Validation of CrIS Dual Regression Sounding Products during the Airborne Suomi-NPP Cal/Val Campaign

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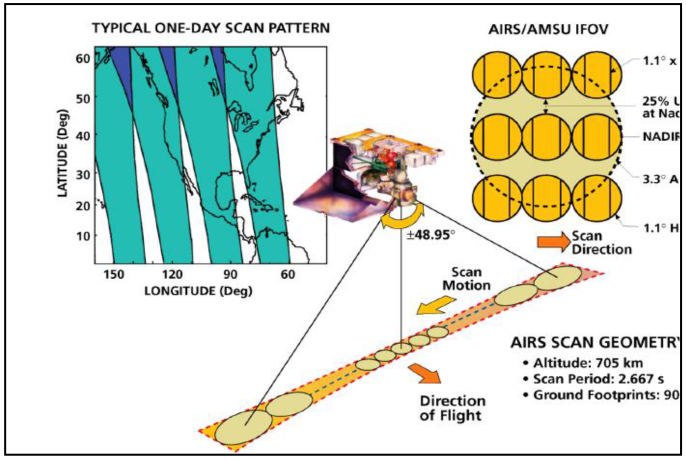
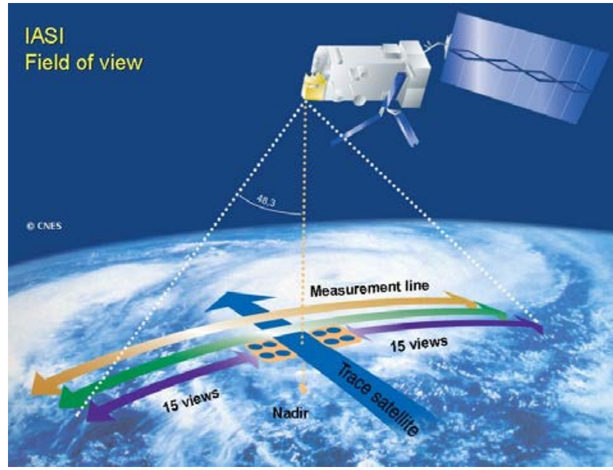
The ER-2 Aircraft Interferometers

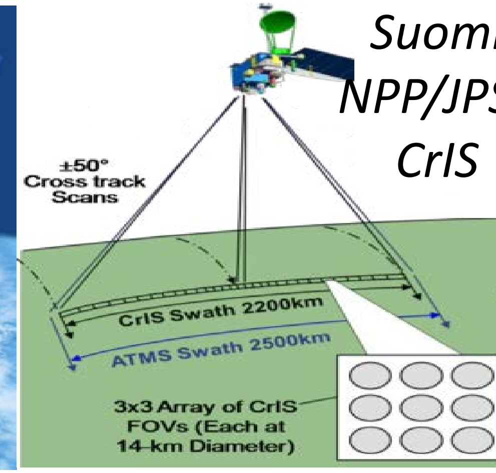
- **NAST-I/SHIS-I** infrared Michelson interferometer
  (9000/4500 spectral channels)
  3.5 – 16 microns @ 0.25 /0.5cm^{-1}
- **Aircraft Accommodation**
  - NAST-I: ER-2 Super pod
  - SHIS: ER-2 Underbelly pod

Instrument	Spatial resolution	Spectral Resolution	Useful Spectral Range	Spatial Sampling
NAST-I	2.6 Km @ 20 Km	0.25 (cm^{-1})	600-2800 (cm^{-1})	~ Contiguous Cross-track scan
SHIS	2.0 Km @ 20 Km	0.50 (cm^{-1})	600-2800 (cm^{-1})	~ Contiguous Cross-track Scan

The Satellite Instruments



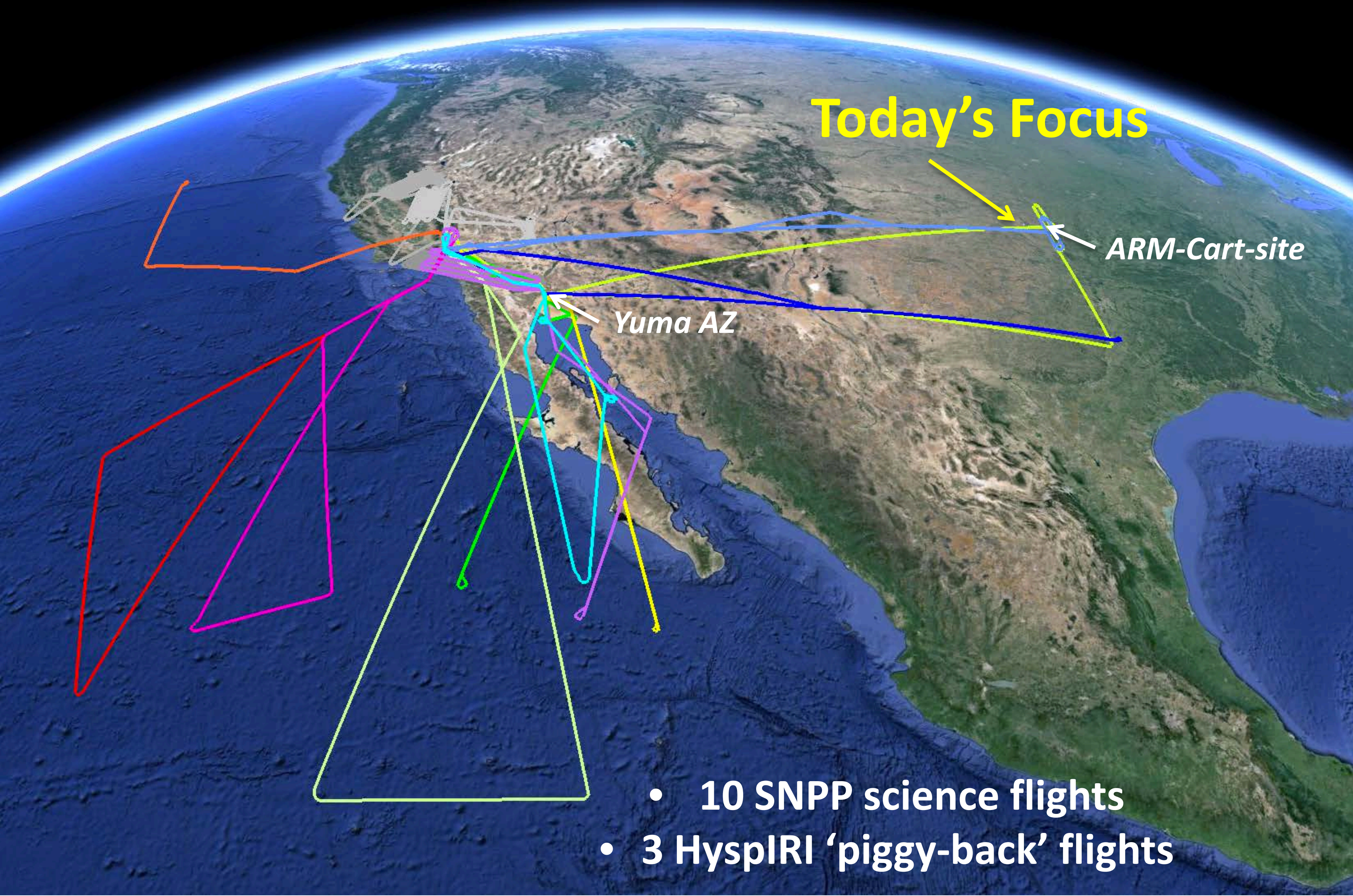




Suomi NPP/JPSS CrIS

Instrument	Spatial resolution	spectral res. (cm^{-1})	spectral rng. (cm^{-1})	spatial sampling
AIRS (2002 -)	3x3 13.5-km (50 km)	~1200 resolving power	645-2700	Contiguous Cross-track scan
IASI-A (2006 -) **IASI-B (2012 -)**	2x2 12.0-km (50 km)	0.25	645-2760	Contiguous Cross-track Scan
CrIS (2011 -)	3 x 3 13-km (50 km)	0.6	645-2700	Contiguous Cross-track

Suomi-NPP Cal/Val Flight Tracks



- 10 SNPP science flights
- 3 HyspIRI 'piggy-back' flights

The Dual Regression Retrieval Algorithm

Global Clear Soundings

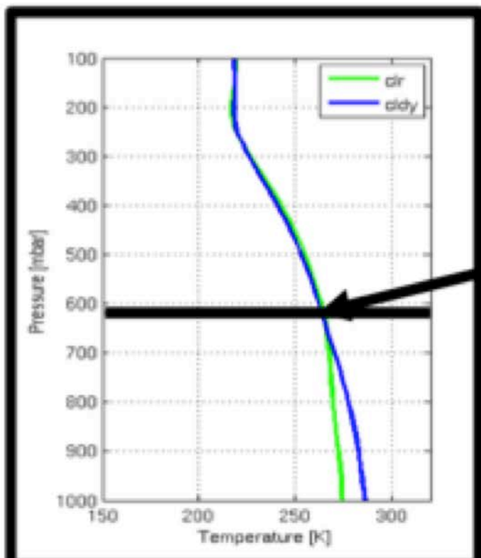
Radiances
(calculated with clear FM)

Clear trained EOF regression results

Global Cloudy Soundings

Radiances
(calculated with cloudy FM)
8 cloud height classes (100-900 hPa)

Cloud trained EOF regression results



Cloud Top Altitude
level where T(cloudy)>T(clear) for $p>p_{cld}$

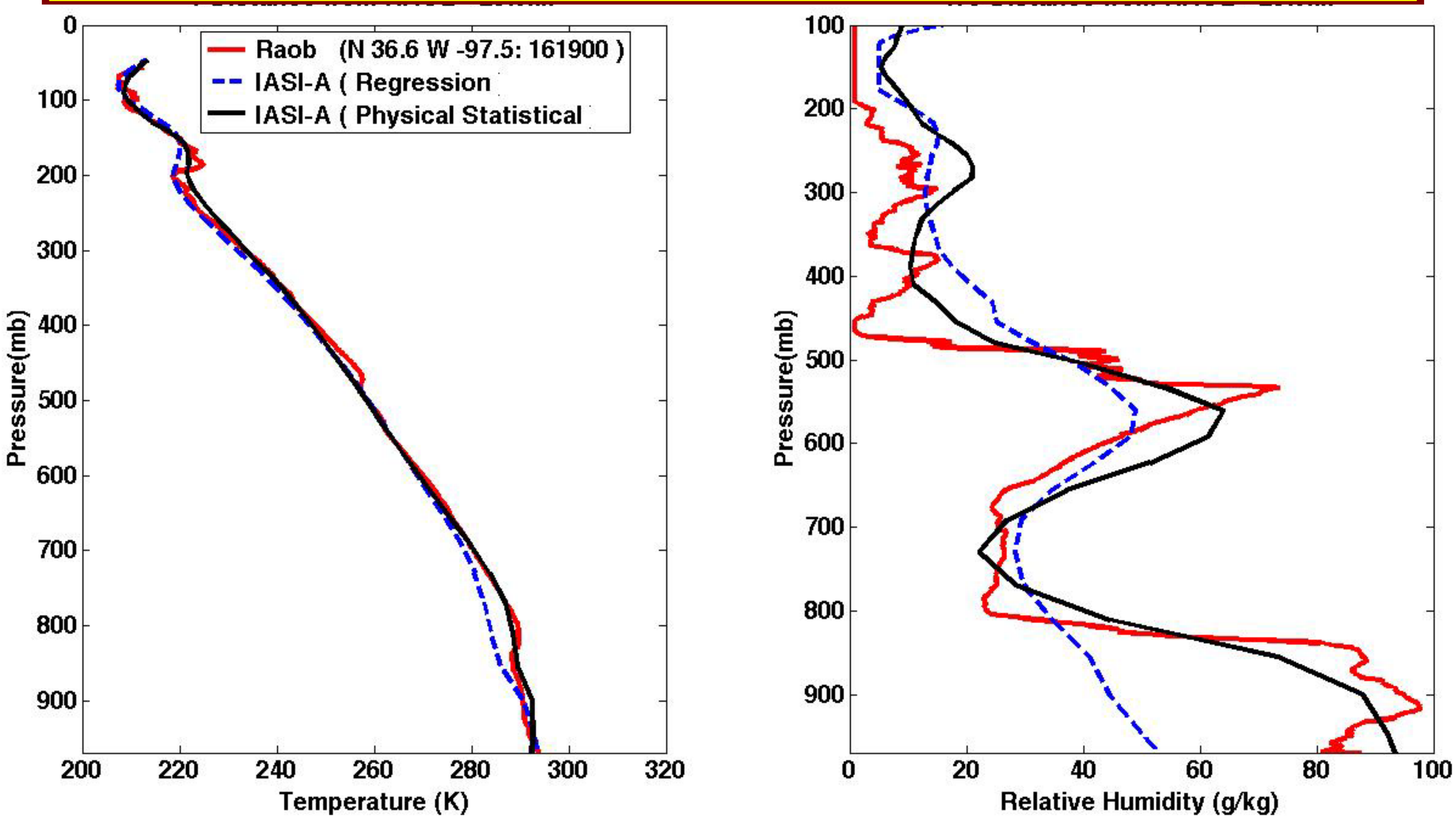
Final Profile
•clear-trained above,
•cloud-trained below cloud level

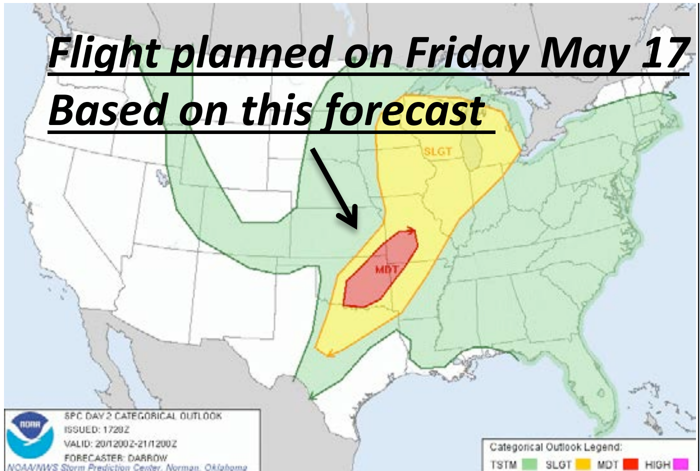
Physical Correction Using Forecast Model Profile

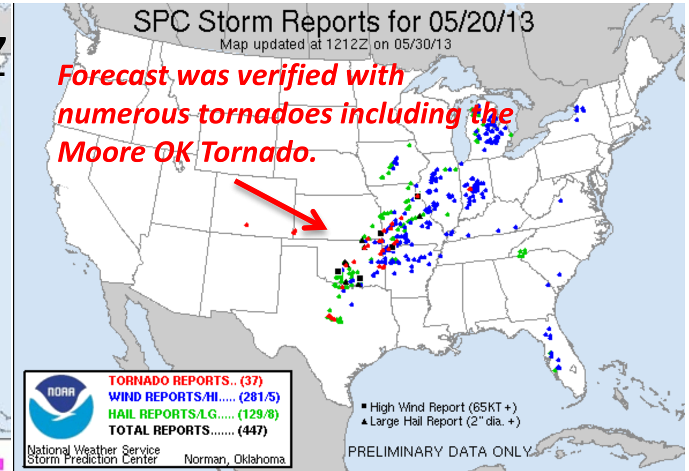
Problem: DR method uses a statistical training data set. Imperfect skill, due to lack of vertical resolution in radiances, leads to local statistical bias.

Solution: Calculate radiances from forecast profile (FP) and perform DR retrieval using simulated radiances. Retrieval Error = Physical Correction.

Physical Correction= FP – FP radiance Retrieval

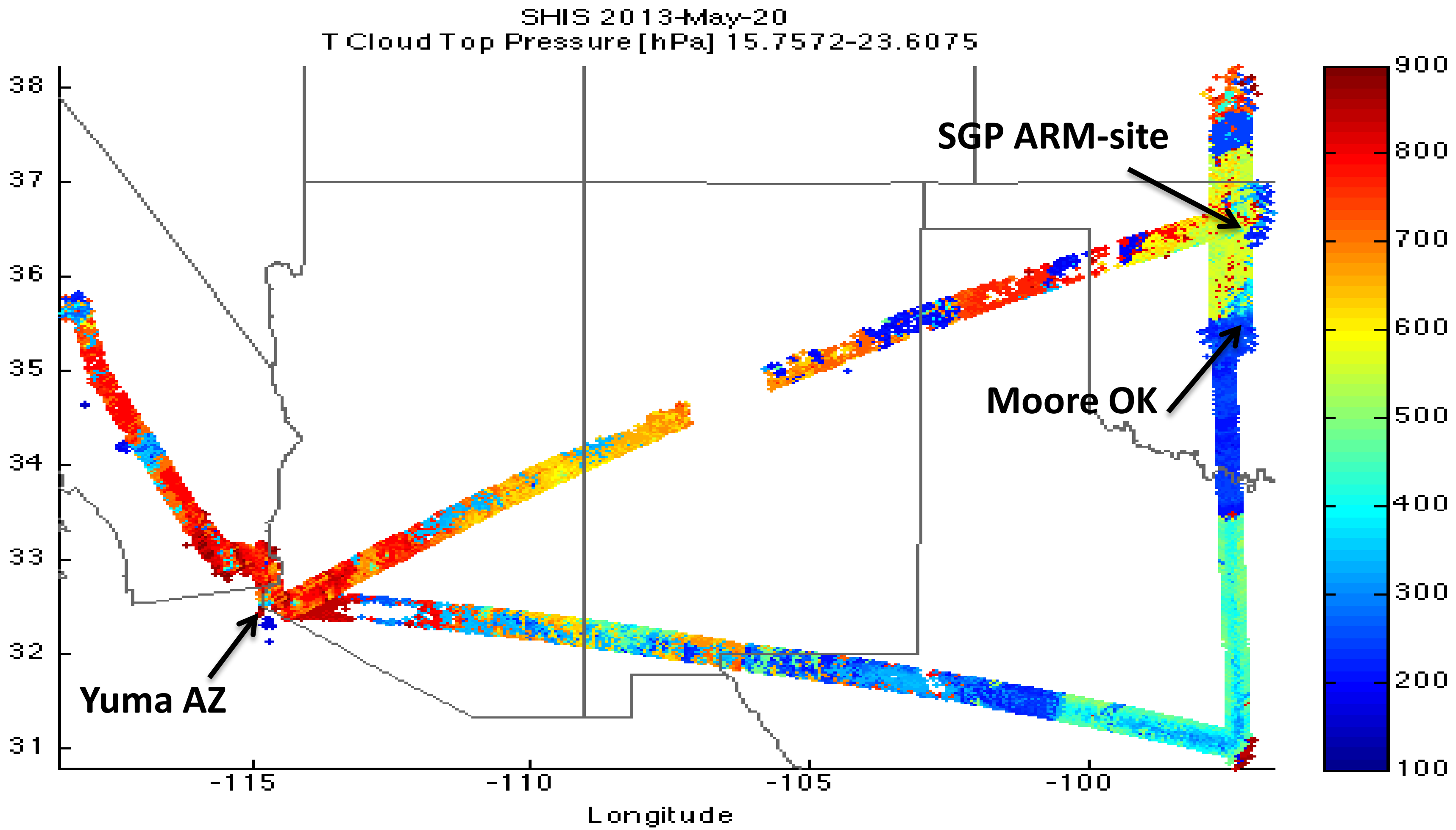




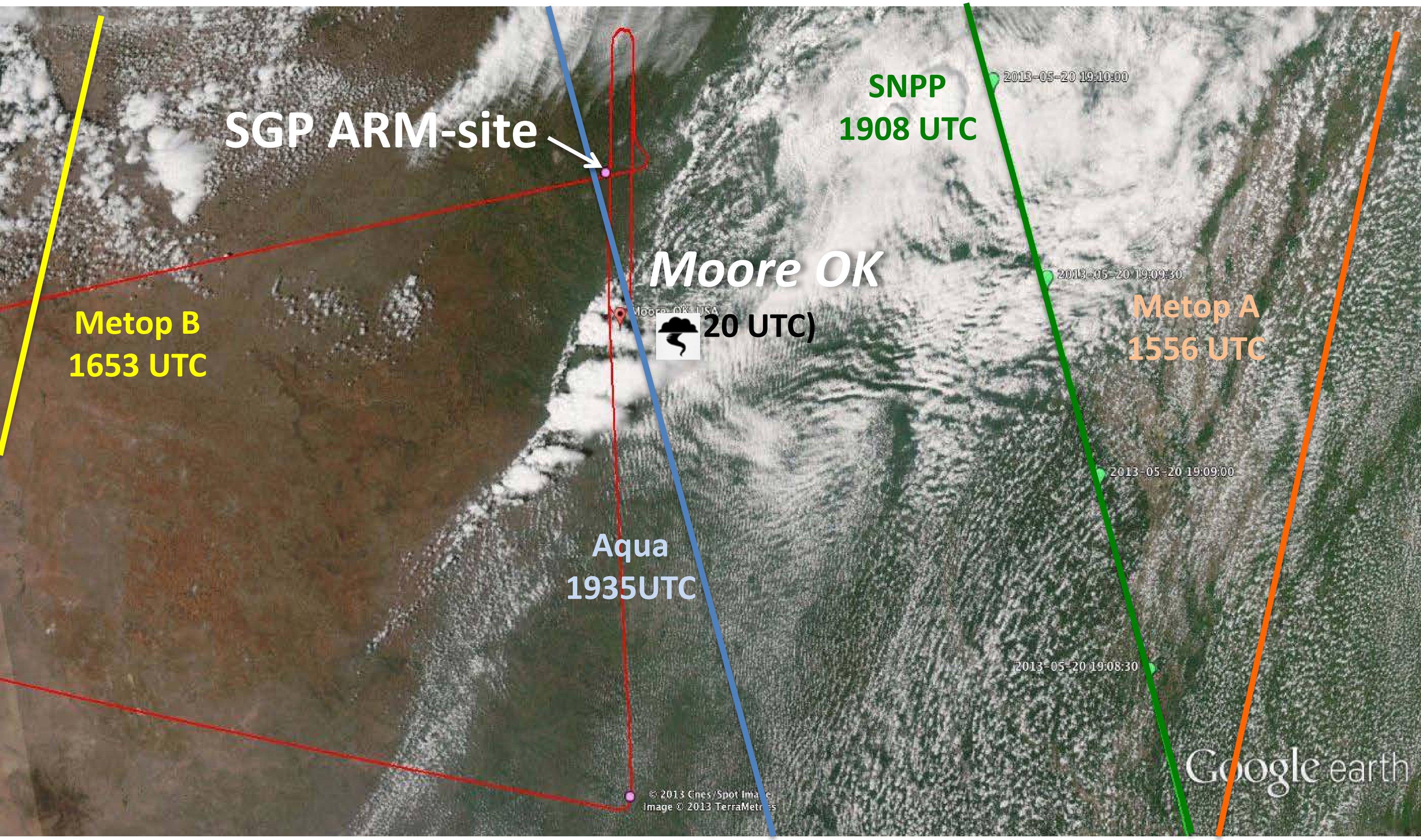


*The **2013 Moore tornado** was an EF5 Tornado that struck Moore, Oklahoma, and adjacent areas on the afternoon of May 20, 2013, with peak winds estimated at 210 miles per hour (340 km/h), killing 23 people (+2 indirectly) and injuring 377 others. The tornado touched down west of Moore at 2:56 PM CDT (19:56 UTC), staying on the ground for 39 minutes over a 17-mile (27 km) path, crossing through a heavily populated section of Moore. The tornado was 1.3 miles (2.1 km) wide at its peak.*

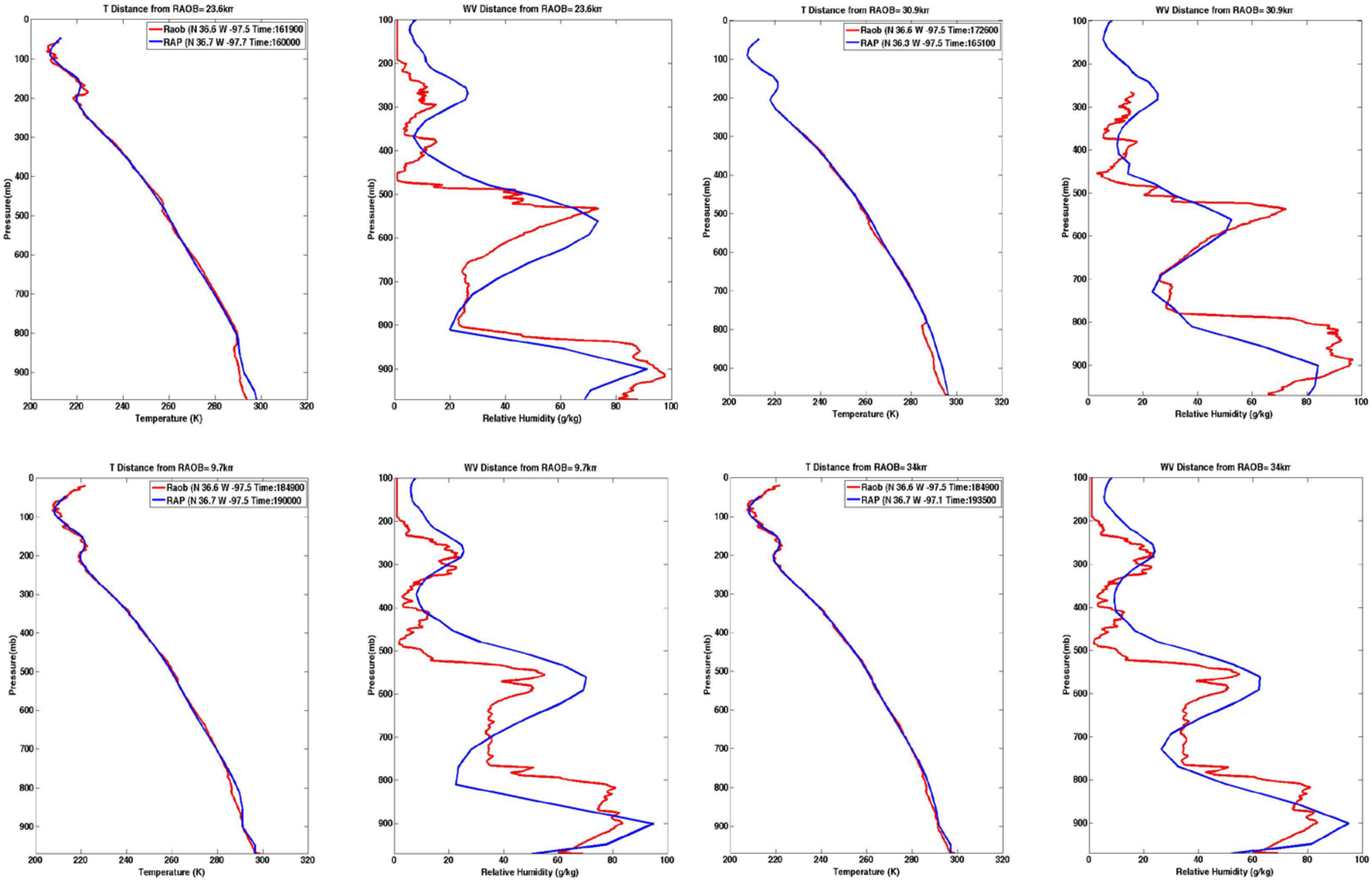
ER-2 Flight Track
Cloud Pressure Altitude



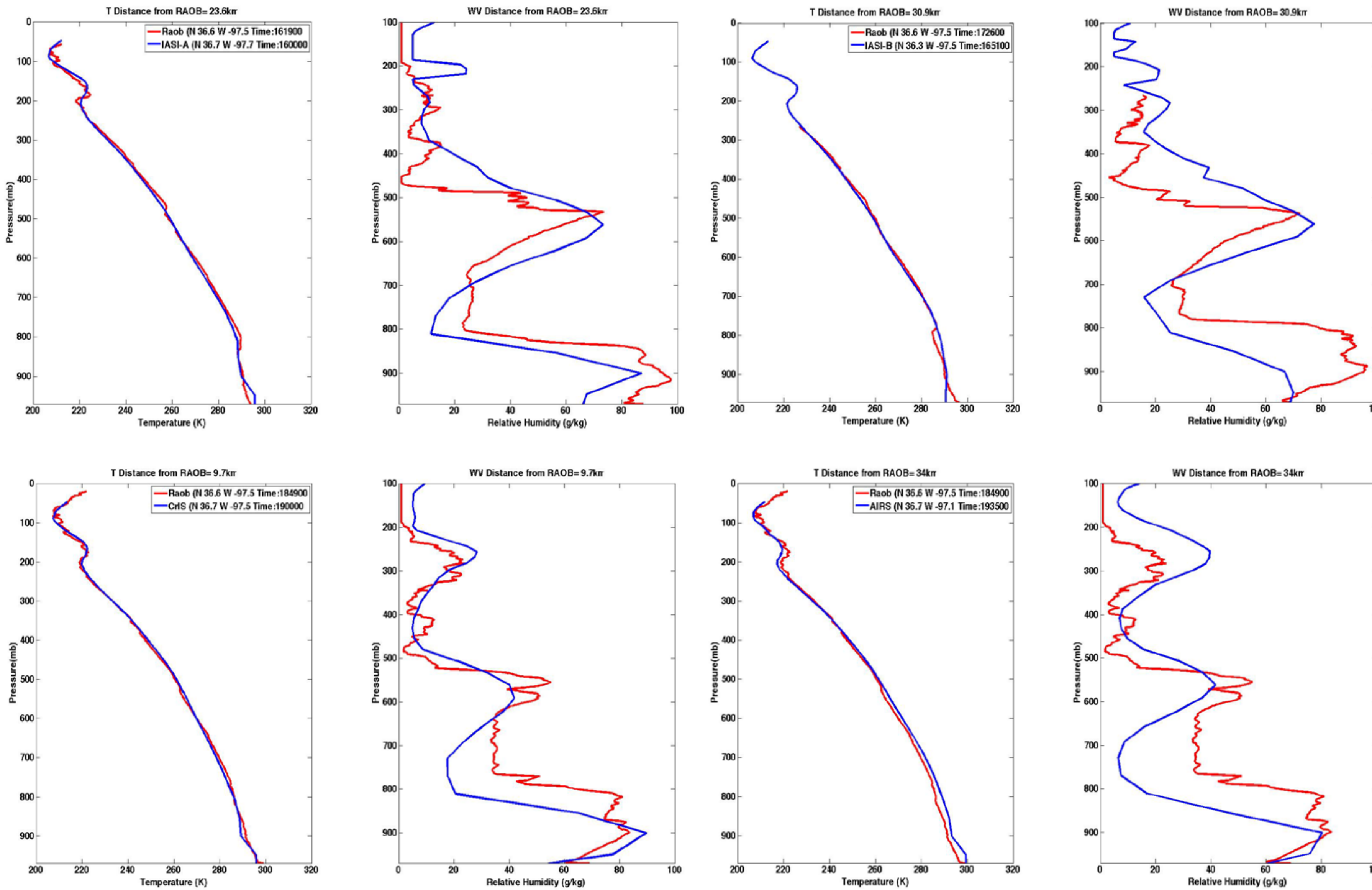
Aircraft Track and Satellite Orbits



RAP Model Profiles Vs ARM-site Radiosondes



Satellite Retrievals Vs ARM-site Radiosondes



Lifted Index Stability Parameter

The **lifted index** (**LI**) is the temperature difference between an air parcel lifted adiabatically T(p) and the temperature of the environment Te(p) at a pressure height in the troposphere of 500 hPa (mb). When the value is positive, the atmosphere (at the respective height) is stable and when the value is negative, the atmosphere is unstable.

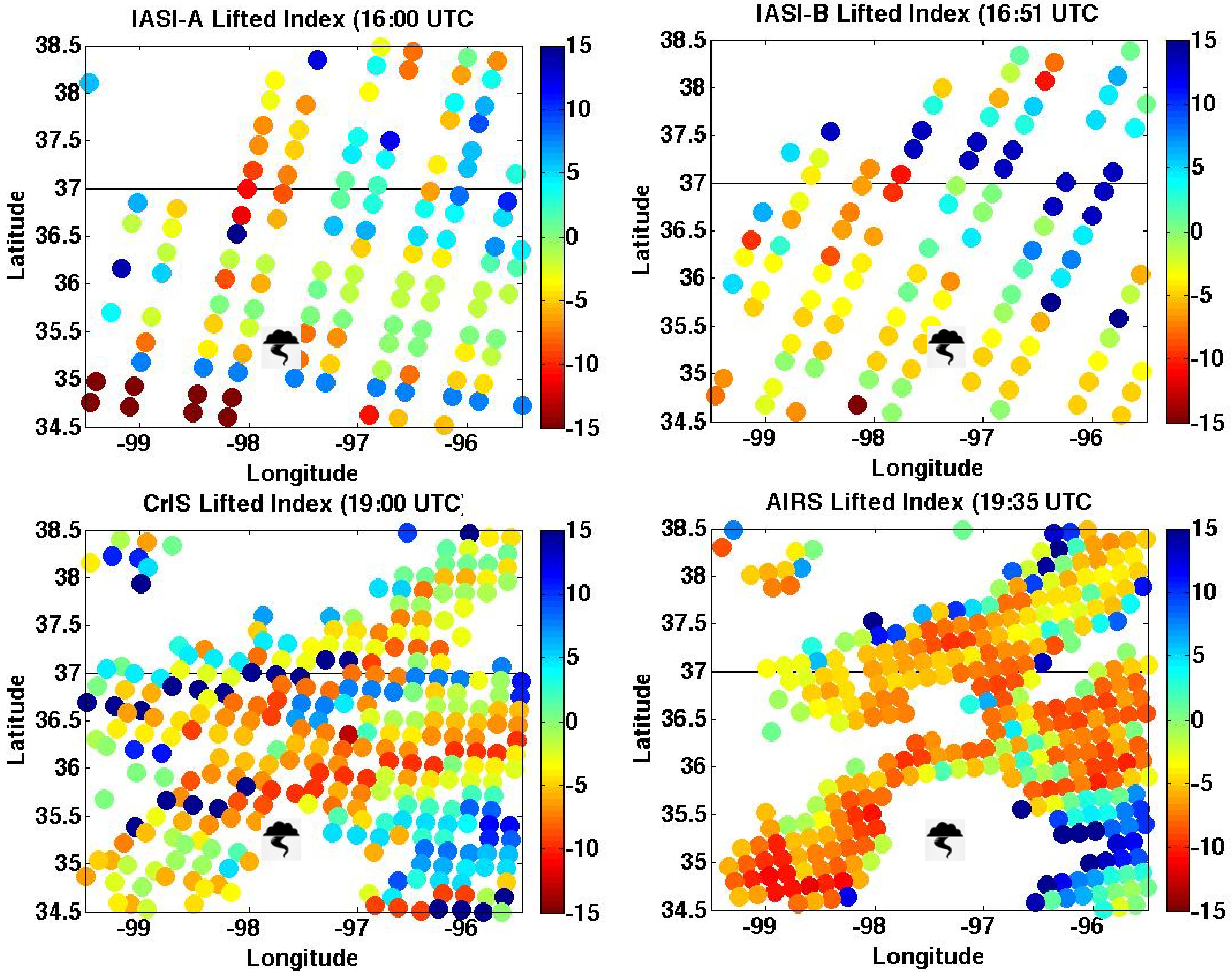
Thunderstorm Potential:

< -5 Very Unstable: Strong Thunderstorm Potential

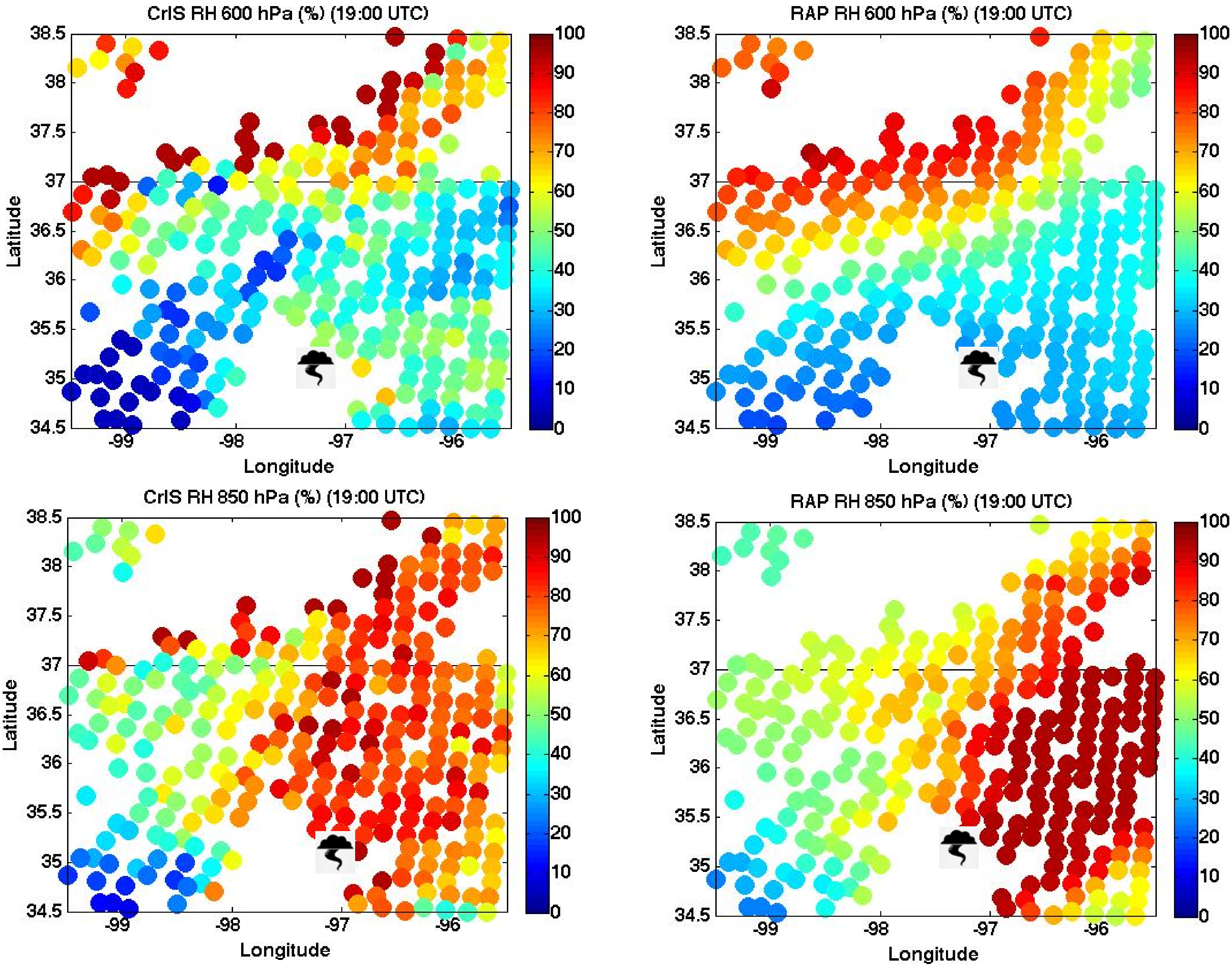
-3 to -5 Unstable: Thunderstorm Probable

0 to -2 Marginally Unstable: Thunderstorms Possible

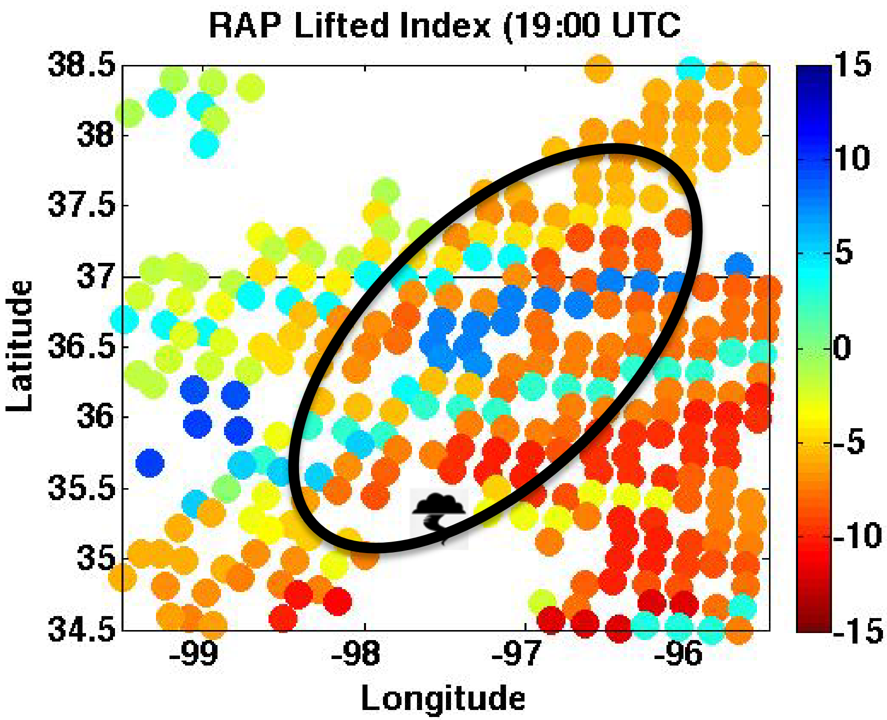
>0: Stable: Thunderstorms Unlikely

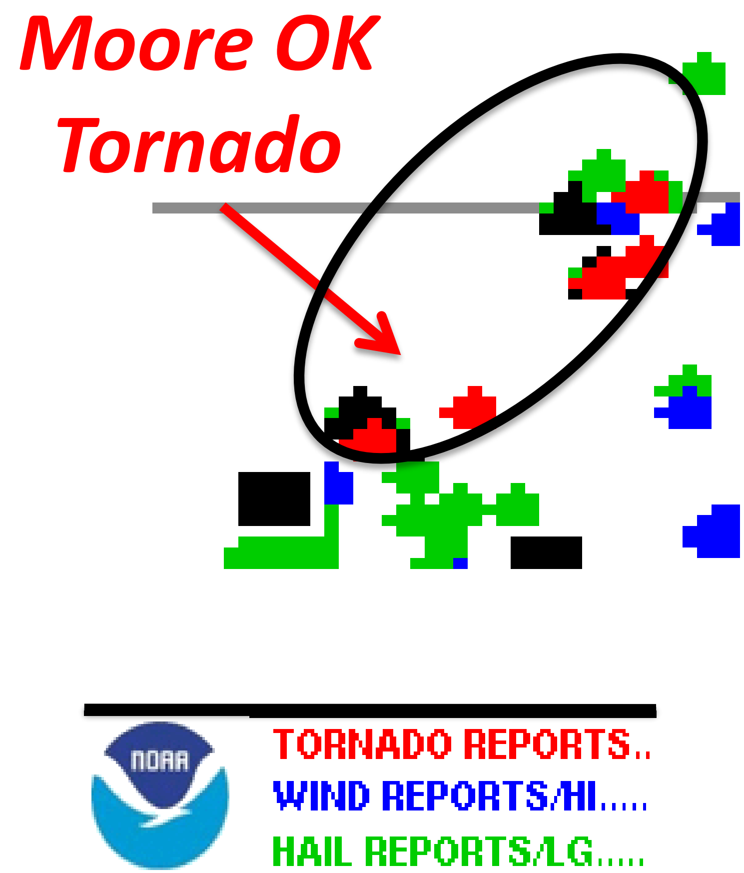


IASI-A Lifted Index (16:00 UTC
IASI-B Lifted Index (16:51 UTC
CrIS Lifted Index (19:00 UTC)
AIRS Lifted Index (19:35 UTC
Latitude
Longitude
38.5
38
37.5
37
36.5
36
35.5
35
34.5
-99
-98
-97
-96
15
10
5
0
-5
-10
-15


CrIS RH 600 hPa (%) (19:00 UTC)
RAP RH 600 hPa (%) (19:00 UTC)
CrIS RH 850 hPa (%) (19:00 UTC)
RAP RH 850 hPa (%) (19:00 UTC)
Latitude
Longitude
38.5
38
37.5
37
36.5
36
35.5
35
34.5
-99
-98
-97
-96
100
90
80
70
60
50
40
30
20
10
0

RAP Model Instability Vs Tornado Reports





Thunderstorm Potential:

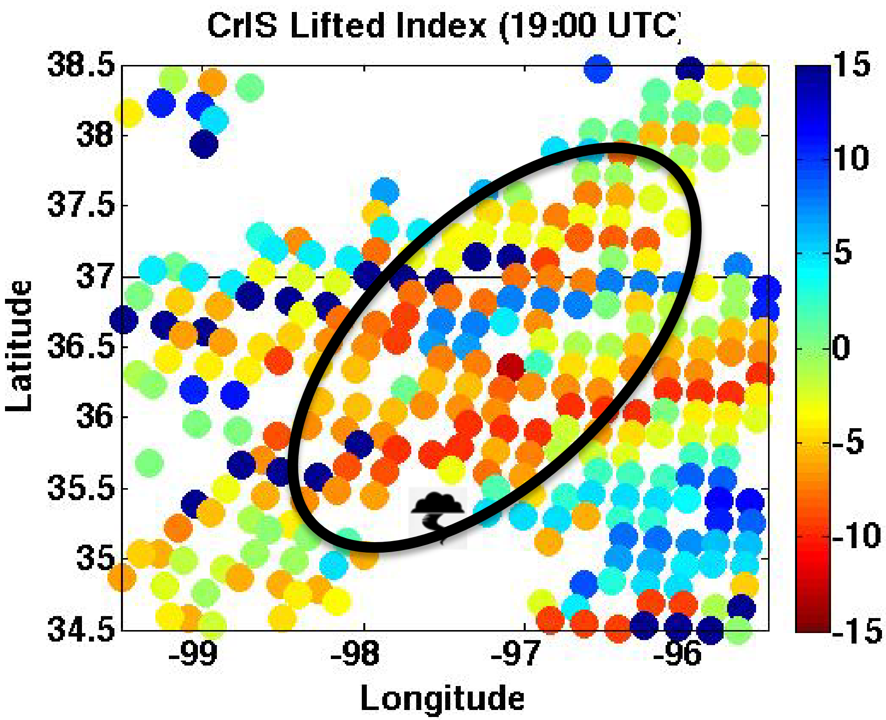
< -5 Very Unstable: Strong Thunderstorm Potential

3 to -5 Unstable: Thunderstorm Probable

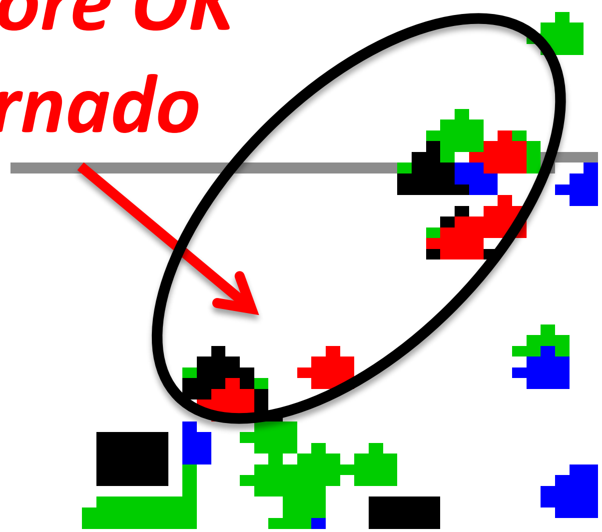
0 to -2 Marginally Unstable: Thunderstorms Possible

>0: Stable: Thunderstorms Unlikely

Suomi-NPP CrIS Instability Vs Tornado Reports



Moore OK Tornado



TORNADO REPORTS..
WIND REPORTS/HI.....
HAIL REPORTS/LG.....

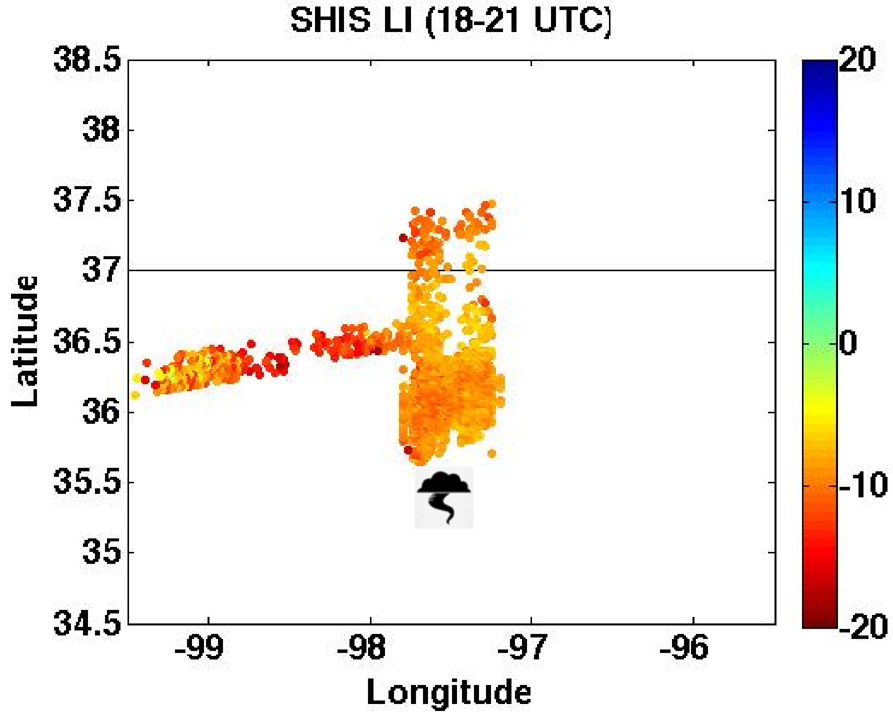
Thunderstorm Potential:

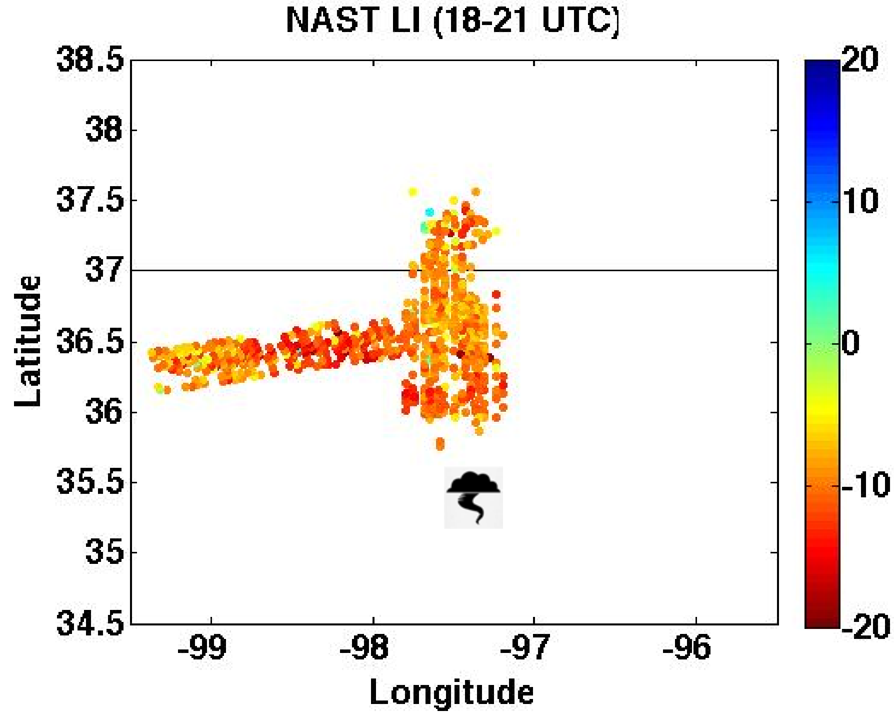
< -5 Very Unstable: Strong Thunderstorm Potential

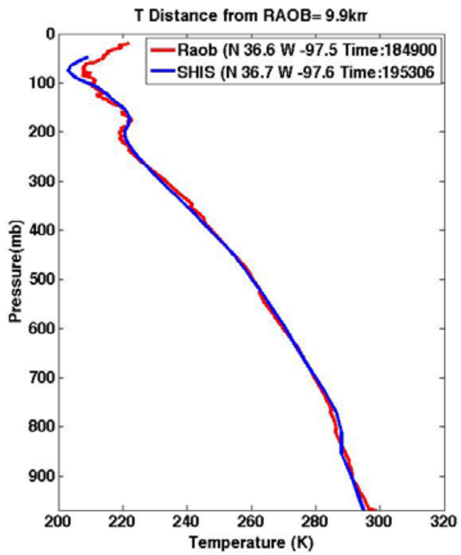
3 to -5 Unstable: Thunderstorm Probable

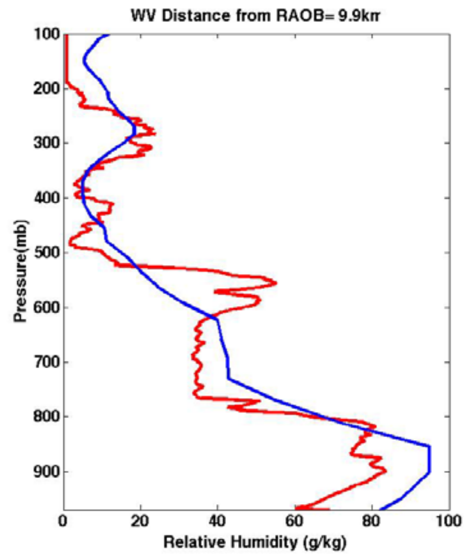
0 to -2 Marginally Unstable: Thunderstorms Possible

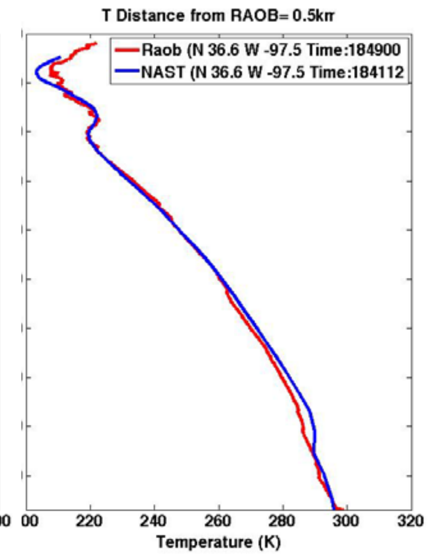
>0: Stable: Thunderstorms Unlikely

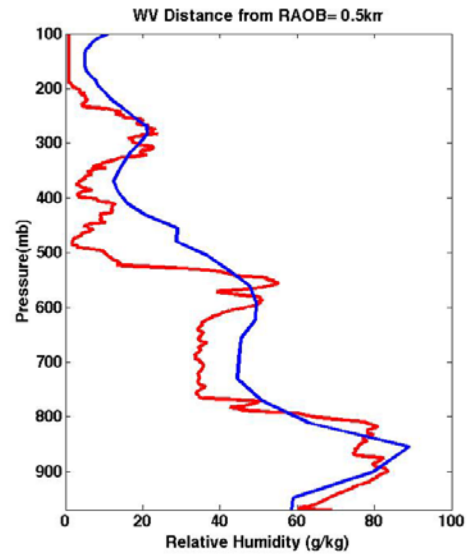

SHIS LI (18-21 UTC)
Latitude
Longitude
20
10
0
-10
-20


NAST LI (18-21 UTC)
Latitude
Longitude
20
10
0
-10
-20

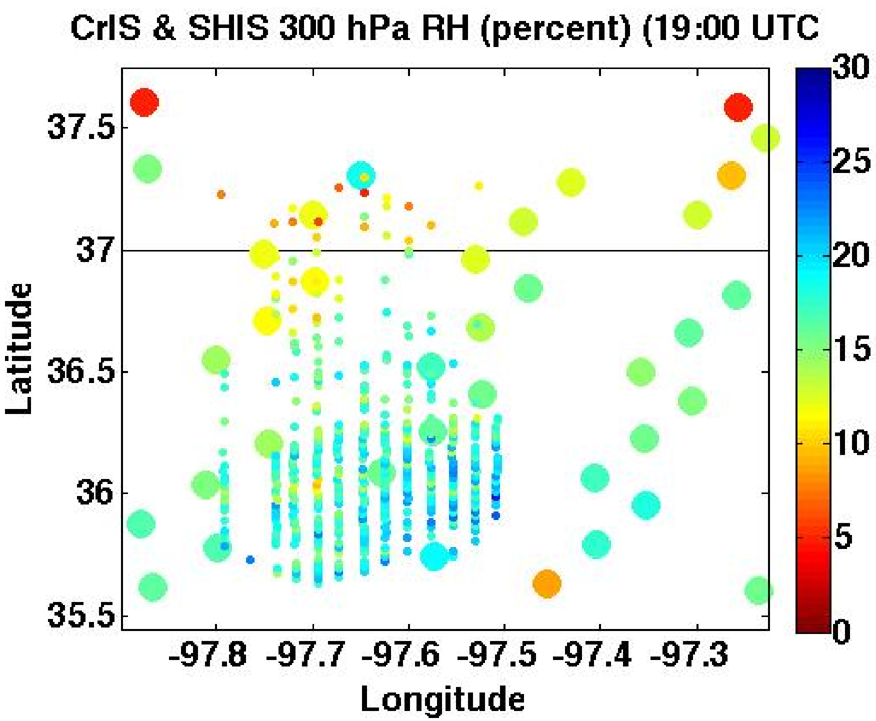

T Distance from RAOB= 9.9km
Raob (N 36.6 W -97.5 Time:184900
SHIS (N 36.7 W -97.6 Time:195306
Pressure(mb)
Temperature (K)

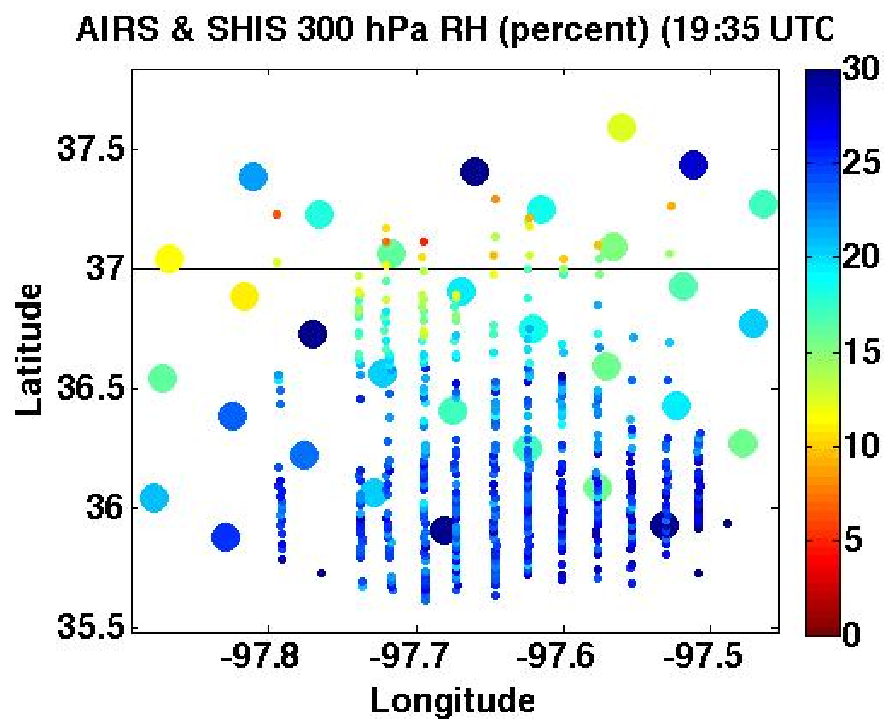

WV Distance from RAOB= 9.9km
Pressure(mb)
Relative Humidity (g/kg)


T Distance from RAOB= 0.5km
Raob (N 36.6 W -97.5 Time:184900
NAST (N 36.6 W -97.5 Time:184112
Temperature (K)


WV Distance from RAOB= 0.5km
Pressure(mb)
Relative Humidity (g/kg)

ER-2 Aircraft Soundings Are Used to Validate Satellite Sounding Time Variations





High spatial resolution (1 – km) ER-2 aircraft soundings are used to validate 35 minute time changes in relative humidity indicated by consecutive CrIS and AIRS humidity soundings

Summary and Conclusions

- CrIS provides retrievals with an accuracy and spatial resolution comparable or better than IASI and AIRS.
- ER-2 SHIS and NAST retrievals can be used to validate time tendencies of high spatial resolution features diagnosed from consecutive satellite
- Satellite soundings provide mesoscale features not yet resolved by the highest spatial resolution NWP models (i.e., RAP/WRF)
- Next step is to validate mesoscale features of Chemistry retrievals already obtained with the thermodynamic retrievals shown here.

Thank You for Your Attention

CrIS/ATMS Retrievals Using an AIRS Science Team Version 6-like Retrieval Algorithm

Joel Susskind, Louis Kouvaris, and Lena Iredell

NASA GSFC Sounder Research Team (SRT)

2014 STAR JPSS Science Teams Annual Meeting
College Park, MD

May 14, 2014

Background

CrIS is the infrared high spectral resolution atmospheric sounder launched on Suomi-NPP in 2011

CrIS/ATMS comprise the IR/MW Sounding Suite on Suomi-NPP

CrIS is functionally equivalent to AIRS, the high spectral resolution IR sounder launched on EOS Aqua in 2002 and ATMS is functionally equivalent to AMSU on EOS Aqua

CrIS is an interferometer and AIRS is a grating spectrometer

- Spectral coverage, spectral resolution, and channel noise of CrIS is similar to AIRS
    - CrIS spectral sampling is roughly twice as coarse as AIRS
    - AIRS has 2378 channels between 650 cm^{-1} and 2665 cm^{-1}
    - CrIS has 1305 channels between 650 cm^{-1} and 2550 cm^{-1}
- Spatial resolution of CrIS is comparable to AIRS

Background (Cont.)

The AIRS Science Team Version 6 retrieval algorithm is currently producing very high quality level-3 Climate Data Records (CDRs) from AIRS that will be critical for understanding climate processes. All products have their own QC flags based on thresholds of error estimates. CDRs include all cases passing AIRS Climate QC, which provides best spatial coverage. AIRS CDRs should eventually cover the period September 2002 through at least 2020.

CrIS/ATMS is the only scheduled follow on to AIRS/AMSU. This research is being done to address the question of how well CrIS/ATMS can be counted on to adequately continue AIRS/AMSU CDRs beyond 2020.

We believe the best results will be obtained if CrIS/ATMS is analyzed using an AIRS Version 6–like retrieval algorithm

NOAA is currently generating CrIS/ATMS products using 2 algorithms: IDPS and NUCAPS. The NUCAPS algorithm is thought to give superior products. We are investigating the CDR capabilities of the NUCAPS algorithm as well.

SRT Research Using CrIS/ATMS

Approach

Analyze CrIS/ATMS using methodology as closely as possible to AIRS Version 6

SRT CrIS/ATMS Version 5.70 is otherwise analogous to AIRS/AMSU Version 6 but uses a regression based guess instead of a Neural-Net guess

Like AIRS Version 6, CrIS/ATMS Version 5.70 uses only shortwave CrIS window channels to determine surface skin temperature T_s, and uses only shortwave CO_2 channels to determine tropospheric *T(p)*

> Using only shortwave window channels and shortwave tropospheric sounding channels allows for better soundings under harder cloud conditions

We have recently obtained CrIS/ATMS Neural-Net coefficients from Bill Blackwell, but they have not yet been successfully implemented at SRT

We plan to optimize and run Version 6-like CrIS/ATMS retrievals when the CrIS/ATMS Neural-Net capability is functioning properly

NOAA Unique CrIS/ATMS Processing System (NUCAPS)

NUCAPS is based on earlier AIRS Science Team retrieval algorithms and produces most products generated by AIRS Version 6.

Possible limitations of NUCAPS with regard to generation of optimal CDRs:

- Channels used and QC methodology are not up to date with AIRS Version 6
- NUCAPS does not use a Neural-Net guess

  Use of a Neural-Net guess improved AIRS Version 6 temperature profiles considerably
- NUCAPS appears to have only a single product independent QC flag and does not generate level-3 products

  We have evaluated NUCAPS level-2 products and generated level-3 products using the single NUCAPS QC flag

We have been told that product dependent QC flags can be generated for NUCAPS. We plan to meet with Antonia Gambacorta and co-workers as to how to properly generate NUCAPS level-3 products.

Comparisons Shown

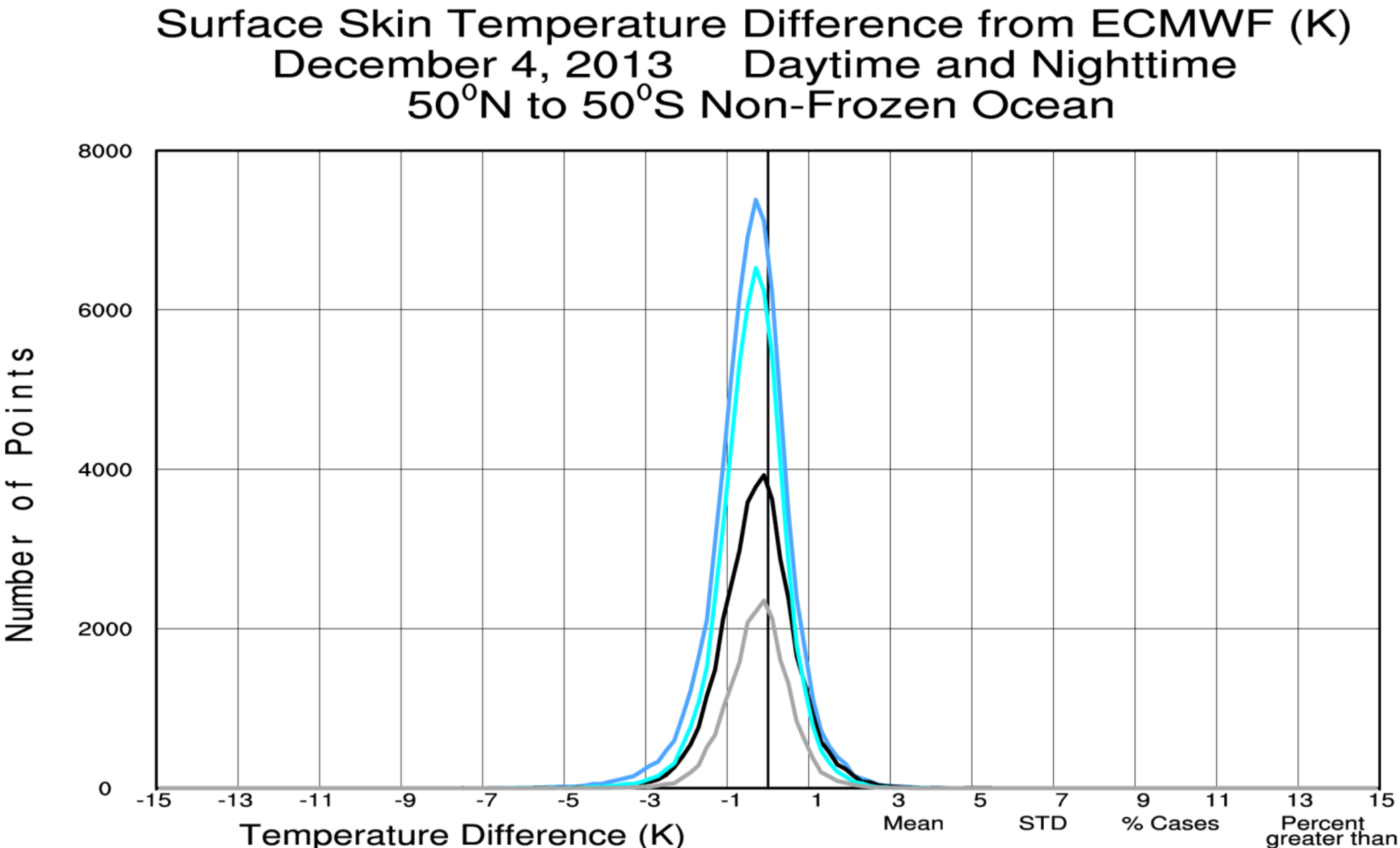
Results are shown for December 2013 for T_s and $T(p)$

- First comparisons show level-2 AIRS/AMSU Version 6 (called AIRS) and CrIS/ATMS Version 5.70 (called CrIS) results using both tight Data Assimilation (DA) QC, which provides the highest accuracy, and looser Climate QC thresholds which provide excellent spatial coverage while maintaining good accuracy. Achieving AIRS/AMSU Version 6 quality results is our goal for CrIS/ATMS, especially from the level-3 CDR perspective

- Second comparisons show level-2 and level-3 AIRS, CrIS, and NUCAPS CrIS/ATMS (called NUCAPS) products

  AIRS and CrIS level-3 products use their product dependent Climate QC flags

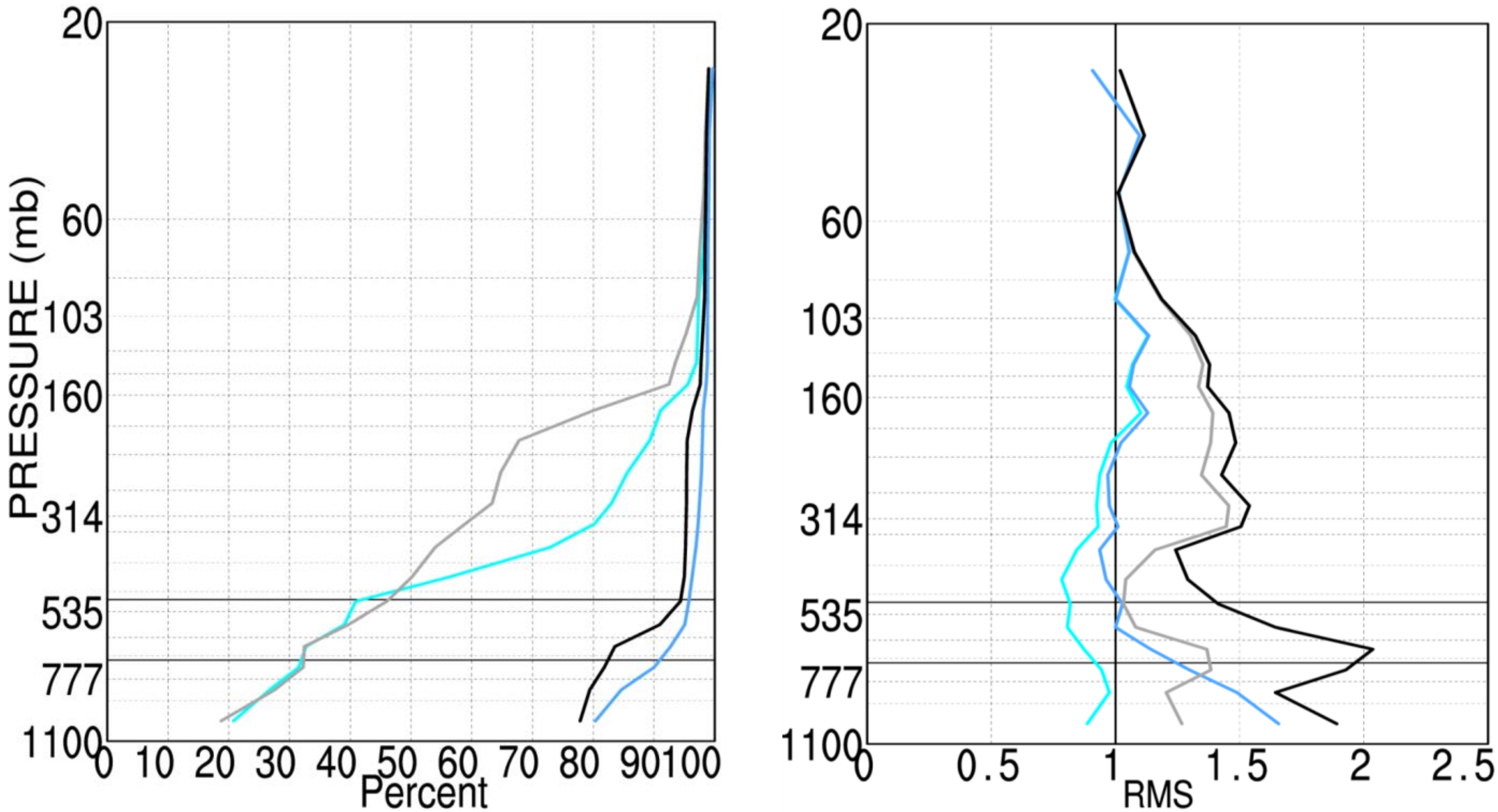
  NUCAPS level-3 products use the NUCAPS single QC flag



		Mean	STD	% Cases	Percent greater than |3K| from mean
AIRS	Climate QC	-0.22	0.92	55.44	1.42
CrIS	Climate QC	-0.06	0.93	30.58	0.86
AIRS	DA QC	-0.18	0.80	44.52	0.61
CrIS	DA QC	-0.04	0.79	15.69	0.32

QC'd CrIS SSTs are reasonably good but QC'd AIRS SSTs are much better as a function of yield. CrIS with Climate QC has good error statistics, but has a much smaller yield and poorer accuracy than AIRS with DA QC.

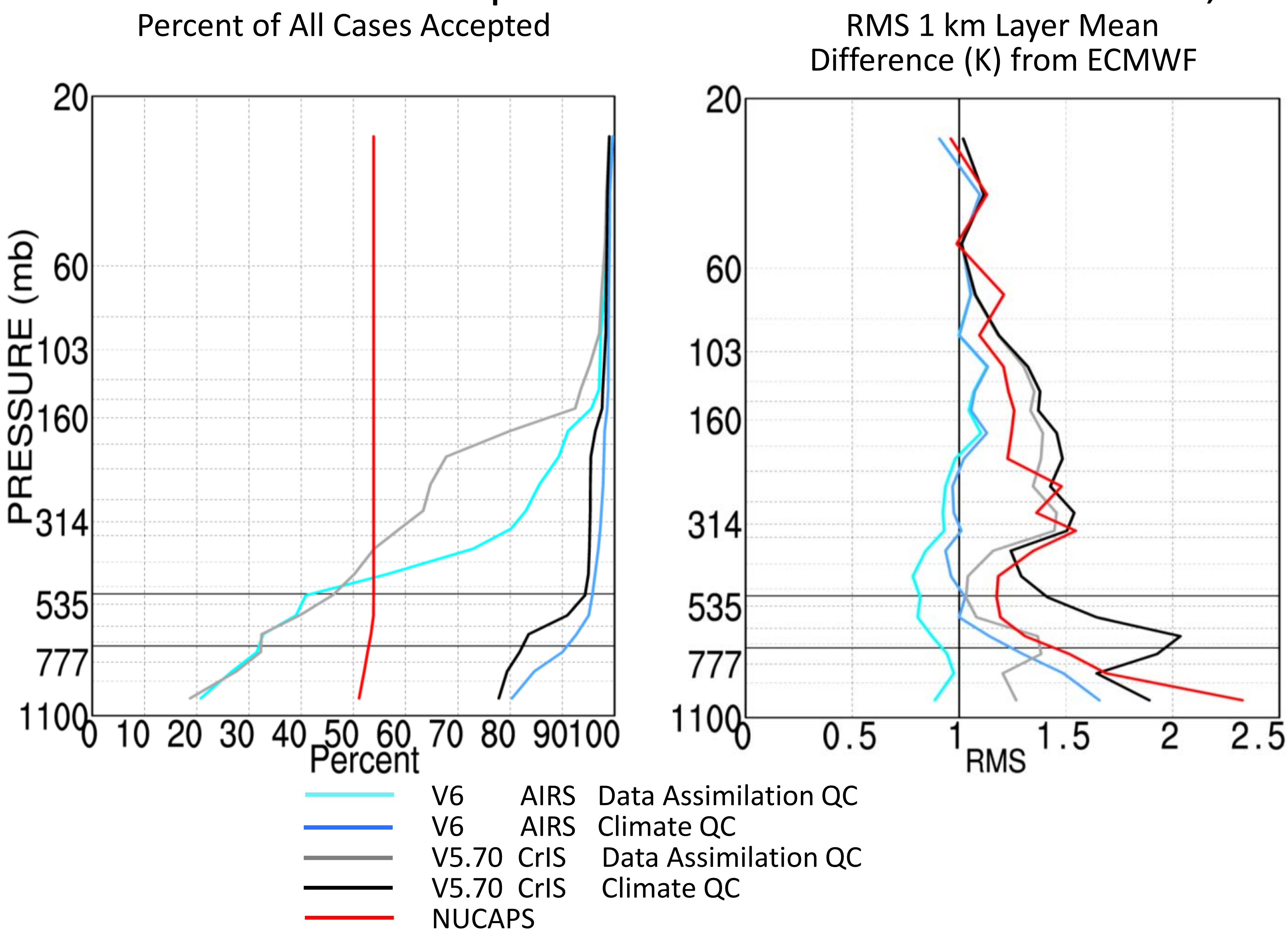
Global Temperature Profile December 4, 2013



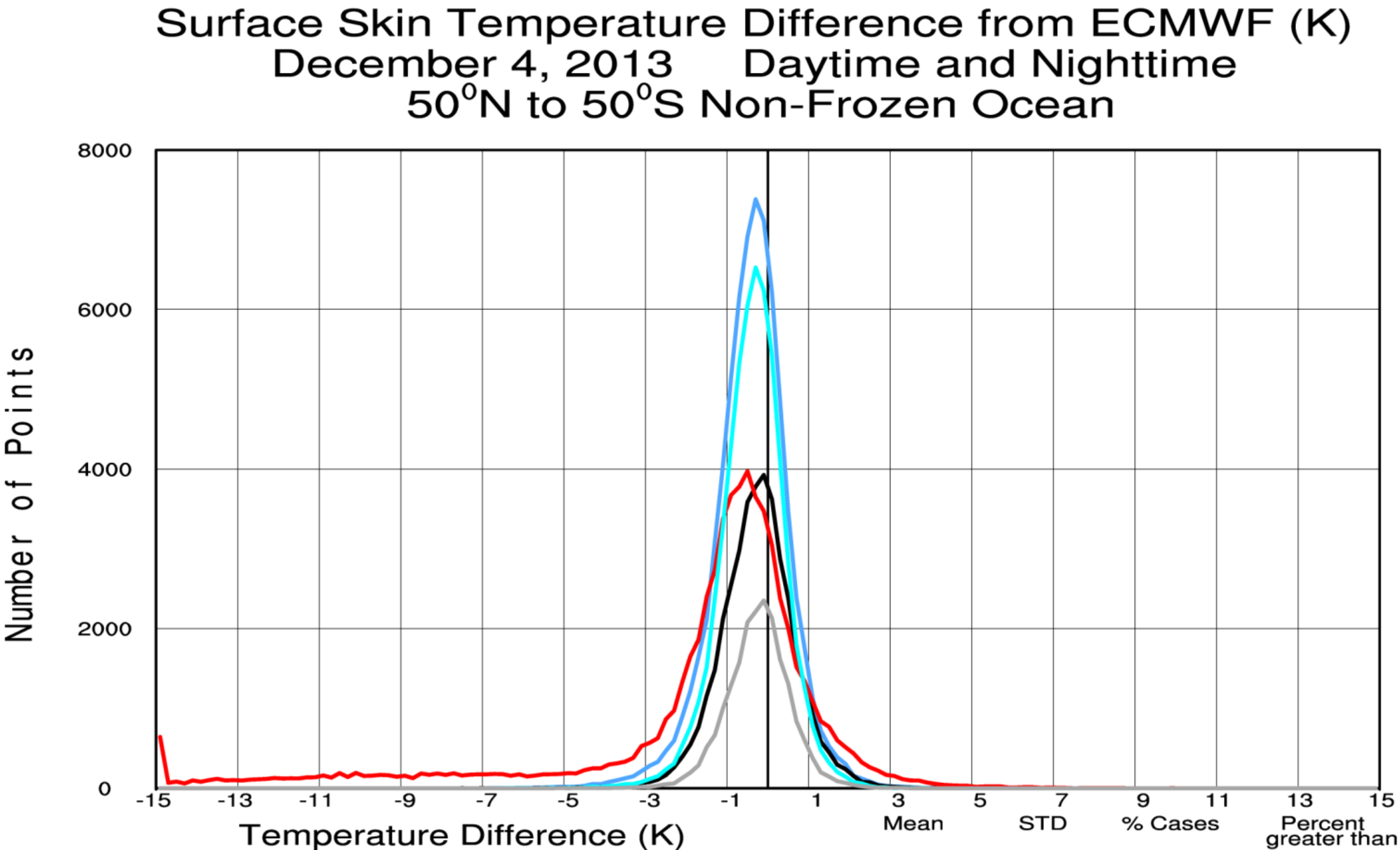
(cyan line)	V6	AIRS	Data Assimilation QC
(blue line)	V6	AIRS	Climate QC
(gray line)	V5.70	CrIS	Data Assimilation QC
(black line)	V5.70	CrIS	Climate QC

AIRS using DA QC has errors less than 1K in troposphere.
AIRS using Climate QC has 80% yield at surface and 95% yield at 500 mb.
CrIS results are poorer than AIRS – should improve with Neural-Net guess.

Global Temperature Profile December 4, 2013



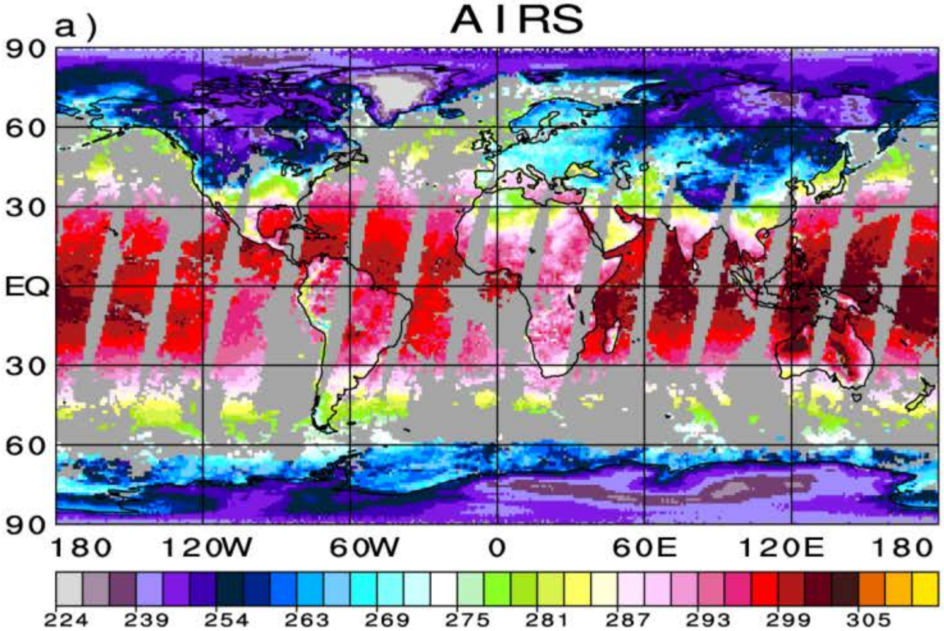
NUCAPS single QC flag accepts 54% of all cases. Yield is different at the surface because of elevated terrain. NUCAPS accuracy is similar to CrIS with Climate QC, but with much lower yield.



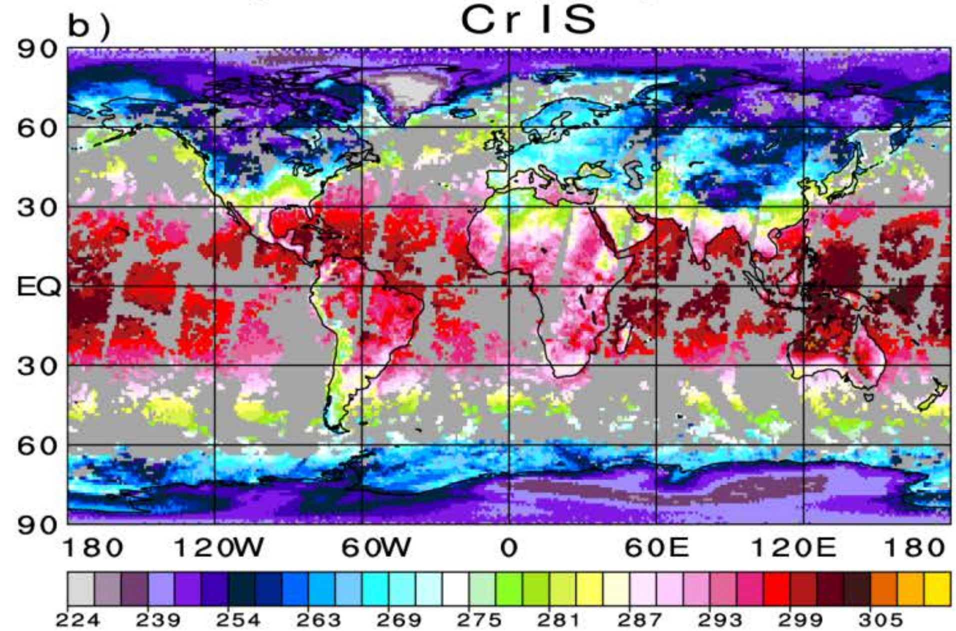
		Mean	STD	% Cases	Percent greater than |3K| from mean
AIRS	Climate QC	-0.22	0.92	55.44	1.42
CrIS	Climate QC	-0.06	0.93	30.58	0.86
NUCAPS	NUCAPS QC	-1.45	3.34	49.88	17.53
AIRS	DA QC	-0.18	0.80	44.52	0.61
CrIS	DA QC	-0.04	0.79	15.69	0.32

Single NUCAPS QC flag accepts ≈ 50% of ocean cases, but many are poor retrievals.
AIRS with Climate QC accepts more cases, with very high accuracy.

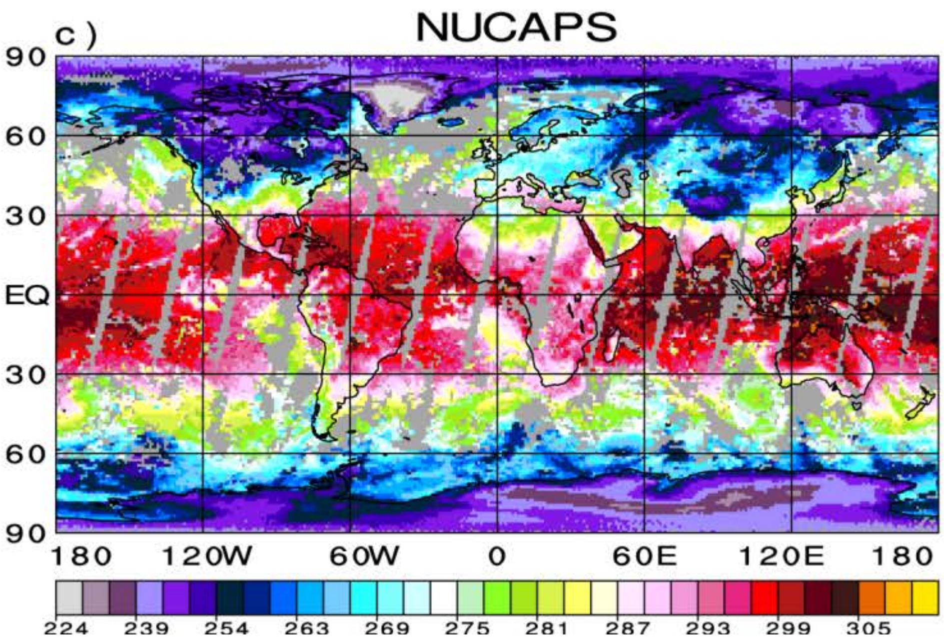
December 4, 2013 Surface Skin Temperature(K) 1:30 AM



Global Mean= 282.98 STD= 15.96 %Fill 67.43



Global Mean= 282.85 STD= 15.55 %Fill 65.76



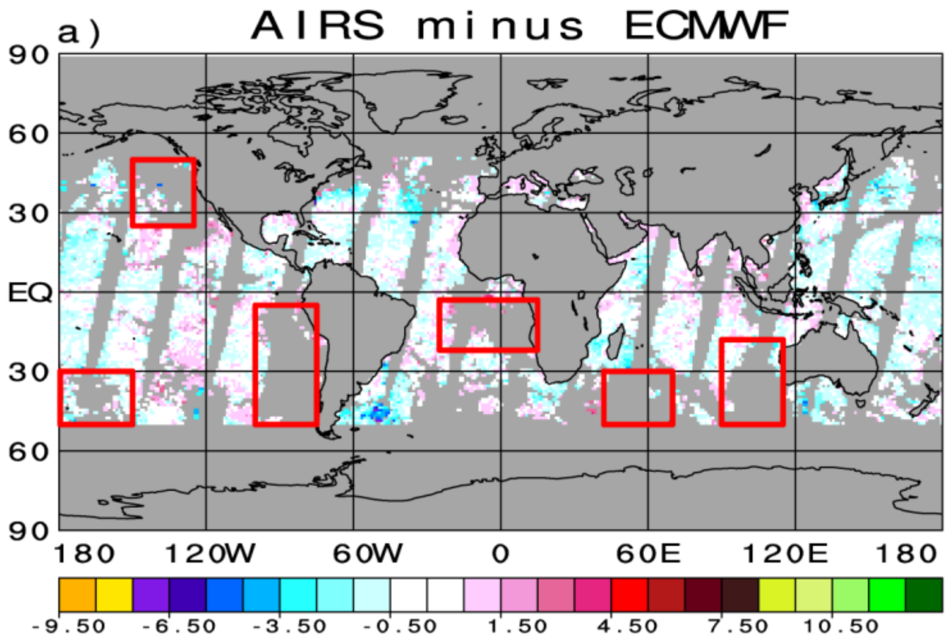
Global Mean= 282.64 STD= 15.02 %Fill 81.20

All level-3 Tskin fields have good land spatial coverage

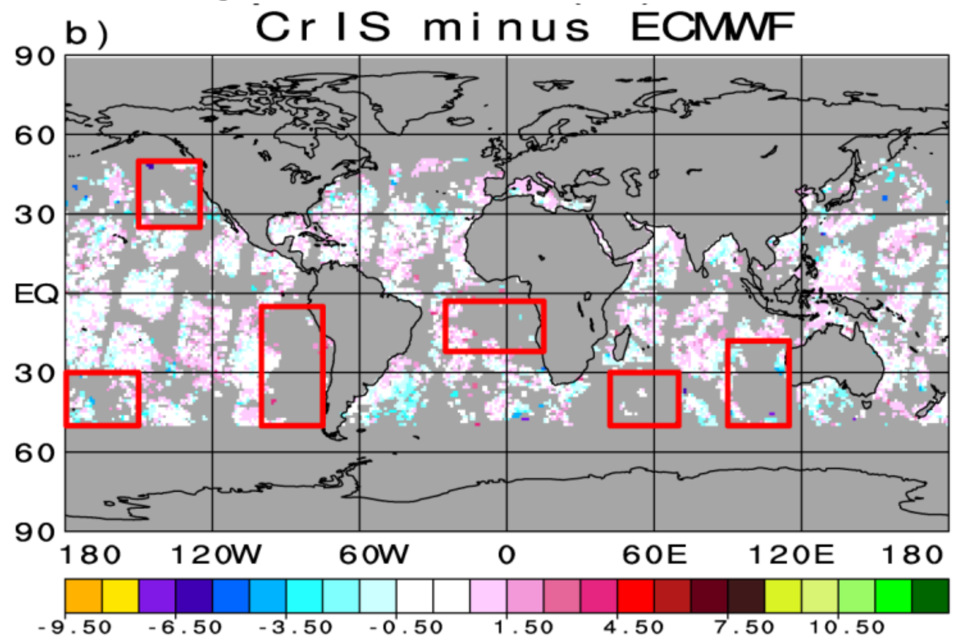
AIRS Ocean Tskin spatial coverage is better than CrIS. Both have large gaps in similar places.

NUCAPS Ocean Tskin spatial coverage is almost complete. This is not necessarily a good result.

