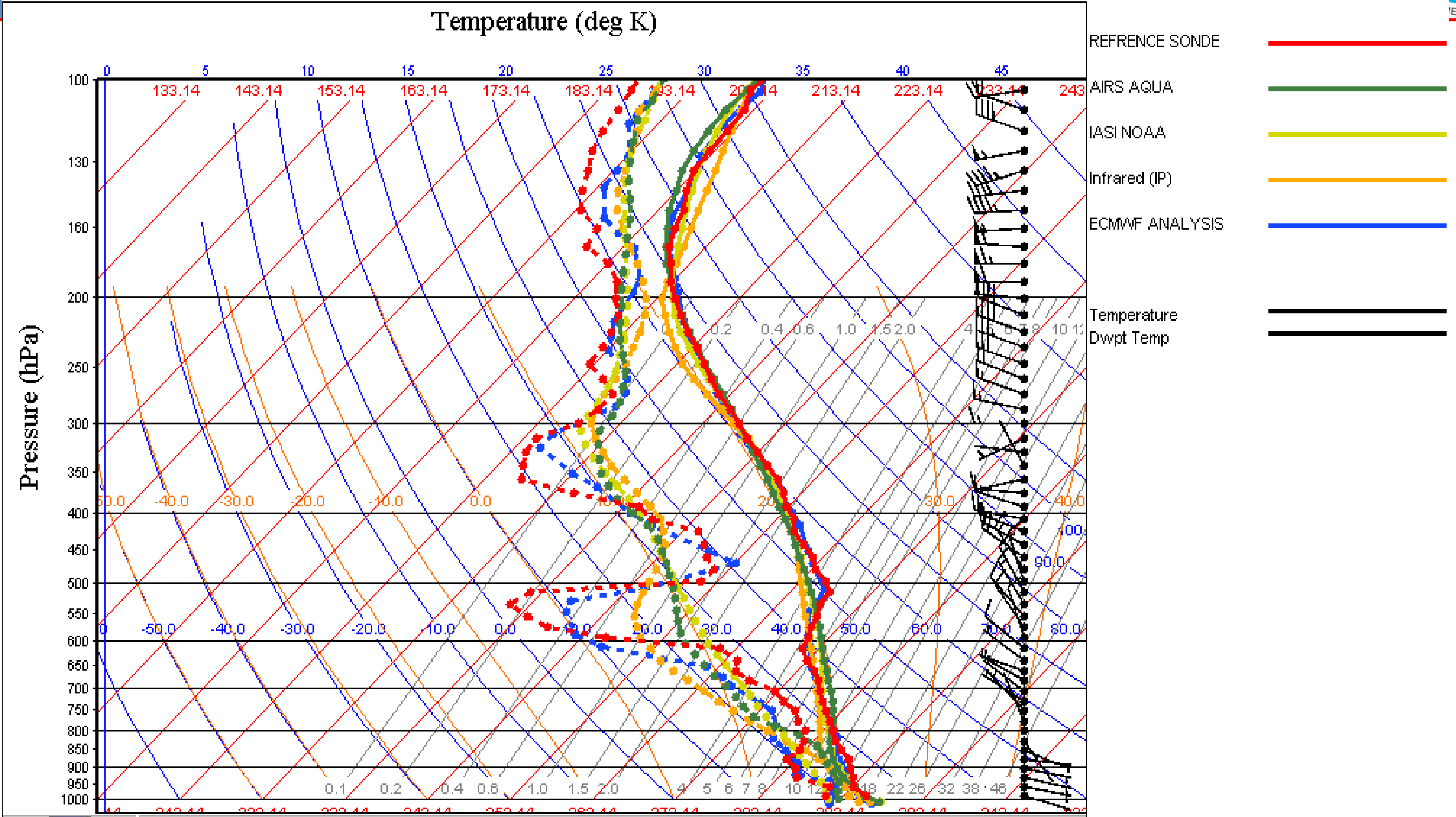


Case Study AEROSE H20

Tony

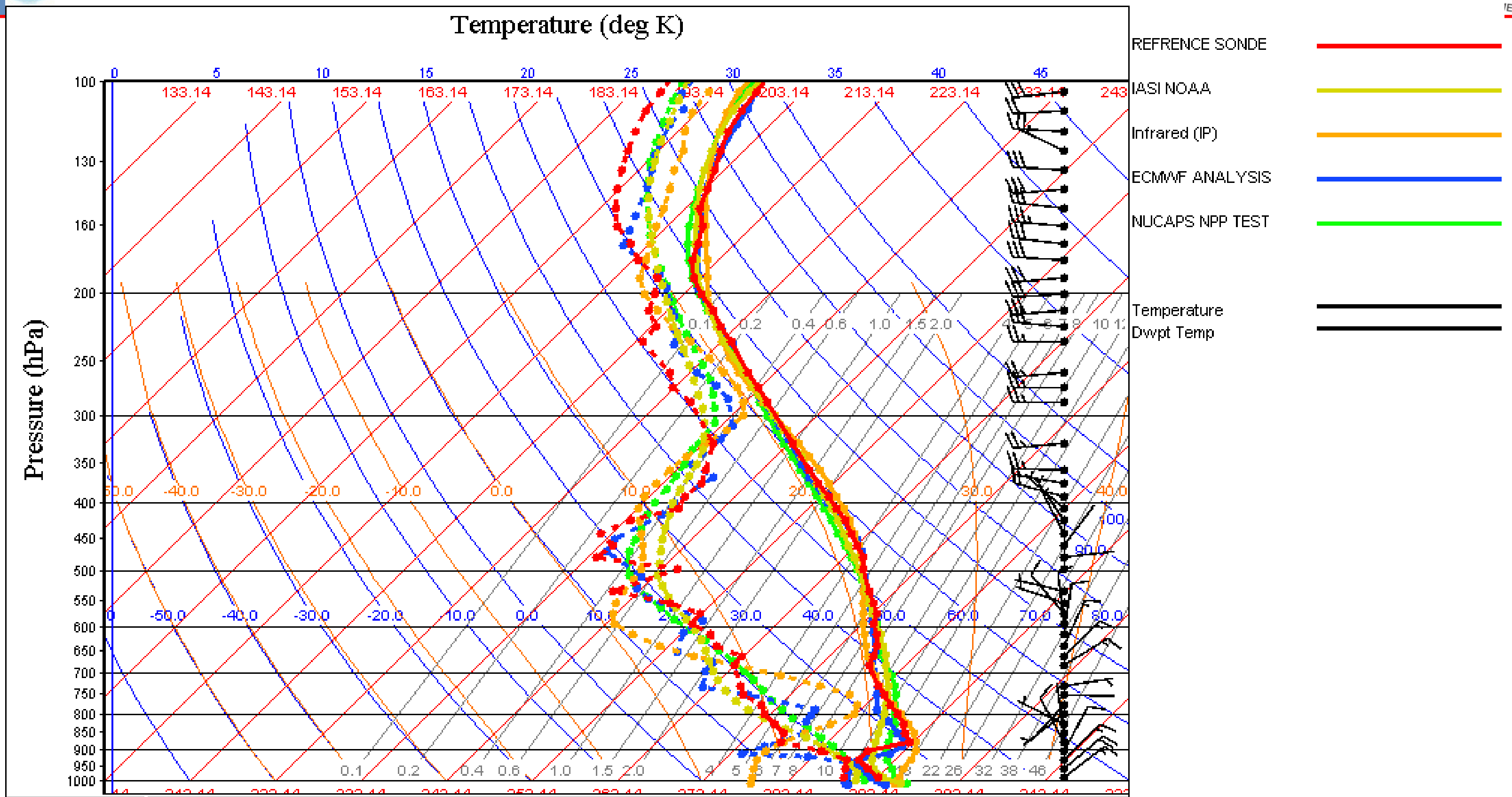
Jan 4 2013

NOAA Products Validation System (NPROVS)

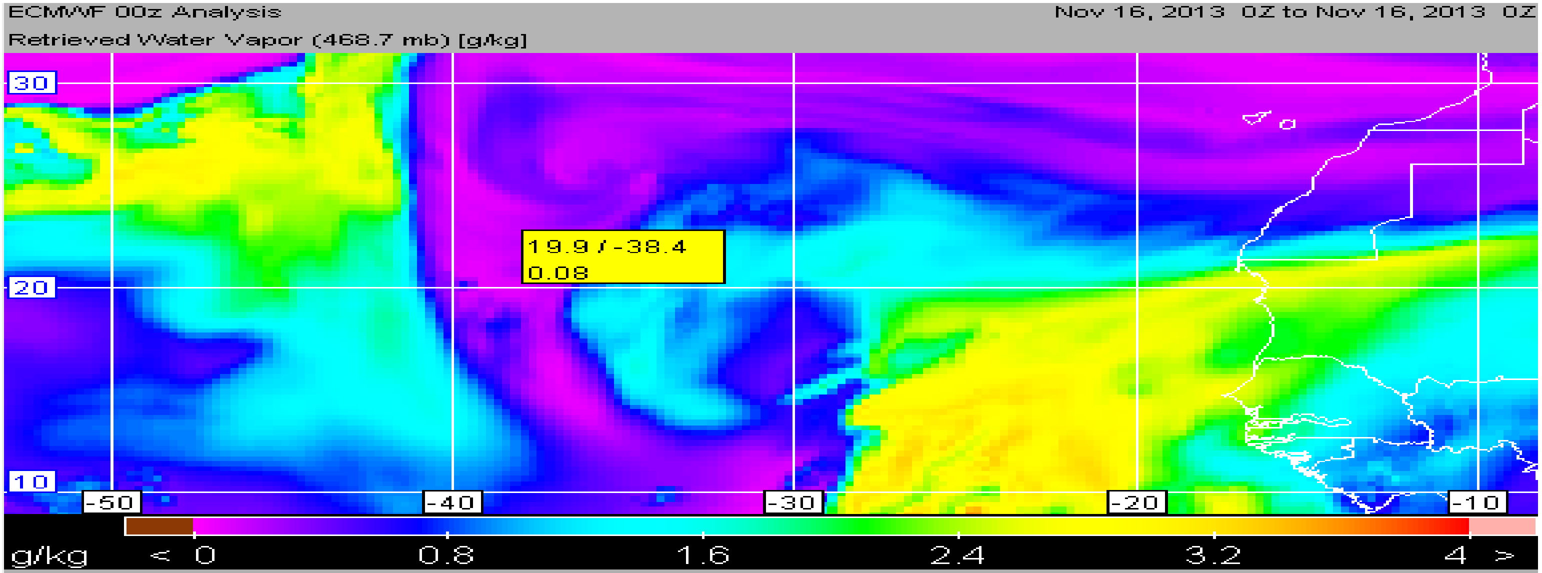


GRUAN Sonde WTEC (80)	11/17/2013 00:05	19.87 N / 38.38 W
AIRS AQUA	11/17/2013 04:04:16 (4 hours)	19.98 N / 38.36 W (12.3 km)
IASI NOAA	11/16/2013 23:27:46 (-0.6 hours)	19.82 N / 38.46 W (10.2 km)
CRIMSS NPP	11/17/2013 04:38:09 (4.6 hours)	19.96 N / 38.16 W (24.8 km)
ECMWF ANALYSIS	11/17/2013 00:00:00 (-0.1 hours)	20.00 N / 38.50 W (18.5 km)

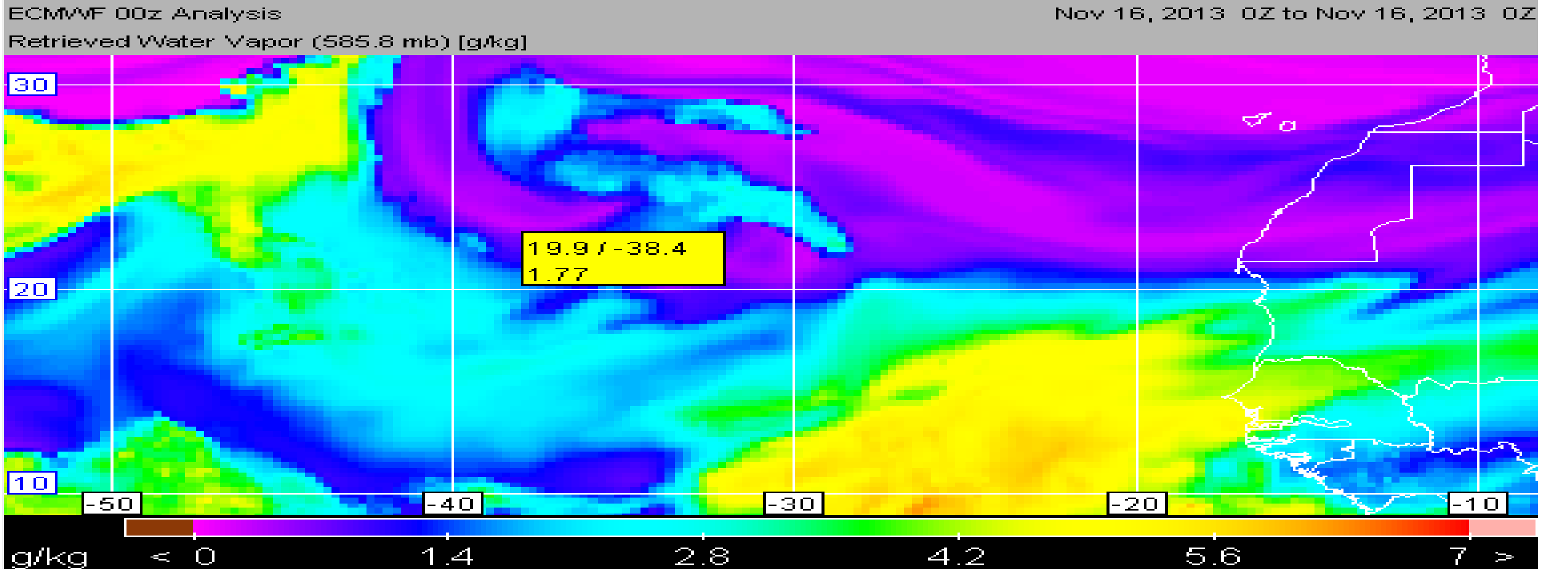
NOAA Products Validation System (NPROVS)



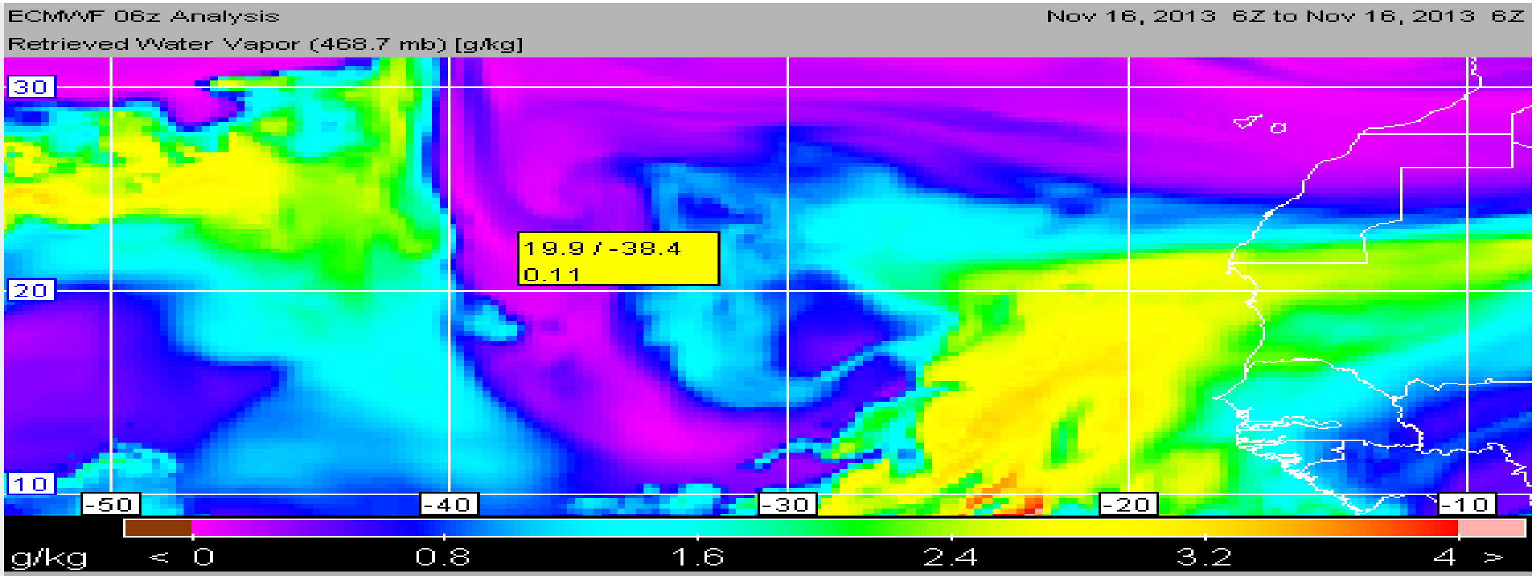
GRUAN Sonde WTEC (80)	11/23/2013 22:16		17.47 N / 23.00 W	
IASI NOAA	11/23/2013 22:41:22	(0.4 hours)	17.58 N / 22.83 W	(21.2 km)
CRIMSS NPP	11/24/2013 02:26:33	(4.2 hours)	17.31 N / 22.09 W	(97.9 km)
ECMWF ANALYSIS	11/24/2013 00:00:00	(1.7 hours)	17.50 N / 23.00 W	(2.6 km)
NUCAPS NPP TEST	11/24/2013 02:26:55	(4.2 hours)	17.31 N / 22.09 W	(97.9 km)