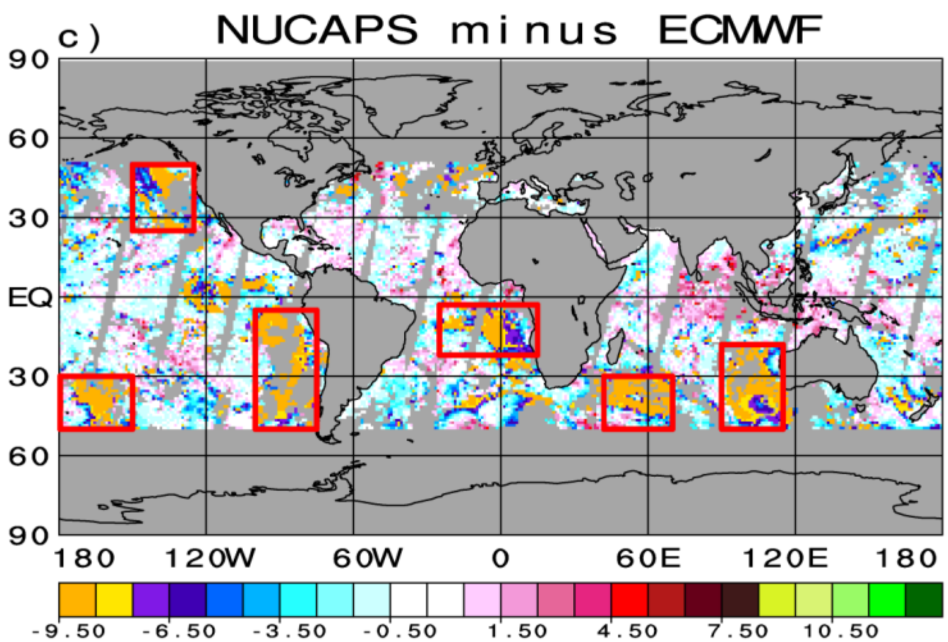
December 4, 2013 Ocean Skin Temperature(K) 50°N to 50°S
1:30 AM/PM Average



Global Mean= -0.27 STD= 0.93 Corr= 0.99



Global Mean= 0.10 STD= 0.92 Corr= 0.99



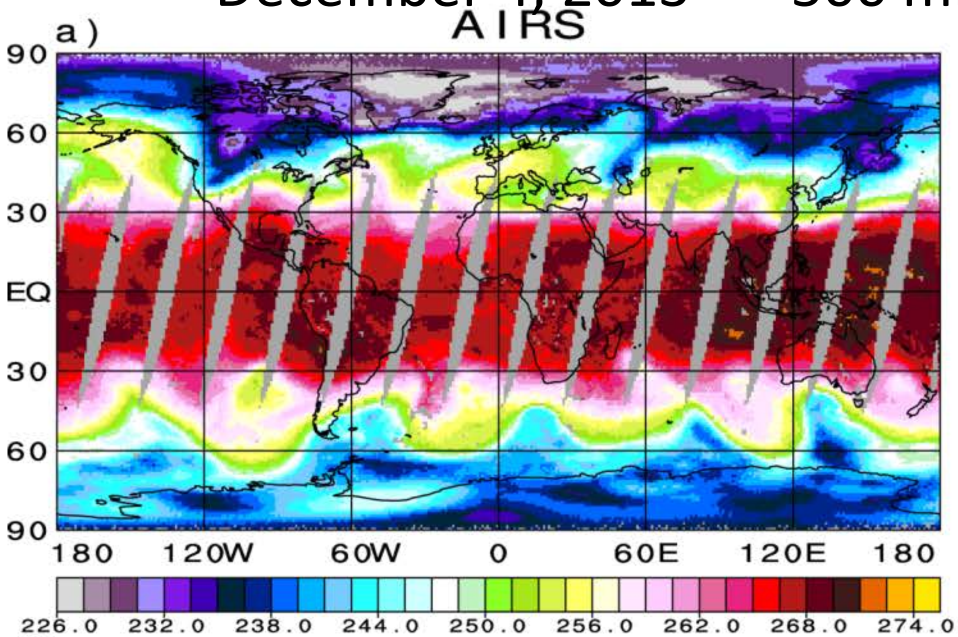
Global Mean= -2.13 STD= 4.07 Corr= 0.91

AIRS has comparable accuracy to CrIS with better spatial coverage

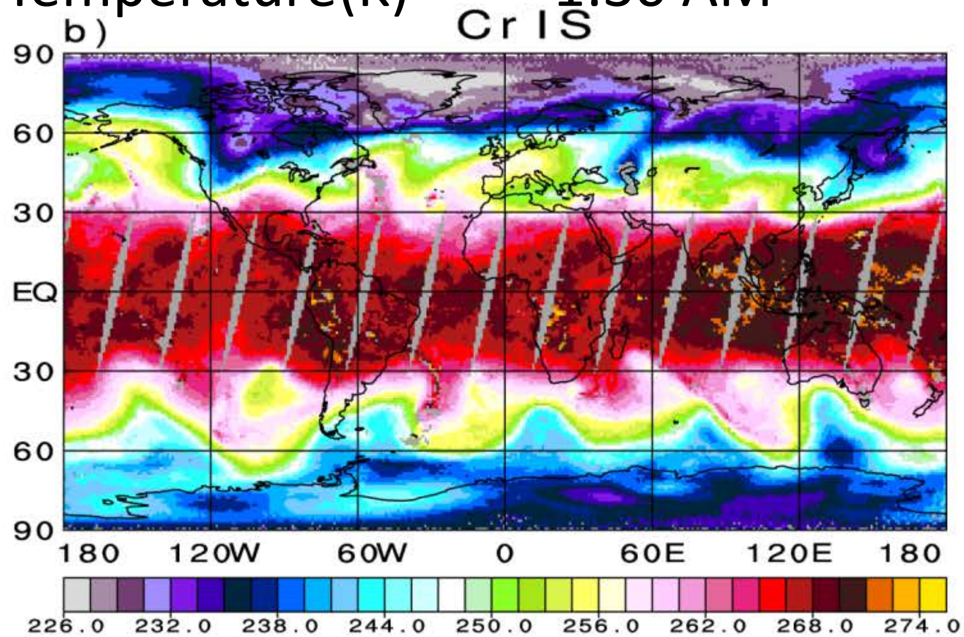
Red boxes indicate sample areas covered by NUCAPS by not AIRS or CrIS

NUCAPS Tskin is considerably too cold in these areas

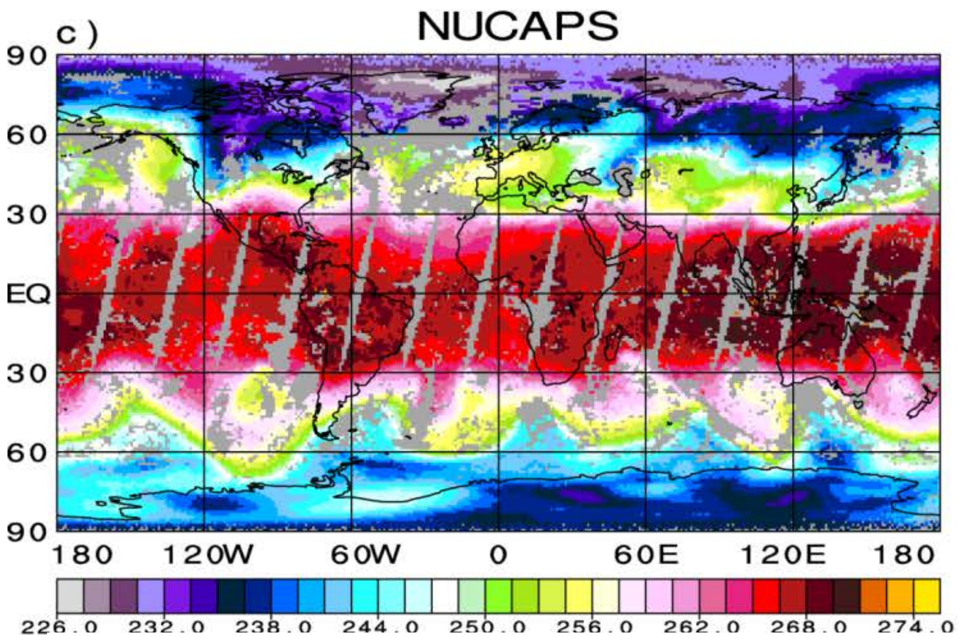
December 4, 2013 500 mb Temperature(K) 1:30 AM



Global Mean= 256.61 STD= 10.60 %Fill 88.38



Global Mean= 257.45 STD= 10.38 %Fill 94.55



Global Mean= 257.60 STD= 9.90 %Fill 81.20

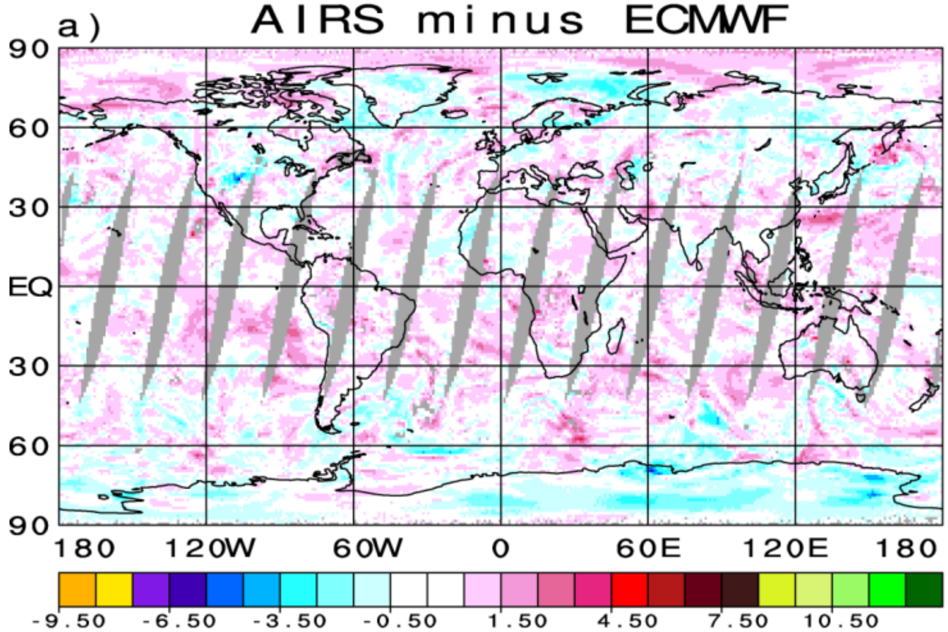
AIRS and CrIS level-3 500 mb temperature fields have almost complete spatial coverage

CrIS covers more grid points because orbit gaps are smaller

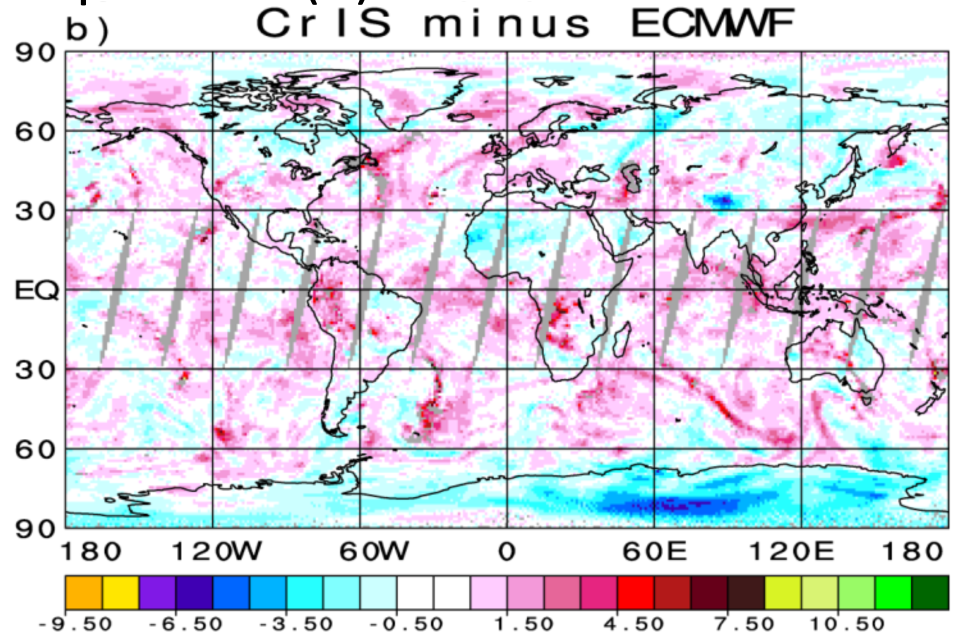
NUCAPS 500 mb temperature spatial coverage is identical to that of Tskin

NUCAPS has gaps at leading edges of cold fronts

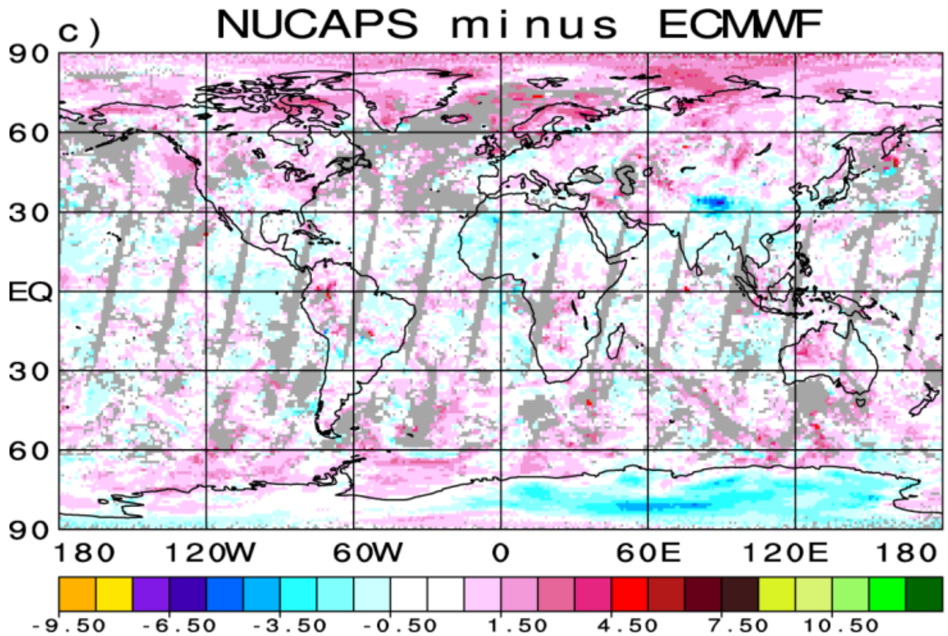
December 4, 2013 500 mb Temperature(K) 1:30 AM



Global Mean= 0.22 STD=0.83 Corr=1.00



Global Mean= 0.32 STD=1.16 Corr=1.00



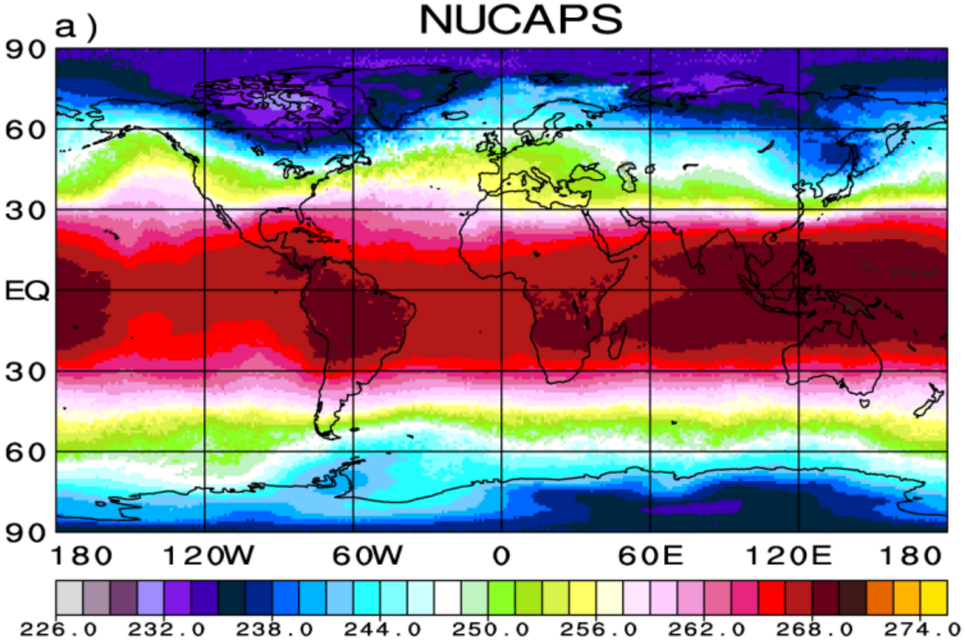
Global Mean= 0.17 STD= 0.94 Corr=1.00

NUCAPS 500 mb temperature "accuracy" is poorer than AIRS but better than CrIS

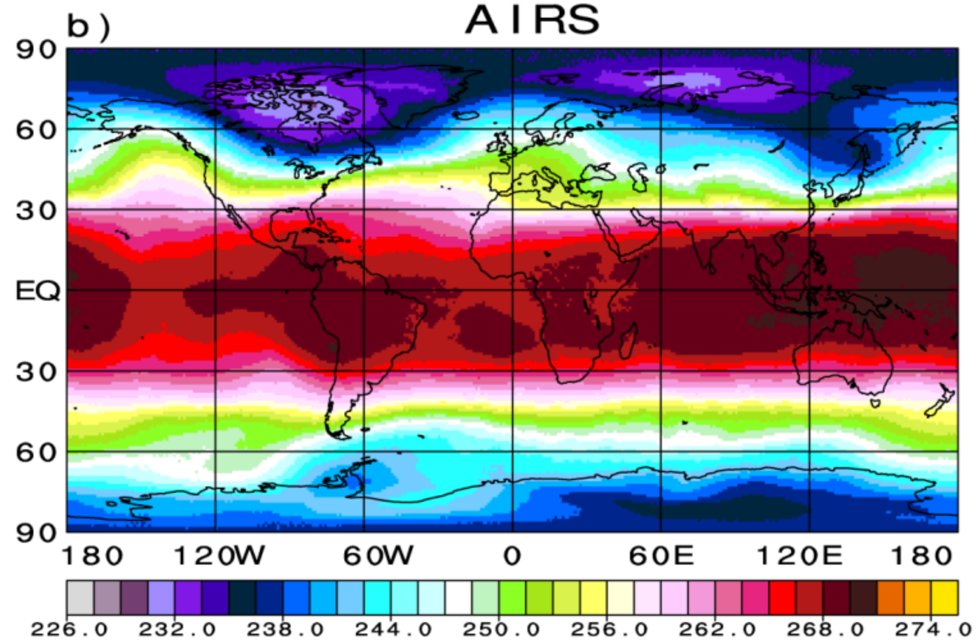
This does not tell the whole story

NUCAPS systematic rejection of leading edges of cold fronts leads to spuriously warm monthly mean temperatures

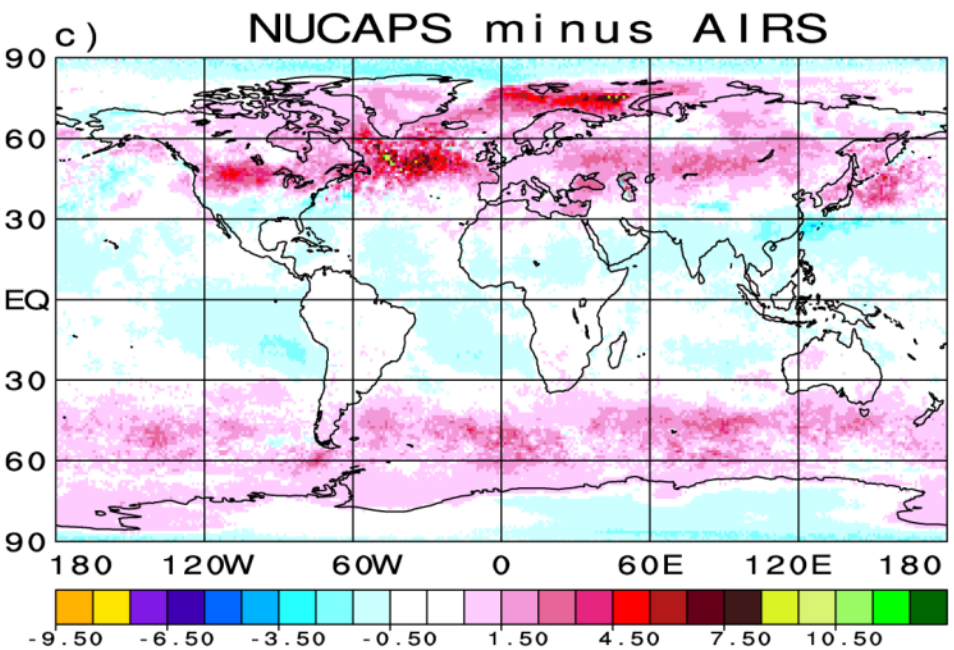
December 2013 Monthly Mean 500 mb Temperature(K) 1:30 AM/PM Average



Global Mean= 258.24 STD= 9.26 %Fill 99.97



Global Mean= 258.04 STD= 9.88 %Fill 100.00

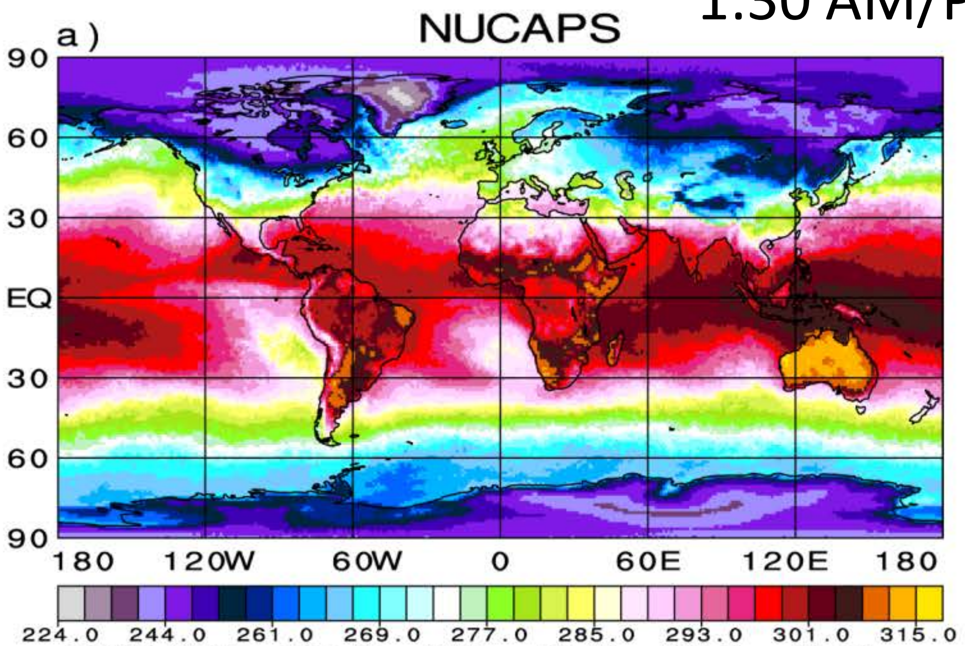


Global Mean= 0.20 STD= 0.97 Corr = 1.00

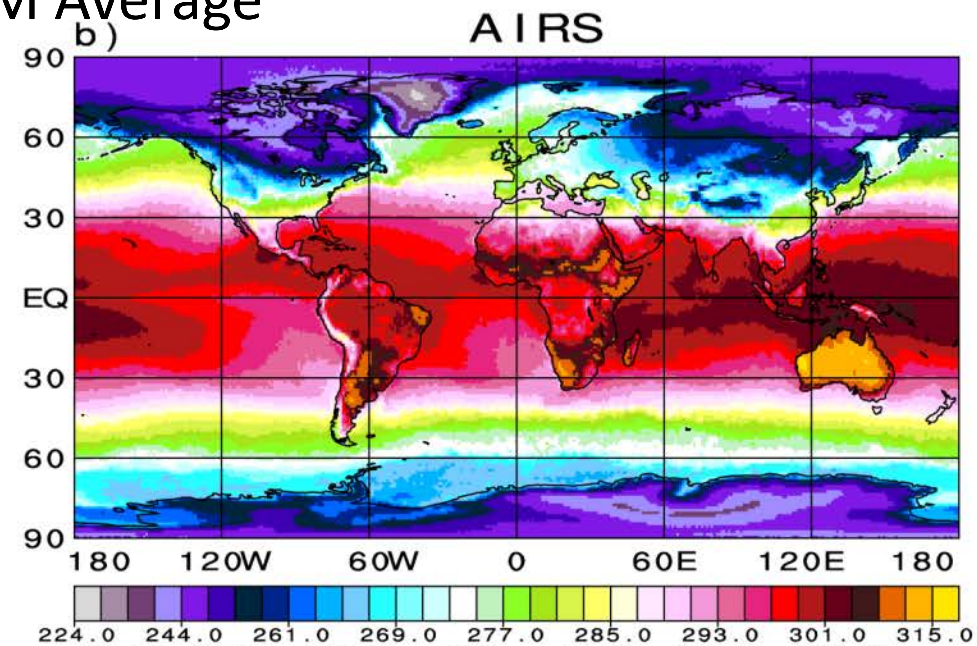
AIRS monthly mean level-3 500 mb temperature is much smoother than NUCAPS at high latitudes because NUCAPS has daily gaps at leading edges of cold fronts.

NUCAPS monthly mean 500 mb temperature is spuriously warm, as compared to AIRS in areas where moving cold front locations were systematically excluded from the monthly mean product.

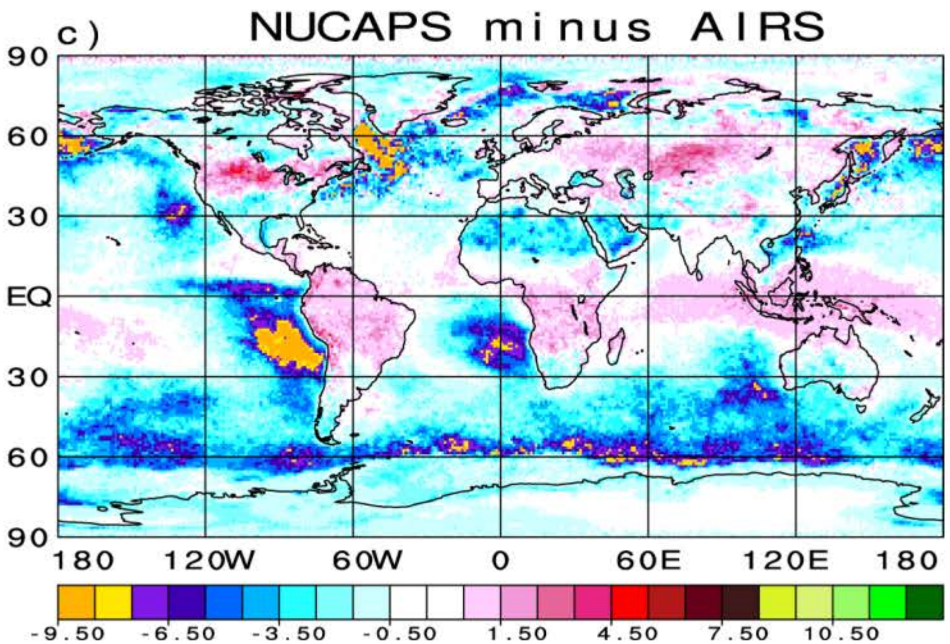
December 2013 Monthly Mean Surface Skin Temperature(K)
1:30 AM/PM Average



Global Mean= 285.43 STD= 14.49 %Fill 99.97



Global Mean= 286.73 STD= 14.00 %Fill 100.00



Global Mean= -1.30 STD= 2.17 Corr = 0.99

NUCAPS level-3 monthly mean sea surface temperatures are spuriously very cold compared to AIRS in areas containing large amounts of cloud cover. This is primarily the result of the single NUCAPS QC flag accepting very poor cases on a daily basis.

There are also significant differences in NUCAPS land surface temperatures as compared to AIRS. This is not necessarily the result of poor QC.

Summary and Plans

- Version 5.70 CrIS/ATMS *T(p)* and T_s retrievals are poorer quality than AIRS/AMSU, especially for T_s. This could be a result of the CrIS shortwave spectral coverage which is truncated at 2550 cm^{-1}. Version-5.70 CrIS/ATMS is now implemented and tested at the JPL Sounder PEATE. We plan to generate Version-5.70 CrIS/ATMS monthly mean level-3 products for a number of months and compare with those of AIRS.
- We want to work with Antonia Gambacorta and co-workers to implement NUCAPS product dependent QC flags. The current NUCAPS product independent QC flags eliminates important cases for *T(p)* and allows bad cases for T_s. We will test these by generating new monthly mean NUCAPS level-3 products and comparing them with AIRS and CrIS 5.70.
- We will begin testing and optimizing CrIS/ATMS Version 6 once the CrIS/ATMS Neural-Net first guess is operating at SRT and then implement and test this system at JPL for a number of months, if not years. We will compare monthly mean inter-month and interannual differences obtained from AIRS, CrIS, and NUCAPS.

High Spectral Resolution CrIS Data

NOAA plans to begin to downlink the full interferogram for all CrIS bands in the future.

Three Issues

- We need a new high spectral resolution CrIS RTA to analyze this data
  Preferably consistent with our current RTA provided by
  Larrabee Strow – must include non-LTE.
- From the long term CrIS CDR perspective, this might introduce a discontinuity in level-3 retrieval products. It might be better to generate long term level-3 CDR products using consistent spectral resolution CrIS data.
- Given this consideration, it would be important to generate two sets of CrIS SDR's: low spectral resolution as before and high spectral resolution.

NASA

Status of the NOAA Operational Hyper Spectral IR + Microwave Retrieval Algorithm

Antonia Gambacorta[1], Walter Wolf[3], Thomas King[1], Chris Barnet[2], Nick Nalli[1], Mike Wilson [1], Kexin Zhang[1], Xiaozhen Xiong[1], Flavio Iturbide Sanchez[1], Changyi Tan[1], Mark Liu [3], Mitch Goldberg[4]

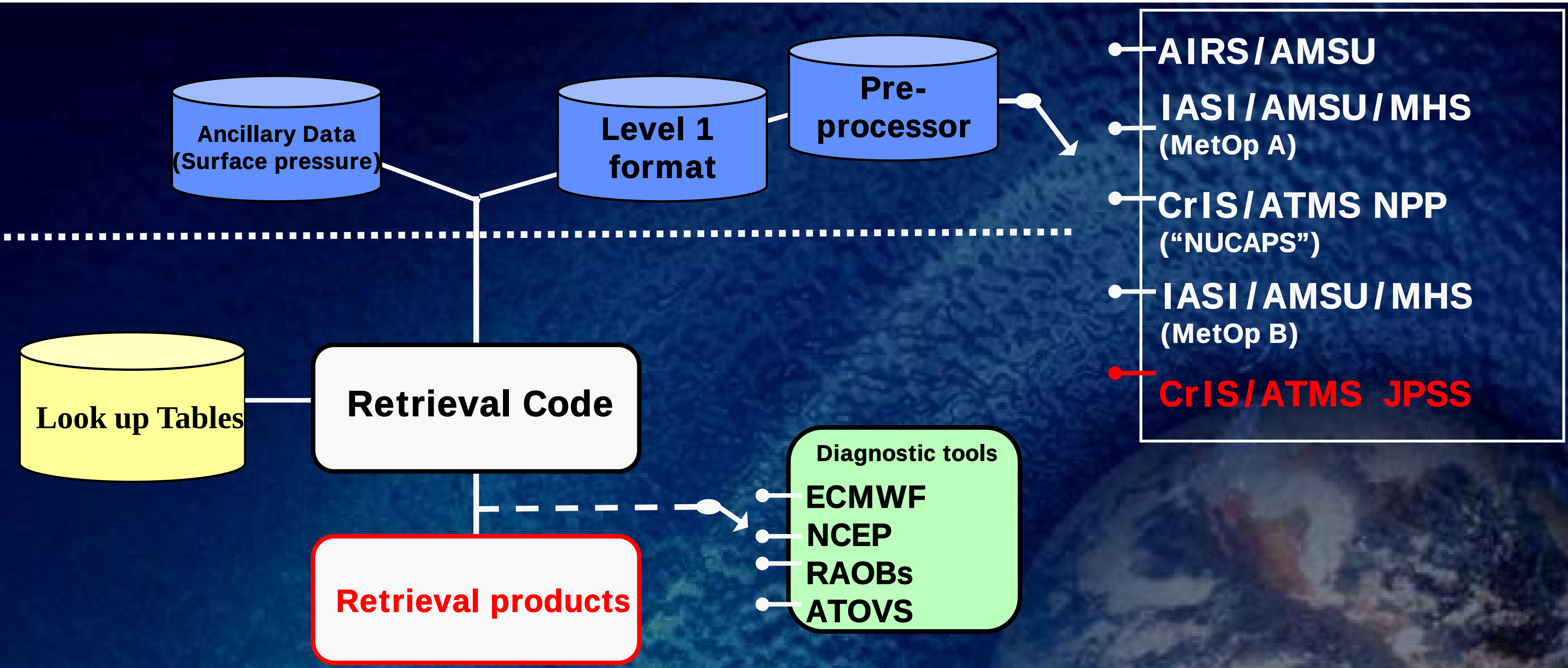
STAR JPSS Annual Science Team Meeting
NOAA Center for Weather and Climate Prediction, College Park, MD
May 14, 2014

(1) I&M System Group
(2) Science and Technology Corporation
(3) NOAA/NESDIS/STAR
(4) NOAA JPSS Office

Outline

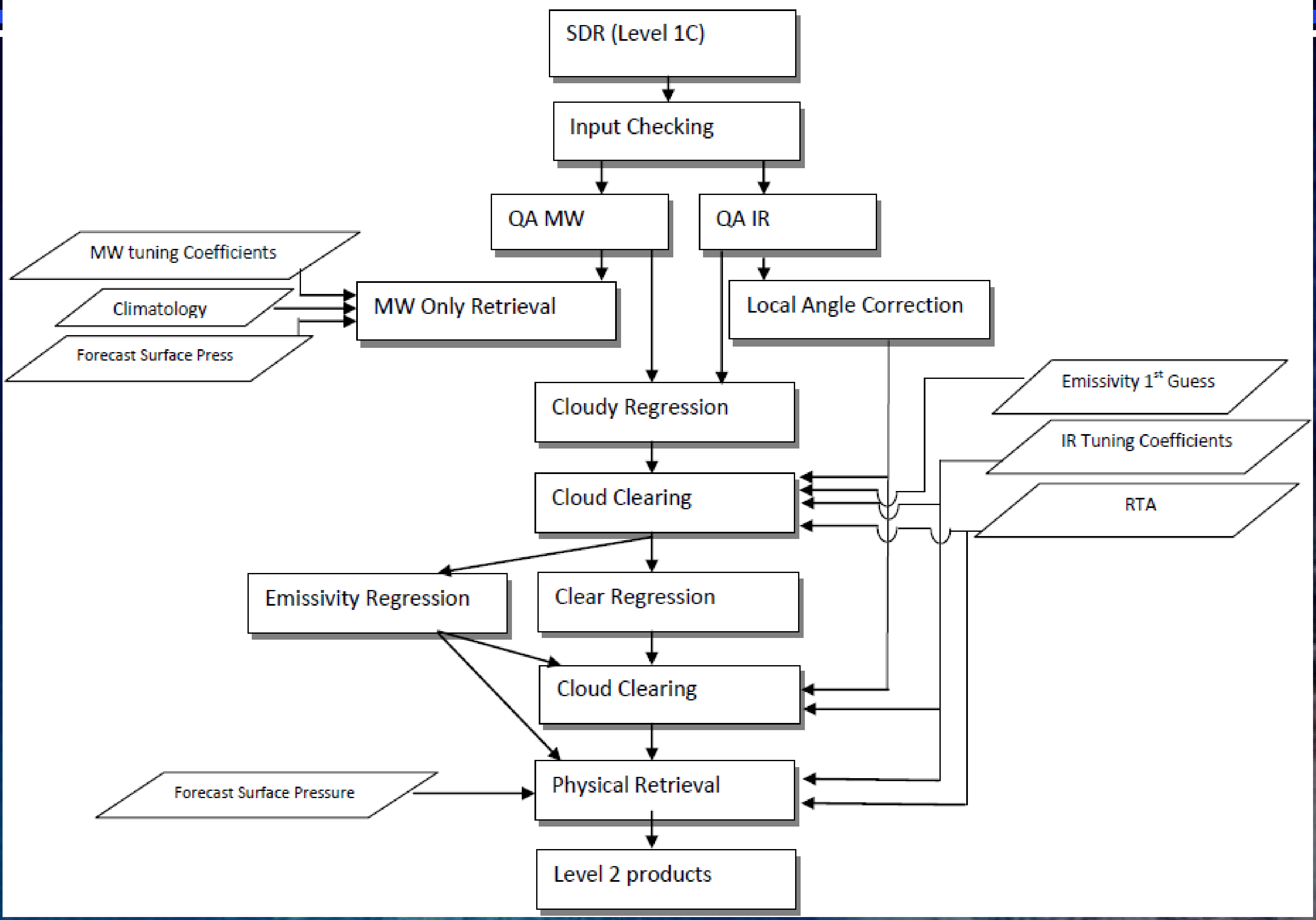
- Architecture of the NOAA operational hyper spectral retrieval algorithm
- Performance assessment: global, ocean, latitudinal regimes
- Cross-comparison of the performance of the CrIS/ATMS, IASI/AMSU/MHS and AIRS/AMSU retrieval systems
- Demonstration experiment of CrIS high resolution retrieval capabilities (CO impact study
- IASI and CrIS ILS distortion effects in presence of scene in-homogeneities
- NUCAPS Project Plan
- Conclusions and future work

The NOAA MW+IR retrieval system



- Using the same retrieval algorithm, same underlying spectroscopy, same set of assumptions and same look up table methodology is a key strategy for a homogeneous multi-satellite integrated dataset of environmental data records.

The NOAA MW+IR retrieval system



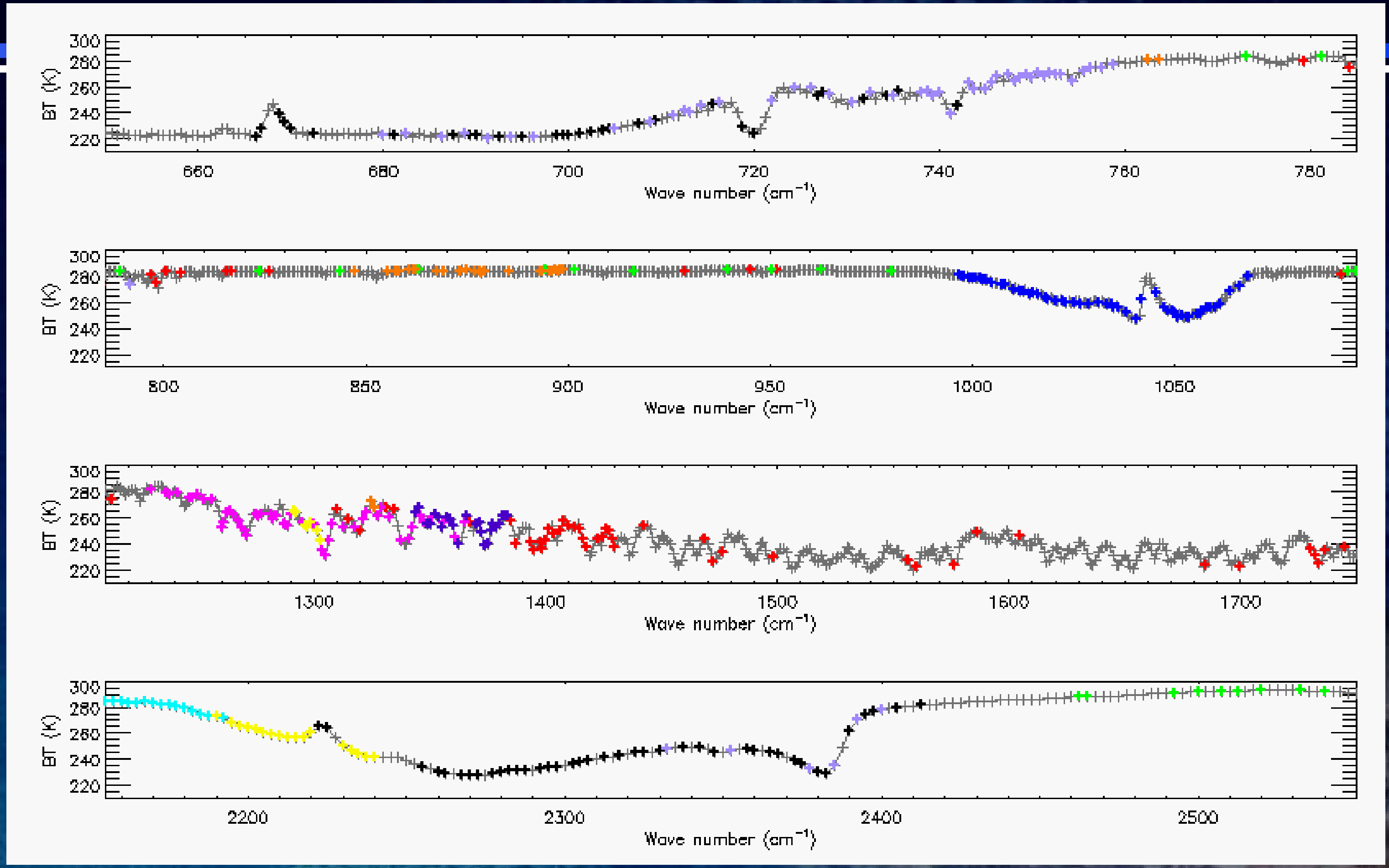
The NOAA MW+IR retrieval system

•A multi-step retrieval algorithm, heritage of the AIRS Science Team Retrieval Algorithm, made of the following main steps:

- 1) a microwave retrieval module which derives cloud liquid water flags
- 2) a fast eigenvector regression retrieval that is trained against the European Center for Medium-Range Weather Forecasts (ECMWF) analysis and CrIS all sky radiances
- 3) a cloud clearing module
- 4) a second fast eigenvector regression retrieval that is trained against ECMWF analysis and CrIS cloud cleared radiances
- 5) the final infrared physical retrieval based on a regularized iterated least square minimization

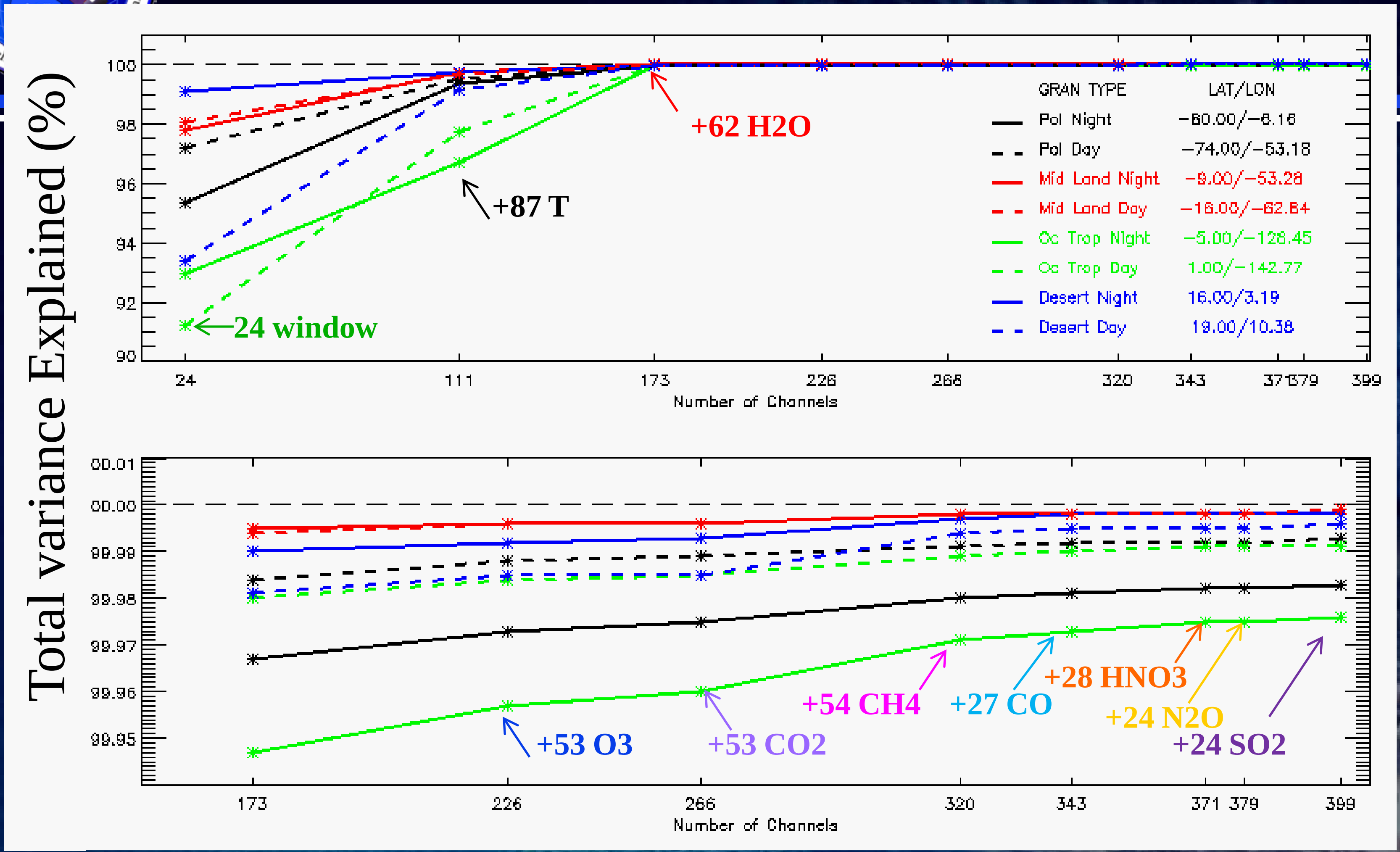
CrIS Operational Channel Selection (Total # of Channels: 399)

EDR	#chns
T	87
Surf	24
HO2	62
O3	53
CO	27
CH4	54
N2O	24
SO2	54
HNO3	28
CO2	53



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

Total Variance Explained



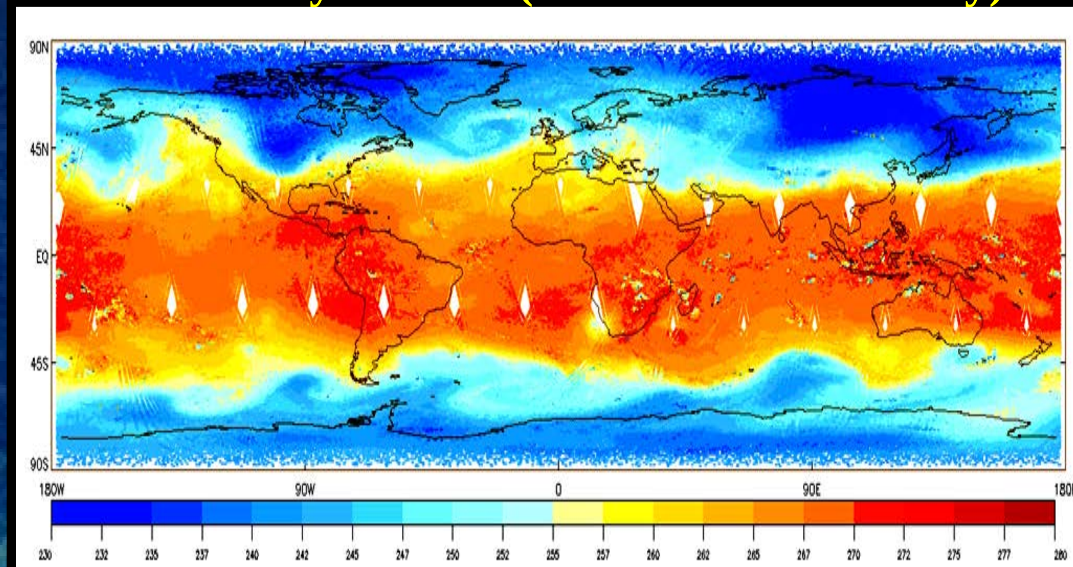
- The full list of 399 selected channels explains ~99.9% of the total atmospheric variance, consistently across all geophysical regimes.
- The first 173 channels (window, temperature and water vapor channels) alone explain ~ 99% of the total atmospheric variance. REF: Gambacorta et al., IEEE, 2013

Operational Retrieval Products

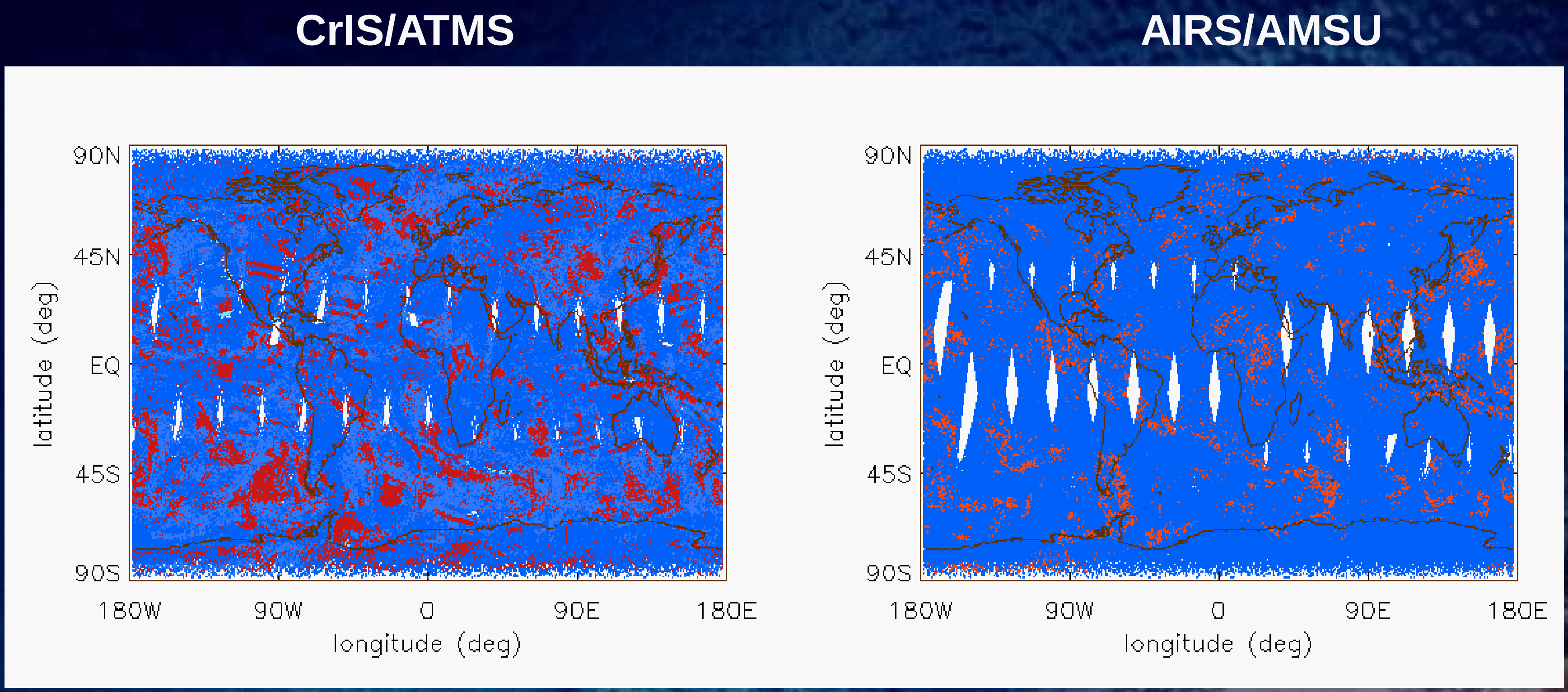
Retrieval Products

Cloud Cleared Radiances	660-750 cm-1 2200-2400 cm-1
Cloud fraction and Top Pressure	660-750 cm-1
Surface temperature	window
Temperature	660-750 cm-1 2200-2400 cm-1
Water Vapor	780 – 1090 cm-1 1200-1750 cm-1
O3	990 – 1070 cm-1
CO	2155 – 2220 cm-1
CH4	1220-1350 cm-1
N2O	1290-1300cm-1 2190-2240cm-1
HNO3	760-1320cm-1
SO2	1343-1383cm-1

NUCAPS Temperature retrieval @ 500mb
January 5th 2014 (Polar Vortex Anomaly)

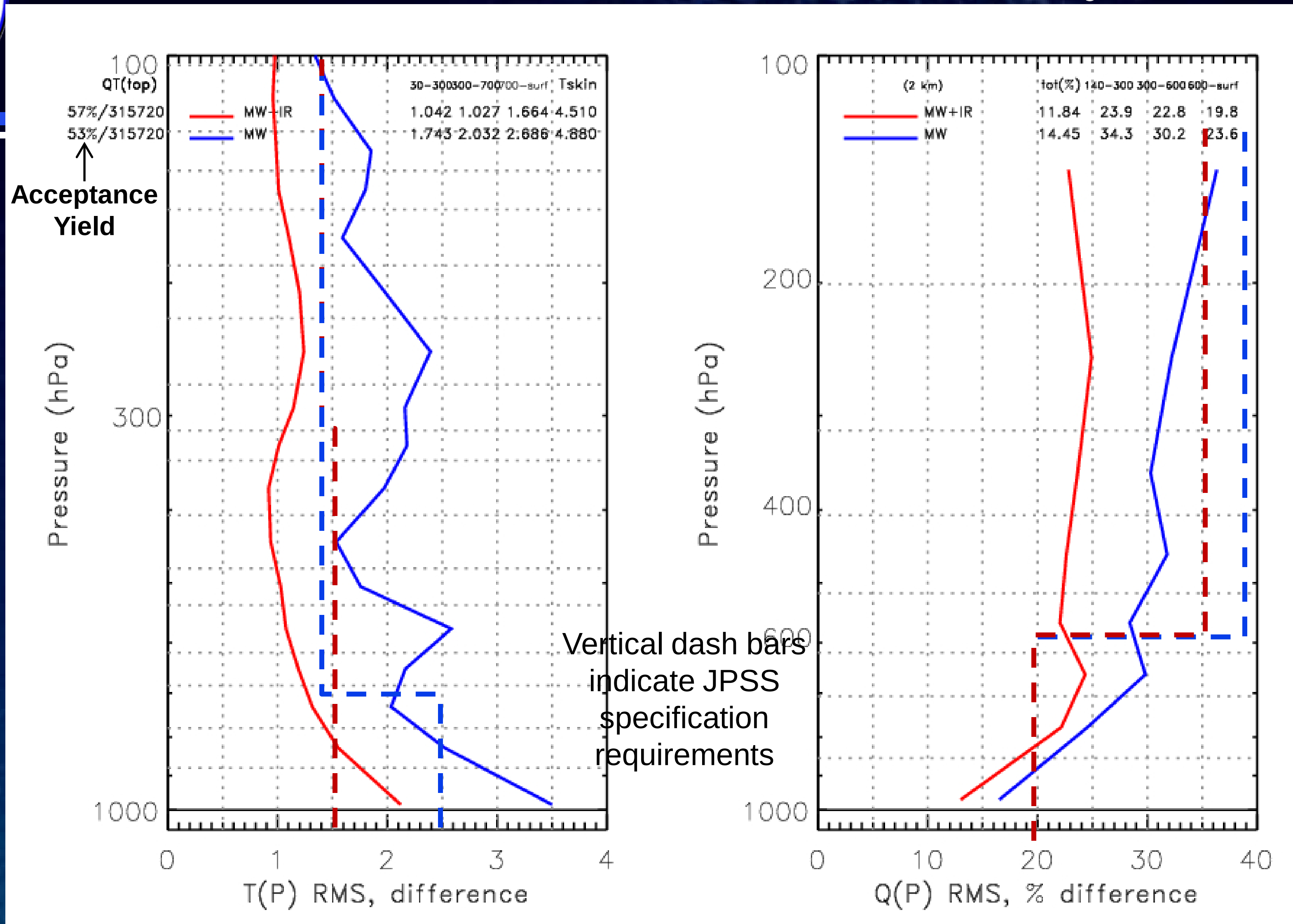


CrIS/ATMS vs AIRS/AMSU retrieval acceptance yield
BLUE= accepted RED = rejected



- AIRS/AMSU global acceptance yield is ~75%
- CrIS/ATMS global acceptance yield is ~60% (retrieval parameters and QC optimization is in progress)

NUCAPS MW+IR & MW Only
Global RMS Statistics vs ECMWF Analysis



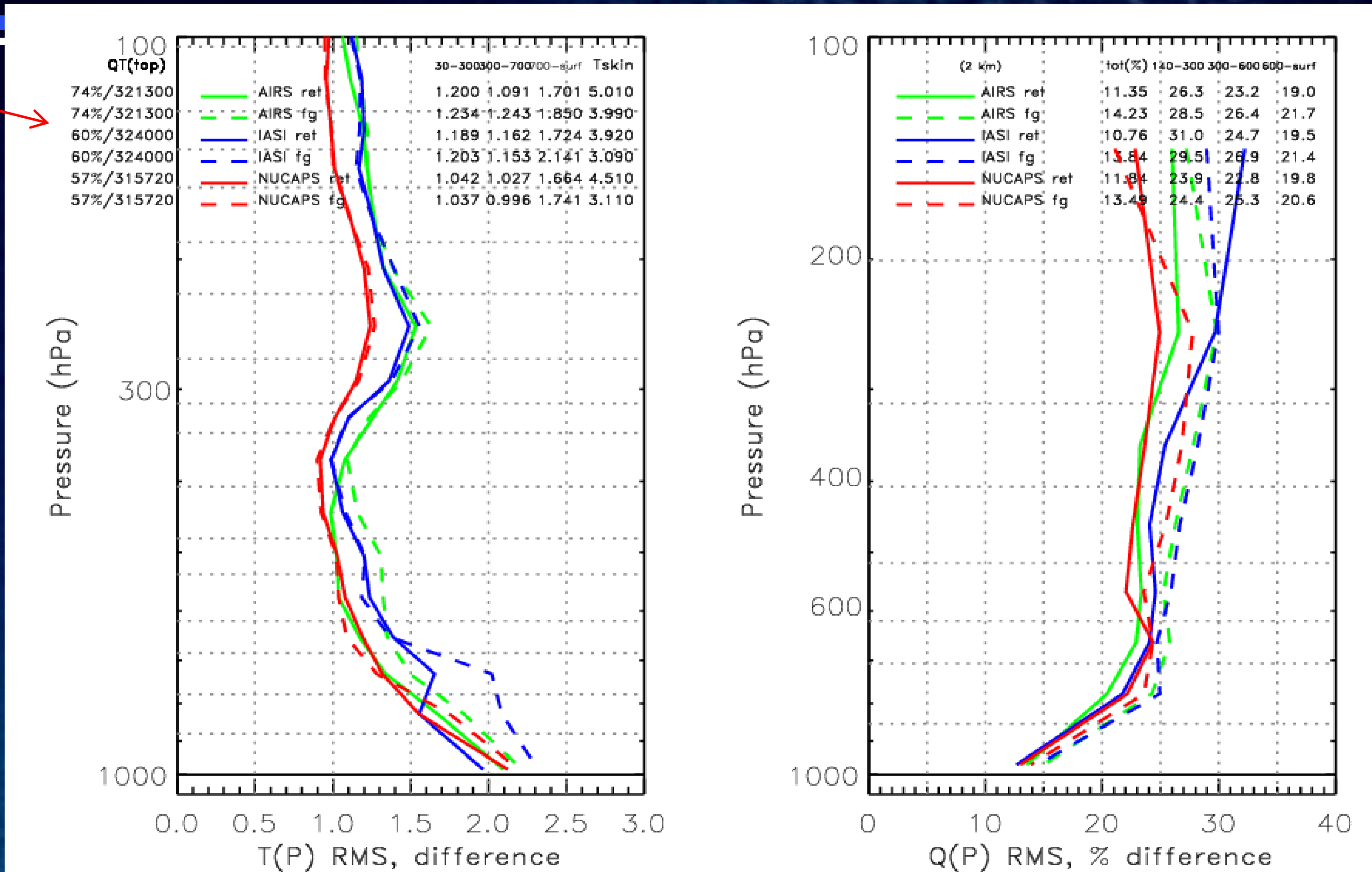
- NUCAPS MW+IR temperature and water vapor generally meet requirements
- NUCAPS MW-Only water vapor meets requirements; temperature needs further optimization

CrIS IASI AIRS

Global RMS Statistics vs ECMWF Analysis

(dash lines = first guess)

QA Acceptance Yield



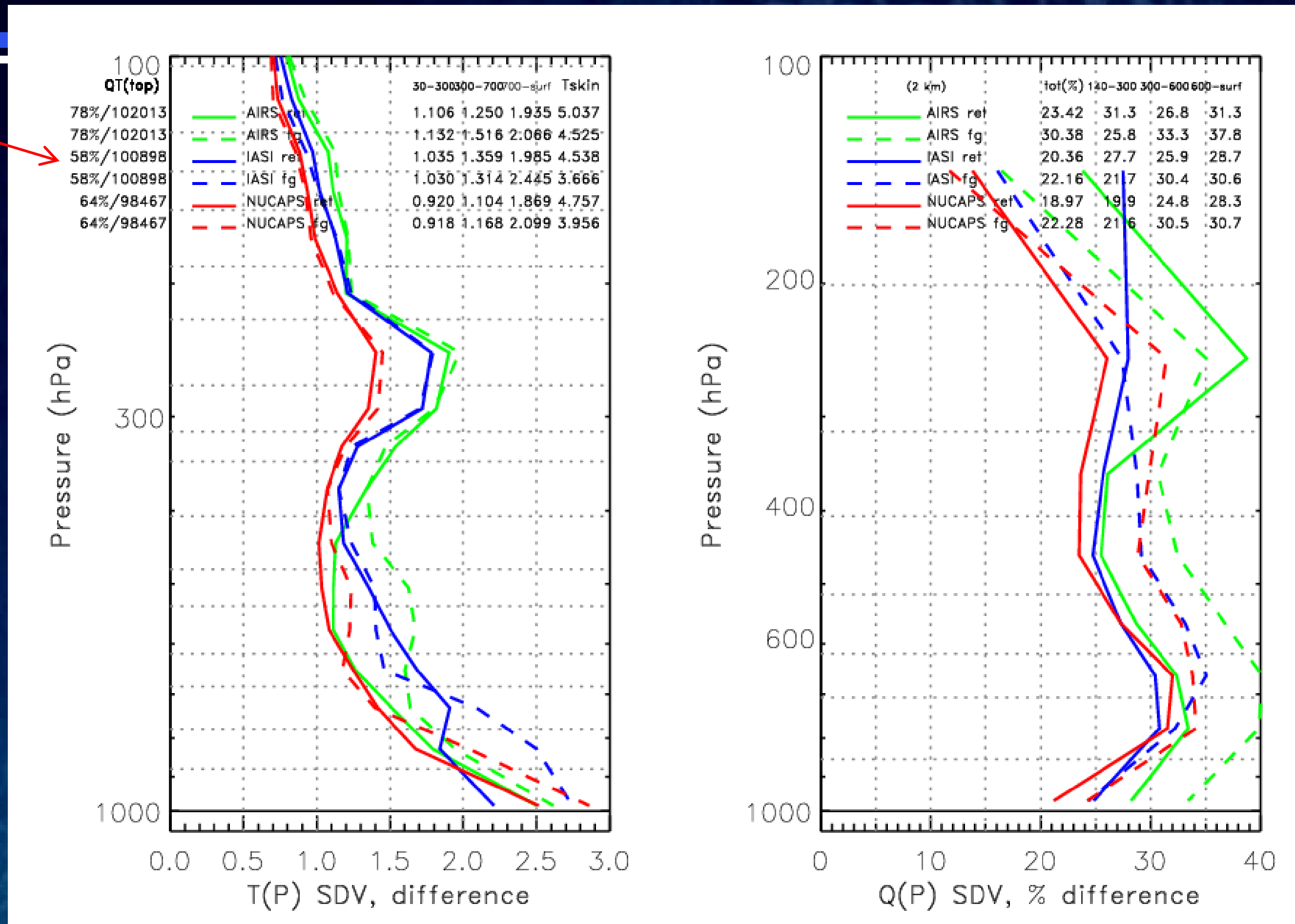
- Retrieval performance is stable and consistent across the three platforms.
- CrIS comparable to AIRS and IASI (10+ year maturity systems)
- Physical retrieval (solid) shows significant departure from first guess (dash line)

CrIS IASI AIRS

SDV Statistics vs ECMWF Analysis – Polar Regime

(dash lines = first guess)

QA Acceptance Yield



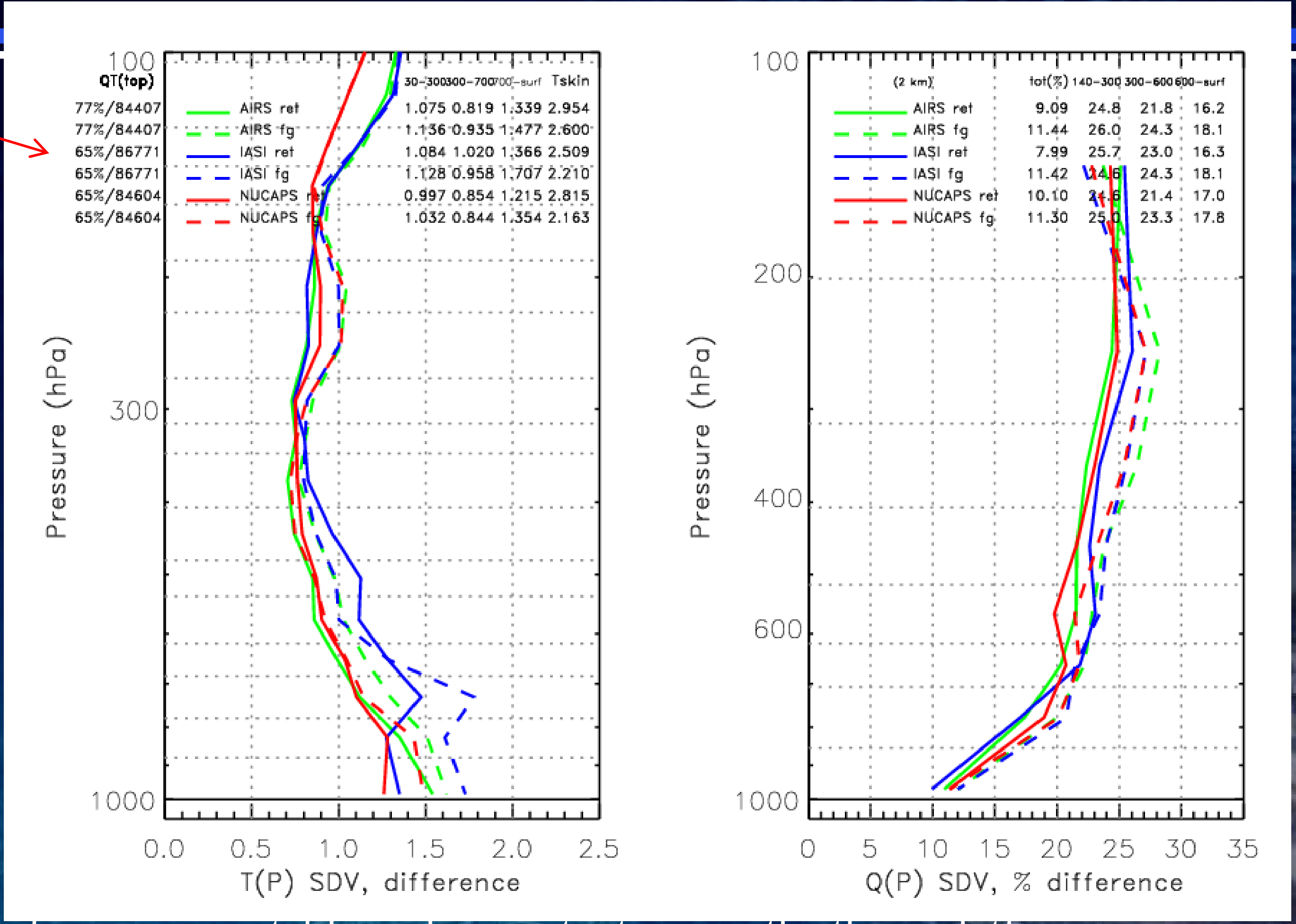
- Retrieval performance is stable and consistent across the three platforms.
- CrIS comparable to AIRS and IASI (10+ year maturity systems)
- Physical retrieval (solid) shows significant departure from first guess (dash line)

CrIS IASI AIRS

SDV Statistics vs ECMWF Analysis – Tropical Regime

(dash lines = first guess)

QA Acceptance Yield



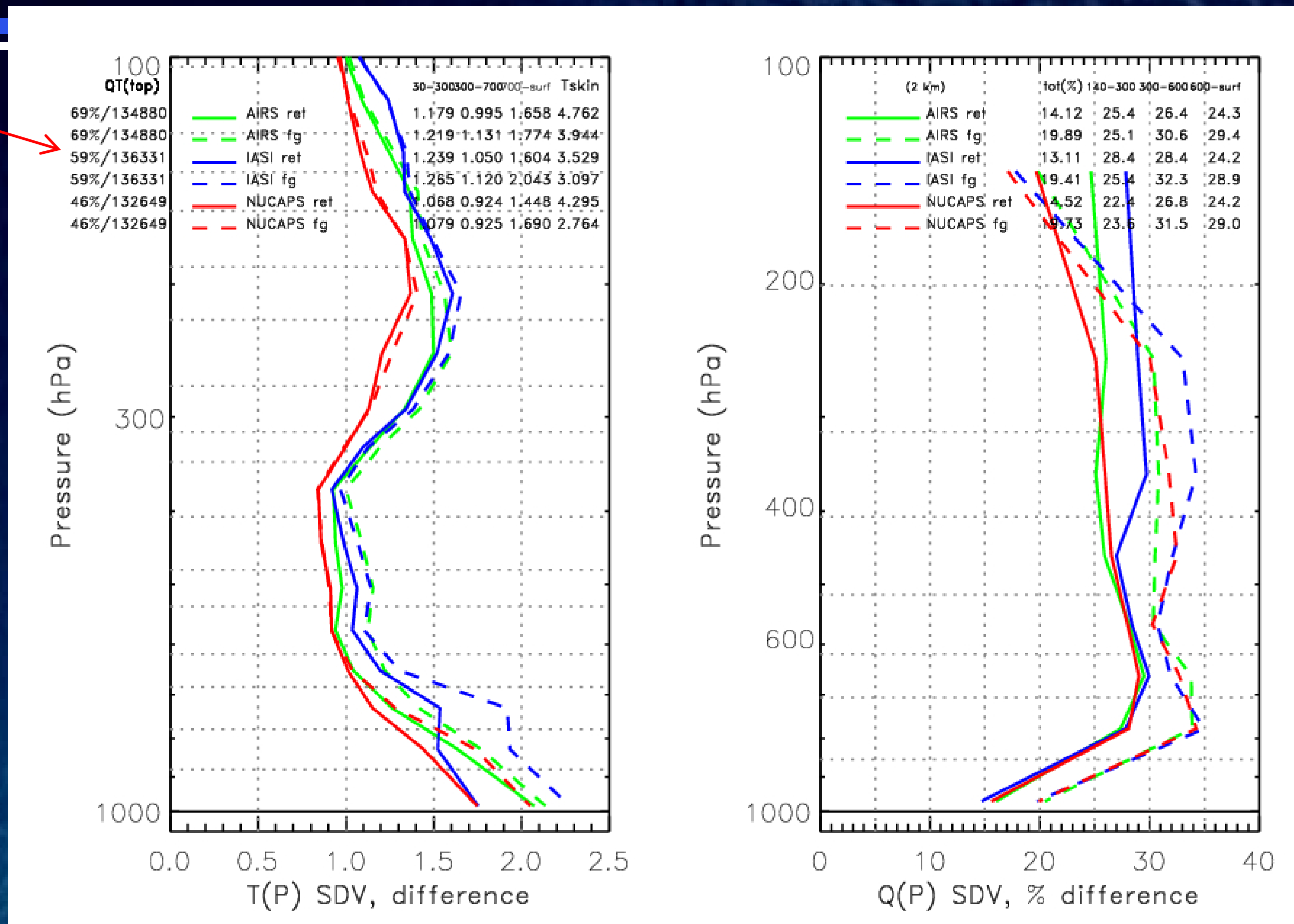
- Retrieval performance is stable and consistent across the three platforms.
- CrIS comparable to AIRS and IASI (10+ year maturity systems)
- Physical retrieval (solid) shows significant departure from first guess (dash line)

CrIS IASI AIRS

SDV Statistics vs ECMWF Analysis – MID LAT Regime

(dash lines = first guess)

QA Acceptance Yield



- Retrieval performance is stable and consistent across the three platforms.
- CrIS comparable to AIRS and IASI (10+ year maturity systems)
- Physical retrieval (solid) shows significant departure from first guess (dash line)

An experiment using higher resolution NPP CrIS measurements: impact on carbon monoxide retrievals

- **The Cross-Track Infrared Sounder (CrIS)** is a Fourier spectrometer covering the longwave (655-1095 cm-1, “LW”), midwave (1210-1750 cm-1, “MW”), and shortwave (2155-2550 cm-1, “SW”) infrared spectral regions.

- **Current operations:**
  - » Maximum geometrical path difference *L* = 0.8 cm (LW), 0.4 cm (MW) and 0.2 cm (SW)
  - » Nyquist spectral sampling (*1/2L*): 0.625 cm-1, 1.25 cm-1 and 2.5 cm-1

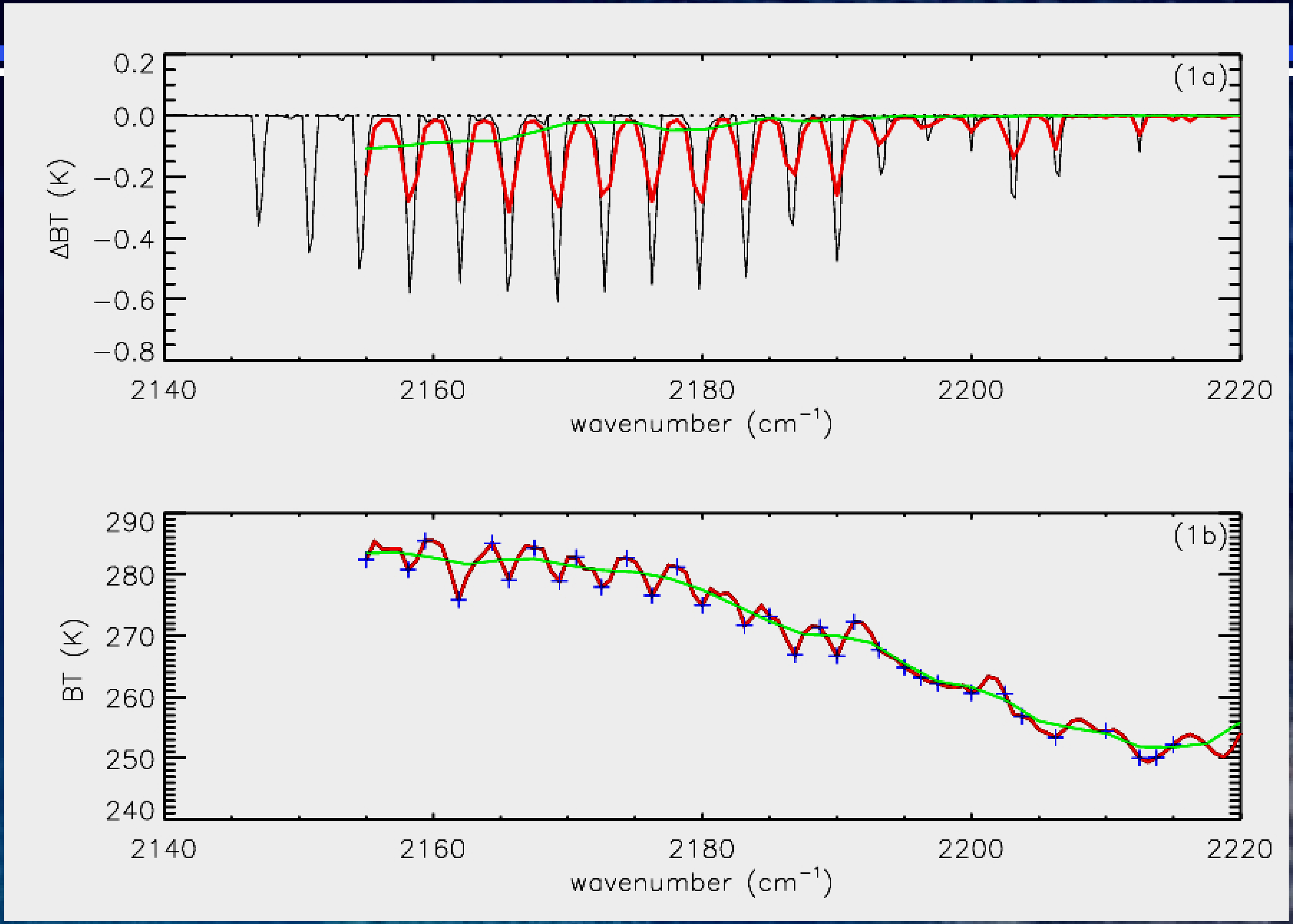
- **Experimental set up** (5 orbits from March 12th 2013)
  - » Maximum geometrical path difference *L* = 0.8 cm in all three bands
  - » Nyquist spectral sampling (*1/2L*): 0.625 cm-1 in all three bands

- **CO retrieval impact study**: CO is expected to benefit the most from the high resolution mode, now increased by a factor of 4 with respect to the operational resolution.

- **Reference:** ***Gambacorta et al., “An experiment using CrIS high spectral resolution measurement for trace gas retrievals: CO retrieval impact study”, IEEE Letters, 2014.***

Sensitivity Analysis to 1% CO perturbation

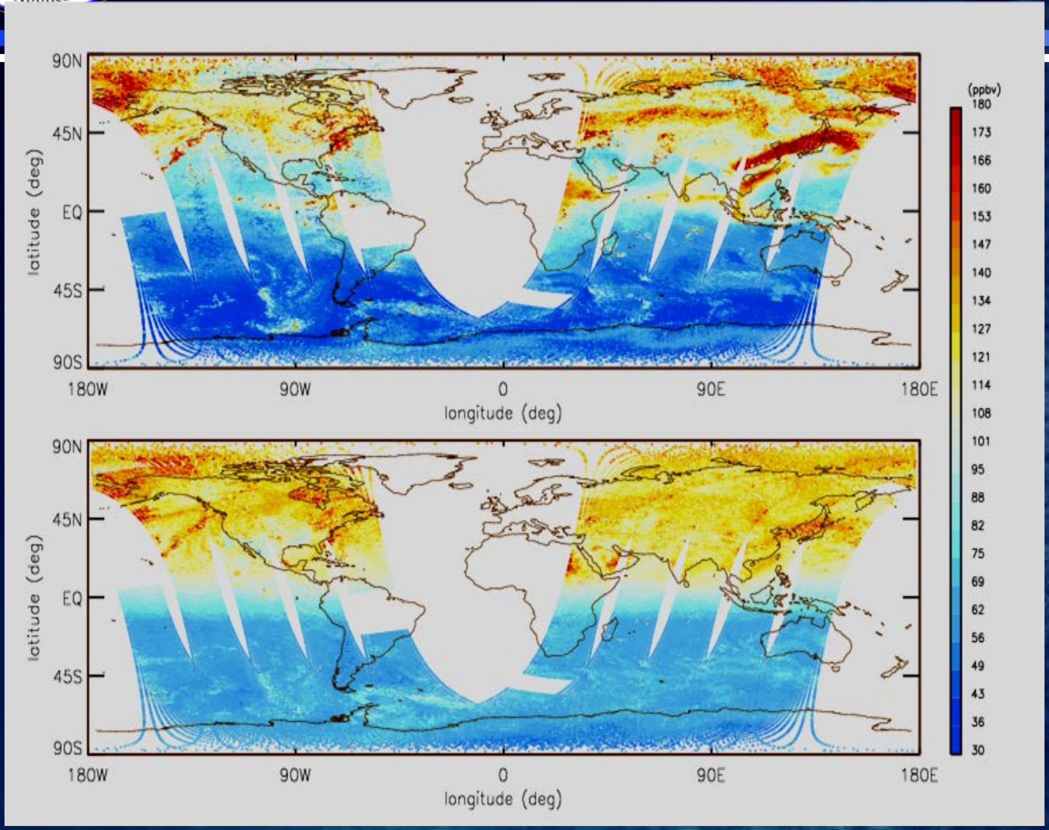
2.5cm^-1   0.625 cm^-1   0.25cm ^-1



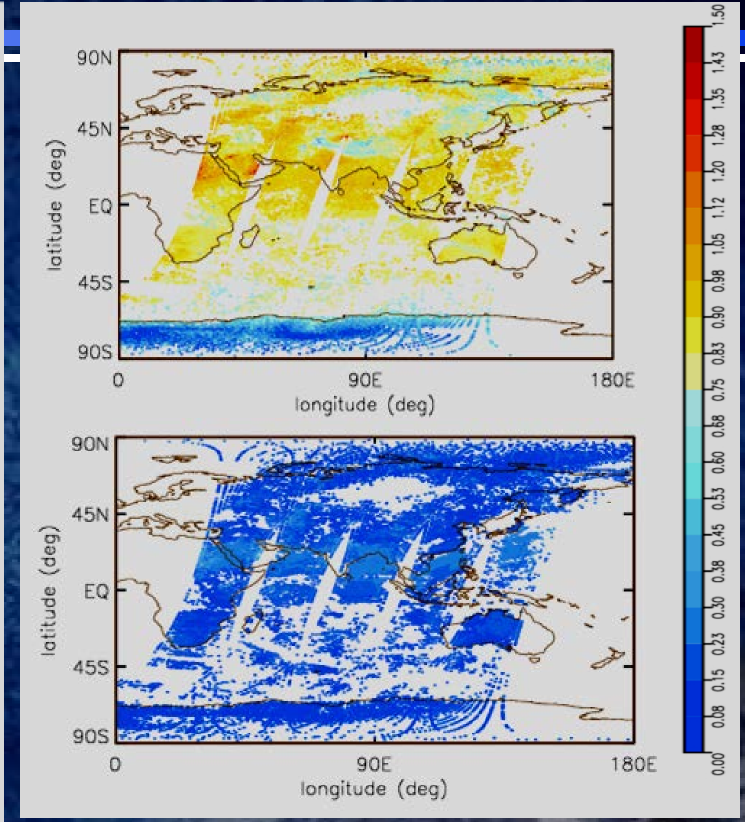
- Only when switched to high spectral resolution, CrIS spectrum (red curve, bottom part) shows the distinctive signature of CO absorption (red and black curve, top figure).
- Blue cross symbols: CO high resolution channel selection.

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

NUCAPS CO retrieval (~450mb)

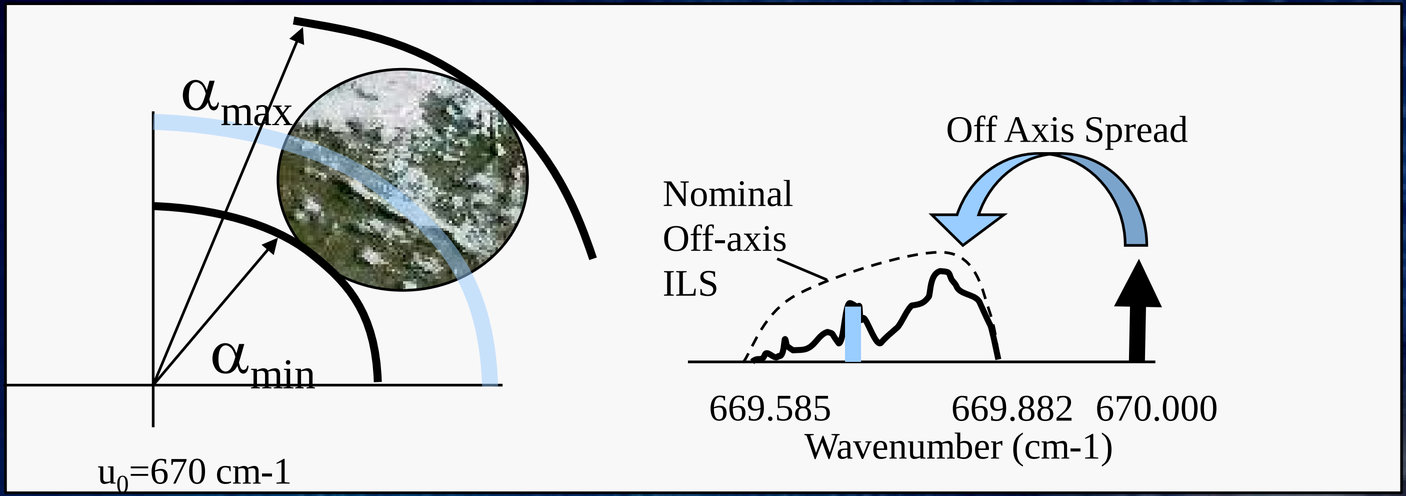


CO DOF



- 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.

FOV ILS Distortion in Presence of Scene Inhomogeneities

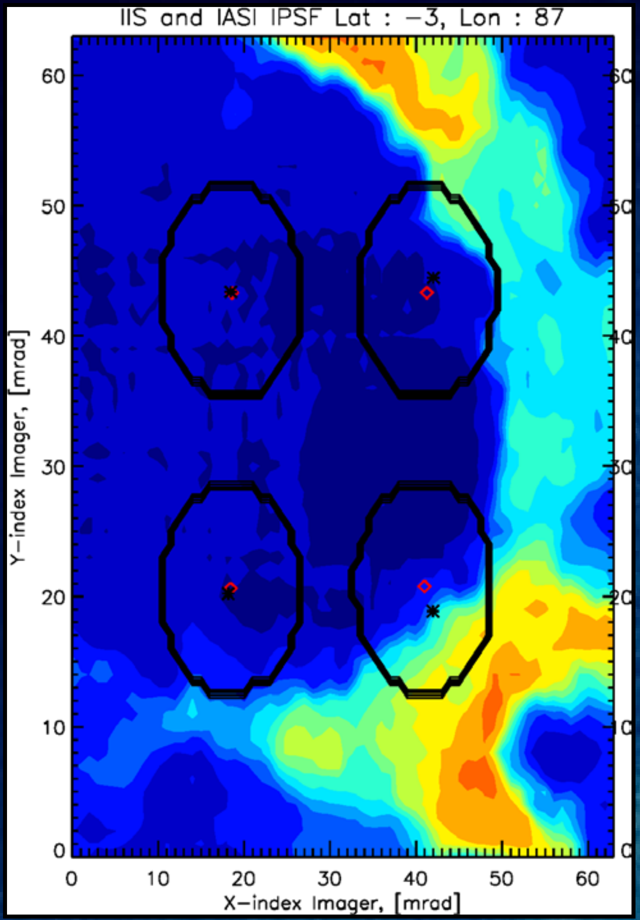


Picture courtesy of Dan Mooney

- Sub pixel scene in-homogeneities (clouds, surface variability, et.) are responsible for a distortion of the nominal off-axis ILS (mainly a frequency shift), introducing an error in the parameterization of the self apodization matrix.
- This error is propagated through the off-axis correction (inversion of the self apodization matrix) introducing an error in the radiance spectrum.

ILS frequency shift computation in presence of scene inhomogeneities: lessons learned from IASI

IIS Imager (64x64 pixels) and IASI FOVs (black contour)



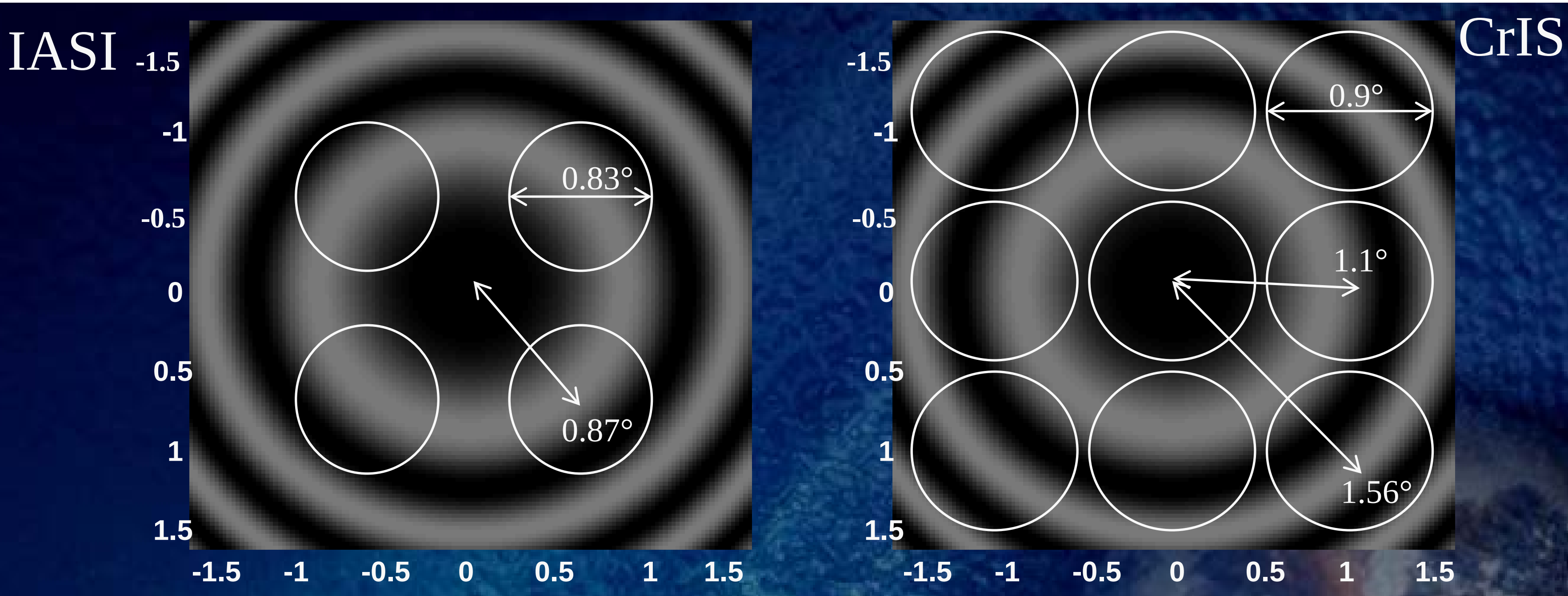
- The ILS distortion due to the presence of scence inhomogeneities is mainly a frequency shift effect, $\delta\nu$, resulting from the angular offset, $\delta\alpha$, between the geometric and radiometric centers of the FOV.

$$\frac{\delta\nu}{\nu} \sim \alpha_0 \delta\alpha$$

<u>Lessons learned from IASI + IIS:</u>

- $\delta\alpha$ distribution results:
  mean = 0.001mrad; 1 sigma = 0.1 mrad
- $\delta\nu/\nu$ =1.5 ppm across the three bands
- Radiance error lower than NEDN across the three bands, hence is negligible.
- Reference: Gambacorta et al.; Proceedings of 2nd IASI International Meeting, Sevrier, 2010.

IASI vs CrIS FOV geometry

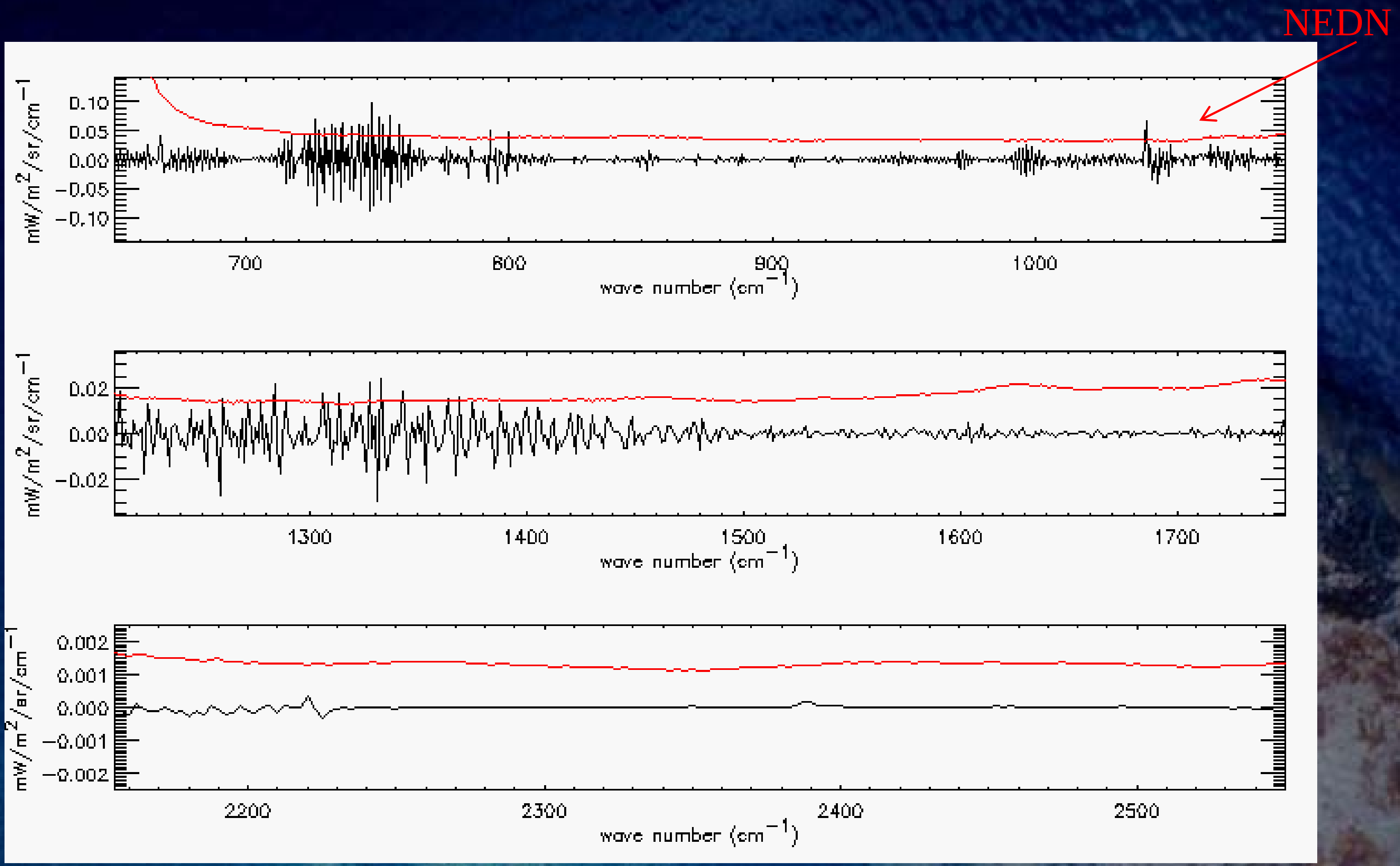


•Applying IASI's δα results to CrIS (assuming surface inhomogeneity and interference ringing are close enough between the two instruments):

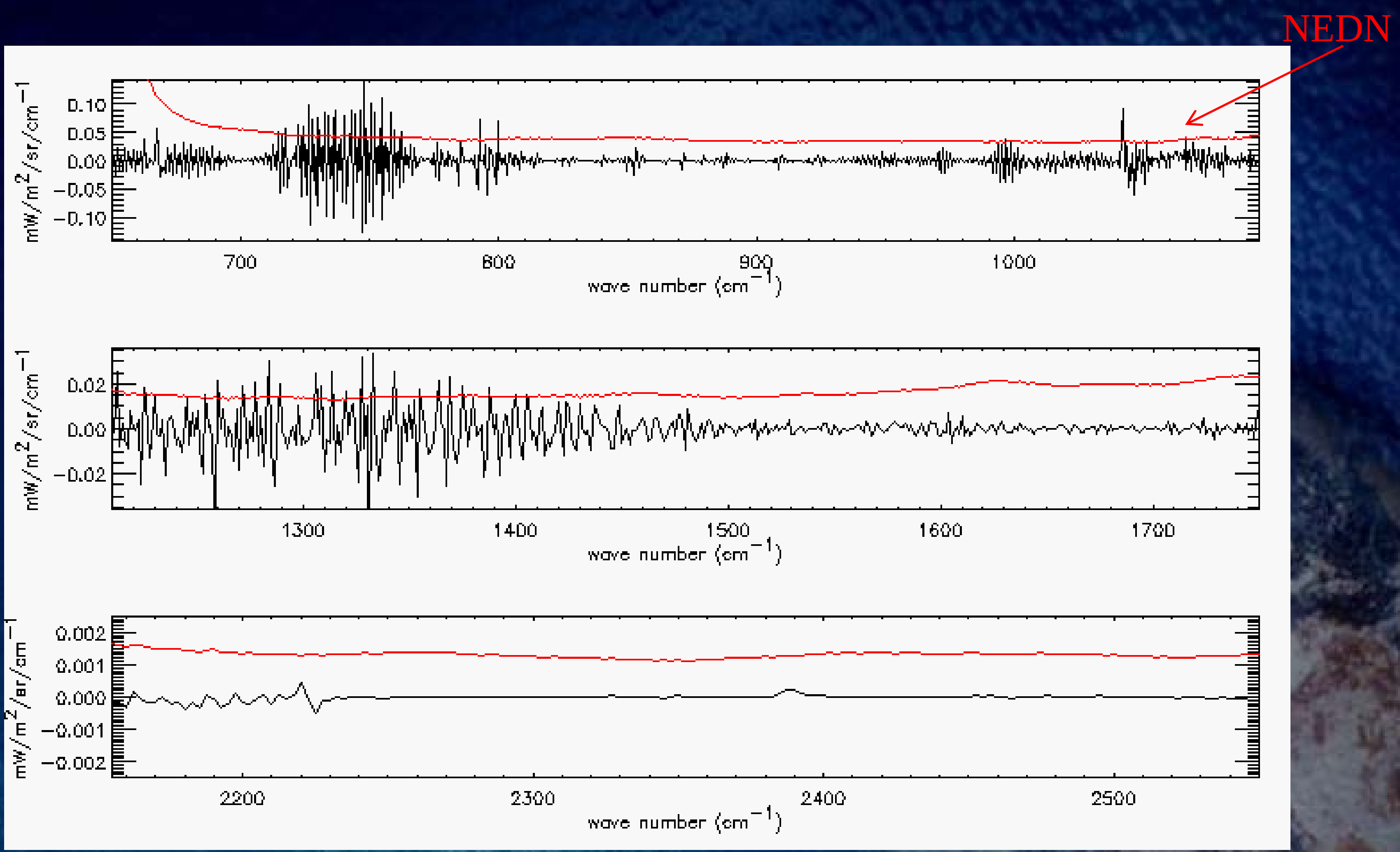
- •CrIS Side Cube (α=1.1°=0.019rad): δν/ν ~ αδα = **1.91e-6**
- •CrIS Corner Cube (α=1.56°=0.027rad): δν/ν ~ αδα = **2.72e-6**

} **< 3ppm**

Radiance error induced by ILS shift
- Side cube -



Radiance error induced by ILS shift
- corner cube -



NUCAPS Project Plan: Task and Schedules

- Schedule (key milestones):
  - » Preliminary Design Review – May 9, 2007
  - » Critical Design Review – Sep. 29, 2008
  - » Test Readiness Review – Sep. 29, 2010
  - » Code Unit Test Review – Oct. 20, 2010
  - » Phase 1 Algorithm Readiness Review – Mar. 14, 2012
  - » NUCAPS Phase 1 Delivery – Mar. 19, 2012
  - » NUCAPS Phase 2 Delivery – Dec. 3, 2012
  - » Phase 2 Algorithm Readiness Review – Jan. 14, 2013
  - » Satellite Product Services Review Board (SPSRB) Briefing for Phase 1 – Jul. 17, 2013
    - – Declared NUCAPS trace gases operational; approved funding.
  - » NUCAPS Phase 1 Operations Commence – Sep. 19, 2013
  - » SPSRB Briefing for Phase 2 – Sep. 18, 2013
    - – Declared NUCAPS T, q, operational in replacement of CrIMSS IDPS; approved funding.
  - » NUCAPS Phase 2 Operations Commence – Oct. 2013

NUCAPS Project Plan:
Task and Schedules

- Schedule (key milestones) continued:
  - » NUCAPS Phase 3 Critical Design Review – Nov. 2013
    - – OLR product delivery
    - – ILS shift in presence of scene in-homogeneities
    - – VIIRS/CrIS collocation
  - » NUCAPS Phase 3 Code Test Review – Mar. 2014
  - » NUCAPS Phase 3 Algorithm Readiness Review – Aug. 2014
  - » NUCAPS Phase 3 DAP Delivery – Sep. 2014
  - » SPSRB Phase 3 briefing – Oct. 2014
  - » NUCAPS Phase 3 Operations Commence – Oct. 2014
  - » AIRS, IASI, CrIS full data record reprocessing for science application ~2015

Conclusion Remarks and ongoing work

- NUCAPS MW+IR retrievals performance:
  - **MW+IR temperature and water vapor generally meet requirements**
  - **MW-Only water vapor meets requirements; temperature needs further optimization**
- Cross – comparison validation efforts have shown consistency across all three systems: CrIS/ATMS, IASI/AMSU/MHS and AIRS/AMSU.
- On going validation and development activity involves the improvement of the intermediate modules of the retrieval algorithm: mw-only retrieval step, first guess, a priori, regularization parameters, rta bias correction,etc.
- We have provided evidence to support the need for high spectral resolution CrIS measurements. The modular architecture of NUCAPS has proven that there is no risk of disruption to the operational processing upon switching to high spectral resolution mode.
- Assessment of the impact of the ILS shift in presence of surface in-homogeneities has been proven negligible for both the IASI and CrIS instruments.
- The results of this effort guarantee continuity to the afternoon orbit sounding as part of a multi-satellite, uniformly integrated, long term data record of atmospheric variables and also serve in preparation of future advanced satellite missions under the Joint Polar Satellite System and IASI Next Generation.

Back Up slides

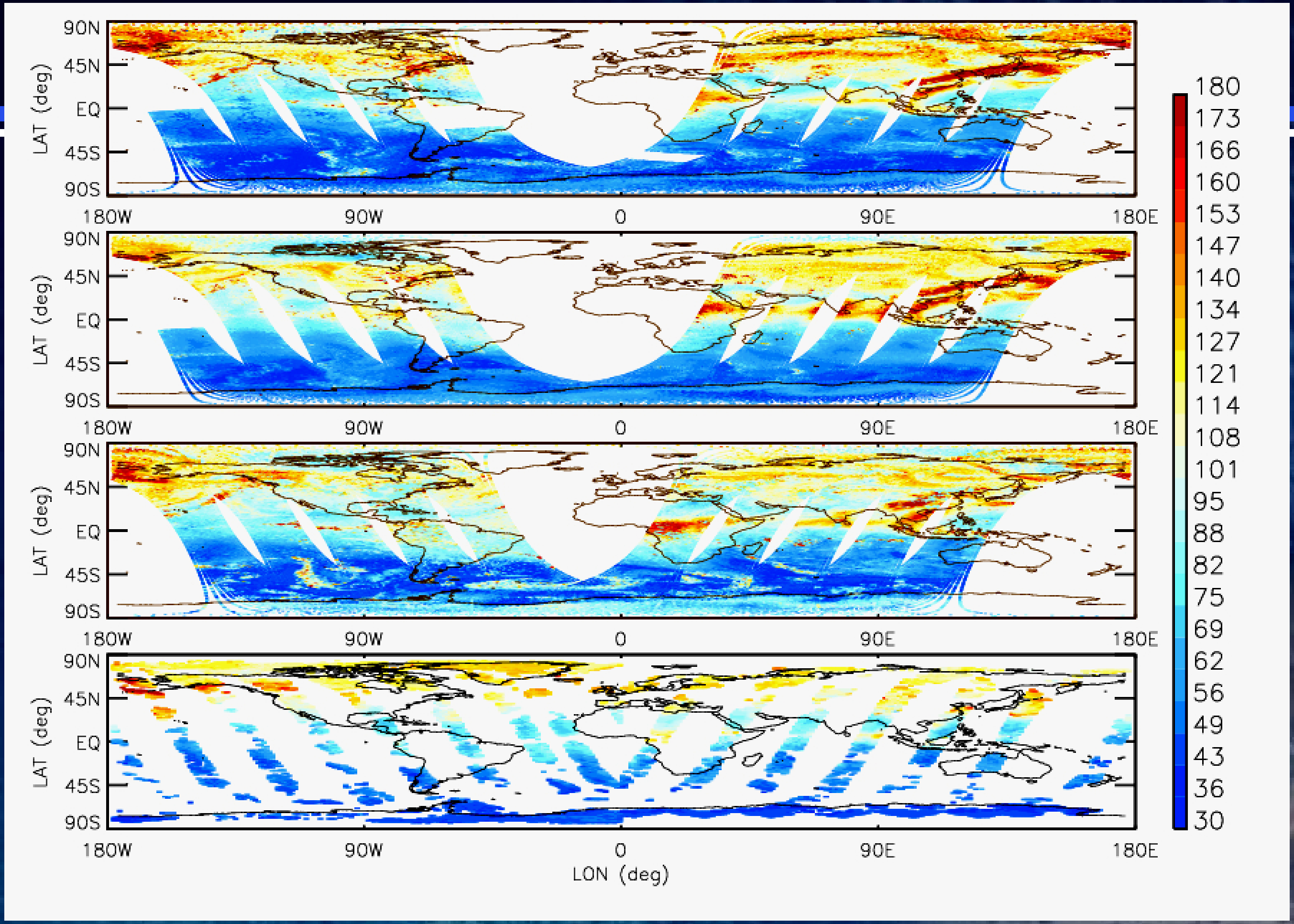
NUCAPS High RES (top), AIRS (second), IASI (third) and MOPITT (bottom) CO retrievals

NUCAPS High RES

AIRS

IASI

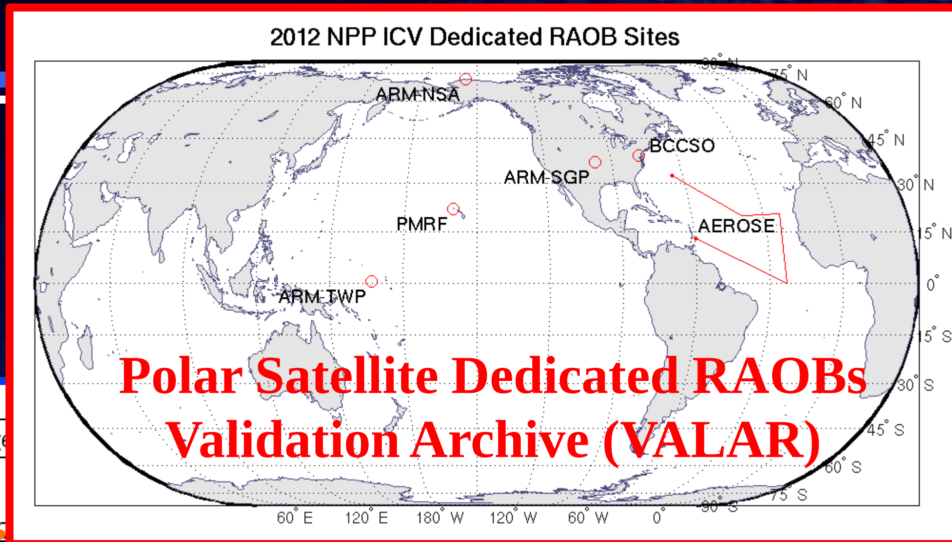
MOPITT



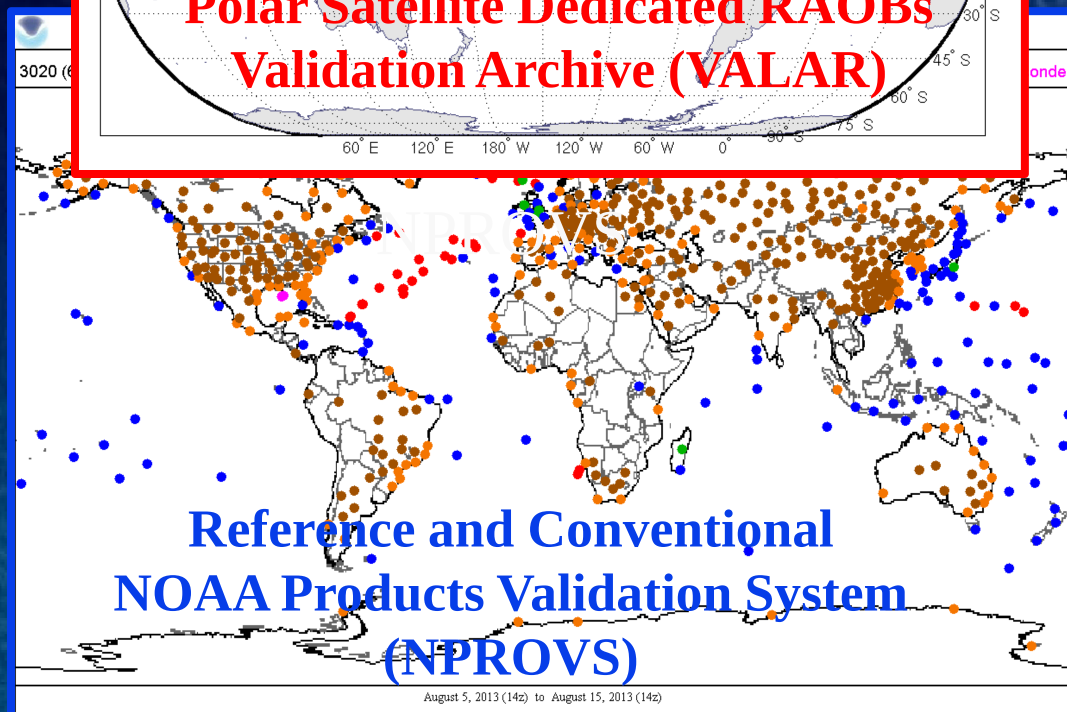
- NUCAPS high resolution CO retrievals show a significantly improved agreement to all three CO satellite products. The observed differences among the four instruments are consistent with what has been previously observed and have been mainly attributed to differences in instrumental spectral resolution, retrieval methods, a priori and thermal contrast diurnal cycle.
- This analysis intended to provide a performance demonstration of the NUCAPS high resolution CO product, in terms of both spatial variability and order of magnitude, in support for the need of high resolution radiance measurements.

Ongoing Retrieval Validation Strategy

Validation
Data
Sample
Yield



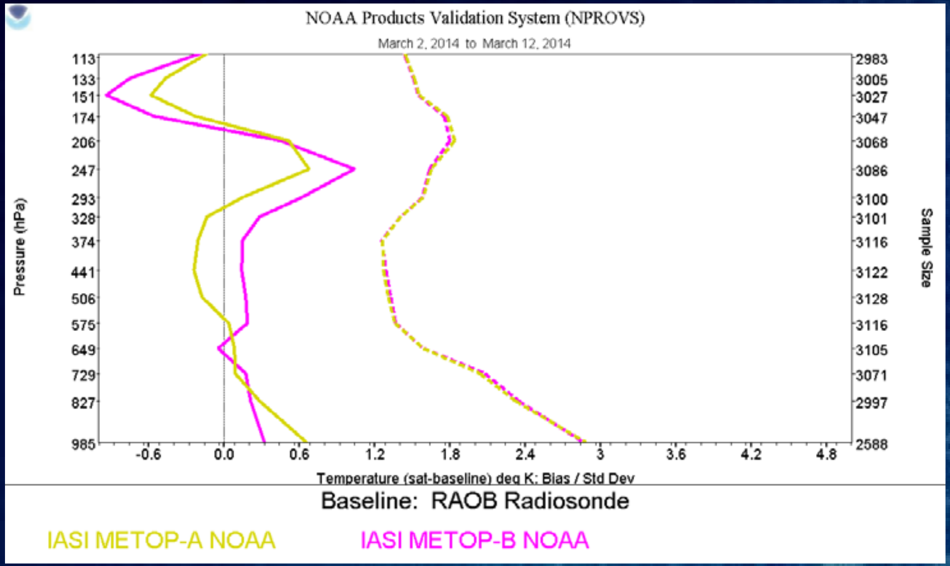
Polar Satellite Dedicated RAOBs Validation Archive (VALAR)

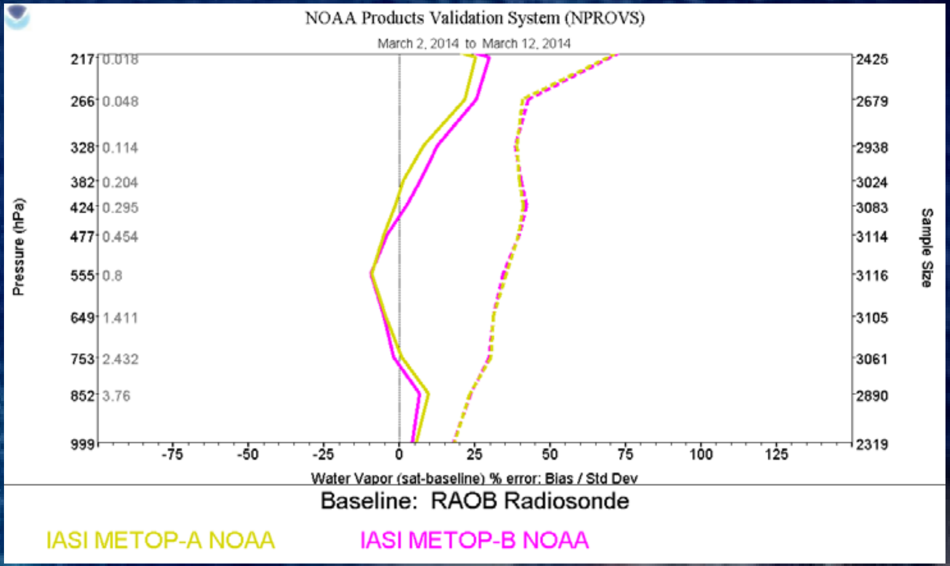


Reference and Conventional NOAA Products Validation System (NPROVS)

Validation
Data
Sample
Quality

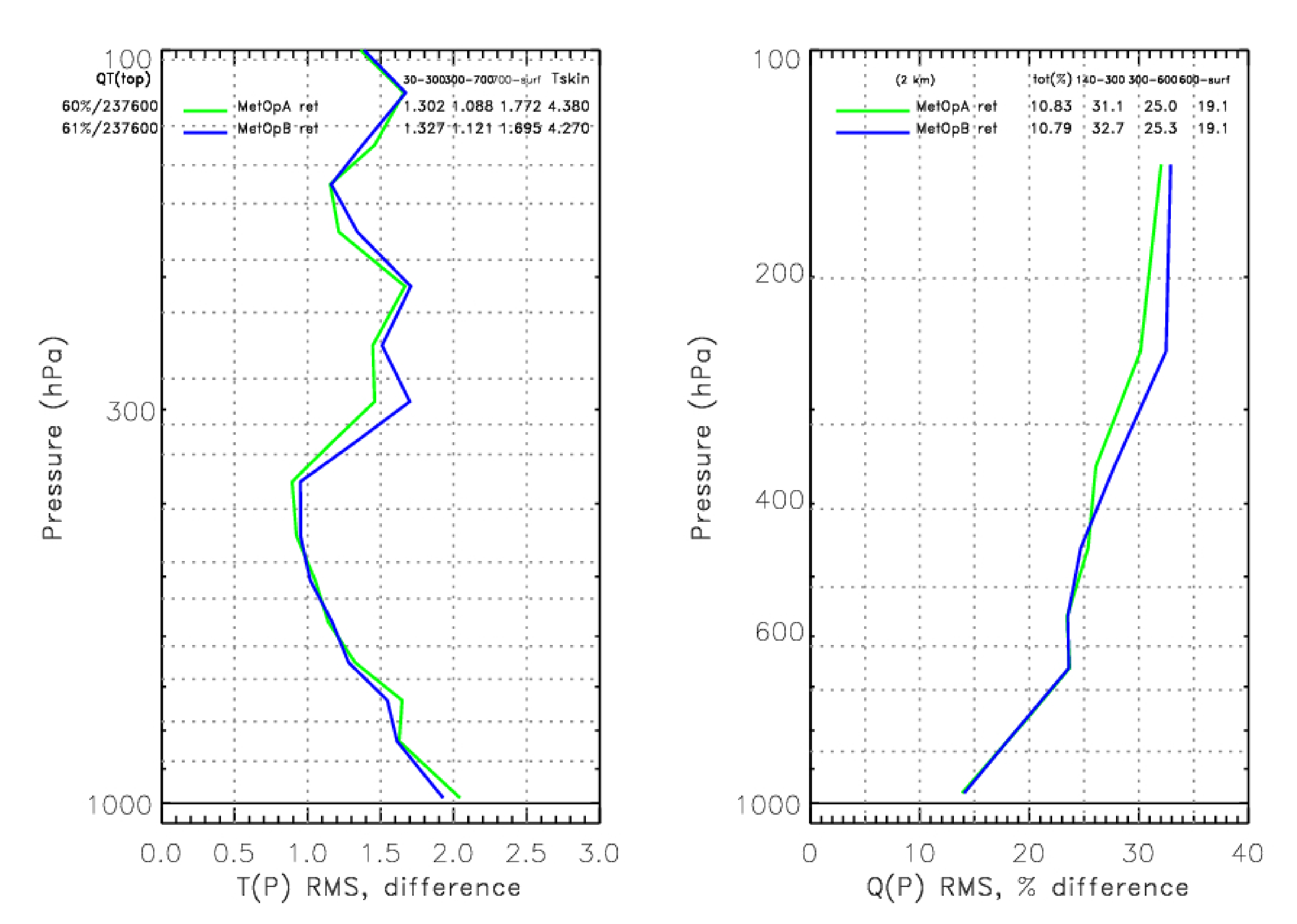
IASI MetOp A vs IASI MetOp B





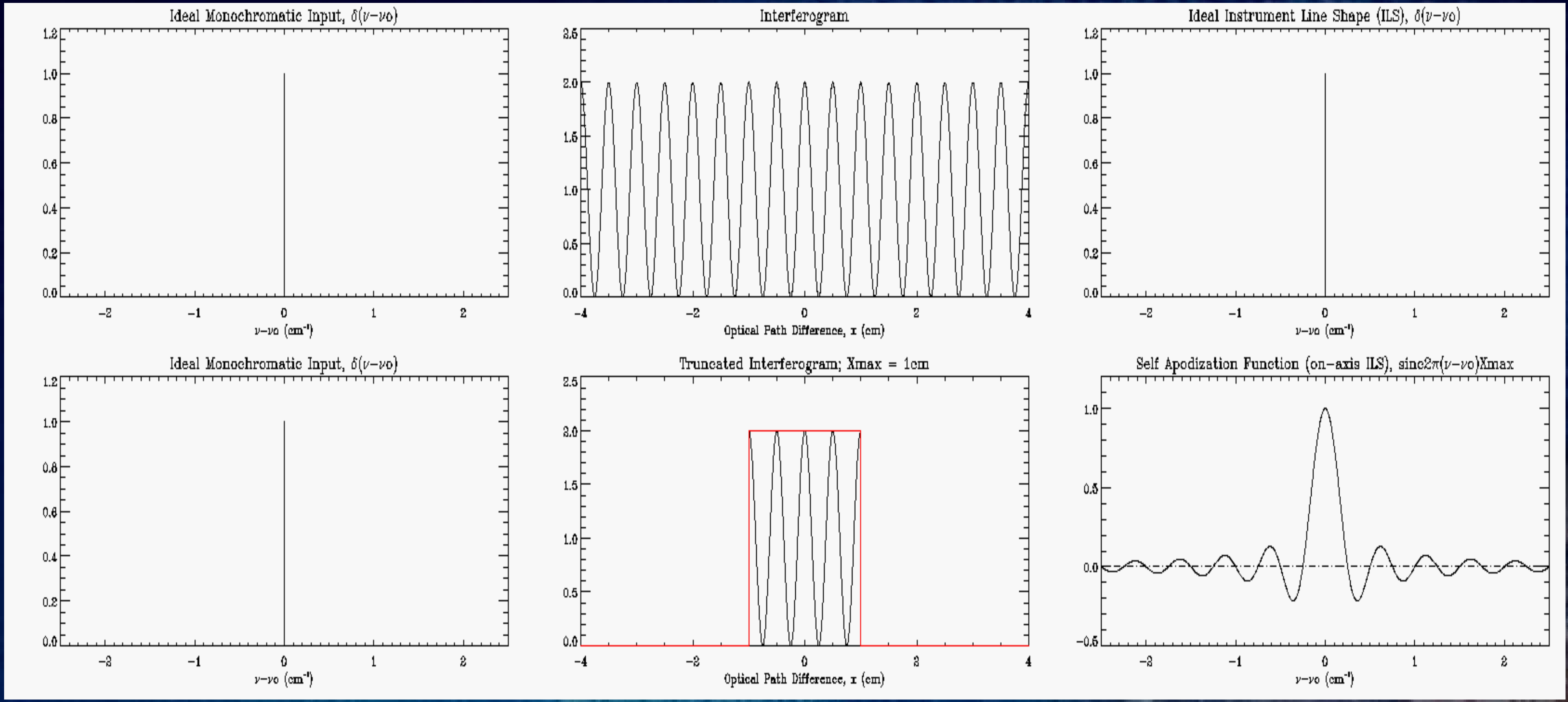
- Same exact code and look up tables used for both systems
- Consistency between the two systems is remarkable

IASI MetOp A IASI MetOp B
Global RMS Statistics vs ECMWF Analysis



- Retrieval performance is stable and consistent between IASI MetOp A and B systems.
- Same exact *code, spectroscopy and look up tables* are used for both.
- Results are consistent with findings from EUMETSAT partners.

Truncation of the Interferogram & Resulting Instrument Line Shape



The Instrument Line Shape resulting from the box-car truncation is a sinc function with pronounced side lobe effects.

Parameter	JPSS Requirements (6/27/2013)
AVMP Clear, surface to 600 mb	20% or 0.2 g/kg
AVMP Clear, 600 to 300 mb	35% or 0.1 g/kg
AVMP Clear, 300 to 100 mb	35% or 0.1 g/kg
AVMP Cloudy, surface to 600 mb	20% of 0.2 g/kg
AVMP Cloudy, 600 mb to 400 mb	40% or 0.1 g/kg
AVMP Cloudy, 400 mb to 100 mb	40% or 0.1 g/kg
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 0.01 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 (clear=1.6)
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 0.01 mb	3.5 K/5-km layer
CH4 (methane) column	1% precision, ±5% accuracy
CO (carbon monoxide) column	3% precision, ±5% accuracy

Recent analysis of the NOAA CrIS/ATMS EDRs in complex weather regimes

Wed. May 14, 2014

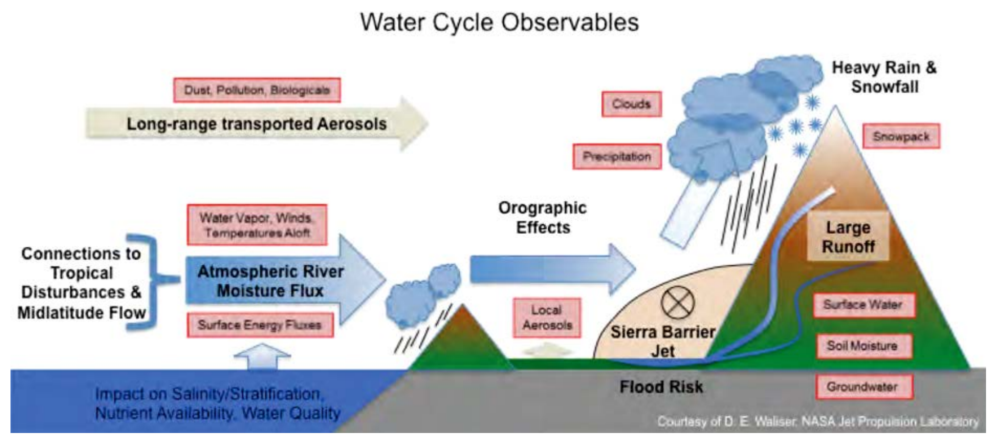
Chris Barnet

Discussion Points

- Brief introduction to atmospheric rivers (ARs)
- CalWater 2 Early Start Campaign, Feb. 2014
  – NUCAPS support of flight planning
  – Comparisons of NUCAPS to CalWater drop-sondes
- CalWater 2 Campaign, Jan/Feb 2015
  – Observing Platforms
  – Synergy with NUCAPS validation

Understanding Atmospheric Rivers (ARs) has national and societal value

- ARs are narrow regions of enhanced WV transport
  - responsible for ≈ 90% of mid-latitude transport (Zhu 1998 MWR)
  - 75% is below 2.25 km

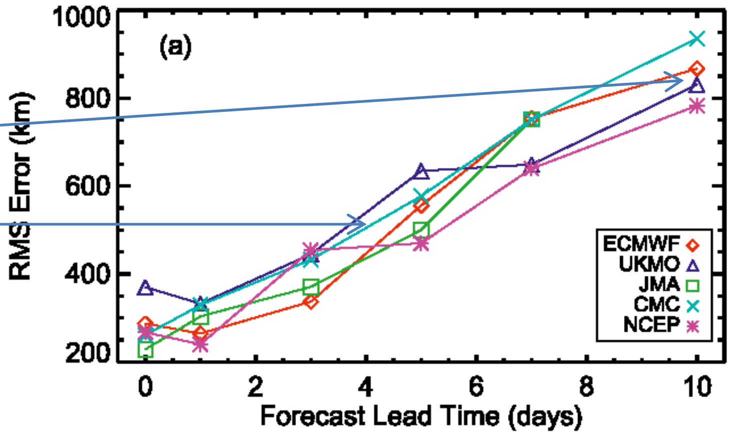


30-50% of annual precipitation on USA west coast is associated with ARs

- Typically within a few extreme precipitation events
- Strongest ARs can create major flooding
  - Jan. 6-8, 2009 a strong event damaged the Hansen Dam (White 2012 BAMS)
  - Warm moist conditions in ARs can accelerate snowmelt
- Northwest USA snowfall tends to come in a few powerful winter ARs
- AR events end ~40% of Northern California droughts (Dettinger 2013 J.Hydro.)
- Large ARs transport 13-26 km^3/day, ~7.5-15 times the average discharge of the Mississippi River (Ralph 2011 Eos)

Atmospheric Rivers are difficult to forecast

- **AR landfall forecast errors are large**
  - ~800 km at 10 day lead-time
  - 3-5 day forecast (~500 km) comparable with hurricane track errors (Wick 2013 Wea. & For.)



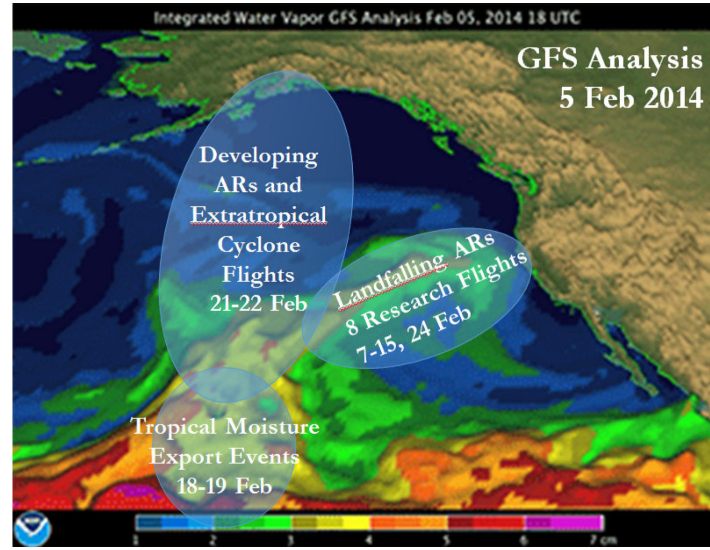
- Calwater 1 field campaign (2009-11) demonstrated that local aerosols and Sierra Barrier Jet plays a major role in modulating orographic precipitation
  - Aerosols carried in long-range flow was shown to affect land-falling ARs (Creamean 2013 Science)

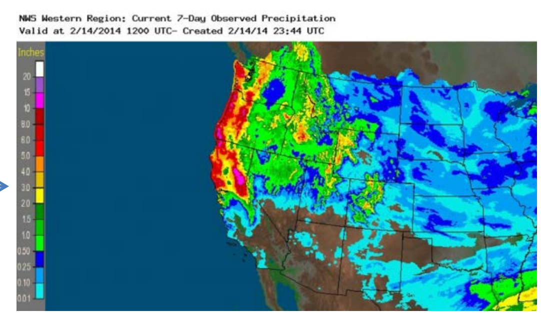
CalWater 2 Early Start NOAA Gulfstream-IV Flights

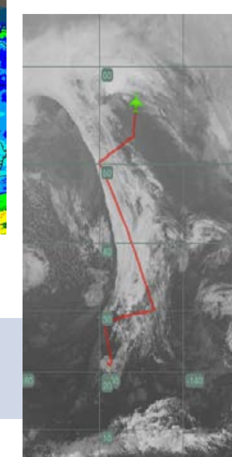
- <u>Objective</u>: Examine the development and structure of atmospheric rivers (ARs) before landfall to improve forecasts of extreme precipitation events along the US West Coast
- <u>Accomplishments</u>:

1. 12 research flights in Eastern Pacific in Feb 2014
2. Measurements included 190 dropsondes released between 8°N – 60°N and tail doppler radar
3. Observations included:

- 2 major land-falling AR events along west coast (Feb.7-15 and Feb. 24)
  - Landfall Feb. 12, 5-10” of rainfall →
  - 1st rainfall of the year for many places
- A developing AR between Hawaii, Alaska and the AR source region between Hawaii and the ITCZ (4 research flights, Feb. 18-22)







Flight Track (HI to AK) – Poleward developing AR

NUCAPS retrieval products easily see location of Atmospheric Rivers

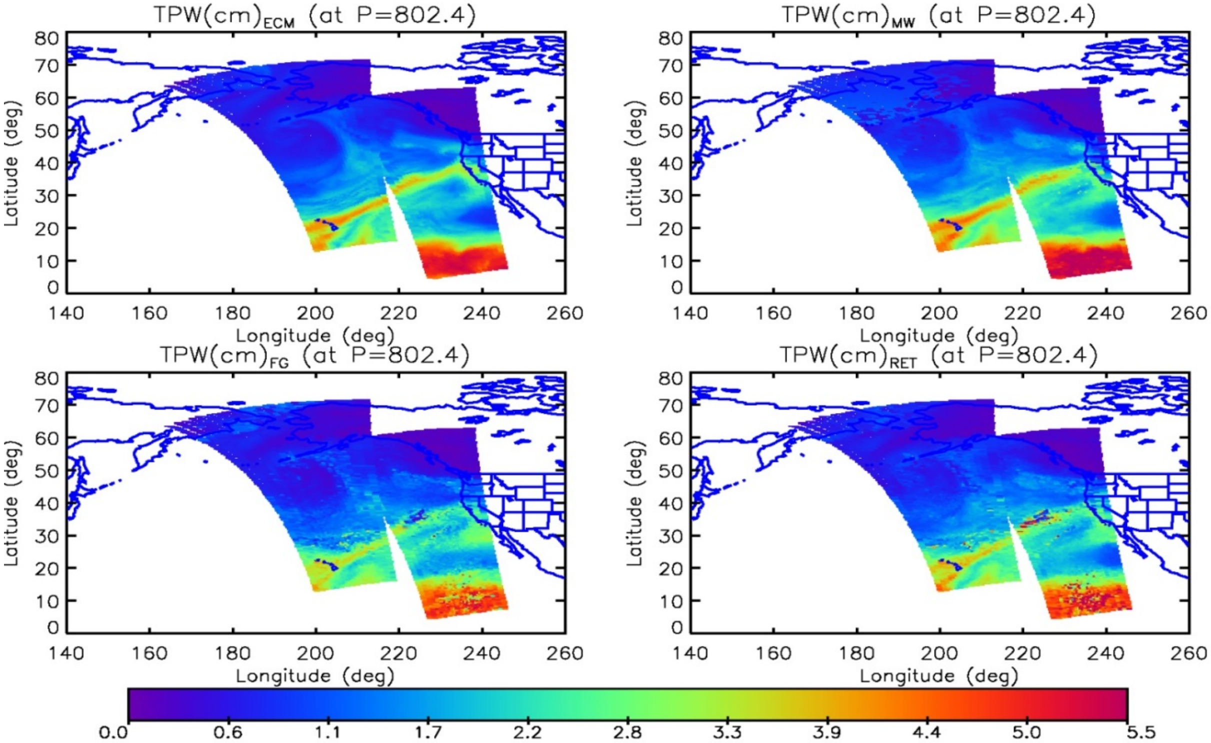
ECMWF and NUCAPS Total Precipitable Water
(ignore label that says (at P=802.4)

Upper Left: ECMWF Analysis

Upper Right: Microwave-Only retrieval

Lower Left: Statistical Regression retrieval

Lower Right: Microwave + infrared retrieval



Note that the regression operator (lower left) is not as spatially coherent as the microwave physical retrieval (upper right). Many of these cases are rejected ; however, the regression operator is a more difficult first guess and leads the final product to have undesirable spatial structure in it.

Provided near real time retrievals to Ryan Spackman (Mission scientist)

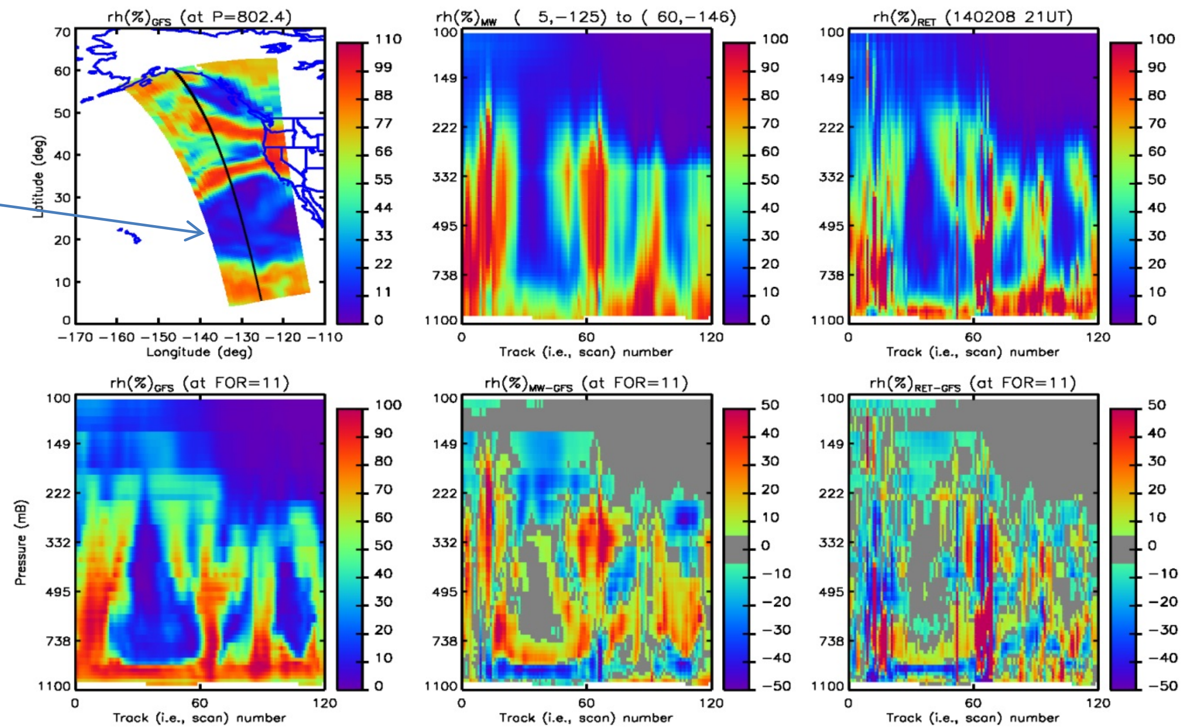
Used NUCAPS science code on U.Wisc PEATE system to process the data

Microwave-only retrieval

Final coupled retrieval

GFS forecast (interpolated to retrieval time and location). Black line is location of cross-sections in other plots

Cross-section of GFS going from south (Scan=1) to North (Scan=120)



Note: Differences could be due to retrieval errors or GFS errors

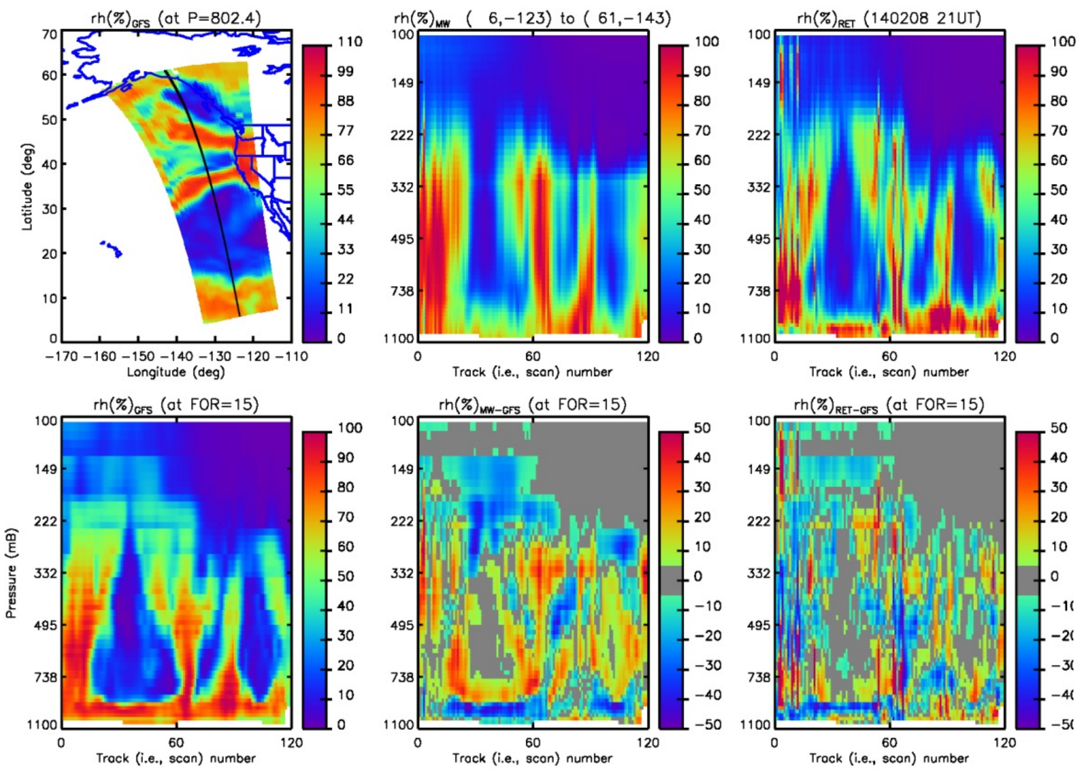
Difference of Microwave-only retrieval and GFS

Difference of coupled retrieval and GFS

Can Retrievals Improve Forecasts? Slide/comments in red are from Ryan

Item 1: AR landfalling forecast errors are large (500 km at 5 day, 200 km at 1 day, Wick et al. 2013)

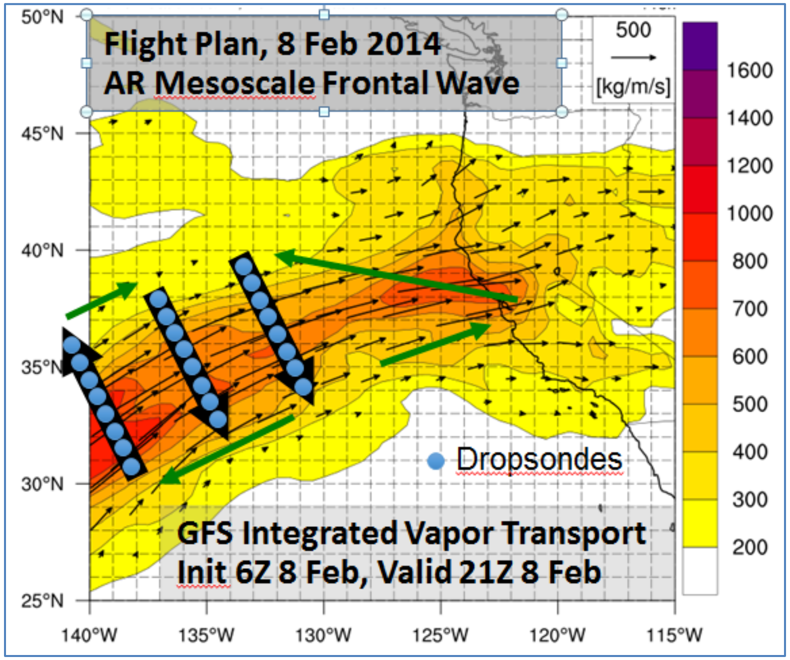
➤ Preliminary analysis suggests retrievals from CrIS and ATMS could improve landfalling forecasts



GFS interpolated to retrieval sampling

ATMS-only retrieval

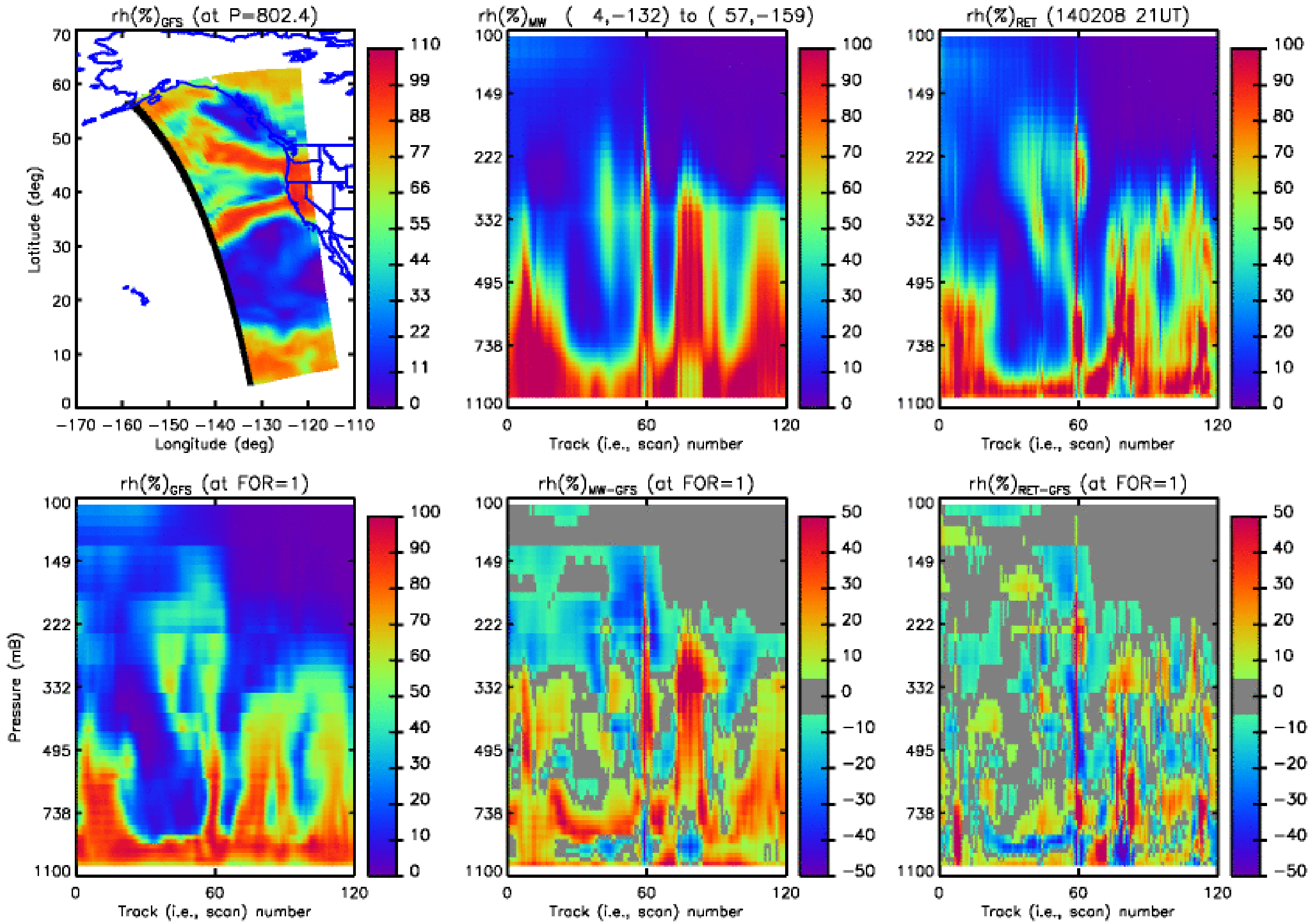
CrIS+ATMS Retrieval



Item 2: Vertical structure of water vapor in ARs is crucial to getting integrated vapor transport correct

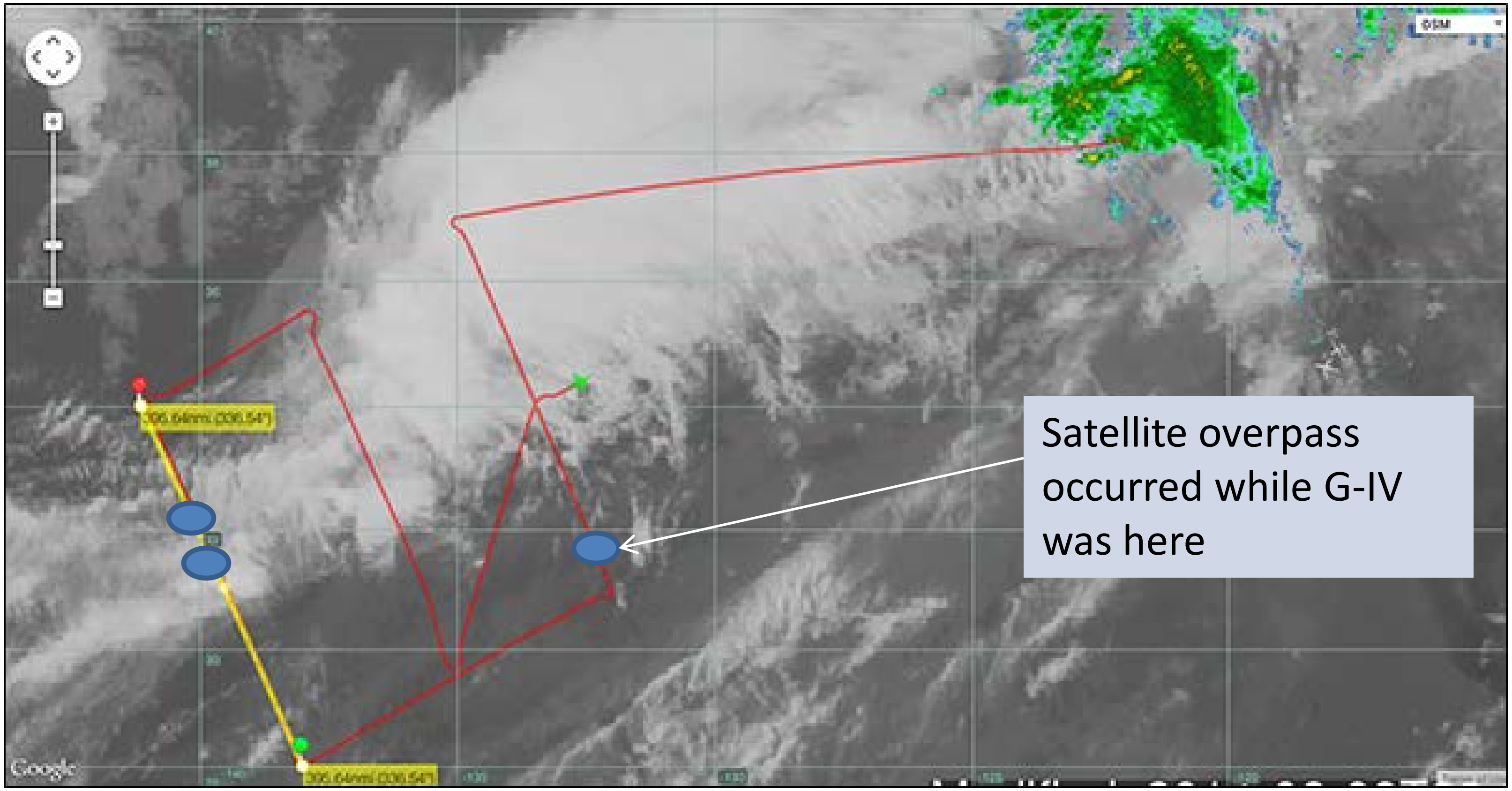
➤ Numerous discrepancies between model and dropsonde data were observed in vertical profiles of water vapor across ARs

Feb. 8, 2014 CrIS/ATMS Retrievals (NOTE: ignoring QC for this movie)



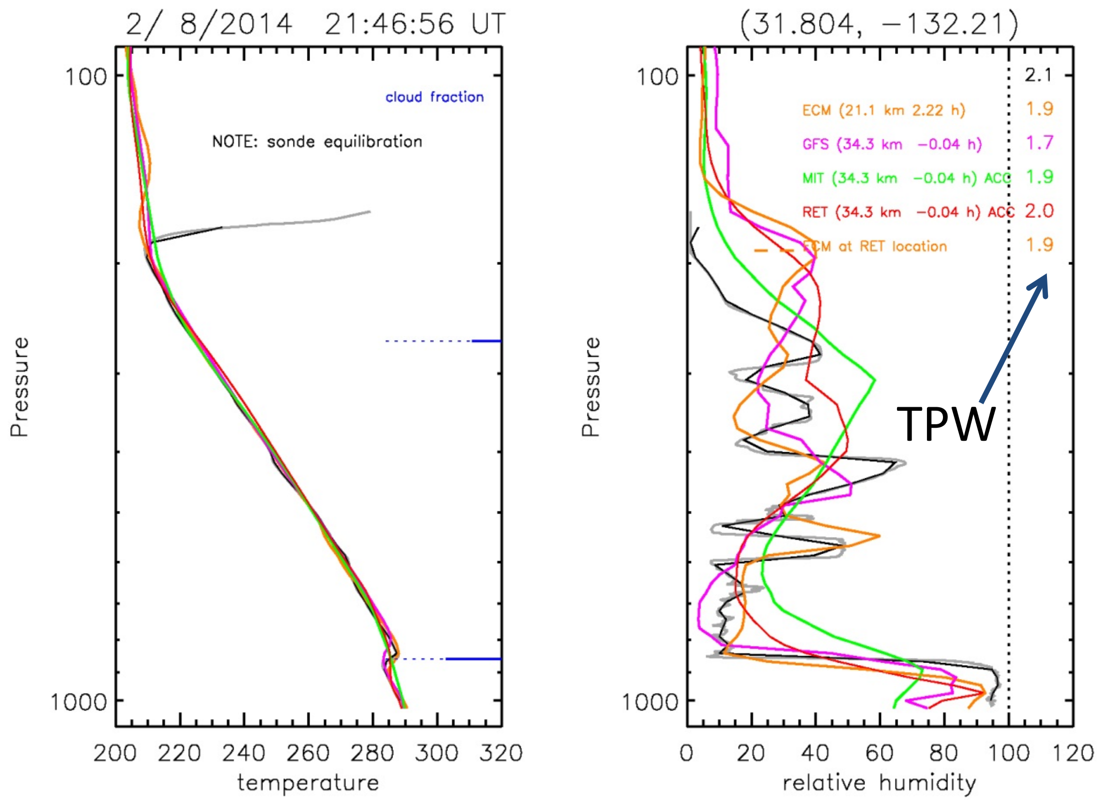
Flight pattern on Feb. 8, 2014
29 sondes were deployed

- Location of 3 sondes along the flight path selected for the next few slides



Comparison to dropsonde co-located (to satellite overpass time

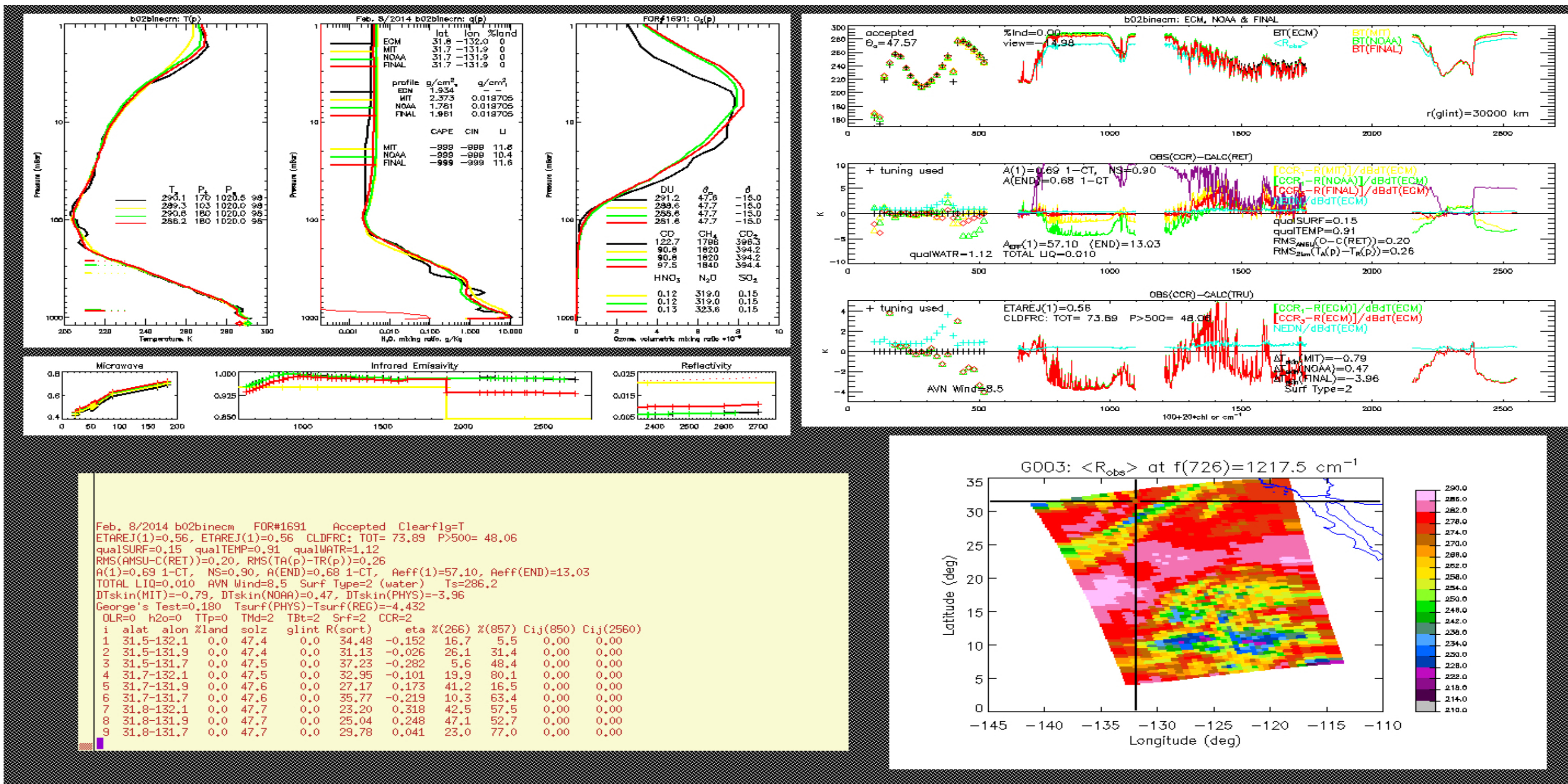
- Black = dropsonde
- Orange = ECMWF 0h analysis at location of the sonde
- Orange dashed is ECMWF at location of retrieval
- Cyan = GFS forecast interpolated to retrieval location
- Green = uW-only retrieval
- Red = IR+uW retrieval



This sonde was located south of the AR. Retrieval (and models) captured much of the vertical structure.

Diagnostic output for this scene (closest retrieval is an *accepted* case)

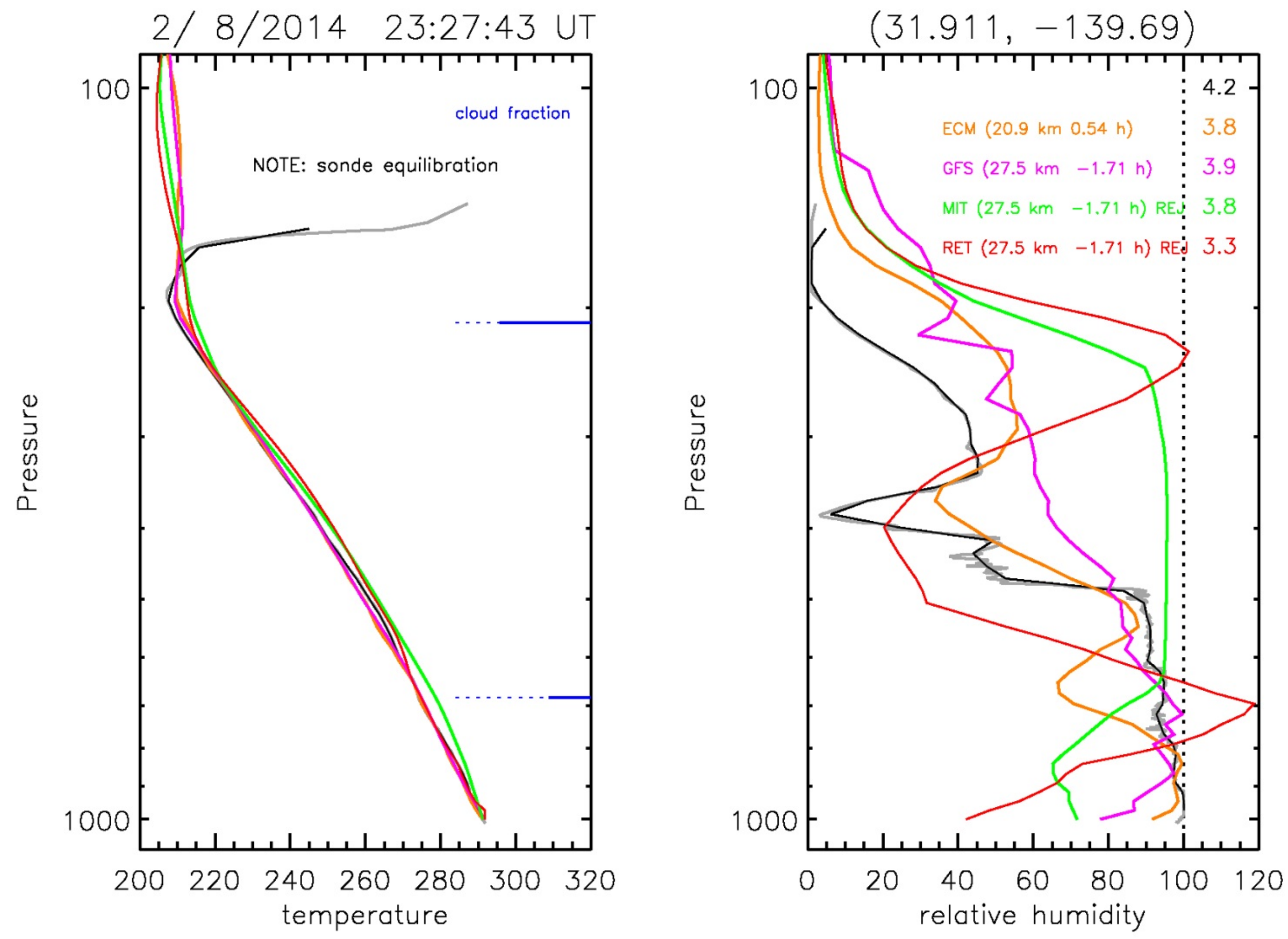
- Samples the region to the south of the AR
  - ECMWF in this graphic is 2.2 hours later



Atmospheric River scene
(sonde dropped 1.7 hour after satellite overpass)

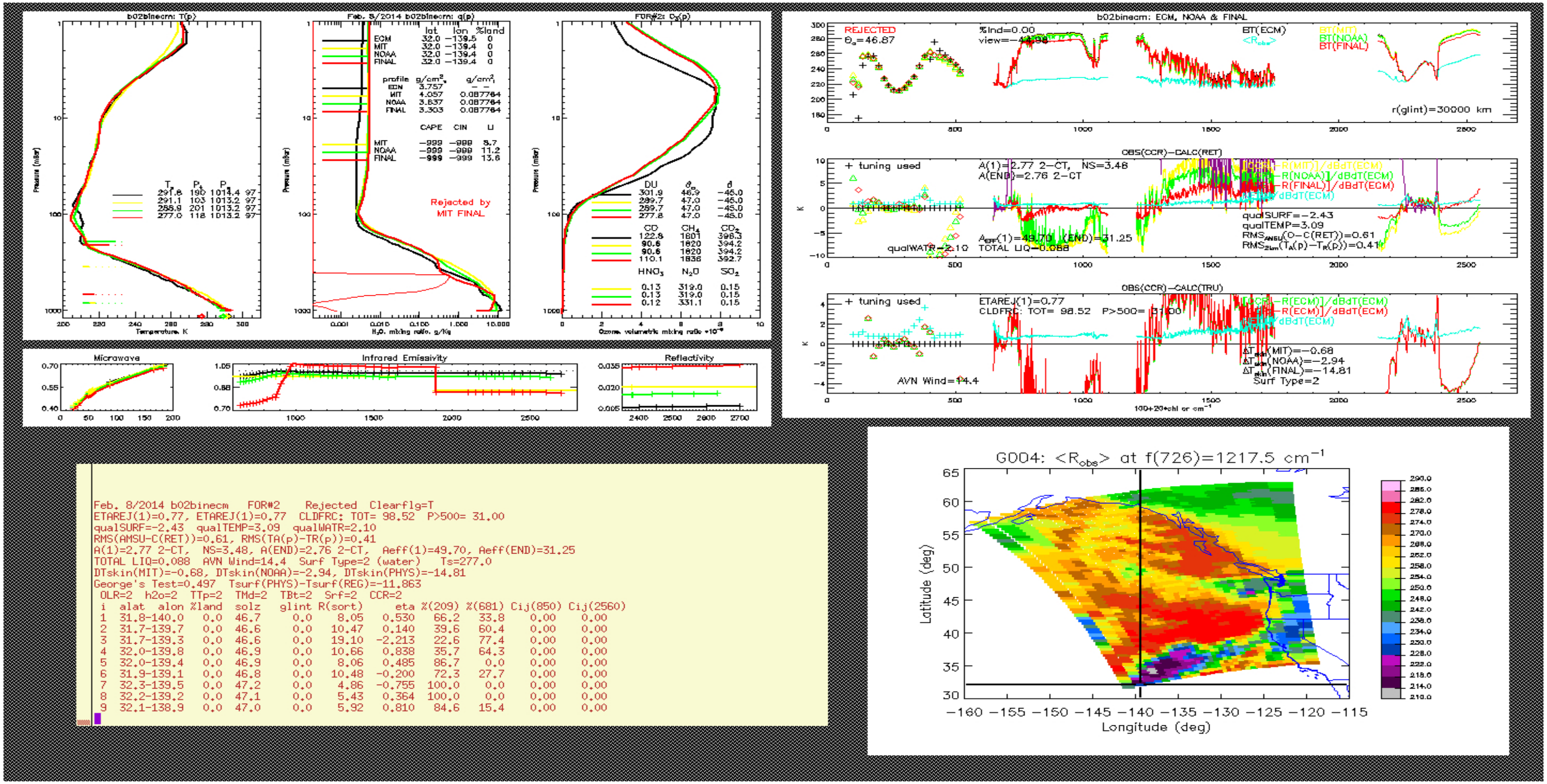
Both uW-only and couple retrieval are rejected at sonde location

Scene is too cloudy and probably precipitating



Diagnostic display for retrieval closest to sonde location (*rejected* case)

- Retrieval within the AR is rejected due to ~98% cloudiness, high liquid water content

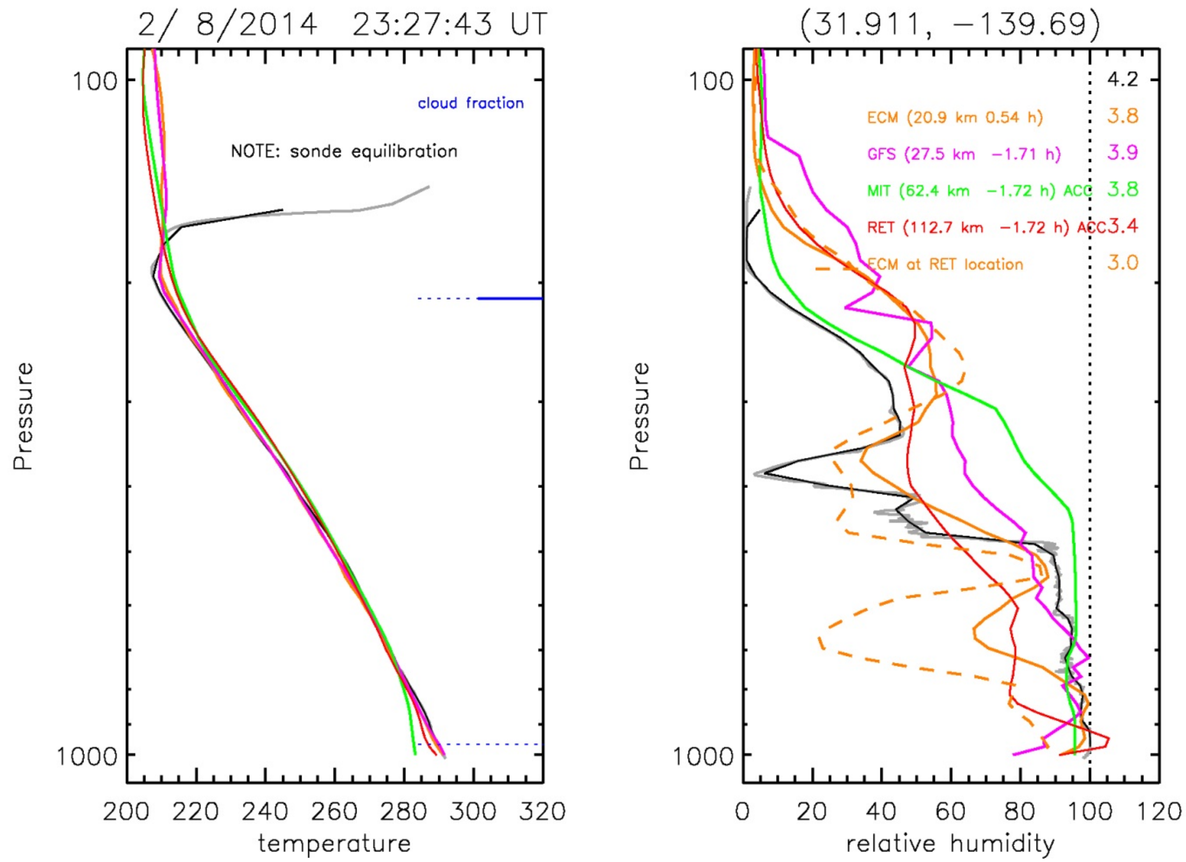


Same Sonde, selected closest ACCEPTED retrieval

In this plot the closest accepted retrieval (red) 113 km away was selected.

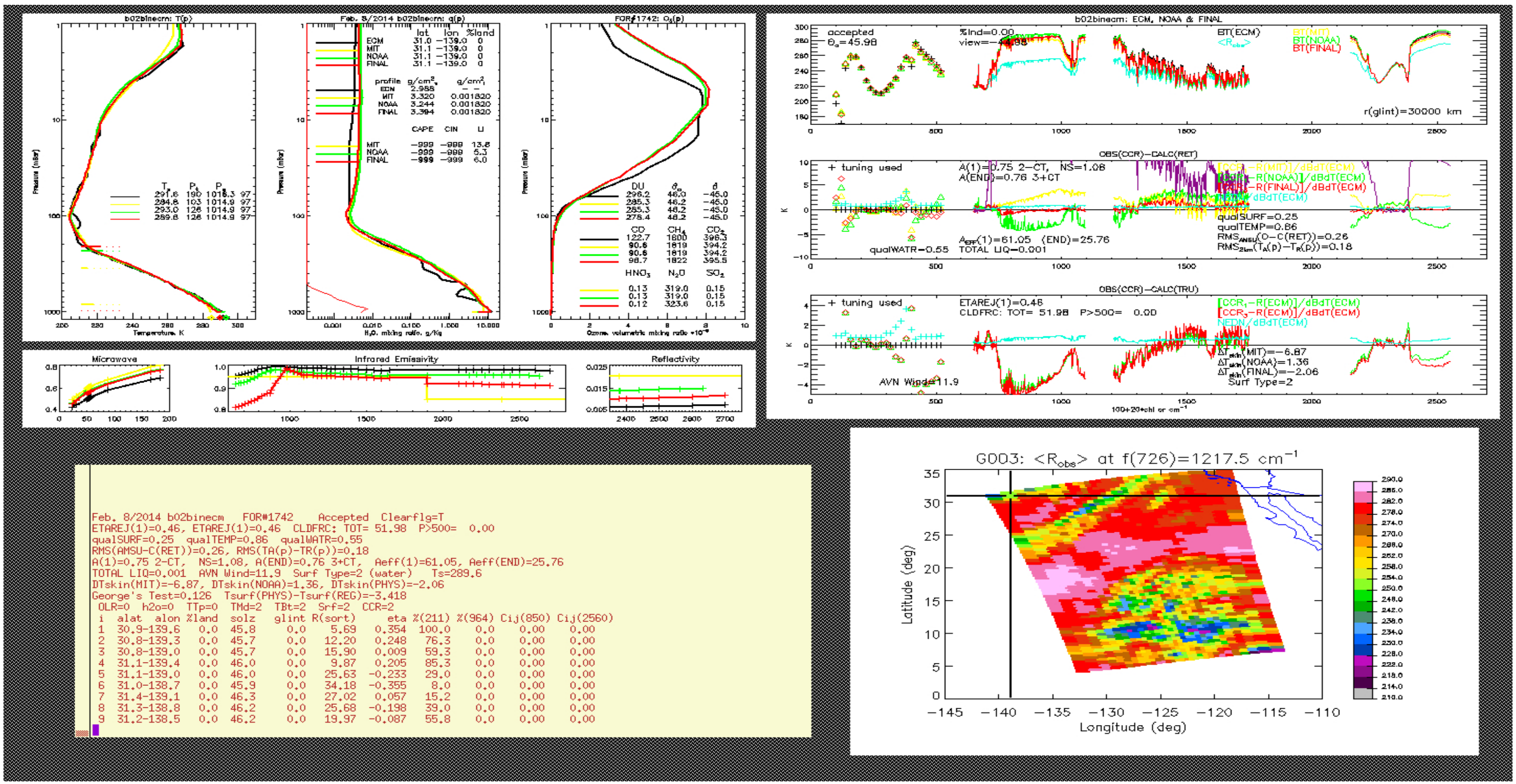
ECMWF is also shown at the retrieval location (dashed orange) .

This retrieval has 3.4 cm IWV compared to 4.2 cm for the sonde and 3.0 at ECMWF co-located with the retrieval



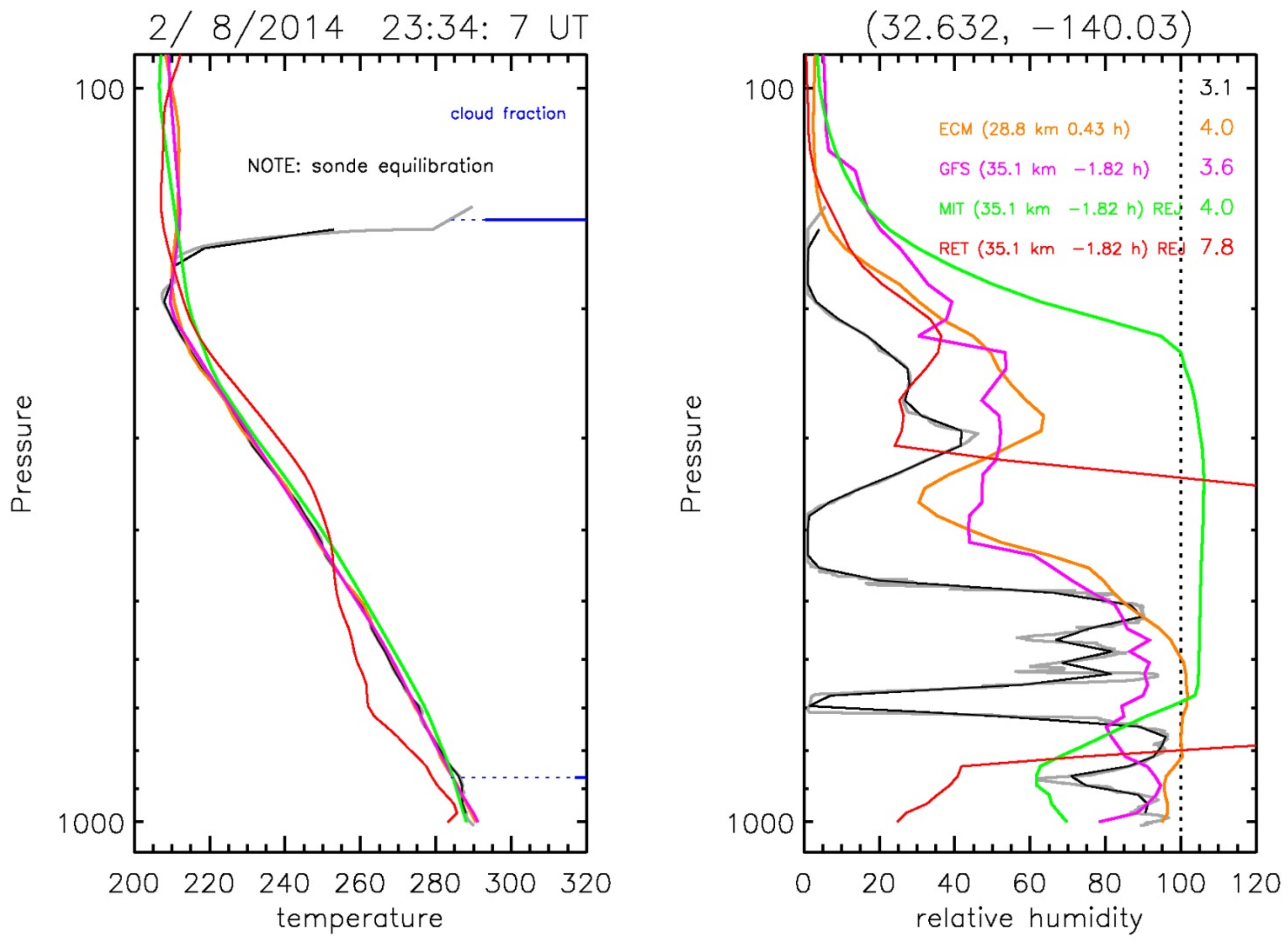
Diagnostic output for closest *accepted* retrieval

- Closest retrieval is to the south of the AR, not relevant for this sonde



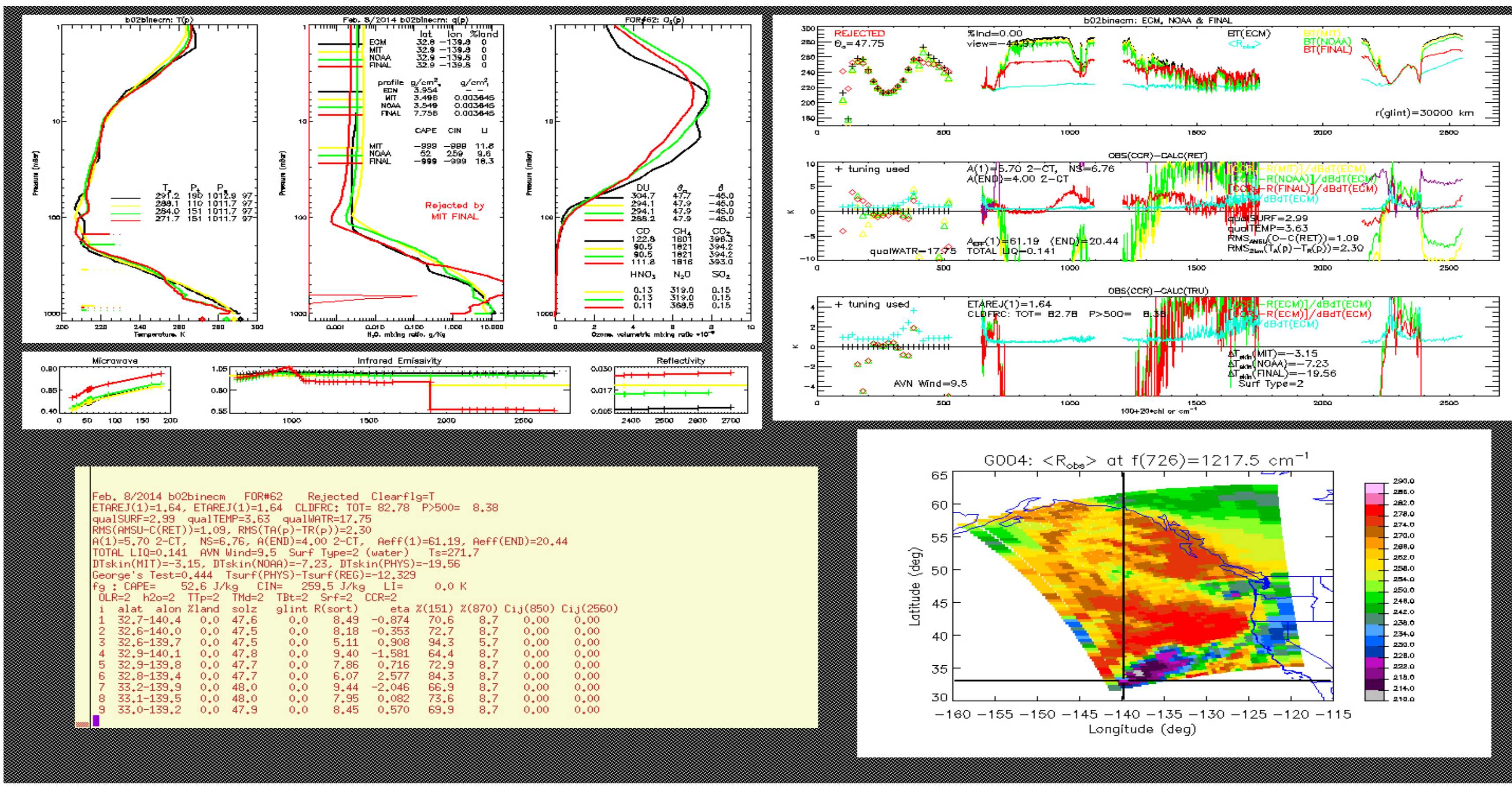
Another example of retrieval within atmospheric river

In this case the coupled retrieval within AR has *serious* problems (but we know it failed)



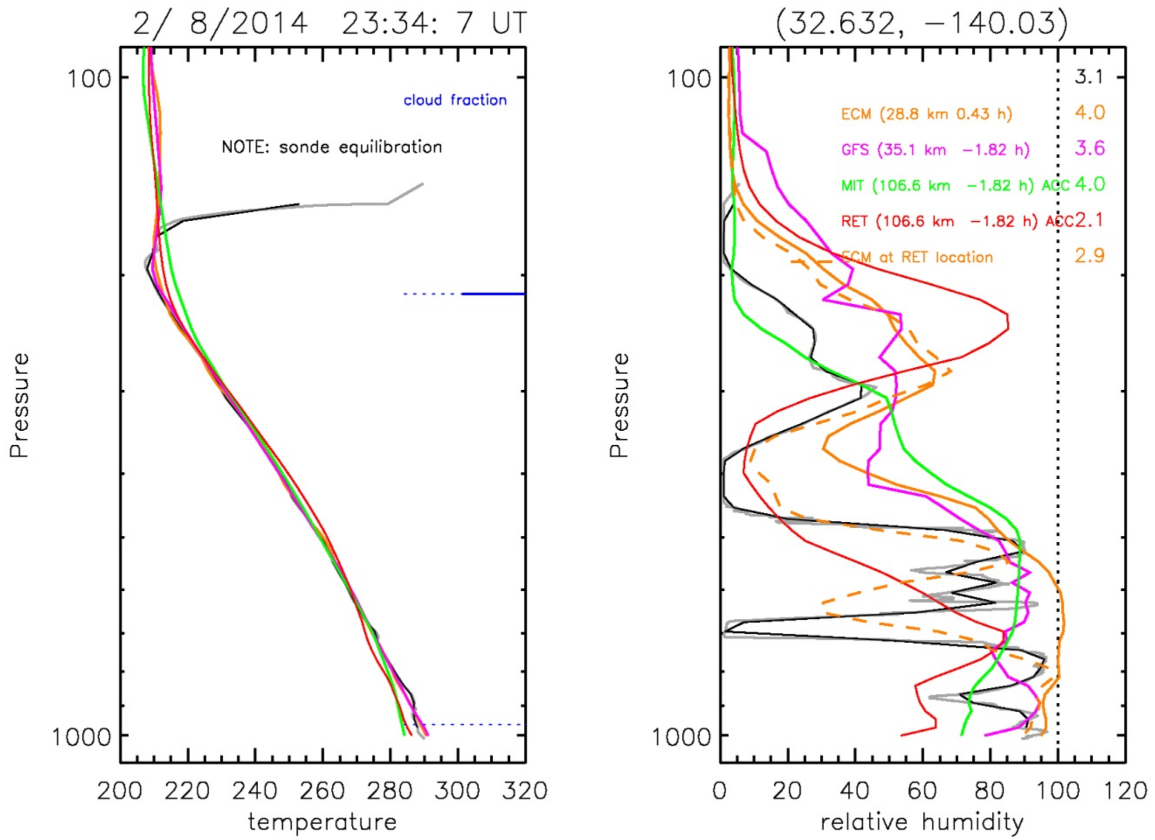
Diagnostic output for closest retrieval (*rejected*)

- Retrieval failed due to high level cloudiness (~80%) and very high liquid water



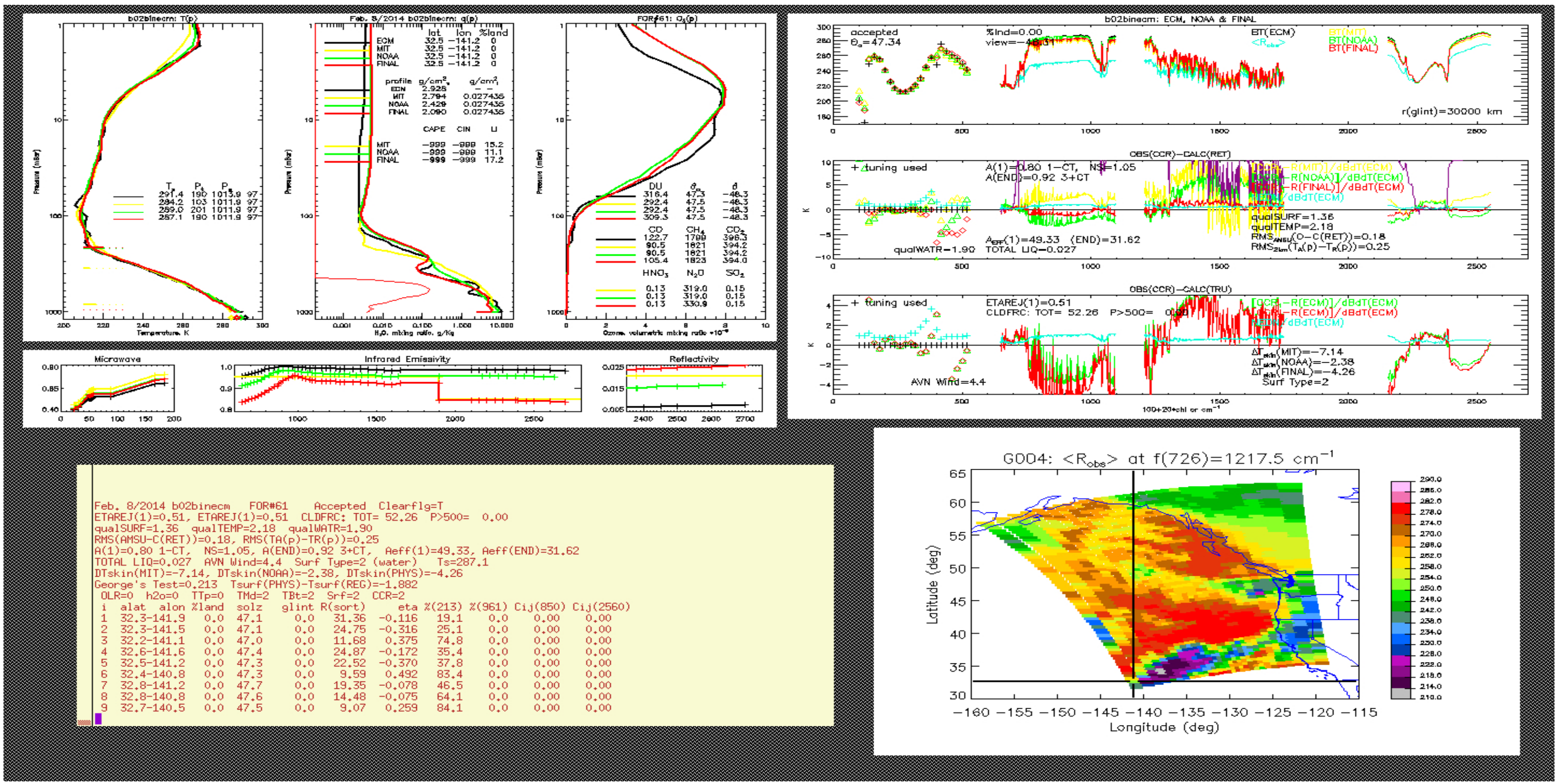
Same sonde with closest *accepted* retrieval

Closest accepted (126 km away) does not match the sonde, but compares well to ECMWF at that location (orange dashed)



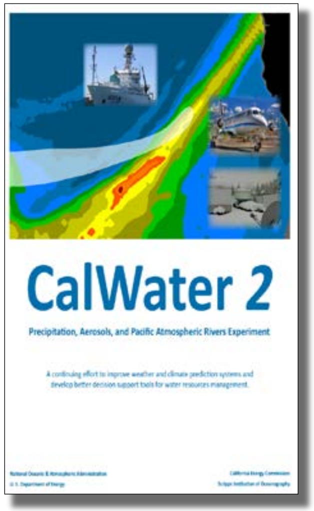
Diagnostic output for closest *accepted* retrieval

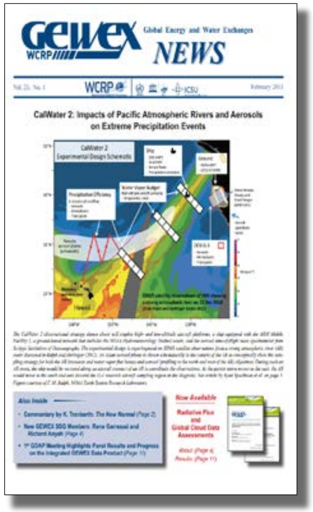
- In this case, the retrieval is near the AR, a very difficult case, very close to limits of acceptance



CalWater 2 Campaign
Jan/Feb 2015

- CalWater 2 white paper is at http://esrl.noaa.gov/psd/calwater
- Coordinated with DOE ACAPEX (ARM Cloud Aerosol Precipitation Experiment)


CalWater 2
Precipitation, Aerosols, and Pacific Atmospheric Rivers Experiment


GEWEX NEWS
Global Energy and Water Exchanges
CalWater 2: Impacts of Pacific Atmospheric Rivers and Aerosols on Extreme Precipitation Events

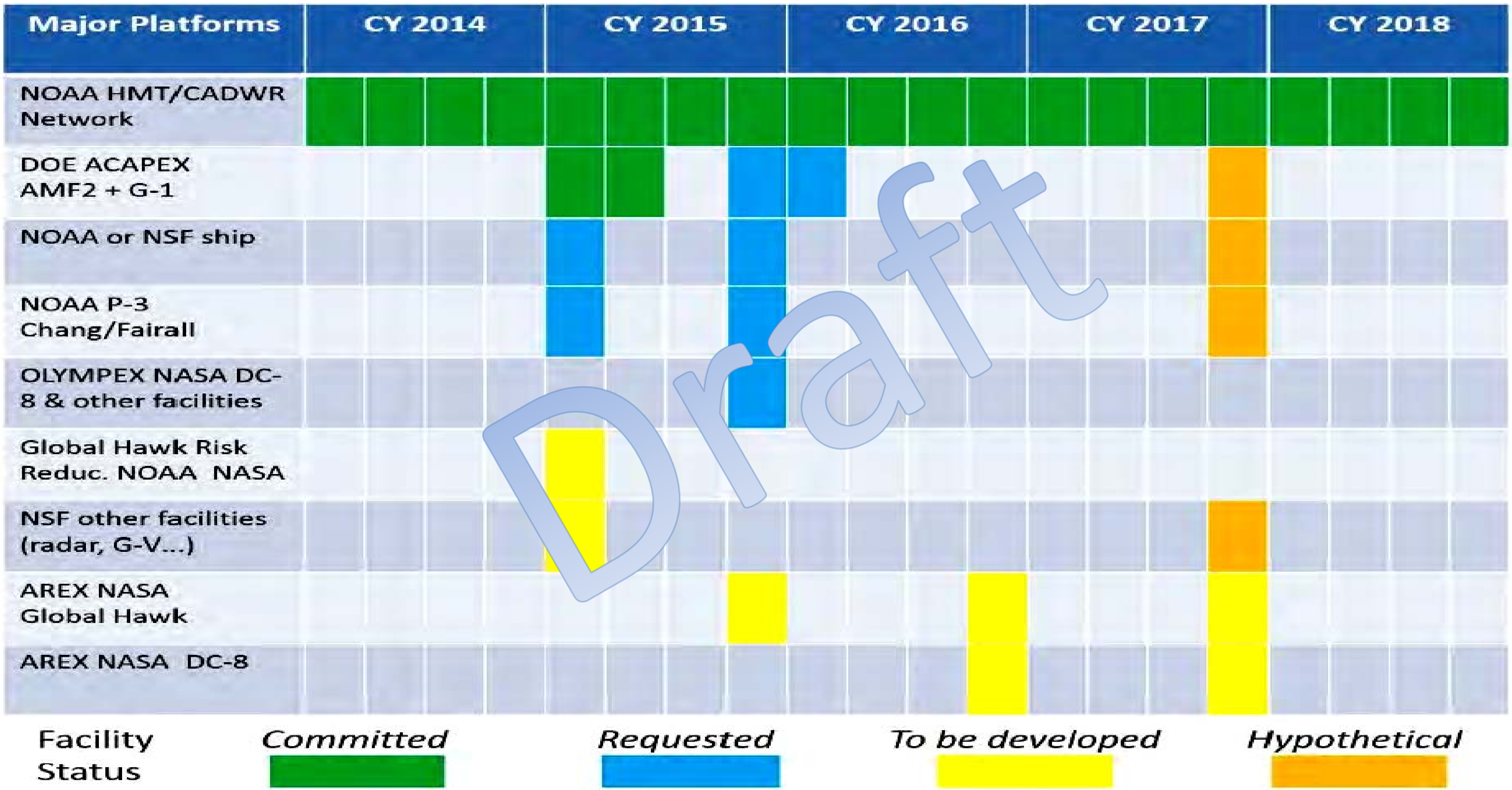
CalWater2 Goals and Science Questions

- Science questions:
  - Role of tropical water and convection in the genesis of ARs
  - Role of air-sea fluxes and ocean mixed layer in evolution of ARs
  - How much rainfall occurs over the ocean?
  - Role of coastal and Sierra Barrier Jets?
  - How do aerosols (both local and long-range) influence cloud and precipitation?
- Goals: Improve prediction systems and develop decision support tools

CalWater 2 five year plan

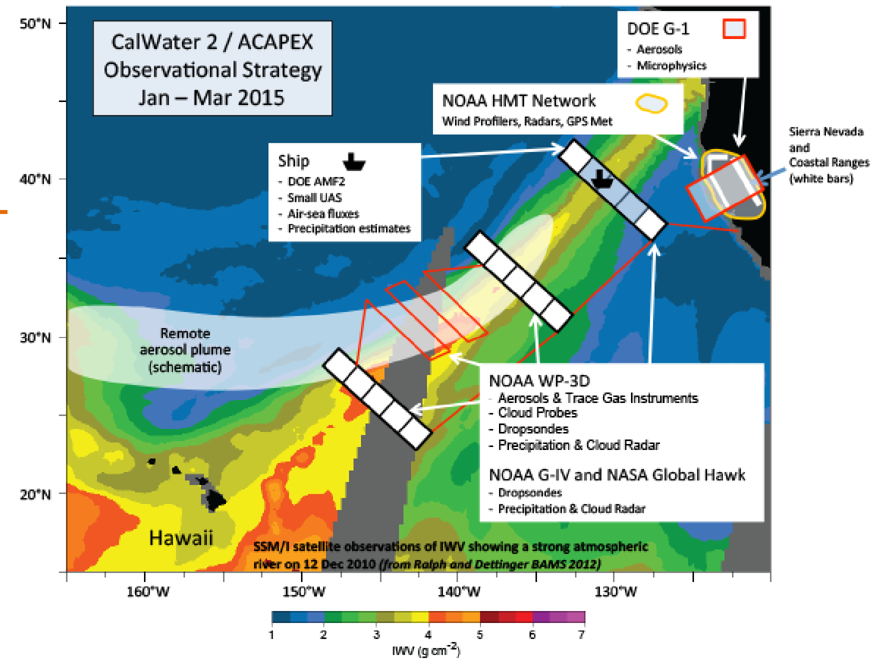
Broad inter-agency coordination

(Scripps, NOAA, DOE, NASA, NSF)



CalWater 2/ACAPEX Observing Strategy

ACAPEX = ARM Cloud Aerosol Precipitation Experiment



Platform	Range of Obs	Expected Duration	Types of sensors
AR Observatories and Hydro-Met Testbed	ARO sites: CA(4), OR(2), WA(1)	Full campaign	Snow level radar (S-band), 449 MHz wind profilers, soil moisture, 10 meter surface tower
NOAA WP-3D	1-22 kft, 4000 km range	80h over 4 weeks	~150 dropsondes, W-band radar, IWRAP Radar, Tail Dopper Radar, Cloud Probes, SFMR
NOAA G-IV	1-45 kft	90h over 6 weeks	~300 dropsondes, Tail Doppler Radar, NOAA O3, SFMR
DOE G-1 with ~40 instruments	1-23 kft	120h over 8 weeks	Cloud properties (Liq/water content, size), aerosol properties (concentration, size, CCN), trace gases (H2O, O3, N2O)
NOAA R.H. Brown	Moves ~5 deg/day	30 days	Aerosol Observing System, Ka ,X, W-Band Cloud Radars, DOE AMF2 , Micropulse LIDAR, Wind Speed, Rain Guages, Sondes

What can be done for CalWater 2

- Retrieval products (T(p), IWV, q(p), O3(p), etc.) can be provided from the archive as was done in Feb. 2012
  - In January 2015 will have ~2 hour latency (was ~8 hour in Feb. 2014)
- Also, there are 3 direct broadcast sites that can provide CrIS/ATMS with ~15 minute latency
  - Each site acquires observations within a radius of ~2000 km
  - Honolulu Hawaii, Corvallis Oregon, Fairbanks Alaska

What these products provide to the CalWater field campaign

- Satellite retrievals can provide synoptic-scale context for the sparse *in-situ* datasets
  - Retrievals can be used to characterize the regime outside the AR (these are usually the accepted cases)
  - Research retrievals can also be employed (e.g., precipitation estimates from ATMS, dust algorithms from CrIS) within the AR.
- BUT --- we are only within the field region for a few seconds
  - It would be mutually beneficial to consider satellite overpass time when planning the mission
    - Deploy more dropsondes with +/- 20 minutes of overpass
    - Ryan Spackman (STC at ESRL) is willing to work with us
- Also, Metop-A, B IASI can be provided, if desired
  - This satellite has overpasses at 9:30 am/9:30 pm local time
  - Latency of ~2 hours, could be of value for flight planning.