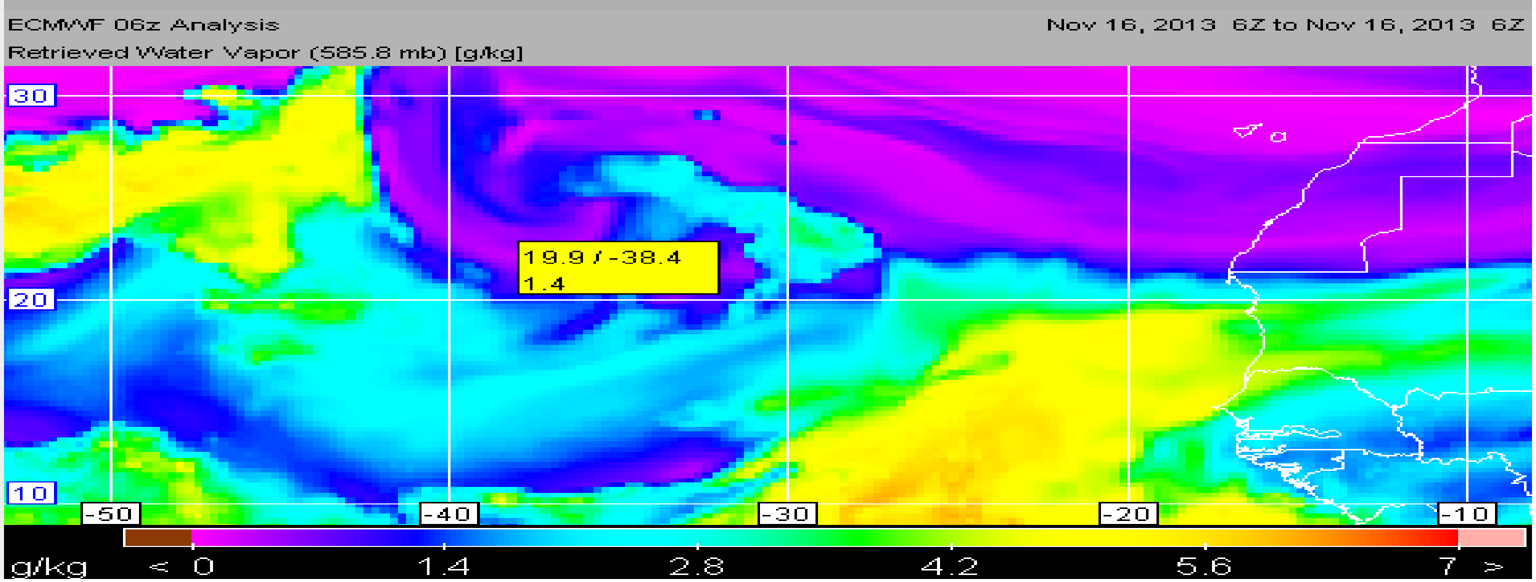


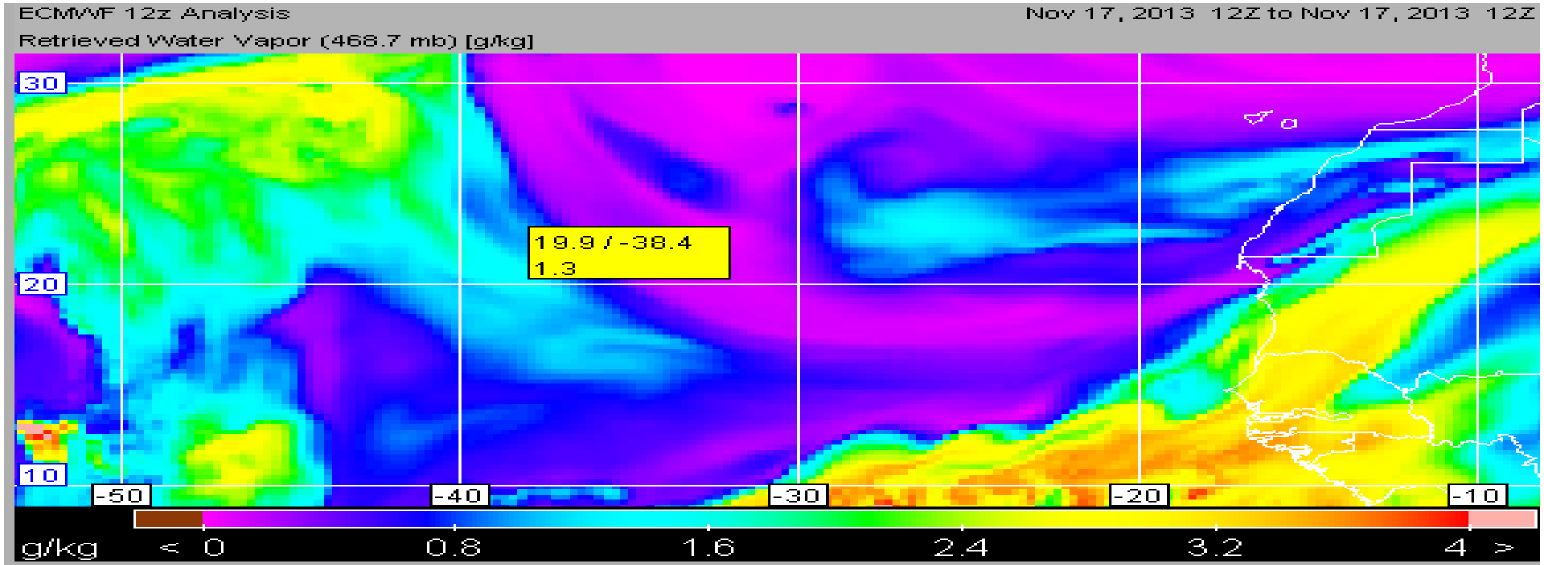
ECMWF 00z Analysis
Nov 16, 2013 0Z to Nov 16, 2013 0Z
Retrieved Water Vapor (468.7 mb) [g/kg]
30
20
10
-50
-40
-30
-20
-10
19.9 / -38.4
0.08
g/kg
< 0
0.8
1.6
2.4
3.2
4 >

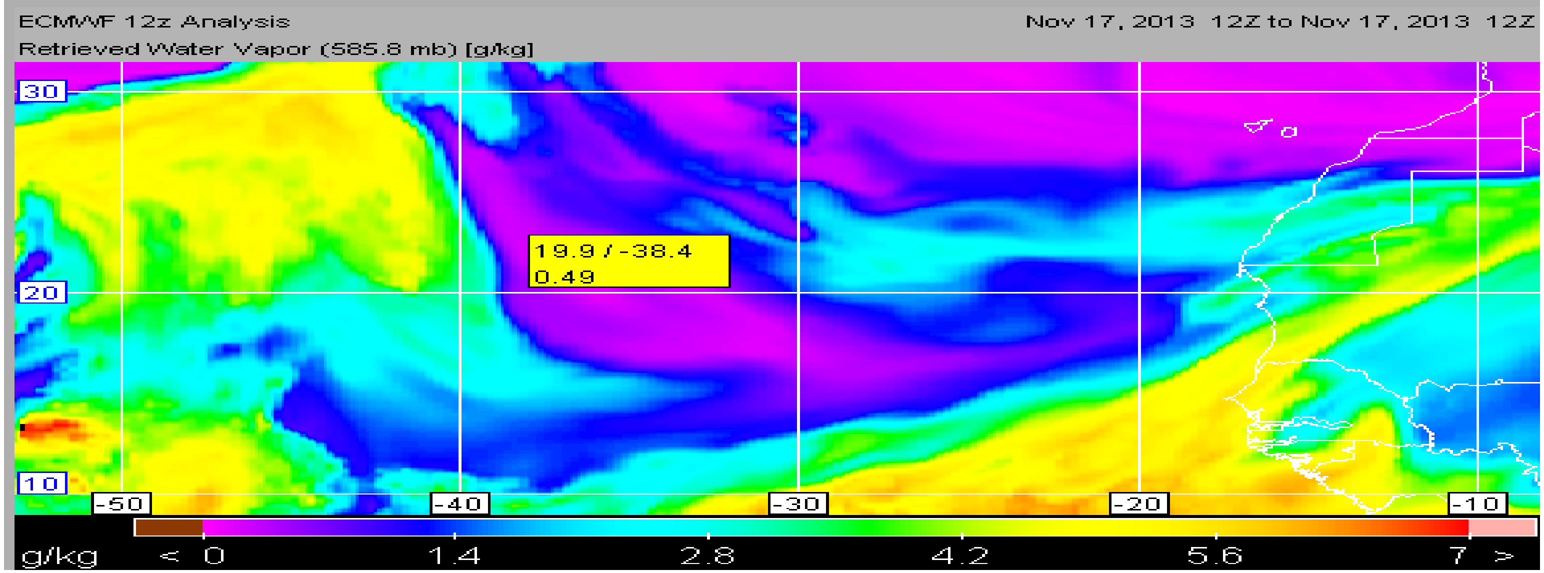


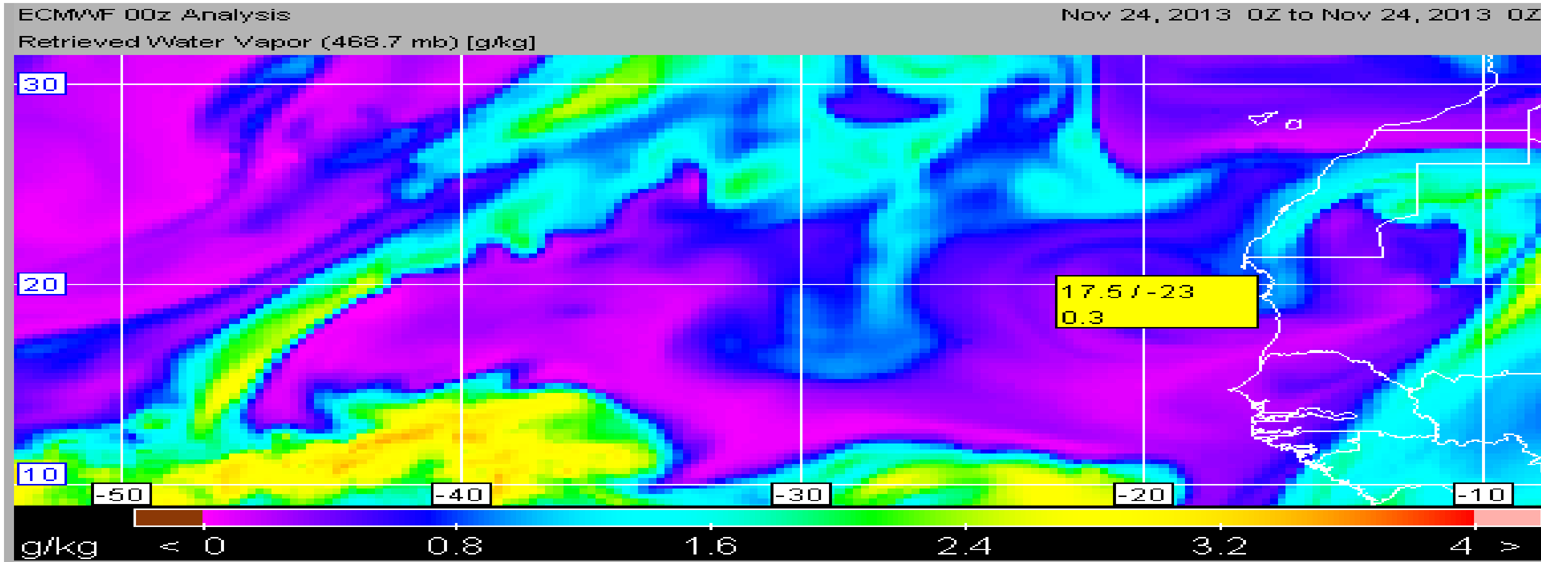
ECMWF 00z Analysis
Nov 16, 2013 0Z to Nov 16, 2013 0Z
Retrieved Water Vapor (585.8 mb) [g/kg]
30
20
10
-50
-40
-30
-20
-10
19.9 / -38.4
1.77
g/kg
< 0
1.4
2.8
4.2
5.6
7 >

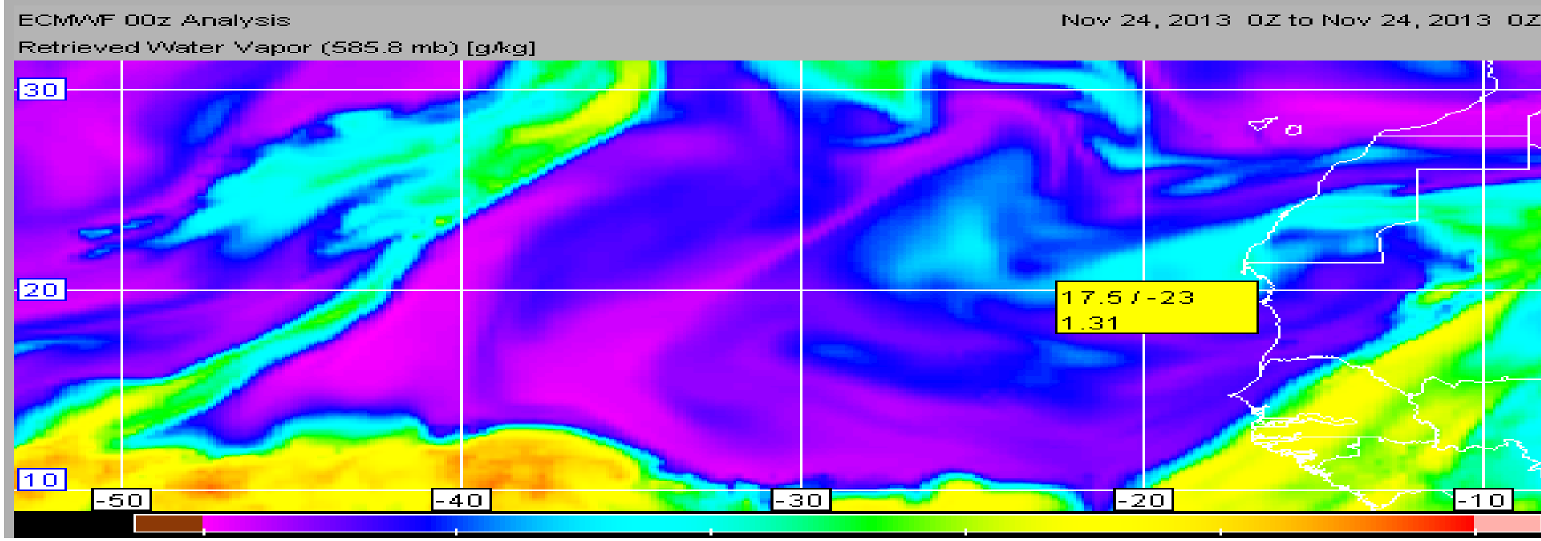

ECMWF 06z Analysis
Nov 16, 2013 6Z to Nov 16, 2013 6Z
Retrieved Water Vapor (468.7 mb) [g/kg]
30
20
10
-50
-40
-30
-20
-10
19.9 / -38.4
0.11
g/kg
< 0
0.8
1.6
2.4
3.2
4 >

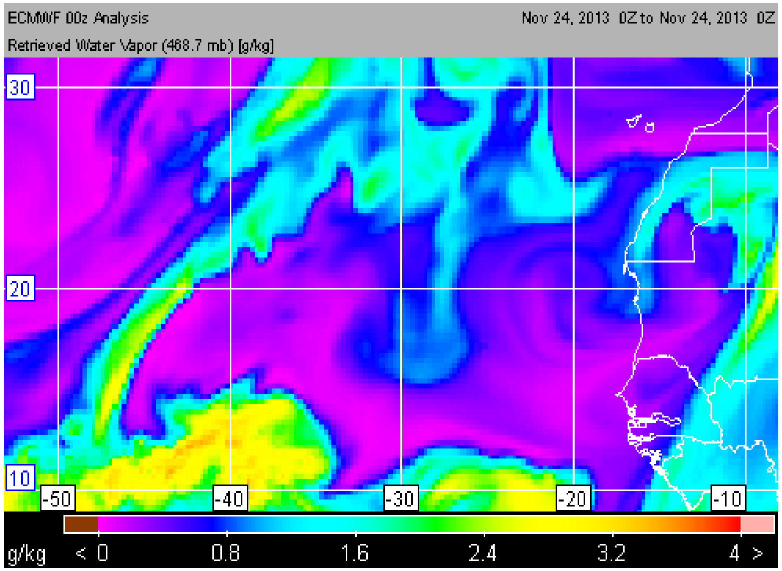

ECMWF 06z Analysis
Nov 16, 2013 6Z to Nov 16, 2013 6Z
Retrieved Water Vapor (585.8 mb) [g/kg]
30
20
10
-50
-40
-30
-20
-10
19.9 / -38.4
1.4
g/kg
< 0
1.4
2.8
4.2
5.6
7 >

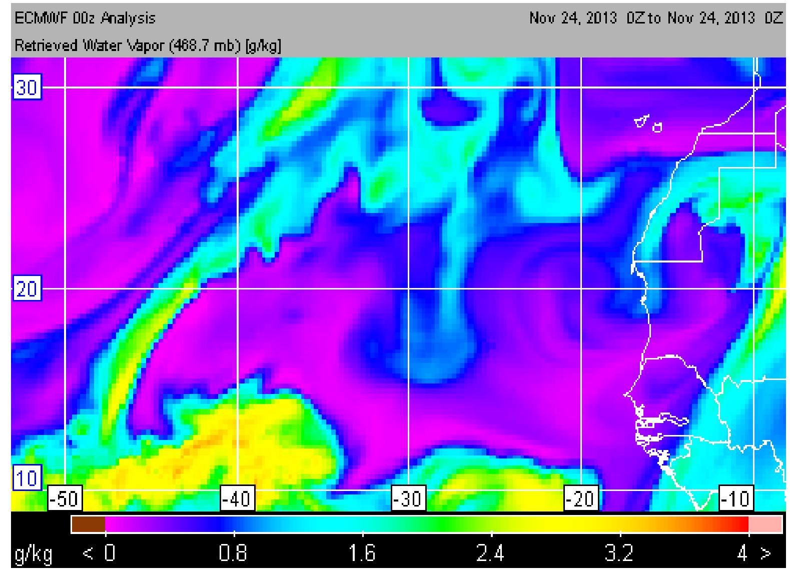

ECMWF 12z Analysis
Nov 17, 2013 12Z to Nov 17, 2013 12Z
Retrieved Water Vapor (468.7 mb) [g/kg]
30
20
10
-50
-40
-30
-20
-10
19.9 / -38.4
1.3
g/kg
< 0
0.8
1.6
2.4
3.2
4 >

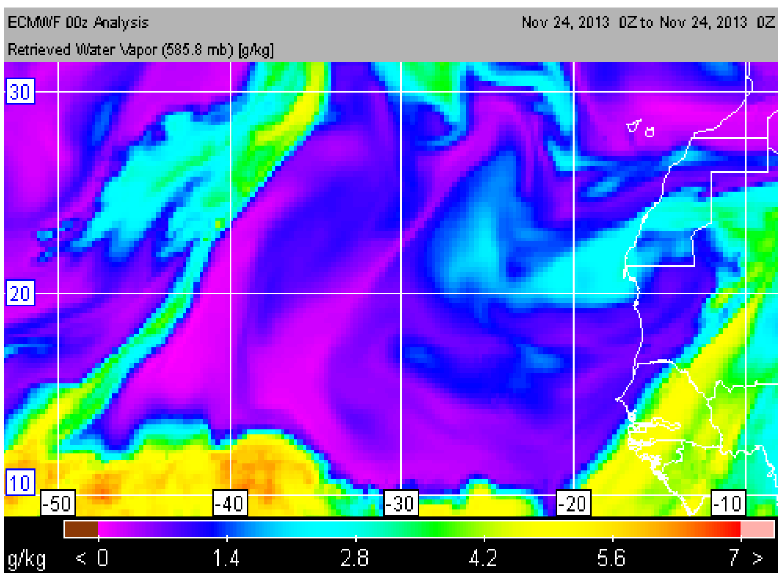

ECMWF 12z Analysis
Nov 17, 2013 12Z to Nov 17, 2013 12Z
Retrieved Water Vapor (585.8 mb) [g/kg]
30
20
10
-50
-40
-30
-20
-10
19.9 / -38.4
0.49
g/kg
< 0
1.4
2.8
4.2
5.6
7 >

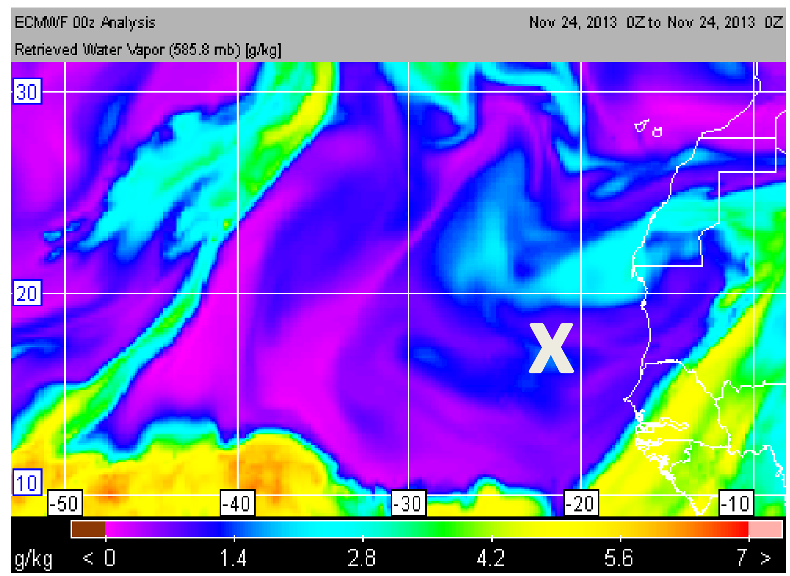

ECMWF 00z Analysis
Nov 24, 2013 0Z to Nov 24, 2013 0Z
Retrieved Water Vapor (468.7 mb) [g/kg]
30
20
10
-50
-40
-30
-20
-10
17.5 / -23
0.3
g/kg < 0 0.8 1.6 2.4 3.2 4 >

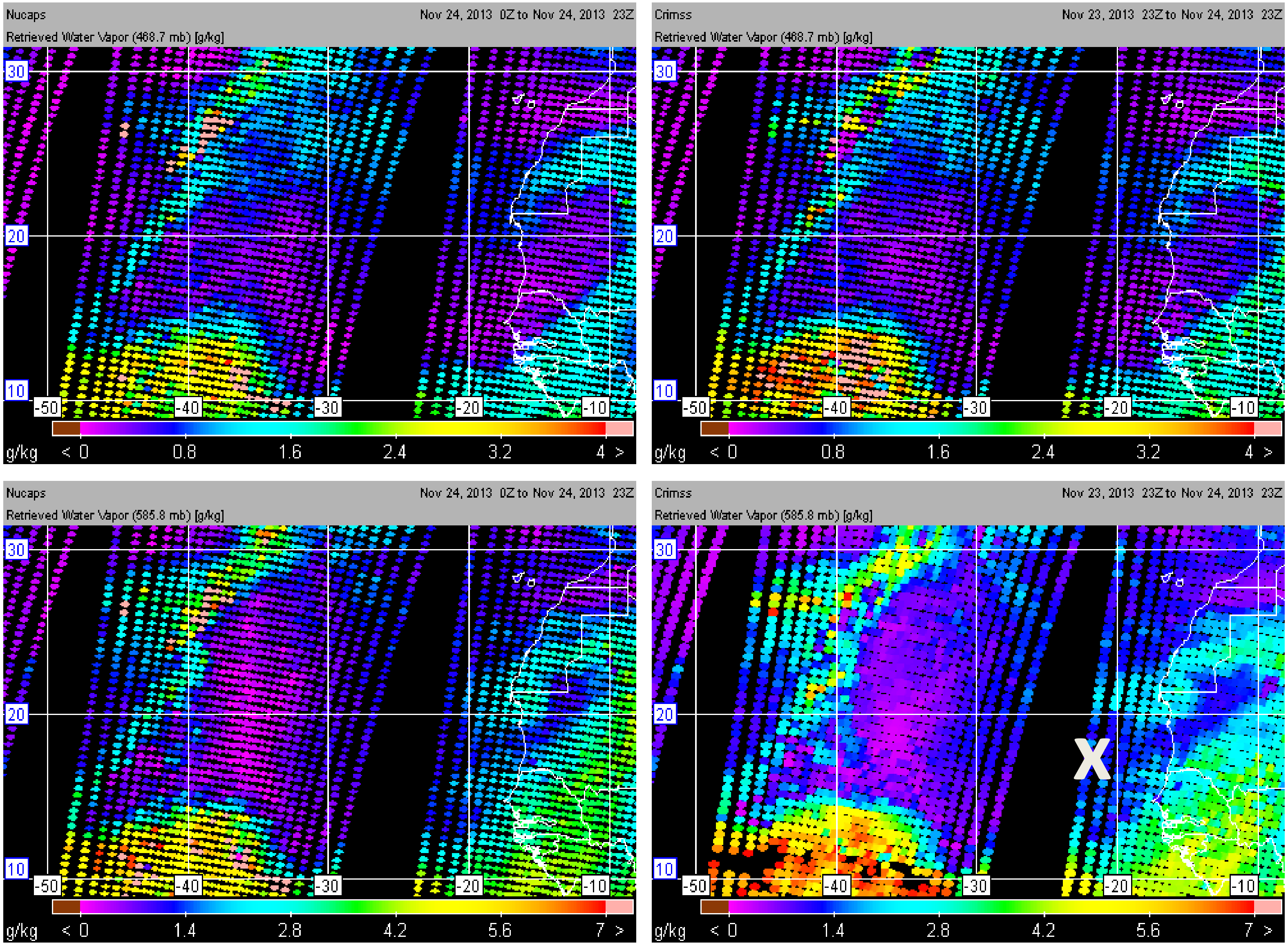

ECMWF 00z Analysis
Nov 24, 2013 0Z to Nov 24, 2013 0Z
Retrieved Water Vapor (585.8 mb) [g/kg]
30
20
10
-50
-40
-30
-20
-10
17.5 / -23
1.31

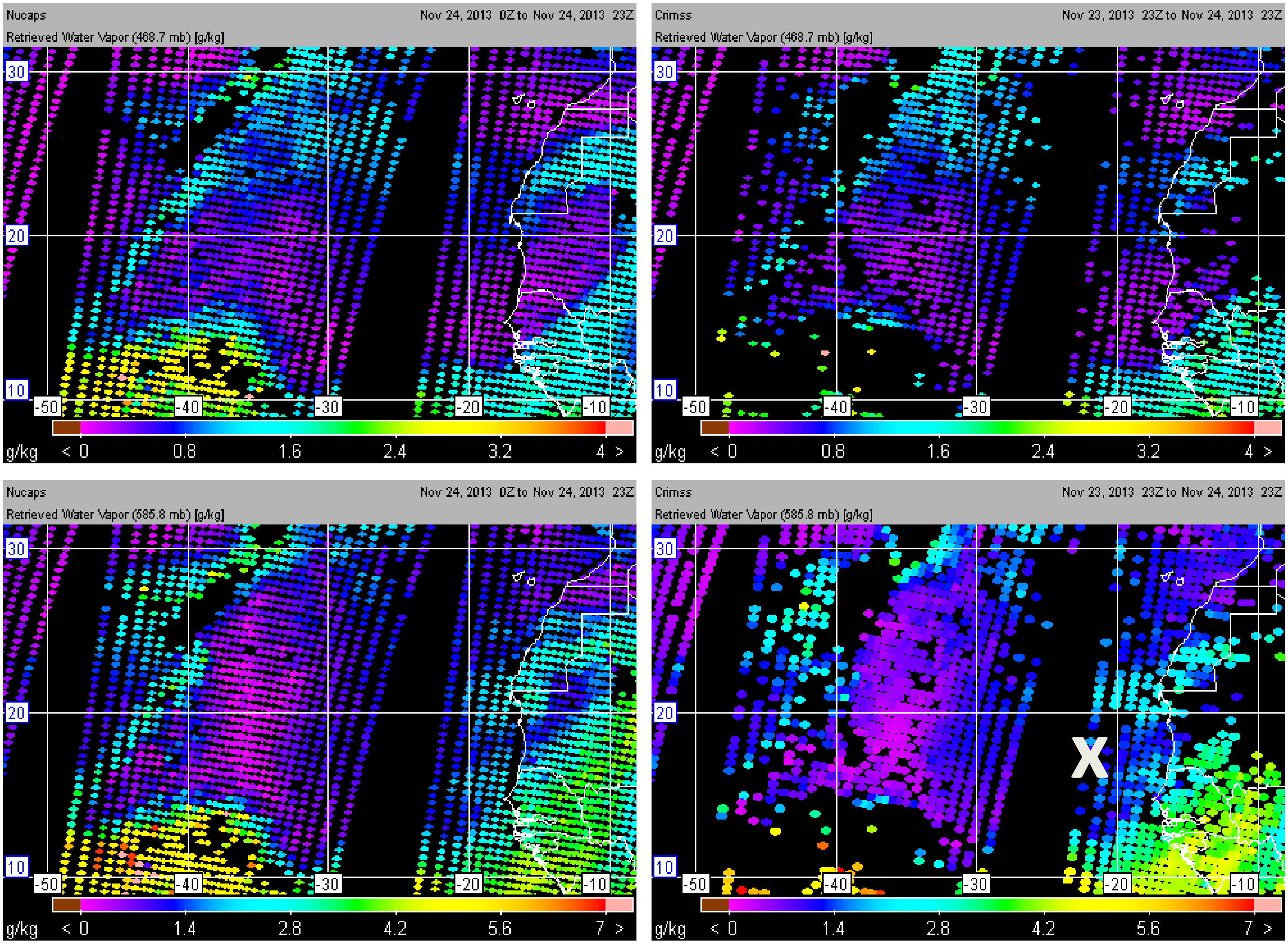

ECMWF 00z Analysis
Nov 24, 2013 0Z to Nov 24, 2013 0Z
Retrieved Water Vapor (468.7 mb) [g/kg]
30
20
10
-50
-40
-30
-20
-10
g/kg
< 0
0.8
1.6
2.4
3.2
4 >

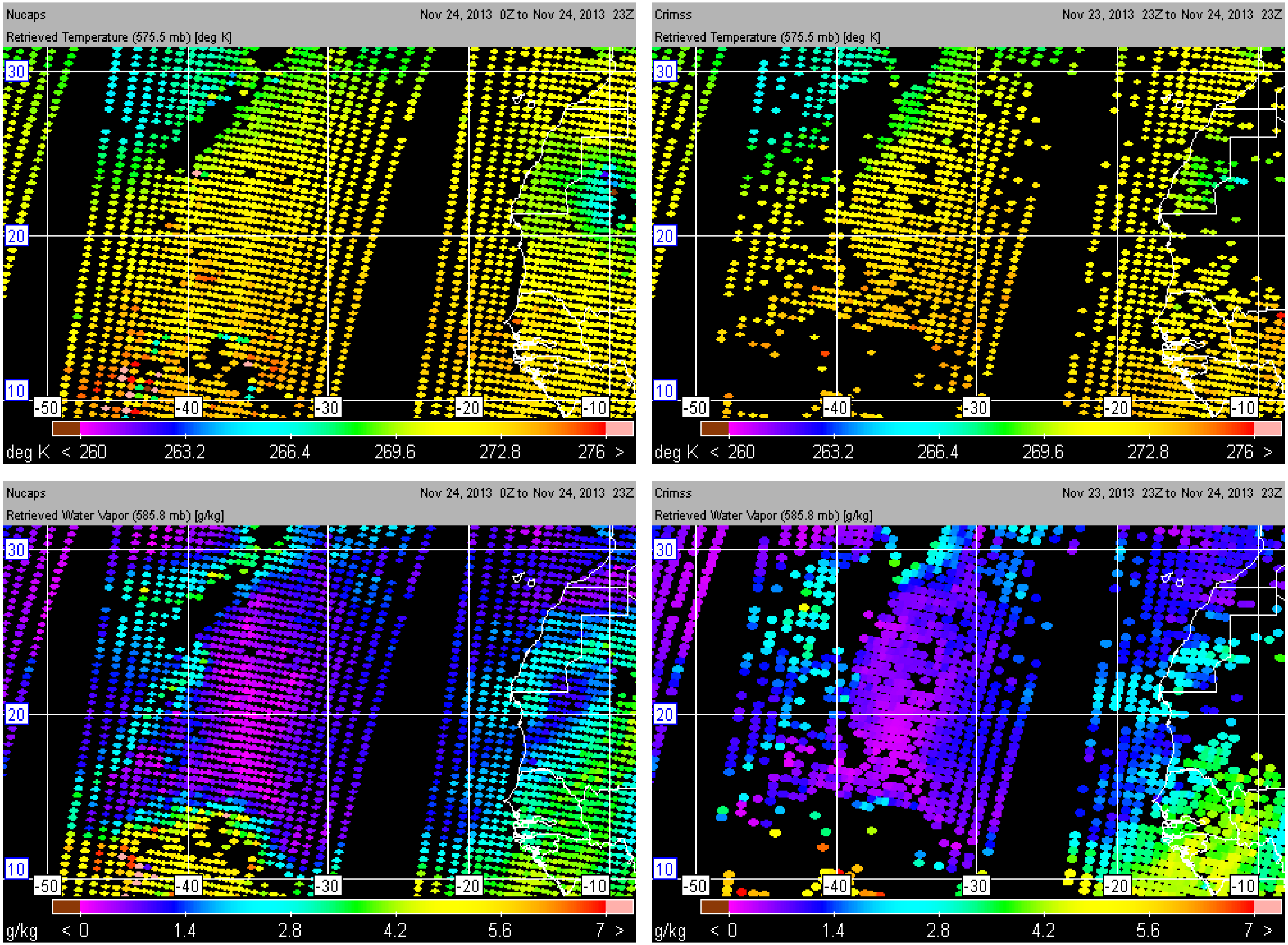

ECMWF 00z Analysis
Nov 24, 2013 0Z to Nov 24, 2013 0Z
Retrieved Water Vapor (468.7 mb) [g/kg]
30
20
10
-50
-40
-30
-20
-10
g/kg
< 0
0.8
1.6
2.4
3.2
4 >


ECMWF 00z Analysis
Nov 24, 2013 0Z to Nov 24, 2013 0Z
Retrieved Water Vapor (585.8 mb) [g/kg]
30
20
10
-50
-40
-30
-20
-10
g/kg
< 0
1.4
2.8
4.2
5.6
7 >


ECMWF 00z Analysis
Nov 24, 2013 0Z to Nov 24, 2013 0Z
Retrieved Water Vapor (585.8 mb) [g/kg]
X
30
20
10
-50
-40
-30
-20
-10
g/kg
< 0
1.4
2.8
4.2
5.6
7 >


Nucaps
Nov 24, 2013 0Z to Nov 24, 2013 23Z
Retrieved Water Vapor (468.7 mb) [g/kg]
30
20
10
-50
-40
-30
-20
-10
g/kg < 0 0.8 1.6 2.4 3.2 4 >
Crimss
Nov 23, 2013 23Z to Nov 24, 2013 23Z
Retrieved Water Vapor (468.7 mb) [g/kg]
g/kg < 0 0.8 1.6 2.4 3.2 4 >
Nucaps
Nov 24, 2013 0Z to Nov 24, 2013 23Z
Retrieved Water Vapor (585.8 mb) [g/kg]
g/kg < 0 1.4 2.8 4.2 5.6 7 >
Crimss
Nov 23, 2013 23Z to Nov 24, 2013 23Z
Retrieved Water Vapor (585.8 mb) [g/kg]
X
g/kg < 0 1.4 2.8 4.2 5.6 7 >


Nucaps
Nov 24, 2013 0Z to Nov 24, 2013 23Z
Retrieved Water Vapor (468.7 mb) [g/kg]
30
20
10
-50
-40
-30
-20
-10
g/kg
< 0
0.8
1.6
2.4
3.2
4 >
Crimss
Nov 23, 2013 23Z to Nov 24, 2013 23Z
Retrieved Water Vapor (468.7 mb) [g/kg]
30
20
10
-50
-40
-30
-20
-10
g/kg
< 0
0.8
1.6
2.4
3.2
4 >
Nucaps
Nov 24, 2013 0Z to Nov 24, 2013 23Z
Retrieved Water Vapor (585.8 mb) [g/kg]
30
20
10
-50
-40
-30
-20
-10
g/kg
< 0
1.4
2.8
4.2
5.6
7 >
Crimss
Nov 23, 2013 23Z to Nov 24, 2013 23Z
Retrieved Water Vapor (585.8 mb) [g/kg]
30
20
10
-50
-40
-30
-20
-10
X
g/kg
< 0
1.4
2.8
4.2
5.6
7 >


Nucaps
Nov 24, 2013 0Z to Nov 24, 2013 23Z
Retrieved Temperature (575.5 mb) [deg K]
deg K < 260 263.2 266.4 269.6 272.8 276 >
Crimss
Nov 23, 2013 23Z to Nov 24, 2013 23Z
Retrieved Temperature (575.5 mb) [deg K]
deg K < 260 263.2 266.4 269.6 272.8 276 >
Nucaps
Nov 24, 2013 0Z to Nov 24, 2013 23Z
Retrieved Water Vapor (585.8 mb) [g/kg]
g/kg < 0 1.4 2.8 4.2 5.6 7 >
Crimss
Nov 23, 2013 23Z to Nov 24, 2013 23Z
Retrieved Water Vapor (585.8 mb) [g/kg]
g/kg < 0 1.4 2.8 4.2 5.6 7 >
30
20
10
-50
-40
-30
-20
-10

Validated Stage 1 Science Maturity Review for Soundings

Presented by
Quanhua (Mark) Liu
September 3, 2014

Outline

- Algorithm Cal/Val Team Members
- Product Requirements
- Evaluation of algorithm performance to specification requirements
  - Evaluation of the effect of required algorithm inputs
  - Quality flag analysis/validation
  - Error Budget
- Documentation
- Identification of Processing Environment
- Users & User Feedback
- Conclusion
- Path Forward

Sounding EDR Cal/Val Team

Name	Organization	Major Task
M. Liu, T. Reale, W.Wolf	NOAA/STAR	Management leads
A. Gambacorta	IMSG@STAR	NUCAPS algorithm lead, X. Xiong, C. Tan, F. Iturbide-Sanchez, K. Zhang:NUCAPS algorithm team member AVTP, AVMP, O_3, OLR, trace gases
N. Nalli	IMSG@STAR	NUCAPS product validation lead
C. Barnet	STC	NOAA CrIS/ATMS EDRs in complex weather regimes
B. Sun, M. Pettey, Frank Tilley, Charlie Brown	IMSG@STAR	NPROVS/NPROVS+
X. Liu	NASA/LaRC	NUCAPS independent assessment
P. J. Mather	DOE	support validation of EDRs
D. Tobin	UW	ARM-RAOBS at NWP, SGP, NSA

Special thanks to T. King, M. Wilson, and Y. Zhou. NUCAPS codes are now under version control in ClearCase.

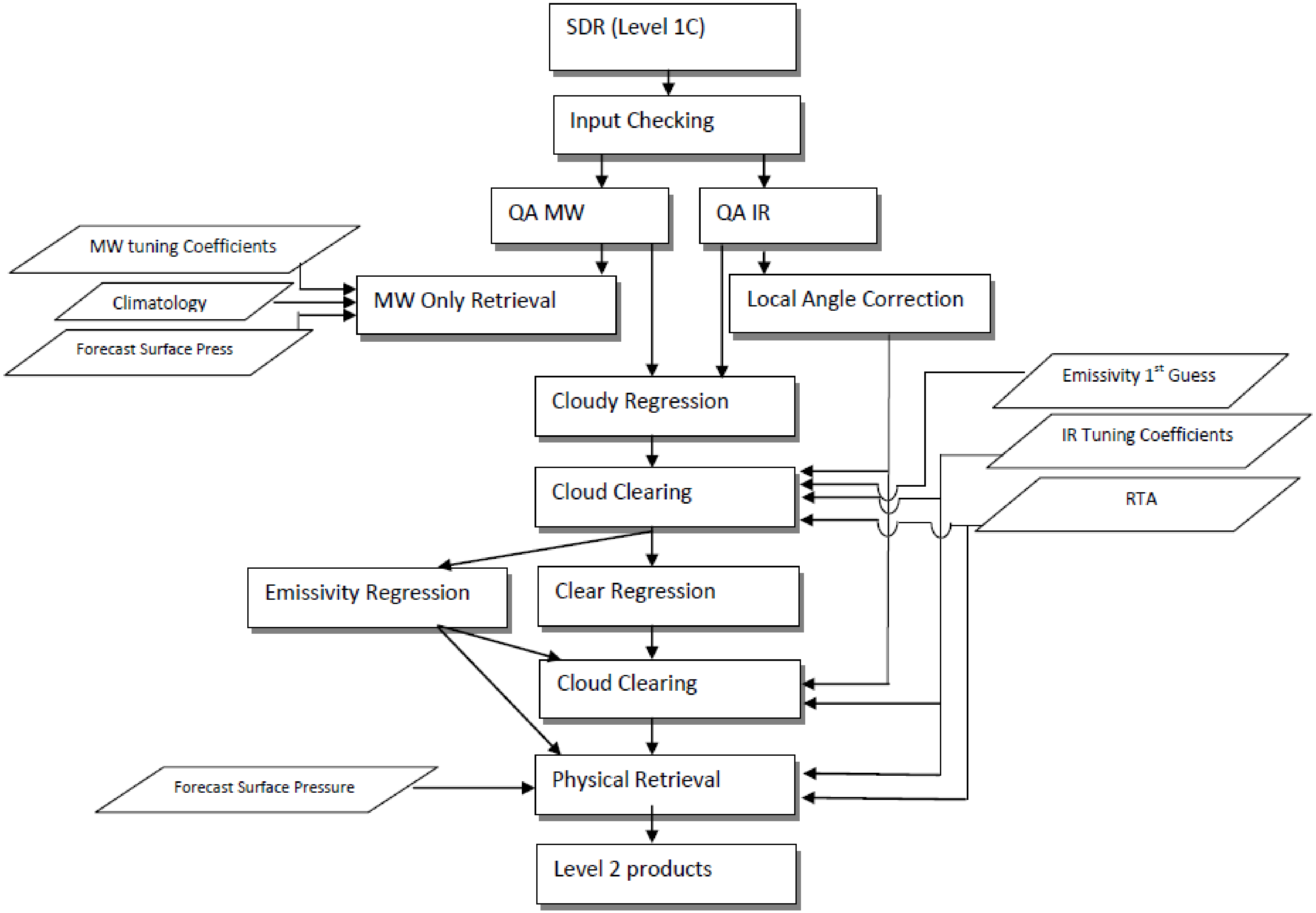
Temperature Profile Requirements

	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	Propose 150 ~ 400 K	Propose 100 ~ 500 K
	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
MW only	700 to 300 mb	1.5 K per km layer	0.5 K per km layer
	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