What we gain from CalWater 2

- I strongly believe that CalWater 2 is an ideal opportunity for satellite validation
  - We test our algorithm in situations that are nationally and socially relevant
  - These are difficult cases for the retrieval
    - As algorithm developers, we need these kinds of scenes to improve the retrieval skill and tailor the quality control.
      - e.g., we can test NUCAPS with ATMS as a formal *a-priori*
    - As participants in the campaign, we gain the expertise of the CalWater science team to develop meaningful products.
    - Other measurements that have been proposed (CO, O3, CO2, aerosols) will help the validation, since CrIS is sensitive to these
  - WFO's have shown interest in direct broadcast CrIS/ATMS products – this is an opportunity to demonstrate their value in the field

QUESTIONS?

Acronyms

- Infrared Instruments
  - AIRS = Atmospheric Infrared Sounder
  - IASI = Infrared Atmospheric Sounding Interferometer
  - CrIS = Cross-track Infrared Sounder
  - HES = Hyperspectral Environmental Suite
- Microwave Instruments
  - AMSU = Advanced Microwave Sounding Unit
  - HSB = Humidity Sounder Brazil
  - MHS = Microwave Humidity Sensor
  - ATMS = Advanced Technology Microwave Sounder
  - AMSR = Advanced Microwave Scanning Radiometer
- Imaging and Cloud Instruments
  - MODIS = MODerate resolution Imaging Spectroradiometer
  - AVHRR = Advanced Very High Resolution Radiometer
  - VIIRS = Visible/IR Imaging Radiometer Suite
  - ABI = Advanced Baseline Imager
  - CALIPSO = Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations
- Other
  - EUMETSAT = EUropean organization for exploitation of METeorological SATellites
  - FOV/FOR = field of view or regard
  - GOES = Geostationary Environmental Operational Satellite
  - IGOS = Integrated Global Observing System
  - ILS = Instrument Line Shape
  - IPCC = Inter-government Panel on Climate Change
  - JPSS = Joint Polar Satellite System
  - METOP = METeorological Observing Platform
  - NDE = NPOESS Data Exploitation
  - NPP = National Polar-orbiting Partnership
  - NUCAPS = NOAA Unique CrIS/ATMS Processing System
  - OCO = Orbiting Carbon Observatory
  - STC = Science and Technology Corporation

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California Institute of Technology
Pasadena, California

What can we learn from 11 years of AIRS observations?

Eric J. Fetzer, Joao Teixeira, Thomas Pagano and Bjorn Lambrigtsen

Jet Propulsion Laboratory / California Institute of Technology

2014 STAR JPSS Science Teams Annual Meeting

13 May 2014

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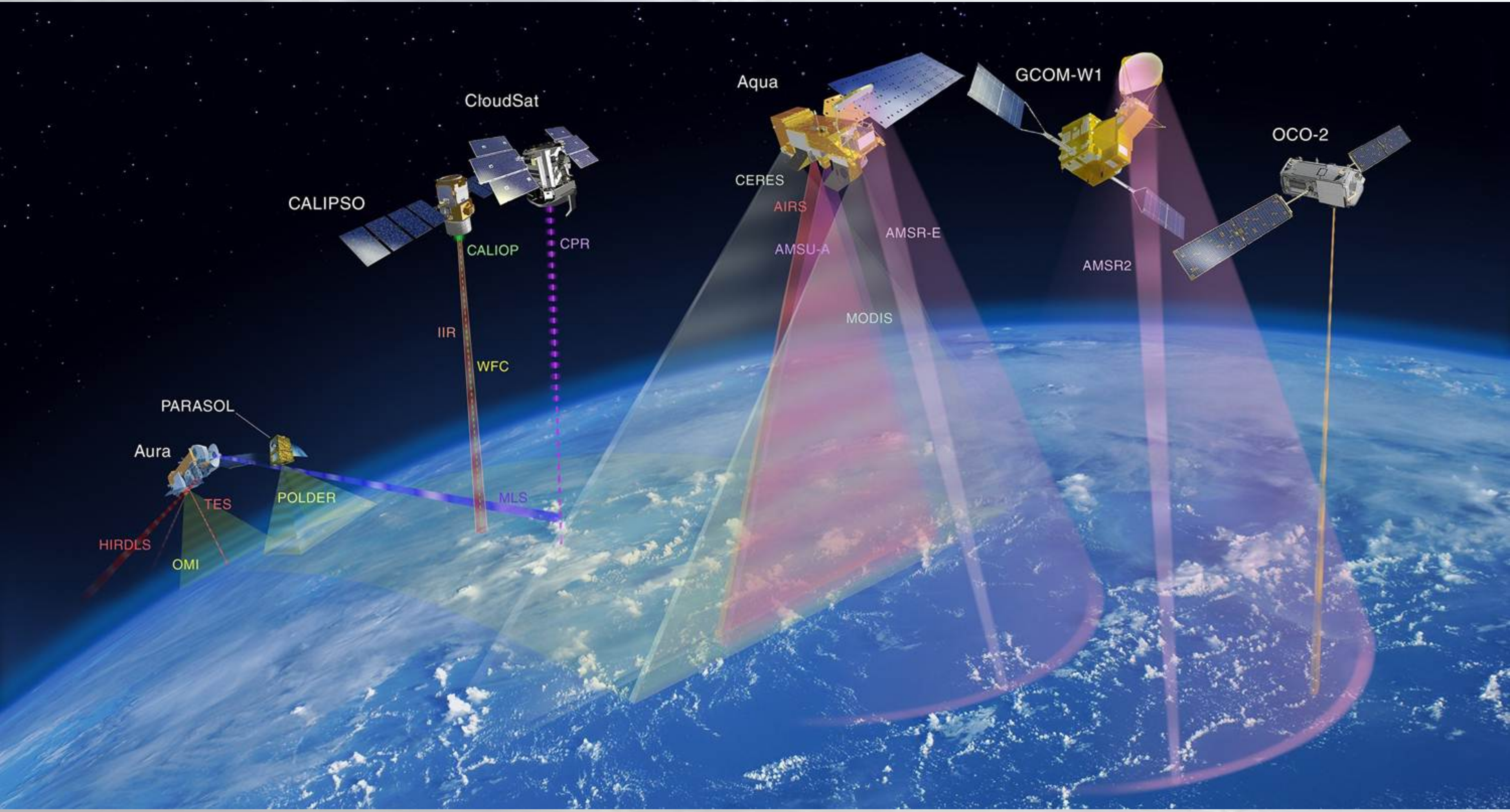
Atmospheric Infrared Sounder on Aqua in the A-Train



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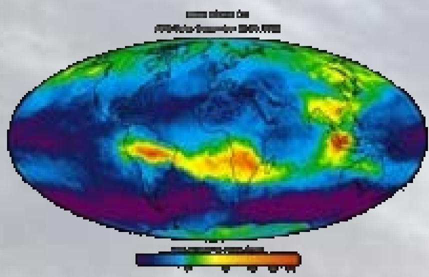
AIRS Key Level 2 Products

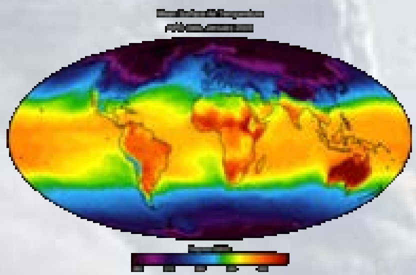
Clouds and Water Vapor Feedback

Greenhouse Gas Forcing

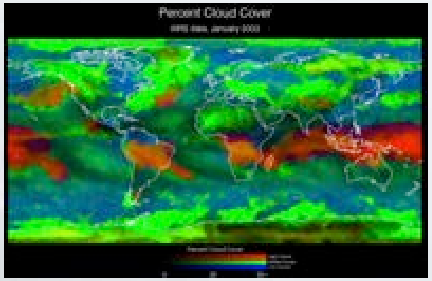
CO



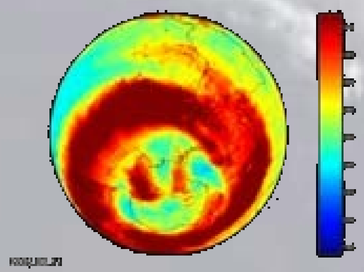
Atmospheric Temperature



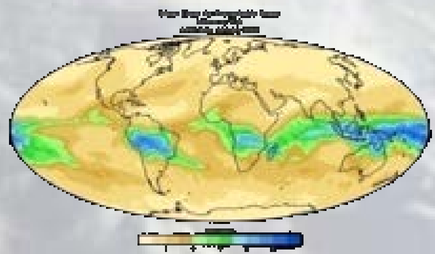
Cloud Properties



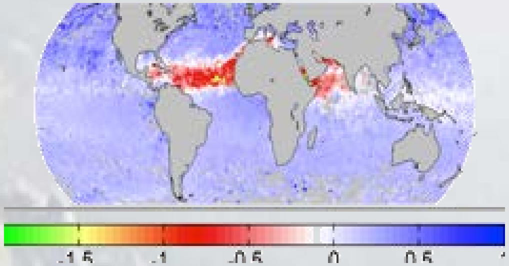
Ozone



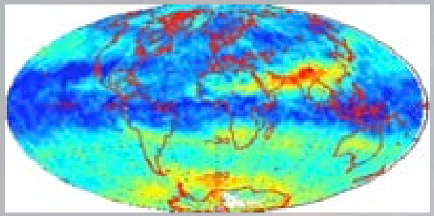
Atmospheric Water Vapor



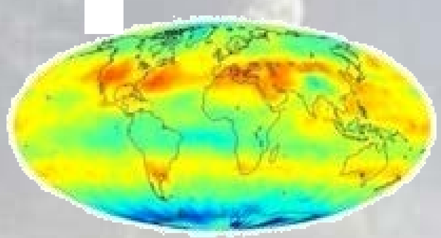
Dust



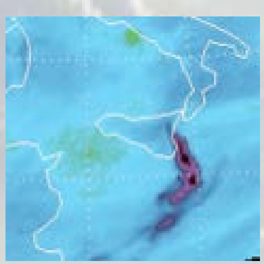
Methane



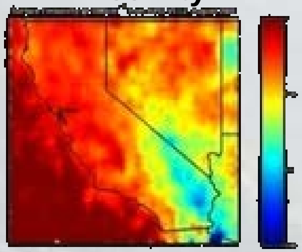
CO2



SO2



Emissivity



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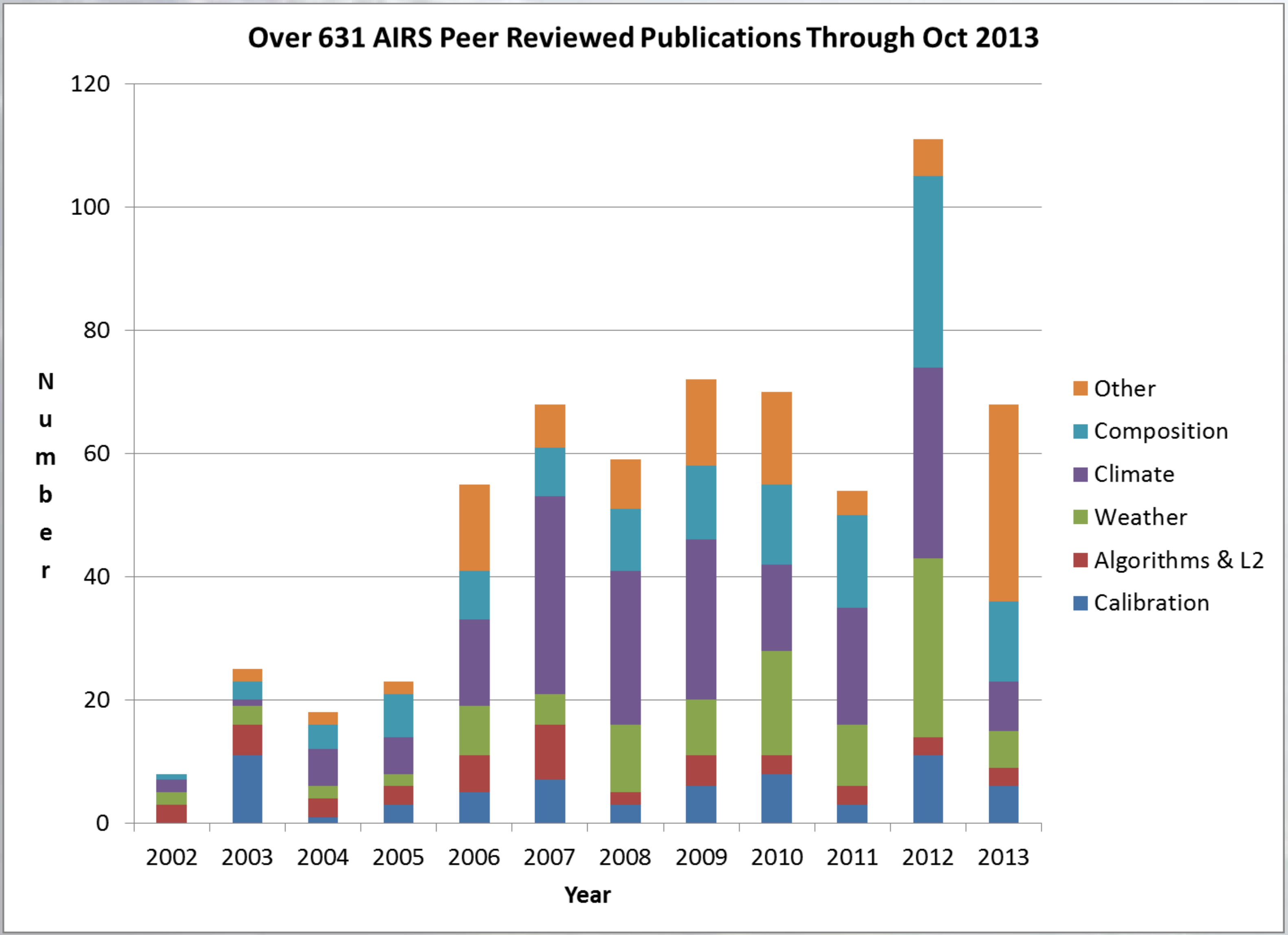
AIRS Supporting Research



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The Strengths of AIRS

Most pertain to CrIS and IASI

- **High infrared spectral resolution and coverage**
  => highest vertical resolution from the IR.
- **Information about temperature and water vapor profiles, trace gases, etc. obtained simultaneously.**
- **Global coverage.**
- **11+ years of data (10 billion spectra, 1 billion retrievals).**

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AIRS Challenges

- **In cloudy scenes most information is obtained in the microwave**
  ⇒ ***Lower vertical resolution than IR.***

- **Global coverage.**

- **11+ years of data (10 billion spectra, 1 billion retrievals).**

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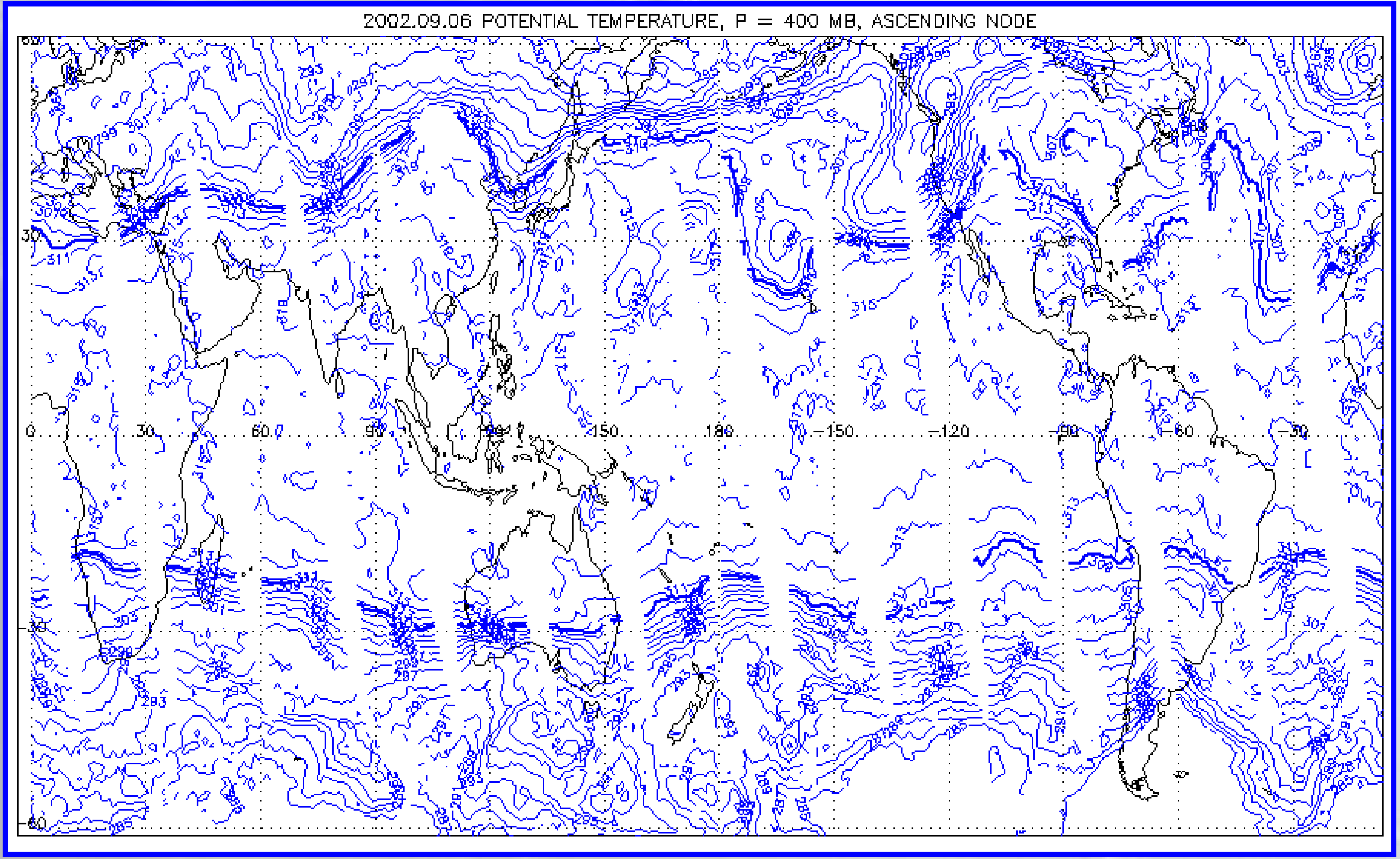
Defining Tropical Conditions at 400 hPa:

Potential Temperature > 310 K

6 Sep 2002



Level 3 Data

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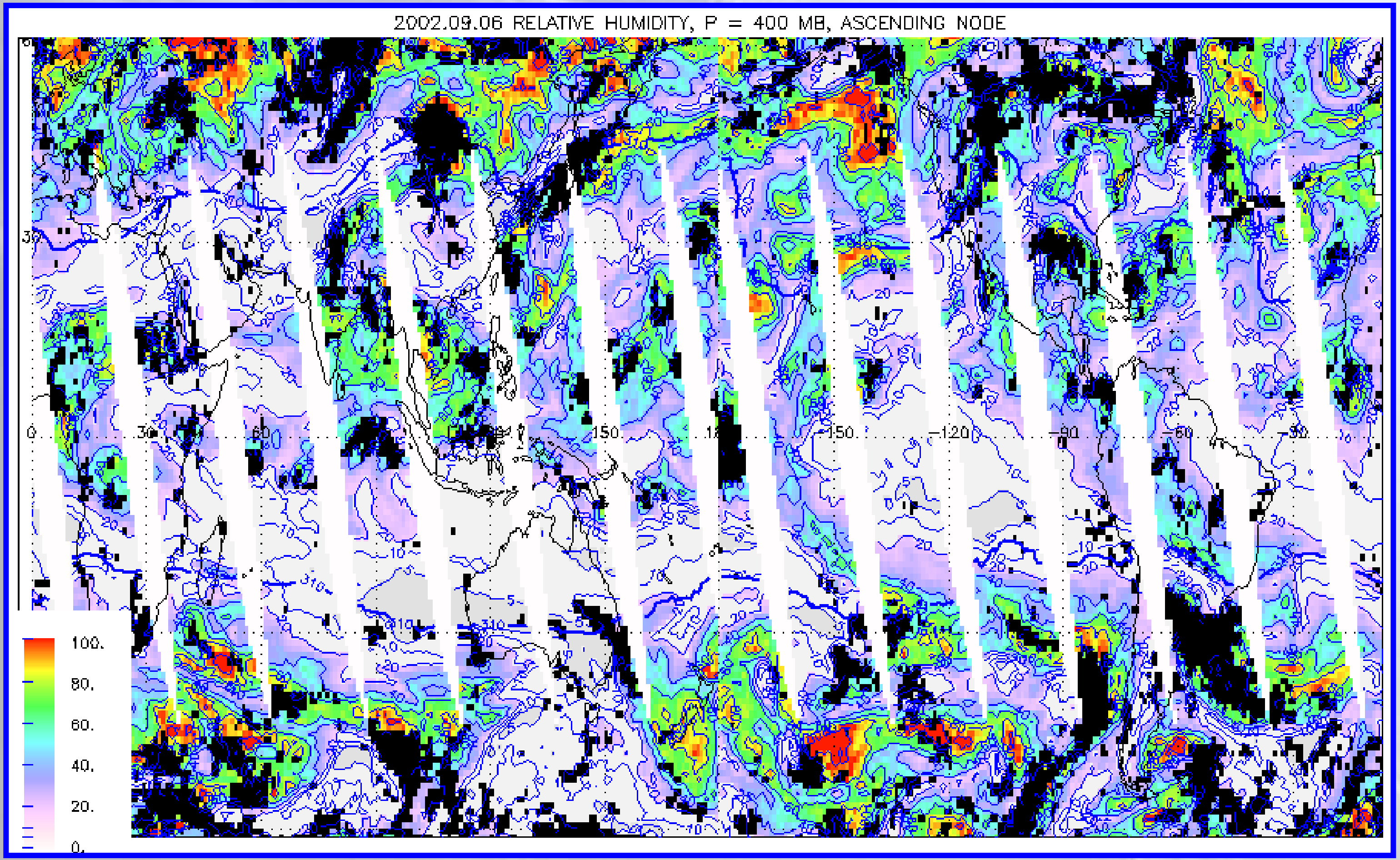
Exploiting AIRS Strengths

Relative Humidity at 400 hPa

6 Sep 2002

Extremely demanding quality control (<100% yield for 1x1° boxes in black).

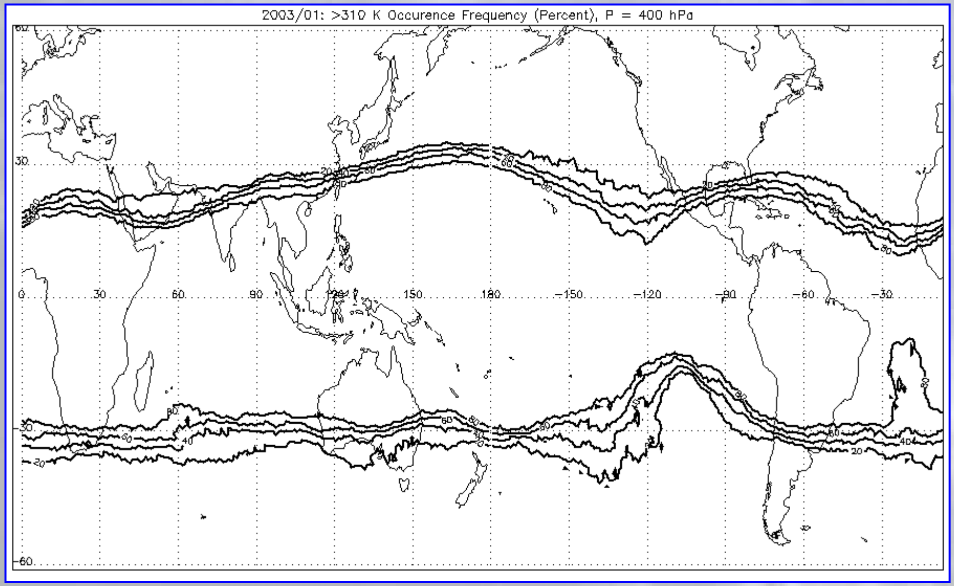


Level 3 Data

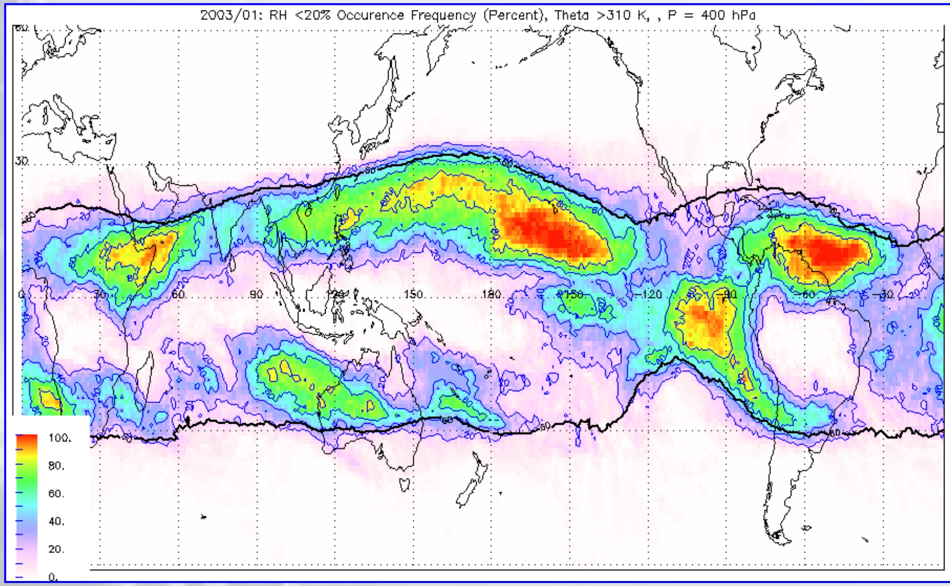
National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

‘Tropical’ Conditions
January 2003



Occurrence Frequency, θ > 310 K at 400 hPa

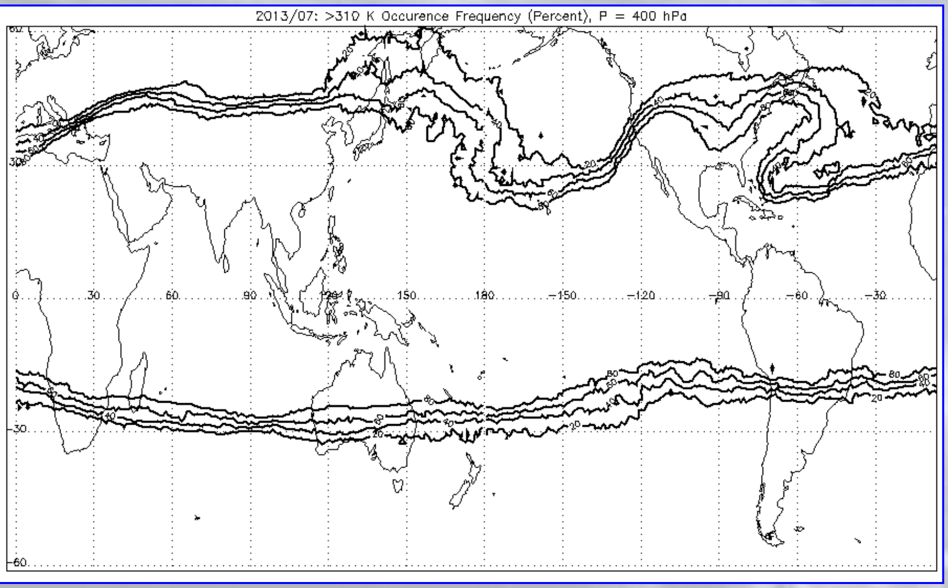


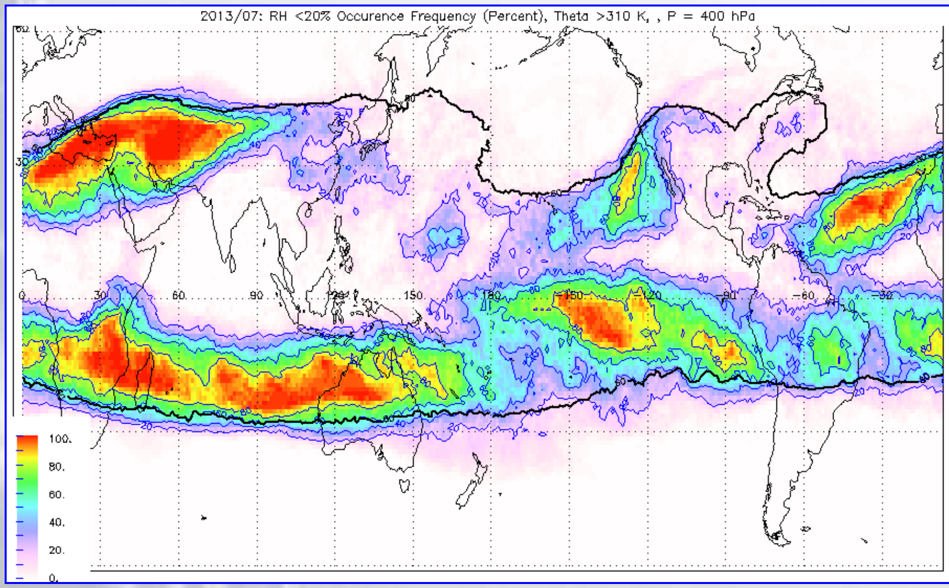
Occurrence Frequency,
Relative Humidity < 20% at 400 hPa
(NOT mean RH)

National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Defining 'Tropical' Conditions Dynamically
July 2013





Occurrence Frequency, θ > 310 K at 400 hPa

Occurrence Frequency,
Relative Humidity < 20% at 400 hPa
(NOT mean RH)

National Aeronautics and Space Administration

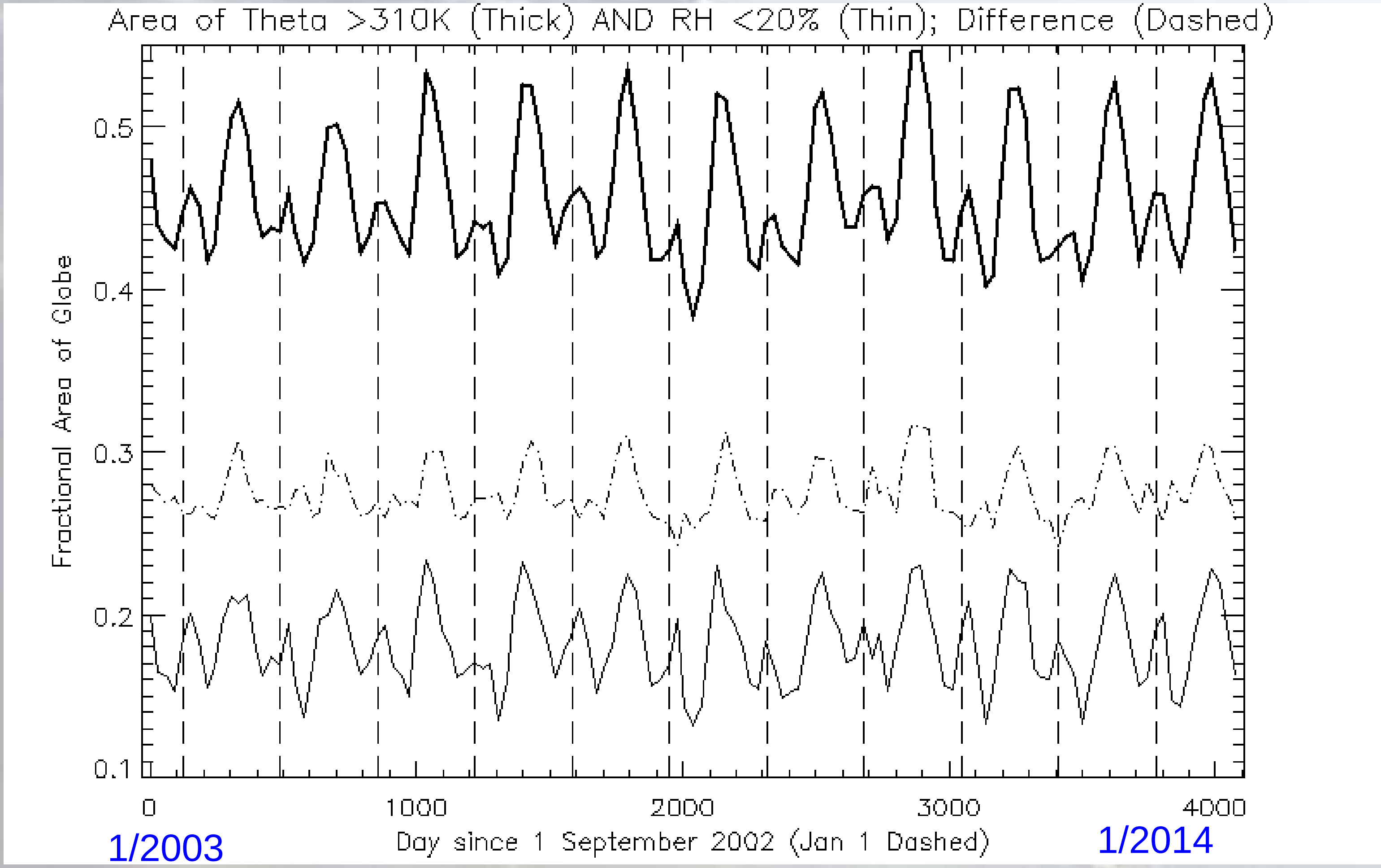
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

400 hPa: Occurrence Frequency Weighted Area

θ > 310 K (thick)

RH < 20% (thin)

Their difference (dashed)



Conclusions: Some Inside Information

- **AIRS has most information in clearer scenes**
  - ***cloud-free conditions not required!***
- **Processes in the dry subtropics may be driving climate sensitivity. See:**
  - ***Fasullo and Trenberth, 2013, Science.***
  - ***Sherwood et al., 2014, Nature.***
- **With 11 years of observations, AIRS likely contains useful climate indices (like relative humidity quantities) in the dry tropics and subtropics.**
  - ***Today's study is a preliminary attempt at creating one index.***

Single FOV ATMS/CrIS Products Under All Sky Condition

X. Liu[1], W. Wu[2], S. Kizer[2], D. Zhou[1], A. Larar[1], P. Yang[3], and W. Smith[4]

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2. SSAI, Hampton VA
3. Texas A & M University
4. University of Wisconsin

Acknowledgement: Q Liu, Y. Han, NOAA cal/val team, CLARREO science team…

Presentation outline

- Motivations
- Principal Component-based Radiative Transfer Model (PCRTM)
- PCRTM retrieval algorithm (PCRTM-RA) and applications
- Summary and Conclusions

Motivations

- Need fast radiative transfer model to handle hyperspectral data
  - Modern sensors have thousands of channels and 0.1-1 million spectra per day
  - Only 4-10% of data are used in satellite data assimilations
- Need fast RT model to handle clouds explicitly
  - Most of the cloudy radiances are not used in data assimilations
  - Difficult to characterize the error in cloud-cleared radiances
- Explore optimal approach for hyperspectral retrievals
  - Retrieve all parameters that contribute to the TOA radiance
  - No need to to perform retrieval on cloud-cleared radiances
  - No need to make assumptions about the inhomogeneity of the scene
  - Provide realistic error estimate on the retrieved parameters
  - More physical cloud parameters can be retrieved
- PCRTM (Principal Component-based Radiative Transfer model) was developed to satisfy the need listed above

Introduction to PCRTM Forward Model

- Explore spectral correlation in hyperspectral data
  - No need to calculate spectrum one channel at a time
  - Compress spectra into compact form using PCA, wavelet, Fourier Series etc
  - Reduce dimension of the data
- PCA is a good approach for compressing spectra and capture information
  - Leading EOFs captures all essential information of thousands of channels
  - PCA has been used to reduce instrument noise and to compress spectra
- PCRTM parameterization is physical-based fast model

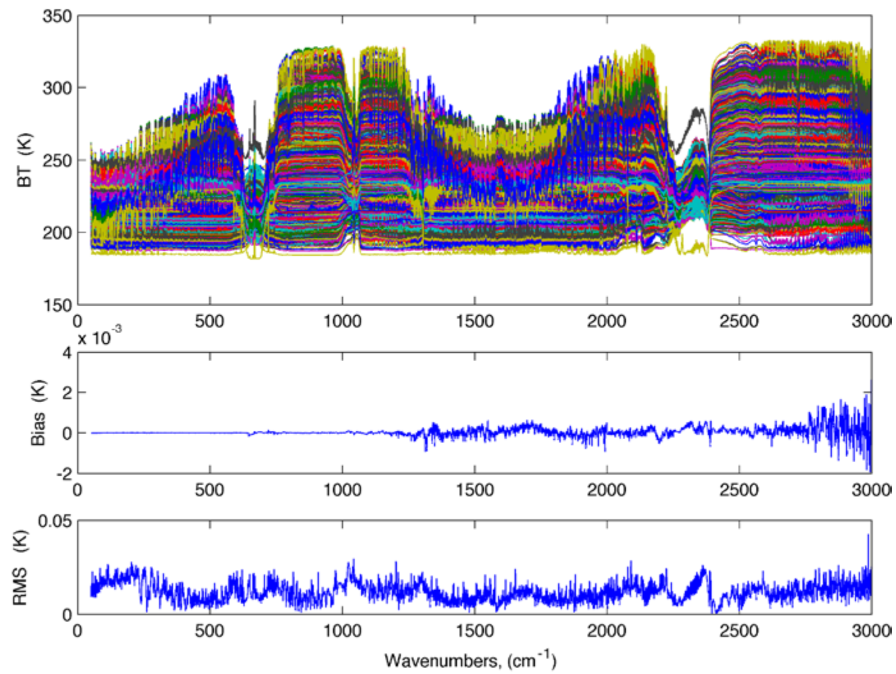
$$y_i = \vec{R}^{ch} \times U_i = \sum_{j=1}^{N_{mono}} \phi_j R_j^{mono} \vec{U}_i = \sum_{j=1}^{N_{mono}} A_j R_j^{mono}$$

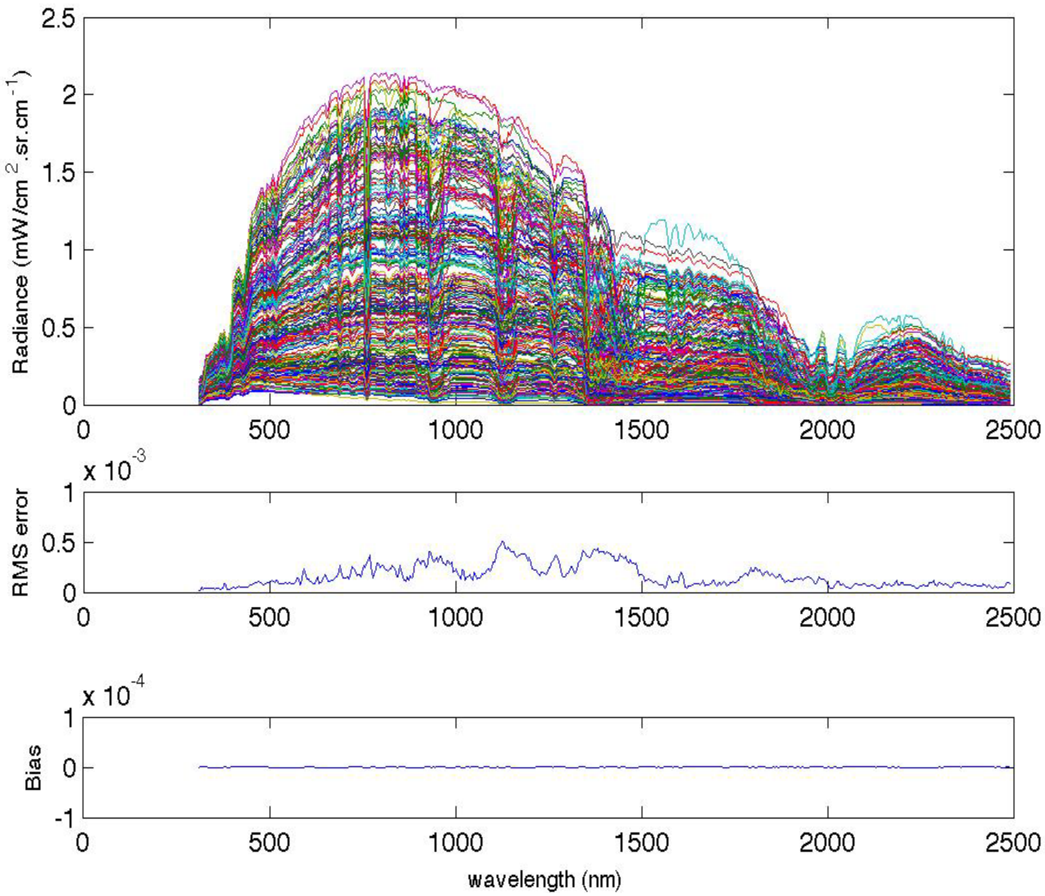
$$\vec{R}^{ch} = \sum_{i=1}^{N_{EOF}} y_i \vec{U}_i + \vec{\varepsilon}$$

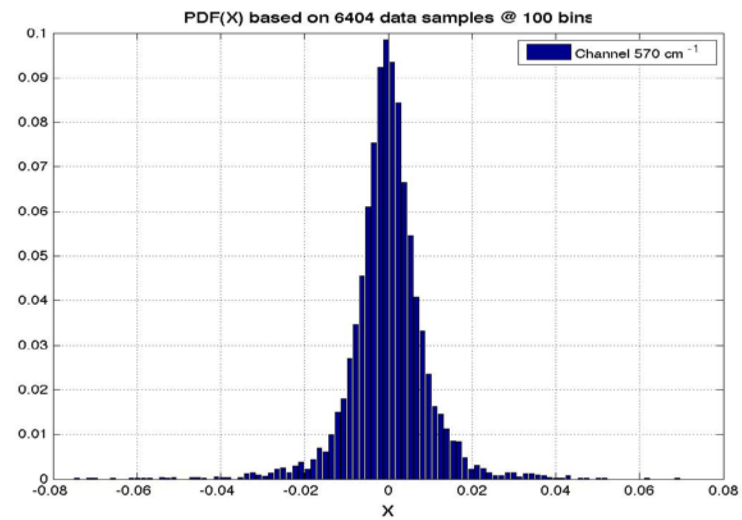
  - Radiative transfer done monochromatically at very few frequencies
  - Very accurate relative to line-by-line (LBL) RT model (< 0.05K or 0.05%)
  - 3-4 orders of magnitude faster than LBL RT models
  - A factor of 2-100 times faster than channel-based RT models
  - Provides Jacobian or radiative kernel needed for retrievals and climate studies
  - Includes accurate cloud RT

Accuracy of PCRTM is very good relative to reference RT models

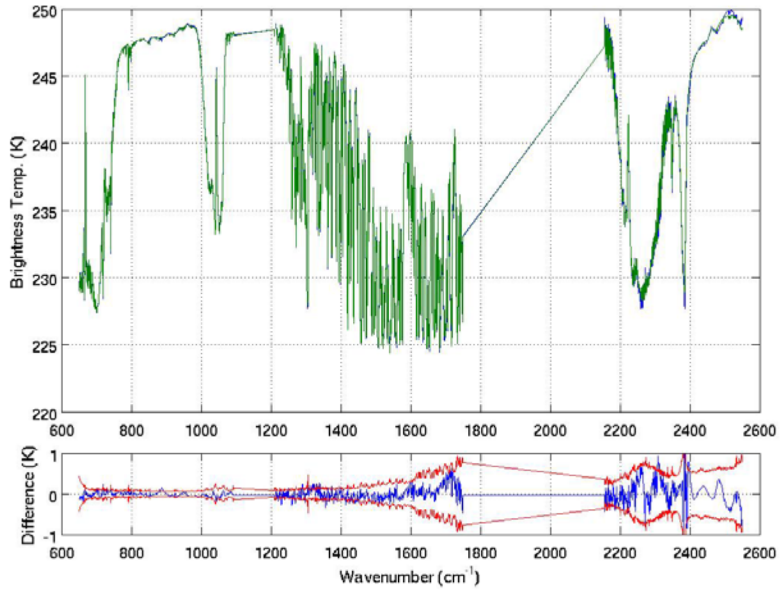
- Bias error relative to LBL is typically less than 0.002 K
- The PDF of errors at different frequencies are Gaussian distribution
- RMS error < 0.03K for IR and < $5x10^{-4}$ $mW/cm^2/sr/cm^{-1}$ for solar (< ~0.02%)

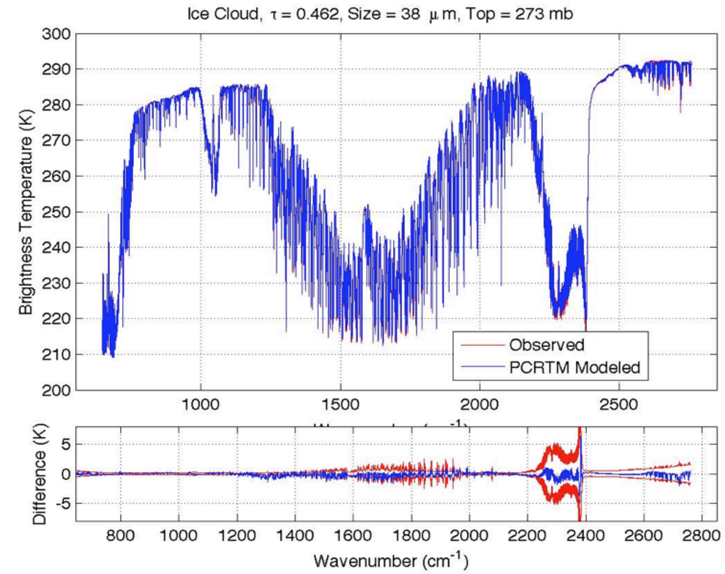


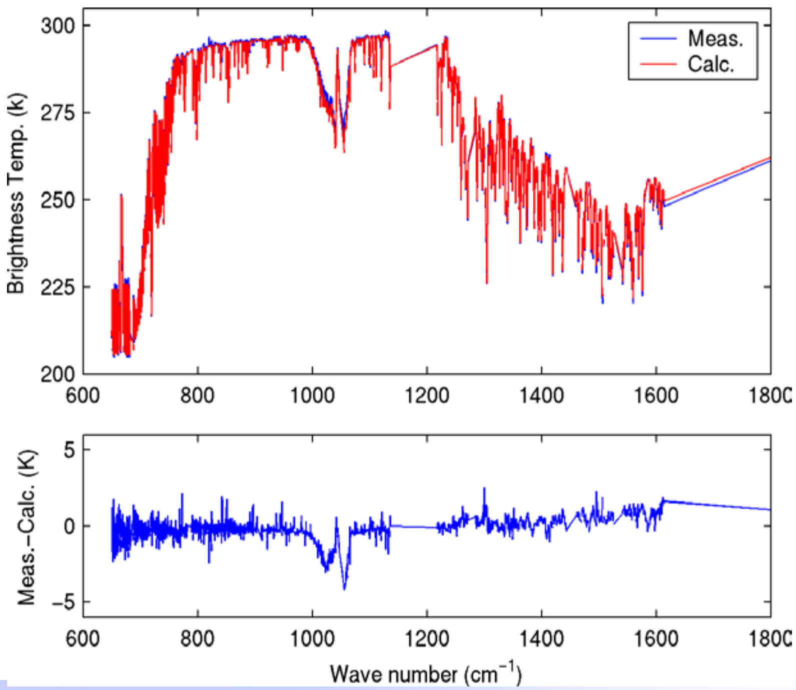


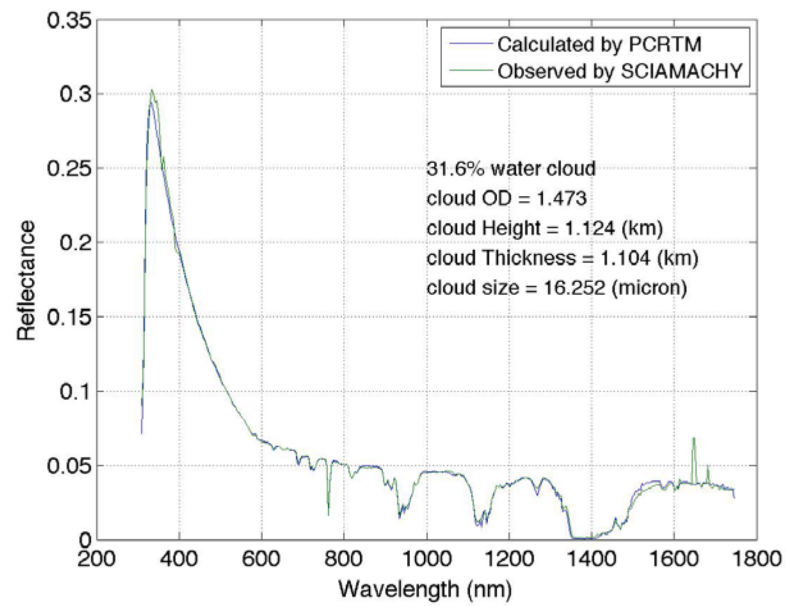


PCRTM has been validated using CrIS, IASI, AIRS, NAST-I, and SCIAMACHY real data









Computational Speed in IR Spectral Region

Sensor	Channel Number	PC score (seconds)	PC score + radiance	PC score + PC Jacobian
CLARREO, 0.1 cm^{-1}	19901	0.014 s	0.022 s	0.052 s
CLARREO, 0.5 cm^{-1}	5421	0.011 s	0.013 s	0.039 s
CLARREO, 1.0 cm^{-1}	2711	0.0096 s	0.012 s	0.036 s
IASI, 0.25 cm^{-1}	8461	0.011 s	0.012 s	0.044 s
AIRS, 0.5-2.5 cm^{-1}	2378	0.0060 s	0.0074 s	0.031 s
CrIS,0.625-2.5 cm^{-1}	1317	0.0050 s	0.0060 s	0.021 s
NAST-I, 0.25 cm^{-1}	8632	0.010 s	0.013 s	0.045 s
S-HIS, 0.5 cm^{-1}	4316	0.008 s	0.008 s	0.038 s
CrIS, 0.625 cm^{-1}	2211	0.009 s	0.009 s	0.033 s

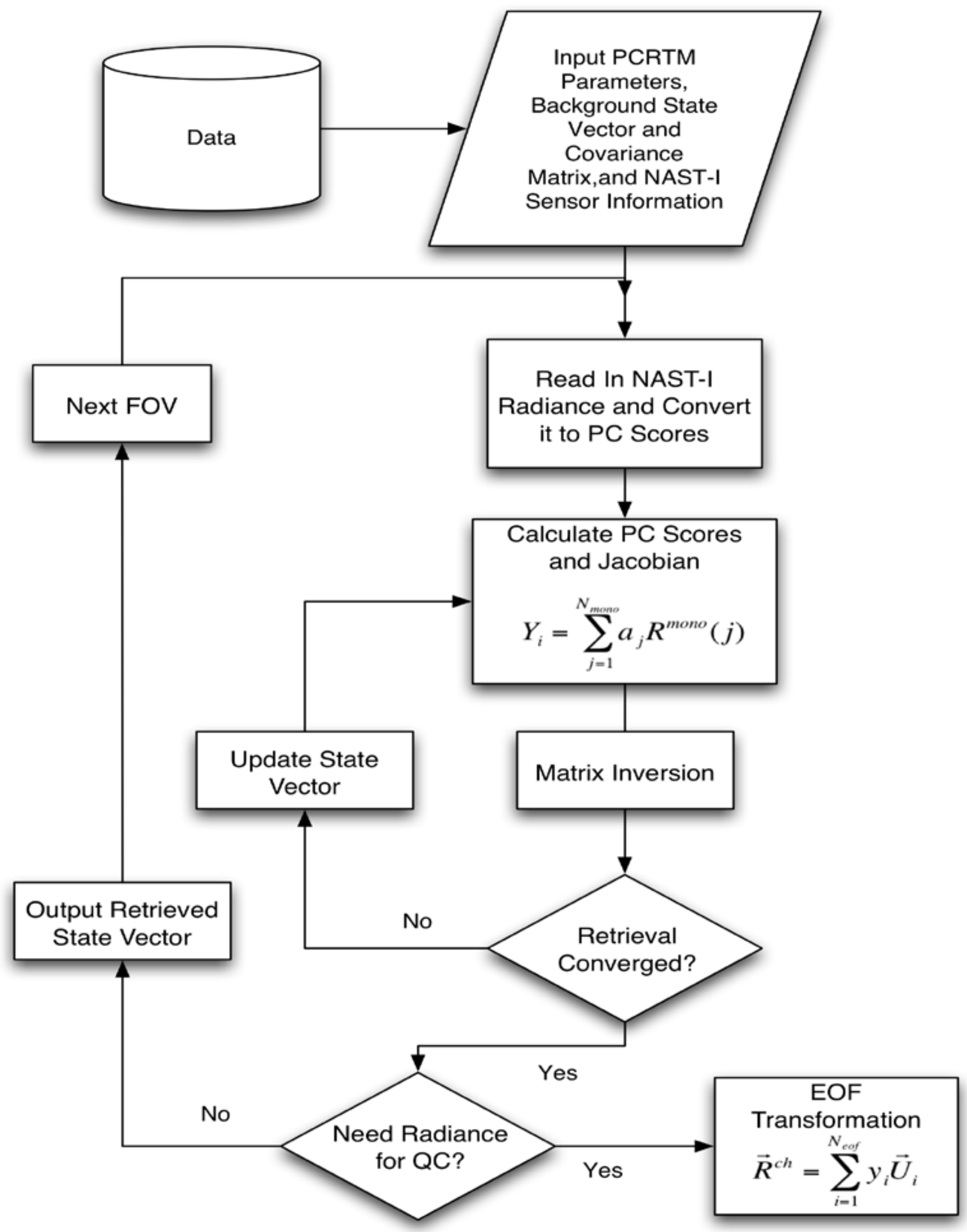
- Milliseconds to fraction of seconds in IR
- CrIS, CrIS-full-res, IASI, NAST-I and S-HIS have multiple databases corresponding to different instrument lineshape function
- Spectral coverage (50-3000 cm^{-1})
- Multilayer, multiple scattering clouds included
- 15 variable trace gases
- It provide radiative kernel/Jacobian with minimum additional computations.

Computational Speed up in Solar Spectral Region

- PCRTM reduces MODTRAN RT calculation by a factor or 28-928 depending on spectral resolution and MODTRAN accuracy chosen
  - PCRTM can handle ice and water clouds
  - Aerosols
  - Various trace gases
  - Land and ocean surfaces
  - Multiple scattering calculation uses 4-32 streams
- It takes 1 day to simulate 1 years of all sky SCIAMACHY spectra using PCRTM with 30 CPUs
- It will take more than 2 years for the MODTRAN to do the same

0.3 μm-2.0 μm	PCRTM RT	MODTRAN RT	speed up
Ocean 1cm^{-1}	956	259029	270
Land 1cm^{-1}	1339	259029	193
Ocean 4nm	279	259029	928
Land 4nm	354	259029	731
Oc/ld 10 nm	109	3079	28

A brief description of the PCRTM Optimal Estimation Retrieval Algorithm



$$X_{n+1}-X_a=(K^TS_y^{-1}K+\lambda I+S_a^{-1})^{-1}K^TS_y^{-1}[(y_n-Y_m)+K(X_n-X_a)]$$

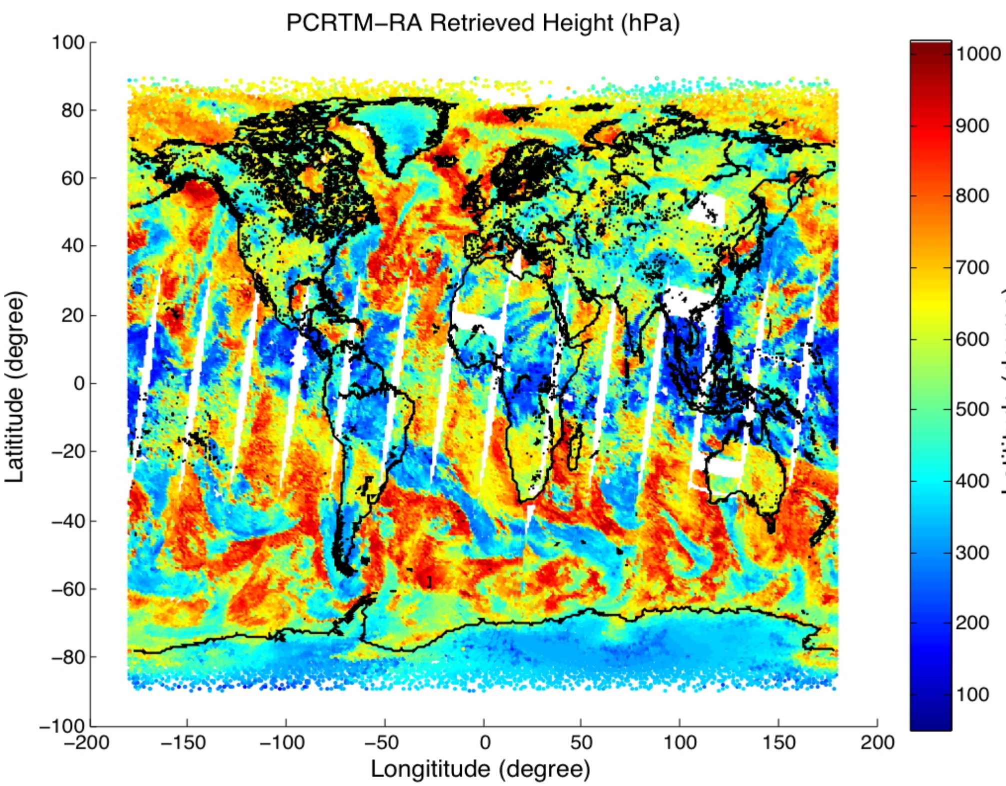
PCRTM models PC scores directly
- Small matrix and vector dimensions
- All 8000 channels from IASI and NAST-I used

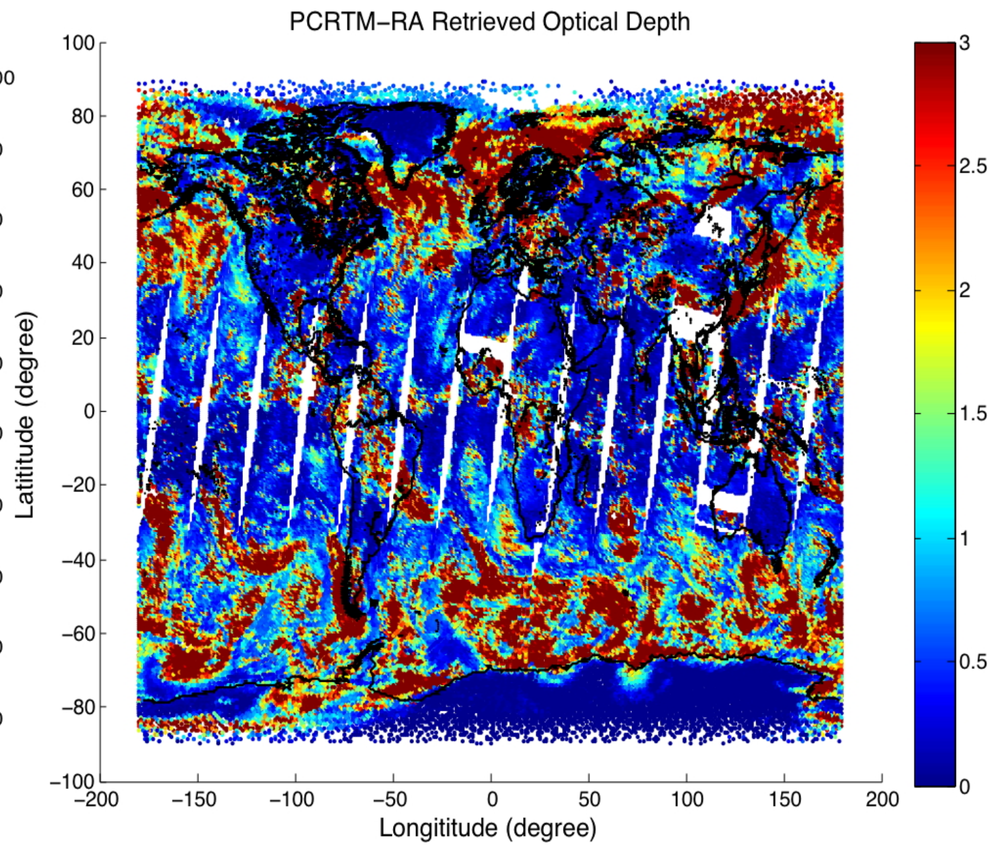
Both y and x vectors are in EOF domain
- Small matrix and vector dimensions
- 100 super channels instead of thousands of channels
- Simply minimizing cost function
- Channel-to-channel correlated noise handled

All parameters retrieved simultaneously
- No need to estimate errors of non-retrieved parameters
- Temperature
- Water
- Trace gases (CO2, CO, CH4, O3, N2O)
- Surface temperature and emissivities
- Cloud optical depth/size/phase/height

Retr. Config/Matrix Dimension	Radiance/Profile	Subset Radiance/ Profile	Radiance PC/ Profile PC
Y	~8400	300	100
X	100	100	41
K	8400x100	300x100	100x41
S_y^{-1}	8400x8400	300x300	100x100
S_x	100x100	100x100	41x41

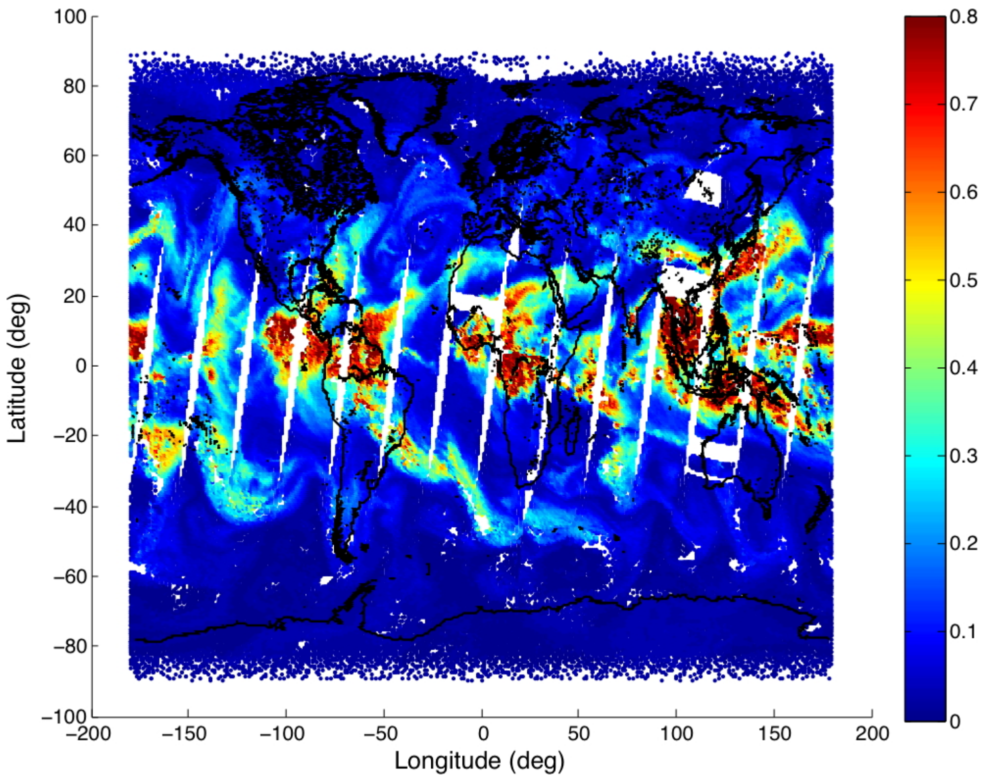
PCRTM-RA Retrieved Cloud Top Pressure and Optical Depth from 5-15-2012 CrIS/ATMS focus day data



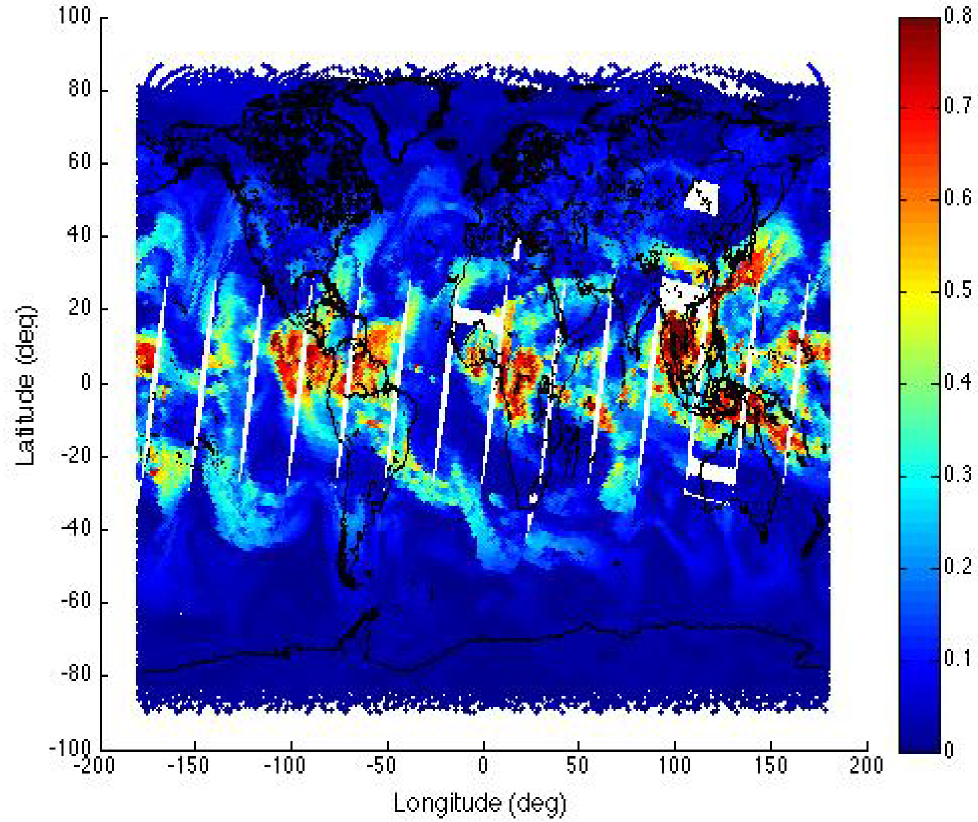


Comparison of PCRTM-RA Retrieved and ECMWF Atmospheric Water Vapor from 5-15-2012 focus day CrIS/ATMS data

Retrieved 300 hPa from CrIS/ATMS using PCRTM-RA

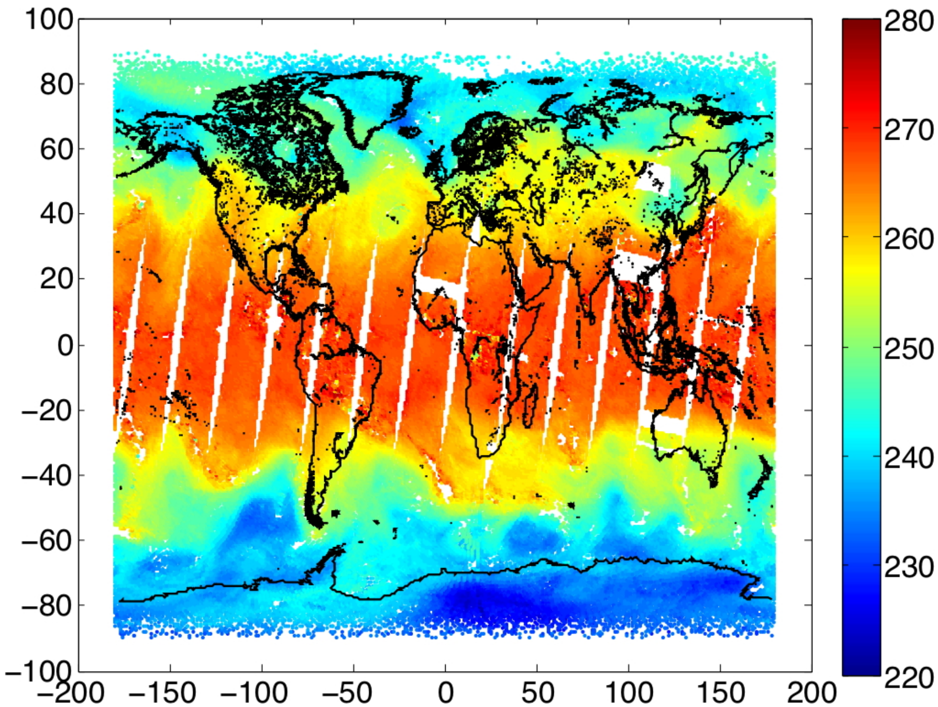


300 hPa from ECMWF

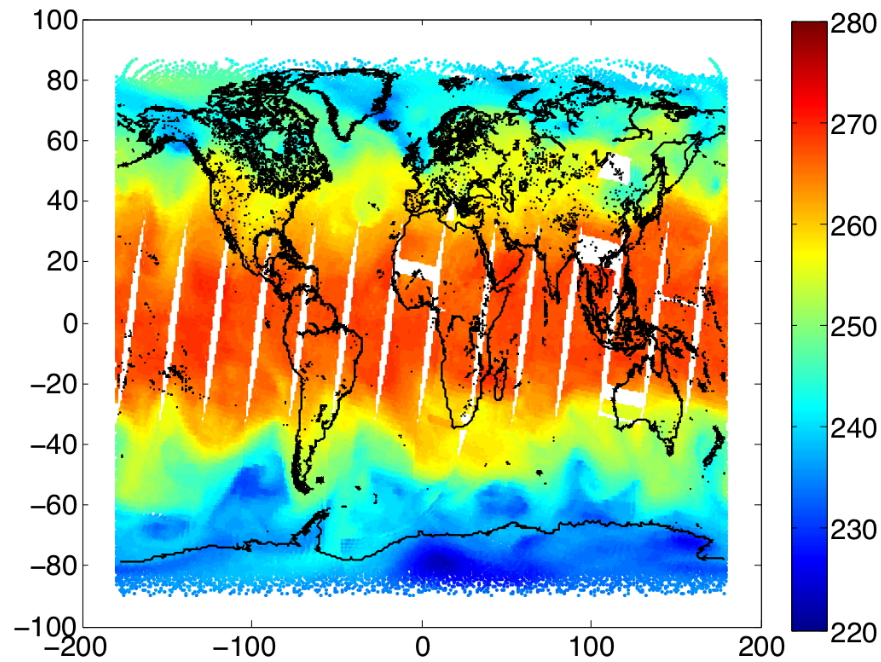


Comparison of PCRTM-RA Retrieved and ECMWF Atmospheric Temperature from 5-15-2012 focus day CrIS/ATMS data

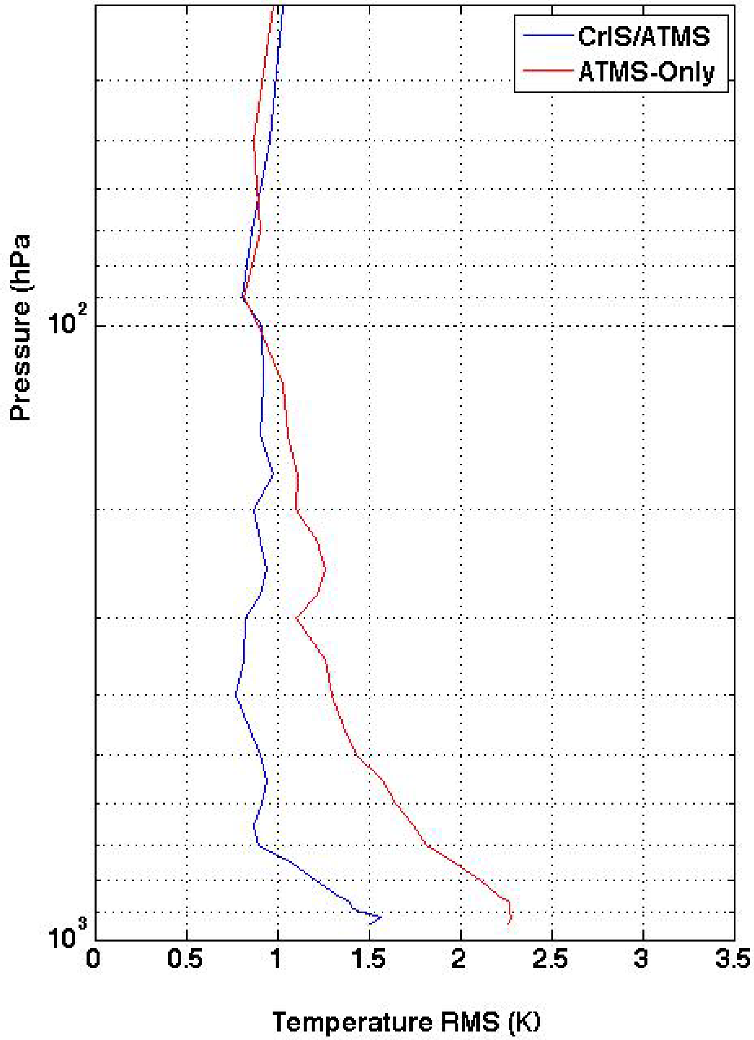
500 hPa Retrieved from ATMS/CrIS using PCRTM_RA

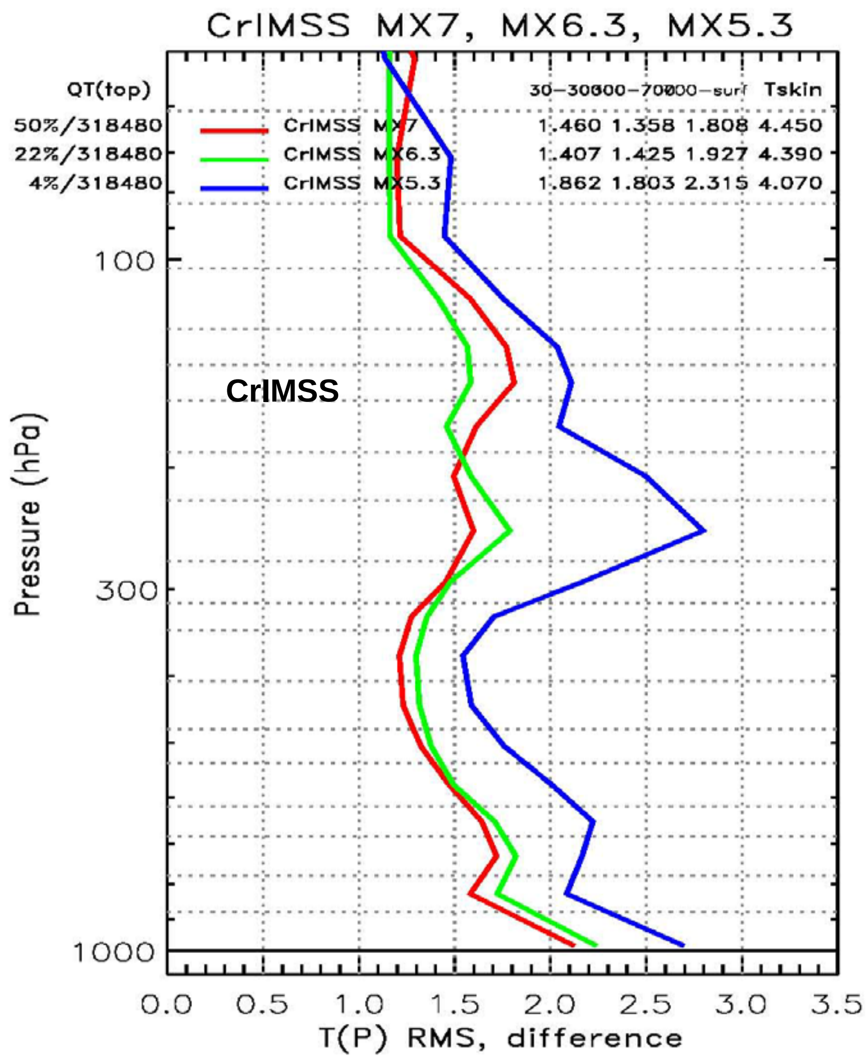


500 hPa Temperature from ECMWF

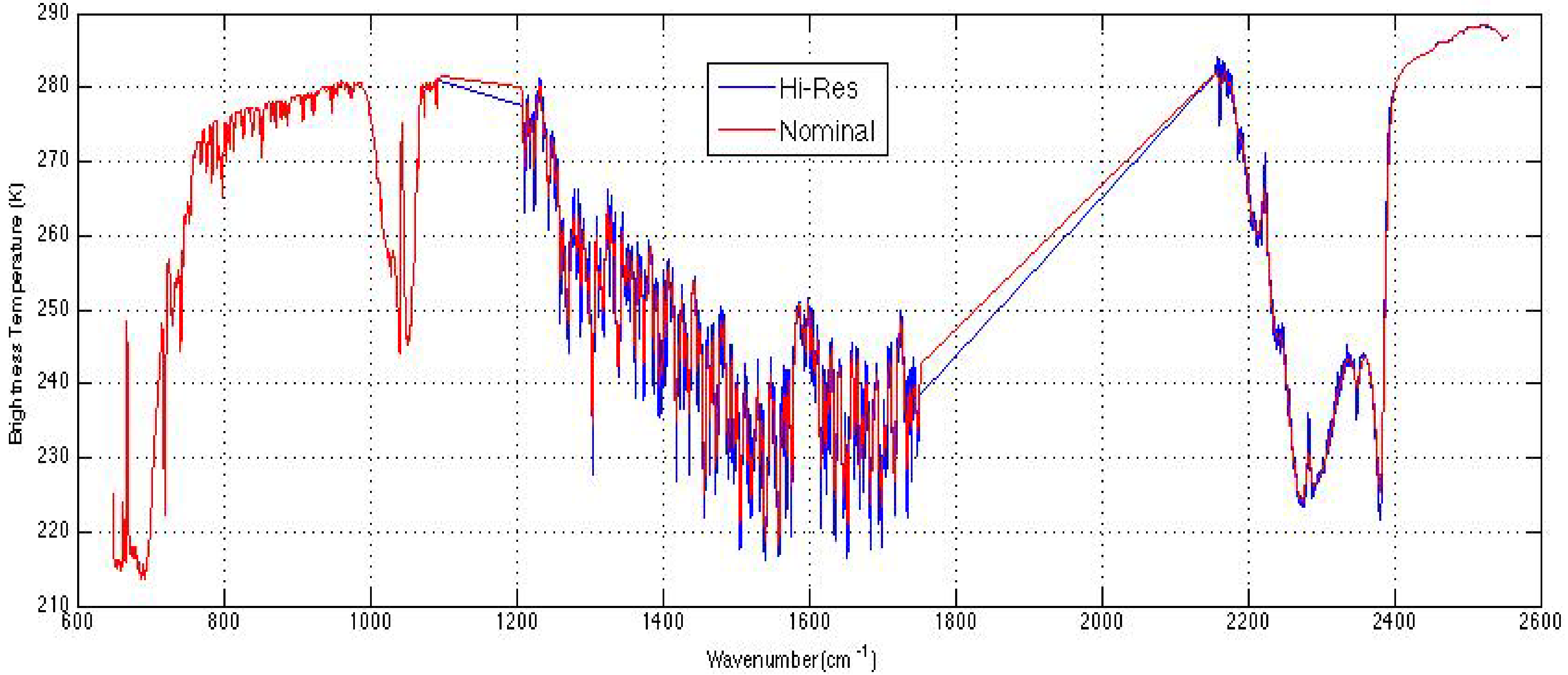


Comparison of PCRTM Temperature Retrieval with Operational CrIMSS





Recent Application of PCRTM to S-NPP CrIS data

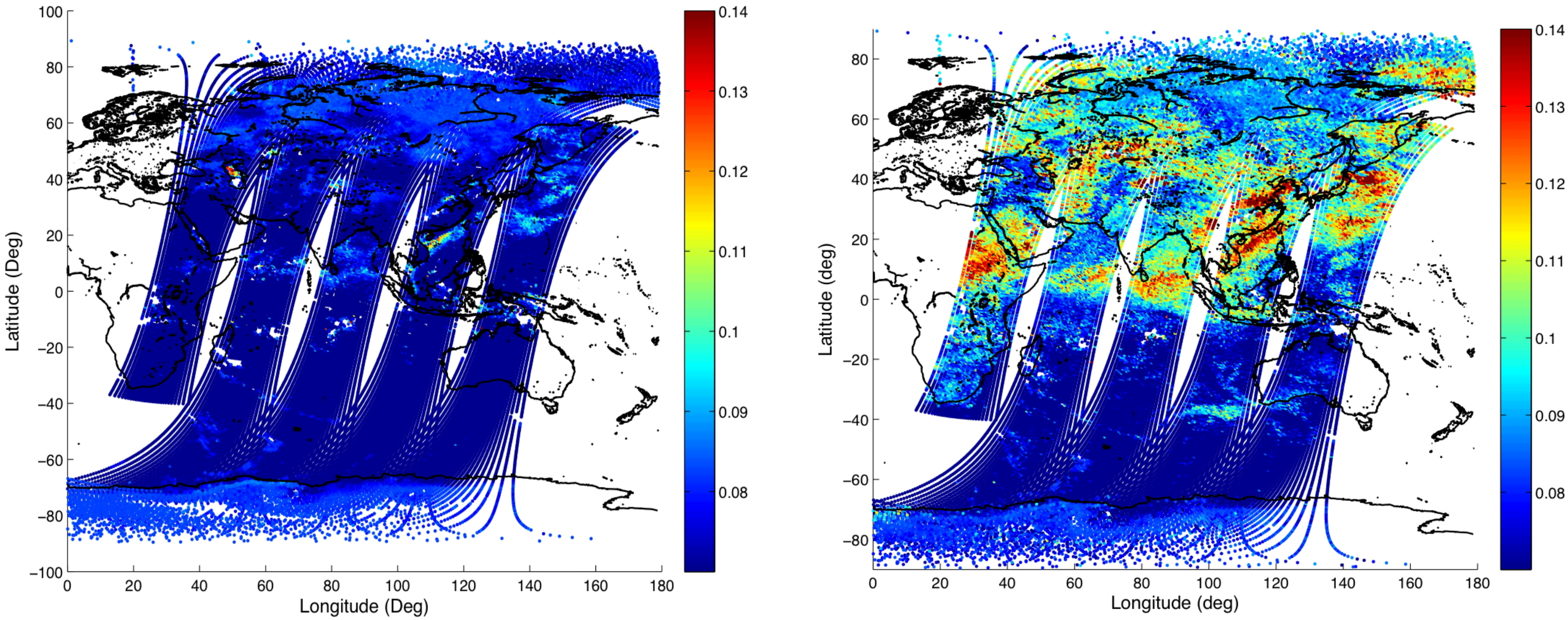


	CrIS (LW)	CrIS (MW)	CrIS (SW)
Nominal Res	0.625 cm^{-1}	1.25 cm^{-1}	2.5 cm^{-1}
High Res.	0.625 cm^{-1}	0.625cm^{-1}	0.625cm^{-}

CO retrieved from full-resolution CrIS data (3-12-2013)

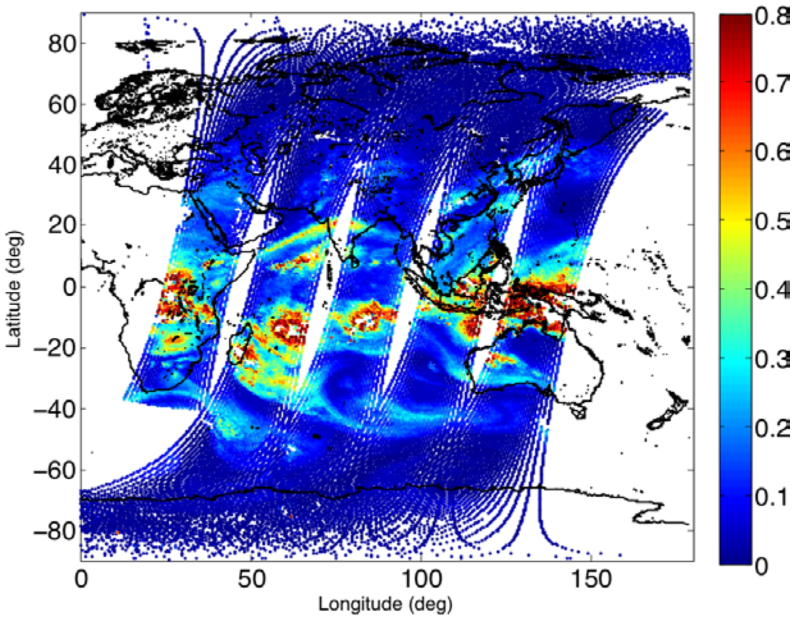
From nominal resolution CrIS using PCRTM-RA