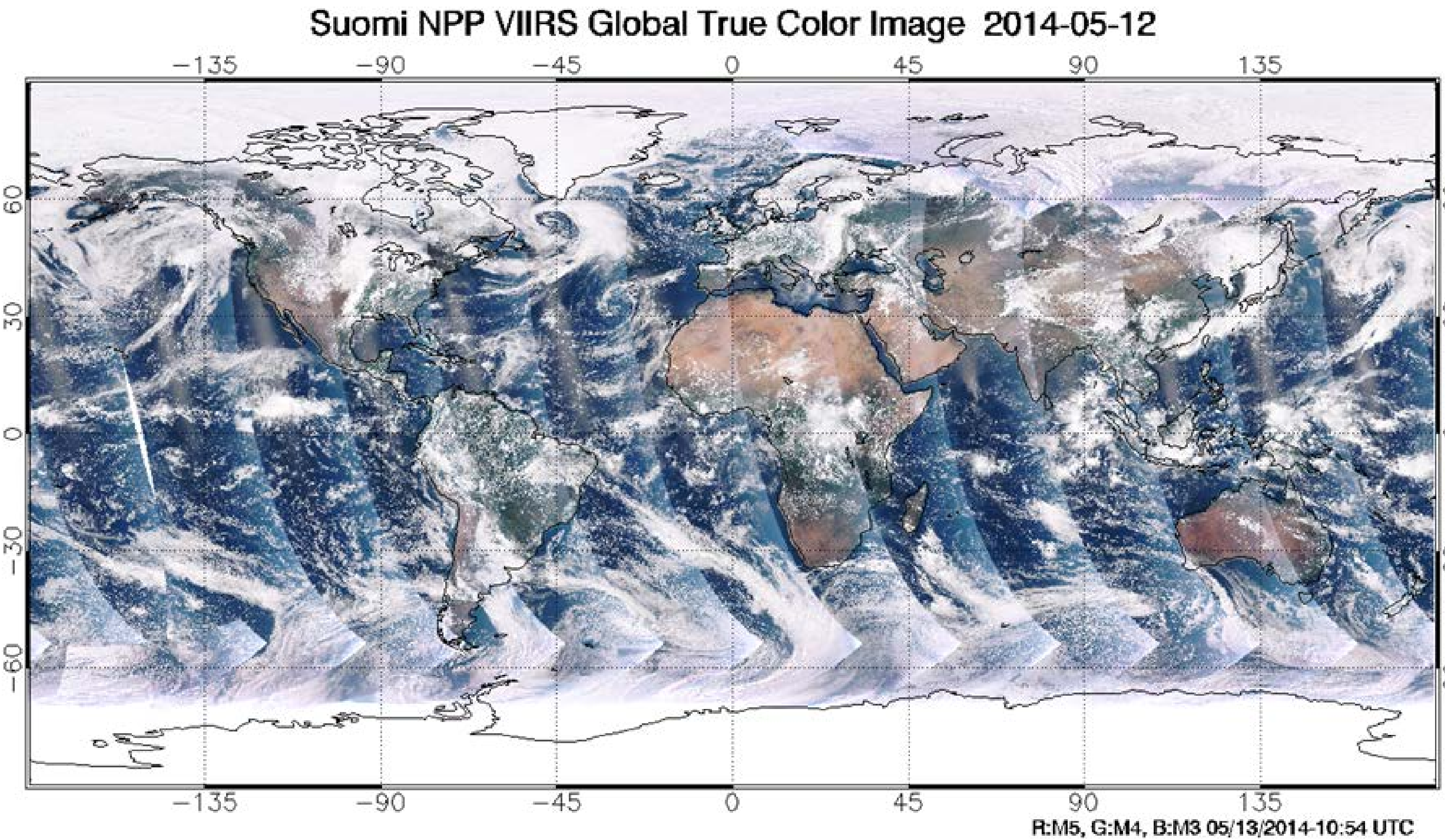
	Attribute	Threshold	Objective
L1RD p41	Geographic coverage	90% every 18 hours	3 hrs
	Vertical Coverage	Surface to 0.5 mb	Surface to 0.5 mb
	Vertical Cell Size	20 ~50 mb	5 ~ 10 mb
	Horizontal Cell Size	50 km at nadir	1 km at nadir
	Mapping Uncertainty	5 km	0.5 km
	Measurement Range	Propose 0.001 ~ 100 g/kg	Propose 0.001 ~ 100 g/kg
	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%
MW only	Cloud >= 50%: Surface to 600mb	Greater of 20% or 0.2 g/kg	10%
	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%

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

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%

Data from Haibing Sun

CCR (CF< 80%)

Using cloud-clearing radiance, IR retrieval data increases from 8.6% to 55%.

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*

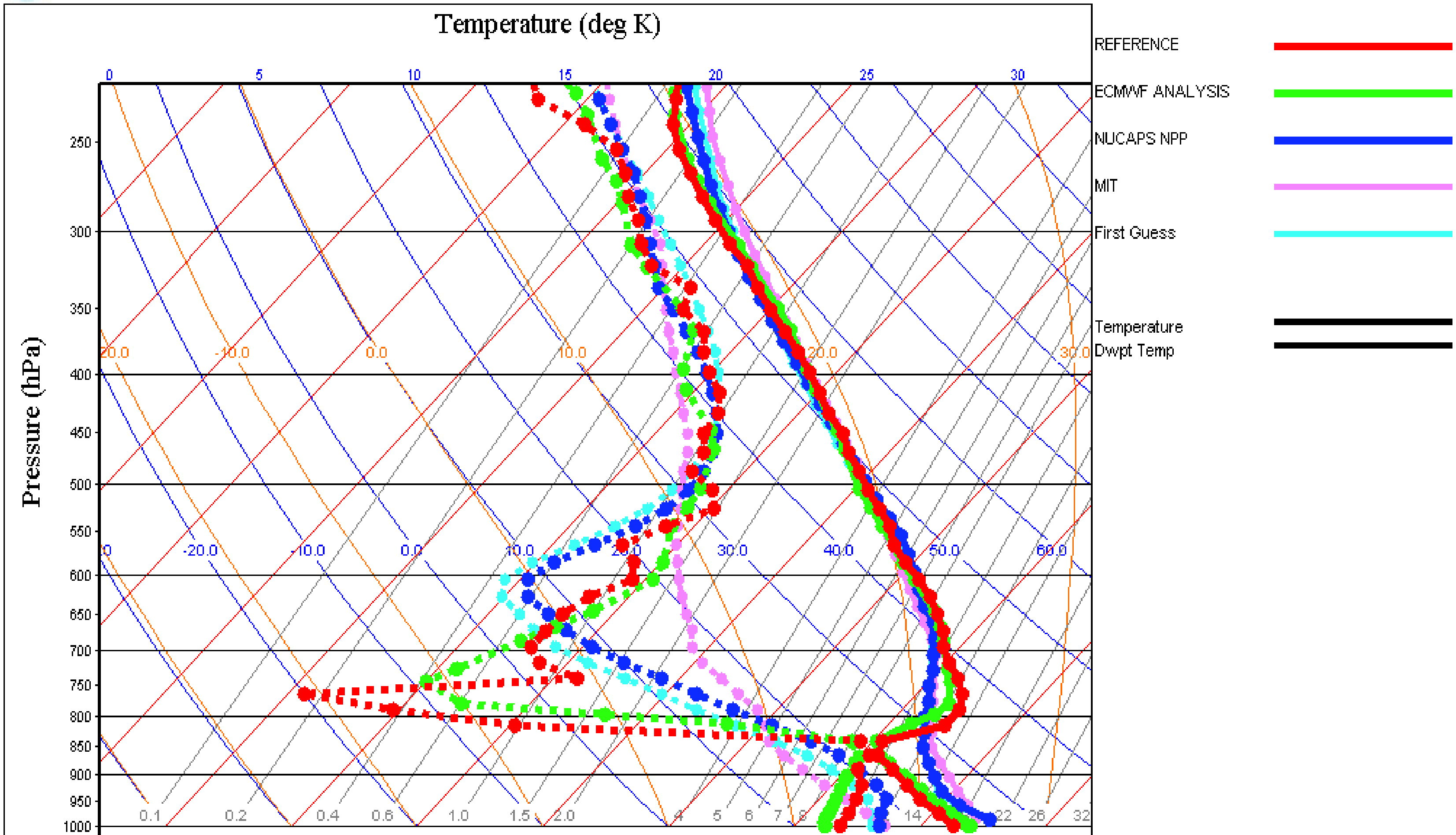
Dedicated for the purpose of satellite validation
Well-specified error characteristics and optimal accuracy
Minimal mismatch errors
Include atmospheric state "best estimates" or "merged soundings"
Reference sondes: CFH, corrected RS92, Vaisala RR01 under Development
Traceable measurement
Detailed performance 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.

NOAA Products Validation System (NPROVS)



GRUAN Sonde 91162 (80)	4/15/2014 23:58		22.04 N / 159.78 W	
ECMWF ANALYSIS	4/16/2014 00:00:00	(0 hours)	22.00 N / 159.75 W	(6.1 km)
NUCAPS NPP	4/16/2014 00:27:59	(0.5 hours)	22.19 N / 159.43 W	(39.1 km)

Data Product Maturity Definition

Validated Stage 1:

Using a limited set of samples, the algorithm output is shown to meet the threshold performance attributes identified in the JPSS Level 1 Requirements Supplement with the exception of the S-NPP Performance Exclusions.

Validation Data Set

Qualitative Analysis

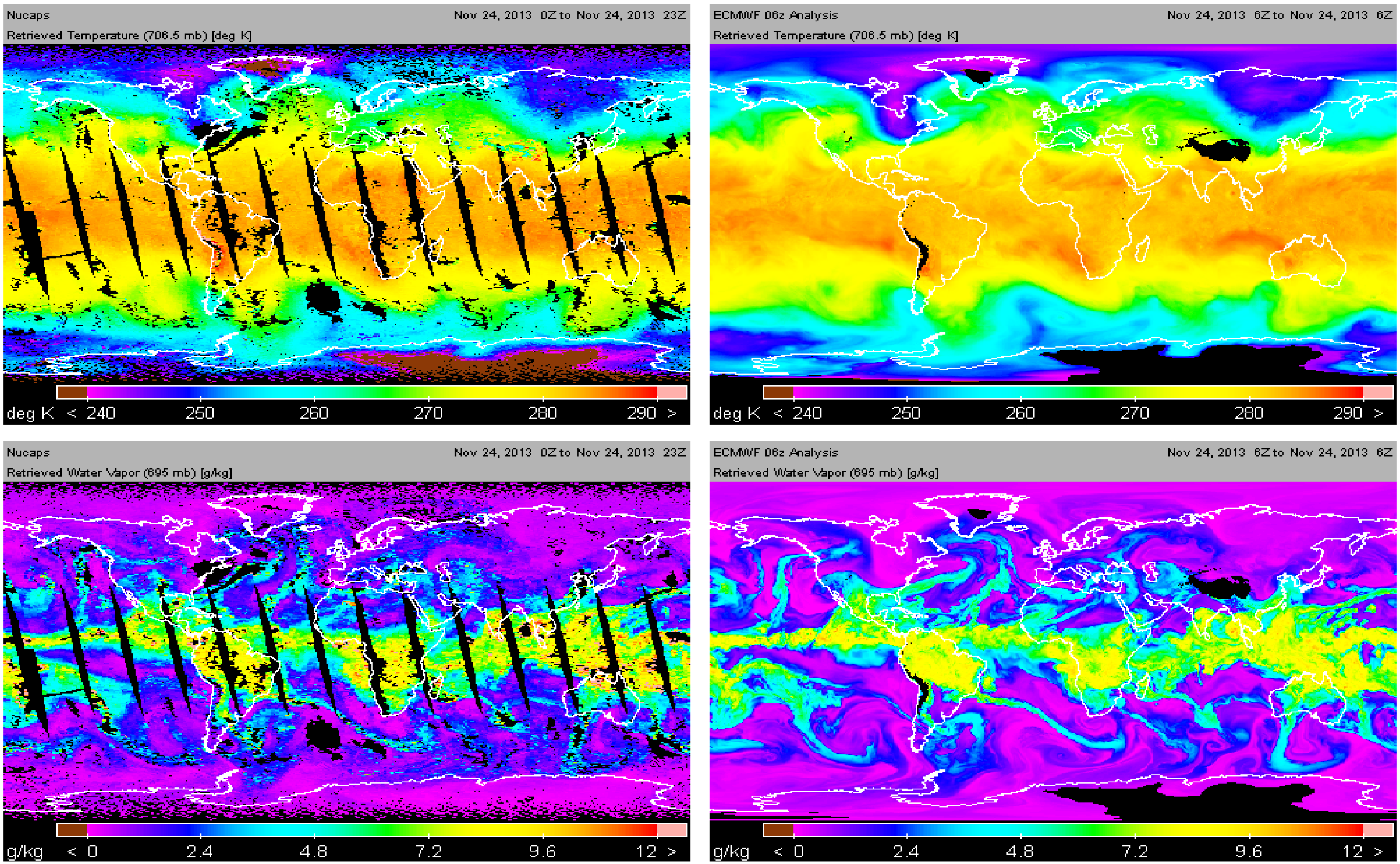
Product global distribution

Quantitative Analysis

a. Aerosols and Ocean Science Expeditions (AEROSE)
b. ECMWF Global Analysis
c. Dedicated radiosondes
 ARM-SGP : Mid-latitude land
 ARM-TWP: Tropical western pacific
 ARM-NSA: Polar area

NUCAPS Products

NUCAPS vs ECMWF, T and H_2O

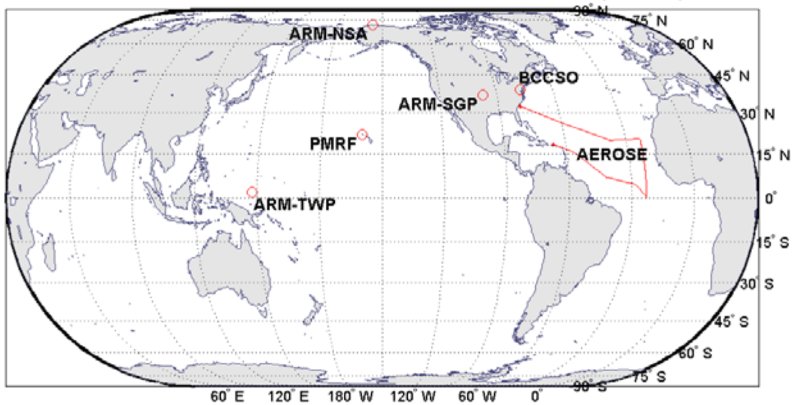


Black indicate where IR+MW and MW-only failed qc …

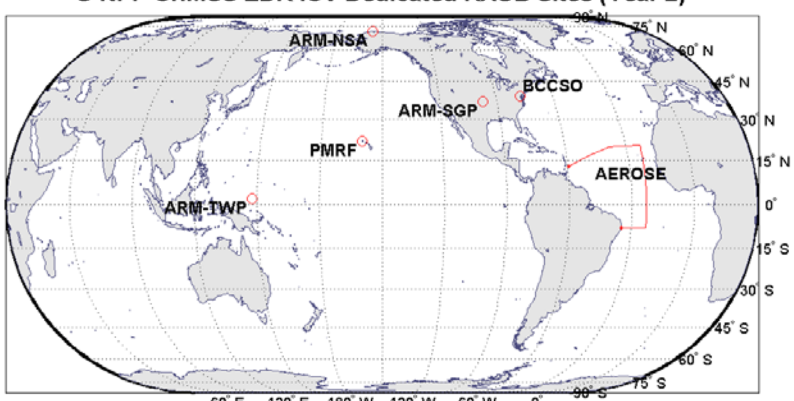
Dedicated and GRUAN Reference RAOB

JPSS S-NPP Dedicated

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



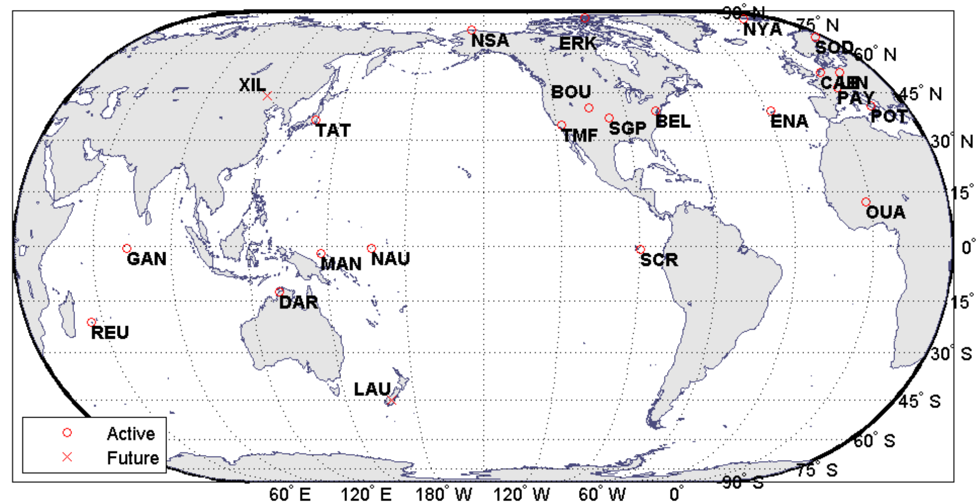
S-NPP CrIMSS EDR ICV Dedicated RAOB Sites (Year 2)



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)

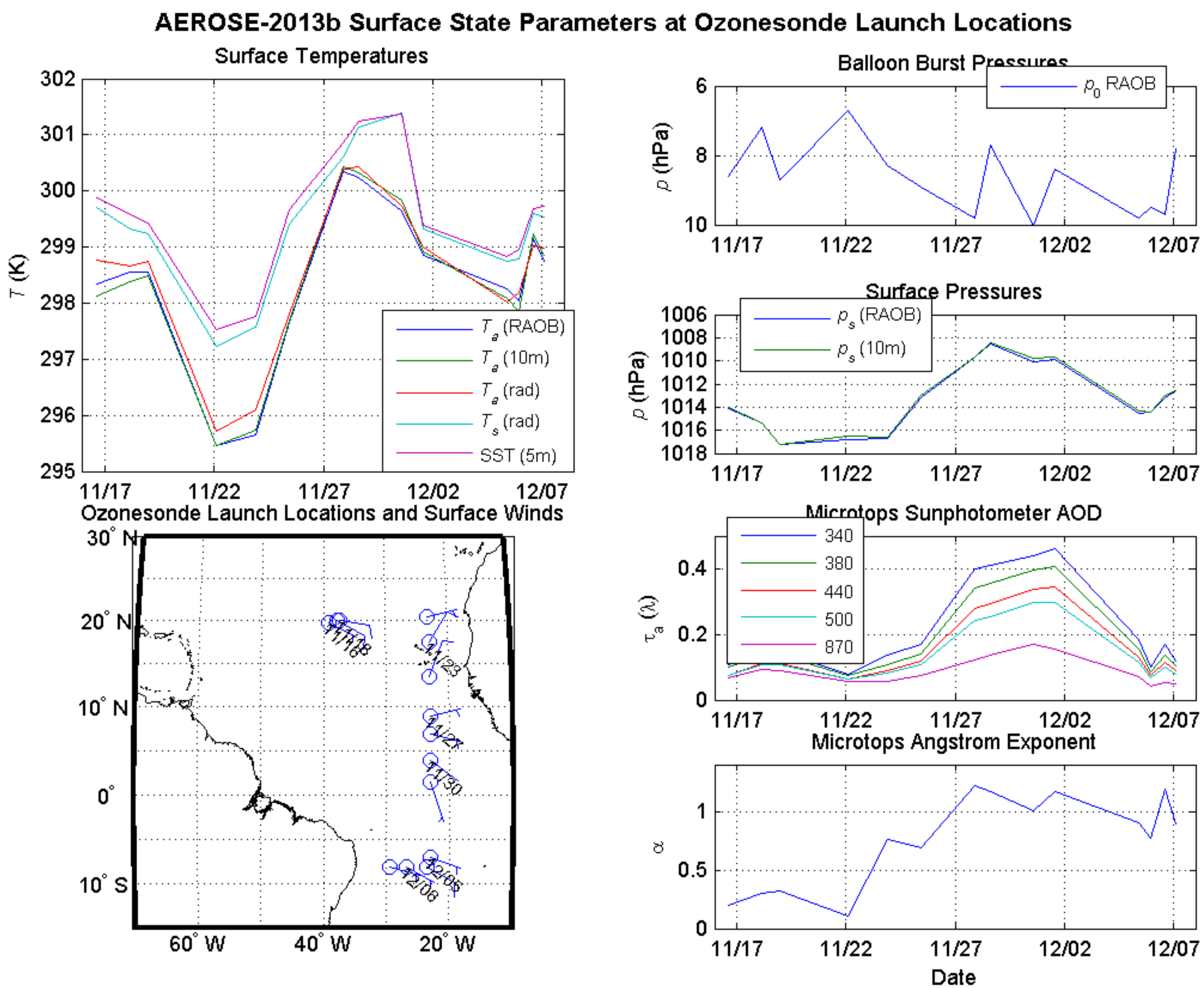
GRUAN RAOB Sites for Sounder EDR ICV



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

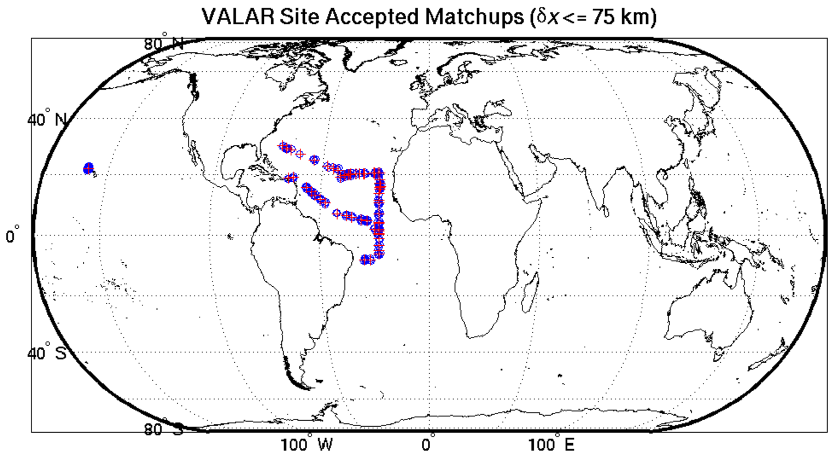
Location	NSA	NYA	OUA	PAY	POT	REU	SRC	SGP	SOD	TAT	TMF	XIL
Lat (deg)	71.32	78.92	12.4	46.81	40.6	-21.08	-0.9	36.61	67.37	36.06	34.39	43.95
Lon(deg)	-156.6	11.92	-1.5	6.95	15.72	55.38	-89.6	-97.49	26.63	140.1	-117.7	116.12

2013 AEROSE State Parameters
$P(z)$, $T(p)$, $U(p)$, O_3(p), T_s, u_s, v_s, AOD

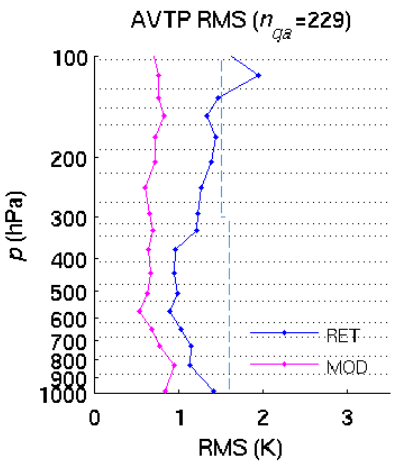


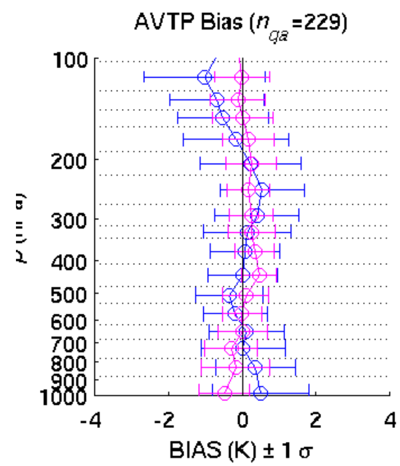
NDE-OPS IR + MW

MOD=ECMWF

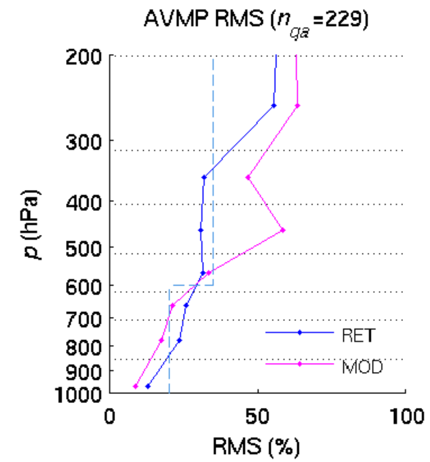


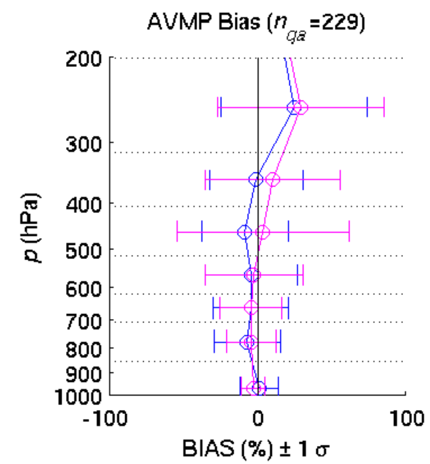
Temperature



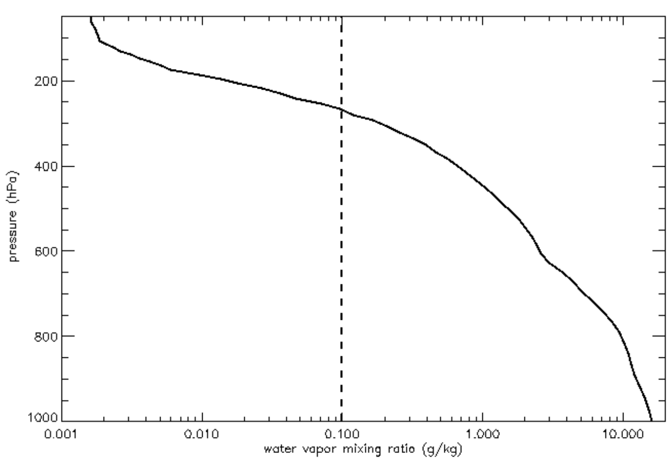


Moisture



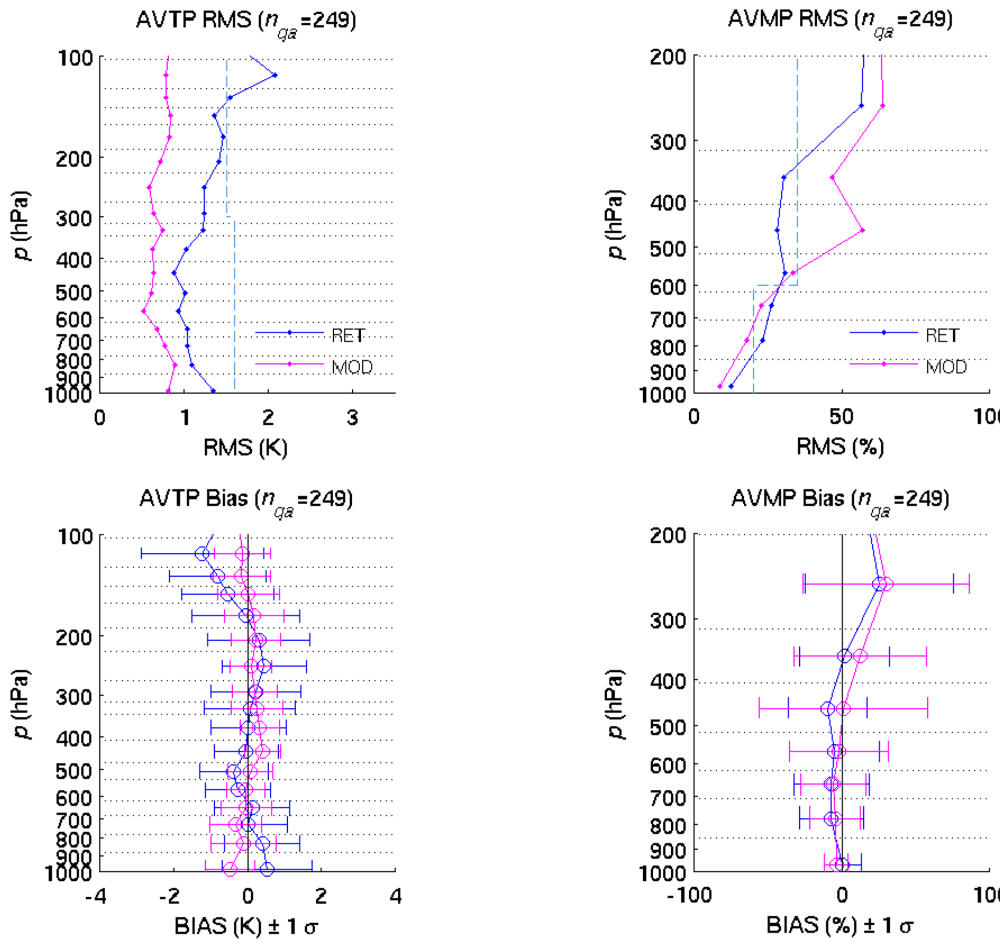


Standard tropical water vapor profile



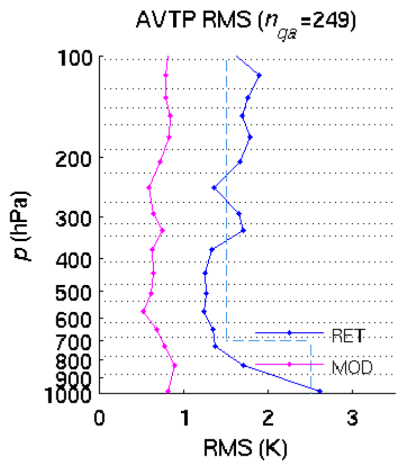
Offline IR + MW

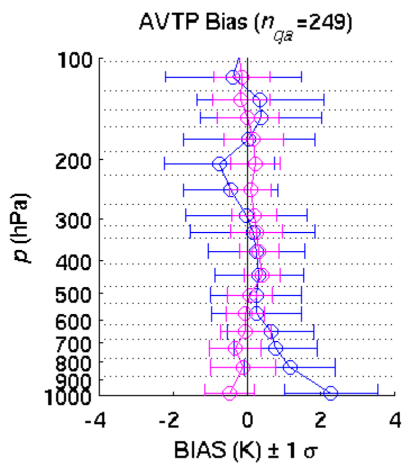
Temperature **Moisture**



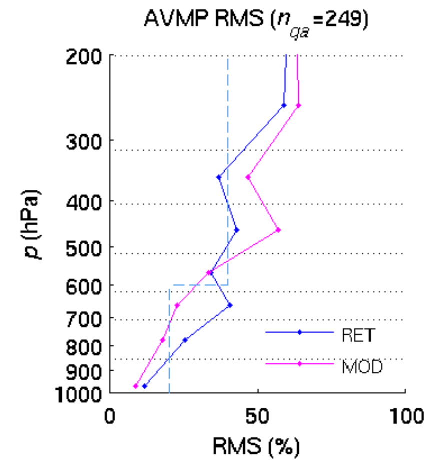
Offline MW-Only (MIT)

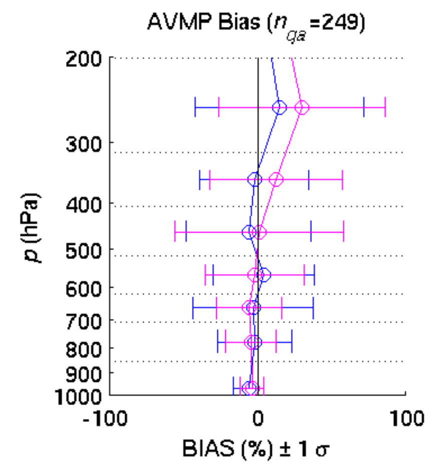
Temperature





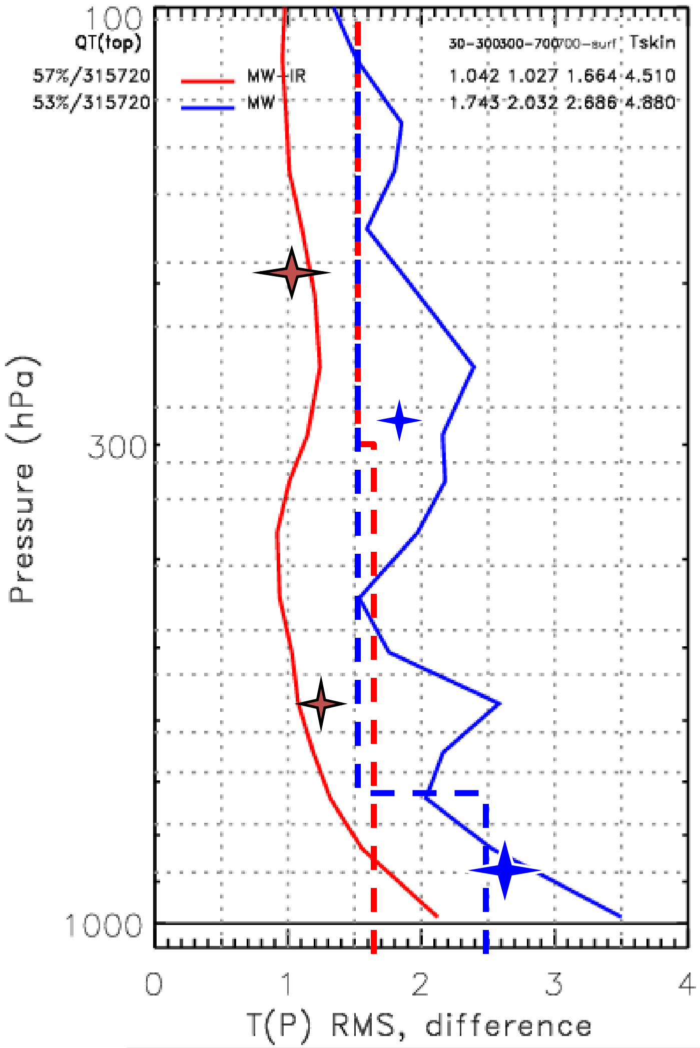
Moisture

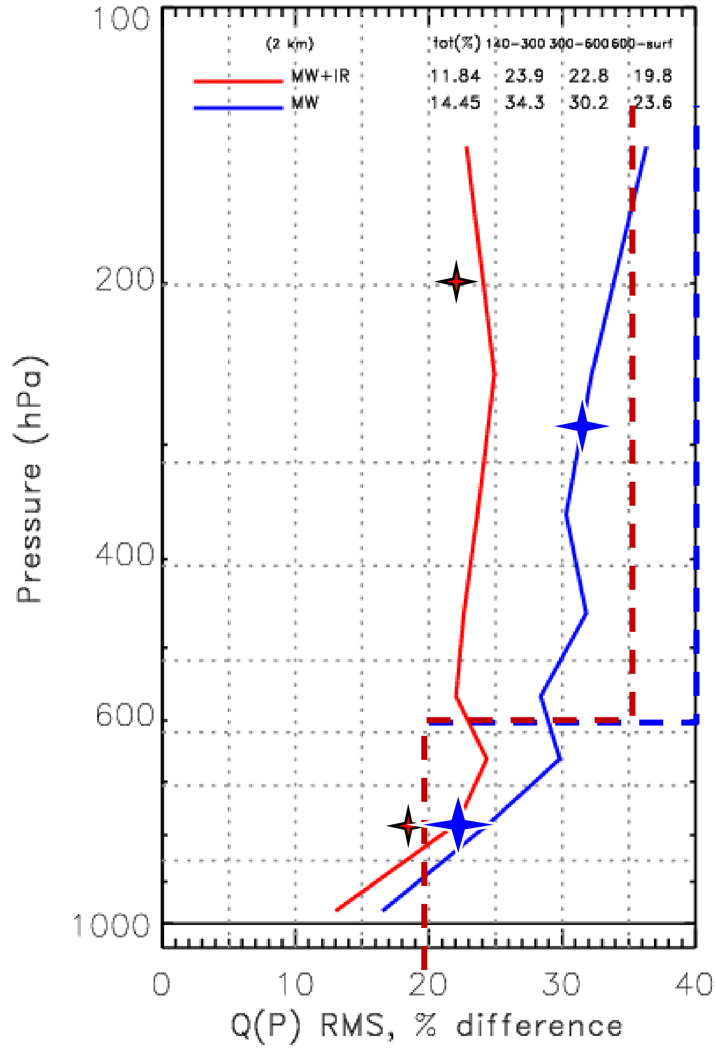




NUCAPS MW+IR & MW Only

Global (land+ocean) vs ECMWF Analysis (focus day 2012-05-15)





JPSS L1RD:
(see next slide)

30 – 300mb	300-SURF
1.042K (Req:1.5K)	1.34K (Req:1.6K)
TOA – 700mb	**700-SURF**
1.88K (Req:1.5K)	2.68K (Req:2.5K)

100 – 600mb	600-SURF
23.3% (Req:35%)	19.8% (Req:20%)
32.2% (Req:40%)	23.6% (Req:20%)

Summary on GLOBAL validation vs ECMWF

green = passed yellow = close red = failed

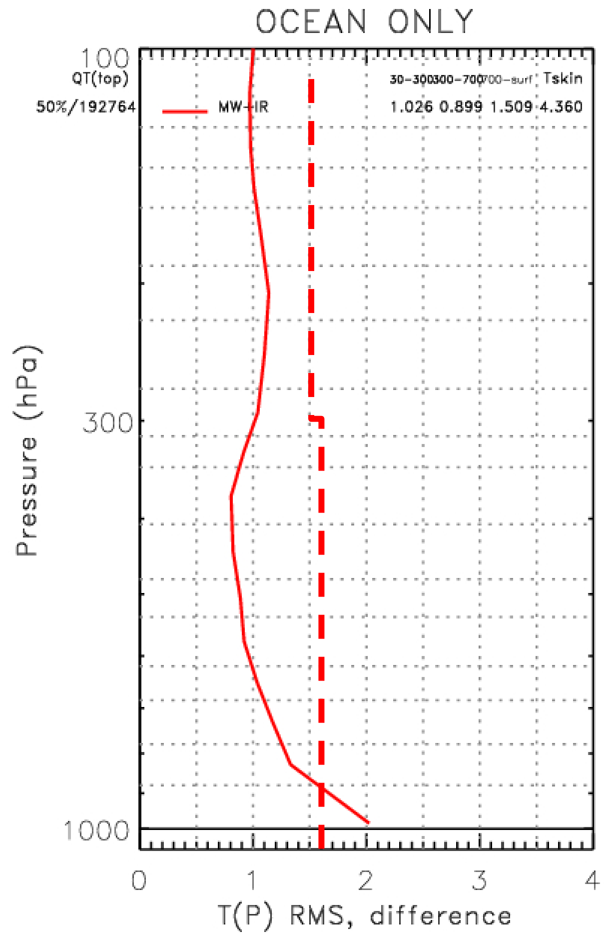
SUMMARY ON MW+IR RESULTS vs JPSS L1RD REQUIREMENTS					
MW+IR TEMPERATURE	RESULTS	JPSS L1RD	MW+IR WATER VAPOR	RESULTS	JPSS L1RD
30 – 300mb	1.04K	1.5K	100 - 600mb	23.3%	35%
300mb - SURF	1.34K	1.6K	600mb -SURF	19.8%	20%