From high resolution CrIS using PCRTM-RA

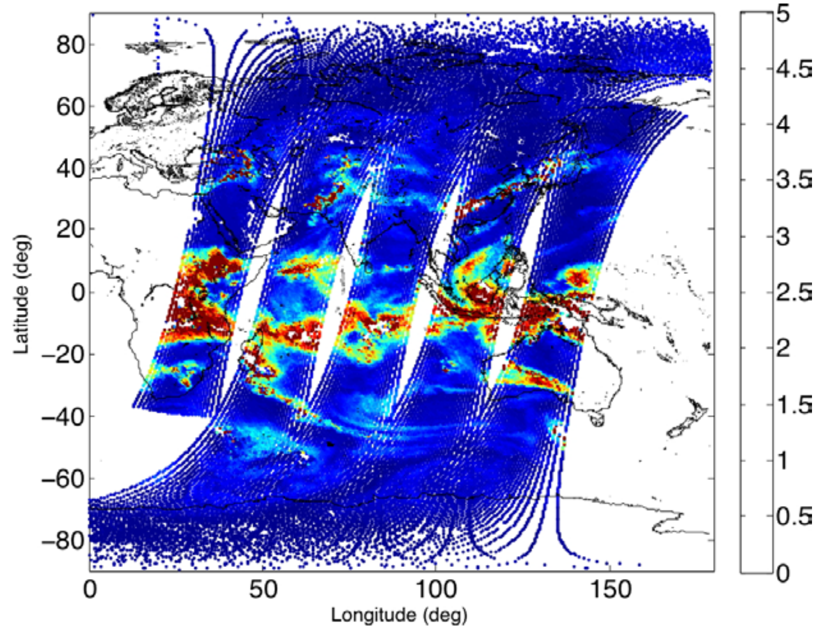


PCRTM-RA Retrieved Atmospheric Temperature from High Resolution CrIS/ATMS

Retrieved 300 hPa H2O from CrIS/ATMS using PCRTM-RA

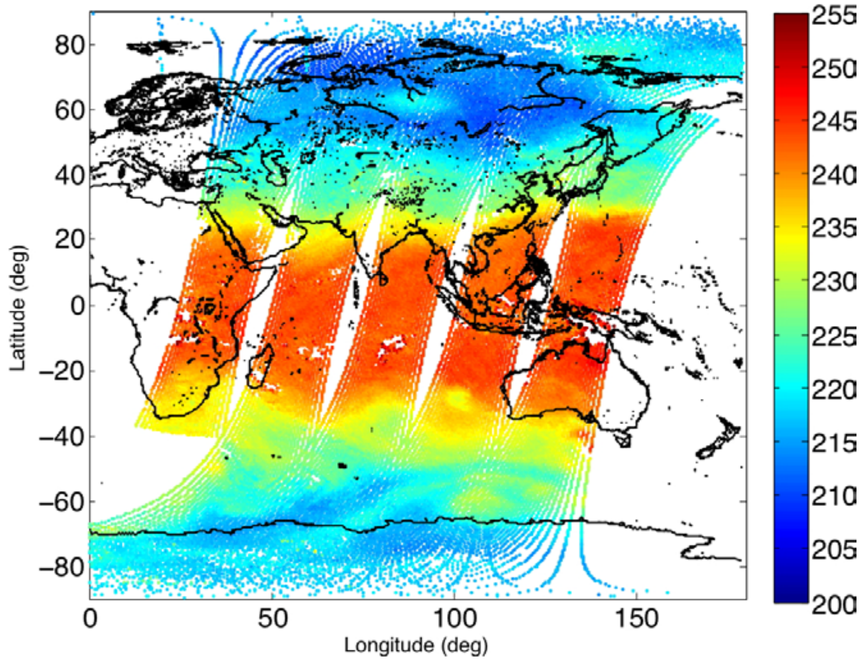


Retrieved 500 hPa H2O from CrIS/ATMS using PCRTM-RA

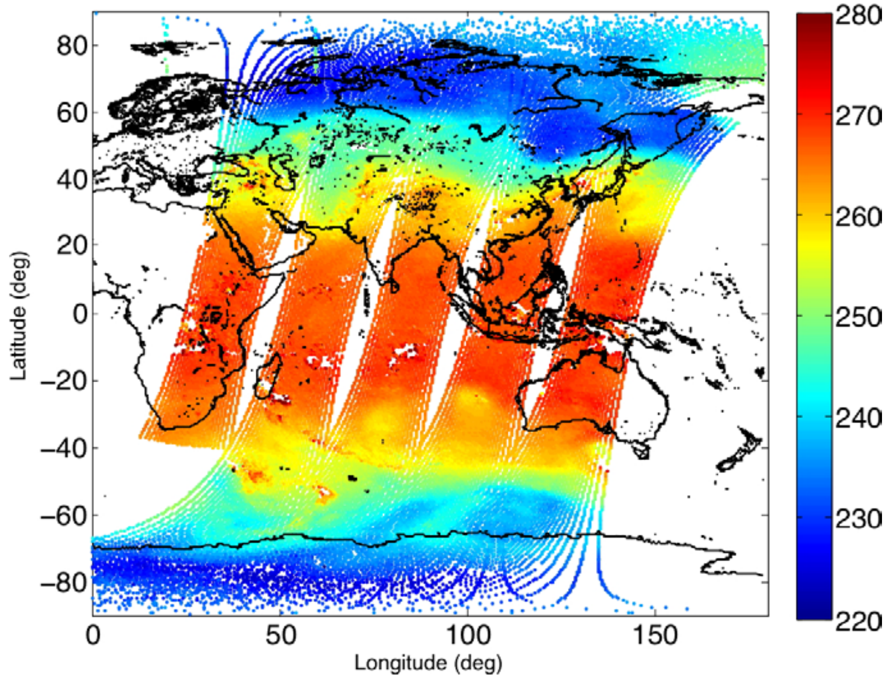


PCRTM-RA Retrieved Atmospheric Temperature from High Resolution CrIS/ATMS

Retrieved 300 hPa Temperature from CrIS/ATMS using PCRTM-RA

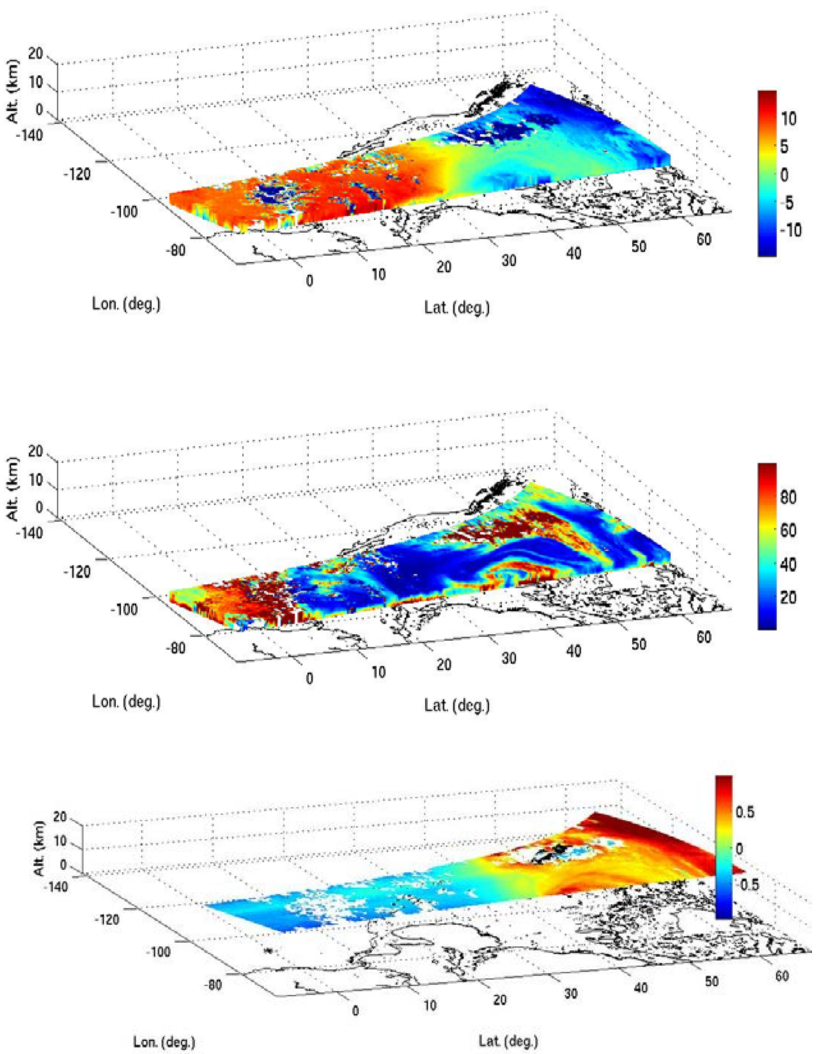


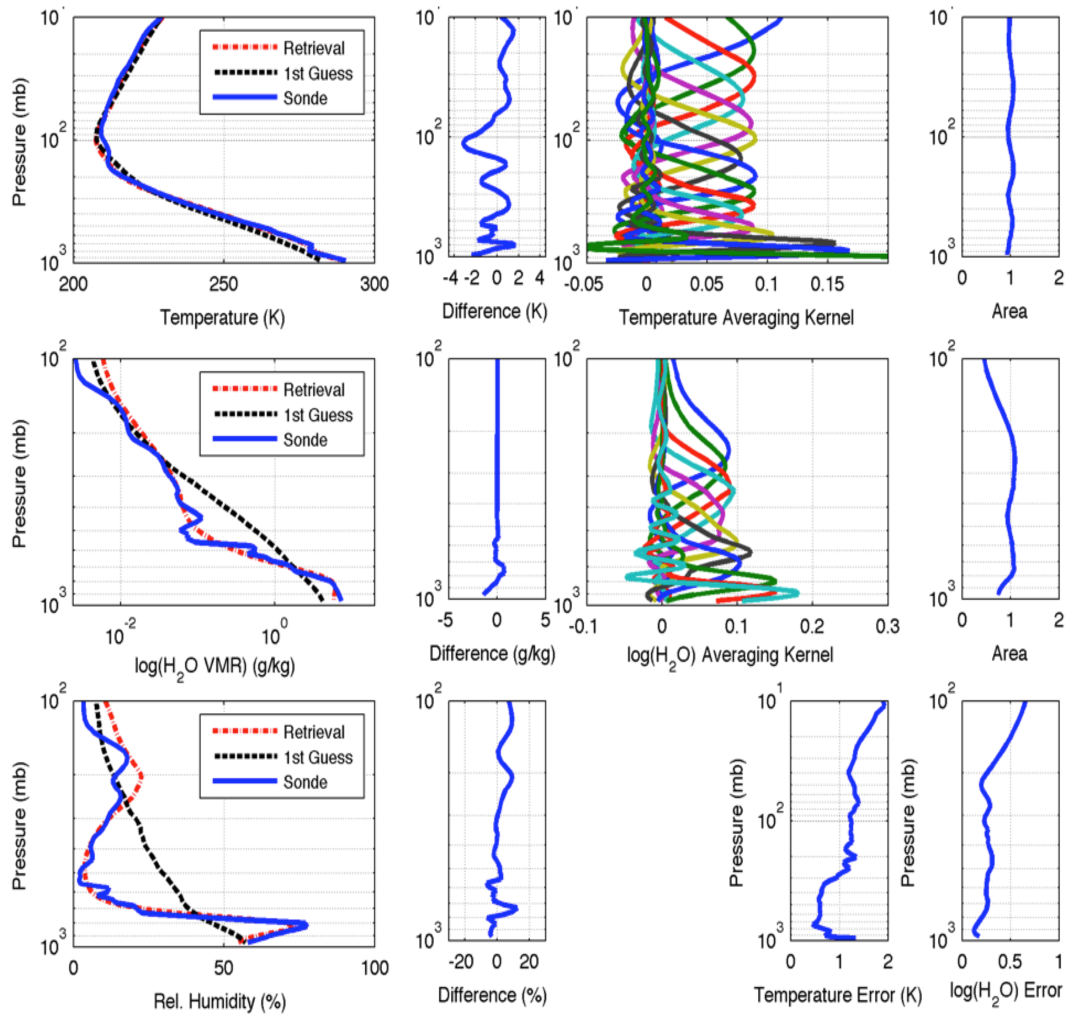
Retrieved 500 hPa Temperature from CrIS/ATMS using PCRTM-RA



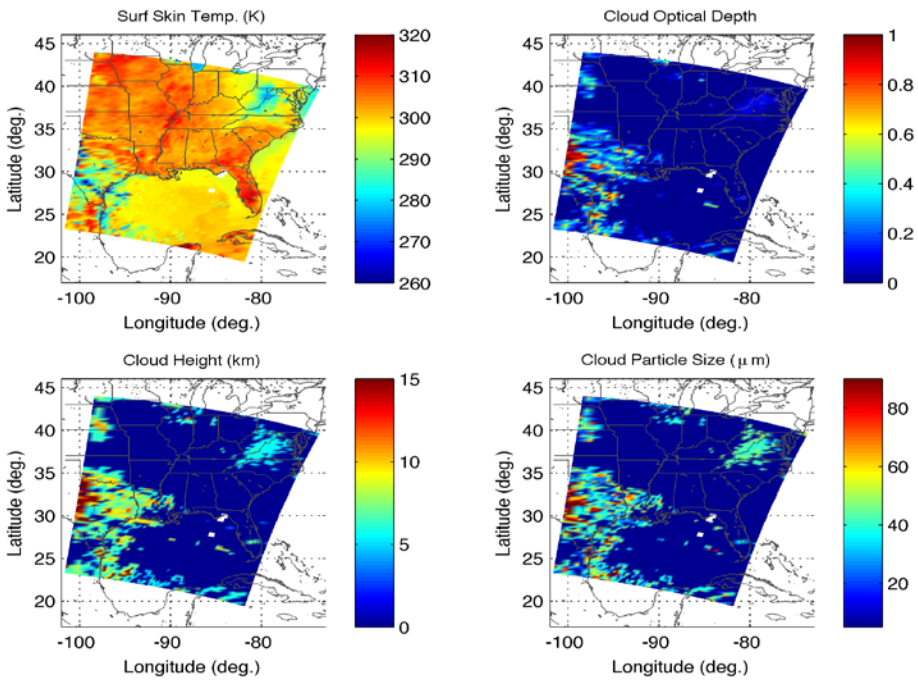
Comparison of PCRTM retrieval with radiosondes

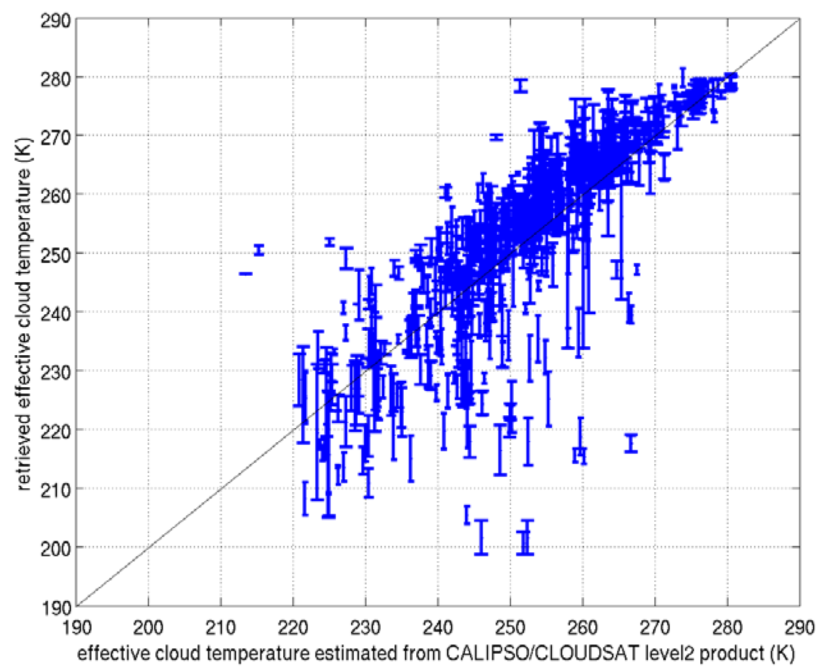
- Temperature, moisture, and ozone cross-sections
- Plots are deviation from the mean
- Fine water vapor structures captured by the retrieval system
- A very cloudy sky condition





Example of retrieved cloud properties



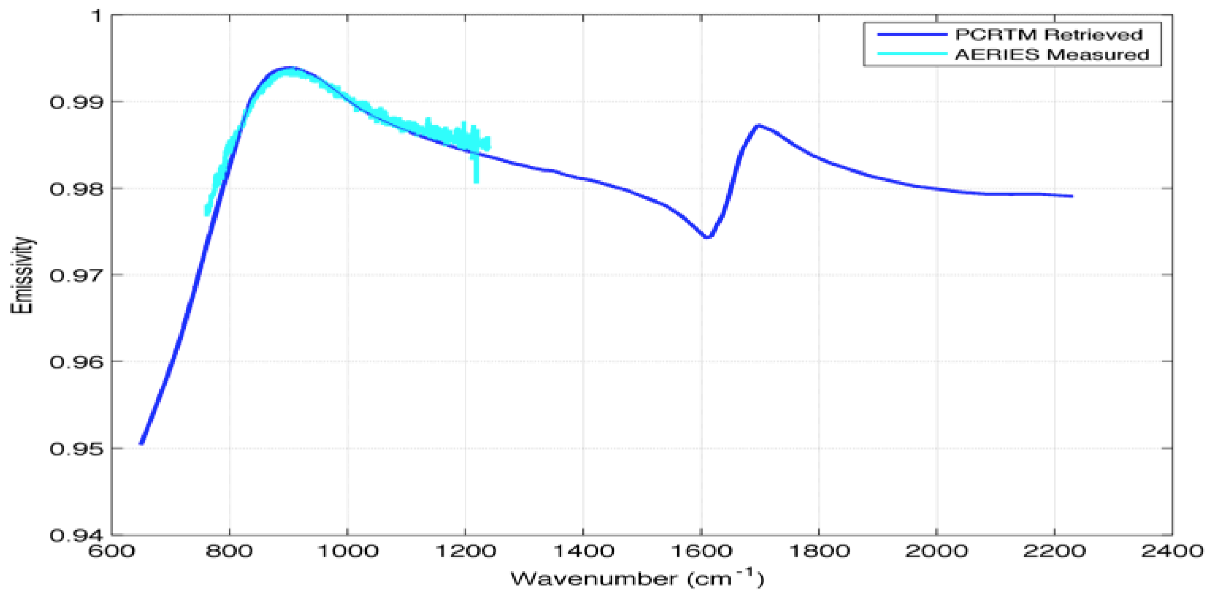


Example of retrieved surface temperature and emssivity and comparison with field validation data

Comparison of PCRTM retrieved surface skin temperature with ARIES measured Tskin

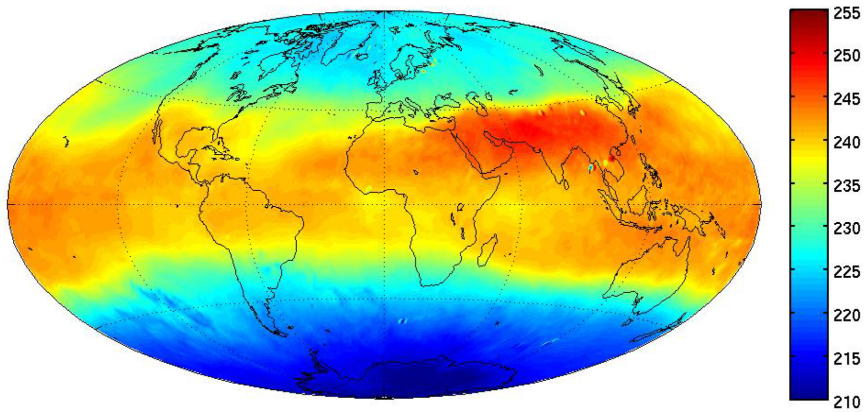
Date	Location	Surface Pressure (hPa)	ARIES Measured skin temperature (K)	IASI-retrieved surface skin temperature (K)
19 April 2007	ARM CART site	972.0	284.7	284.8
29 April 2007	Gulf of Mexico	1021.7	297.8	297.6
30 April 2007	Gulf of Mexico	1017.5	298.6	298.1
4 May 2007	Gulf of Mexico	1009.9	297.4	297.1

Comparison of retrieved ocean emissivity with ARIES aircraft measurements

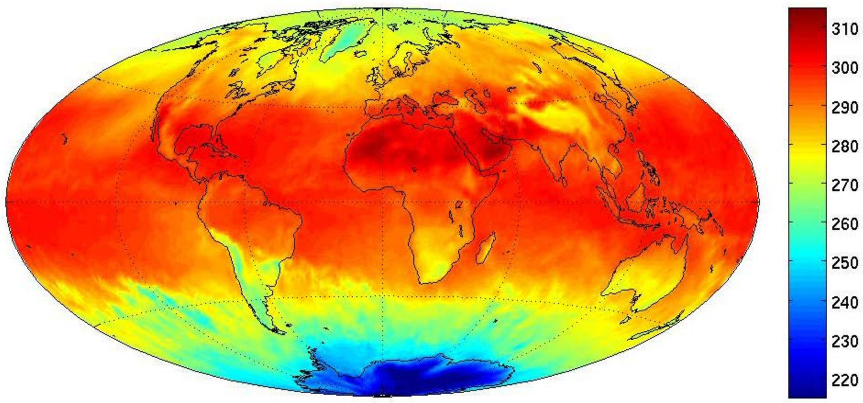


Example of retrieved global distribution of climate related properties retrieved using the PCRTM algorithm

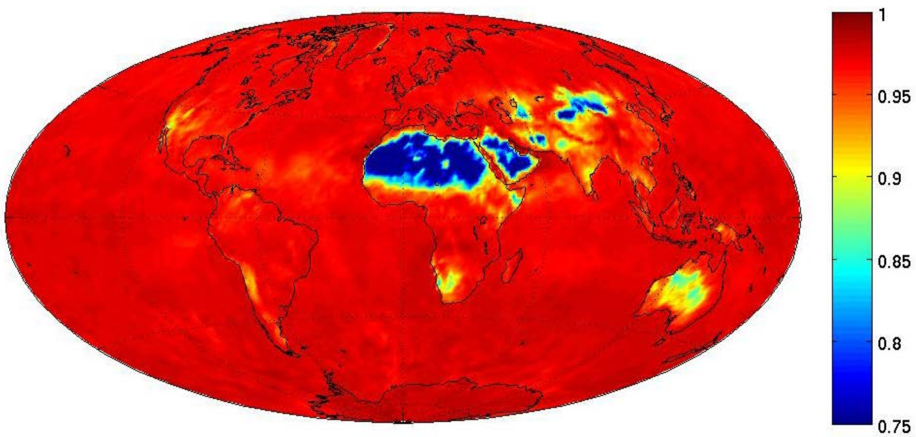
Atmospheric temperature at 9 km for July 2009



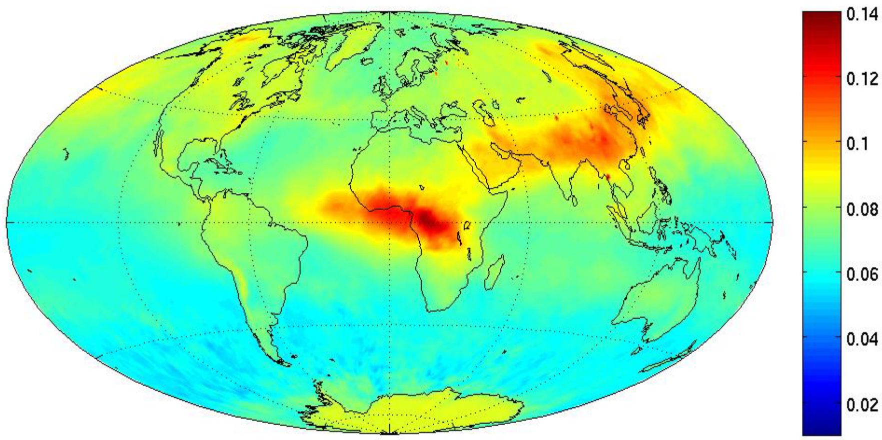
Surface skin temperature for July 2009



Surface emissivity for July 2009



Atmospheric carbon monoxide mixing ratio for July 2009



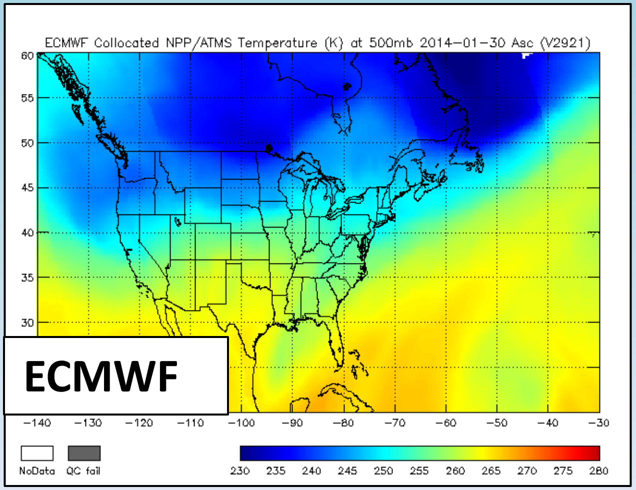
Summary and conclusions

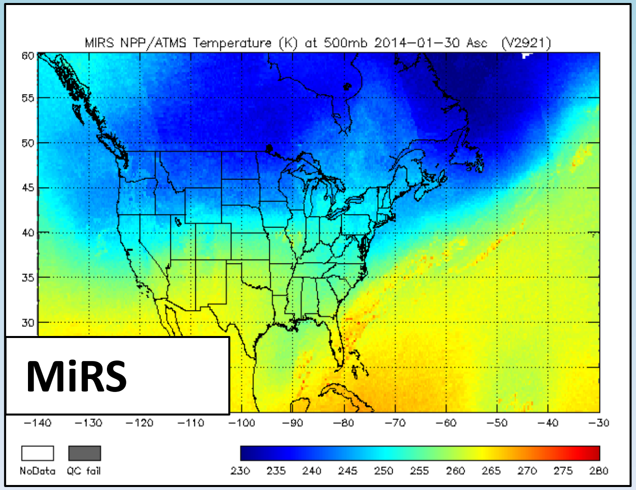
- Forward model is a key component in analyzing hyperspectral data
  - PCRTM has been developed for numerous satellite and airborne sensors
  - Covers spectral range from 0.31 μm to 200 μm
  - With 15 variable trace gases
  - Multiple scattering clouds included
  - Physical and accurate
  - Very fast relative to LBL and traditional fast RT models
  - Been applied to numerous hyperspectral sensors: AIRS, IASI, CrIS, NAST-I, SCIAMACHY
- PCRTM-RA developed to use full spectral information
  - Atmospheric temperature profile
  - Atmospheric water vertical profiles
  - Trace gas profiles,
  - Cloud height, particle size, phase, effective temperature, optical depth
  - Surface properties (Tskin, emissivity …)
- PCRTM-RA system now includes MW channels
  - CRTM used as forward model
  - Improves performance below thick clouds
  - Designed for ATMS/CrIS, ATMS/Hi-Res CrIS, AMSU/AIRS, AMSU/IASI, CLARREO
  - Can do MW-only, IR-only, or MW+IR
- Advantages of PCRTM-RA
  - No need to assume the scene inhomogeneity and estimate cloud-clearing error
  - Full multiple scattering effect accounted for through a fast parameterization
  - Full spectral channels used with all relevant parameters retrieved simultaneously
  - Good error estimate on retrieved variables

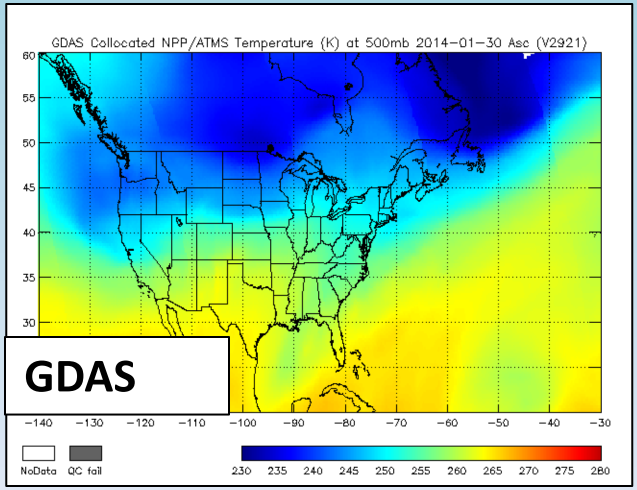
MiRS Science Improvements and ATMS Sounding Products

Chris Grassotti, Jerry Zhan, Tanvir Islam, Craig Smith, Pan Liang, Sid Boukabara, Kevin Garrett
NOAA/NESDIS/STAR
NOAA/JCSDA

STAR JPSS Annual Science Team Meeting
14 May 2014







Outline

- MiRS Description
- Technical/Science Improvements
- Performance Comparisons (SNPP/ATMS)
- Applications
- Summary/Plans

MiRS Description

MiRS Key Features:

- 1D-Variational Approach; consistent across sensors
- Cost Function measures fit to observations, and departure from a priori background
- All elements of state vector retrieved simultaneously (T(p), q(p), clw(p), rwp(p), iwp(p), Tskin, emissivity(freq)
- Derived products from core retrieval: TPW, RR, cryospheric products
- Retrieval in reduced EOF space
- Uses CRTM for forward and Jacobian computation
- SW architecture: same common set of underlying modules; facilitates extension to new sensors

MiRS Sensors

- Running operationally at NOAA (OSPO):
  - N-18, N-19, [Metop-A], Metop-B (hr) AMSU/MHS, [F16], F18 SSMI/S,
  - S-NPP ATMS (delivered to NDE/OSPO late 2012, operational Feb 2014),
  - Megha-Tropiques SAPHIR (delivered in March 2014)
- Experimentally run at STAR:
  - TRMM TMI, GCOM-W1 AMSR2, planned GPM GMI
- Currently being extended to F17, (eventually F19)

MiRS Assessments

- In STAR, all operational satellites/sensors run daily
- Routine monitoring and assessments include comparisons with:
  - GDAS, ECMWF, raobs (T, q, LST)
  - Surface rain gauges, TMI 2A12, CPC daily (RR)
  - F17 NRT (NASA Team) and NIC/IMS, OSI-SAF (sea ice)
  - SNODAS, GlobSnow, JAXA/AMSR2 (SWE)
- Results posted to website
  - http://www.star.nesdis.noaa.gov/smcd/mirs
- Retrieval product files available via website and ftp
  - Last 7 days: N18, N19, MetopA, MetopB, SNPP, F18

MiRS Science and Technical Improvements: **CRTM**

- **All prior MiRS DAPs used an early version of CRTM (pCRTM)**
  - o Good performance generally, but
  - o Extension to new sensors was cumbersome (coefficient file format differences)
  - o Leveraging improvements and fixes to CRTM difficult
- **New CRTM (2.1.1) implemented in MiRS for all sensors in STAR test environment; evaluation and tuning ongoing (may go to 2.1.3)**
- **Testing nearly compete and will be part of next official MiRS release in Summer 2014**
- **CRTM 2.1.x:**
  - o Complete overhaul of interface
  - o More sophisticated representation of hydrometeor data structures (rain, ice, graupel, snow) and the simulation of scattering effects, ocean surface reflection
- **Incorporating improvements, fixes, new sensors within MiRS will be much simpler**

MiRS Science and Technical Improvements: **Background Constraint**

- MiRS (operational) currently utilizes a priori state vectors and error covariances based on a global climatologies tied to surface types

- New "dynamic" background developed

- Based on 1 year of ECMWF analyses (2012)

- Atmospheric Background (**mean T, q, clw**) stored on a smoothed 5 x 5 deg grid, with temporal variation by month, and diurnally (**covariances** still global)

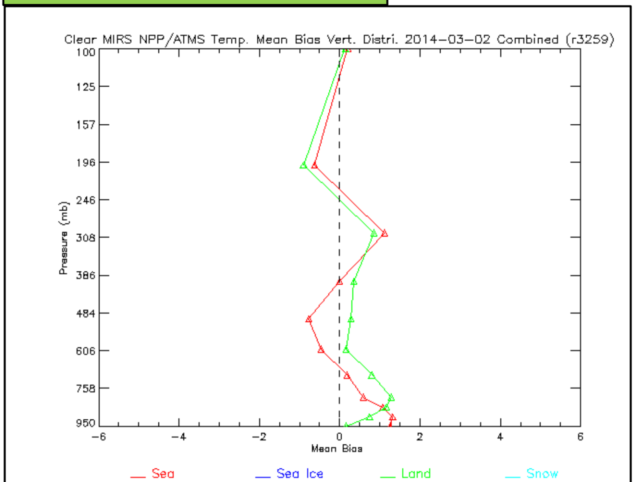
- Additional smoothness within MiRS (interpolation to FOV location in space and time)

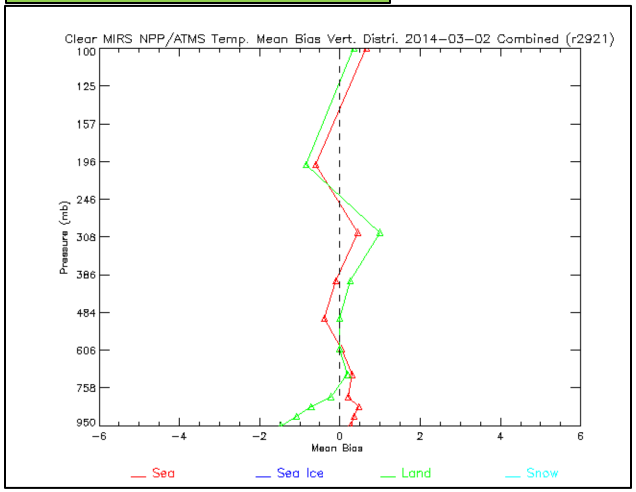
- Already part of the operational MiRS for MT/SAPHIR (v10.0); will be operational for all sensors in next release

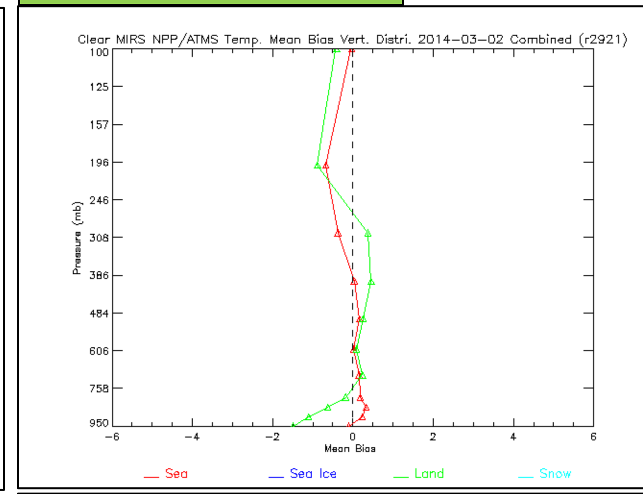
MiRS Sounding Performance Assessments: **Temperature Profile**

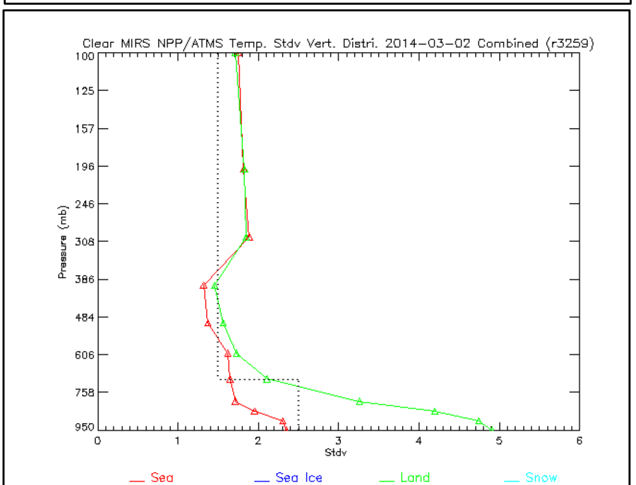
2014-03-02: Global

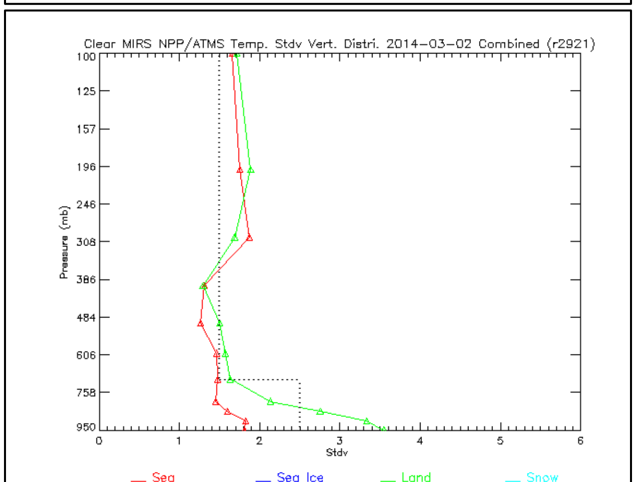
Operational MiRS	Test MiRS	Test MiRS
MIRS- ECMWF	MIRS- ECMWF	MIRS- GDAS

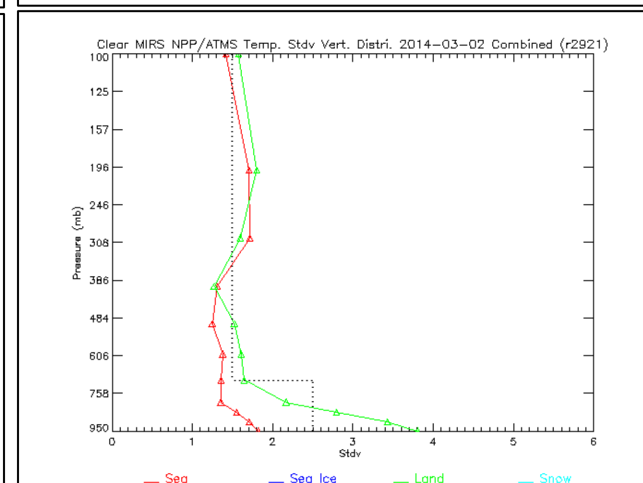










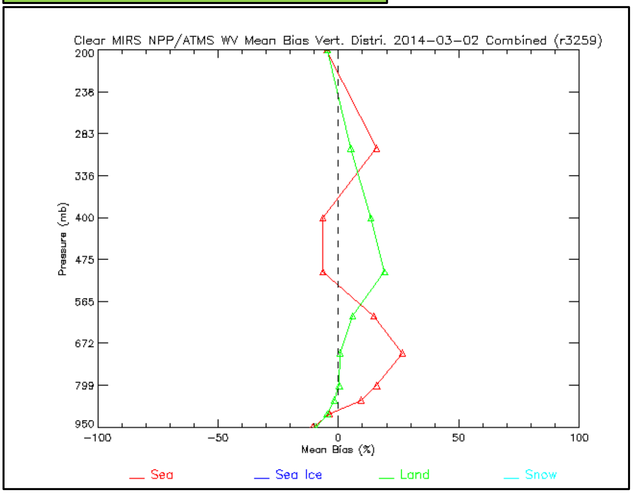


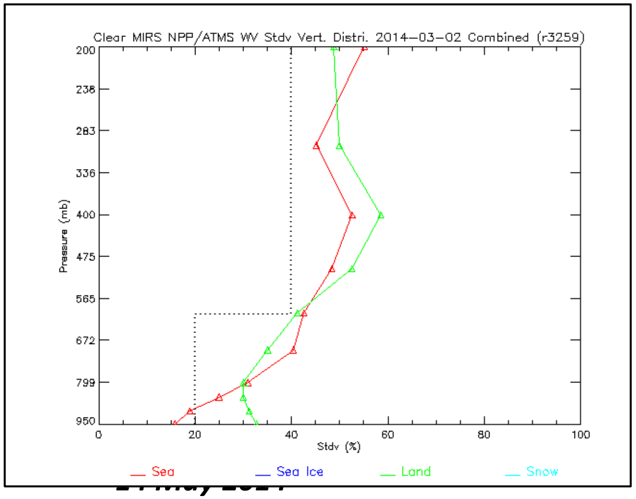
MiRS Sounding Performance Assessments:
Water Vapor Profile

2014-03-02: Global

Operational MiRS

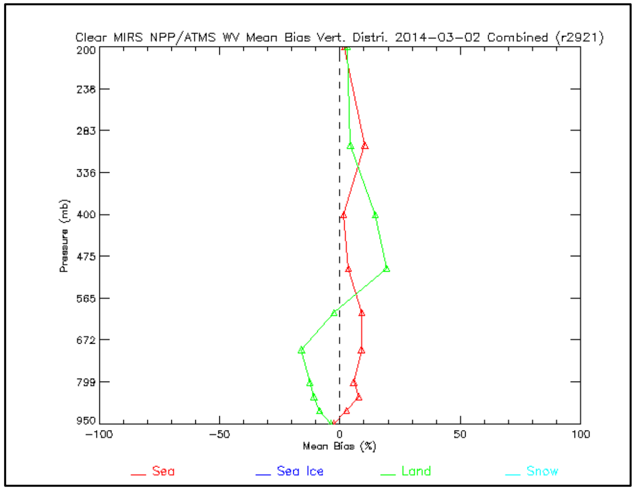
MIRS- ECMWF

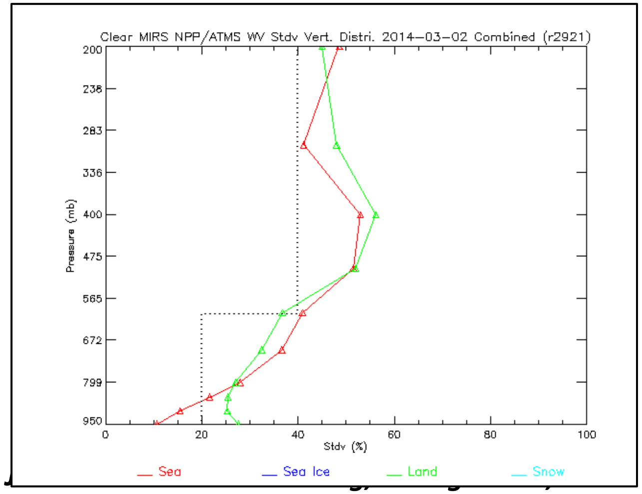




Test MiRS

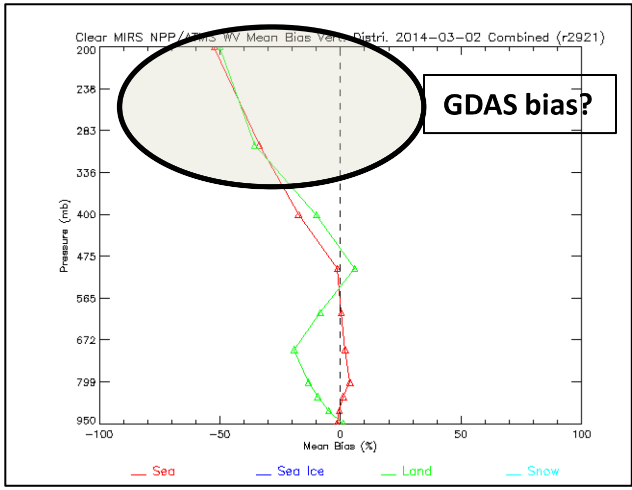
MIRS- ECMWF

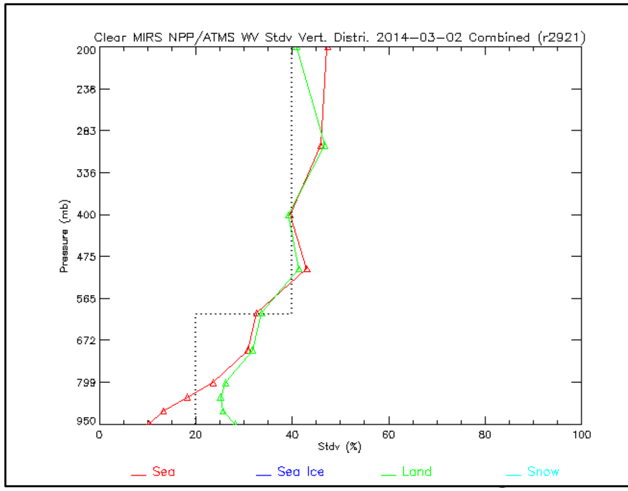




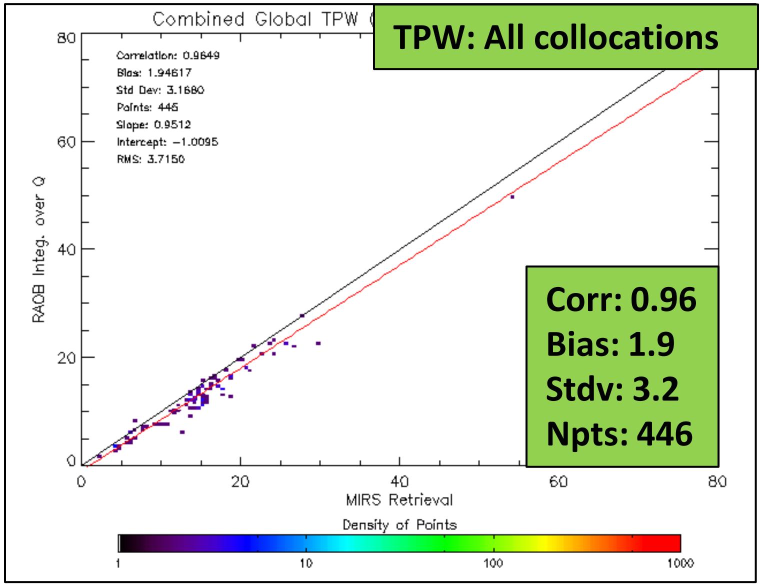
Test MiRS

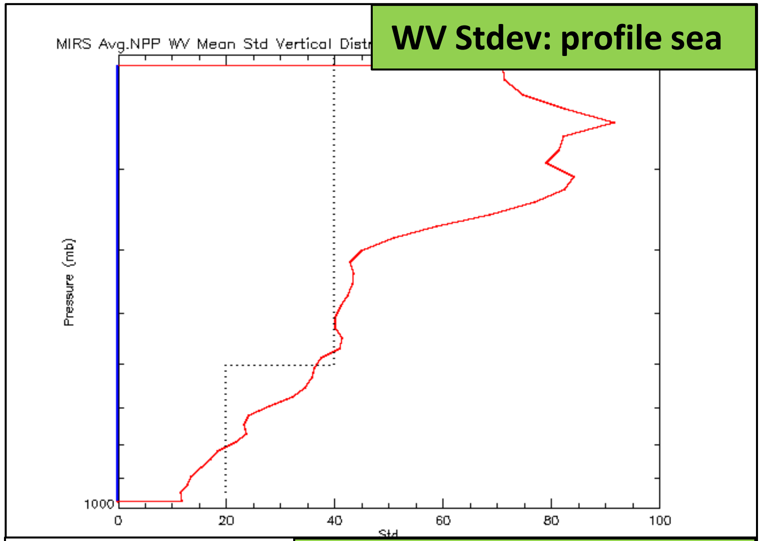
MIRS- GDAS

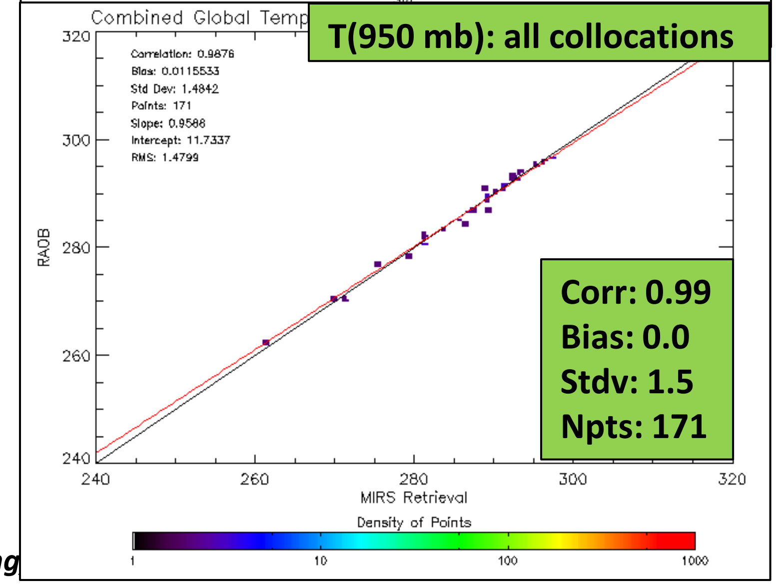




Raob vs. GDAS Analysis:
TPW, WV, Temperature







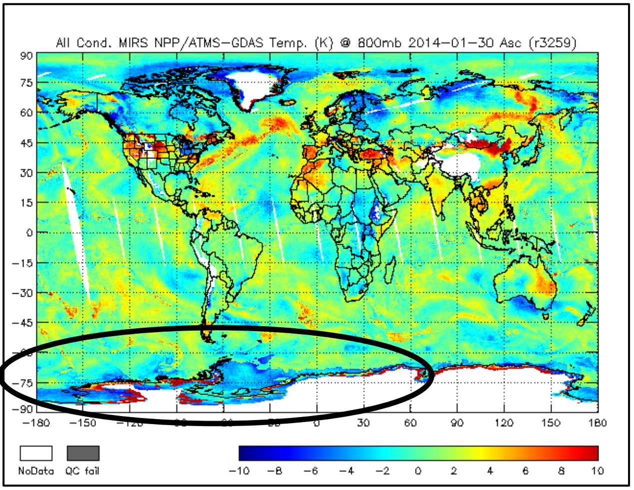
Collocations on 2014-05-10

MiRS Sounding Performance Assessments: 800 hPa Temperature

2014-01-30: Global

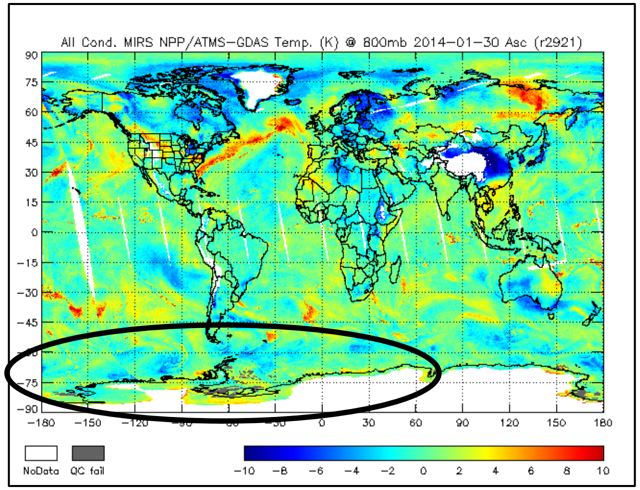
Operational MiRS

MIRS- GDAS

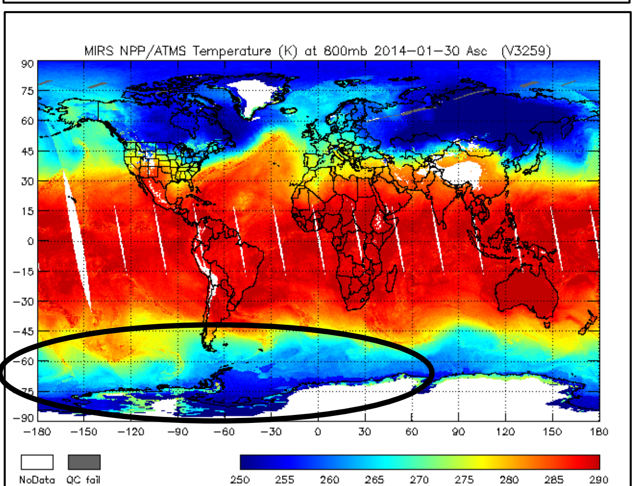


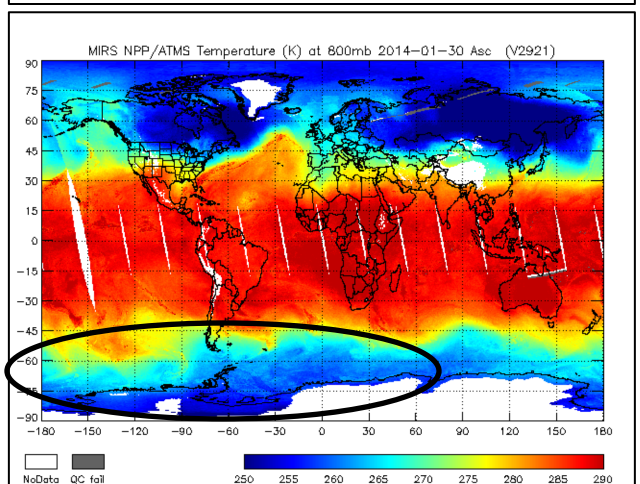
Test MiRS

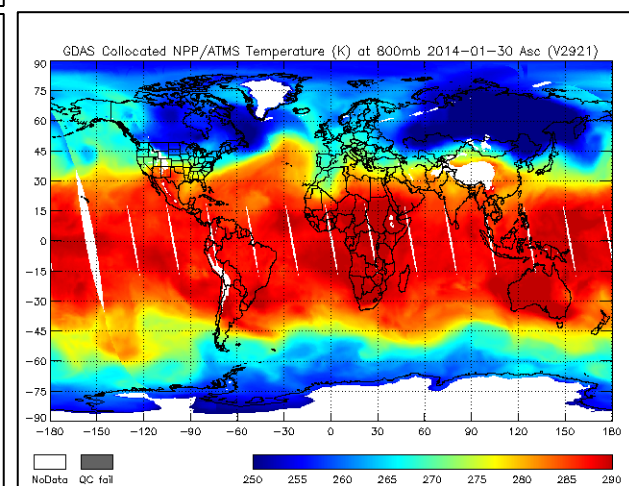
MIRS- GDAS



- Reduction in bias over all surface types
- Better consistency near Antarctic sea ice

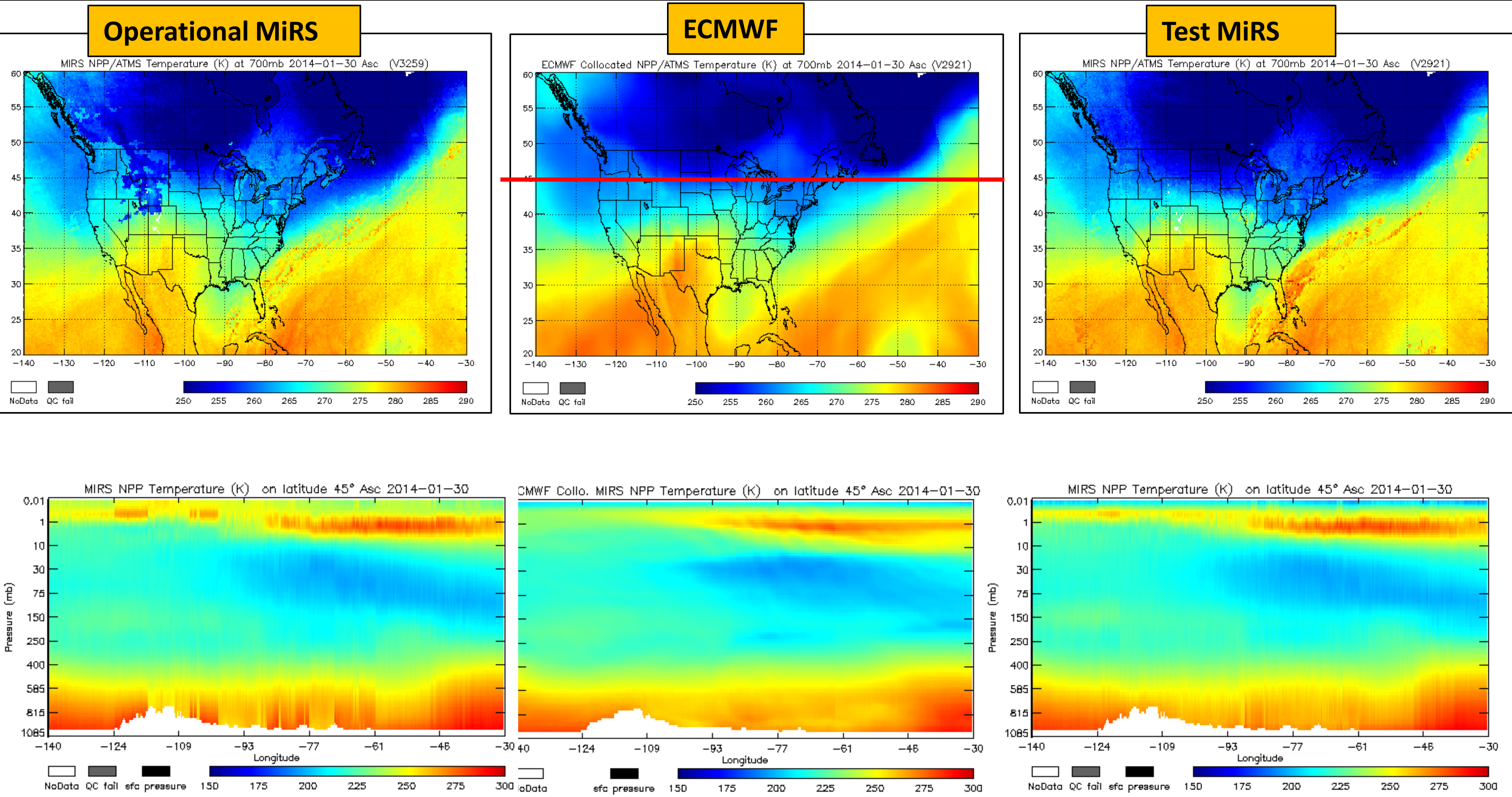






MiRS Sounding Performance Assessments: **700 hPa Temp, and Cross-sections**

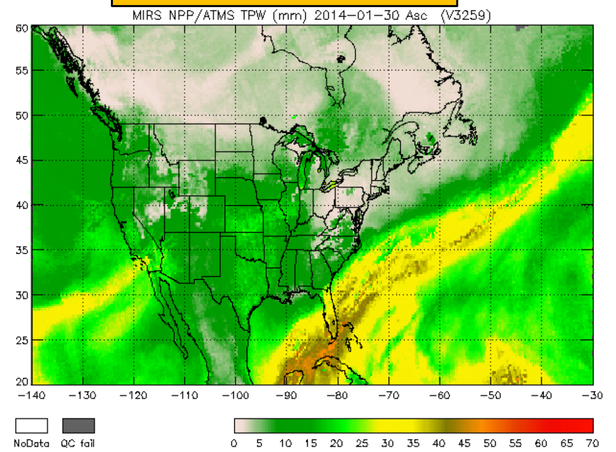
2014-01-30



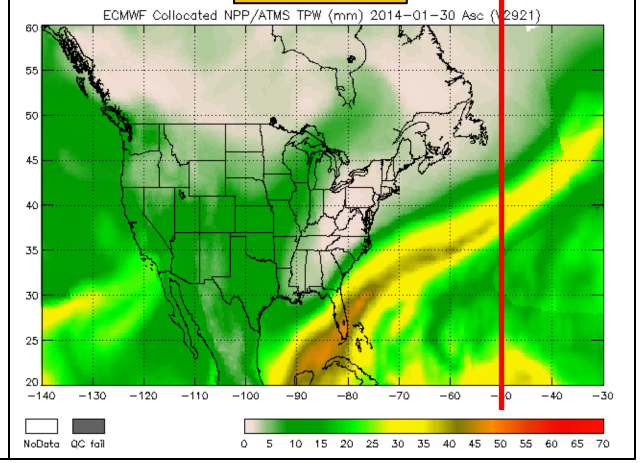
MiRS Sounding Performance Assessments: **TPW, and Cross-sections**

2014-01-30

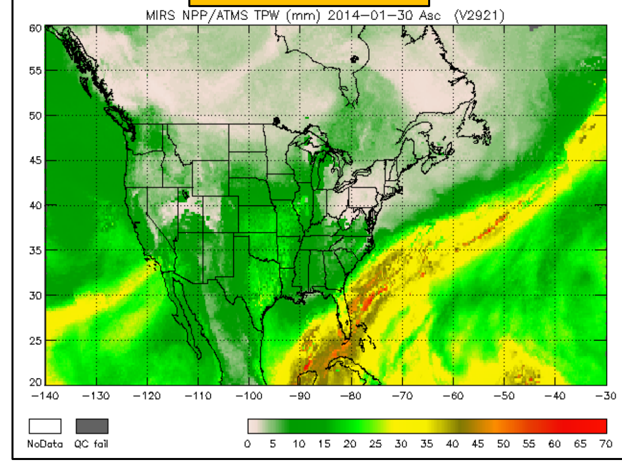
Operational MiRS

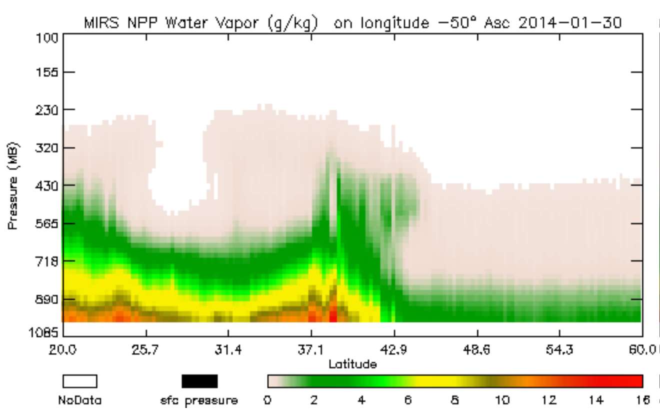


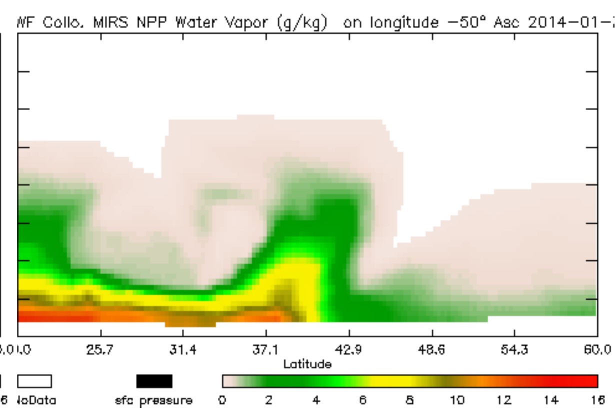
ECMWF

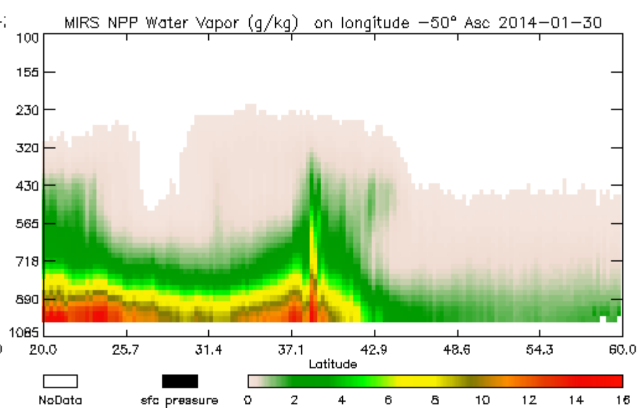


Test MiRS







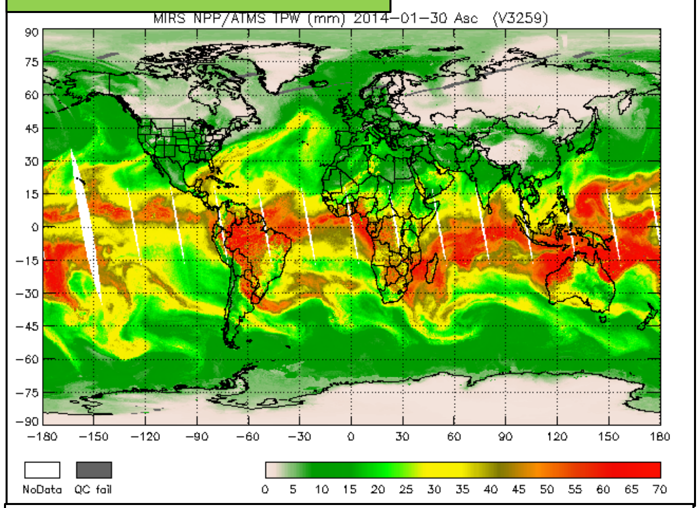


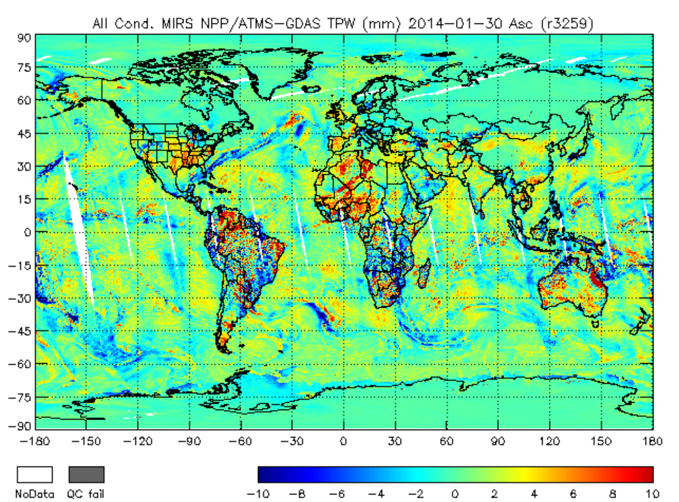
MiRS Sounding Performance Assessments: **Total Precipitable Water**

2014-01-30: Global

Operational MiRS

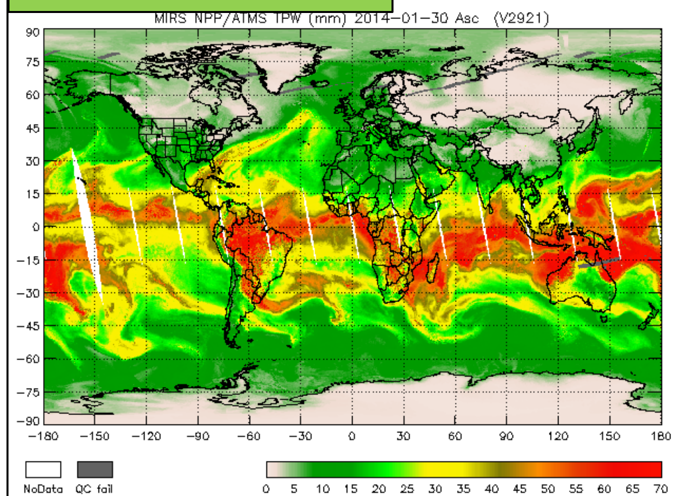
MIRS- GDAS

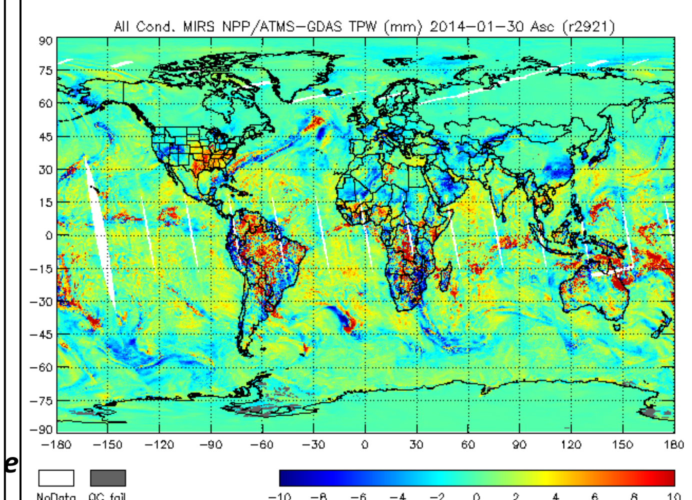




Test MiRS

MIRS- GDAS





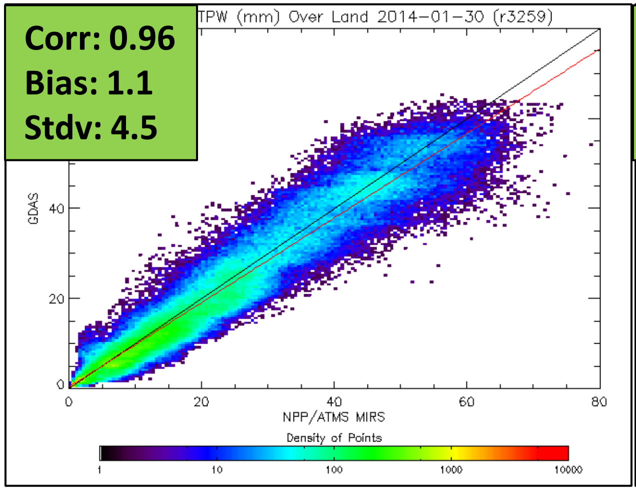
MiRS Sounding Performance Assessments:
Total Precipitable Water

MIRS- GDAS

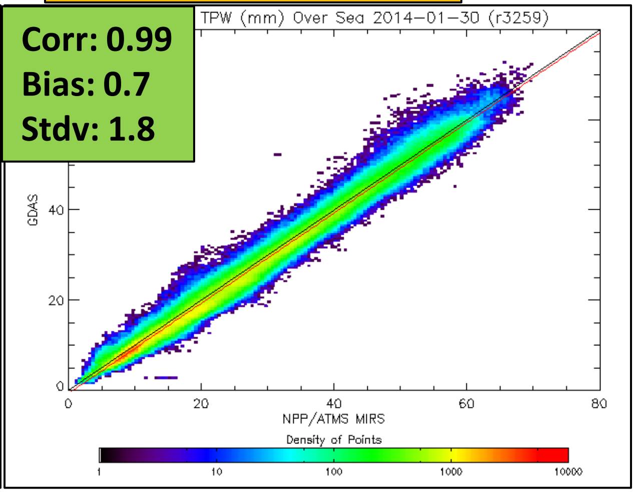
2014-01-30: Global

Operational MiRS

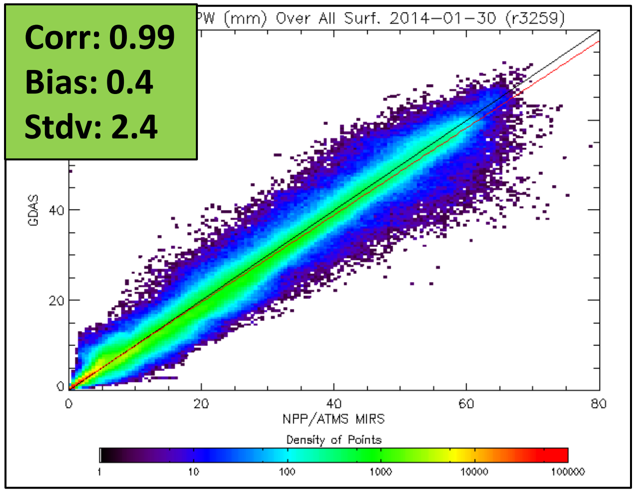
Corr: 0.96
Bias: 1.1
Stdv: 4.5



Corr: 0.99
Bias: 0.7
Stdv: 1.8



Corr: 0.99
Bias: 0.4
Stdv: 2.4



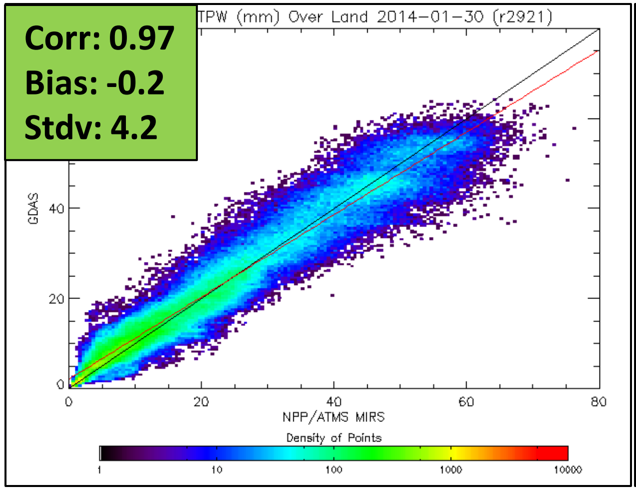
Land

Sea

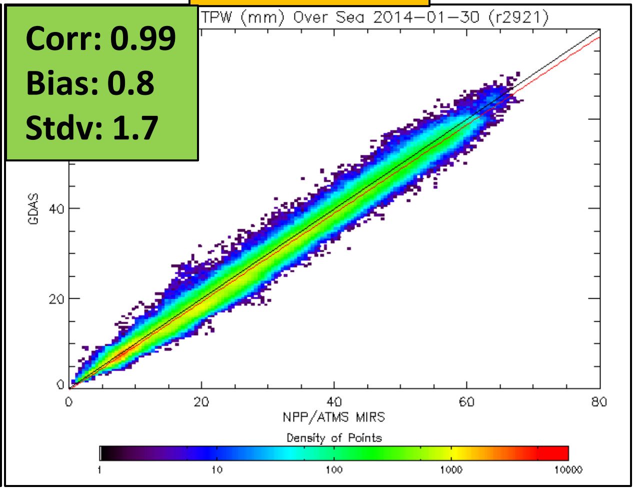
All

Test MiRS

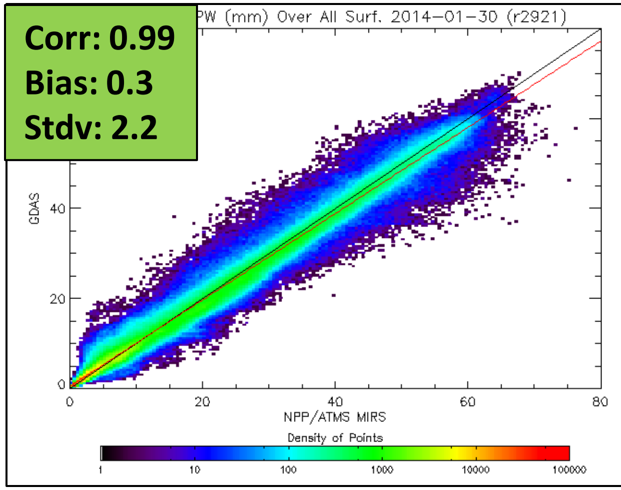
Corr: 0.97
Bias: -0.2
Stdv: 4.2



Corr: 0.99
Bias: 0.8
Stdv: 1.7

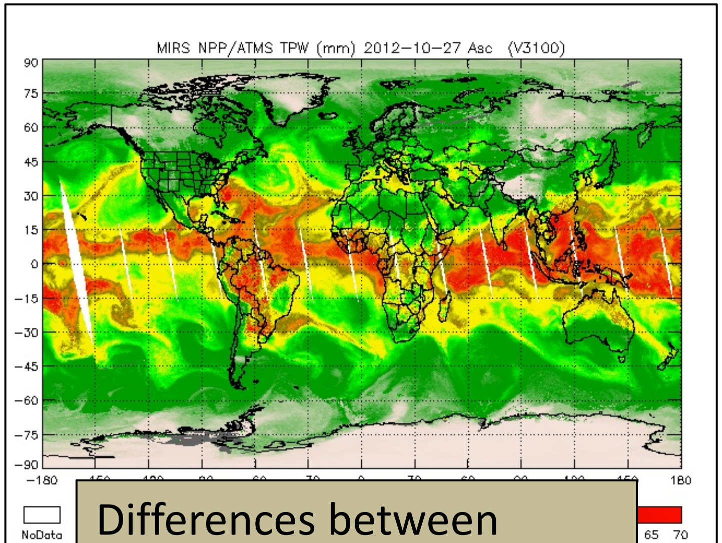


Corr: 0.99
Bias: 0.3
Stdv: 2.2

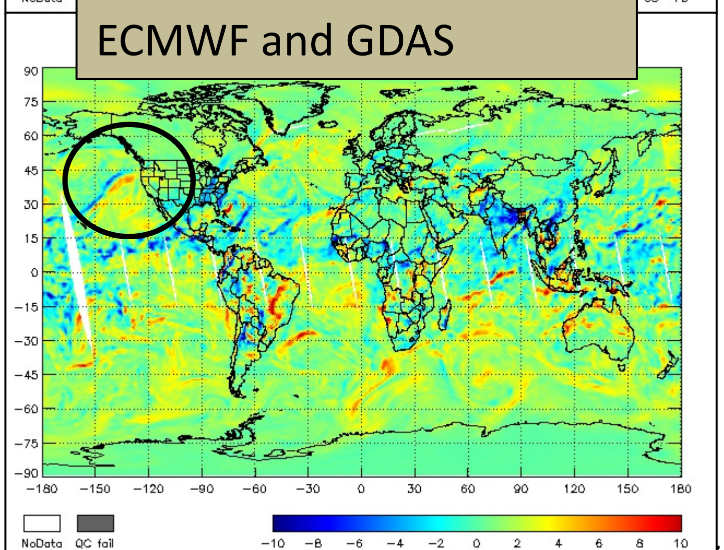


MiRS Sounding Performance: TPW

Test MiRS



Differences between ECMWF and GDAS



Summary of TPW Performance

Compared to ECMWF: 2012-10-27

	Bias (mm)	*Stdv (mm)*	*Corr.*	*RMSE (mm)*
Ocean	0.46	2.55	0.98	2.59
Land	0.48	4.47	0.95	4.50
Sea-Ice	0.42	1.28	0.82	1.35
Snow	0.25	0.89	0.93	0.92

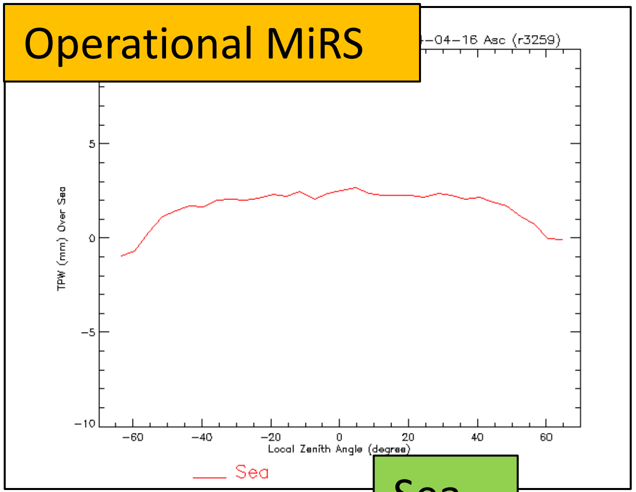
Compared to Raobs: Jul – Sep 2013

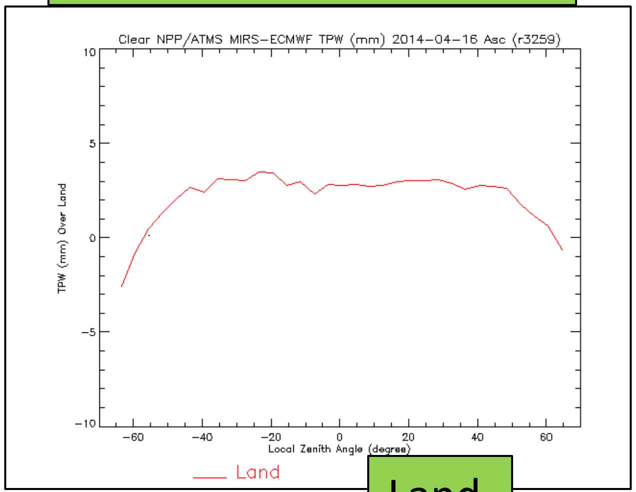
	SNPP bias/stdv (mm)	*NOAA-19 bias/stdv (mm)*	*Metop-A bias/stdv (mm)*
Ocean	7.25/15.40 (%)	8.26/15.69 (%)	8.89/13.7 (%)
Land	2.39/23.65 (%)	5.68/23.76 (%)	2.57/22.11 (%)

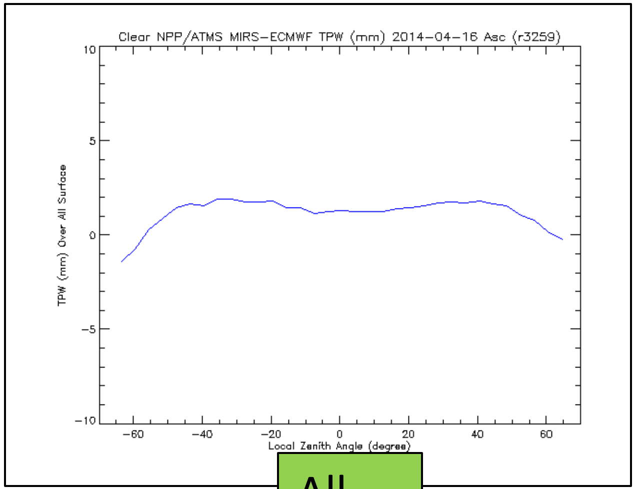
MiRS Sounding Performance Assessments: TPW Scan-dependent Bias

2014-04-16: vs. ECMWF

Operational MiRS

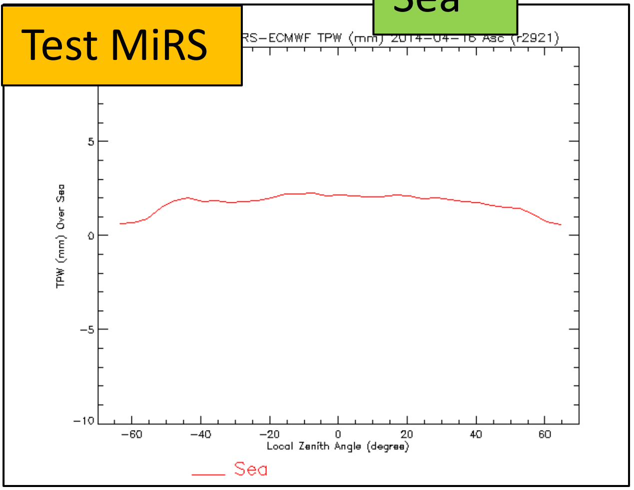


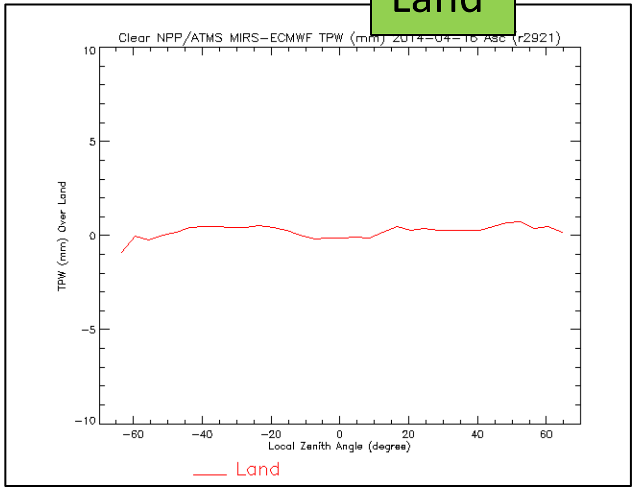


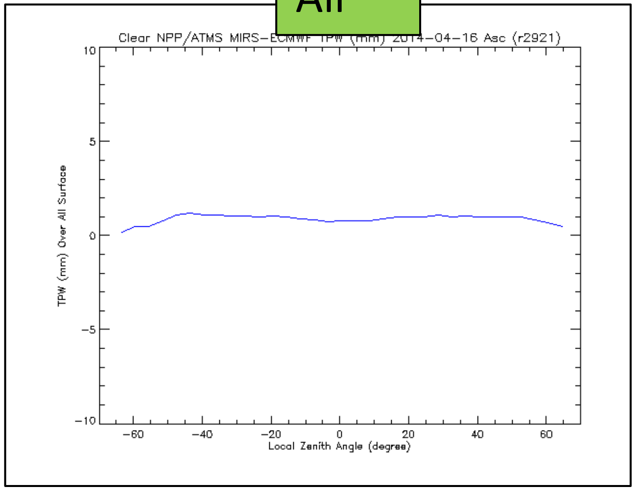


Sea | Land | All

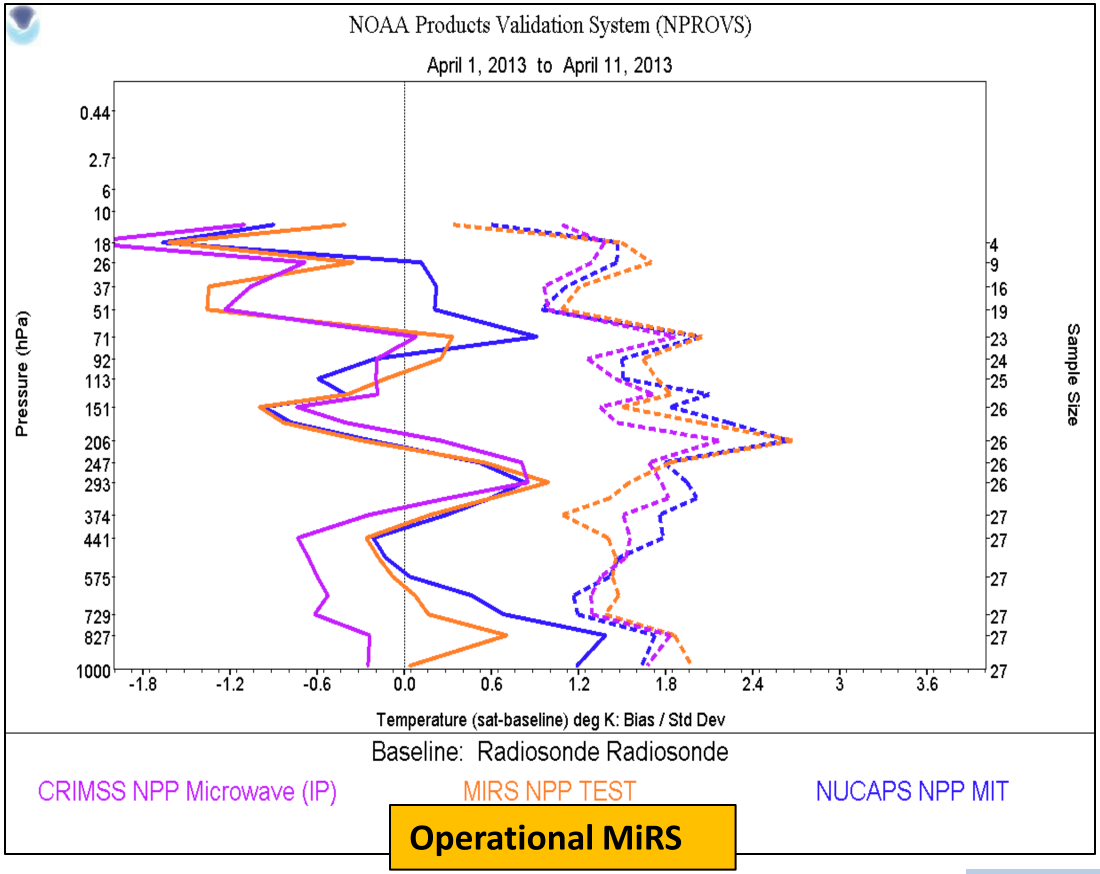
Test MiRS







Sounding Assessment via NPROVS



NPROVS performs assessment and intercomparisons by comparing several algorithms/ several sensors to common reference of radiosondes

Provided by T. Reale

MiRS Application: Rapid Hurricane Intensification (1)

MiRS/ATMS T,RH profiles used to compute ***(case of Hurricane Leslie, 2012)*****:**

-Radial-height cross section

- Temperature Anomaly

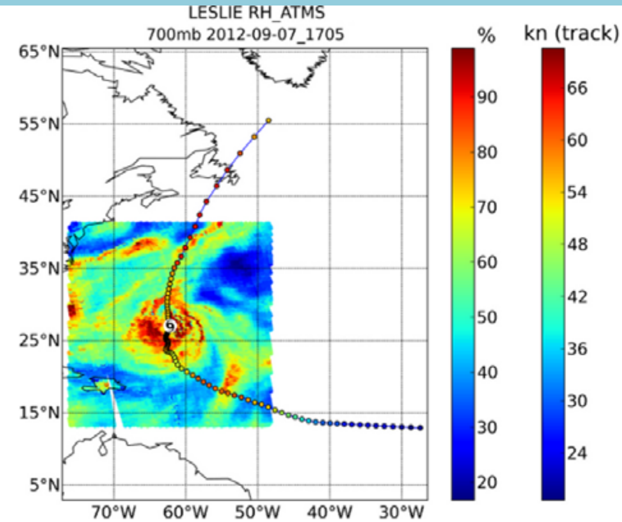
-500-800mb averaged values

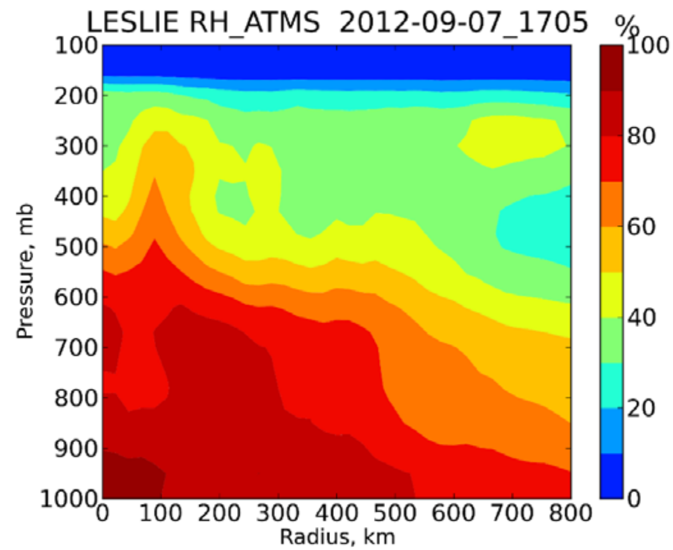
These are fed to :

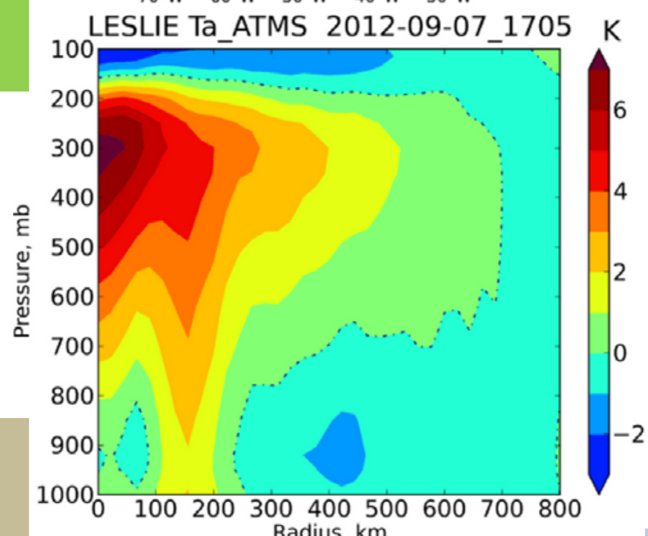
- Maximum Potential Intensity (**MPI**) algor.

MPI is then fed to :

- Rapid Intensification Index (**RII**) algor.





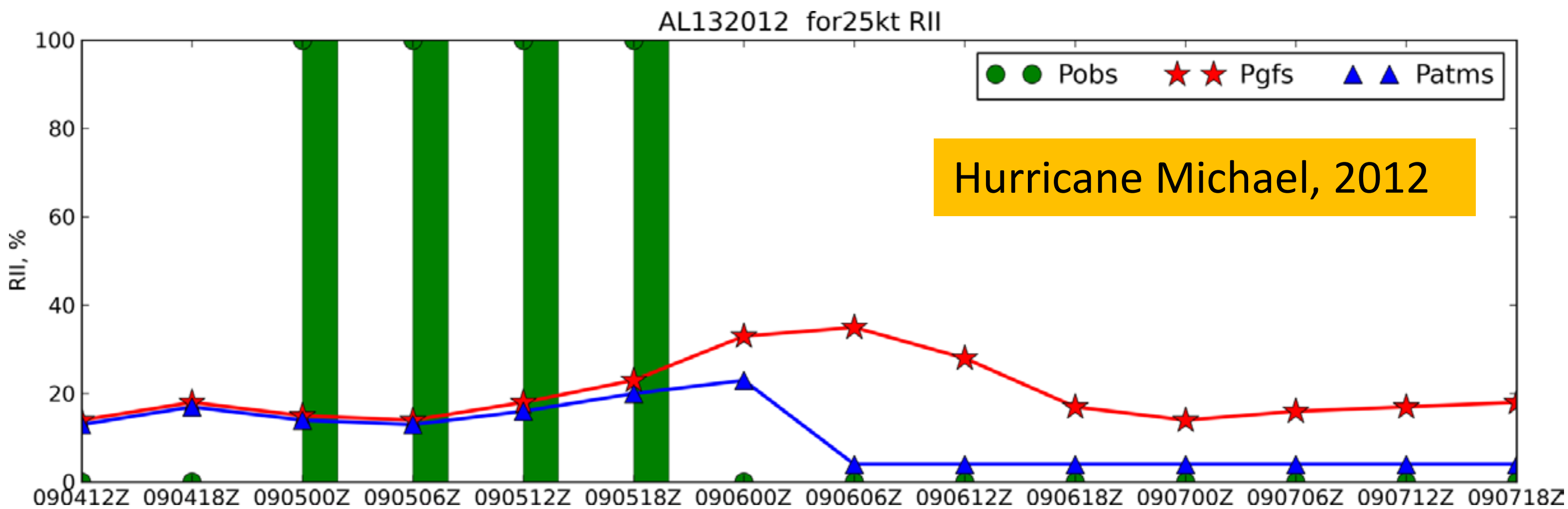


1. Average T, RH between r = 500 to 800 km to get $\overline{T}(p)$, $\overline{RH}(p)$
2. Input $\overline{T}(p)$, $\overline{RH}(p)$ environmental profiles to Emanuel (1988) MPI algorithm
3. Replace empirical MPI with ATMS MPI in RII and models

Slide courtesy of Galina Chirokova and Mark DeMaria

Rapid Intensification Forecast (2): GFS vs. MIRS/ATMS Inputs

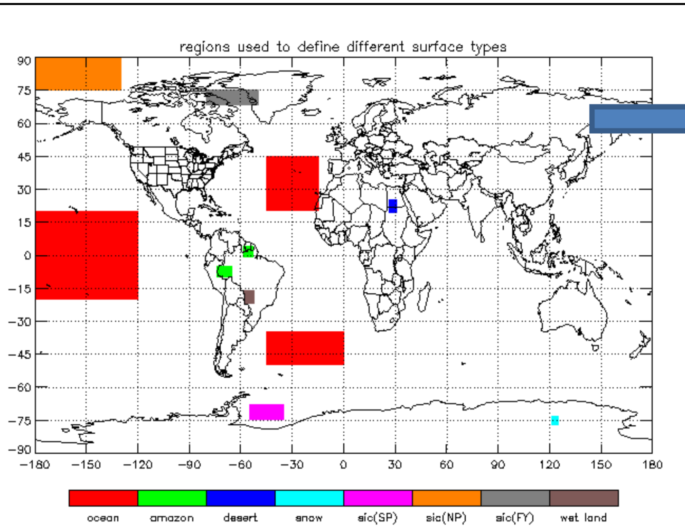
Atlantic Basin: The bias of RI index (between obs. and RII algorithm output) is 1.67 when MiRS/ATMS data is used as inputs and 1.87 when GFS I is used.