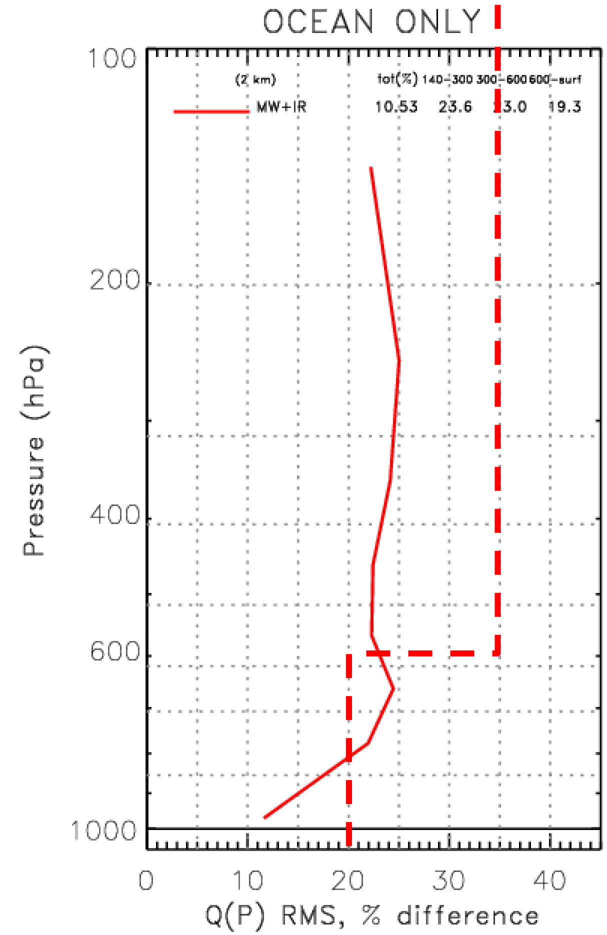
SUMMARY ON MW-ONLY RESULTS vs JPSS L1RD REQUIREMENTS					
MW-ONLY TEMPERATURE	RESULTS	JPSS L1RD	MW-ONLY WATER VAPOR	RESULTS	JPSS L1RD
30 – 700mb	1.88K	1.5K	100 - 600mb	32.2%	40%
700mb - SURF	2.68K	2.5K	600mb -SURF	23.6%	20%

- **NUCAPS MW+IR fully meets requirements globally**
- **NUCAPS MW-Only is close to fully meets spec.**
  - **Possible isues are**:
    - 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 model
    - Uncertainty in the retrievals
  - **Ongoing NUCAPS improvement activity:**
    - Improve NUCAPS look up tables (RTA tuning and first guess)
    - Improve validation methodology by using dedicated RAOBs: **see ahead**

GLOBAL OCEAN VALIDATION

NUCAPS MW+IR vs ECMWF Analysis (focus day 2012-05-15)

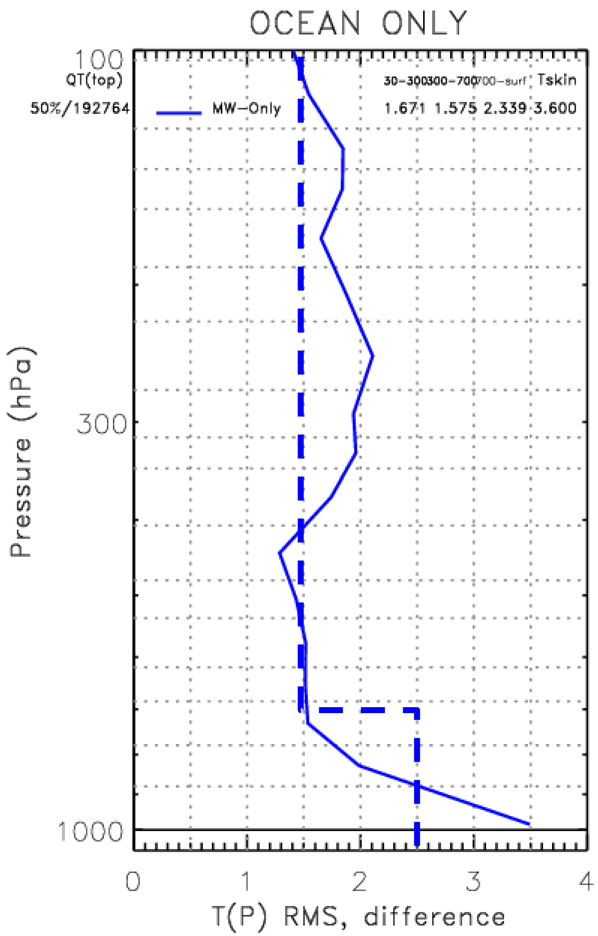


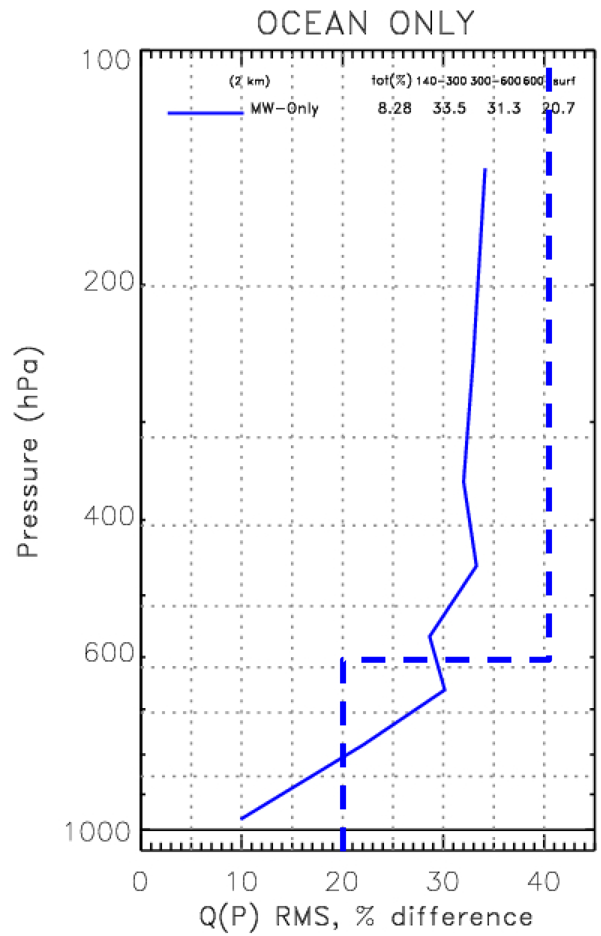


SUMMARY ON OCEAN MW+IR RESULTS vs JPSS L1RD REQUIREMENTS					
MW+IR TEMPERATURE	RESULTS	JPSS L1RD	MW+IR WATER VAPOR	RESULTS	JPSS L1RD
30 – 300mb	1.02K	1.5K	100 - 600mb	23.3%	35%
300mb - SURF	1.20K	1.6K	600mb -SURF	19.3%	20%

GLOBAL OCEAN VALIDATION

NUCAPS MW Only vs ECMWF Analysis (focus day 2012-05-15)





SUMMARY ON OCEAN MW-ONLY RESULTS vs JPSS L1RD REQUIREMENTS

MW-ONLY TEMPERATURE	RESULTS	JPSS L1RD	MW-ONLY WATER VAPOR	RESULTS	JPSS L1RD
30 – 700mb	1.55K	1.5K	100 - 600mb	32.4%	40%
700mb - SURF	2.33K	2.5K	600mb -SURF	20.7%	20%

Summary on OCEAN validation vs ECMWF

green = passed yellow = close red = failed

SUMMARY ON OCEAN MW+IR RESULTS vs JPSS L1RD REQUIREMENTS					
MW+IR TEMPERATURE	RESULTS	JPSS L1RD	MW+IR WATER VAPOR	RESULTS	JPSS L1RD
30 – 300mb	1.02K	1.5K	100 - 600mb	23.3%	35%
300mb - SURF	1.20K	1.6K	600mb -SURF	19.3%	20%

SUMMARY ON OCEAN MW-ONLY RESULTS vs JPSS L1RD REQUIREMENTS					
MW-ONLY TEMPERATURE	RESULTS	JPSS L1RD	MW-ONLY WATER VAPOR	RESULTS	JPSS L1RD
30 – 700mb	1.55K	1.5K	100 - 600mb	32.4%	40%
700mb - SURF	2.33K	2.5K	600mb -SURF	20.7%	20%

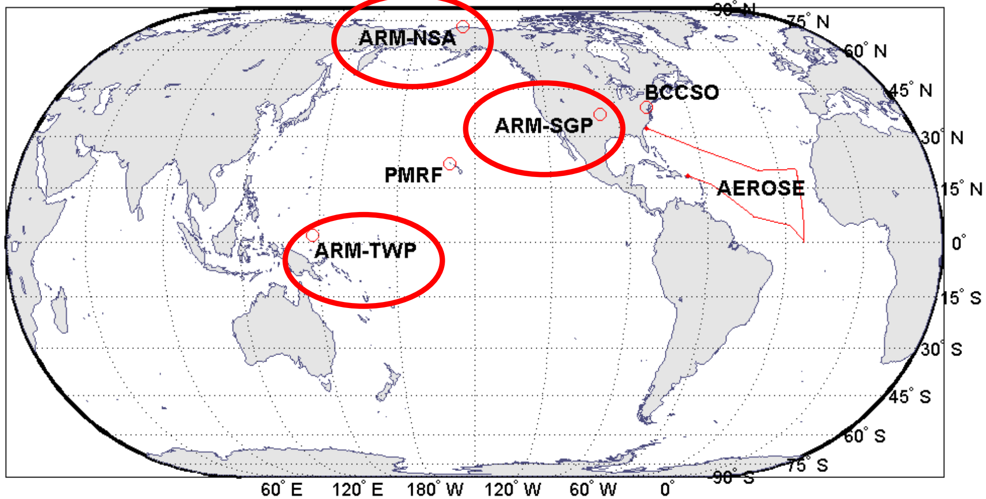
- **NUCAPS MW+IR fully meets requirements over ocean**
- **NUCAPS MW-Only is close to fully meet spec.**
  - **Possible issues are:**
    - Residual temporal and spatial mismatch between retrievals and model: ECMWF mismatch is +/- 1.5 hour and +/- 0.25 deg and we use both forecast and analysis depending on UT time.
    - Uncertainty in the ECMWF model
    - Uncertainty in the retrievals
  - **Ongoing NUCAPS improvement activity:**
    - Improve NUCAPS look up tables (RTA tuning and first guess)
    - Improve validation methodology by using dedicated RAOBs: **see ahead**

NUCAPS validation vs ARM

- JPSS funded dedicated (time and location) wrt NPP
- **Global** ensemble, ~ 3 month field campaign (2012):
  - Tropical Western Pacific (TWP)
  - Southern Great Plans (SGP)
  - North Slope of Alaska (NSA)

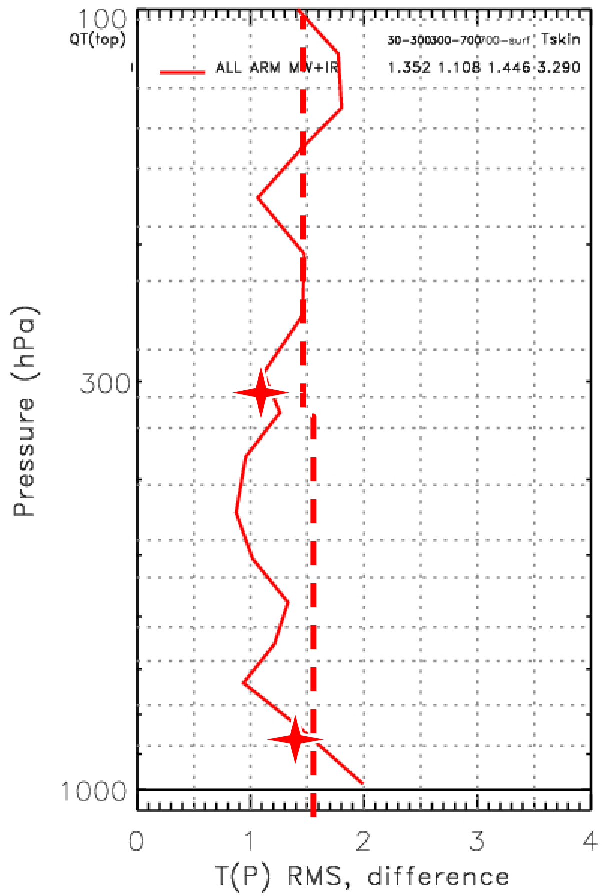
RAOB Site	Lat (deg)	Lon (deg)
ARM-SGP	36.6	-97.5
ARM-NSA	71.3	-156.6
ARM-TWP	2.06	147.43

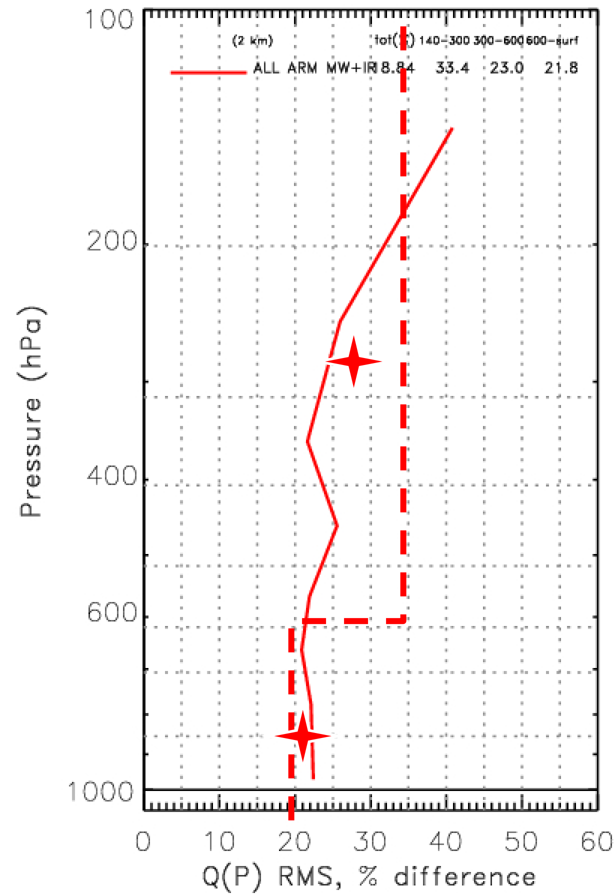
S-NPP CrIMSS EDR ICV Dedicated RAOB Sites (Year 1)



NUCAPS MW+IR

RMS Statistics vs ARM TWP, SGP, NSA Dedicated RAOBs

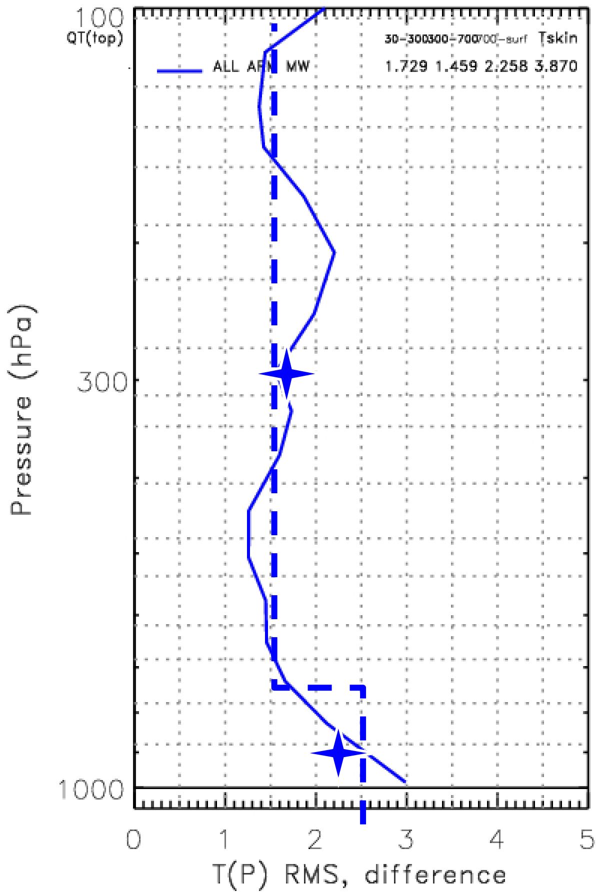


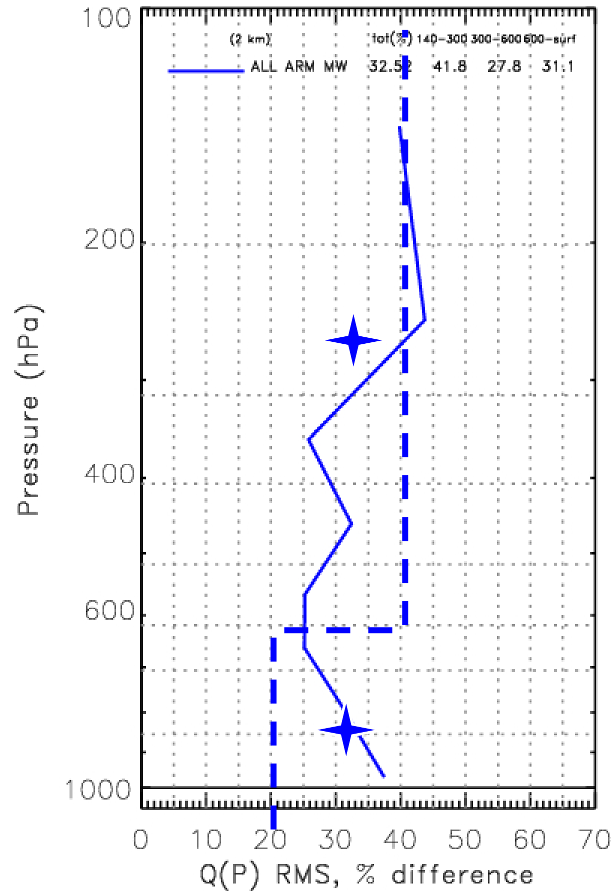


SUMMARY ON MW+IR RESULTS vs JPSS L1RD REQUIREMENTS					
MW+IR TEMPERATURE	RESULTS	JPSS L1RD	MW+IR WATER VAPOR	RESULTS	JPSS L1RD
30 – 300mb	1.35K	1.5K	100 - 600mb	28.2%	35%
300mb - SURF	1.25K	1.6K	600mb -SURF	21.8%	20%

NUCAPS MW Only

RMS Statistics vs ARM TWP, SGP, NSA Dedicated RAOBs





SUMMARY ON MW-ONLY RESULTS vs JPSS L1RD REQUIREMENTS					
MW-ONLY TEMPERATURE	RESULTS	JPSS L1RD	MW-ONLY WATER VAPOR	RESULTS	JPSS L1RD
30 – 700mb	1.59K	1.5K	100 - 600mb	34.8%	40%
700mb - SURF	2.25K	2.5K	600mb -SURF	31.1%	20%

Summary on global validation vs ARM dedicated RAOBs

green = passed yellow = close red = failed

SUMMARY ON MW+IR RESULTS vs JPSS L1RD REQUIREMENTS					
MW+IR TEMPERATURE	RESULTS	JPSS L1RD	MW+IR WATER VAPOR	RESULTS	JPSS L1RD
30 – 300mb	1.35K	1.5K	100 - 600mb	28.2%	35%
300mb - SURF	1.25K	1.6K	600mb -SURF	21.8%	20%

SUMMARY ON MW-ONLY RESULTS vs JPSS L1RD REQUIREMENTS					
MW-ONLY TEMPERATURE	RESULTS	JPSS L1RD	MW-ONLY WATER VAPOR	RESULTS	JPSS L1RD
30 – 700mb	1.59K	1.5K	100 - 600mb	34.8%	40%
700mb - SURF	2.25K	2.5K	600mb -SURF	31.1%	20%

• **The NUCAPS system meets requirements globally** except for water vapor MW-only (31.1% vs 20%) in the layer 600mb – surface and the water vapor MW+IR (21.8% vs 20%) in the layer 600mb - surface .