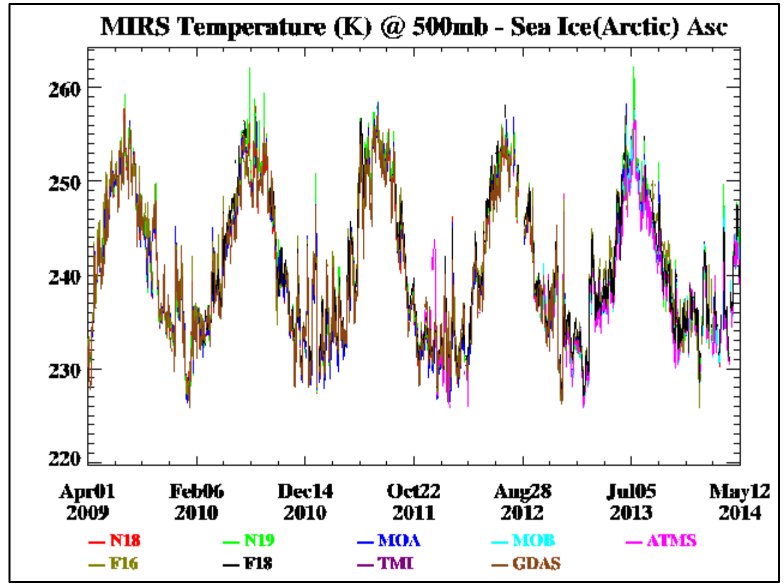


Atlantic Basin: Preliminary results for the RII forecast show up to 3.1% increase in Brier Skill Score with the use of MiRS/ATMS data, and for the center-fix algorithm up to 10% better center location as compared to the first guess position from the NHC real-time forecast positions.

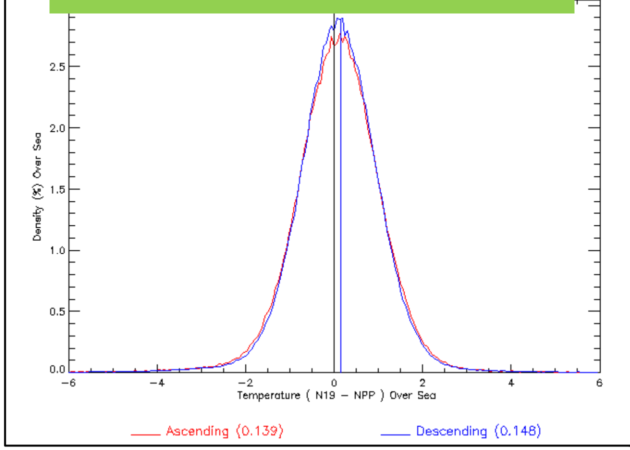
Slide courtesy of Galina Chirokova and Mark DeMaria

MiRS-Derived Products:
Time Series, Inter-sensor consistency

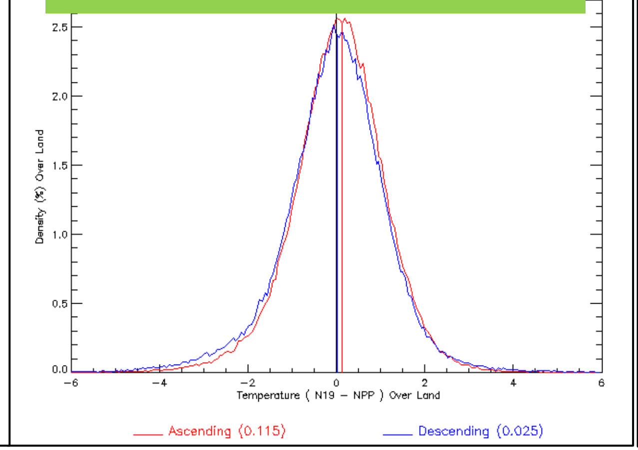




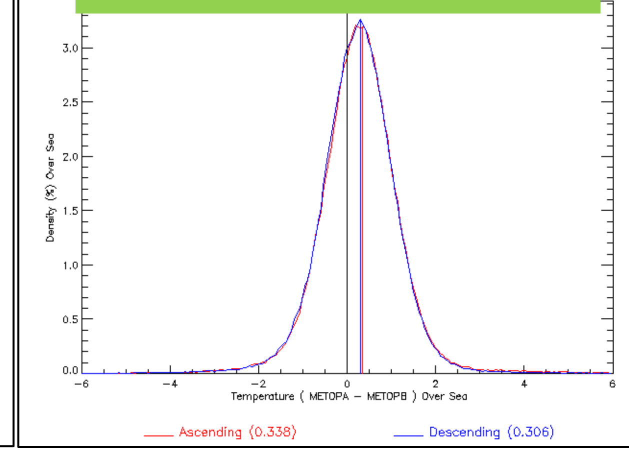
T(p) at 500mb over sea (global) N19-SNPP



T(p) at 500mb over land (global) N19-SNPP



T(p) at 500mb over sea (global) MetopA-Metop-B



MiRS Science Improvement Activities

Improvement Area	Integration Status	Work remaining	Expected completion	Included in next major DAP delivery (Summer 2014)
New Dynamic Mean Background/A Priori (T, WV, Tskin, CLW)	**Fully integrated**	None	Complete	Yes
New CRTM (v2.1.x)	**Fully integrated**	None	Complete	Yes
Hydrometeors/rain rate	**Fully integrated**	• RWP over land • Update RR=f(RWP, IWP, CLW) relationship	June 2014	Yes
Extend MiRS to high-resolution for all current operational sensors, and for F17/SSMIS	**Fully integrated**	• Hydrometeor validation with CRTM 2.1.1 • Validation for F17	June 2014	Yes
New Dynamic Emissivity Background/A Priori	**Initial testing**	• Testing ROIs • Temporal dependence • Global implementation and assessment	December 2014	No
New radiometric bias correction approach (e.g. air mass, rainy, etc.)	**Not started**	Most work still TBD	TBD	No
Integration with GPROF hydrometeors (e.g. FG,BG, Covariances, RR=f(RWP,IWP)…)	**D. Duncan (Kummerow PhD student), In progress**	Started November 2013	Early 2015	No

Summary

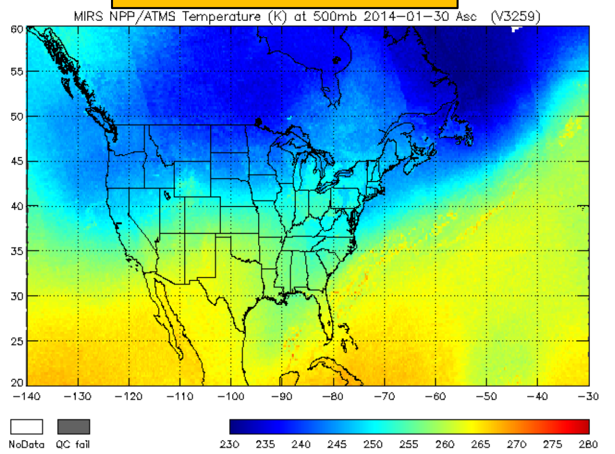
- Significant updates to MiRS algorithm: improved sounding performances for SNPP/ATMS (and other sensors).
    - T and wv biases reduced, although some increase seen in low level T bias (negative) over land
    - T and wv std dev reduced, especially over land
    - TPW bias and std dev reduced over land
    - Soundings more horizontally consistent due to updated a priori background
- Improvements seen across seasons/years
- These updates will be contained in next major release of MiRS scheduled for summer 2014 (v11.0)
    - Extension of all sensors to high resolution (N18, N19, F18)
    - Extension to F17 SSMIS
- Extension of MiRS to JPSS-1 will be simplified based on experience and software development with SNPP

Backup Slides

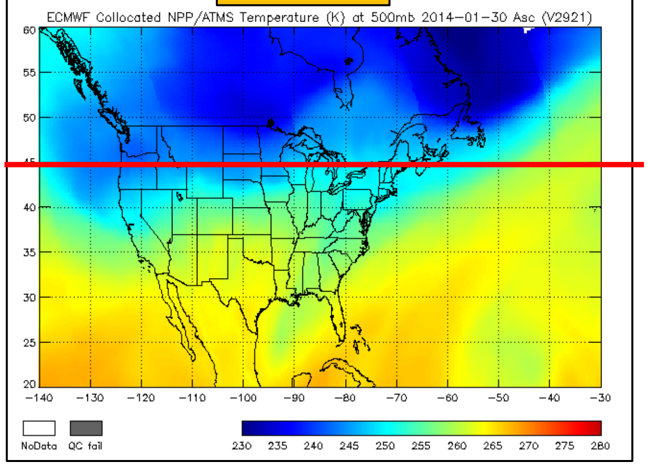
MiRS Sounding Performance Assessments:
500 hPa Temp, and Cross-sections

2014-01-30

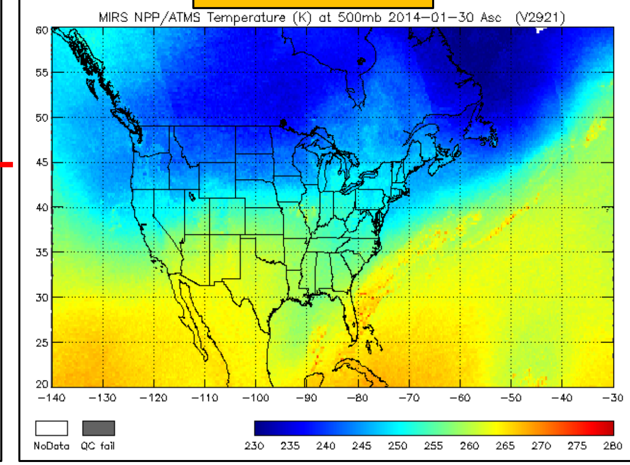
Operational MiRS

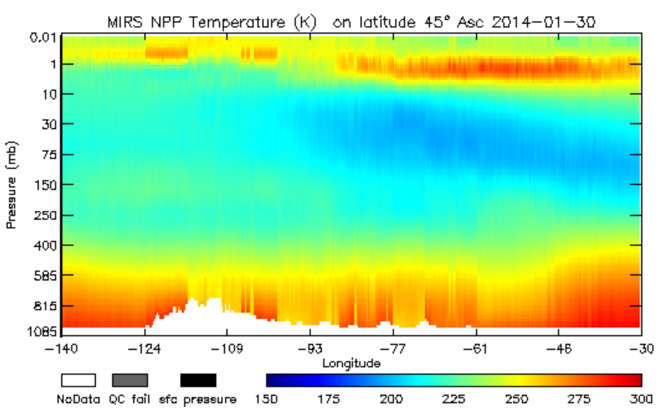


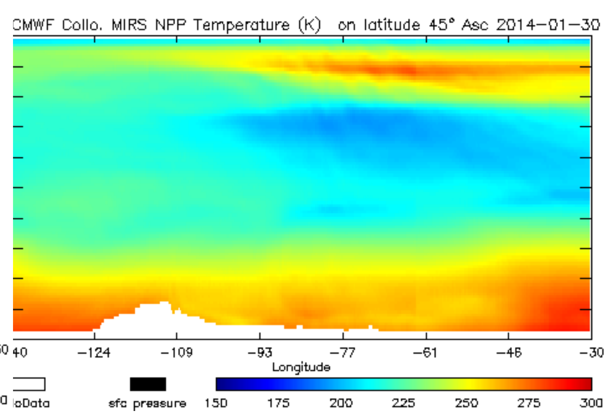
ECMWF

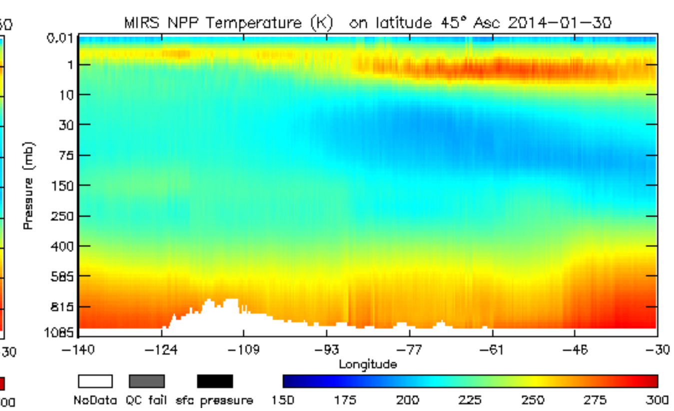


Test MiRS



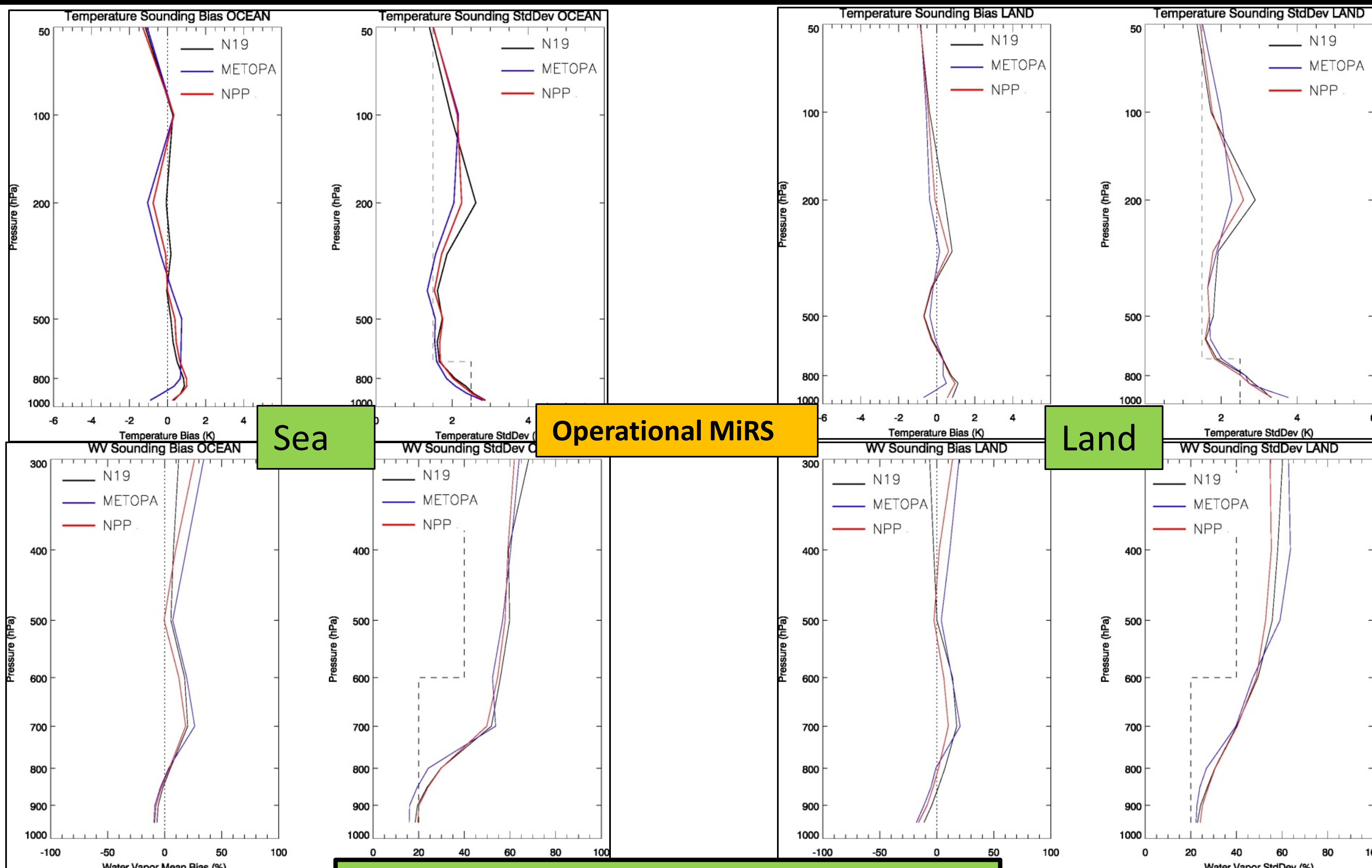






MiRS Sounding Performance Assessments: Radiosonde Comparison

Collocations July – September 2013 (~25,000 pts)



Raob matchups provided by T. Reale

Updates on NUCAPS Operational Products and Services

A.K. Sharma

Sounding Product Area Lead

May 14, 2014

Outline

- Overview
  - Products, Requirements, Team Members, Users, Accomplishments
- SNPP Algorithms Evaluation:
  - Algorithm Description, Validation Approach and Datasets, Performance *vs.* Requirements, Risks/Issues/Challenges, Quality Monitoring, Recommendations
- Future Plans
  - Plan for JPSS-1 Algorithm Updates and Validation Strategies, Schedule and Milestones
- Summary

NUCAPS Team Members

Team Members:

STAR: Walter Wolf, Thomas King, Chris Barnet, Antonia Gambacorta, Letitia Soulliard, Larisa Koval, Haibing Sun, Kexin Zhang, Xingpin Liu, Yunhui Zhao, Peter Keehn

OSPO: A.K. Sharma, Oleg Roytburd, William Oconnor

NDE: Tom Schott, Geoff Goodrum, Kevin Berberich, Peter MacHarrie, Dylan Powell

NUCAPS Users

- **U.S. Users:**
  - NCEP (John Deber, Andrew Collard, Dennis Keyser)
  - GMAO (Emily Liu)
  - AWIPS (Jim Heil)
  - STAR (Tony Reale, Murty Divakarla, Kexin Zhang, Xingpin Liu)
  - CLASS (Phil Jones)
- **International Users:**
  - EUMETSAT (Simon Elliott)
    - UK Met Office (Nigel Atkinson)
    - ECMWF (Tony McNally)
    - DWD (Reinhold Hess)
    - Meteo-France (Lydie Lavanant)
    - Plus other EUMETSAT members states
  - CMC (Louis Garand)
  - EC (Sylvain Heilliette)
  - JMA (Hidehiko Murata)
  - BOM (John Le Marshall)

NUCAPS Products and Services

- Objectives
  - Provide CrIS/ATMS NOAA Unique Products within three hours of observation (or 20 minutes of data receipt from IDPS) to NWS and DOD.

Products:

- Temperature, moisture, pressure profiles
- Cloud cleared radiances
- Atmospheric trace gas products
- Principal components
- QA/QC Science products for Operational Monitoring
- EDR Validation Products: Global Grids, Matchups, and Binaries

NUCAPS System Requirements

- *The NUCAPS shall generate CrIS thinned radiance products for NWP center users.* (product, functional)
- *NUCAPS shall generate CrIS full spatial resolution granule files containing all CrIS FOVs and FORs for all 1305 channels.*
- *The NUCAPS shall generate trace gas profile products for U.S users.* (product, functional)
- *The NUCAPS software shall generate atmospheric temperature and moisture profiles for AWIPS derived from CrIS/ATMS radiances.*
- *The NUCAPS shall write the retrieval products for AWIPS in netCDF4 format.*
- *The NUCAPS shall generate CrIS Cloud-clear Radiance (CCR) products for NWP centers and CLASS.* (product, operational)
- *The NUCAPS shall generate daily global products for system validation, maintenance, and development.* (product, operational)
- *The NUCAPS software shall produce data files for science quality monitoring of SDR and EDR data.*
- *The product s shall be available within three hours of observation.* (performance)

NUCAPS System Requirements

- ***The BUFR table shall contain the following variables. Variables with parentheses indicate dimensionality.*** **(product)**

Satellite ID
ID of originating center
Satellite instrument
Satellite classification
Year
Month
Day
Hour
Minute
Second
Subsattellite Latitude
Subsattellite Longitude
Latitude
Longitude
Satellite Height
Satellite Zenith
Satellite Azimuth
Solar Zenith
Solar Azimuth

Orbit Number
Granule Number
Scan Line
CrIS FOR
CrIS FOV
Land Fraction
Land-Sea-Coast-Flag
Cloud Fraction
Cloud Height
CrIS Channels(1305)
CrIS Radiances(1305)
CrIS Quality Flag 1
CrIS Quality Flag 2(3)
CrIS Quality Flag 3(3)
CrIS Quality Flag 4(3)
CrIS Quality Flag 5
CrIS Quality Flag 6

NUCAPS System Requirements

***The NUCAPS shall generate profiles of following trace gases derived from a retrieval of CrIS/ATMS radiances:* (product, functional)**

Ozone
Carbon Monoxide
Carbon Dioxide
Methane
Volcanic Sulfur Dioxide Product
Nitric Acid
Nitrous Oxide

Trace gas profiles shall have the following accuracy

O3: 20%/5-km near tropopause
O3: 10% total column
CO: 40% mid-trop column (w/ 0.2 cm OPD SW band)
CH4: 1% mid-trop column
CO2: 1% mid-trop column
HNO3: 50% mid-trop column. (product, performance)

Trace gas profiles shall meet the following spatial specifications:

Global coverage.
Horizontal resolution of ≈50 km (Set of 9 CrIS FOV's collocated with ATMS FOR).

NUCAPS System Requirements

The retrieval product for AWIPS shall contain the following variables.

CrIS FOR	Time
Latitude	Longitude
View Angle	Ascending/Descending Status
Topography	Surface Pressure
Skin Temperature	Quality Flag
Pressure (at 100 levels)	Effective Pressure (at 100 levels)
Temperature (Kelvin at 100 levels)	H2O (g/g at 100 levels)
O3 (ppb at 100 levels)	Liquid H2O (g/g at 100 levels)
Ice/Liquid Flag (at 100 levels)	SO2 (g/g at 100 levels)
Stability parameters	

- *Note: This is a subset of the existing set of variables produced by the retrieval. It is our understanding that NDE will extract this subset of variables.*

NUCAPS System Requirements

The EDR product shall contain the following variables calculated on each CrIS FOR:

Ice/liquid flag (at 100 levels)
CH_4 layer column density (at 100 levels)
CH_4 mixing ratio (at 100 levels)
CO_2 mixing ratio (at 100 levels)
HNO_3 layer column density (at 100 levels)
HNO_3 mixing ratio (at 100 levels)
N_2O layer column density (at 100 levels)
N_2O mixing ratio (at 100 levels)
SO_2 layer column density (at 100 levels)
SO_2 mixing ratio (at 100 levels)
Microwave emissivity
MIT microwave emissivity
Infrared emissivity
MIT infrared emissivity
Infrared surface emissivity
First Guess infrared surface emissivity
Infrared surface reflectance
Atmospheric Stability
Cloud infrared emissivity
Cloud reflectivity

NUCAPS System Requirements

The EDR product shall contain the following trace gas profiles and surface and cloud properties calculated on each CrIS FOR:

Time
Latitude
Longitude
View Angle
Satellite Height
Mean CO2
Solar Zenith
Ascending/Descending Status
Topography
Land-Sea-Coast Flag
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)
H2O layer column density (at 100 levels)
H2O mixing ratio (at 100 levels)
First Guess H2O layer column density (at 100 levels)
First Guess H2O mixing ratio (at 100 levels)
MIT H2O layer column density (at 100 levels)
MIT H2O mixing ratio (at 100 levels)
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)

CrIS Requirements

Caveat:

The current CrIS instrument's spectral resolution in the short-wave band is too low for retrieval of carbon monoxide and carbon dioxide within requirements.

NUCAPS Plan Schedules

Schedule (key milestones):

- Preliminary Design Review – May , 2007
- Critical Design Review – Sept, 2008
- Test Readiness Review – Sept, 2010
- Code Unit Test Review – Oct, 2010
- Phase 1 Algorithm Readiness Review – March, 2012
- NUCAPS Phase 1 Delivery – Mar, 2012
- NUCAPS Phase 2 Delivery – Dec, 2012
- Phase 2 Algorithm Readiness Review – Jan, 2013
- NDE Implementation of NUCAPS Phase 2 – Jan 2013
- SPSRB Briefing – September 2013
- Operations Commence – Oct, 2013

SNPP Activities

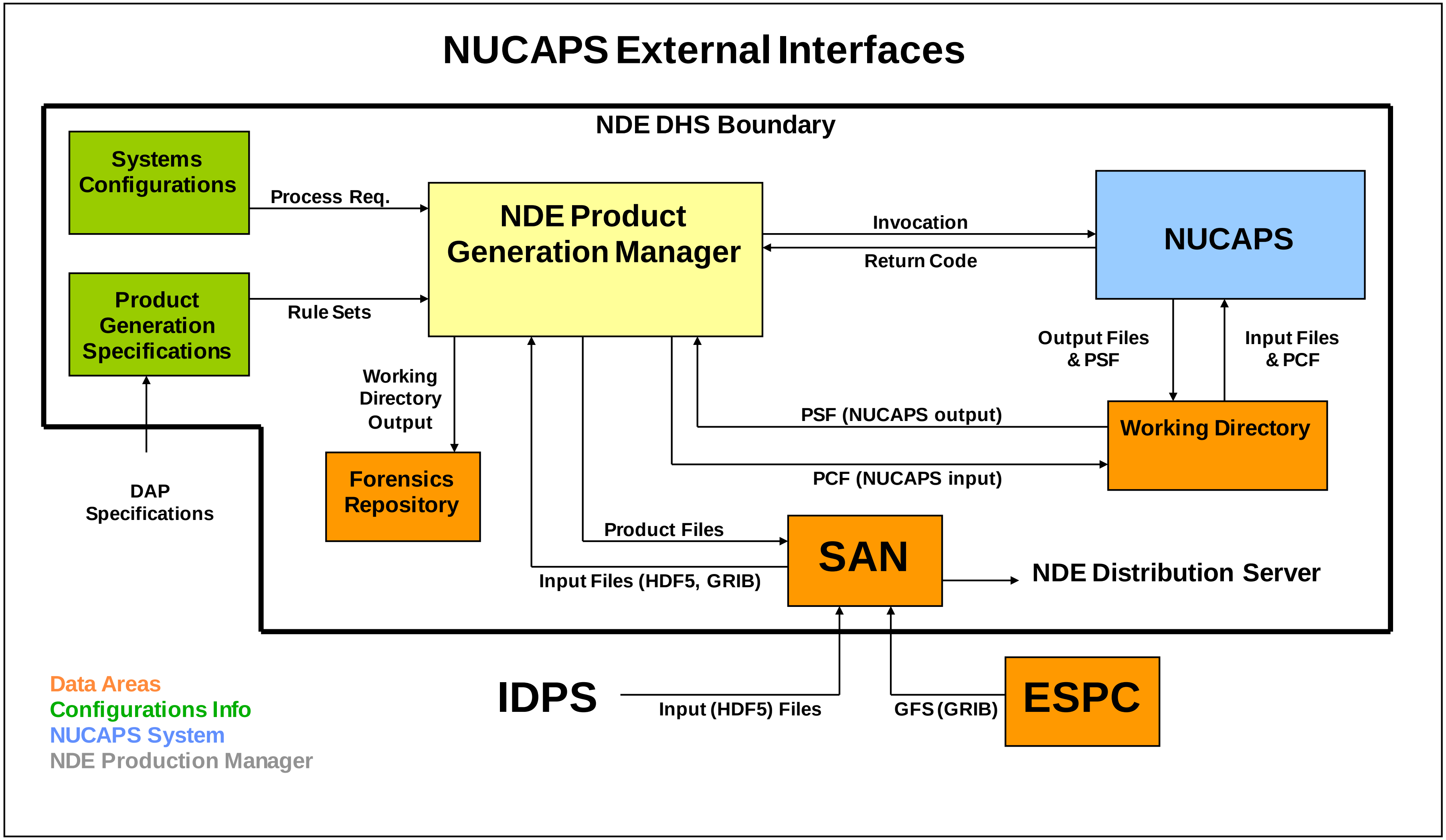
Suomi NPP EDR Cal/Val Milestones

Date	Milestone
28 Oct 2011	Suomi NPP Launch
08 Nov 2011	ATMS First Light
17 Nov 2011	NPP reaches mission orbit
21 Nov 2011	VIIRS First Light
Dec 2011 – Jan 2012	ATMS Tuning
18 Jan 2012	CrIS First Light
Feb 2012	Beta ATMS SDR
Feb–Jun 2012	CrIS Tuning
Apr 2012	Beta CrIS SDR
Apr–May 2012	Segue into ICV phase
31 Jul 2012	*Beta Maturity EDR Validation Report*
Nov 2012	*Provisional Maturity EDR*
Apr 2013	*Stage 1 Validated EDR*

Suomi NPP CrIMSS EDR Maturity

Algorithm	Beta	Provisional	Val 1	Val 2	Val 3
AVTP AVMP AVPP	L + 9m Jul 2012	L + 12m Oct 2012	L + 18m Apr 2013	L + 24m Oct 2013	L + 36m Oct 2014

NUCAPS External Interfaces



JPSS Specification Performance Requirements

- **NGAS Algorithm:** Optimal Estimation (OE) method, no front-end regression
  - AVTP, AVMP, AVPP, O_3-IP, surface skin temperature and emissivity retrieved simultaneously
  - **Non-precipitating scenes**
  - **Code implementations**
    - **IDPS** operational product (42/22 layer)
    - NGAS science code (100 layer)

- **NUCAPS Algorithm:** AIRS approach, multi-step iterative method, front-end regression
  - NUCAPS science code (100 layer)
  - Operational product in Sept 2013

"Partly Cloudy" – ≤50% cloudiness
"Cloudy" – >50% cloudiness

- *Clear* – the CrIMSS EDR retrieval algorithm detected no cloud within a FOR;
- *Cloudy* – the CrIMSS EDR algorithm detected overcast cloud or more than three layers of clouds within a FOR;
- *Partly Cloudy* – the CrIMSS algorithm detected one to three layers of clouds.

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

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

NUCAPS Algorithms Evaluation

- The NOAA Unique CrIS/ATMS Processing System (NUCAPS) is an inversion algorithm, heritage of the AIRS Science Team and NOAA IASI inversion algorithm (same code, same underlying spectroscopy) applied to the CrIS and ATMS Sounding System data.
  - Inputs: CrIS and ATMS radiances
  - Outputs: Temperature, Water Vapor, cloud cleared radiance, trace gases, cloud parameters

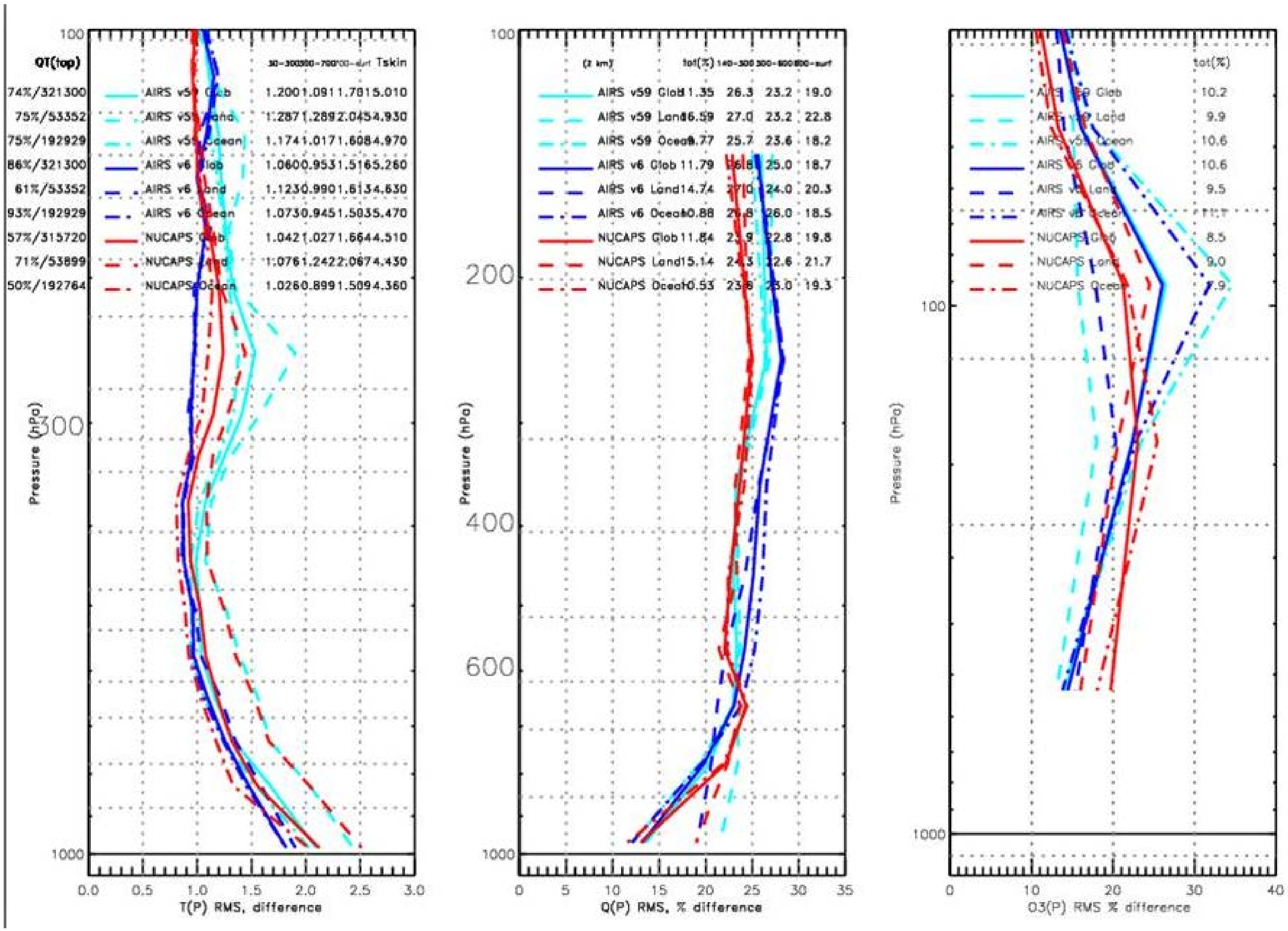
- Outline of the validation results presented in this review:
  - **Part I: Temperature, water vapor , ozone**
    - Global, Tropical, Mid-Latitude, Polar; Day/Night; Ocean/Land regimes validation versus
      - collocated ECMWF and AVN analyses
      - AIRS operational version 6 retrievals (uses same spectroscopy as NUCAPS, neural network first guess)
      - AIRS version 5.9 retrievals (uses same spectroscopy and retrieval algorithm as NUCAPS)
  - **Part II: Temperature and geo-potential height**
    - Collocated cal/val RAOBs over Hawaii (tropical ocean regime)
  - **Part III: Cloud clearing radiance; cloud fraction and top pressure**
    - OBS – CALC results, comparisons with AIRS
  - **Part IV: Trace gases: ozone, methane, CO_2, CO, HNO_3, N_2O**
    - Global map comparisons of NUCAPS and AIRS collocated retrievals

T, q Retrieval Statistics vs ECWMF; o3 vs AVN

NUCAPS: ECMWF trained ccr FG (dash), final RET (solid)

AIRS v5.9: ECMWF trained ccr FG (dash), final RET (solid)

AIRS v6: NN FG (dash), final RET (solid)



ocean only (dash dot), land only (dash), and global (solid)

Courtesy: Antonia Gambacorta

http://ospo2.espc.nesdis.noaa.gov/Products/atmosphere/soundings/nucaps/NUCAPS_gridded.html

NUCAPS Sounding Products

SNPP Granule Composite Images

Description.

Select an archive date:

Saturday, March 29, 2014 [Go]

Sunday, March 30, 2014

	NUCAPS / SNPP	
Temperature	0-12 Z	12-24 Z
Methane (CH4)	0-12 Z	12-24 Z
Carbon Monoxide (CO)	0-12 Z	12-24 Z
Carbon Dioxide (CO2)	0-12 Z	12-24 Z
Water Vapor (H2O)	0-12 Z	12-24 Z
Ice Liquid Flag	0-12 Z	12-24 Z
Liquid H20	0-12 Z	12-24 Z
Ozone (O3)	0-12 Z	12-24 Z
Quality Flag	0-12 Z	12-24 Z

There are two time periods available for each group of data:

- Time period 1 covers from 00Z to 12Z of the current day.
- Time period 2 covers from 12Z to 24Z of the current day.

http://ospo2.espc.nesdis.noaa.gov/Products/atmosphere/soundings/nucaps/NUCAPS_gridded.html

NUCAPS Sounding Products

SNPP Global Gridded 0.5 deg lat x 2 deg lon Images

Description.

Select an archive date:

Wednesday, May 7, 2014 | Go

Thursday, May 8, 2014

	NUCAPS / SNPP
Temperature	0-24 Z
Methane (CH4)	0-24 Z
Carbon Monoxide (CO)	0-24 Z
Carbon Dioxide (CO2)	0-24 Z
Water Vapor (H2O)	0-24 Z
Liquid H20	0-24 Z
Ozone (O3)	0-24 Z

Soundings Links

Soundings Home

ATOVS Soundings

GGCP

IASI

MIRS Sounding Products

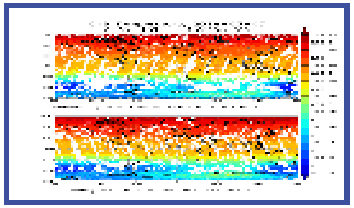
Skew-T Profiles: GOES | POES

Sounder DPI

Satellite Cloud Product

NUCAPS Gridded Temperature

Thursday, May 8, 2014 0-24Z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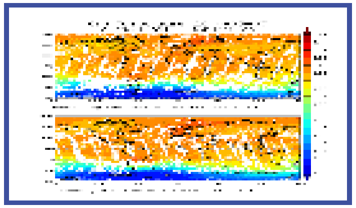
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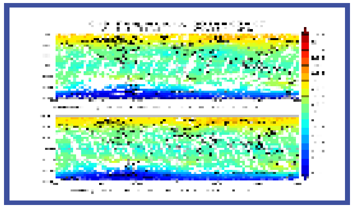
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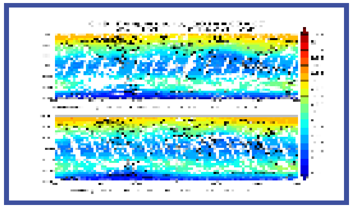
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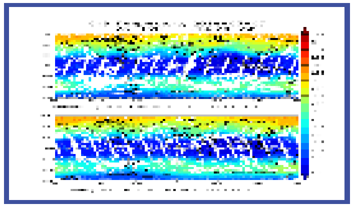
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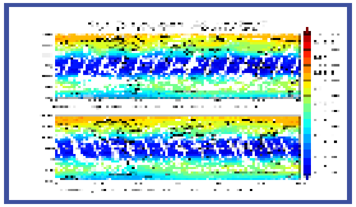
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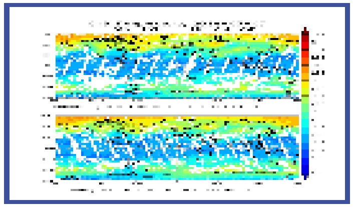
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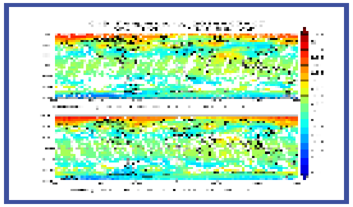
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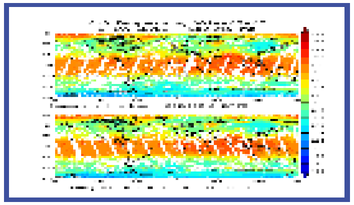
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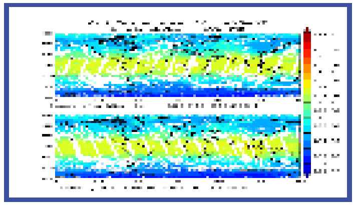
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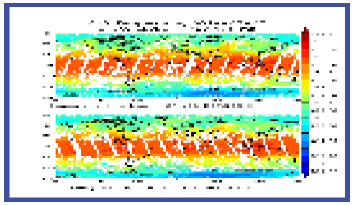
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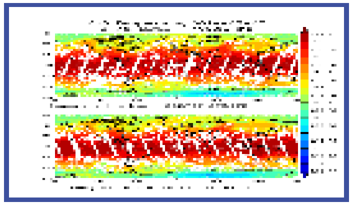
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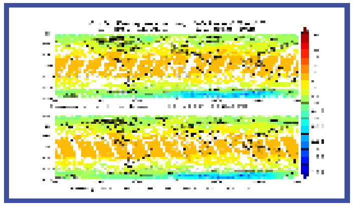
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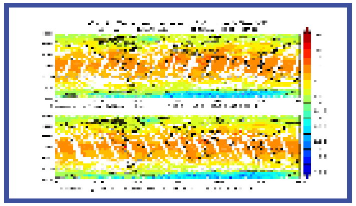
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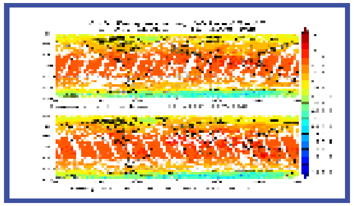
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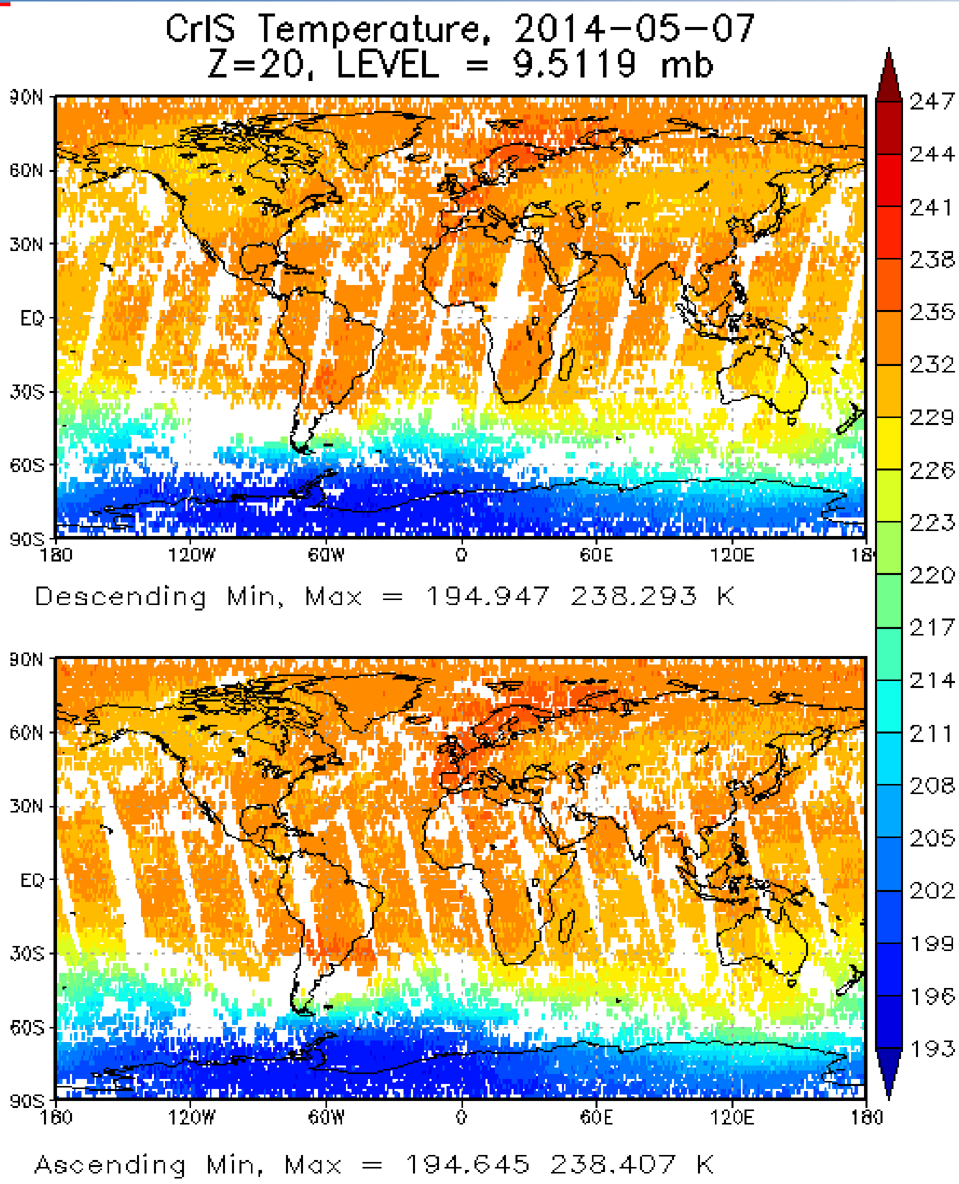
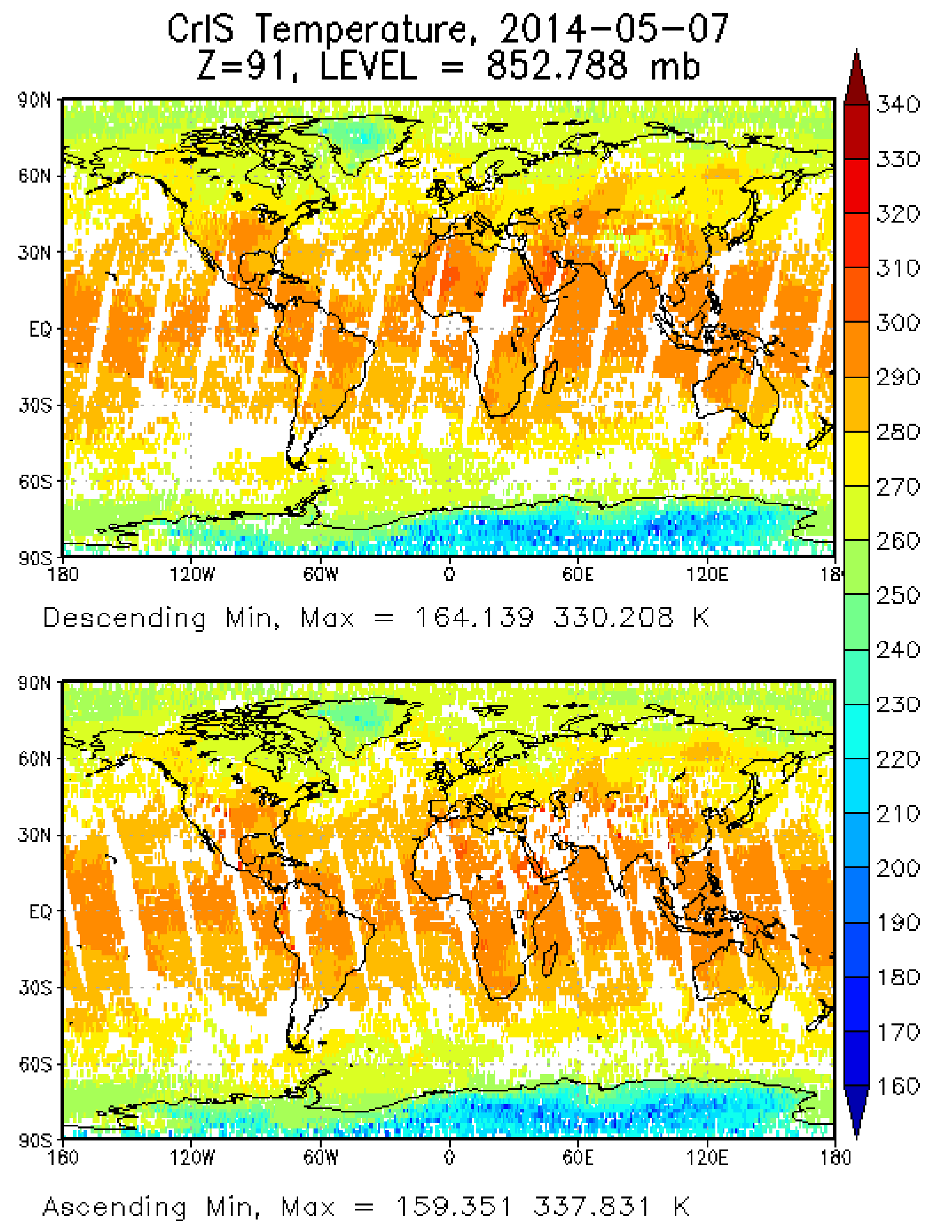
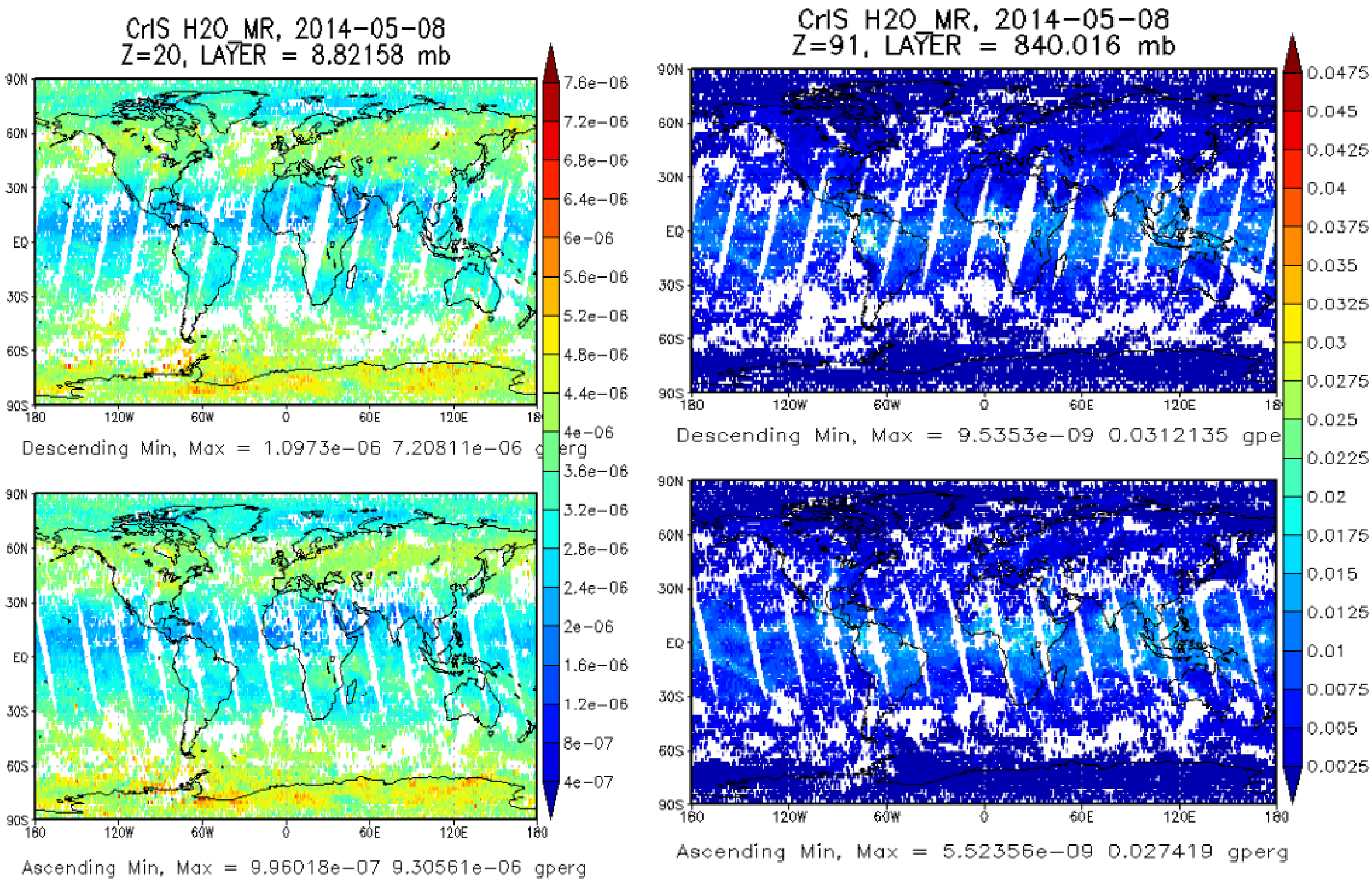
NUCAPS Level Temperatures

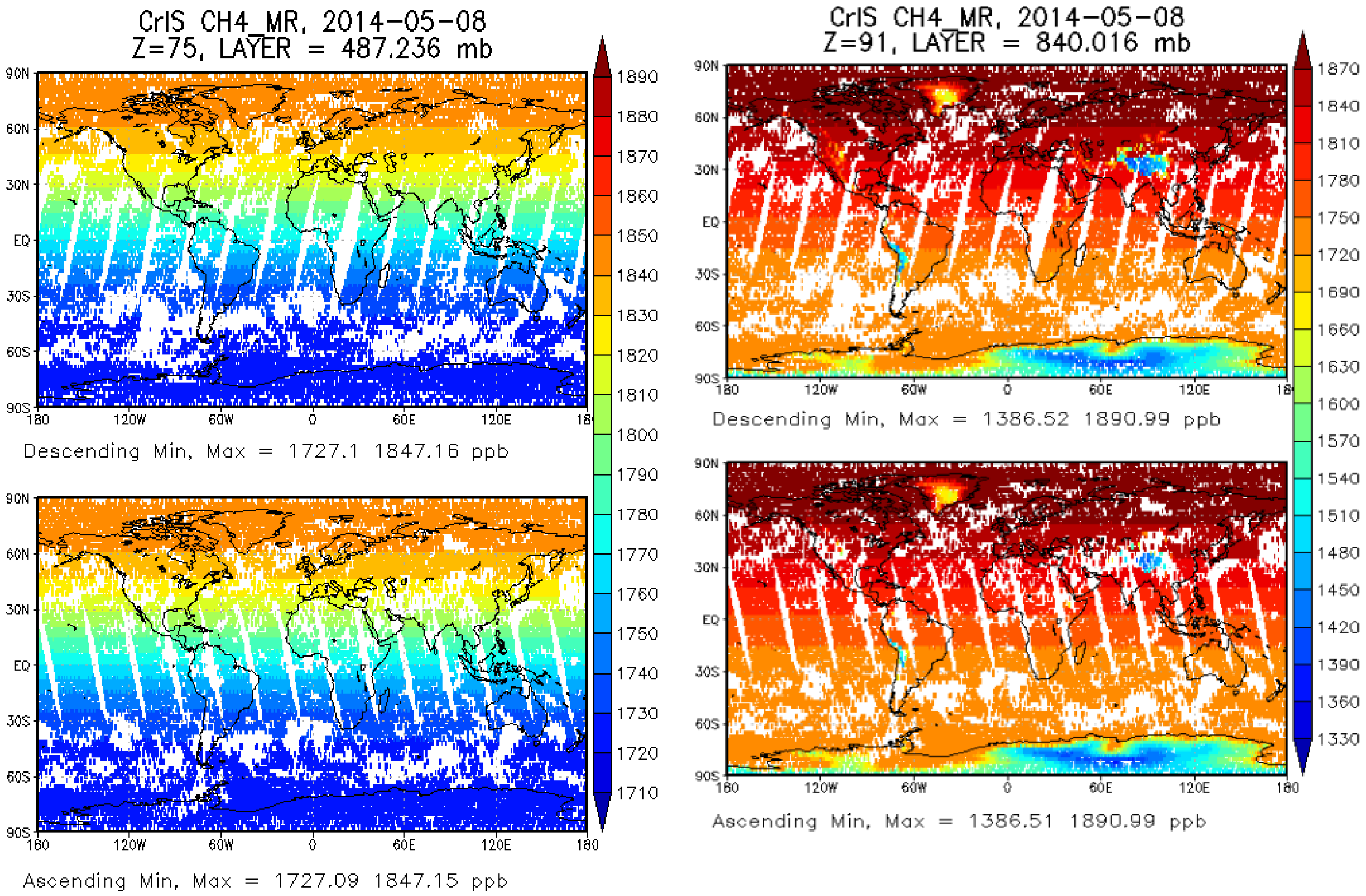




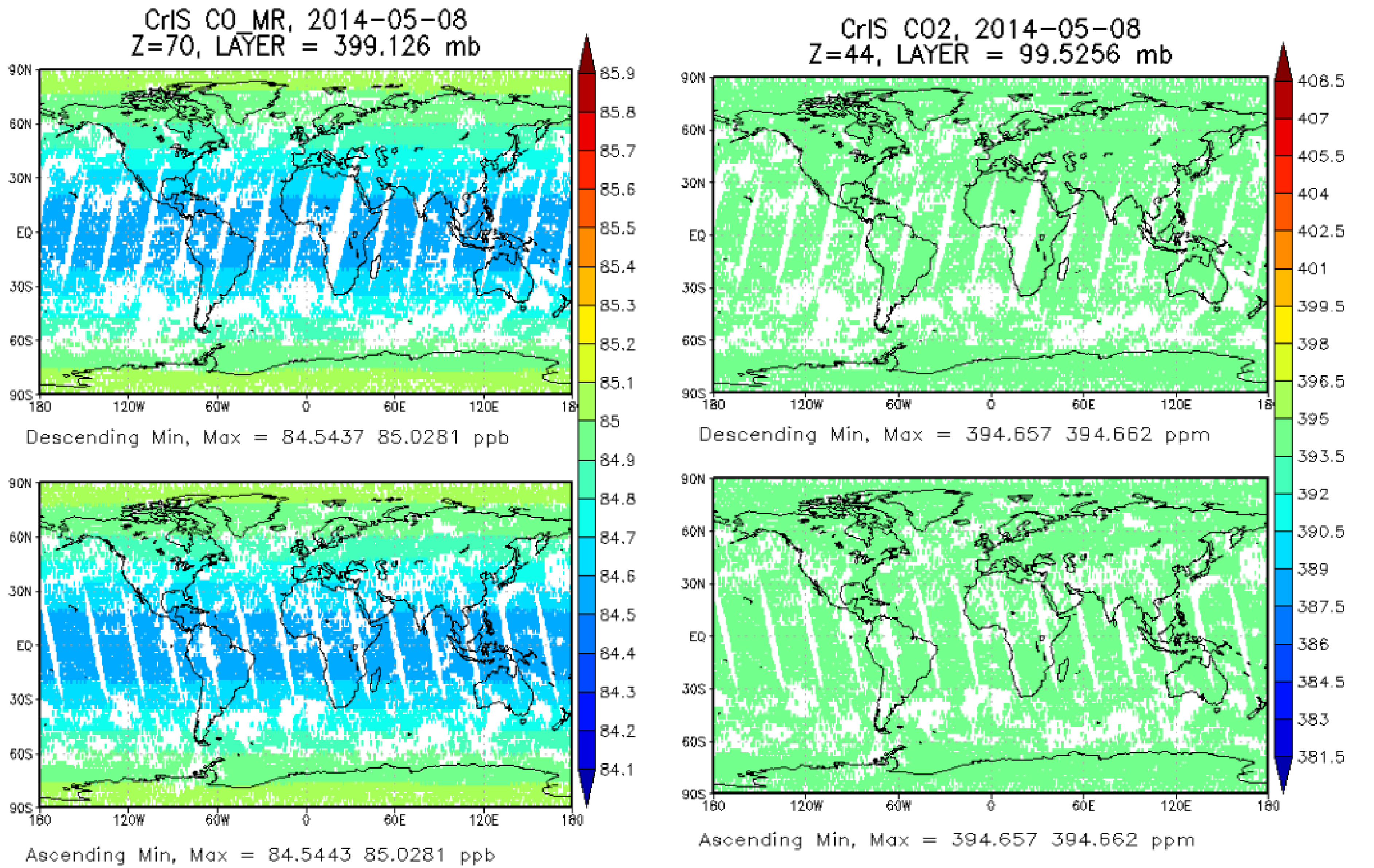
NUCAPS Layer H2O MR



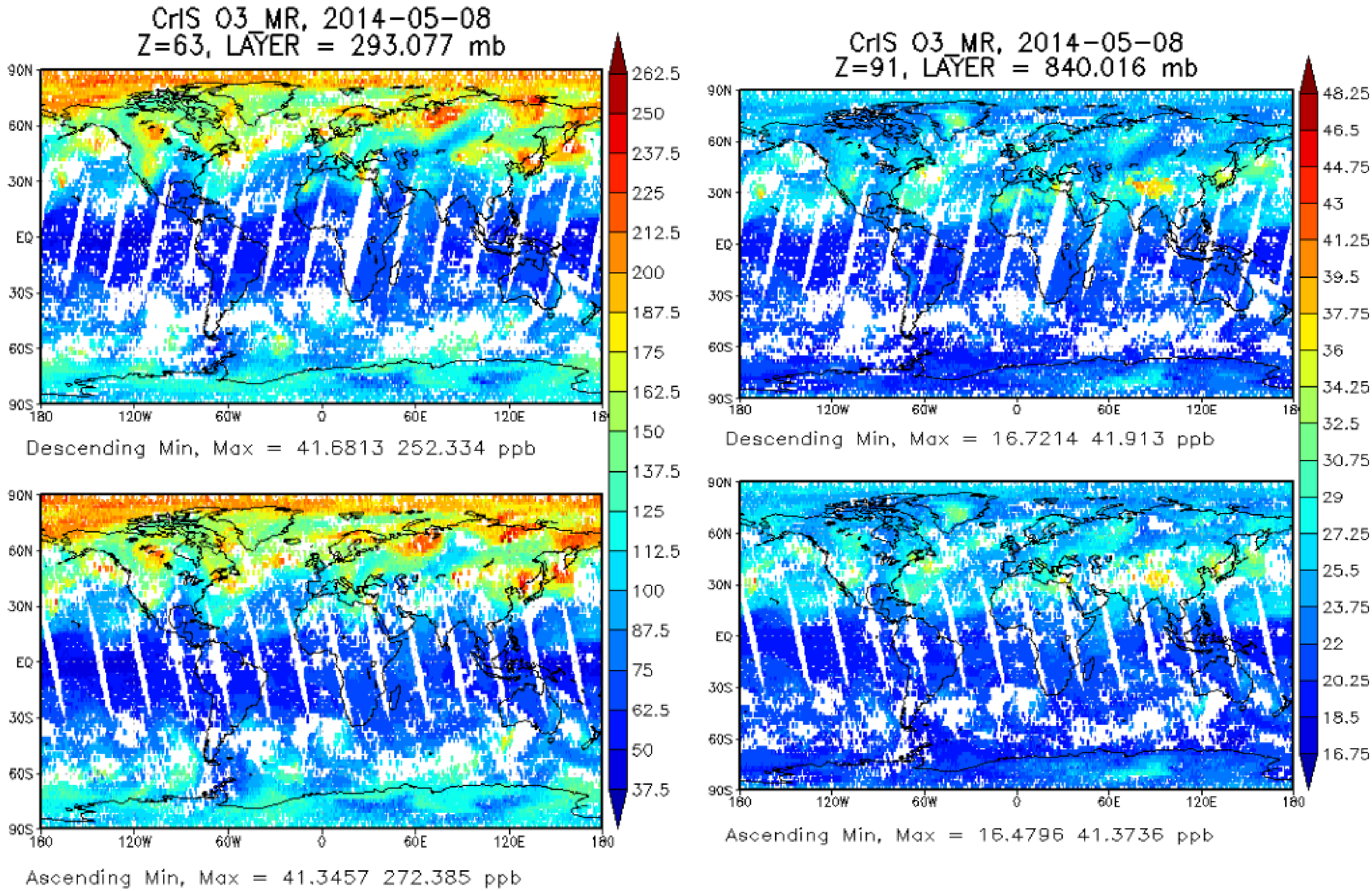
NUCAPS Layer CH4 MR



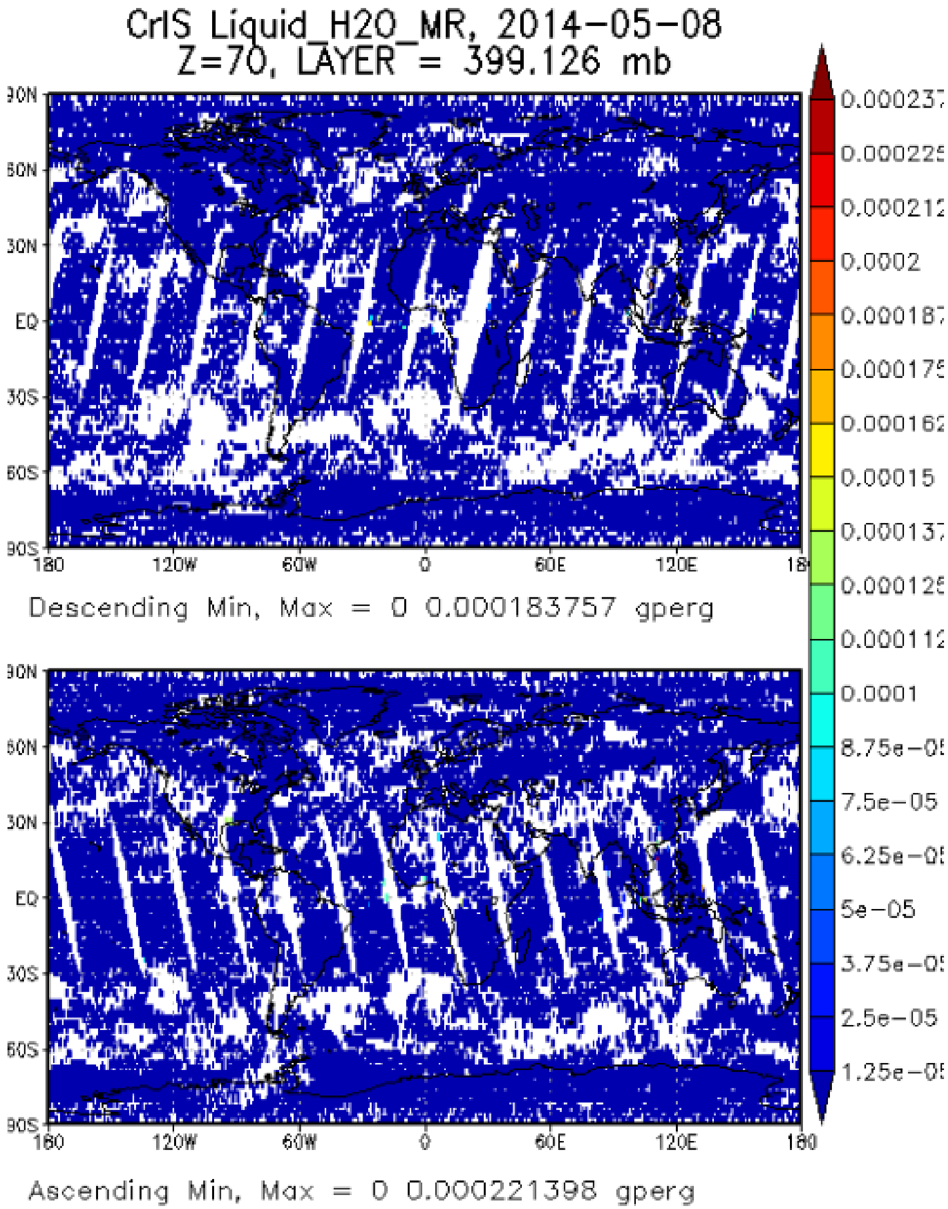
NUCAPS Layer CO MR

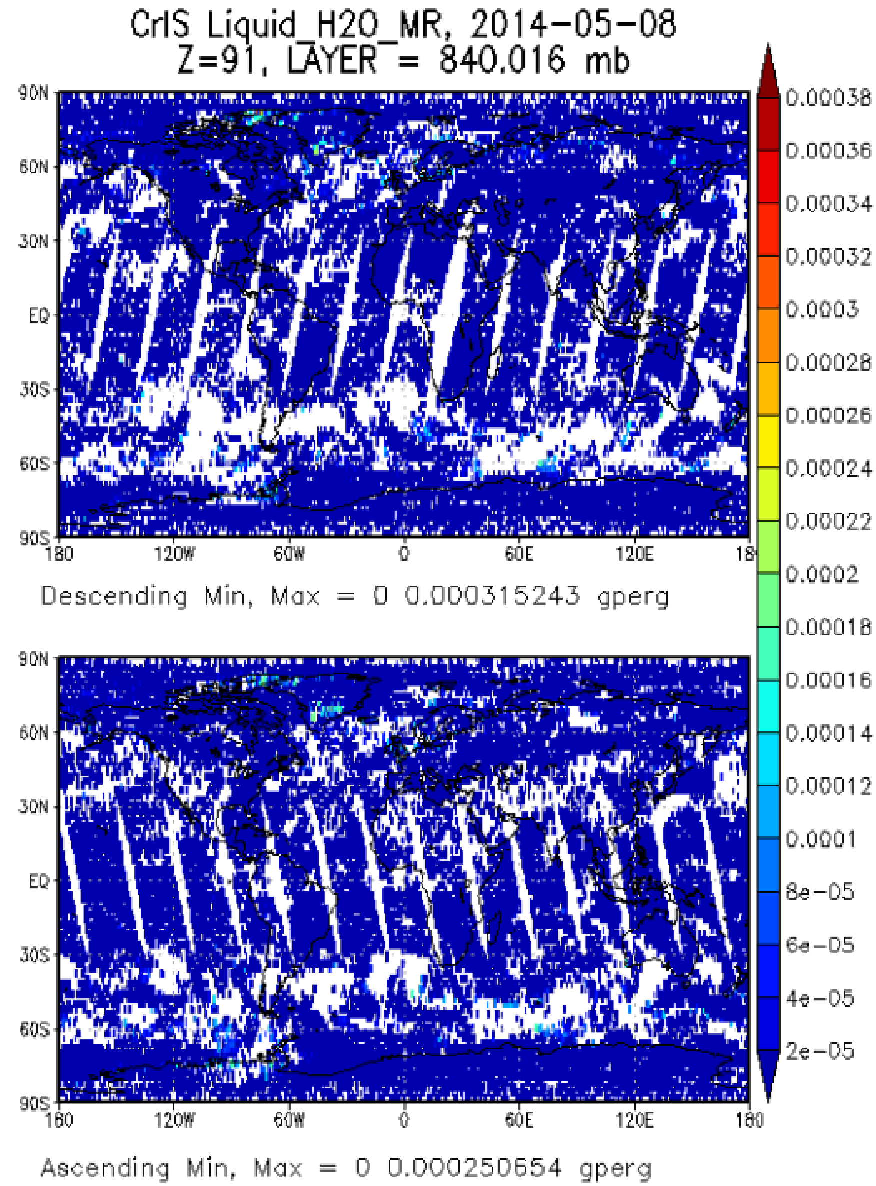


NUCAPS Layer Ozone MR



NUCAPS Layer Liquid H2O MR



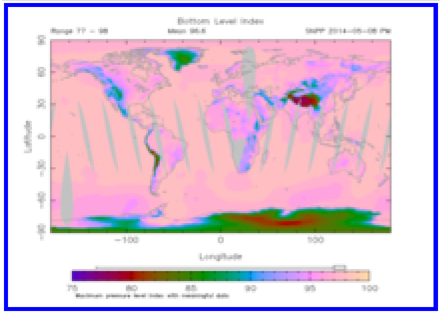


NUCAPS EDR Images for 2014-05-08 PM - SNPP

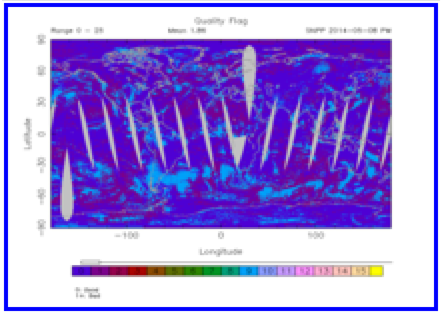
Internal links: [Single Level Parameters] [Ice Liquid Flag] [Mixing Ratio of Carbon Dioxide] [Mixing Ratio of Carbon Monoxide] [Mixing Ratio of Liquid Water] [Mixing Ratio of Methane] [Mixing Ratio of Ozone] [Mixing Ratio of Water Vapor] [Temperature]

Flags (Enumeration)

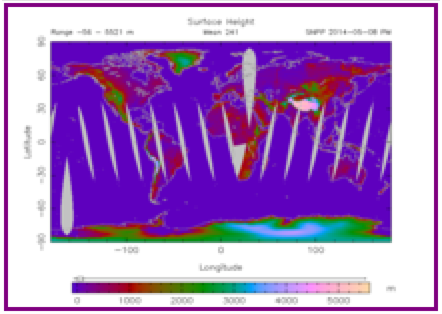
Bottom Level Index



Quality Flag



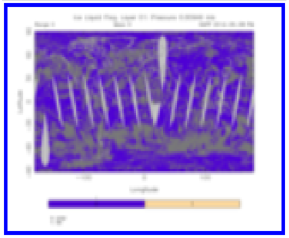
Surface Height



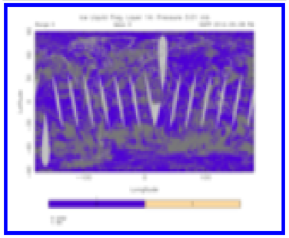
Ice Liquid Flag

Single Level Parameters

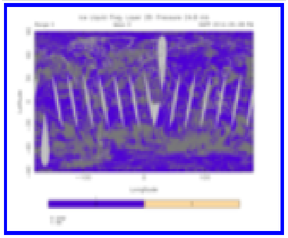
L001: 0.00949 mb



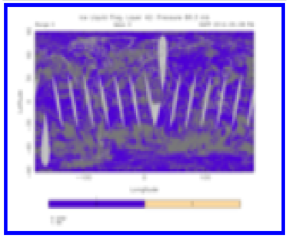
L014: 3.01 mb



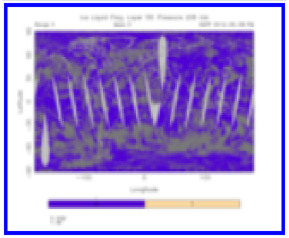
L028: 24.8 mb



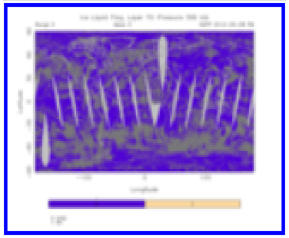
L042: 86.3 mb



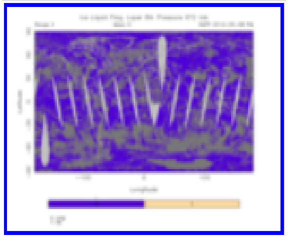
L056: 206 mb



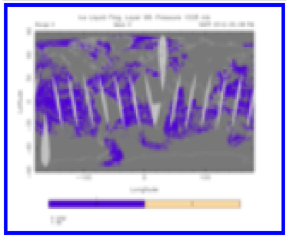
L070: 399 mb



L084: 672 mb



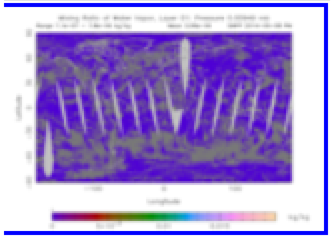
L098: 1028 mb



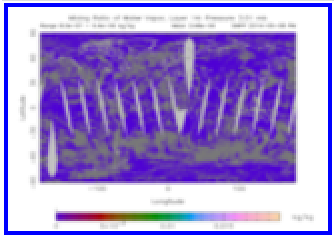
NUCAPS Products Images

Mixing Ratio of Water Vapor

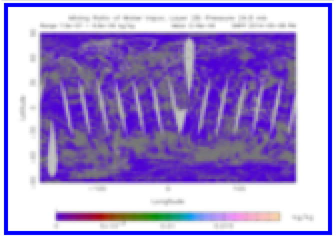
L001: 0.00949 mb



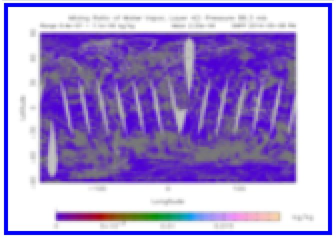
L014: 3.01 mb



L028: 24.8 mb



L042: 86.3 mb



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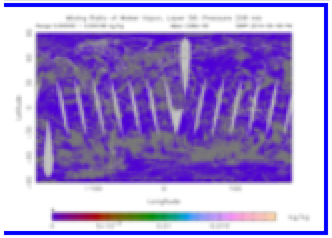
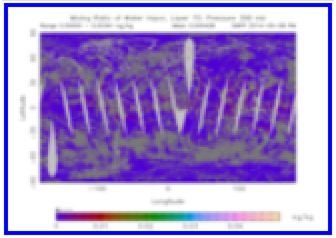


L070: 399 mb



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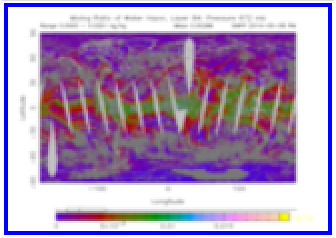

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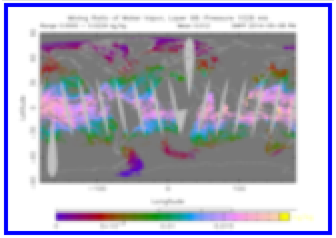
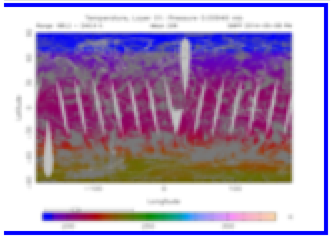


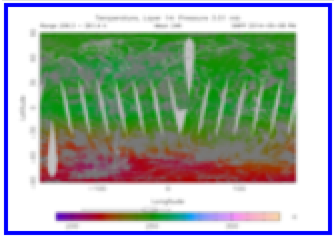
More Mixing Ratio of Water Vapor levels

Temperature

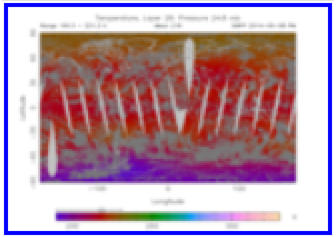
L001: 0.00949 mb



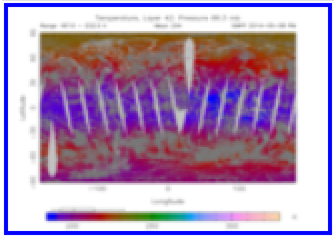
L014: 3.01 mb



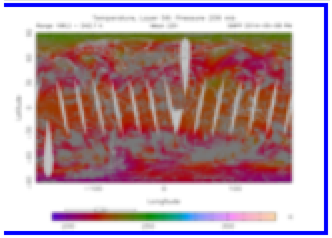
L028: 24.8 mb



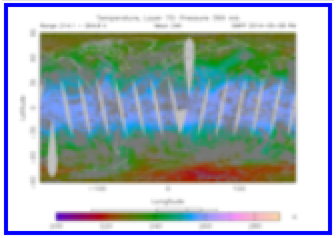
L042: 86.3 mb



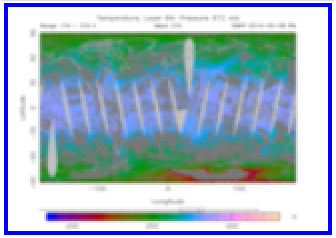
L056: 206 mb



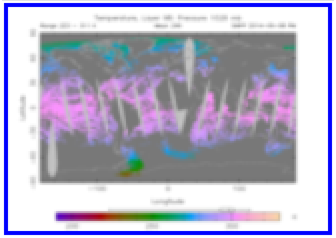
L070: 399 mb



L084: 672 mb

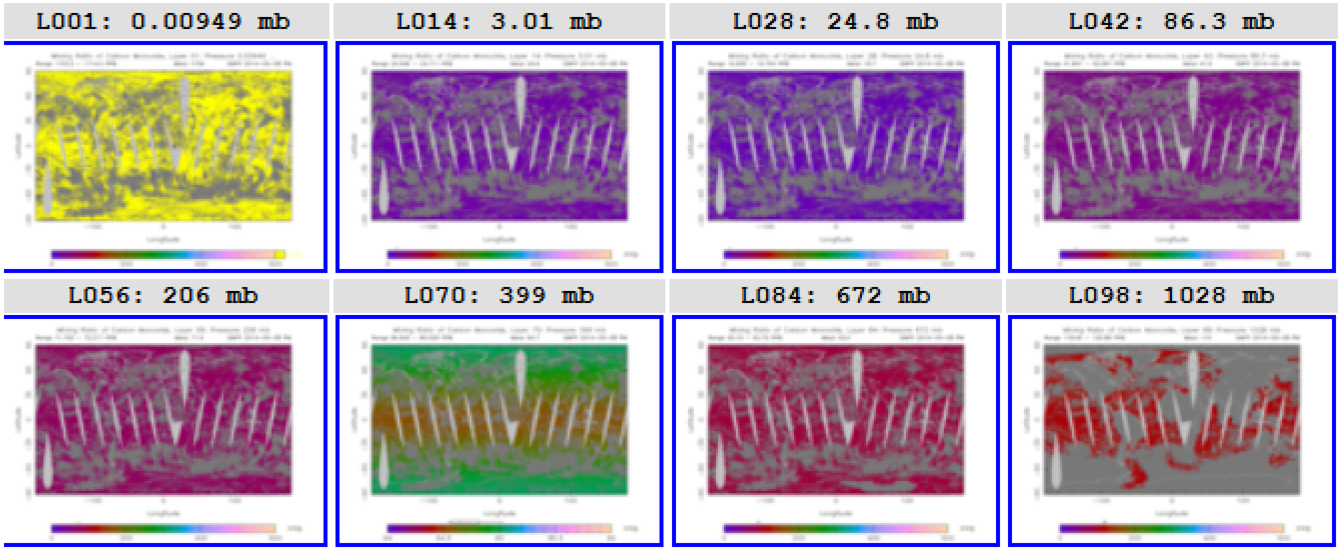


L098: 1028 mb



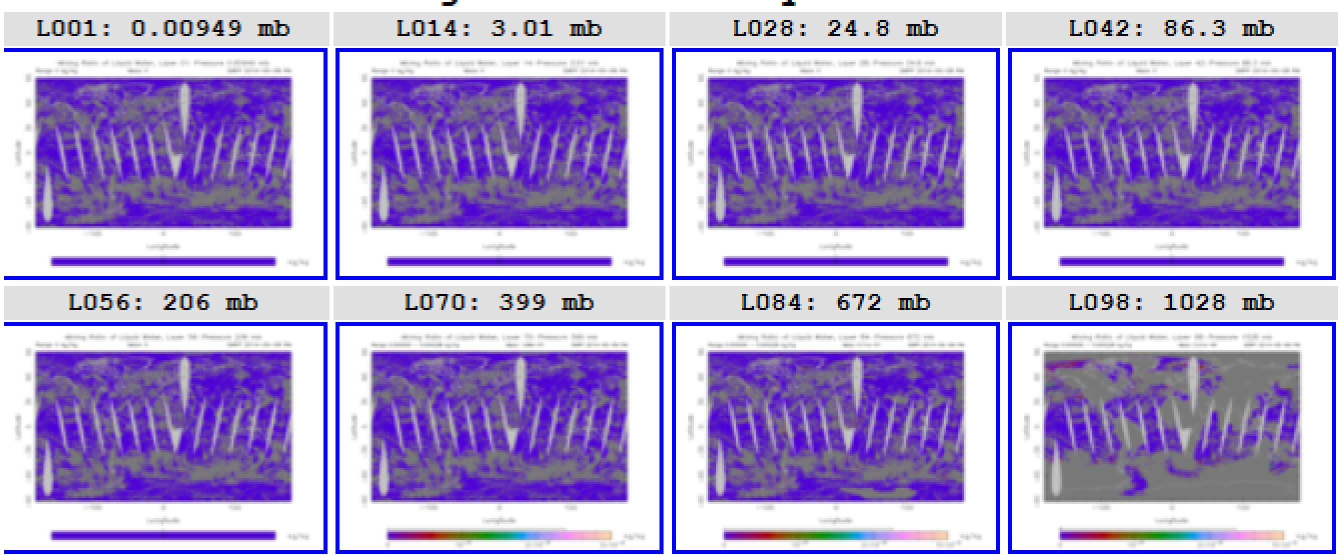
NUCAPS Layer CO, Liquid Water MRs

Mixing Ratio of Carbon Monoxide



More Mixing Ratio of Carbon Monoxide levels

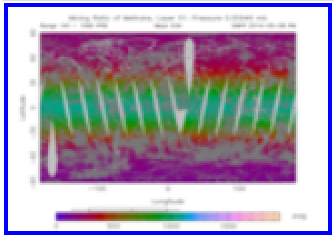
Mixing Ratio of Liquid Water



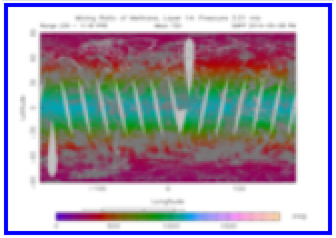
NUCAPS Layer CH4, O3 MRs

Mixing Ratio of Methane

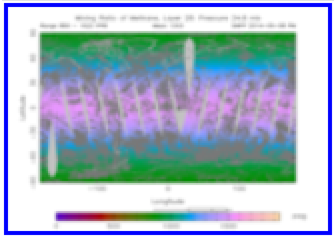
L001: 0.00949 mb



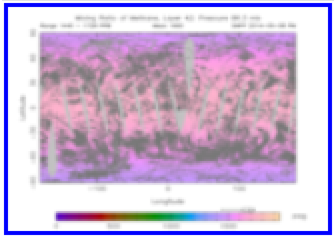
L014: 3.01 mb



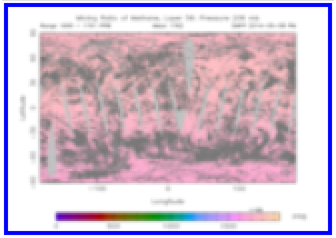
L028: 24.8 mb



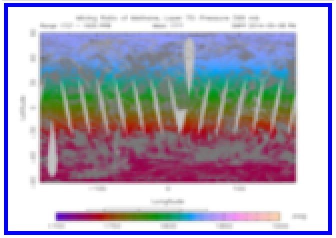
L042: 86.3 mb



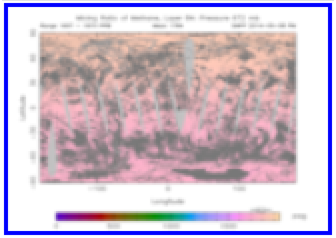
L056: 206 mb



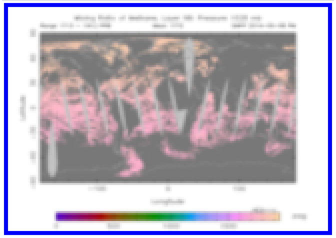
L070: 399 mb



L084: 672 mb



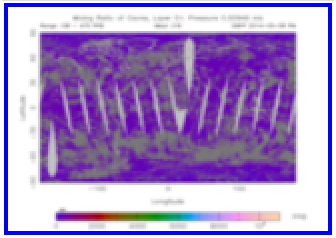
L098: 1028 mb



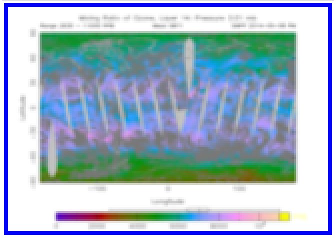
More Mixing Ratio of Methane levels

Mixing Ratio of Ozone

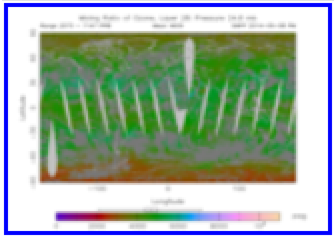
L001: 0.00949 mb



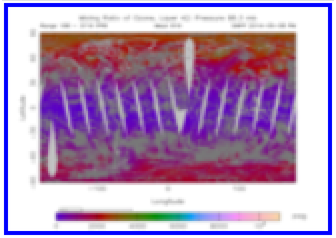
L014: 3.01 mb



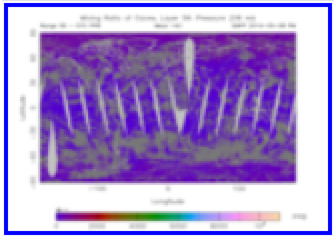
L028: 24.8 mb



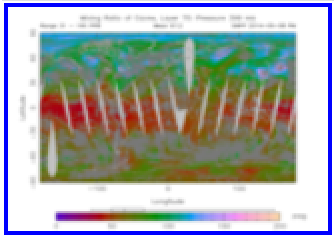
L042: 86.3 mb



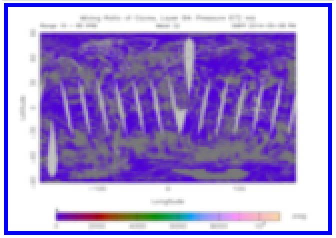
L056: 206 mb



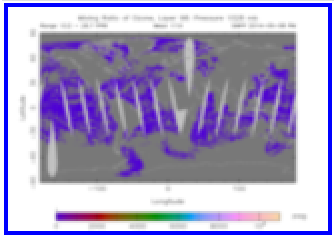
L070: 399 mb



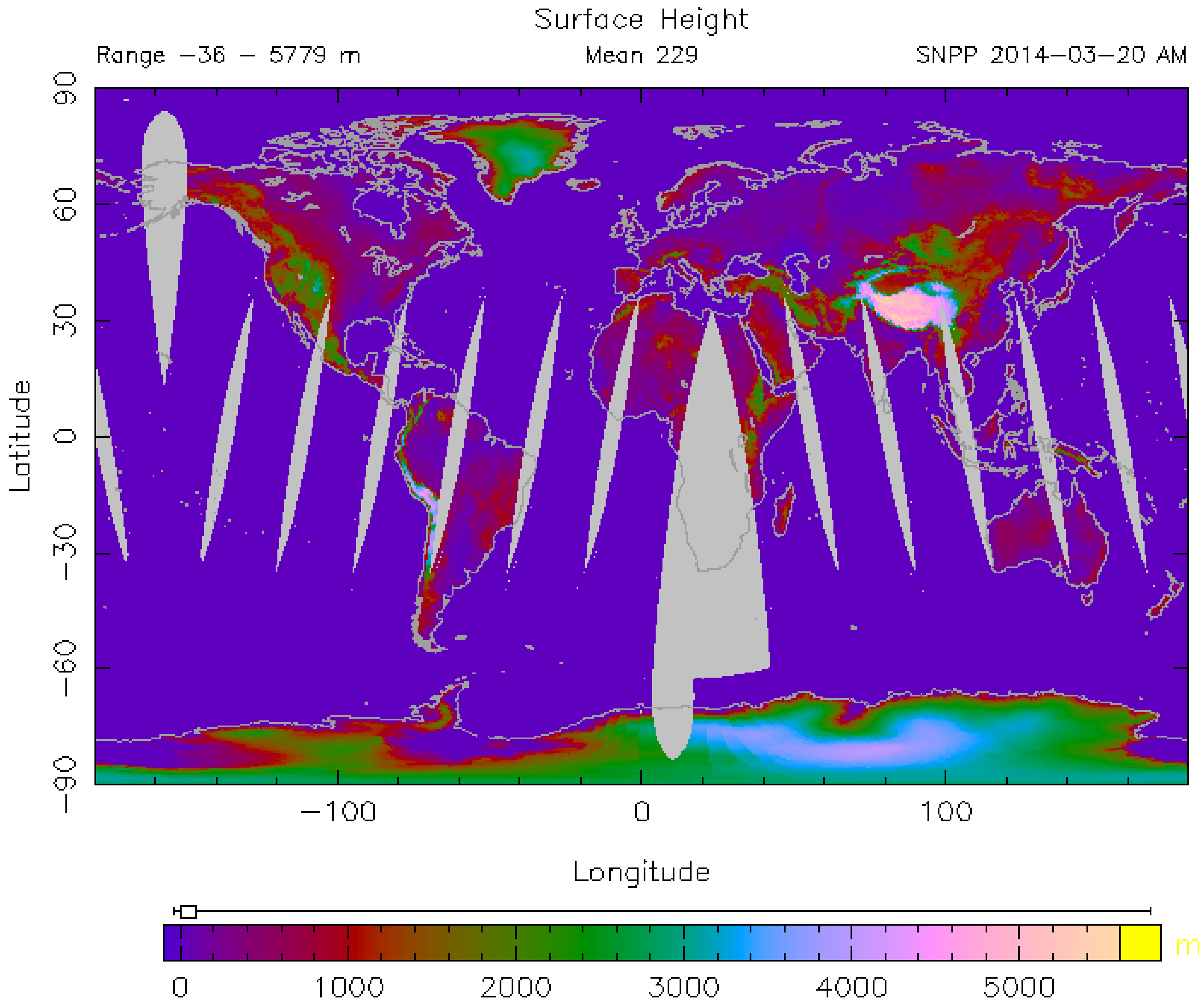
L084: 672 mb



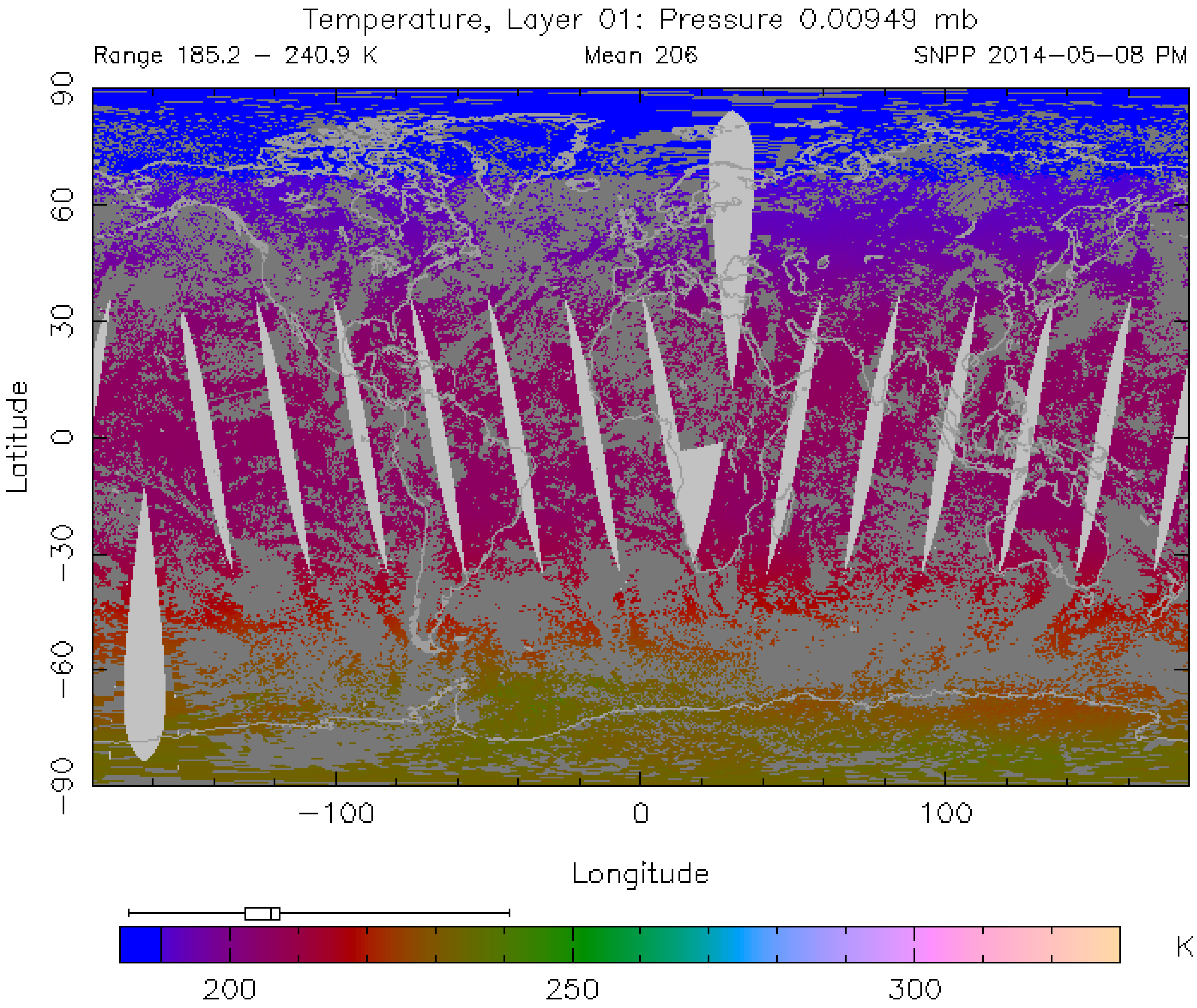
L098: 1028 mb



NUCAPS Surface Height



NUCAPS Level Temperature



NUCAPS Level Temperature

Temperature, Layer 90: Pressure 815 mb

Loop Mode:

Forward | Sweep

Animation Mode:

<< | Stop | >>

Speed:

Slower | Faster

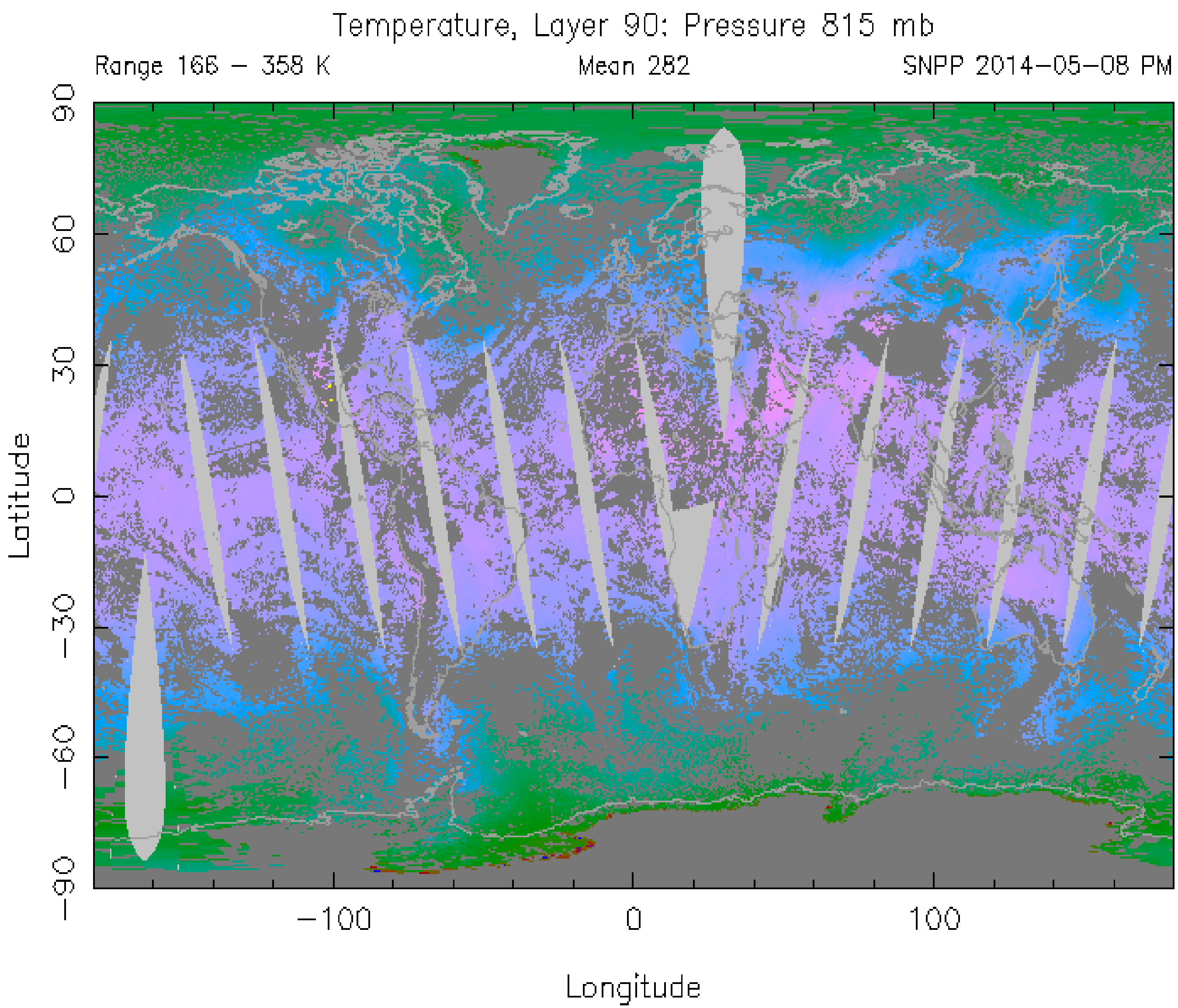
Advance:

< | >

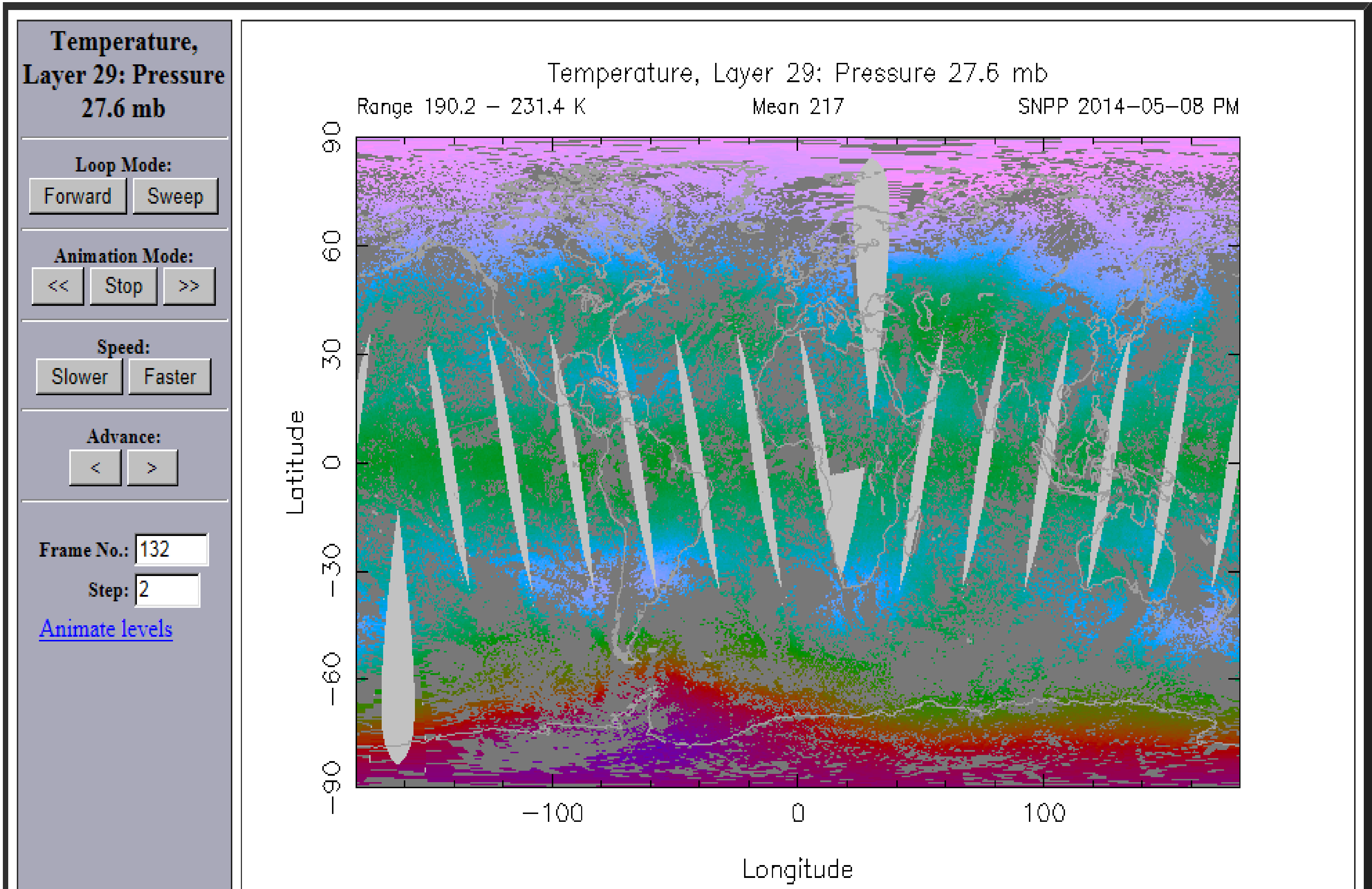
Frame No.: 132

Step: 2

Animate levels



NUCAPS Level Temperatures



NUCAPS Layer Ozone Mixing Ratio

Mixing Ratio of Ozone, Layer 14: Pressure 3.01 mb

Loop Mode:

Forward | Sweep

Animation Mode:

<< | Stop | >>

Speed:

Slower | Faster

Advance:

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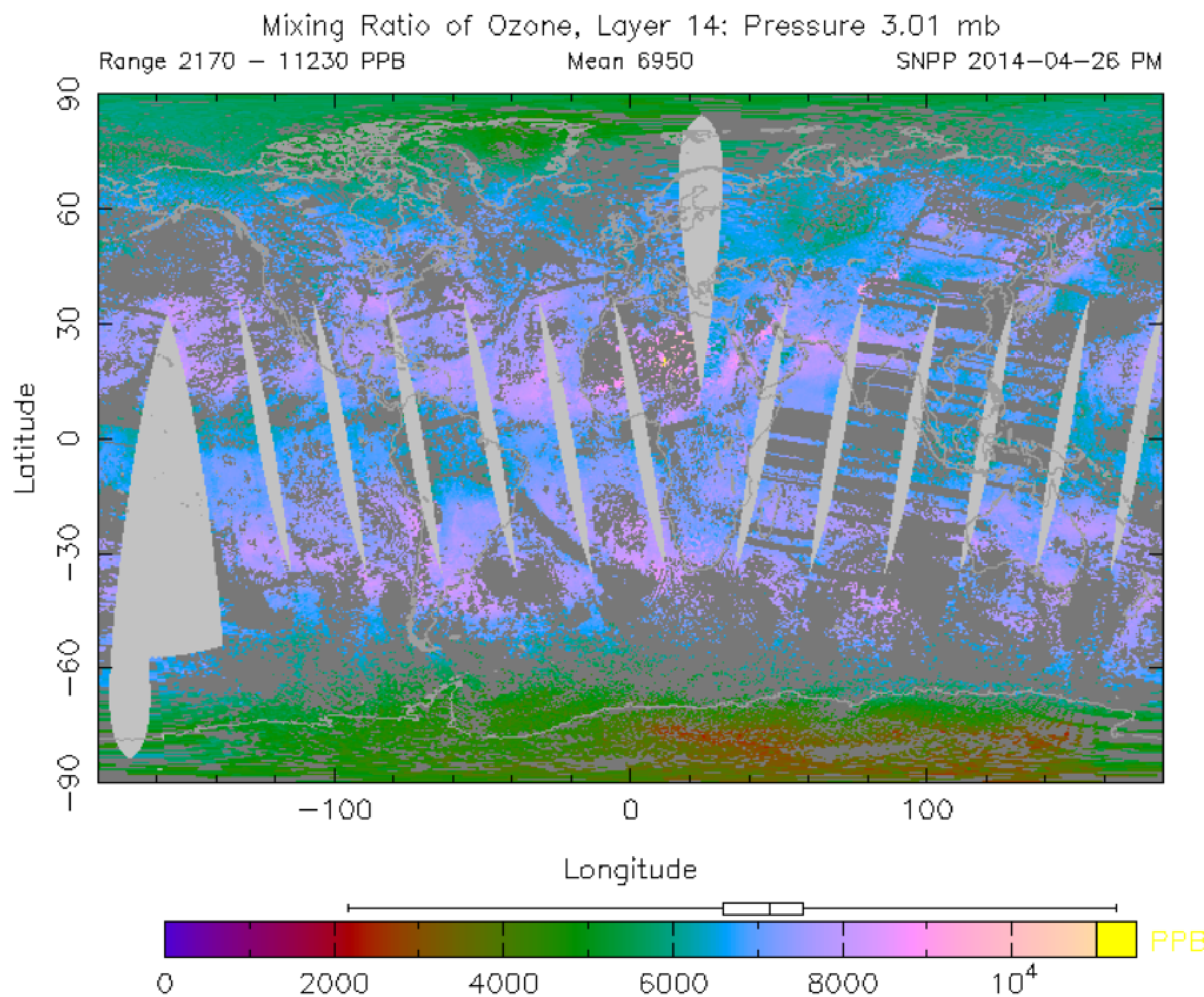
Frame No.: 108

Step: 2

Animate levels



NUCAPS Layer CH4 MR

Mixing Ratio of Methane, Layer 10: Pressure 1.13 mb

Loop Mode:
Forward Sweep

Animation Mode:
<< Stop >>

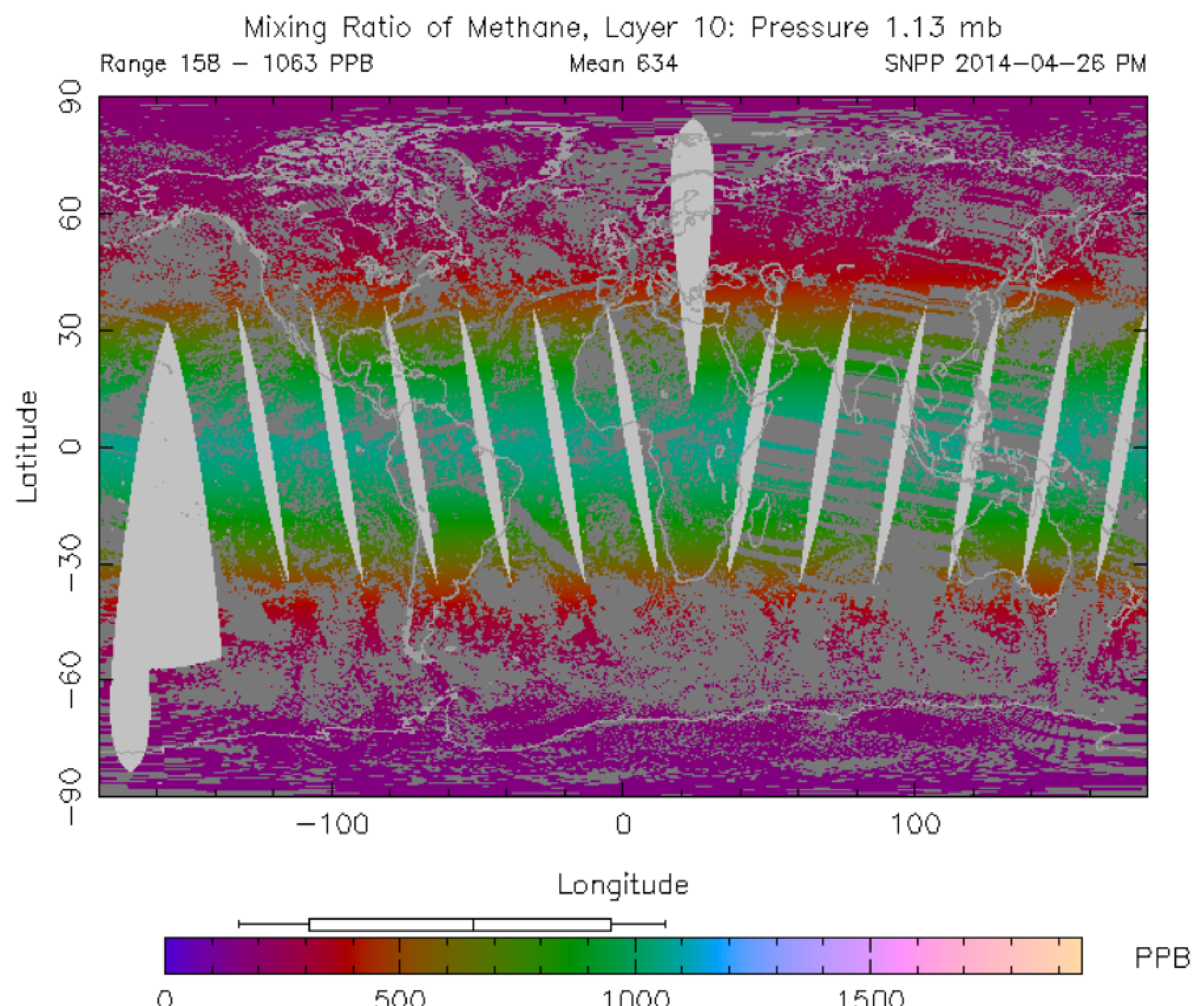
Speed:
Slower Faster

Advance:
< >

Frame No.: 109

Step: 2

Animate levels



NUCAPS Layer CO MR

Mixing Ratio of Carbon Monoxide, Layer 91: Pressure 840 mb

Loop Mode:
Forward | Sweep

Animation Mode:
<< | Stop | >>

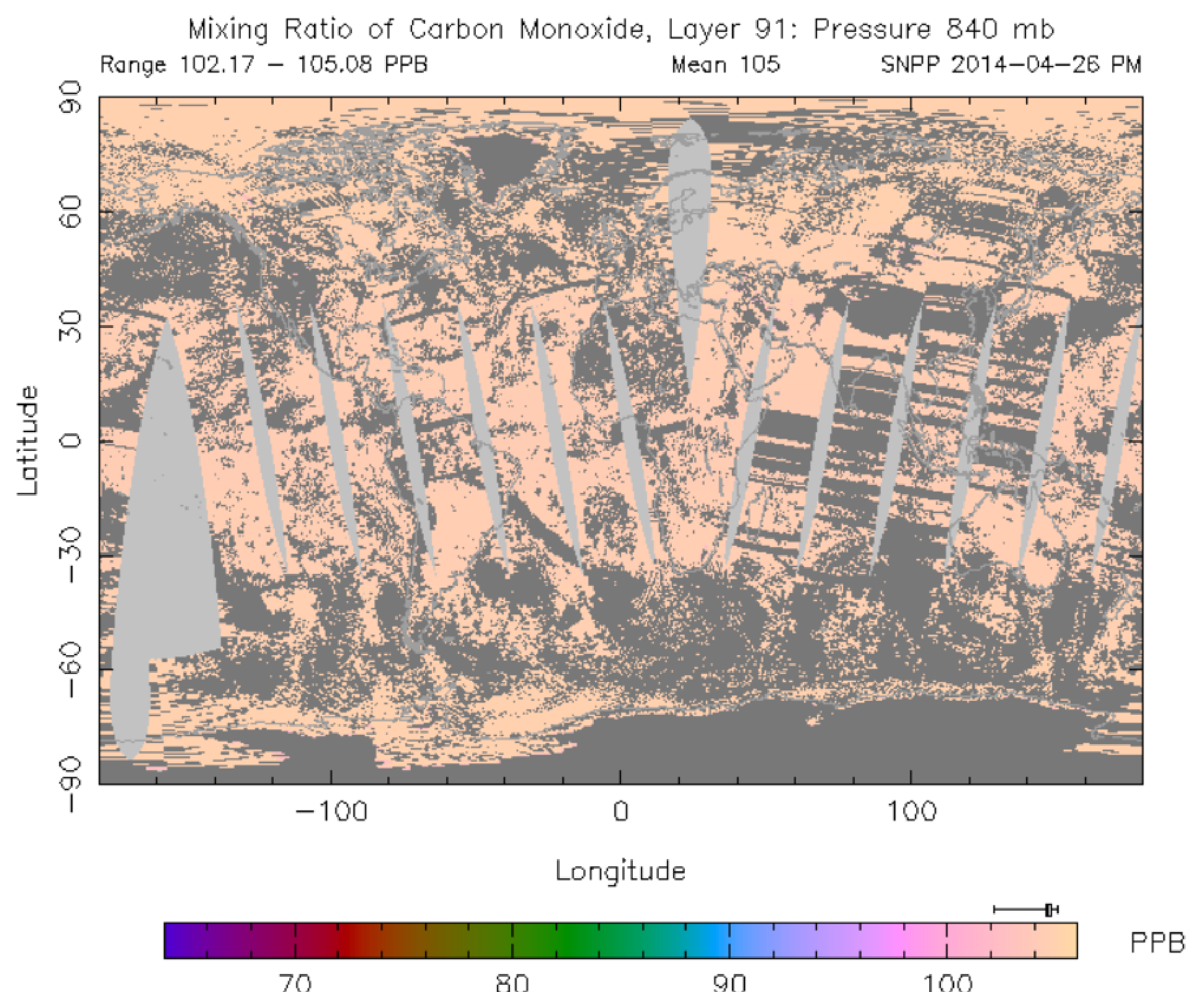
Speed:
Slower | Faster

Advance:
< | >

Frame No.: 109

Step: 2

Animate levels



NUCAPS Layer CO2 MR

Mixing Ratio of Carbon Dioxide, Layer 63: Pressure 293 mb

Loop Mode: Forward Sweep

Animation Mode: << Stop >>

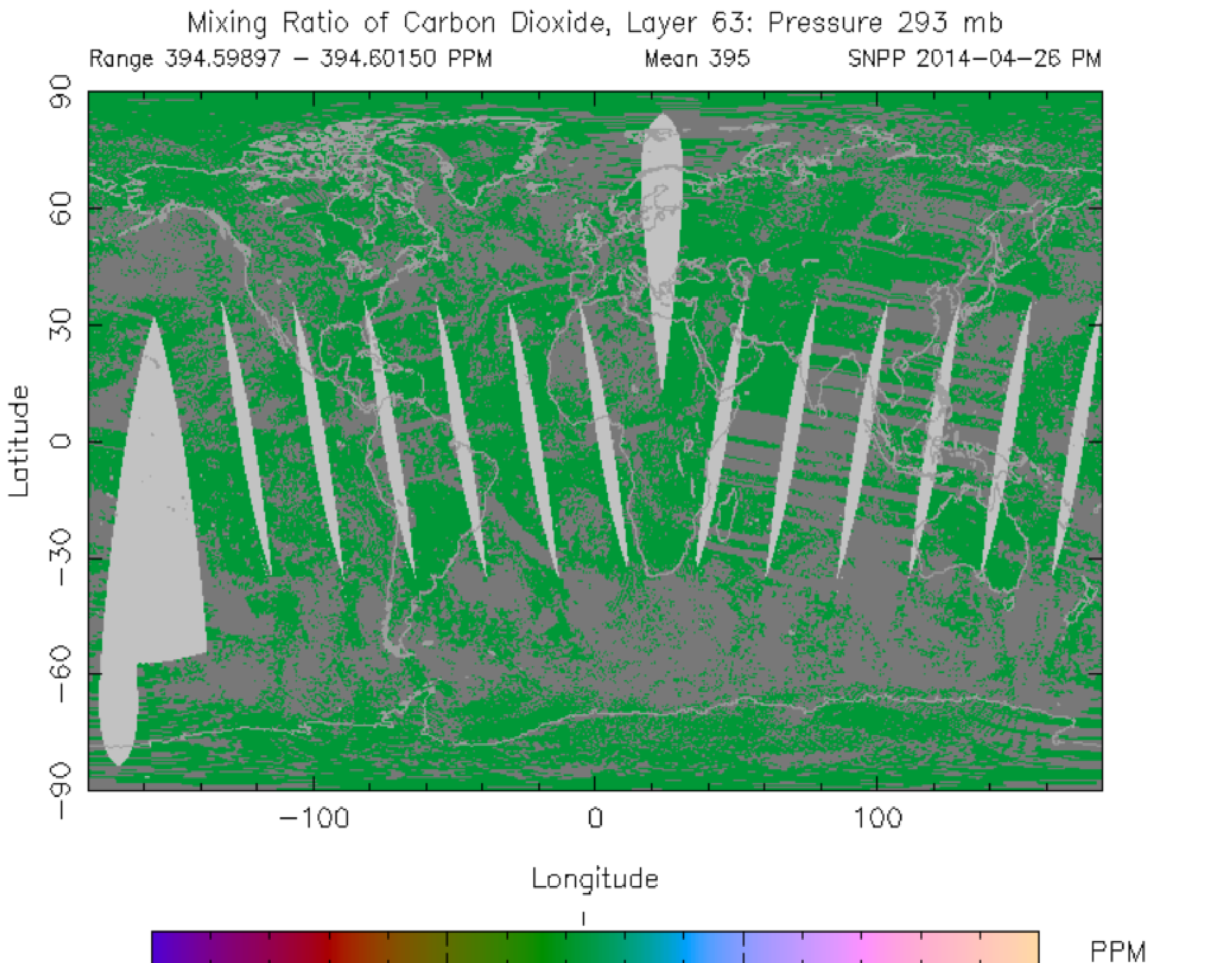
Speed: Slower Faster

Advance: < >

Frame No.: 109

Step: 2

Animate levels



NUCAPS Accomplishments

- STAR EPL process was used for NUCAPS system Development
- NUCAPS code met the SPSRB software standards and OSPO security standards
- NUCAPS system successfully transition to ESPC operation
- NUCAPS QA/QC Monitoring Tools were developed and used for validating the products

NUCAPS Future Plans

- Ongoing optimization study includes channels, perturbation functions, first guess and damping parameter.

- Use dedicated cal/val field campaign in situ measurements to fully assess NUCAPS retrieval performance of temperature, water vapor, cloud cleared radiance, cloud parameters and trace gases.

- Leverage ongoing scientific collaborations (low cost activities for NOAA) to perform trace gas validation.

- CrIS OLR development and implementation for ESPC operation.

- Full Resolution RDR's for CrIS SW and MW bands to support carbon products.

- Improve the Quality of CO, CO2, and CH4 by employing the full-resolution.

- Enhancement of real time NUCAPS Quality Monitoring System for JPSS-1 products validation.

- NPROVS can be operationalized for JPSS-1 for validating the products.

- Plan for JPSS-1 Algorithm Updates and Validation using existing tools developed at OSPO

NUCAPS Summary

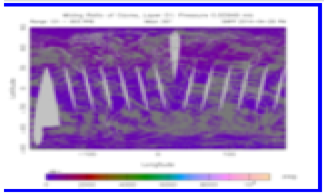
- NUCAPS System meets the user requirements.
- Trace Gas products pending validation.
- NUCAPS QA/QC system was developed and is being used for product monitoring
- Compared IASI and NUCAPS products using OSPO QA/QC interactive tool.
- NUCAPS Products maturity demonstrated for prime time use.

Backup Slides

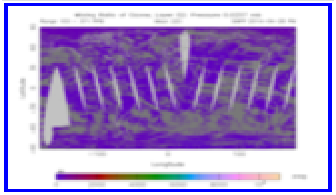
Mixing Ratio of Ozone Images for 2014-04-26 PM - SNPP

Mixing Ratio of Ozone

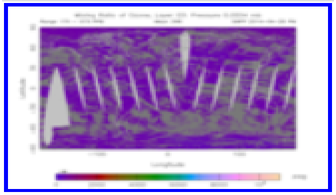
L001: 0.00949 mb



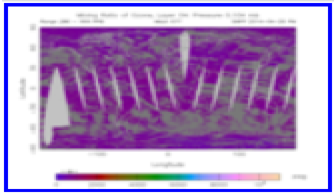
L002: 0.0257 mb



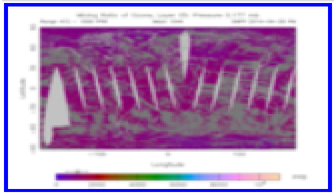
L003: 0.0554 mb



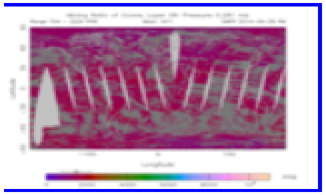
L004: 0.104 mb



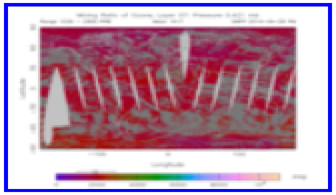
L005: 0.177 mb



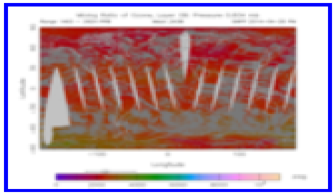
L006: 0.281 mb



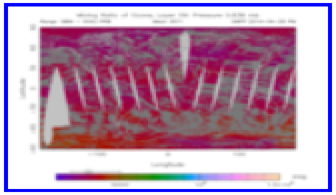
L007: 0.421 mb



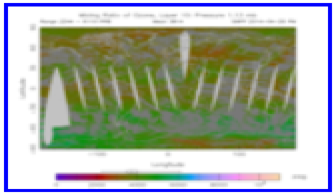
L008: 0.604 mb



L009: 0.838 mb



L010: 1.13 mb



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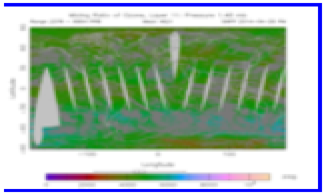

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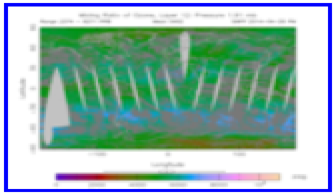

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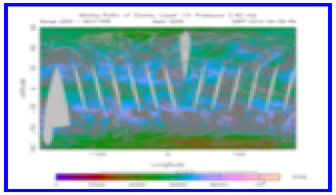
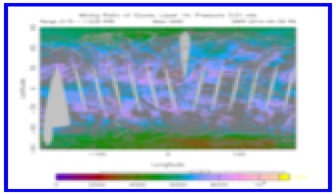
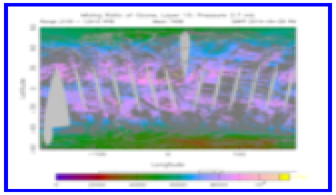


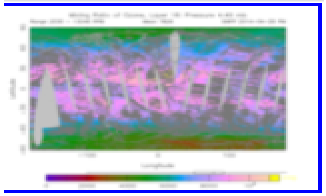
L014: 3.01 mb



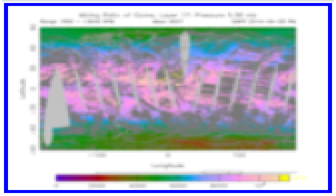
L015: 3.7 mb



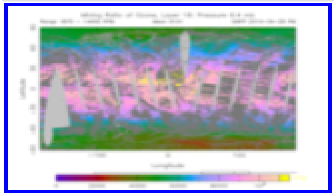
L016: 4.49 mb



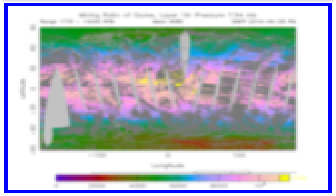
L017: 5.38 mb



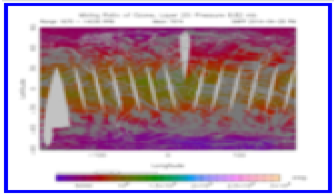
L018: 6.4 mb



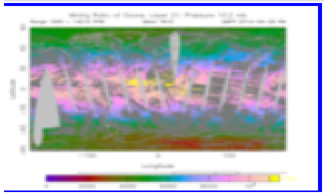
L019: 7.54 mb



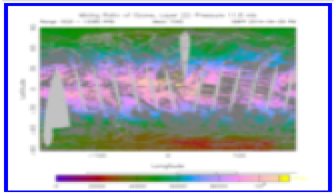
L020: 8.82 mb



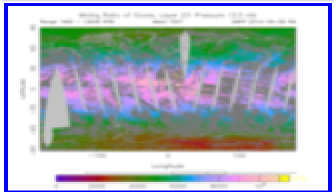
L021: 10.2 mb



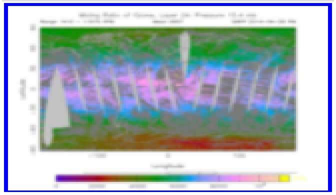
L022: 11.8 mb



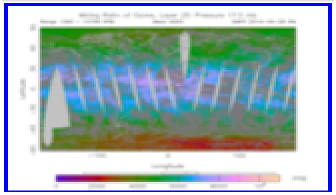
L023: 13.5 mb



L024: 15.4 mb



L025: 17.5 mb



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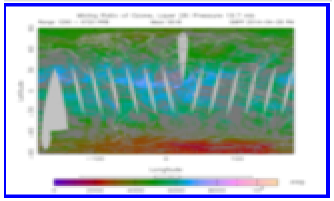
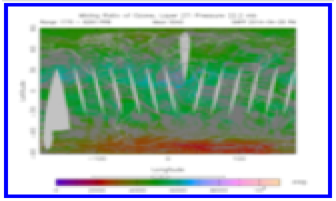
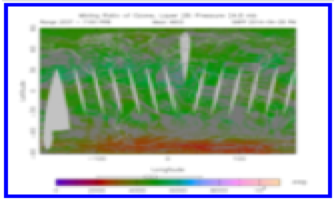
L026: 19.7 mb



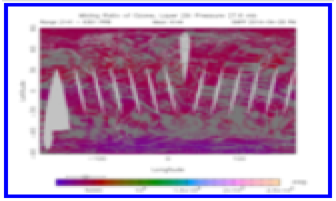
L027: 22.2 mb



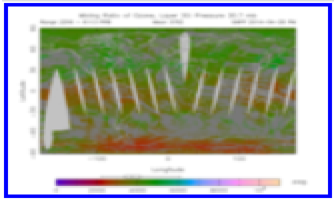
L028: 24.8 mb



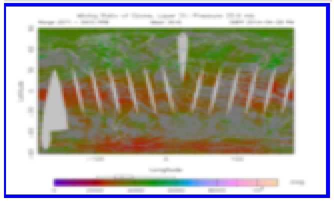
L029: 27.6 mb



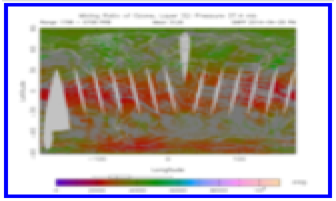
L030: 30.7 mb



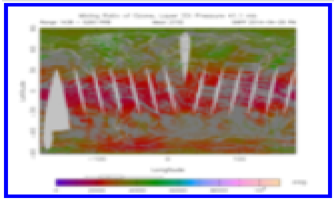
L031: 33.9 mb



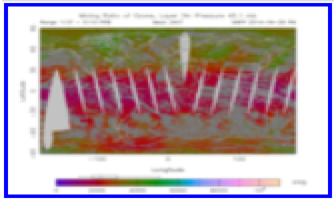
L032: 37.4 mb



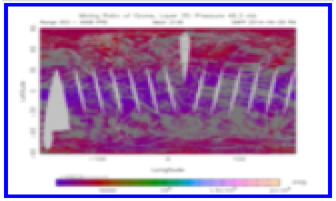
L033: 41.1 mb



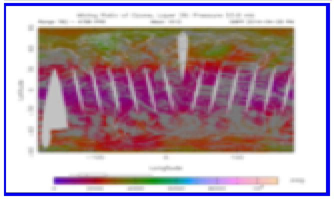
L034: 45.1 mb



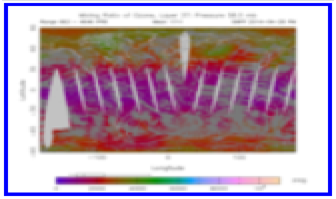
L035: 49.3 mb



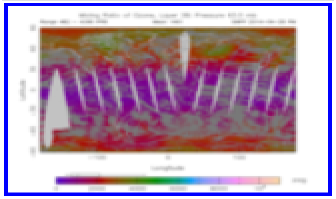
L036: 53.8 mb



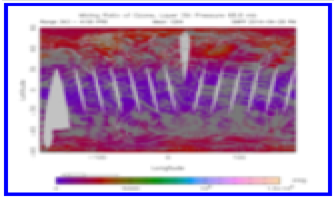
L037: 58.5 mb



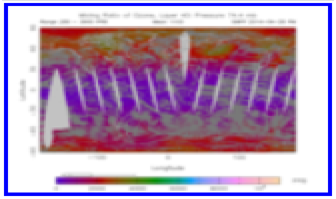
L038: 63.5 mb



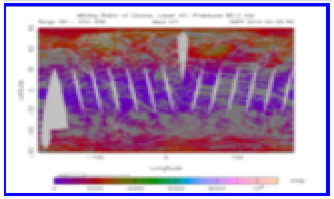
L039: 68.8 mb



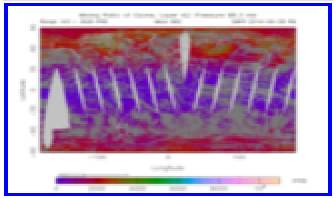
L040: 74.4 mb



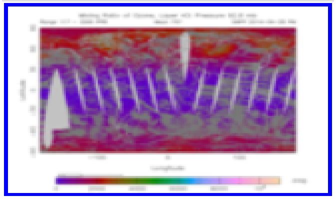
L041: 80.2 mb



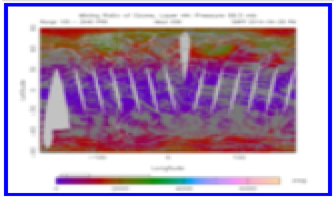
L042: 86.3 mb



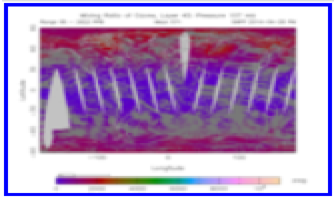
L043: 92.8 mb



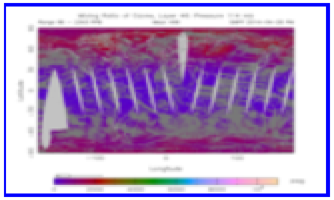
L044: 99.5 mb



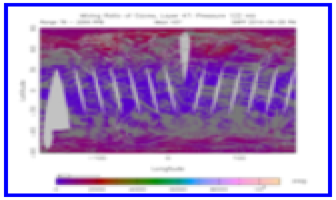
L045: 107 mb



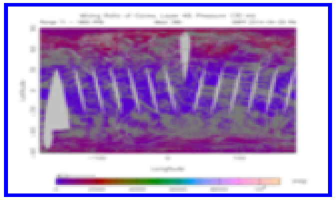
L046: 114 mb



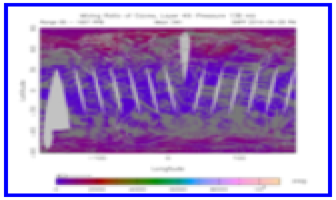
L047: 122 mb



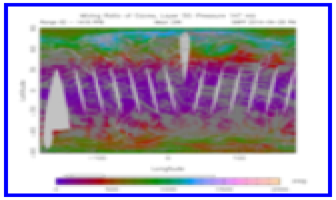
L048: 130 mb



L049: 138 mb



L050: 147 mb



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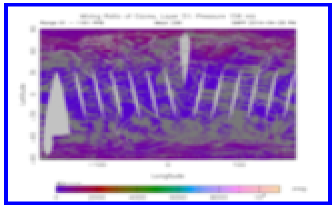
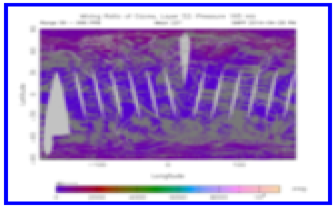
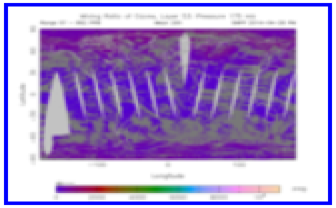
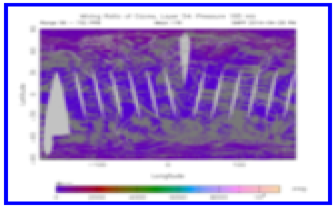
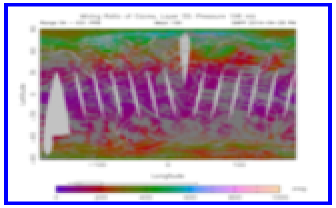
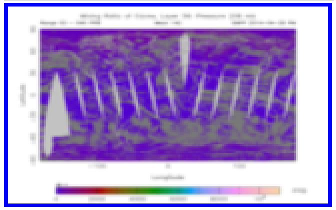
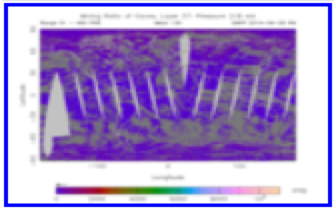
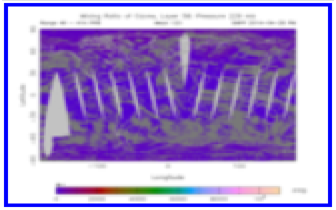
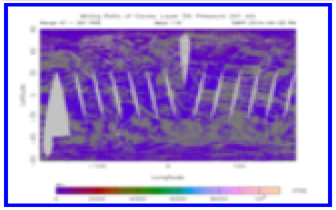
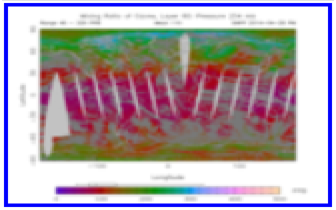
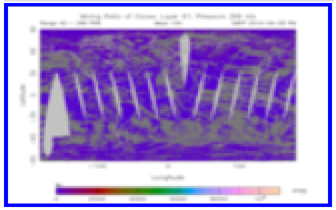
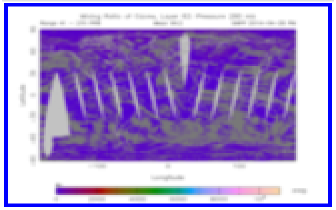
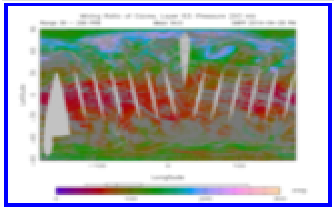
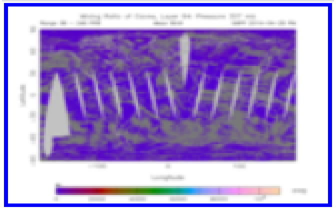
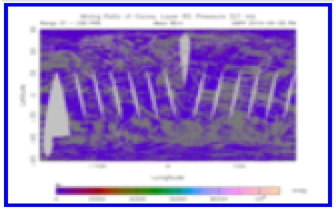
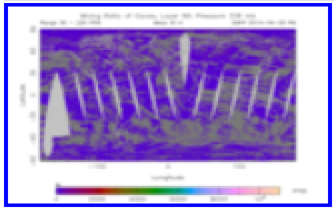
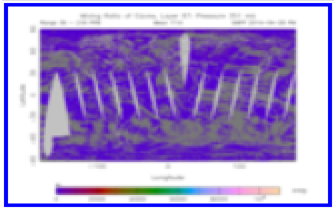
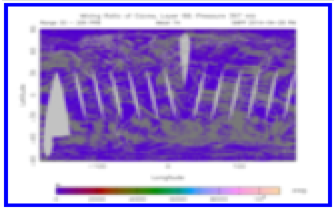
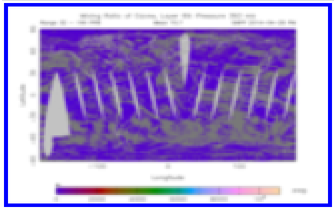
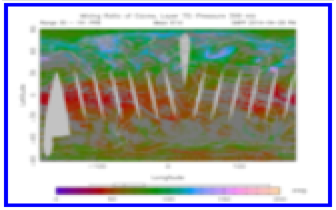
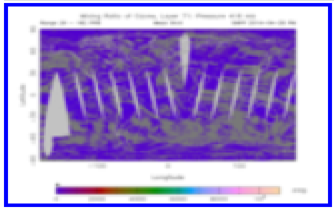
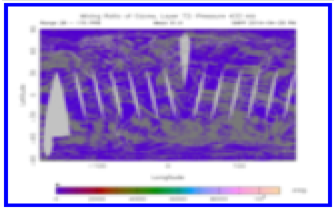
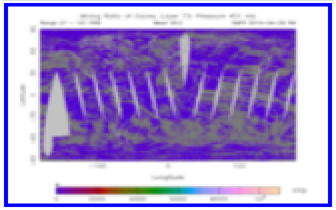
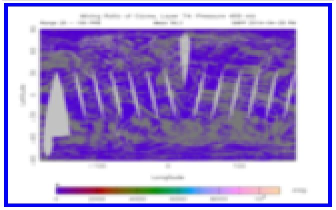
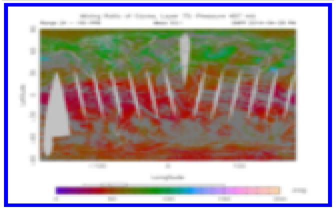
L051: 156 mb	L052: 165 mb	L053: 175 mb	L054: 185 mb	L055: 196 mb
				
L056: 206 mb	**L057: 218 mb**	**L058: 229 mb**	**L059: 241 mb**	**L060: 254 mb**
				
L061: 266 mb	**L062: 280 mb**	**L063: 293 mb**	**L064: 307 mb**	**L065: 321 mb**
				
L066: 336 mb	**L067: 351 mb**	**L068: 367 mb**	**L069: 383 mb**	**L070: 399 mb**
				
L071: 416 mb	**L072: 433 mb**	**L073: 451 mb**	**L074: 469 mb**	**L075: 487 mb**
				

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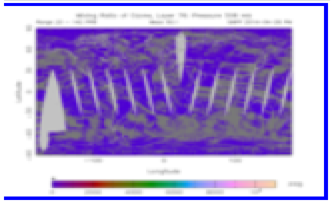
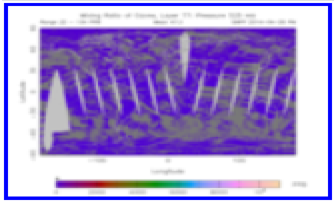
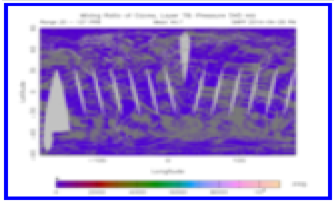
L076: 506 mb



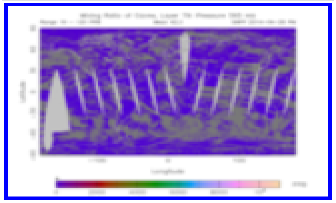
L077: 525 mb



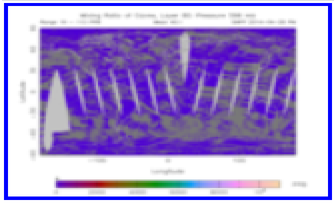
L078: 545 mb



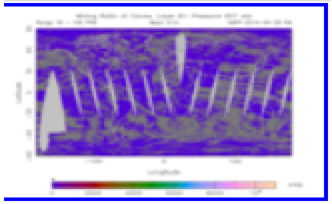
L079: 565 mb



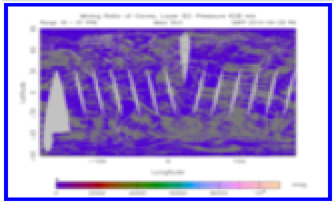
L080: 586 mb



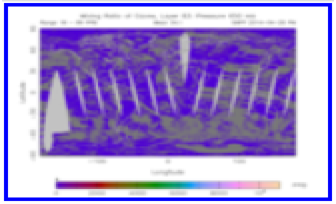
L081: 607 mb



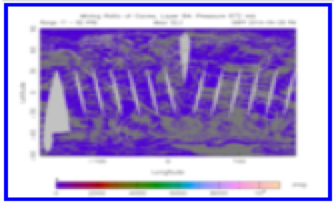
L082: 628 mb



L083: 650 mb



L084: 672 mb



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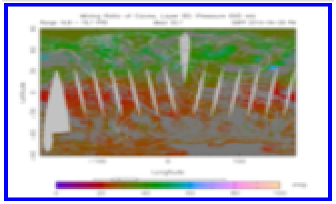

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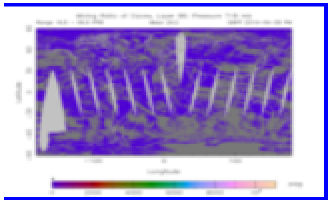
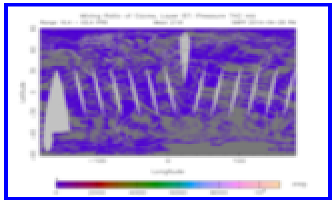
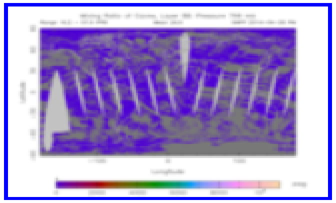


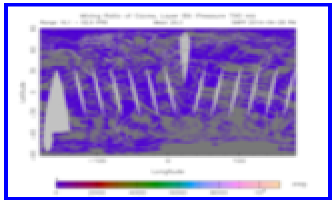
L087: 742 mb



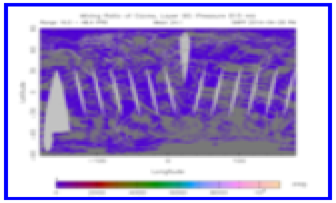
L088: 766 mb



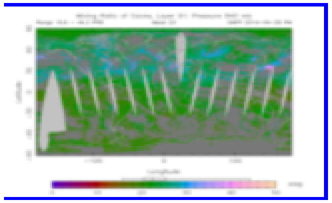
L089: 790 mb



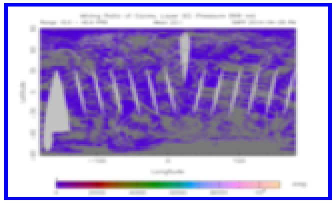
L090: 815 mb



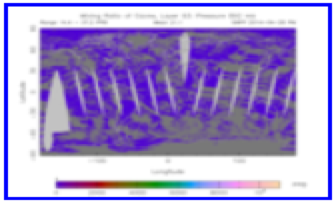
L091: 840 mb



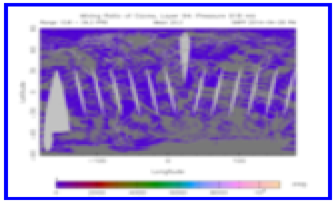
L092: 866 mb



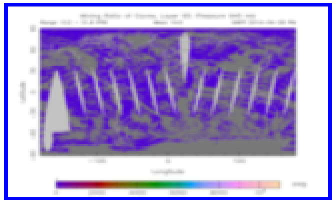
L093: 892 mb



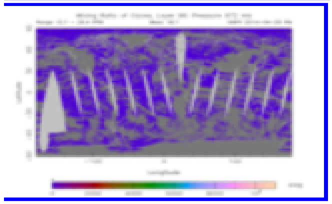
L094: 918 mb



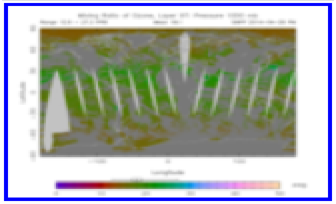
L095: 945 mb



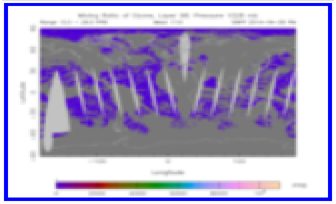
L096: 972 mb



L097: 1000 mb



L098: 1028 mb



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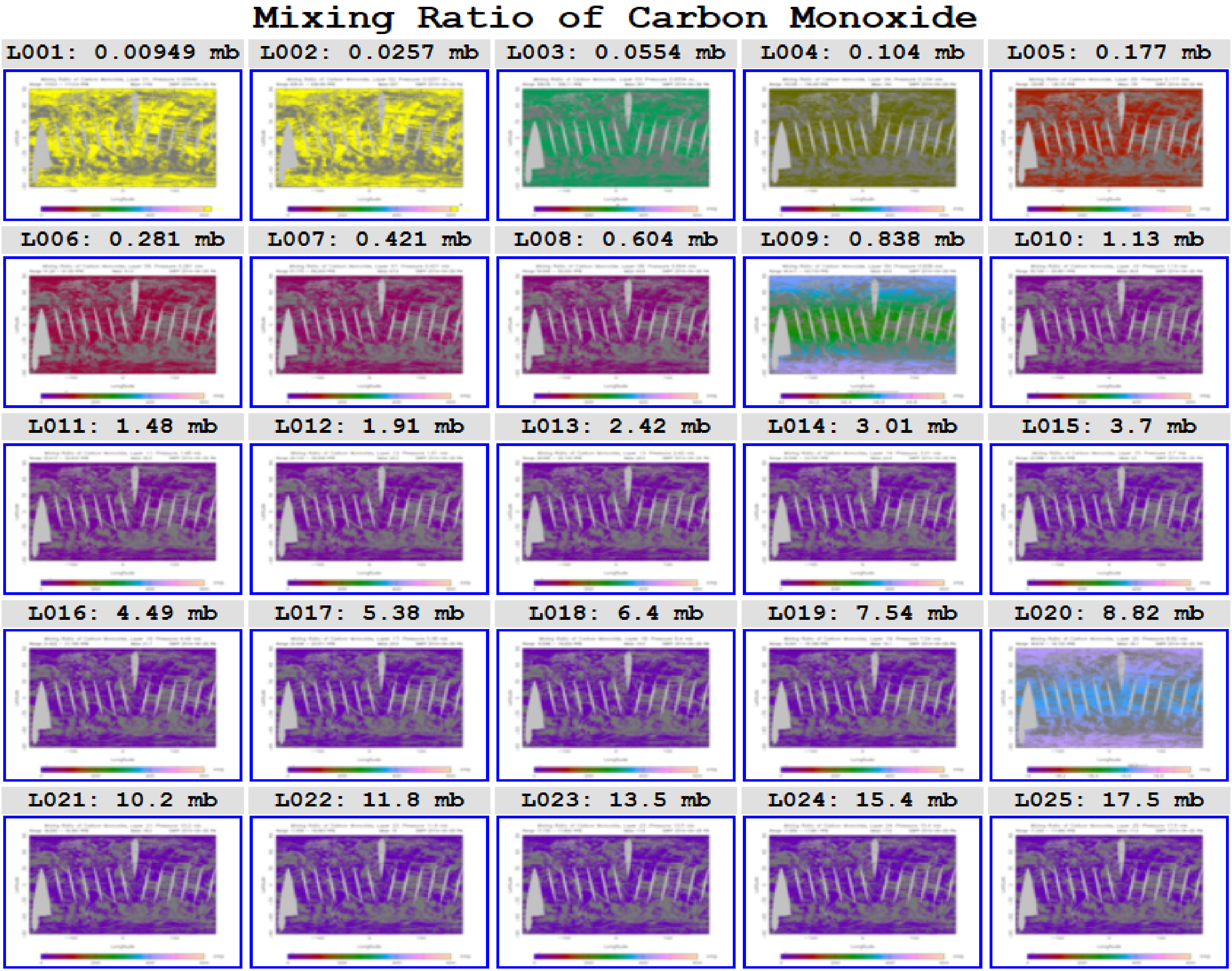

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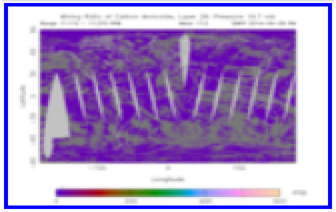
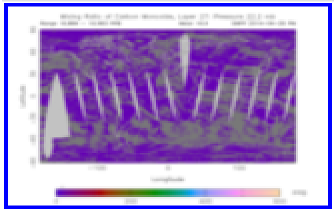
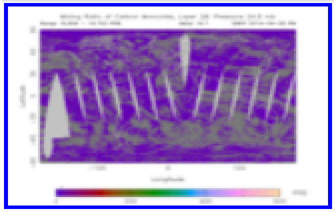
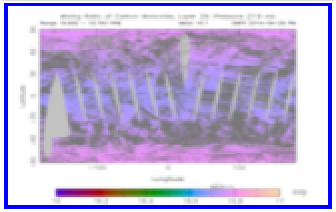
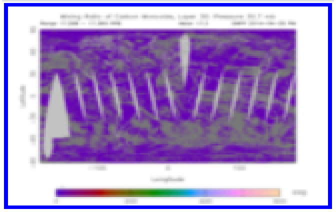
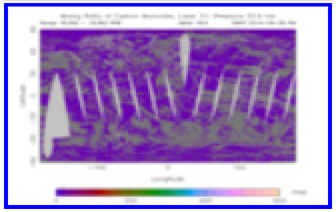
L026: 19.7 mb


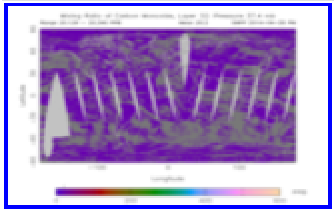
L027: 22.2 mb


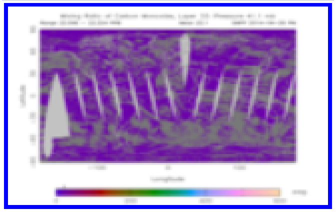
L028: 24.8 mb


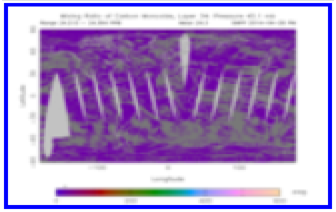
L029: 27.6 mb


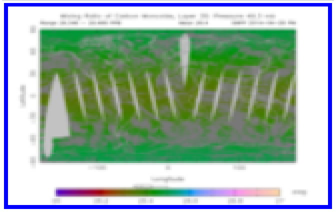
L030: 30.7 mb


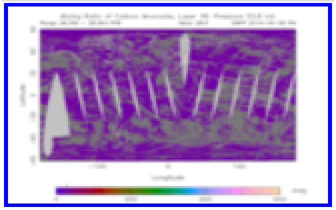
L031: 33.9 mb


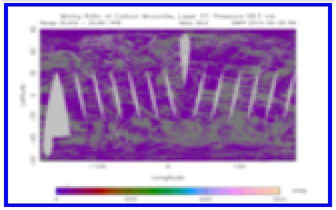
L032: 37.4 mb


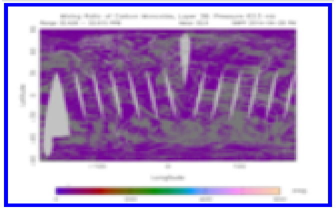
L033: 41.1 mb


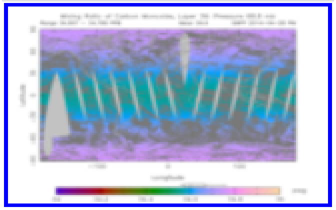
L034: 45.1 mb


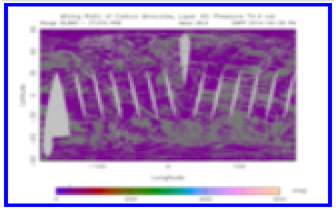
L035: 49.3 mb


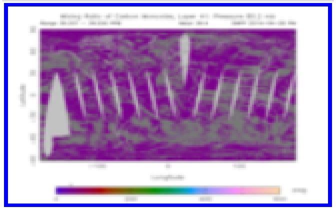
L036: 53.8 mb


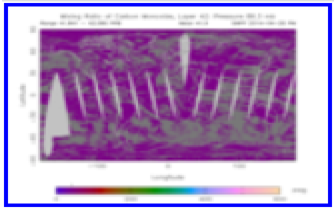
L037: 58.5 mb


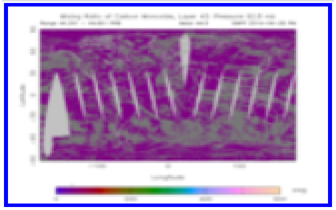
L038: 63.5 mb


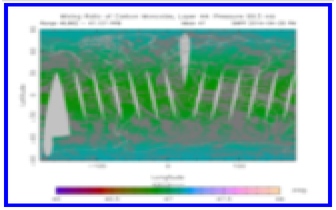
L039: 68.8 mb


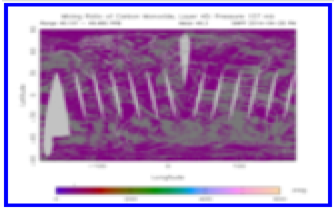
L040: 74.4 mb


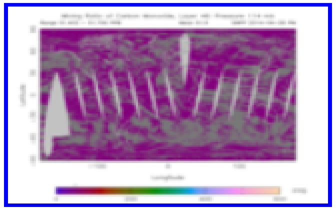
L041: 80.2 mb


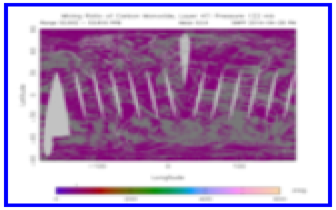
L042: 86.3 mb


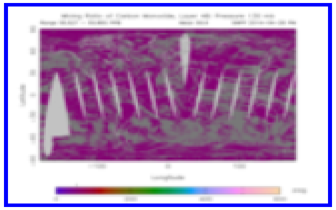
L043: 92.8 mb


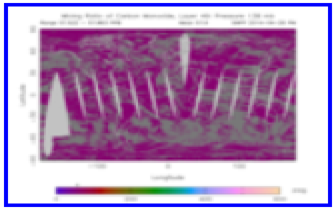
L044: 99.5 mb


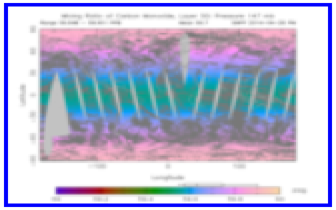
L045: 107 mb


L046: 114 mb


L047: 122 mb


L048: 130 mb


L049: 138 mb


L050: 147 mb


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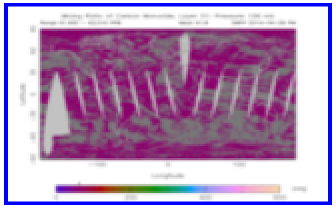
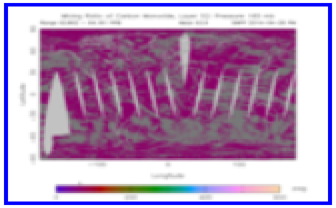
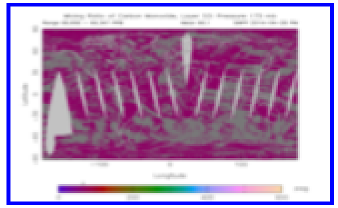
L051: 156 mb



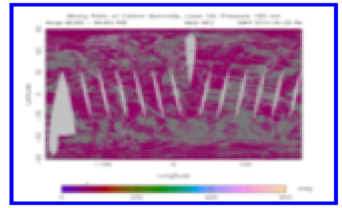
L052: 165 mb



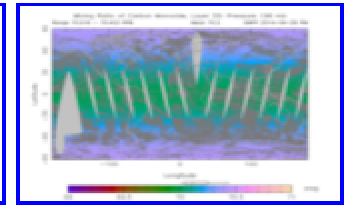
L053: 175 mb



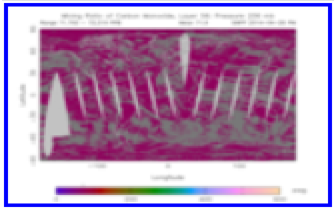
L054: 185 mb



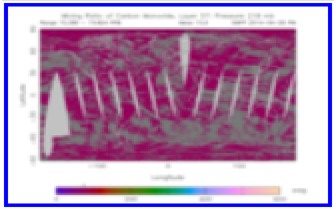
L055: 196 mb



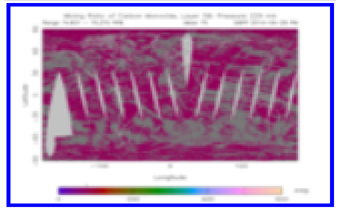
L056: 206 mb



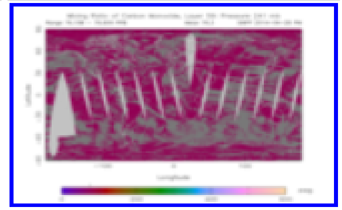
L057: 218 mb



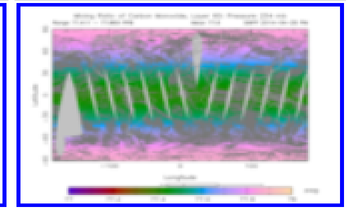
L058: 229 mb



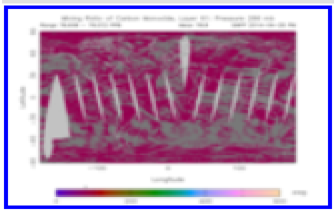
L059: 241 mb



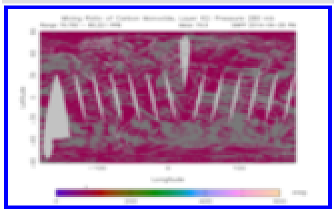
L060: 254 mb



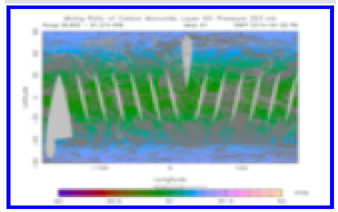
L061: 266 mb



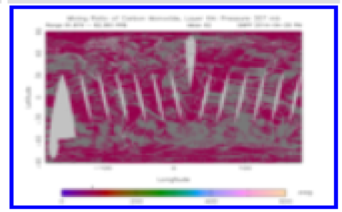
L062: 280 mb



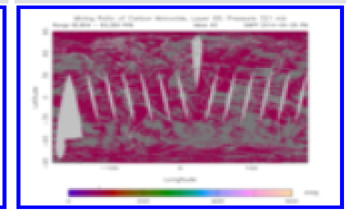
L063: 293 mb



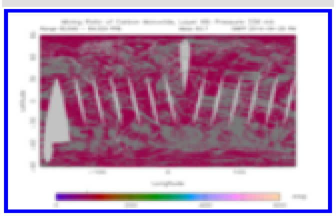
L064: 307 mb



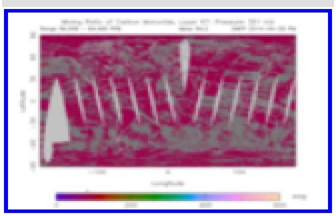
L065: 321 mb



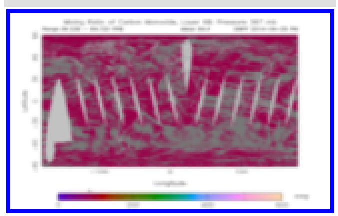
L066: 336 mb



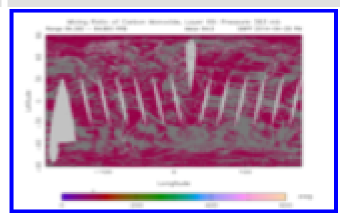
L067: 351 mb



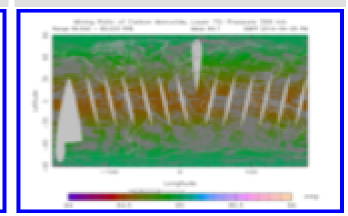
L068: 367 mb



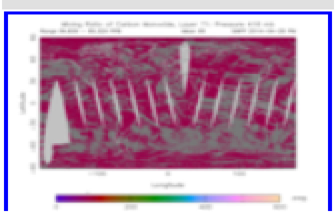
L069: 383 mb



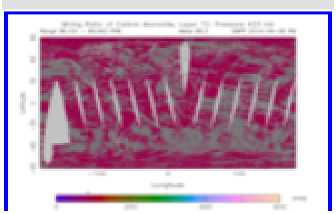
L070: 399 mb



L071: 416 mb



L072: 433 mb



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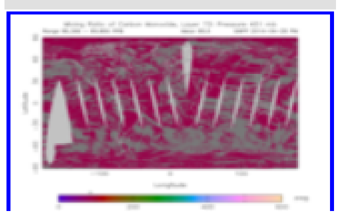
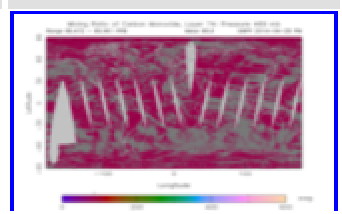
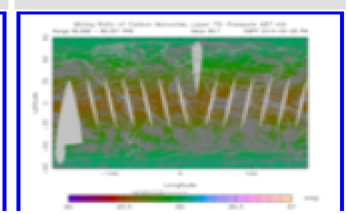


L074: 469 mb



L075: 487 mb



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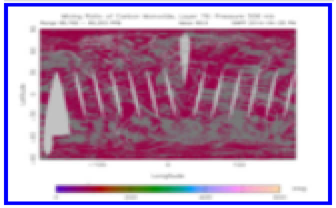
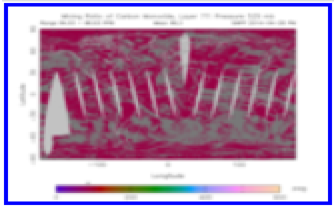
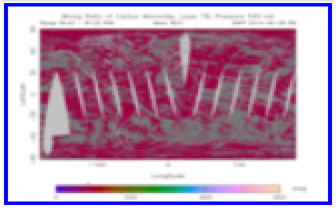
L076: 506 mb



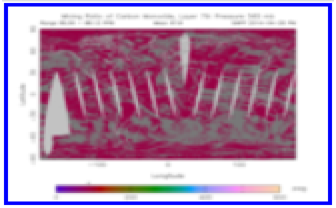
L077: 525 mb



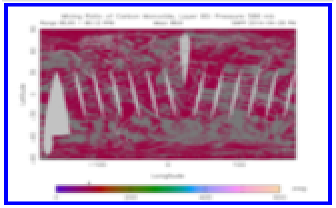
L078: 545 mb



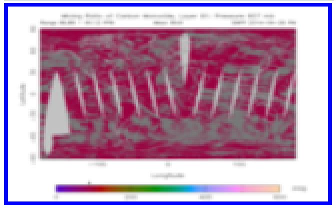
L079: 565 mb



L080: 586 mb



L081: 607 mb



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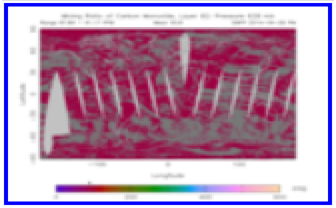
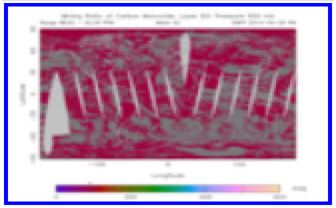
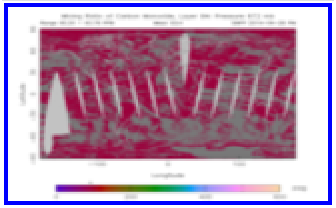


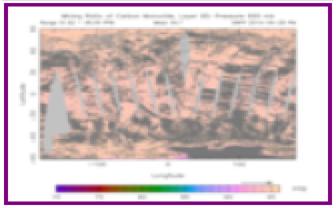
L083: 650 mb



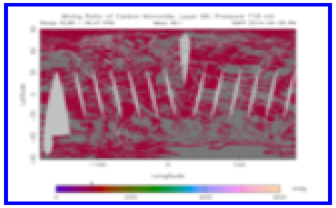
L084: 672 mb



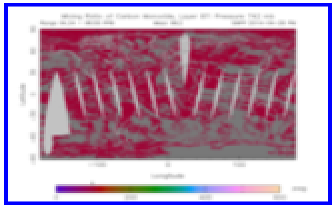
L085: 695 mb



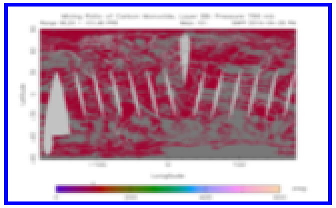
L086: 718 mb



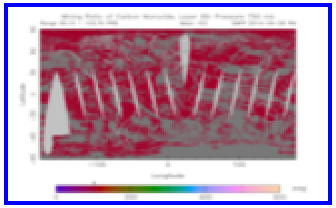
L087: 742 mb



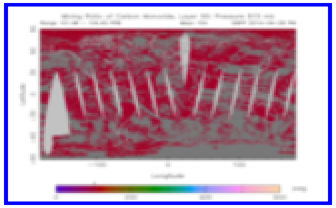
L088: 766 mb



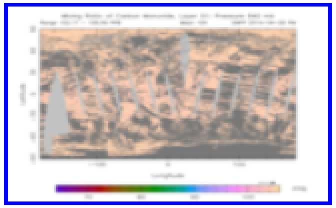
L089: 790 mb



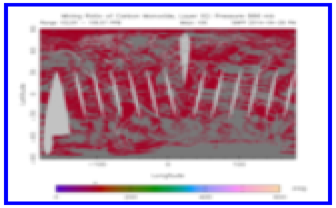
L090: 815 mb



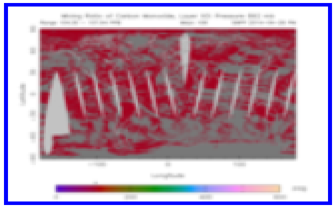
L091: 840 mb



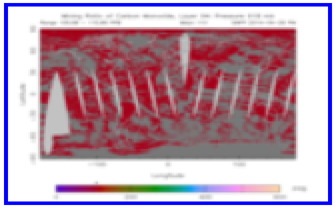
L092: 866 mb



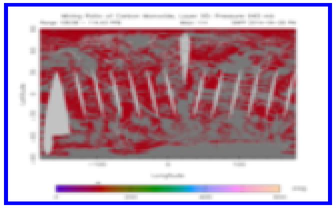
L093: 892 mb



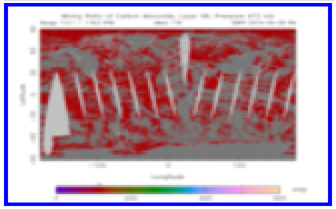
L094: 918 mb



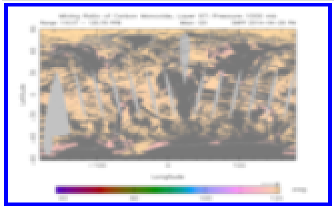
L095: 945 mb



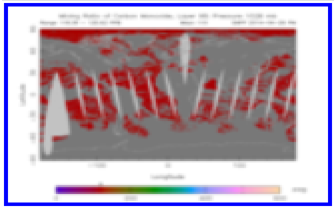
L096: 972 mb



L097: 1000 mb



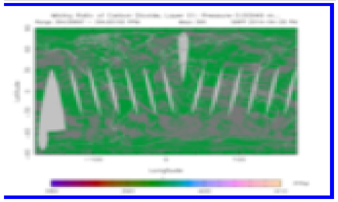
L098: 1028 mb



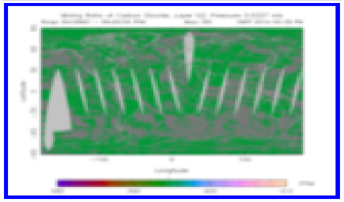
Mixing Ratio of Carbon Dioxide Images for 2014-04-26 PM - SNPP

Mixing Ratio of Carbon Dioxide

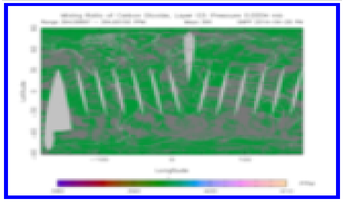
L001: 0.00949 mb



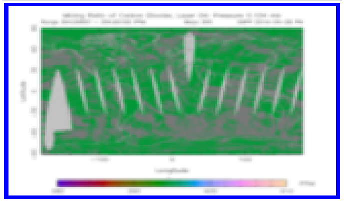
L002: 0.0257 mb



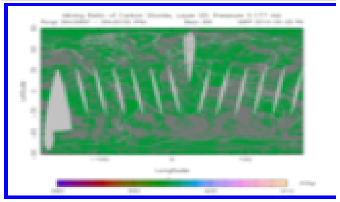
L003: 0.0554 mb



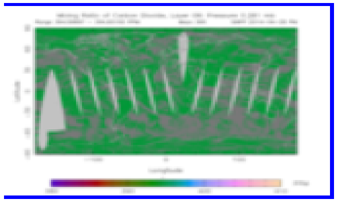
L004: 0.104 mb



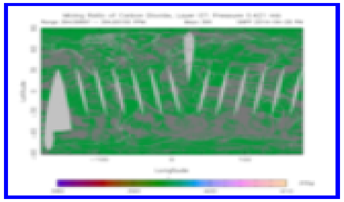
L005: 0.177 mb



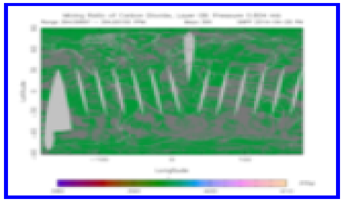
L006: 0.281 mb



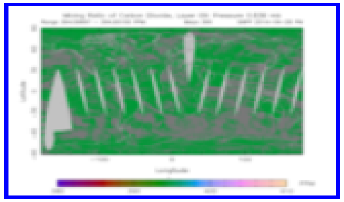
L007: 0.421 mb



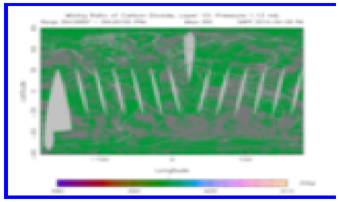
L008: 0.604 mb



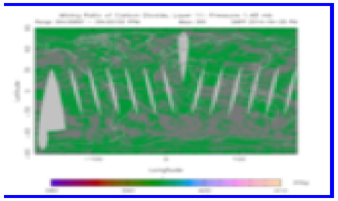
L009: 0.838 mb



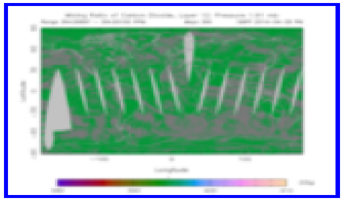
L010: 1.13 mb



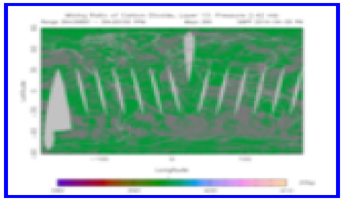
L011: 1.48 mb



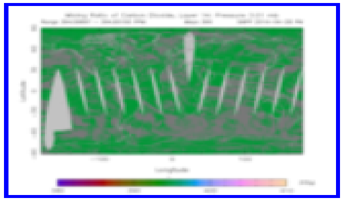
L012: 1.91 mb



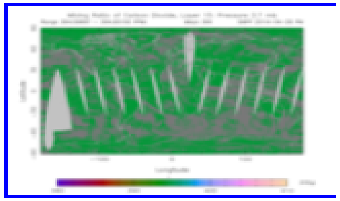
L013: 2.42 mb



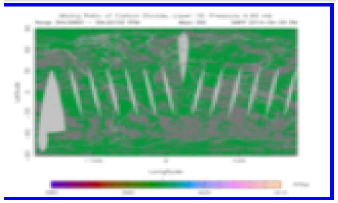
L014: 3.01 mb



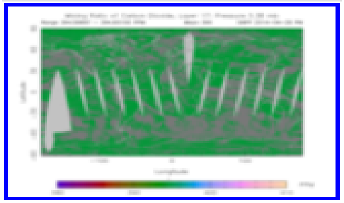
L015: 3.7 mb



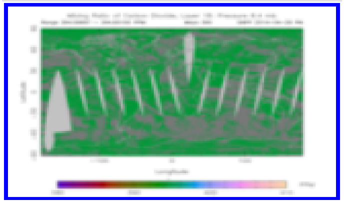
L016: 4.49 mb



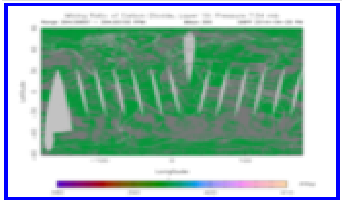
L017: 5.38 mb



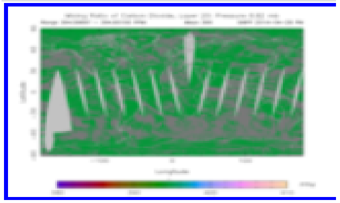
L018: 6.4 mb



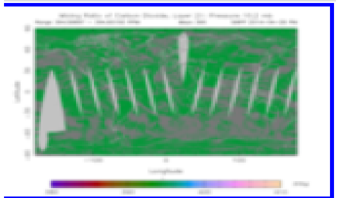
L019: 7.54 mb



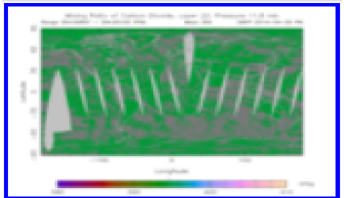
L020: 8.82 mb



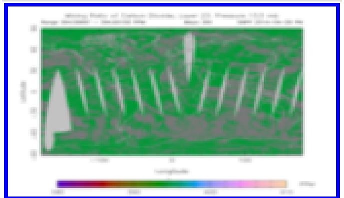
L021: 10.2 mb



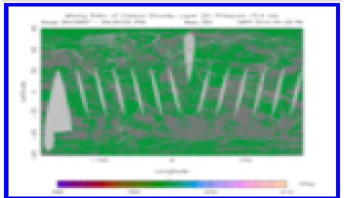
L022: 11.8 mb



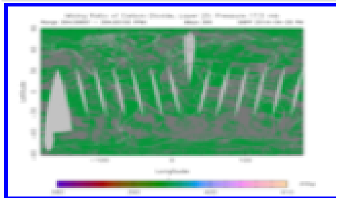
L023: 13.5 mb



L024: 15.4 mb



L025: 17.5 mb



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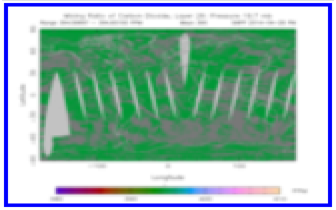
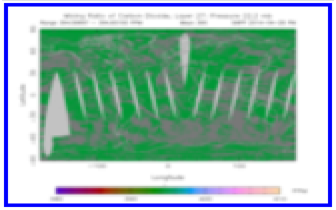
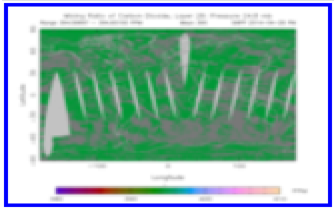
L026: 19.7 mb



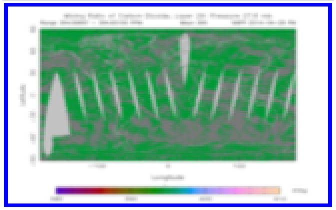
L027: 22.2 mb



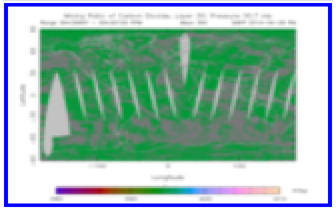
L028: 24.8 mb



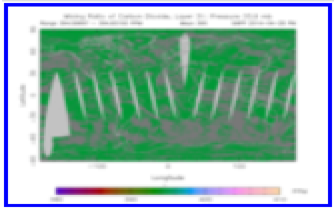
L029: 27.6 mb



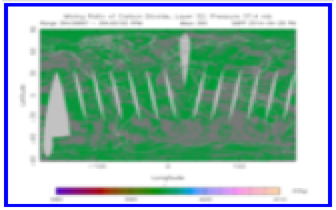
L030: 30.7 mb



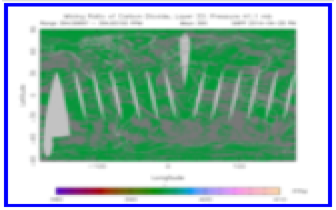
L031: 33.9 mb



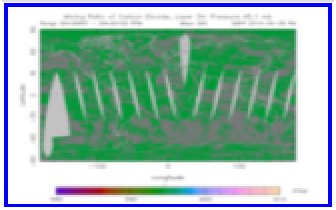
L032: 37.4 mb



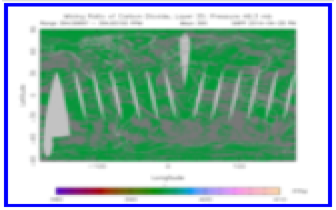
L033: 41.1 mb



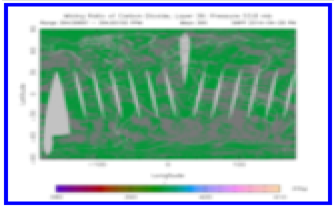
L034: 45.1 mb



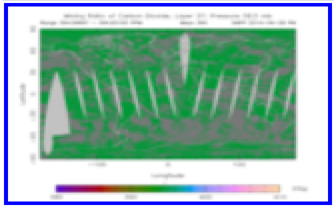
L035: 49.3 mb



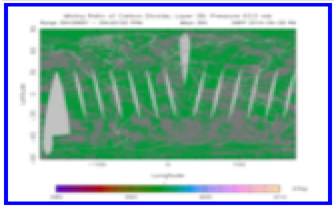
L036: 53.8 mb



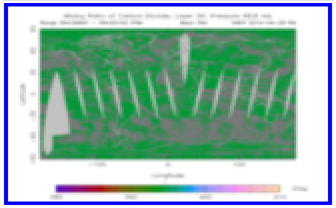
L037: 58.5 mb



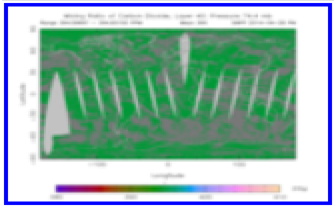
L038: 63.5 mb



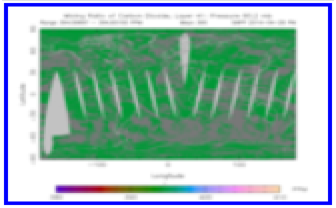
L039: 68.8 mb



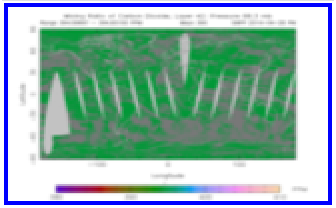
L040: 74.4 mb



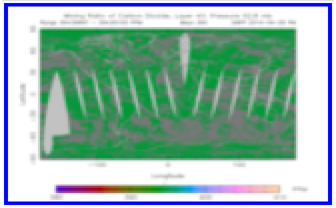
L041: 80.2 mb



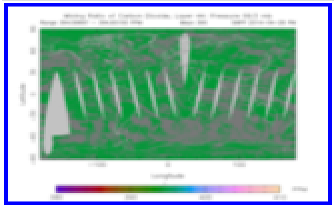
L042: 86.3 mb



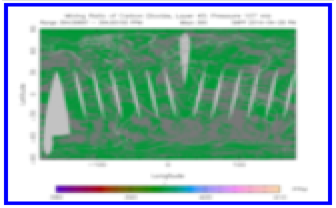
L043: 92.8 mb



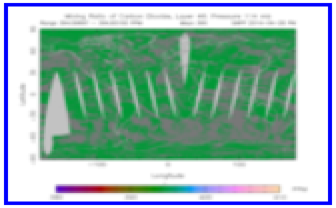
L044: 99.5 mb



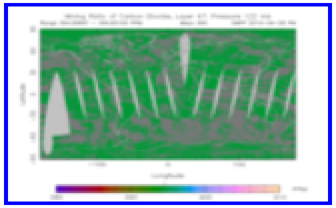
L045: 107 mb



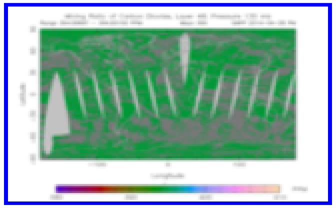
L046: 114 mb



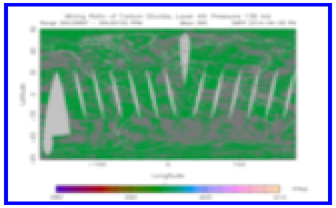
L047: 122 mb



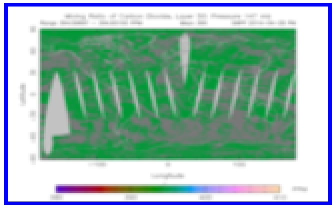
L048: 130 mb



L049: 138 mb



L050: 147 mb



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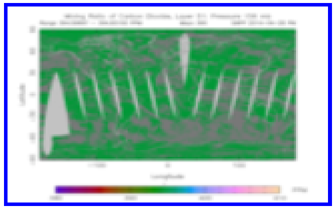
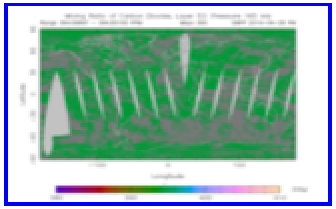
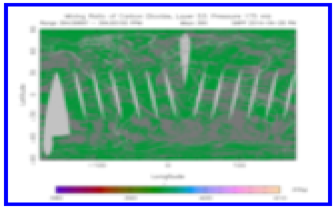
L051: 156 mb