•**Possible issues are:**

- •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)
- •Uncertainty in the retrievals: we are aware that there is a need for updating the look up tables and a possible bug in the MW-only retrieval module but just did not have enough time to fix it (ongoing NUCAPS improvement activity)

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

Evaluation of the effect of required algorithm inputs (1)

- Required Algorithm Inputs
  - Primary Sensor Data: CrIS, ATMS
  - Ancillary Data: GFS surface pressure
  - Upstream algorithms: UV O_3
  - LUTs:

ATMS bias correction

CrIS bias correction

Regression Coefficients for the first guess

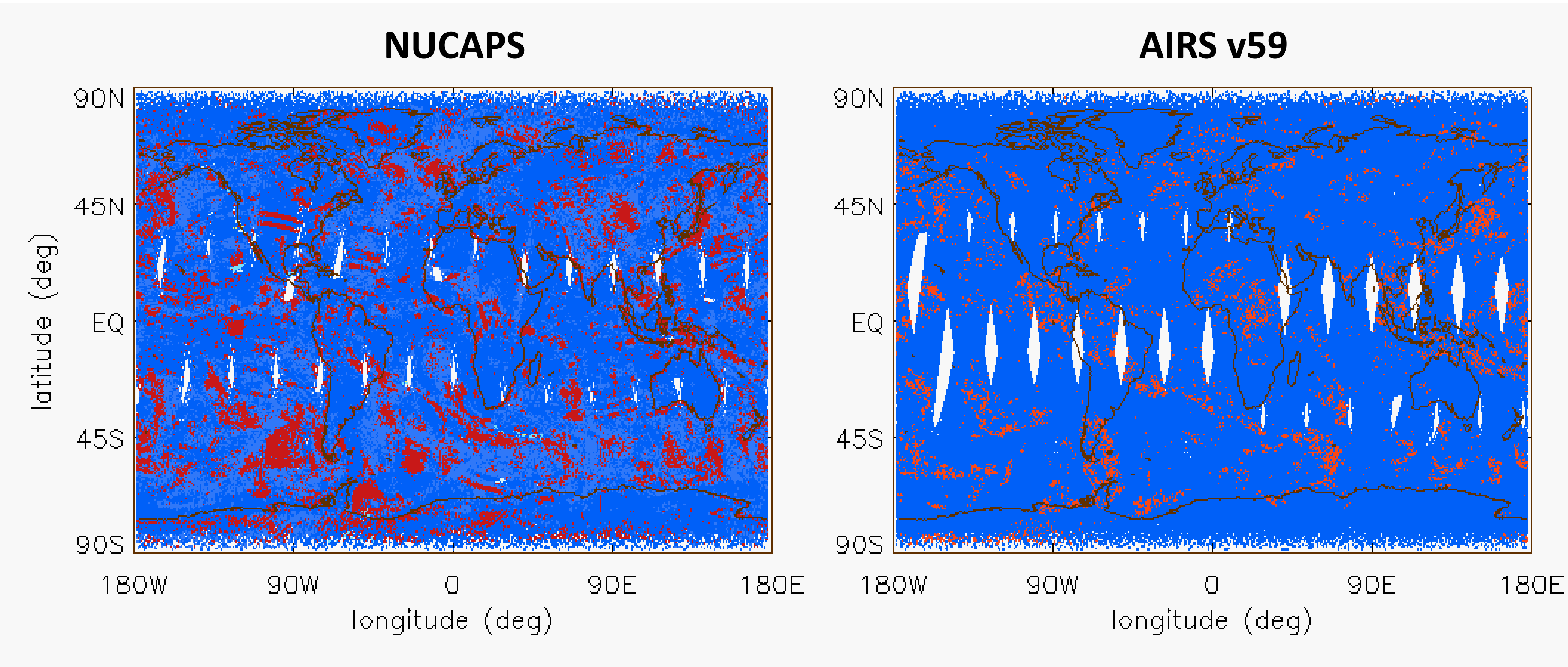
tuning parameters

CRTM cloud and aerosol optical properties, surface emissivity, transmittance coefficients

Evaluation of the effect of required algorithm inputs (2)

- Evaluation of the effect of required algorithm inputs
  - Study / test cases
  1. CrIS/ATMS, IASI/AMSU/MHS
  2. ECMWF global analysis and 6h forecast
  3. Conventional radiosondes
  4. Trace gases from various sources
  5. GFS surface pressure
  - Results
  1. CrIS/ATMS
  2. GFS global analysis
  3. Dedicated radiosondes
  4. Aerosols and Ocean Science Expeditions (AEROSE)
  5. ECMWF global analysis

NUCAPS vs AIRS v59 acceptance yield
(blue = accepted red = rejected)



- **NUCAPS global acceptance yield is ~60% (focus day 2012/05/15)**
- **AIRS v59 global acceptance yield is ~75% (focus day 2012/05/15)**
- **Ongoing activity: QA optimization reflecting instrument properties**

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	
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	NUCAPS MW only has tougher requirement than MiRS. MiRS 3 K (sea clear), 5.5 K (land)
700 to 300 mb	1.5 K per km layer	1.88 K per km layer	MiRS 2 K (sea clear), 2.5 K (land)
300 to 30 mb	1.5 K per 3 km layer	1.88 K per 3 km layer	MiRS 2 K
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	

IR + MW

MW only

MiRS Precision L1RD p44

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%	
600 to 300 mb	Greater of 35% or 0.1 g/kg	23.3%	
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%	MiRS 36% (sea clear), 53% (land)*
600 to 400 mb	Greater of 40% or 0.1 g/kg	32.2%	MiRS 63% (sea ocean), 61% (land)*
400 to 100 mb	Greater of 40% or 0.1 g/kg	32.2%	MiRS 67% (see clear), 67% (land)*

IR + MW

MW only

* MiRS uncertainty is calculated from its precision and accuracy (see L1RD p42).

Documentation

- The following documents will be updated and provided to the EDR Review Board before AERB approval:
  - Current or updated ATBD

  YES

  - Current or updated OAD

  No, different documentation requirements specifically for SPSRB to support OSPO

  - README file for CLASS

  http://gis.ncdc.noaa.gov/geoportal/catalog/search/resource/details.page?id=gov.noaa.ncdc:C00868

  http://www.ospo.noaa.gov/Products/atmosphere/soundings/nucaps/index.html

  - Product User's Guide (Recommended)

  NUCAPS External User Manual (Jan. 2013)

Identification of Processing Environment

- IDPS or NDE build (version) number and effective date
  - NDE, version 1. NOAA CLASS publicly released since April 8, 2014.
- Algorithm version
  - NUCAPS Version 1
- Version of LUTs used
  - NUCAPS LUT version 1
- Version of PCTs used
  - NA
- Description of environment used to achieve validated stage 1
  - IBM at NOAA/OSPO
  - Linux at NOAA/STAR

Users & User Feedback

- **User list**
  - NOAA CLASS
  - AWIPS-II
  - FNMOC – Fleet Numerical Meteorology and Oceanography Center
  - Nowcasting
  - Direct broadcast
  - Support SDR data monitoring, retrieval products and SDR have the same time, the same location, and the same footprint.
  - Timely temperature and moisture profiles for the warning of severe weather (Mark DeMaria) , e.g. atmospheric stability condition for tropical storm. For tornado warning, retrieval products of higher spatial resolution (~ 10 km) is needed.
  - Basic and applied geophysical science research/investigation
    - E.g., over 590 AIRS peer reviewed publications have appeared in the literature since launch of Aqua (*Pagano et al.,* 2013)

- **Feedback from users**
  - Two meetings with forecasters, color-coded flags to be done for AWIPS II

- **Downstream product list**

  No

- **Reports from downstream product teams on the dependencies and impacts**

  No

Support CrIS SDR

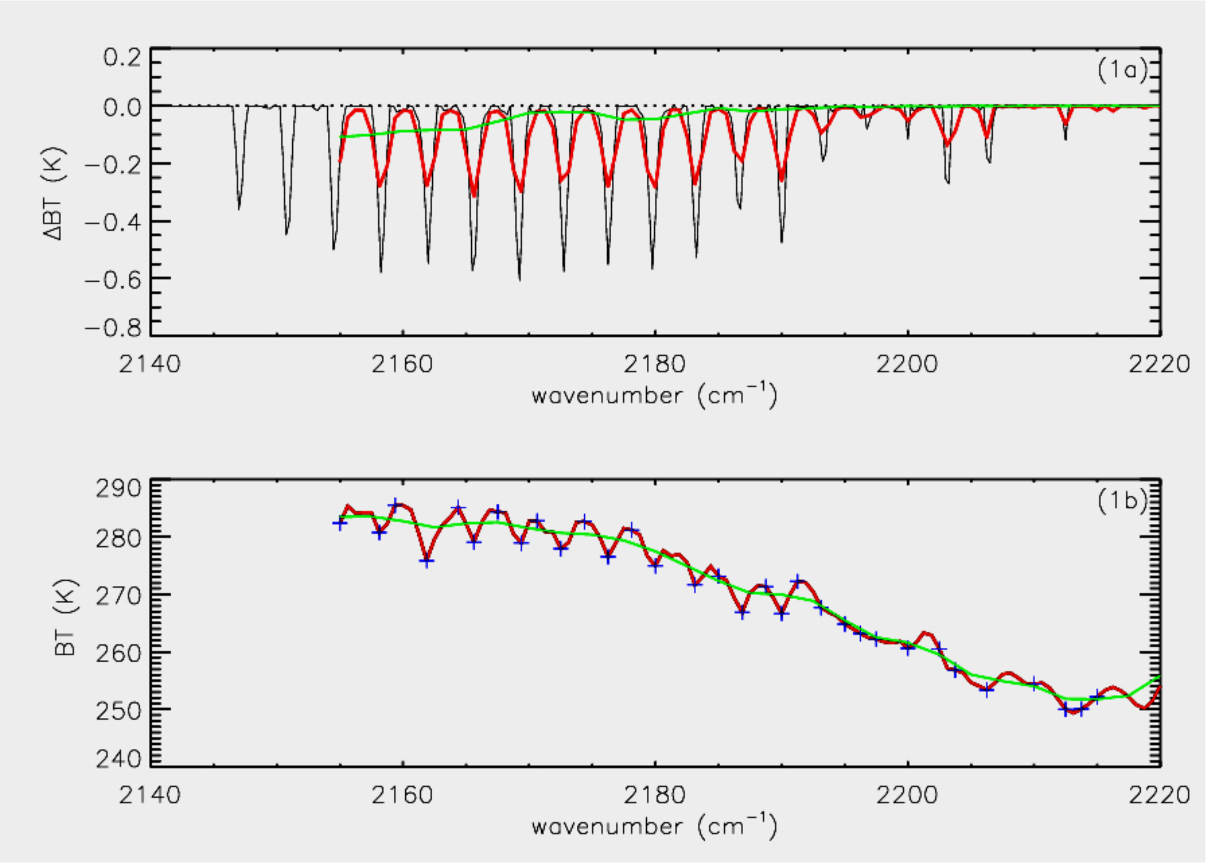
- Full Spectral Requirement
  - CrIS full spectral data are required for trace gas retrievals.

- 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

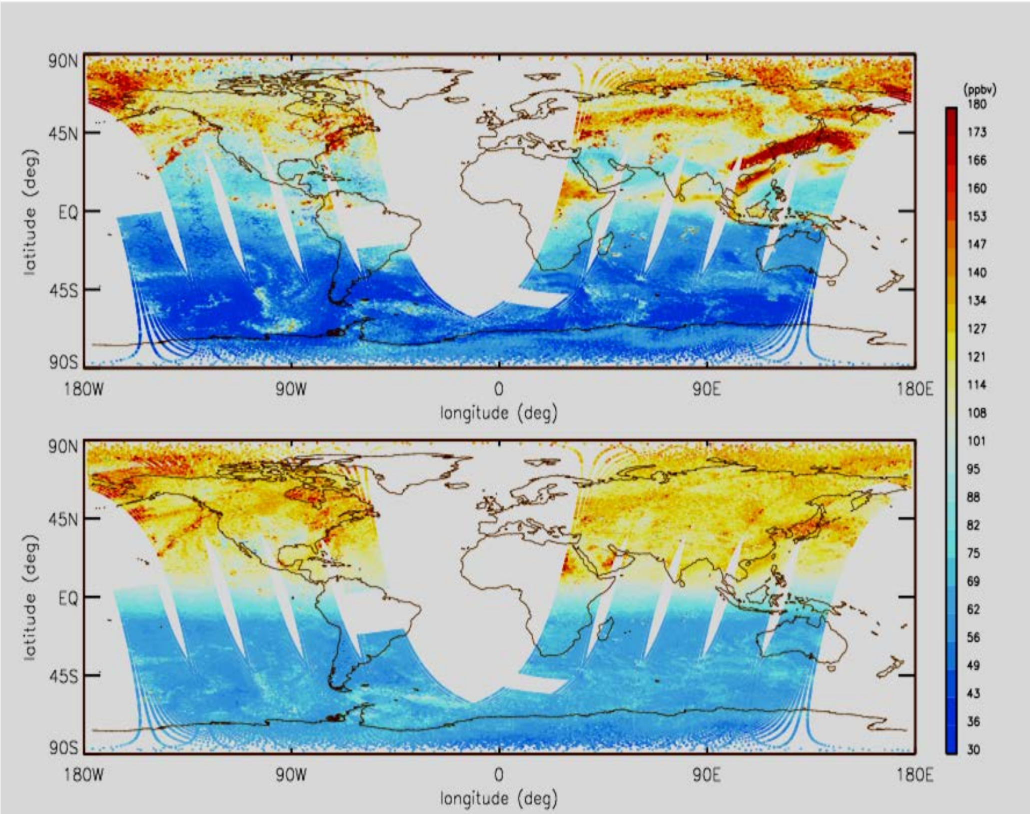


Ref: ***Gambacorta et al., IEEE Geoph. And Rem. Sen. Letters, 2014.***

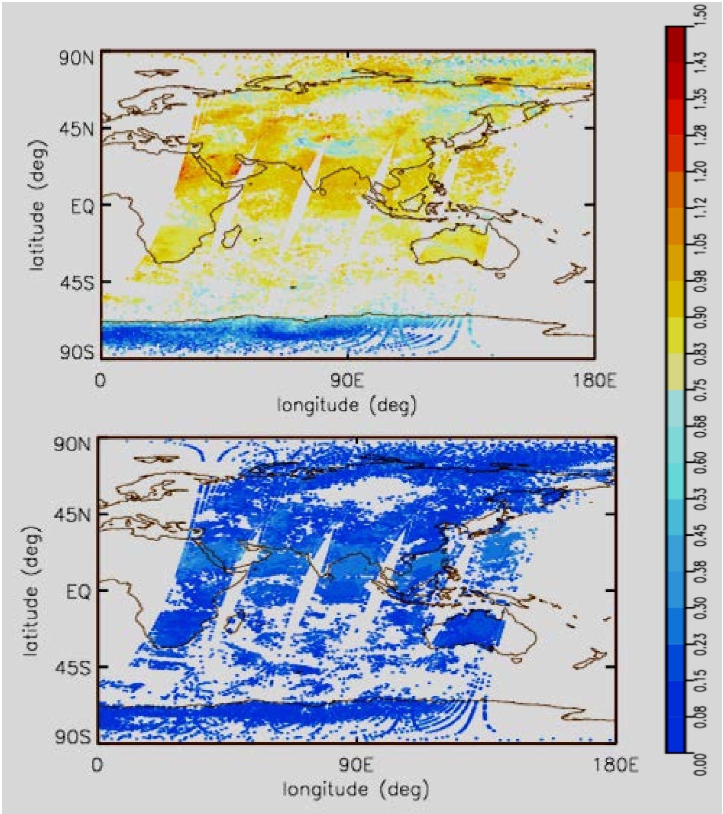
- Only when switched to high spectral resolution, CrIS spectrum (red curve, bottom part) shows the distinctive signature of CO absorption (red and black curve, top figure).
- Blue cross symbols: CO high resolution channel selection.

CO high resolution (top) vs operational low resolution results (bottom)

NUCAPS CO retrieval (~450mb)



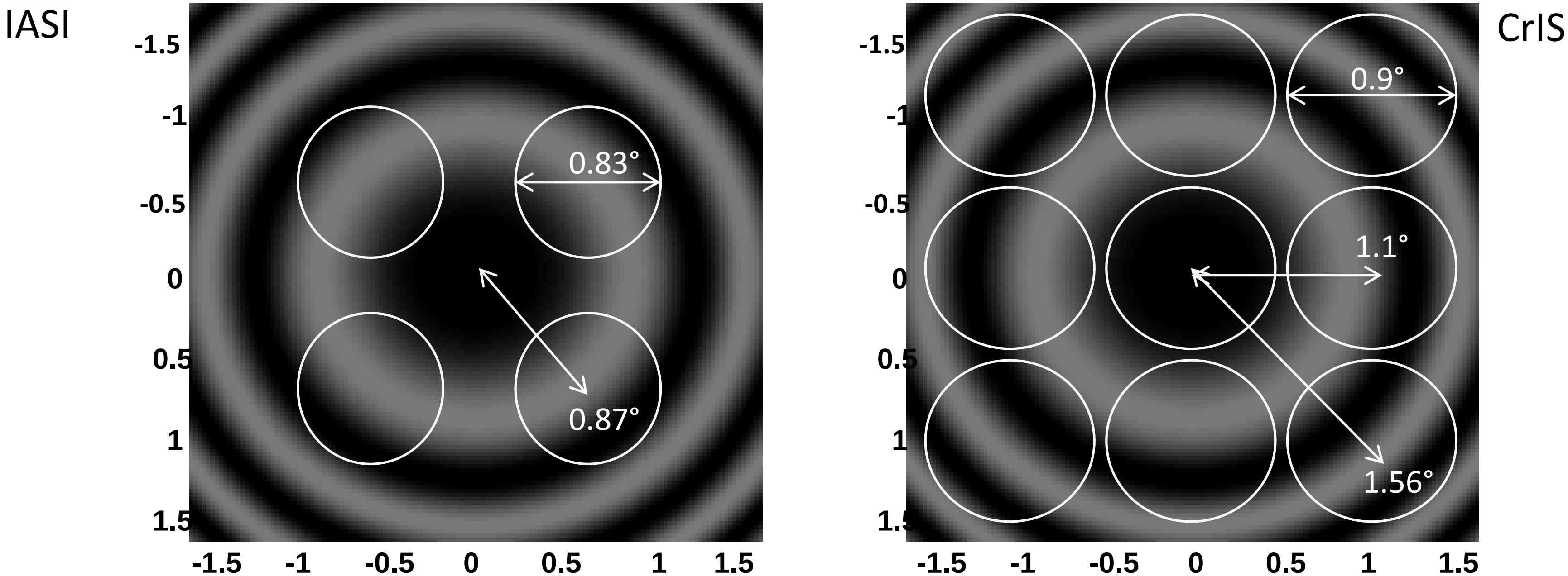
CO DOF



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

- The higher information content enables a larger departure from the a priori, hence the increased spatial variability observed in the high spectral resolution map (top left) compared to the low resolution (bottom left).
- A demonstration experiment in support for the need of high spectral resolution CrIS measurements.
- NUCAPS modular architecture has proven that there is no risk of disruption to the operational processing upon switching to high spectral sampling.

IASI vs CrIS FOV geometry



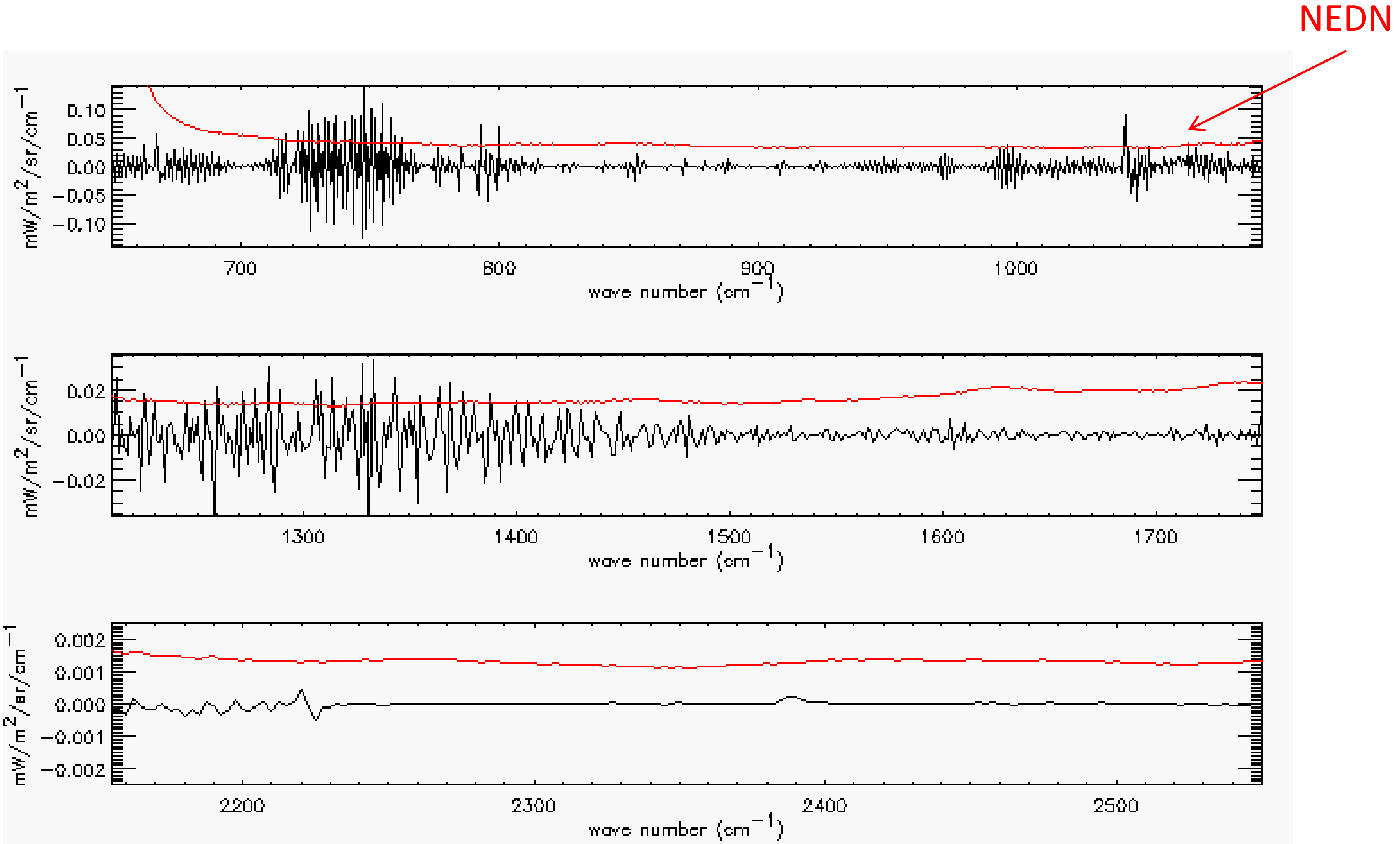
Gambacorta et al., Proc. ATOVS Meeting, 2014.

•Applying IASI's δα results to CrIS (assuming surface inhomogeneity and interference ringing are close enough between the two instruments):

- •CrIS Side Cube (α=1.1°=0.019rad): δν/ν ~ αδα = **1.91e-6**
- •CrIS Corner Cube (α=1.56°=0.027rad): δν/ν ~ αδα = **2.72e-6**

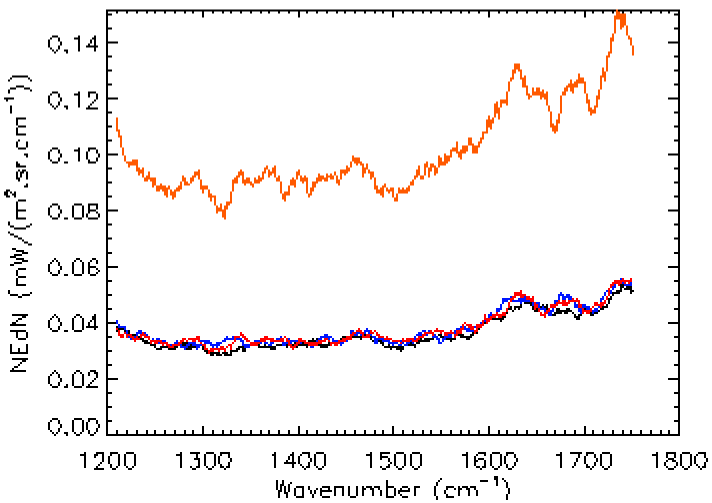
< 3ppm

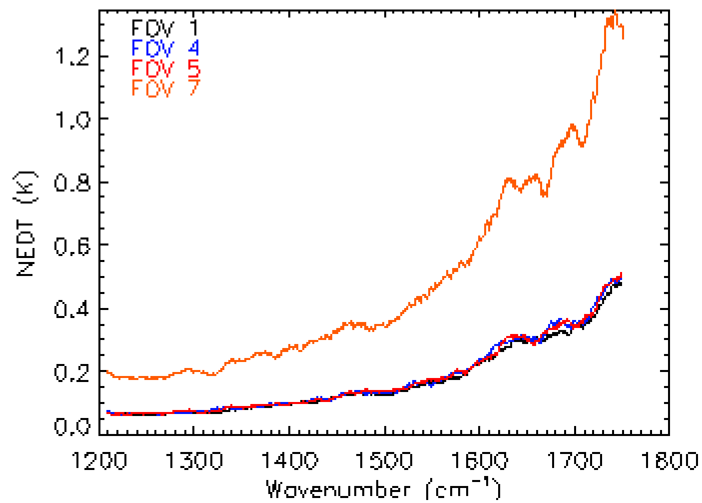
Radiance error induced by ILS shift
- corner cube -



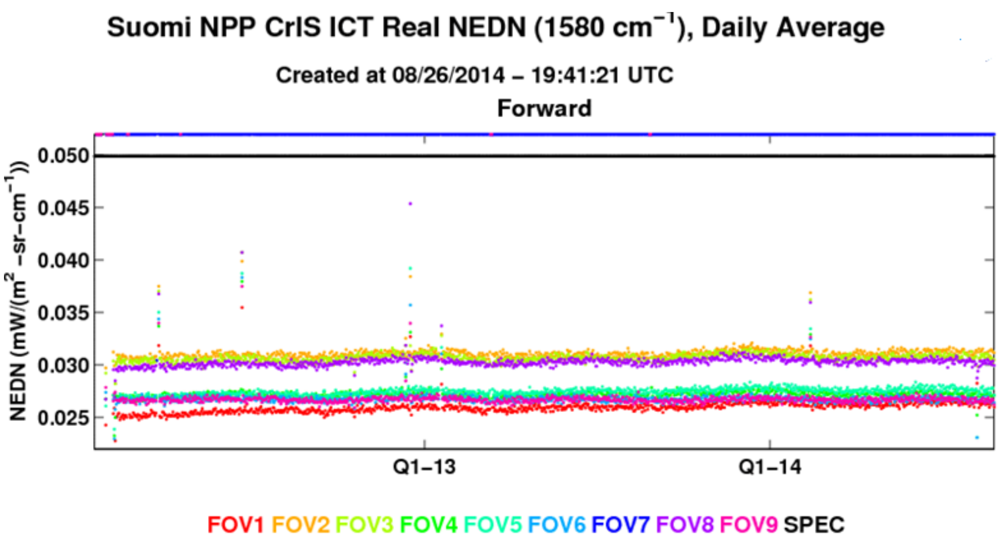
Gambacorta et al., Proc. ATOVS Meeting, 2014.

Discard FOV 7 in CrIS full spectral data

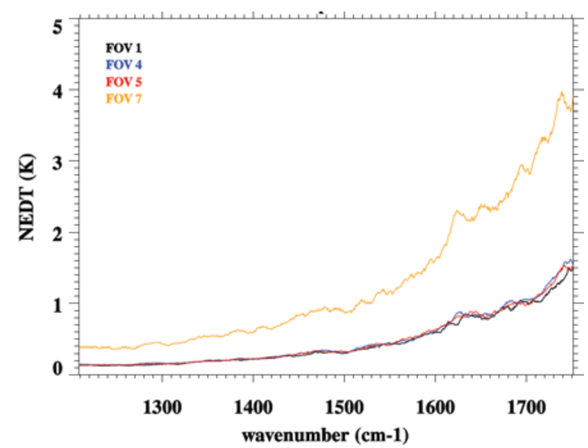




Tref=250K



Tref=220K



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.
  - The Sounding Team therefore recommends that the NUCAPS AVTP and AVMP achieve the maturity of the Stage 1 validation.
- Caveats:
  - Color-code quality flag needed for forecasters.
  - MW retrieval algorithm needs to be further investigated.
  - Updates IR and MW surface emissivity tables

Path Forward (1)

- Planned further improvements

1) Make quality flag simple
2) Improve MW only performance
3) Update IR+MW surface emissivity tables
4) Standardize retrieval code
5) Improve trace gas retrieval algorithm
6) Investigate the impact by using radiance and NEDN directly

Path Forward (2)

- Planned Cal/Val activities / milestones

  - NUCAPS Phase 3 Algorithm Readiness Review – Sep 2014
  - NUCAPS Phase 3 DAP Delivery – Sep 2014
  - Improvement of MW only Retrieval – Nov. 2014
  - MW+IR QC Flag –- Nov. 2014
  - CrIS OLR Algorithm Tuning, Validation, and Verification – Nov. 2014
  - SPSRB Phase 3 briefing – Nov. 2014
  - NUCAPS Phase 3 Operations Commence – Nov. 2014
  - Unified Hyperspectral Sensors' Sounding System – Dec. 2014
  - CrIS full spectral channel selection for NWP and NUCAPS – Mar. 2015
  - CrIS Full Spectral Data in Sounding System – Sep. 2015
  - Trace Gas (CO, CO_2, and CH_4) Algorithm Tuning, Validation, and Verification –June 2016
  - AIRS, IASI, CrIS Full Data Record Reprocessing for Science Application – Dec. 2016.

BACK UP SLIDES

Dedicated Soundings

- Soundings for specific weather events
  - High spatial resolution (single FOV ~ 12 km at nadir):
    - needed for monitoring atmospheric stability;
    - needed for hurricane studies;
    - high accuracy needed under cloudy conditions;
  - Integration of satellite product information:
    - Cloud EDRs
    - UV total ozone and stratospheric ozone profile
    - Surface temperatures
    - Aerosol EDRs
  - Precise radiative transfer calculations for the given small area

NUCAPS-AWIPS meeting

1	Name	Organization and address
2	bill sjoberg	JPSS Office, Greenbelt, MD
3	bonnie reed	JPSS Ground System Division
4	brian motta	NWS/Forecast Decision Training
5	anthony mostek	NWS/FORECAST DECISION TRAINING BRANCH
6	dan nietfeld	NWS/CR/WFO/VALLEY NE
7	antonia gambacorta	NESDIS/STAR
8	thomas king	NESDIS/STAR
9	murty divakarla	NESDIS/STAR
10	lihang zhou	NESDIS/STAR JPSS manager
11	Quanhua (Mark) Liu	NESDIS/STAR
12	scottl Lindstrom	Space Science and Engineering Center
13	james heil	NWS/OBSERVING SERVICES DIVISION
14	walter wolf	NESDIS/STAR
15	nick nalli	NESDIS/STAR
16	tony reale	NESDIS/STAR
17	bill line	NWS/SCIENCE SUPPORT BRANCH
18	kevin schrab	NWS, Observing Services Division
19	Bomin Sun	NOAA/STAR
20	chris barnet	TECHNOLOGY, PLANNING, AND INTEGRATION

NUCAPS Products (1)

Mean CO_2
Surface Pressure
Skin Temperature
MIT Skin Temperature
First Guess Skin Temperature
Microwave Surface Class
Microwave Surface Emissivity
Number of Cloud Layers
Retrieval Quality Flag
Cloud Top Pressure
Cloud Top Fraction
Pressure (at 100 levels)
Effective Pressure (at 100 levels)
Temperature (at 100 levels)
MIT Temperature (at 100 levels)
First Guess Temperature (at 100 levels)
H_2O layer column density (at 100 levels)
H_2O mixing ratio (at 100 levels)
First Guess H_2O layer column density (at 100 levels)
First Guess H_2O mixing ratio (at 100 levels)
MIT H_2O layer column density (at 100 levels)
MIT H_2O mixing ratio (at 100 levels)

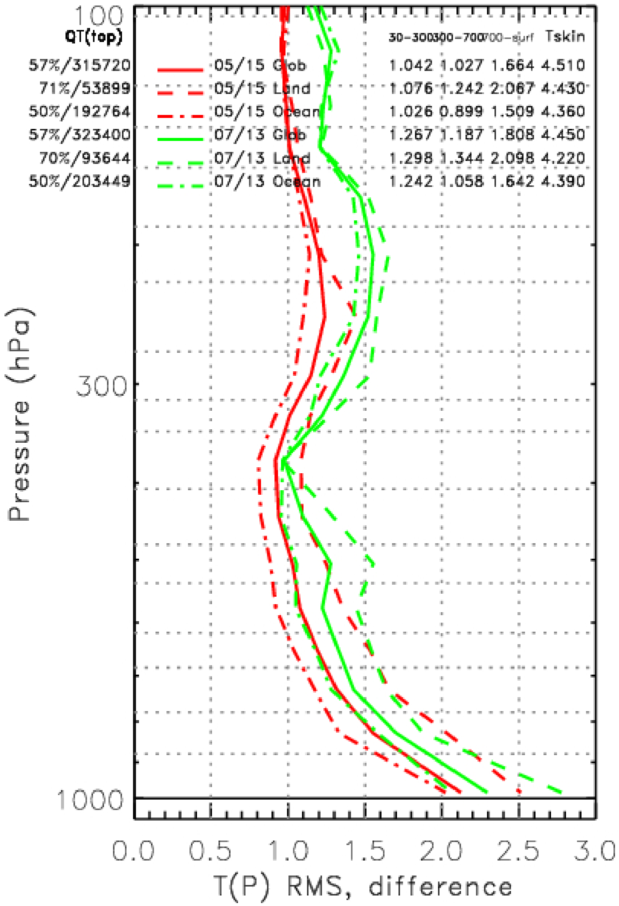
NUCAPS Products (2)

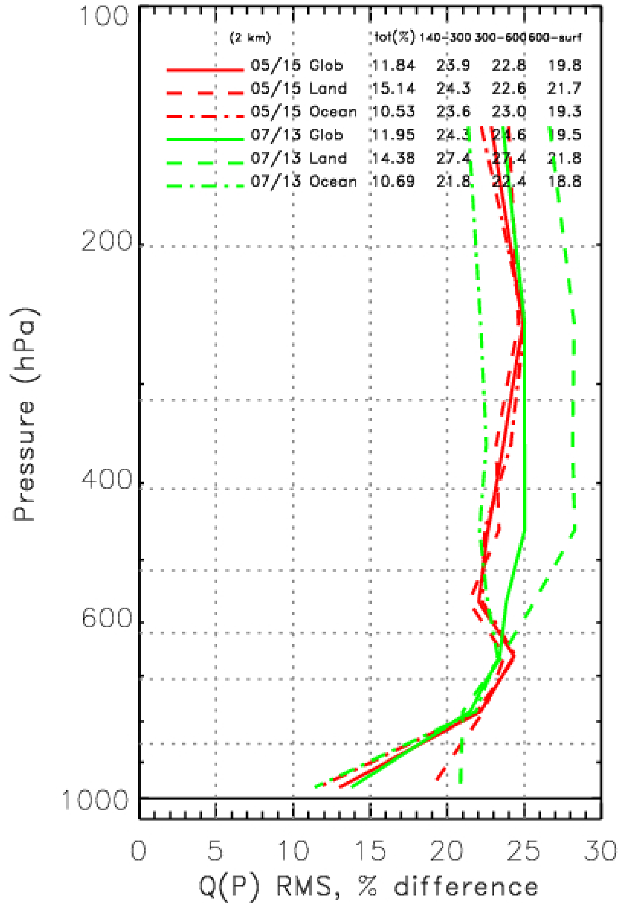
O3 layer column density (at 100 levels)
O3 mixing ratio (at 100 levels)
First Guess O3 layer column density (at 100 levels)
First Guess O3 mixing ratio (at 100 levels)
Liquid H2O layer column density (at 100 levels)
Liquid H2O mixing ratio (at 100 levels)
Ice/liquid flag (at 100 levels)
CH4 layer column density (at 100 levels)
CH4 mixing ratio (at 100 levels)
CO2 mixing ratio (at 100 levels)
HNO3 layer column density (at 100 levels)
HNO3 mixing ratio (at 100 levels)
N2O layer column density (at 100 levels)
N2O mixing ratio (at 100 levels)
SO2 layer column density (at 100 levels)
SO2 mixing ratio (at 100 levels)
Microwave emissivity
MIT microwave emissivity
Infrared emissivity
MIT infrared emissivity
Infrared surface emissivity

NUCAPS Products (3)

First Guess infrared surface emissivity
Infrared surface reflectance
Atmospheric Stability
Cloud infrared emissivity
Cloud reflectivity
Stability

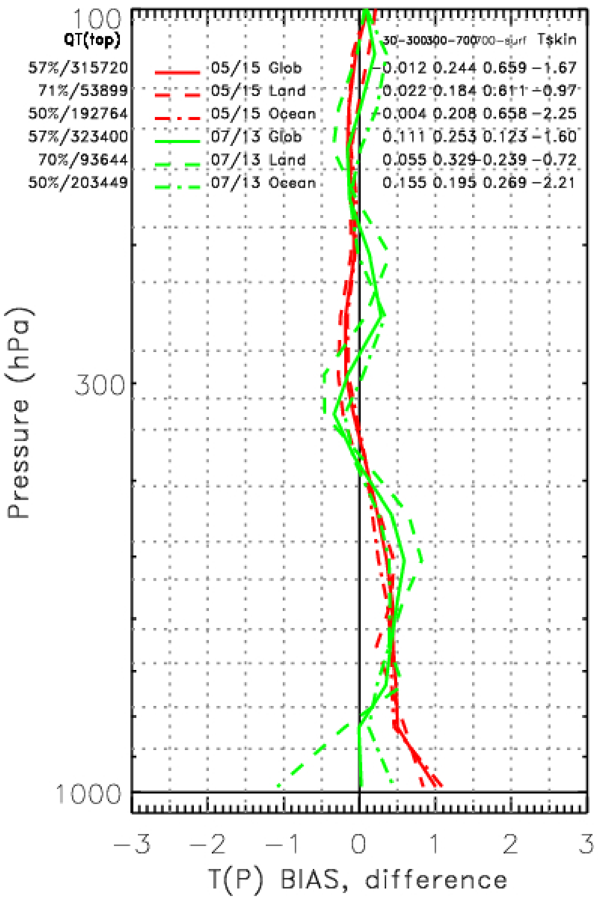
05/15 vs 07/13 focus day RMS statistics

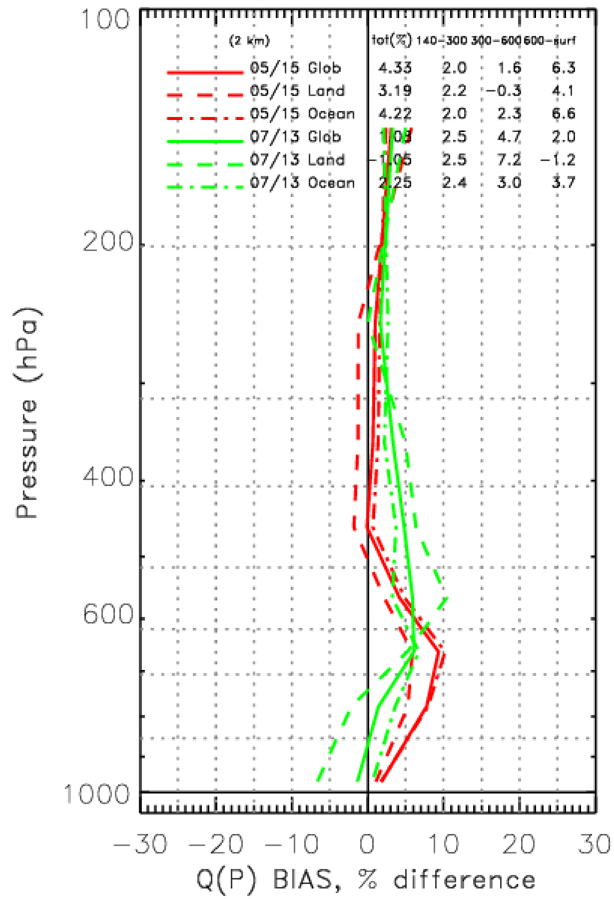




Significance: NUCAPS performance is stable and robust over multiple focus days, including those not used for tuning and regression training :05/15 focus day (red curves) was used for training, 07/13 (green curves) was not.

05/15 vs 07/13 focus day BIAS statistics





Significance: NUCAPS performance is stable and robust over multiple focus days, including those not used for tuning and regression training :05/15 focus day was used for training, 07/13 was not.