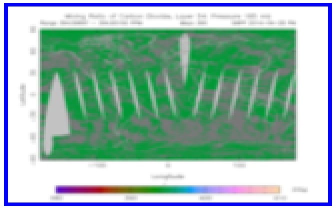
L052: 165 mb



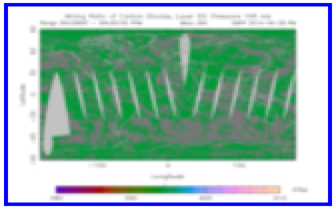
L053: 175 mb



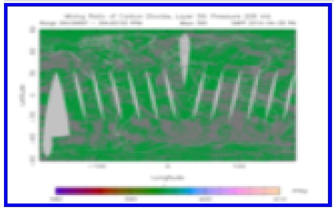
L054: 185 mb



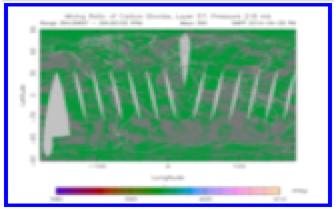
L055: 196 mb



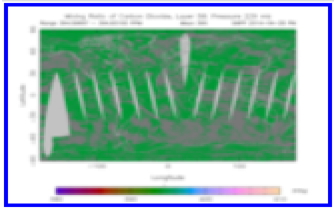
L056: 206 mb



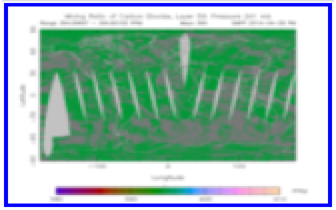
L057: 218 mb



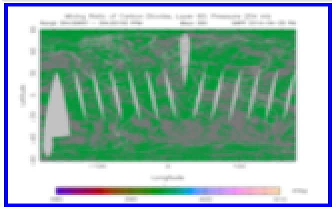
L058: 229 mb



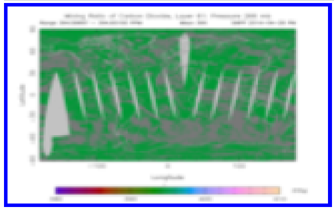
L059: 241 mb



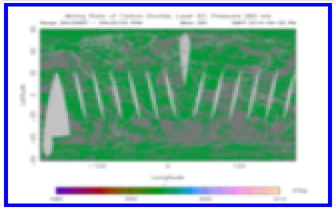
L060: 254 mb



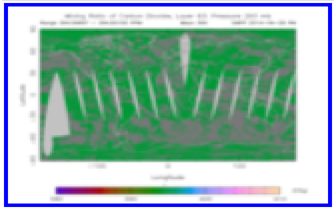
L061: 266 mb



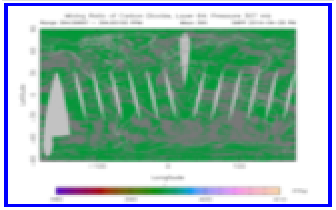
L062: 280 mb



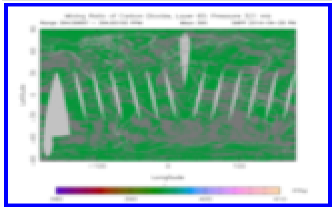
L063: 293 mb



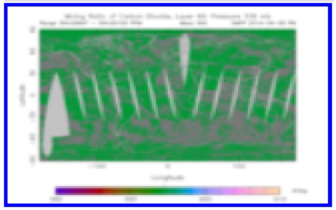
L064: 307 mb



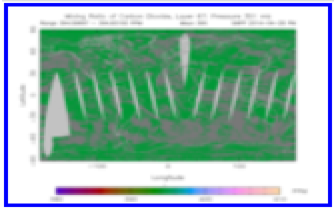
L065: 321 mb



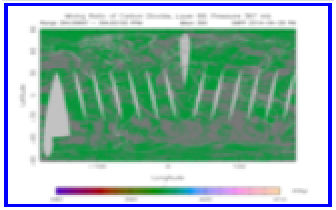
L066: 336 mb



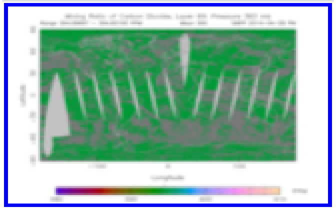
L067: 351 mb



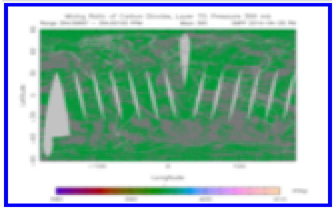
L068: 367 mb



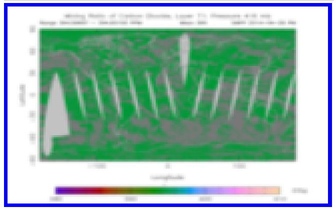
L069: 383 mb



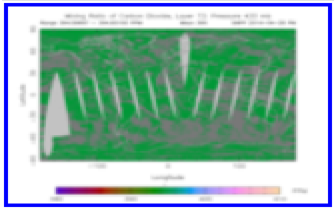
L070: 399 mb



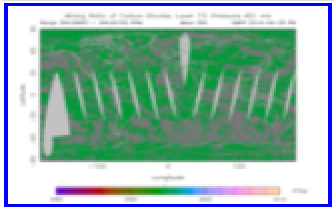
L071: 416 mb



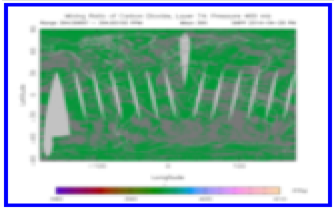
L072: 433 mb



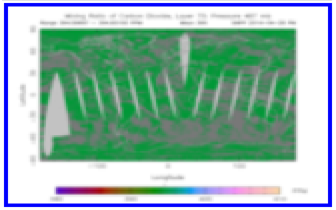
L073: 451 mb



L074: 469 mb

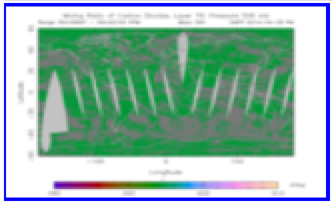


L075: 487 mb

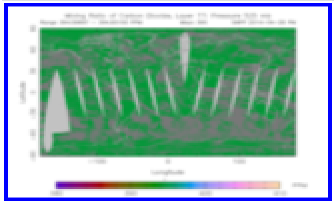


Mixing Ratio of Carbon Dioxide Images for 2014-04-26 PM - SNPP

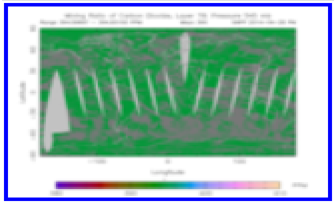
L076: 506 mb



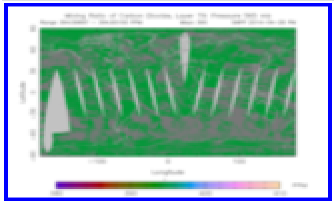
L077: 525 mb



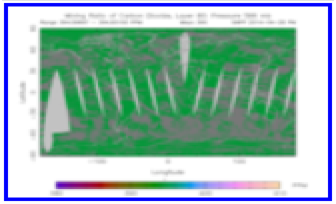
L078: 545 mb



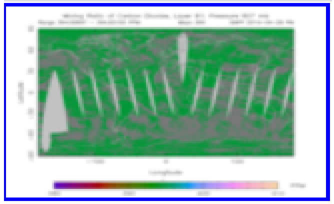
L079: 565 mb



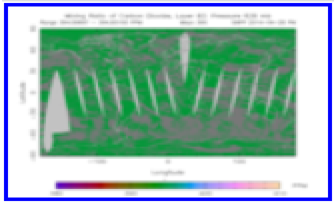
L080: 586 mb



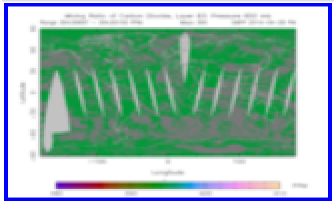
L081: 607 mb



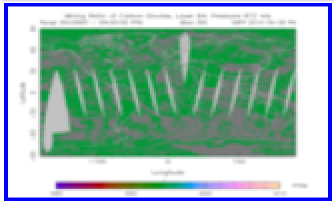
L082: 628 mb



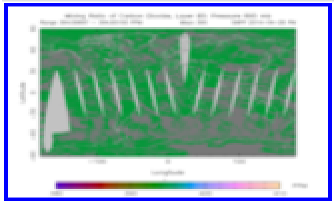
L083: 650 mb



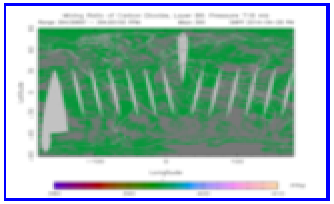
L084: 672 mb



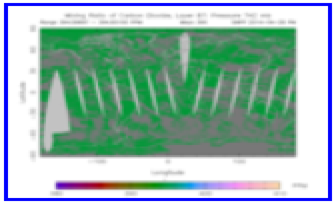
L085: 695 mb



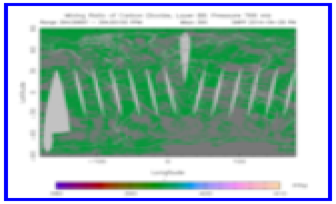
L086: 718 mb



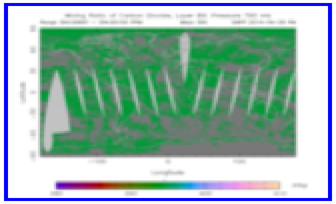
L087: 742 mb



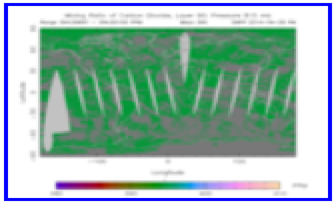
L088: 766 mb



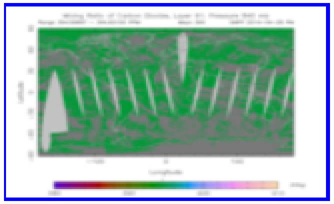
L089: 790 mb



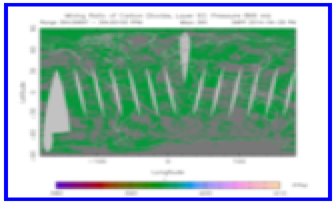
L090: 815 mb



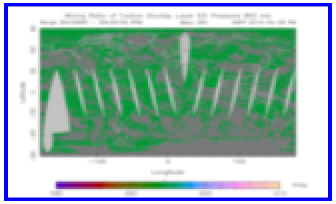
L091: 840 mb



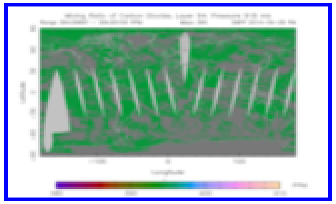
L092: 866 mb



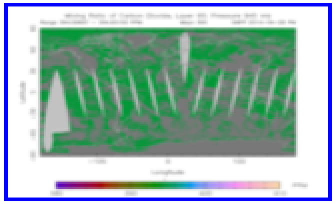
L093: 892 mb



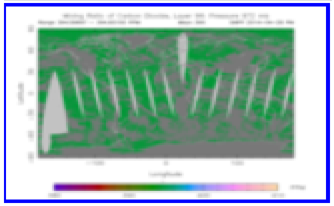
L094: 918 mb



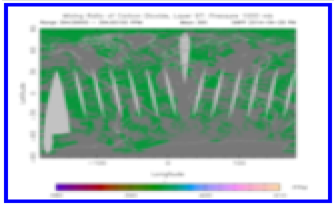
L095: 945 mb



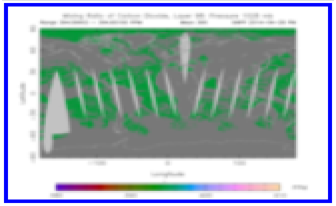
L096: 972 mb



L097: 1000 mb



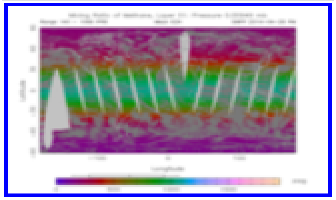
L098: 1028 mb



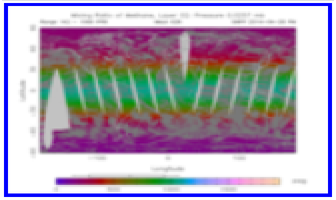
Mixing Ratio of Methane Images for 2014-04-26 PM - SNPP

Mixing Ratio of Methane

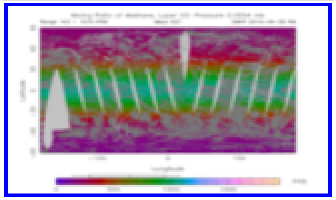
L001: 0.00949 mb



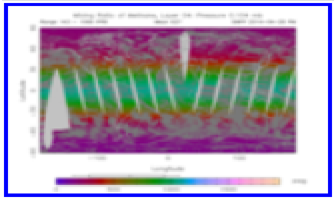
L002: 0.0257 mb



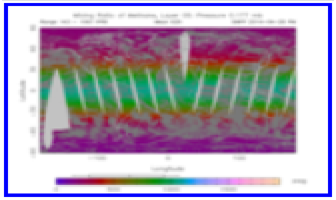
L003: 0.0554 mb



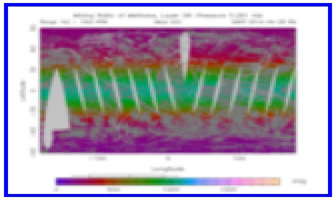
L004: 0.104 mb



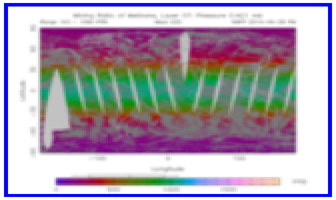
L005: 0.177 mb



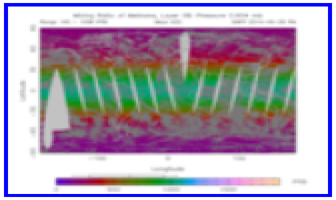
L006: 0.281 mb



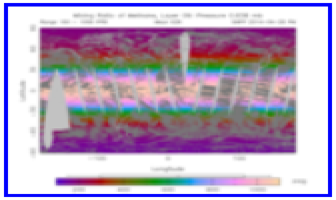
L007: 0.421 mb



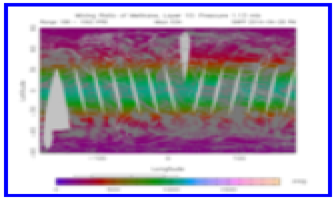
L008: 0.604 mb



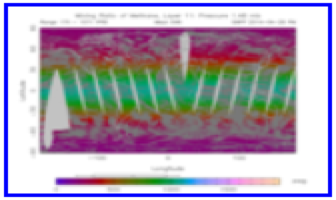
L009: 0.838 mb



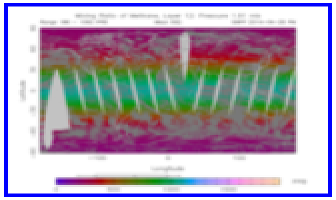
L010: 1.13 mb



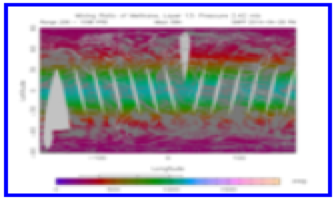
L011: 1.48 mb



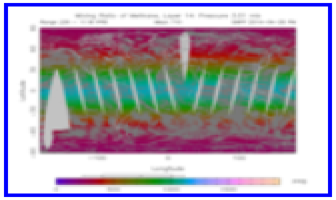
L012: 1.91 mb



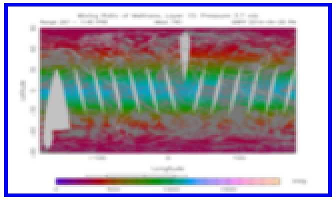
L013: 2.42 mb



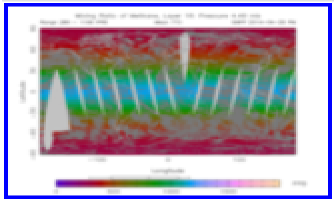
L014: 3.01 mb



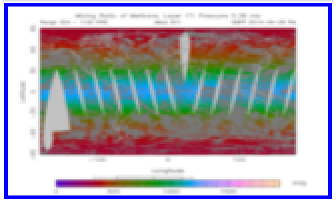
L015: 3.7 mb



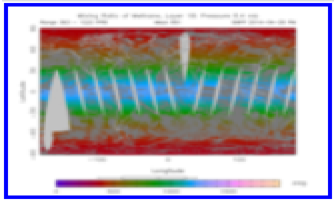
L016: 4.49 mb



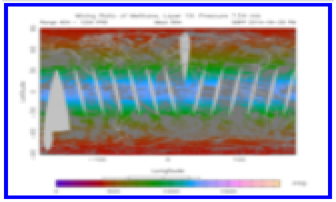
L017: 5.38 mb



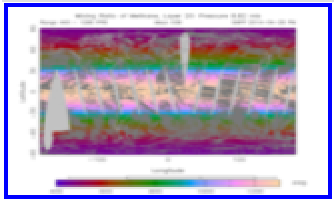
L018: 6.4 mb



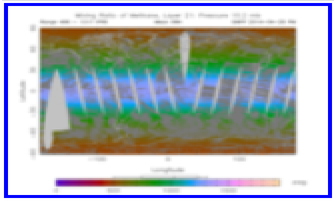
L019: 7.54 mb



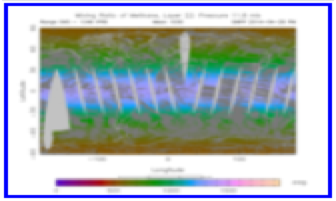
L020: 8.82 mb



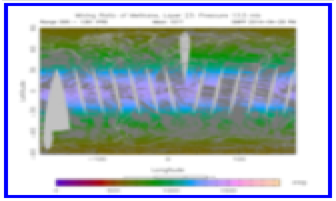
L021: 10.2 mb



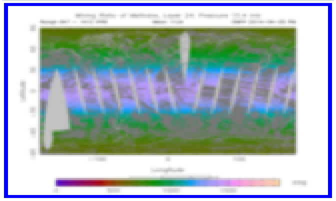
L022: 11.8 mb



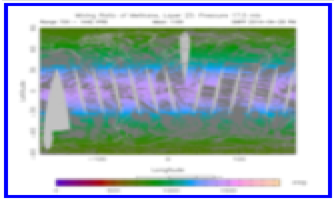
L023: 13.5 mb



L024: 15.4 mb

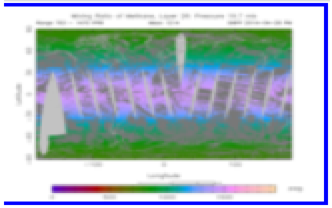


L025: 17.5 mb

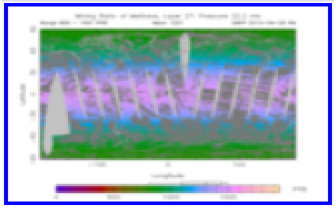


Mixing Ratio of Methane Images for 2014-04-26 PM - SNPP

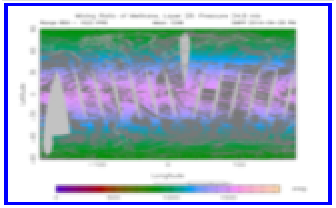
L026: 19.7 mb



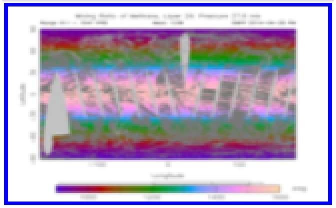
L027: 22.2 mb



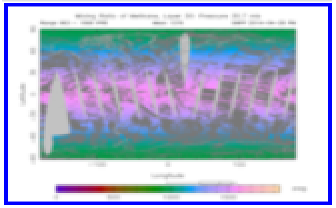
L028: 24.8 mb



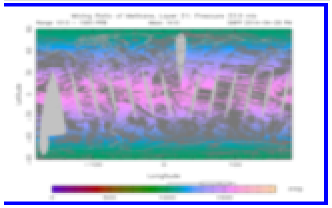
L029: 27.6 mb



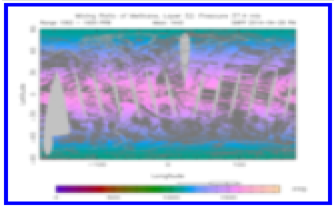
L030: 30.7 mb



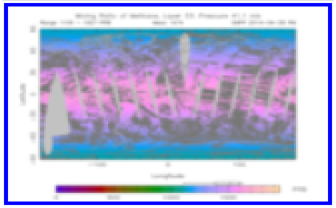
L031: 33.9 mb



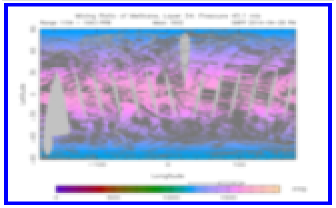
L032: 37.4 mb



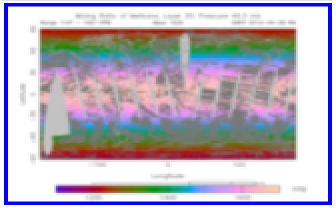
L033: 41.1 mb



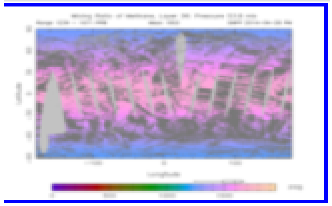
L034: 45.1 mb



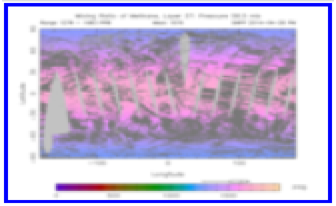
L035: 49.3 mb



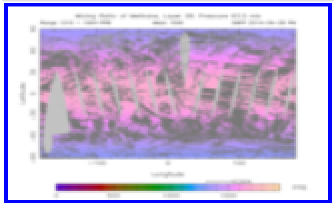
L036: 53.8 mb



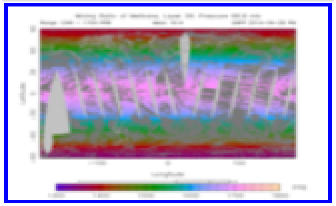
L037: 58.5 mb



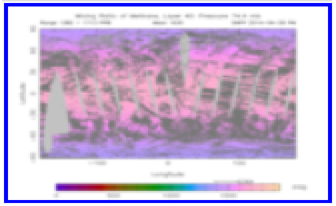
L038: 63.5 mb



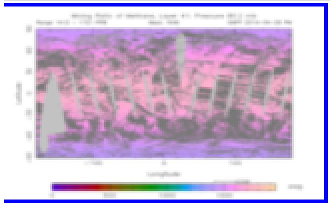
L039: 68.8 mb



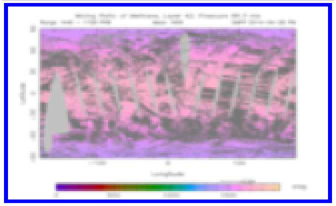
L040: 74.4 mb



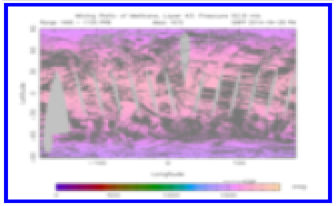
L041: 80.2 mb



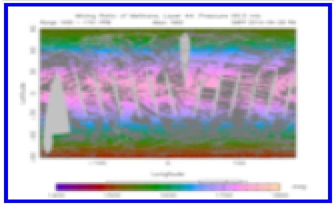
L042: 86.3 mb



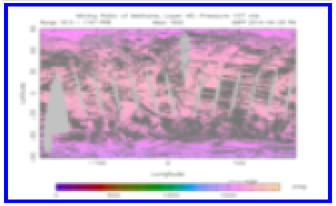
L043: 92.8 mb



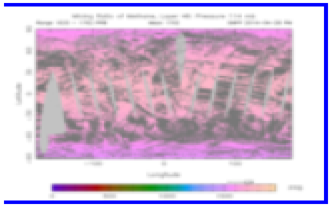
L044: 99.5 mb



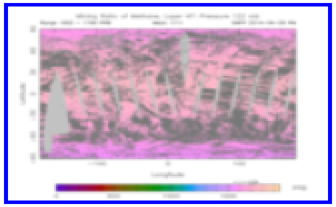
L045: 107 mb



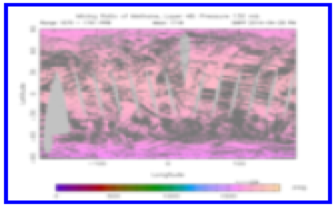
L046: 114 mb



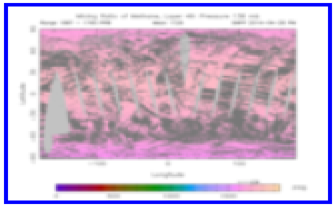
L047: 122 mb



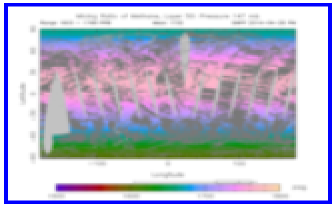
L048: 130 mb



L049: 138 mb



L050: 147 mb



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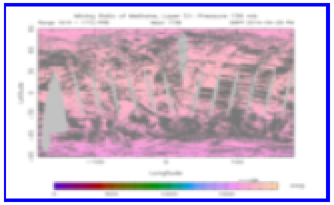
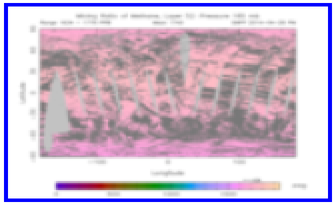
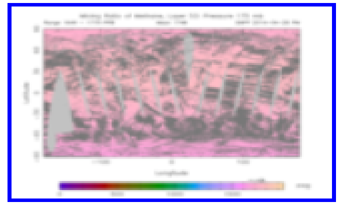
L051: 156 mb



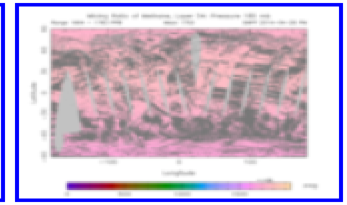
L052: 165 mb



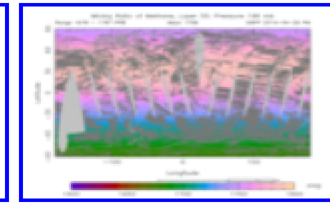
L053: 175 mb



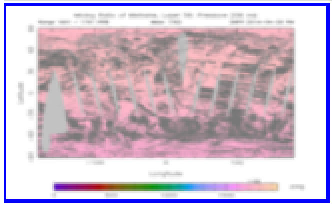
L054: 185 mb



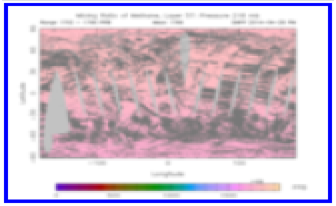
L055: 196 mb



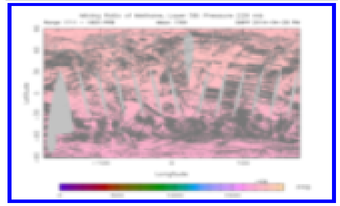
L056: 206 mb



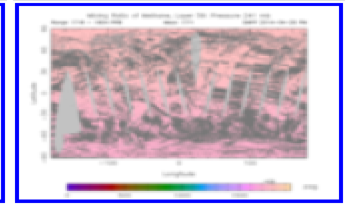
L057: 218 mb



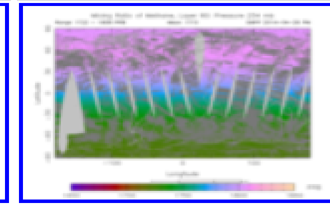
L058: 229 mb



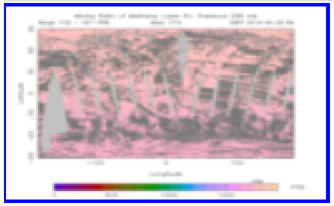
L059: 241 mb



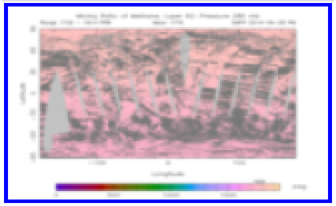
L060: 254 mb



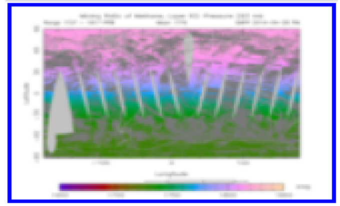
L061: 266 mb



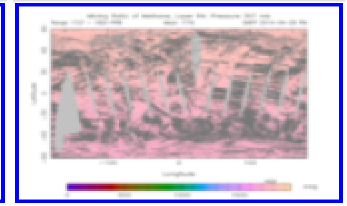
L062: 280 mb



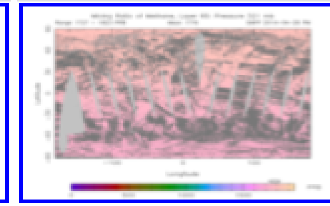
L063: 293 mb



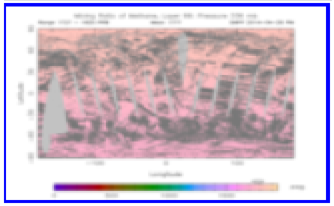
L064: 307 mb



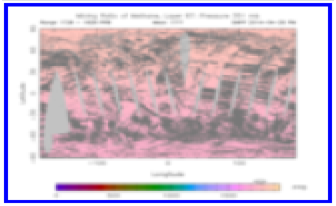
L065: 321 mb



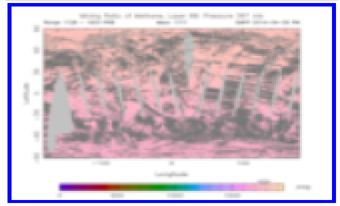
L066: 336 mb



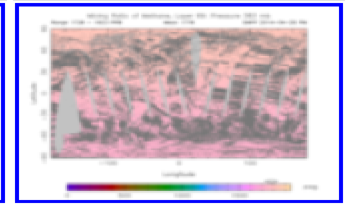
L067: 351 mb



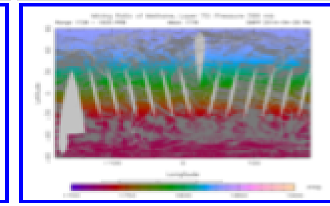
L068: 367 mb



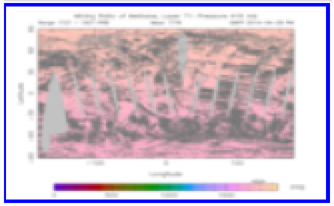
L069: 383 mb



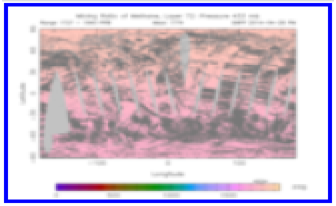
L070: 399 mb



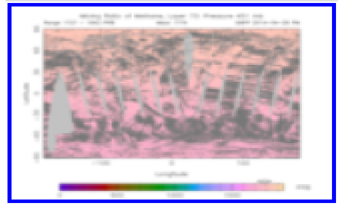
L071: 416 mb



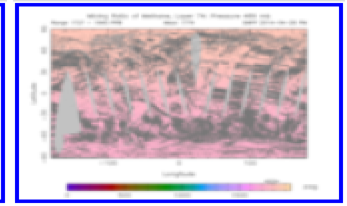
L072: 433 mb



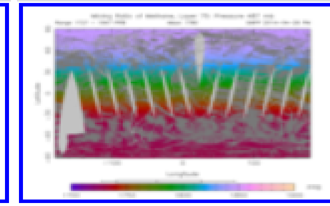
L073: 451 mb



L074: 469 mb



L075: 487 mb



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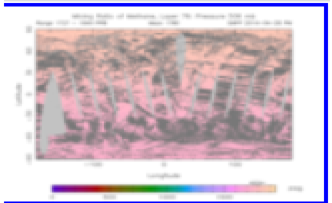
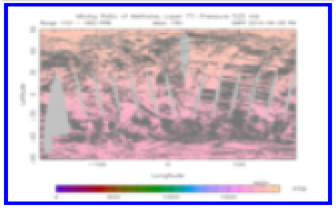
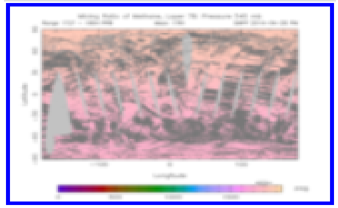
L076: 506 mb



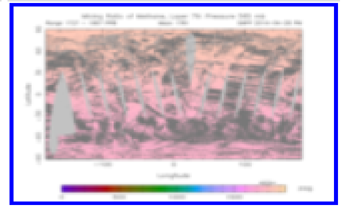
L077: 525 mb



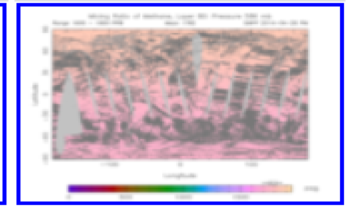
L078: 545 mb



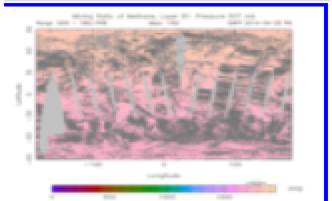
L079: 565 mb



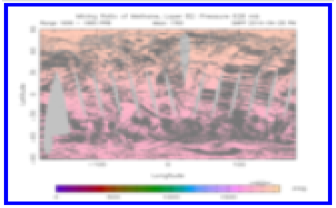
L080: 586 mb



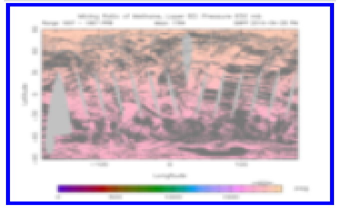
L081: 607 mb



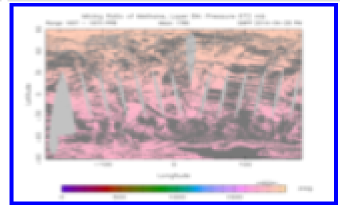
L082: 628 mb



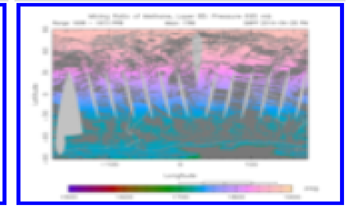
L083: 650 mb



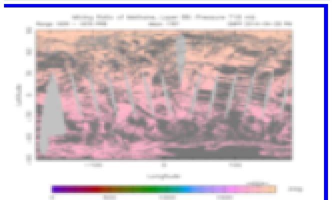
L084: 672 mb



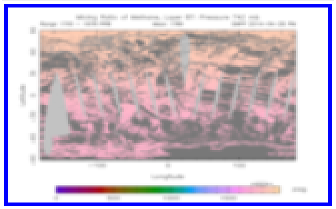
L085: 695 mb



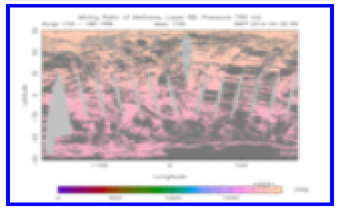
L086: 718 mb



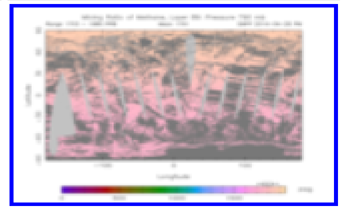
L087: 742 mb



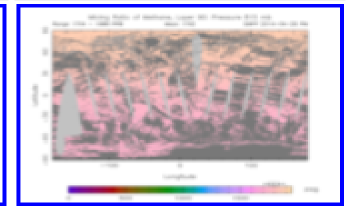
L088: 766 mb



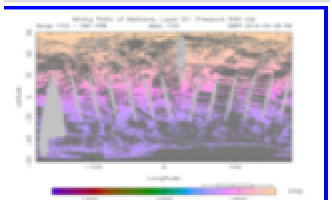
L089: 790 mb



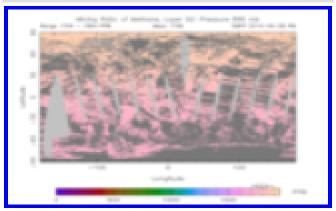
L090: 815 mb



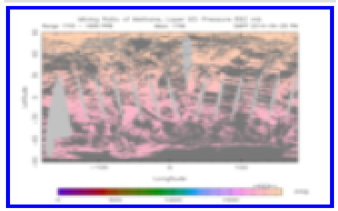
L091: 840 mb



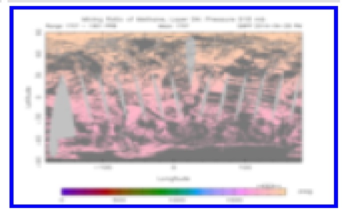
L092: 866 mb



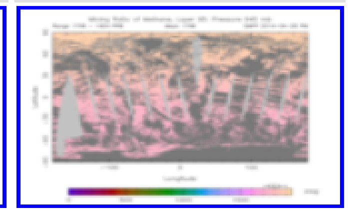
L093: 892 mb



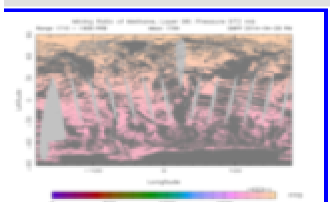
L094: 918 mb



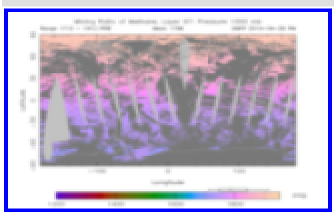
L095: 945 mb



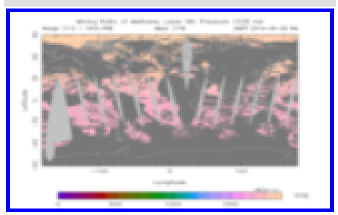
L096: 972 mb



L097: 1000 mb



L098: 1028 mb



NOAA Products Validation System (NPROVS) and NPROVS+

Tony Reale and Mark Liu
Center for Satellite Applications and Research (STAR)

Bomin Sun, Michael Pettey, Frank Tilley, Charles Brown
(IMSG)

Nick Nalli, Flavio Iturbide, Chengyi Tan, Antonia Gambacorta,
Xiaozhen Xiong, Murty Divakarla
(IMSG)

Alternative Title:

Standardized Validation at NOAA STAR

Message

Science is hard enough!

Why bother going through the extra effort of re-inventing the validation datasets again and again?

NPROVS / NPROVS+ does it for you.

Lets all use them!

Outline

- NPROVS
- NPROVS+
- Reference and Dedicated RAOB
- EDRs and SDRs
- Analytic Interface (EDGE)
- Collocation Strategy
- EDR Results
- “K” uncertainty Analysis
- GPSRO

EDR VALIDATION

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

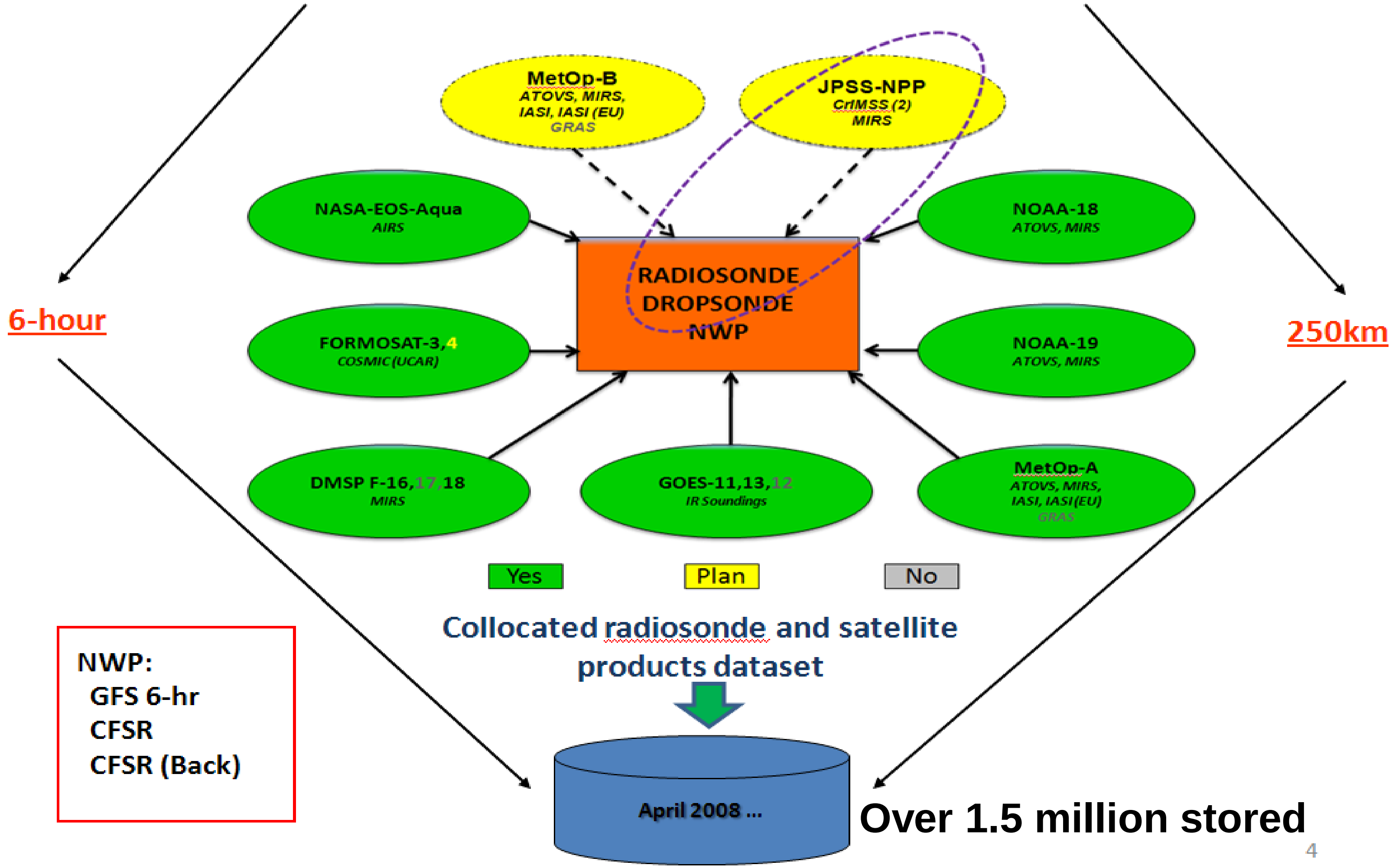
Dataset	Sampling	Characteristics
ECMWF/GFS	Global	±3 hour, model errors, select "Focus Days"
NUCAPS EDR	Global, exact match	NOAA Unique using CrIS/ATMS Significant diagnostic capability
AIRS EDR Products	Global, near exact	NOAA Unique / NASA v6 after April 2013; Orbits are aliased, 16d repeat, different 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)

NOAA Products Validation System (NPROVS)

Centralized Radiosonde and Collocation Processing



Over 1.5 million stored

4

Conventional RAOB

Every Day !!

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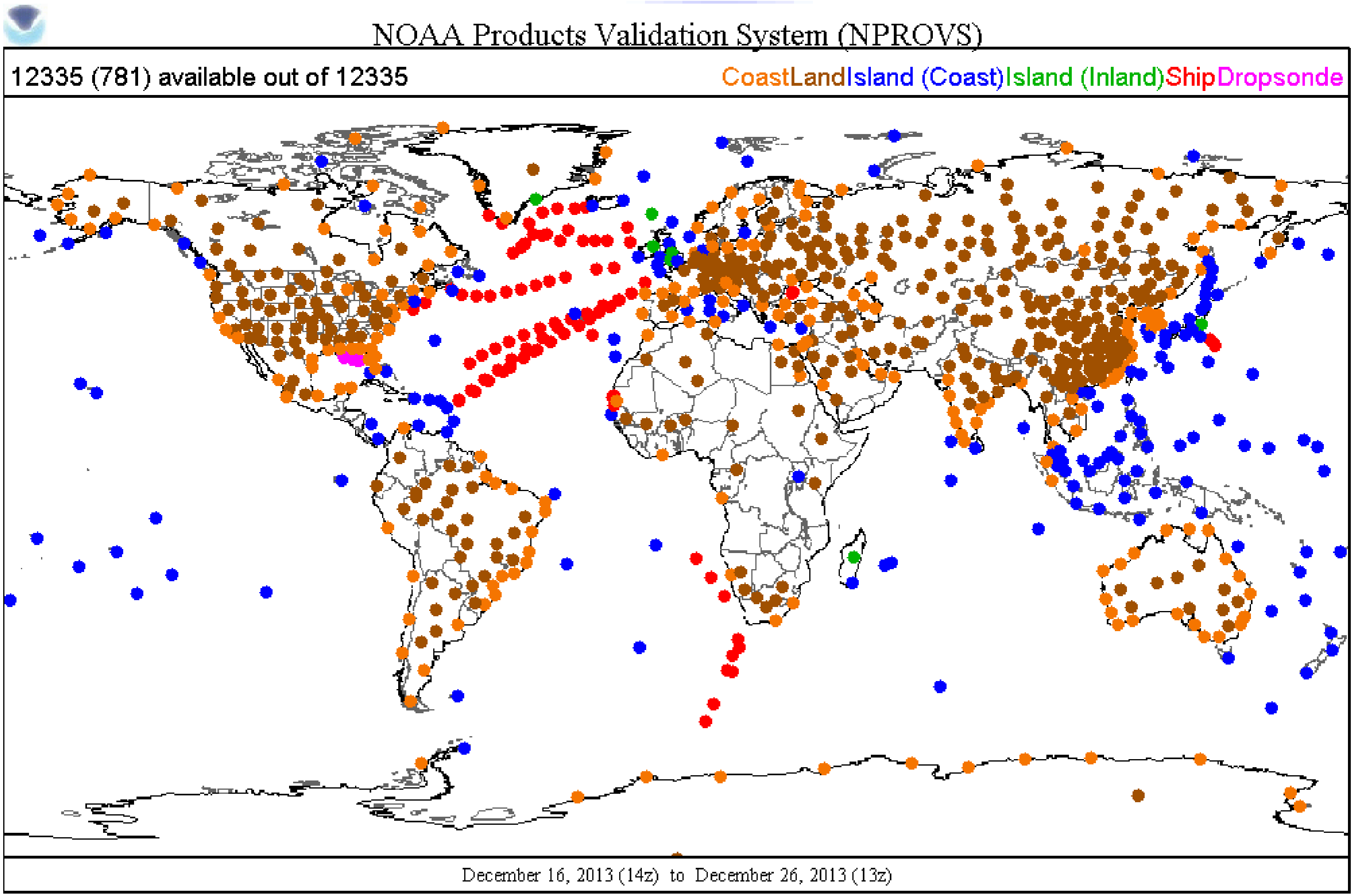
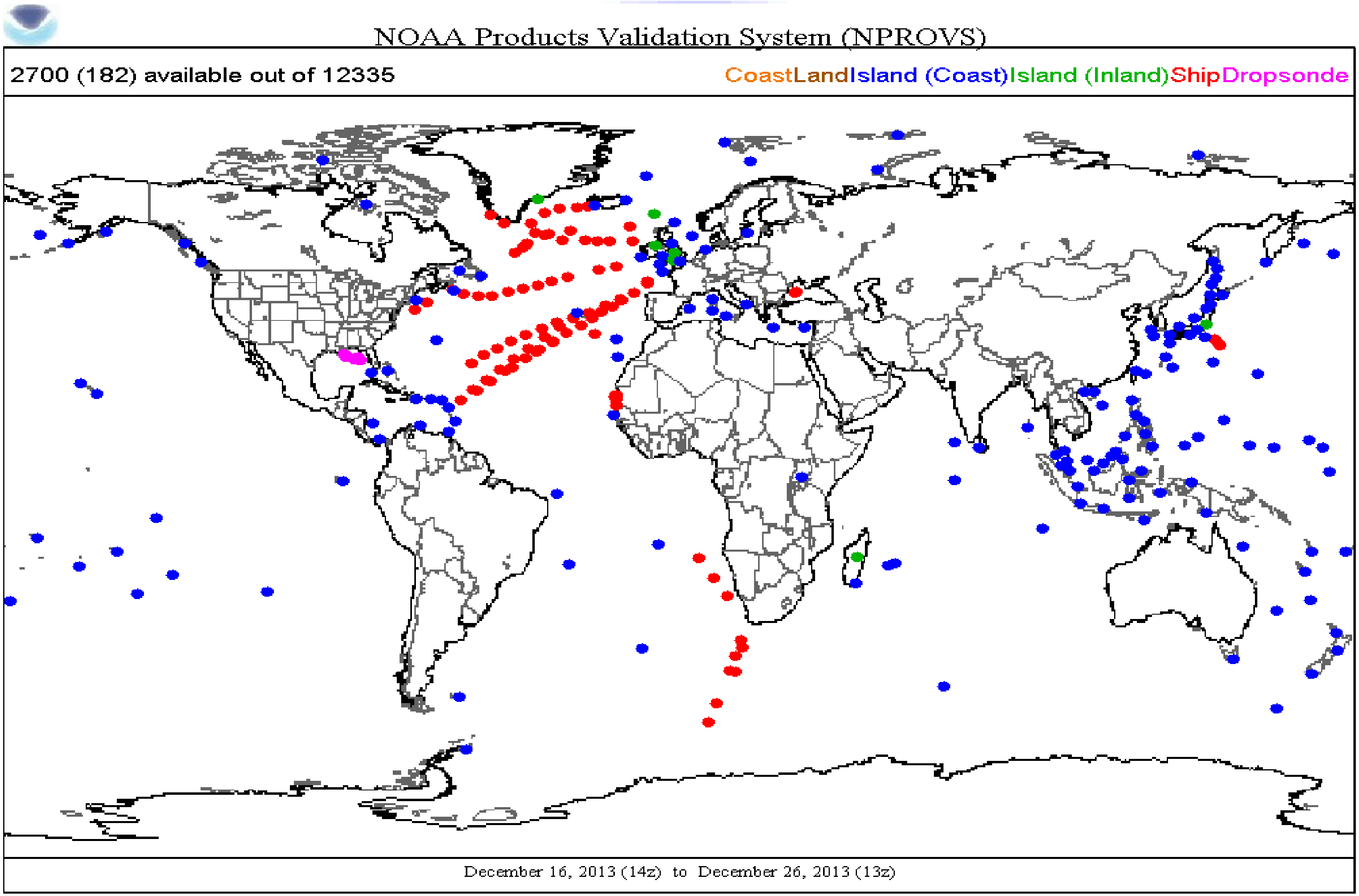
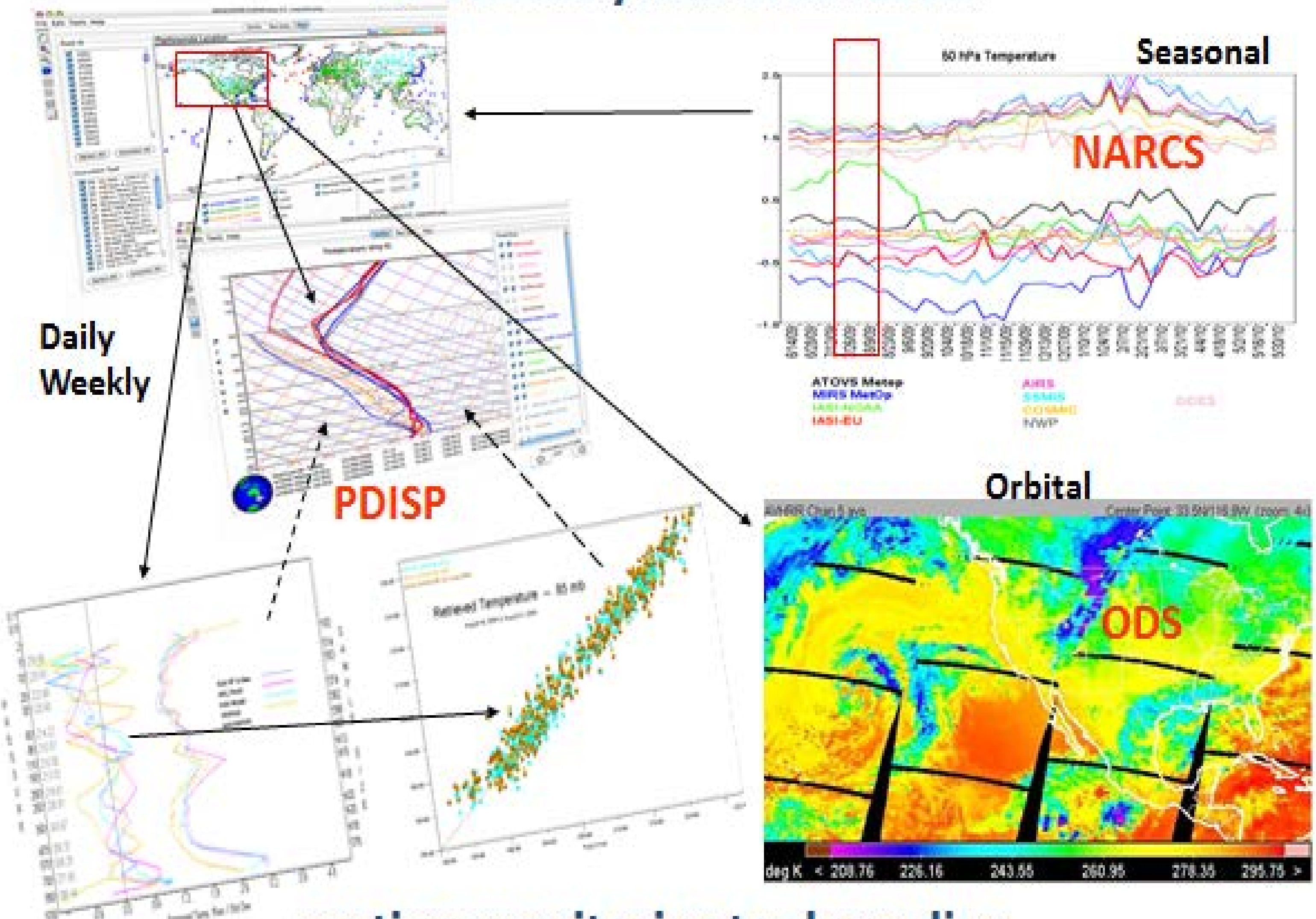


NPROVS Collocations 12/16 to 12/26 2013 … 12,335



Maritime Validation dataset …

EDGE Analytical Interface ...

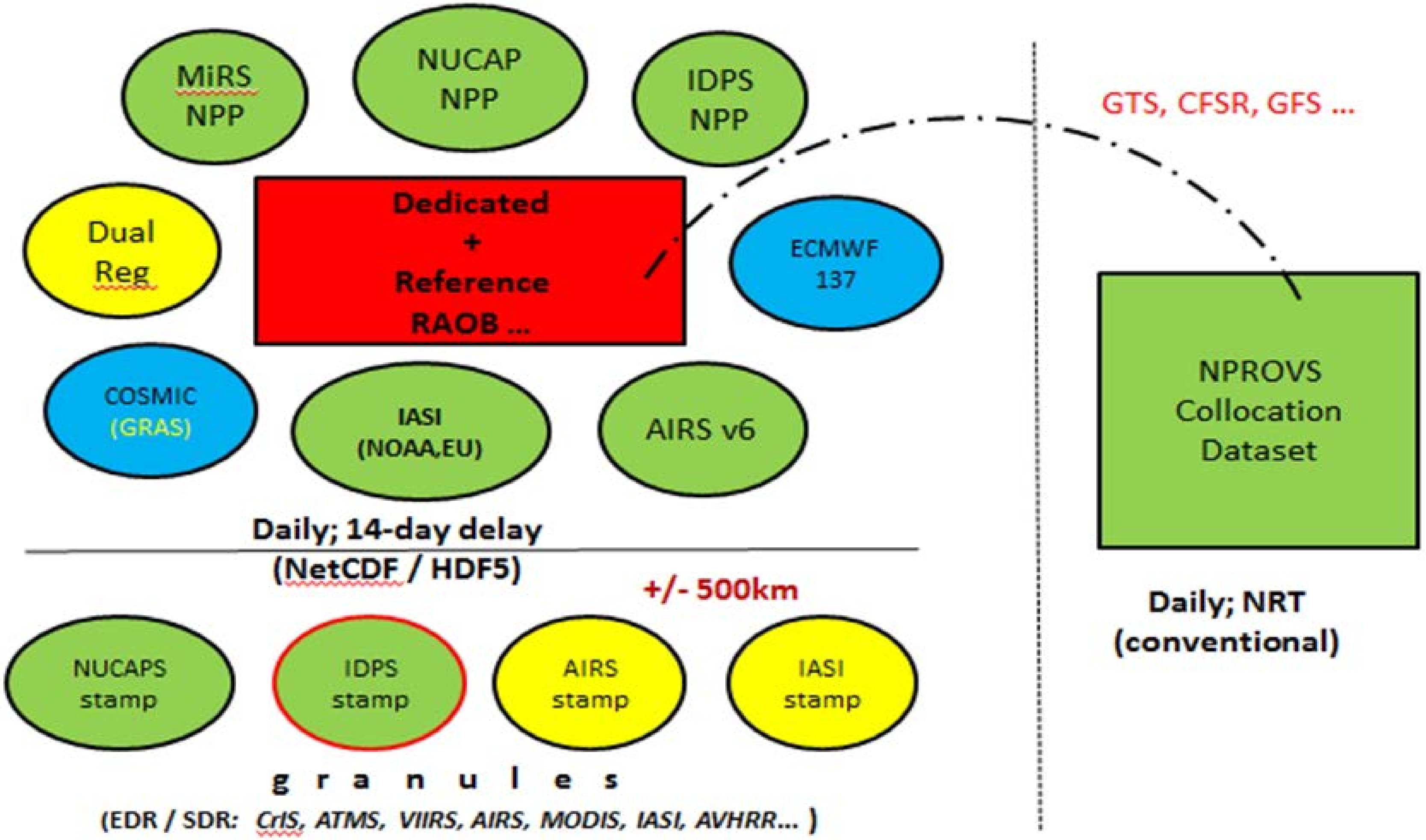


... routine monitoring to deep dive

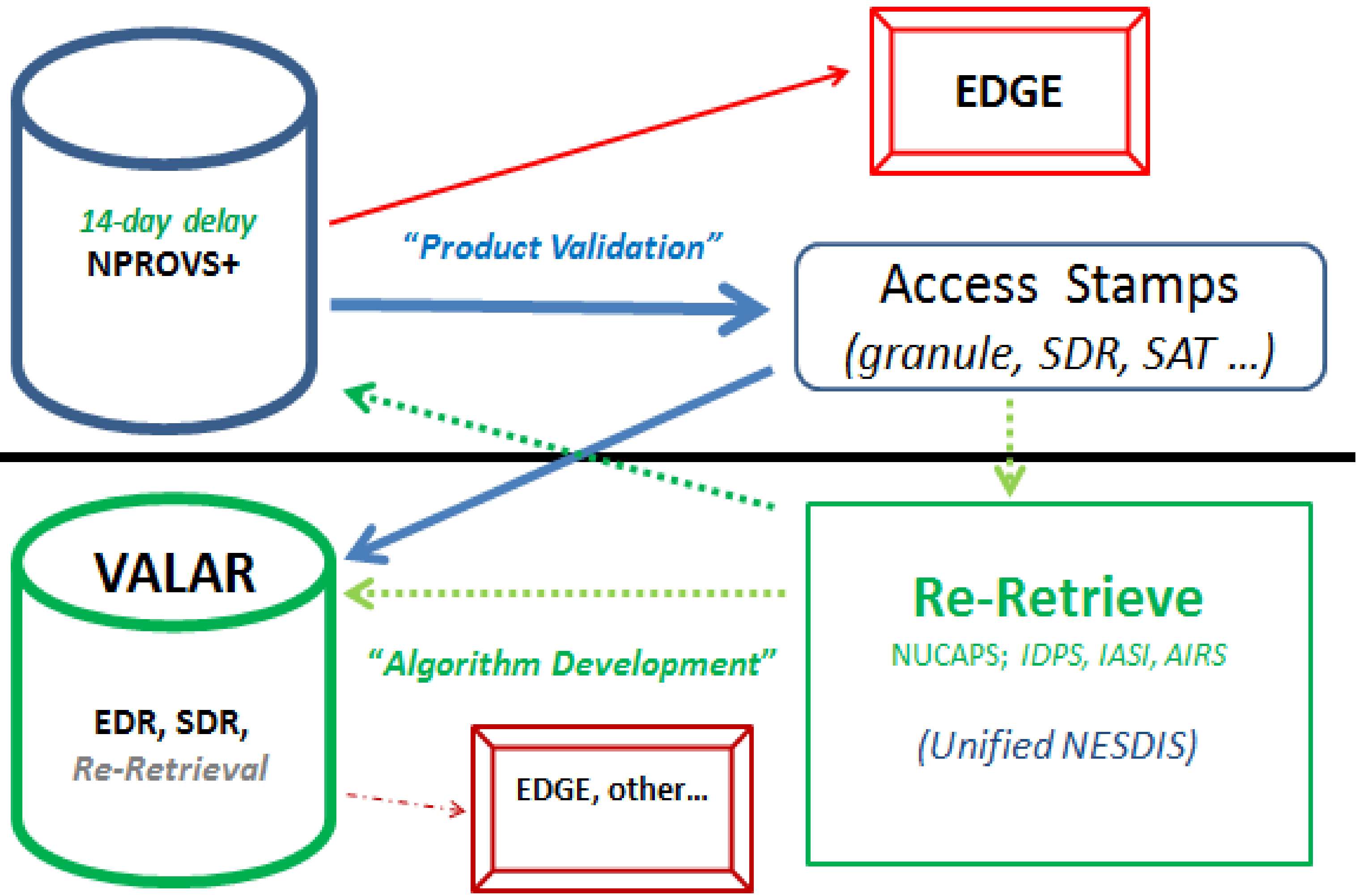
NPROVS web site provides
summary statistics,
validation datasets,
graphical applets (JAVA)
PDISP and **NARCS**

http://www.star.nesdis.noaa.gov/smcd/opdb/nprovs

NOAA Products Validation System + (NPROVS+)



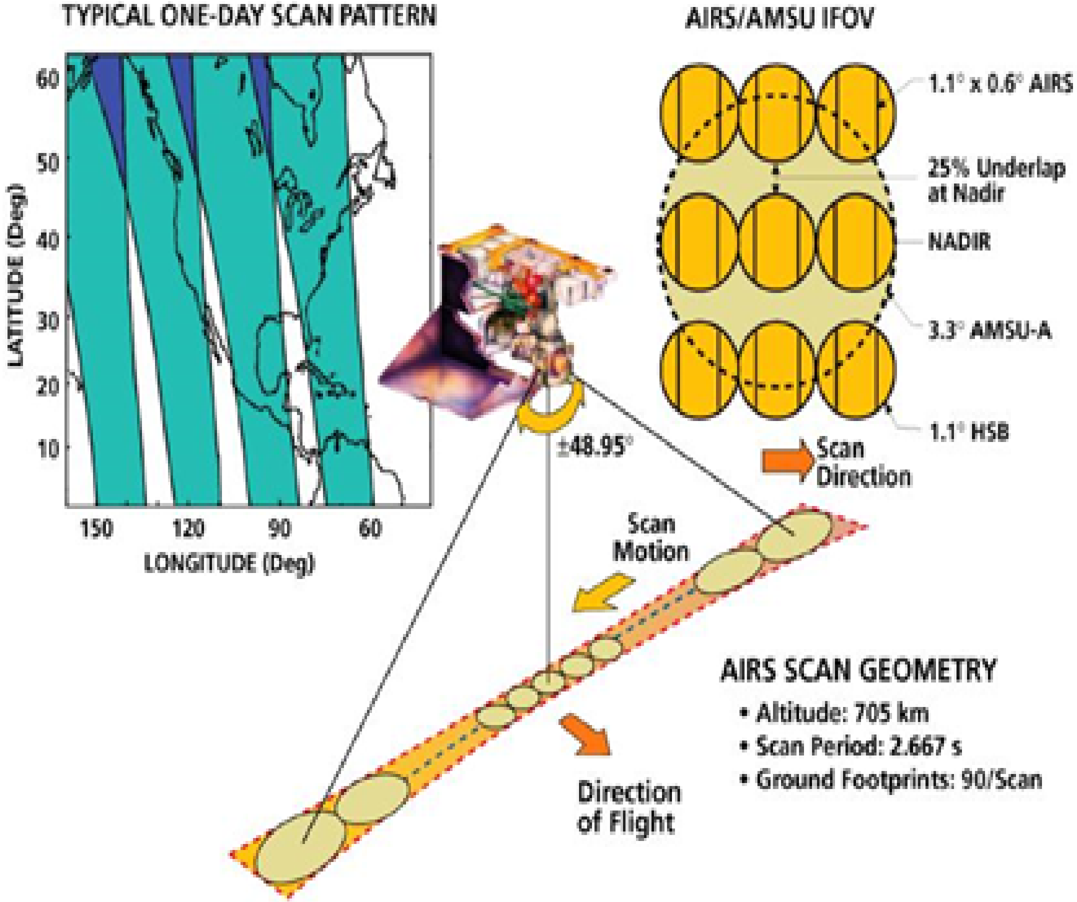
Every Day !!



Unified Validation and Development

Nick Nalli Presentation …

- 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

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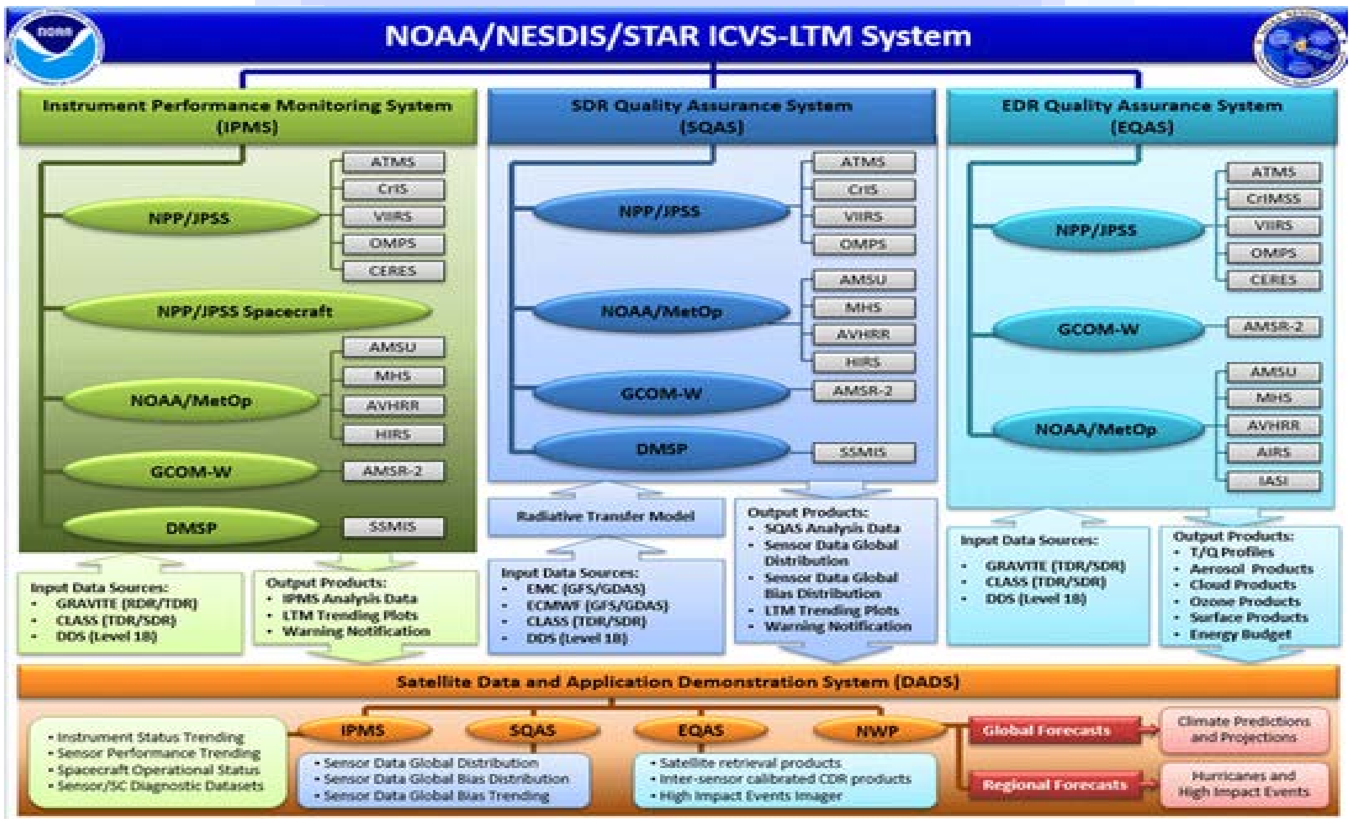
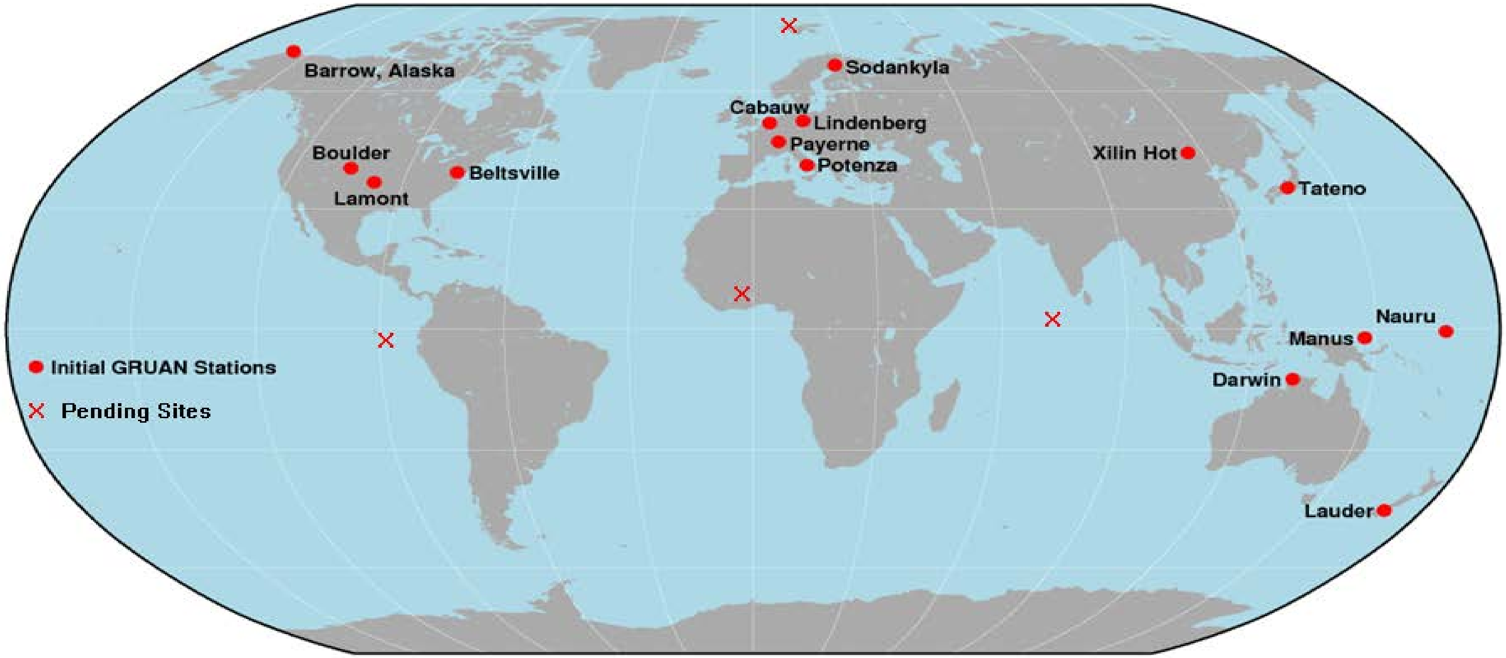


ICVS: Long-Term Sensor Calibration/Validation Monitoring (SDR) from Space
(http://www.star.nesdis.noaa.gov/icvs/index.php)

GCOS "Reference" Upper AIR Network (GRUAN)



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

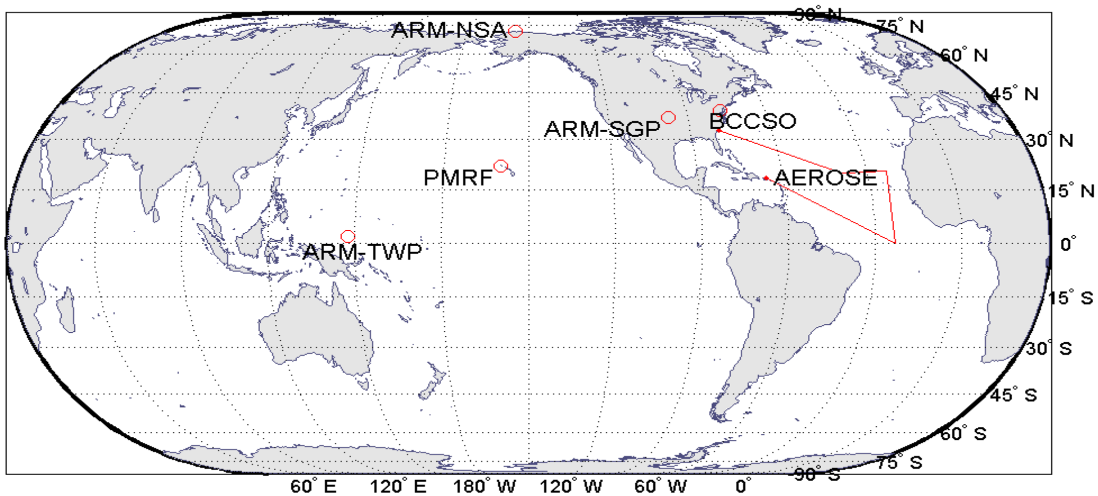
… special Tuesday session on satellite synergies

… 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)

	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

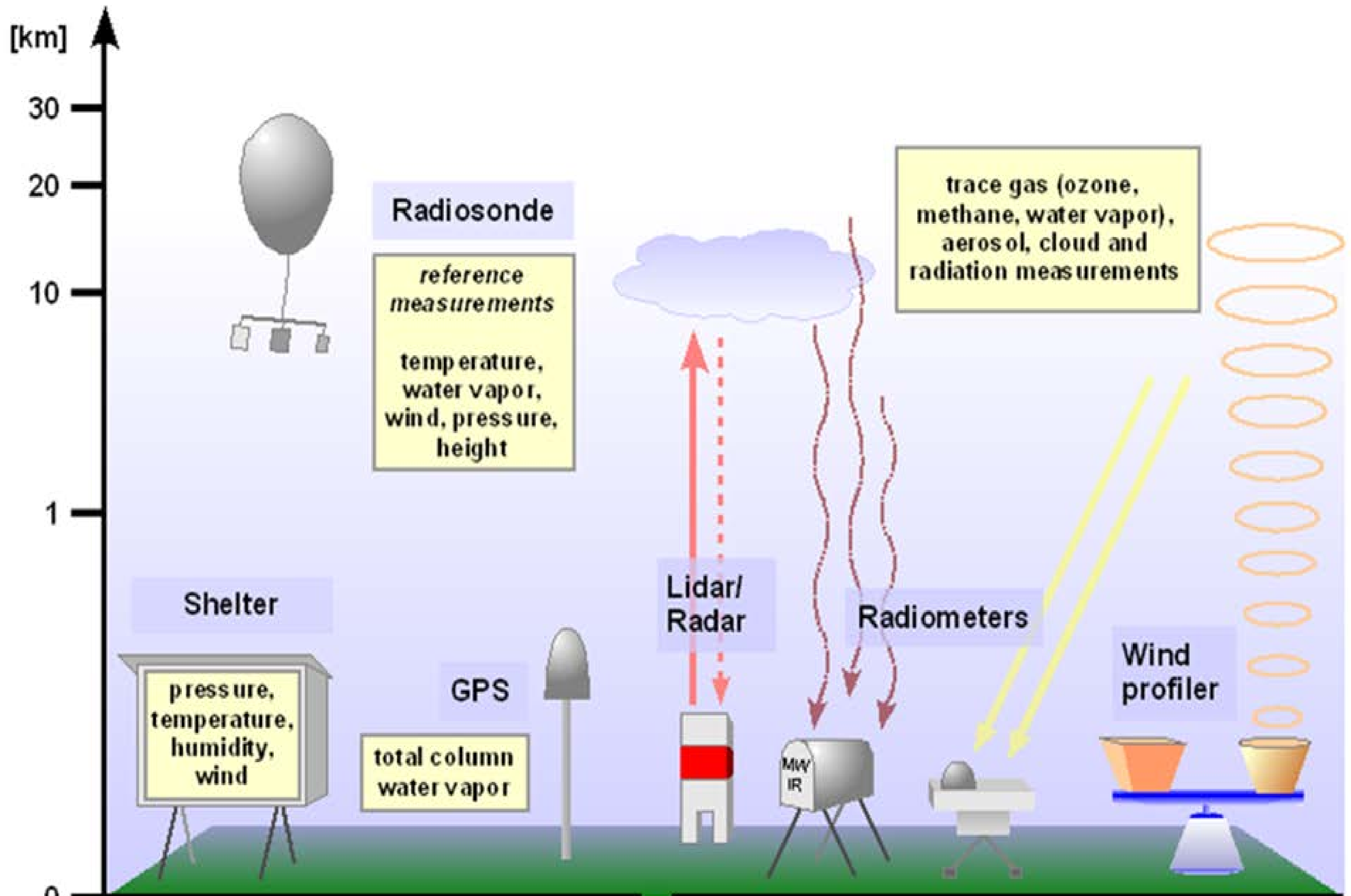
Dedicated S-NPP RS92 RAOB funded by JPSS CrIMSS Project

NPP CrIMSS EDR ICV Dedicated RAOB Sites



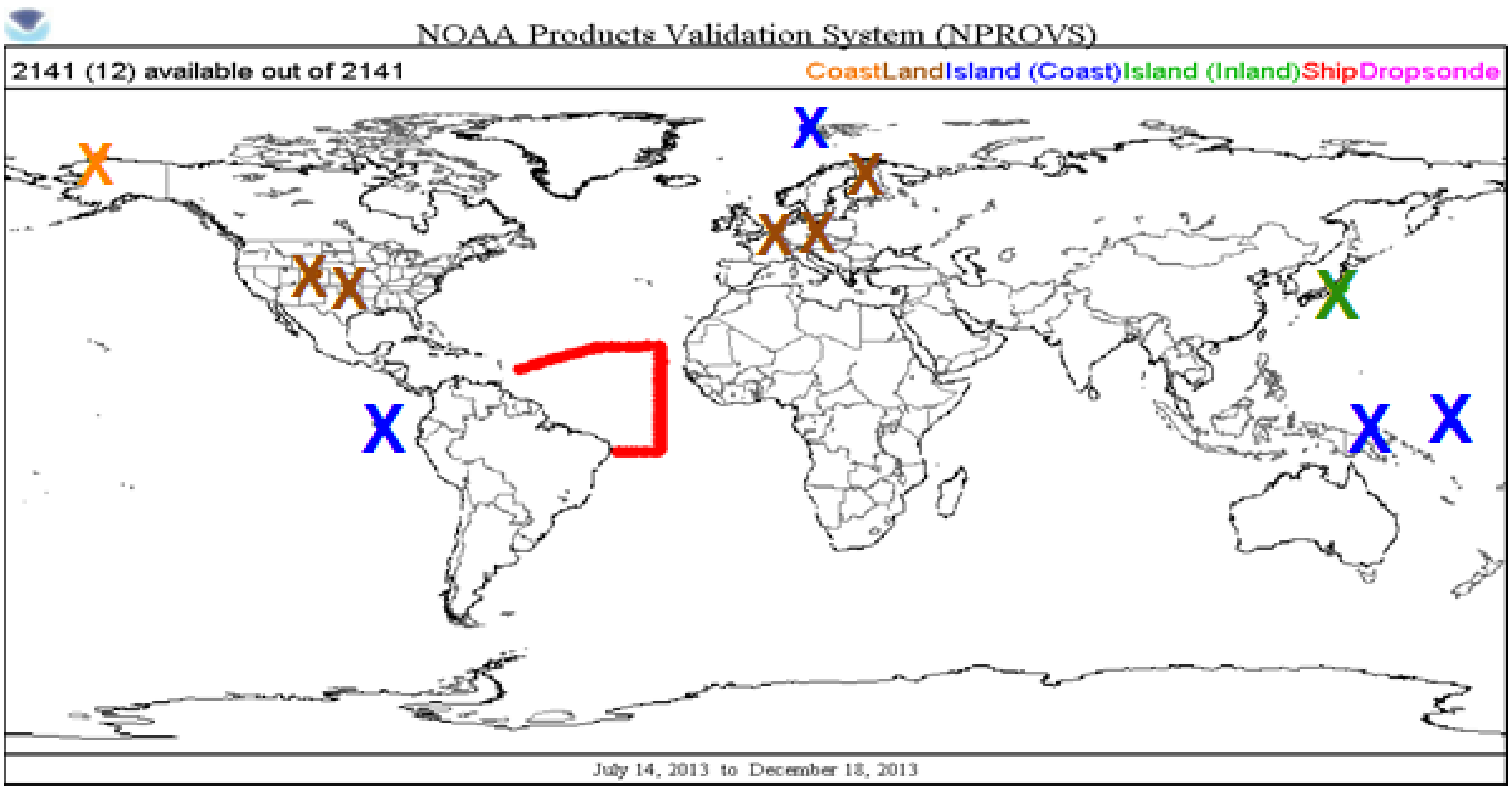
… ongoing re-structure of ARM scheduling to provide “sustained” year round coverage per 3 days *… Borg, Tobin, Mather …*

GRUAN Processed Dedicated RAOB !!



Characterization of atmospheric column well suited to assess satellite product

NPROVS+



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

(3600 collocations and 1000 dedicated as of mid-April …)

Collocation Strategy

- Reference/dedicated RAOB (RS92) is anchor
- Digicora, GRUAN, GTS … (3 flavors)
- Append Ancillary (lidar, etc as available, retrospective …)
- Compress to 1km layers (also retain original hi-density)
- **Single closest satellite EDR within +/- 6hr and 150km (250km for COSMIC)**
- NWP (GFS 6-hr, CFSR and ECMWF Anal …)
- For hyperspectral (S-NPP, MeTop, Aqua) append all EDRs within 500km of RAOB … **VALAR**
- Append associated SDR (traceable to ICVS) … **VALAR**

Results

- NUCAPS Validation
  - IR+MW
  - MW-only including MiRS
  - Trends
  - Yield, QC flag
- Integrating GRUAN Uncertainty
  - “K” statistics
  - AIRS v6 uncertainty analysis
- GPSRO
  - RAOB Radiation Correct

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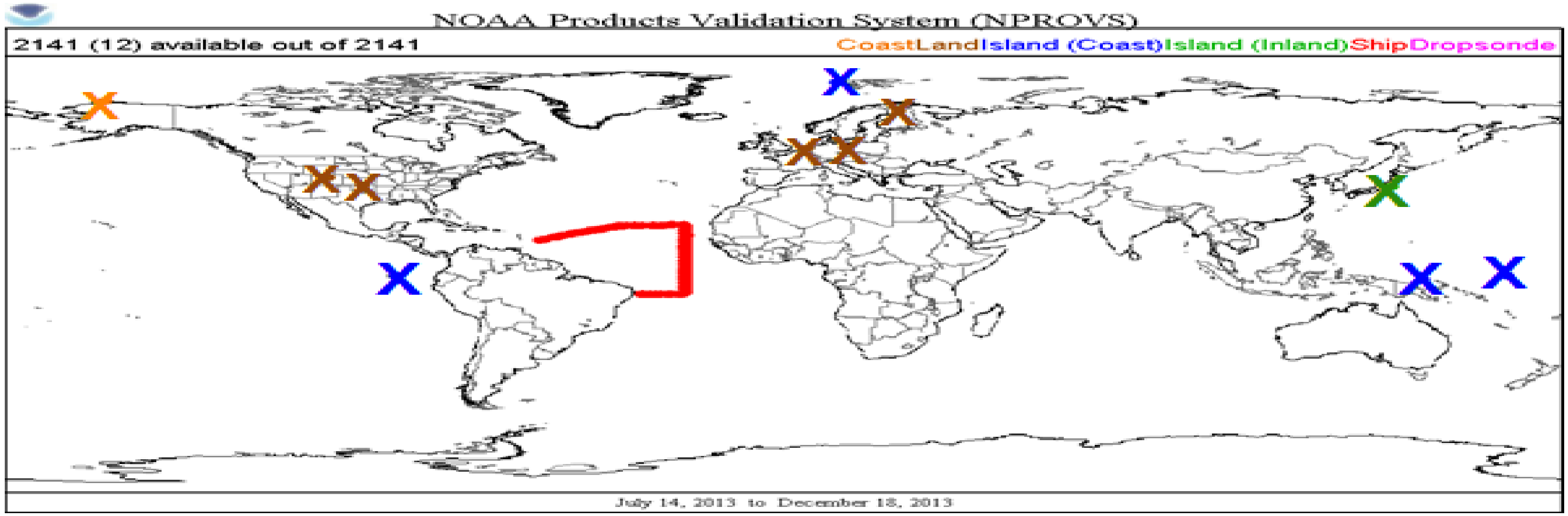
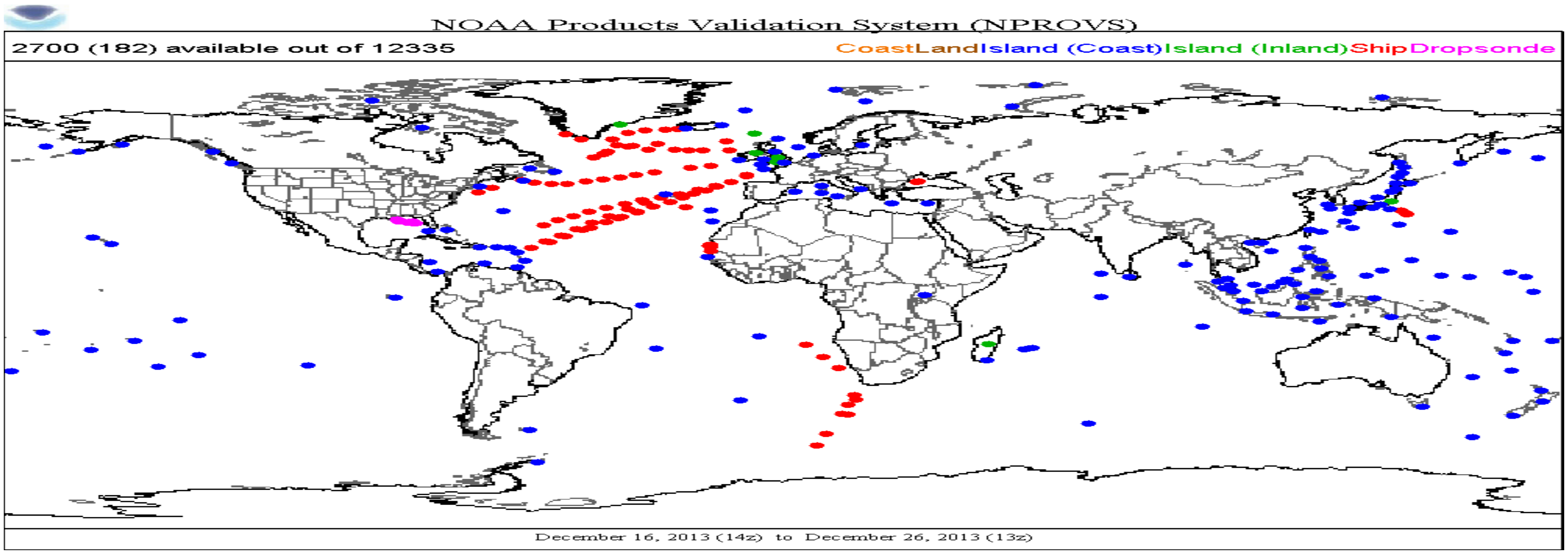
NPROVS+

PDISP

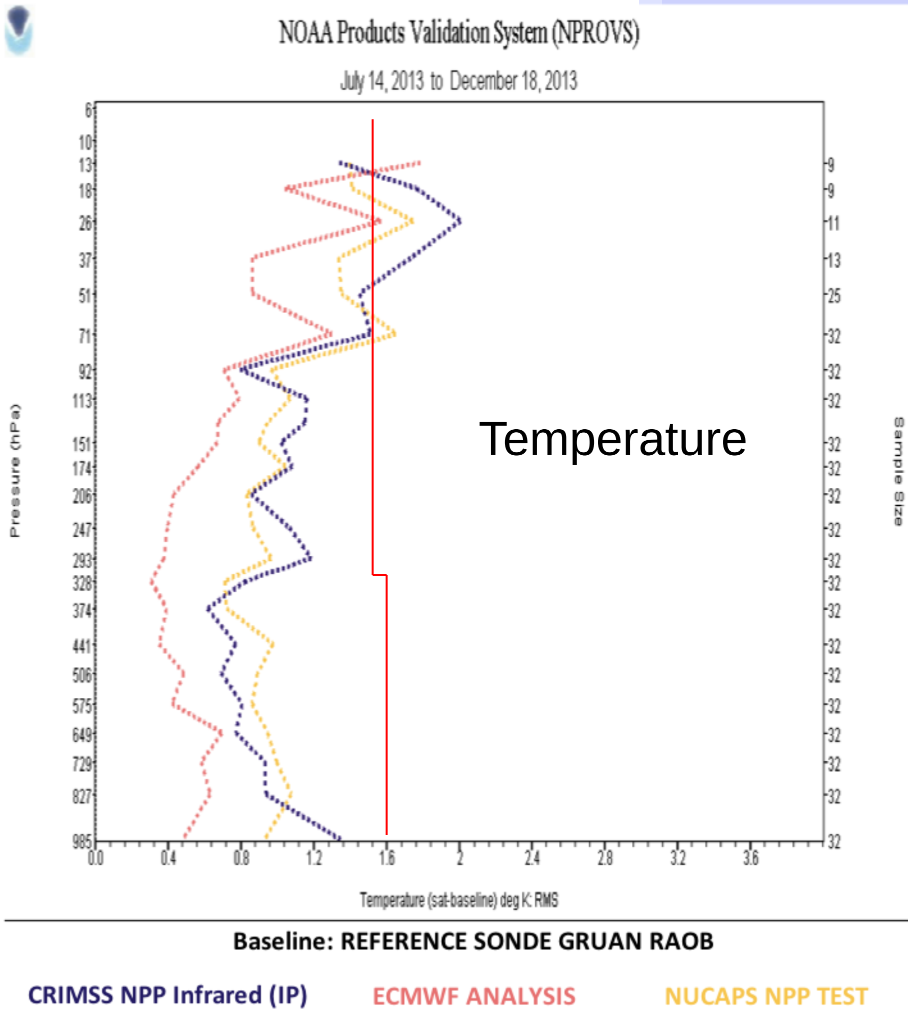


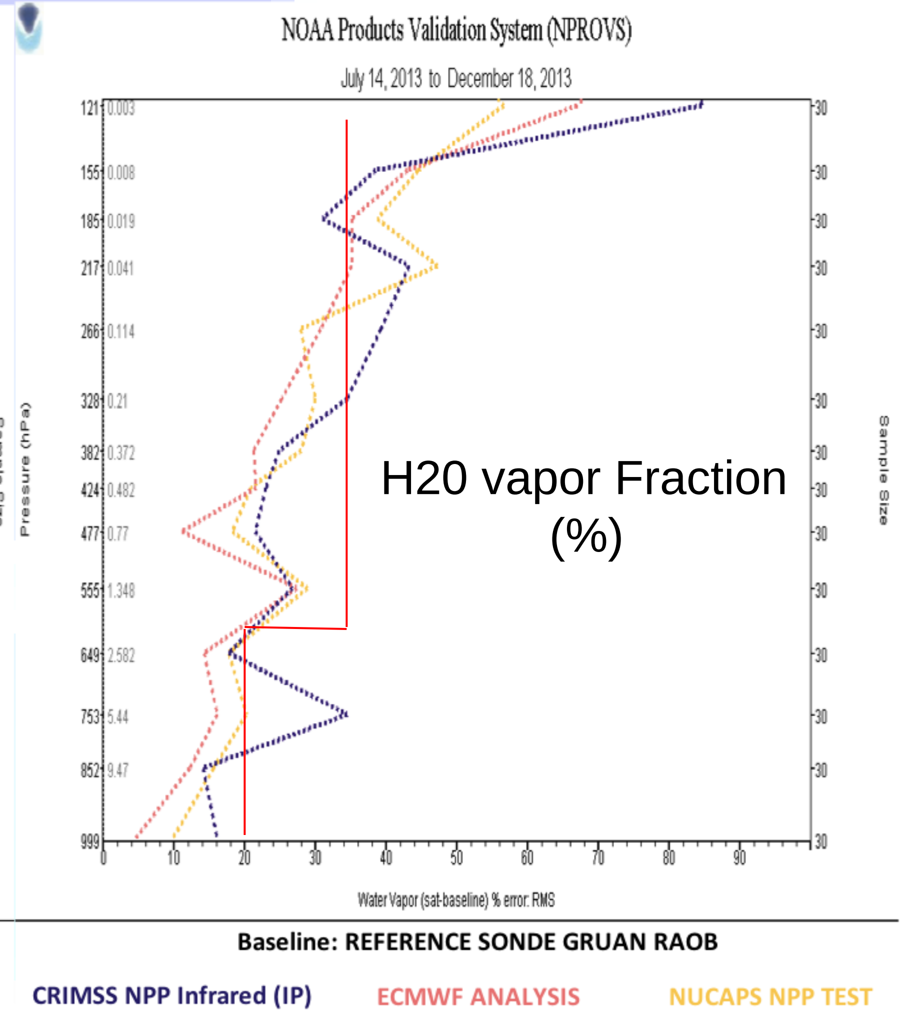


NPROVS Maritime

SAT-minus-RAOB Vertical Statistic

(PDISP)

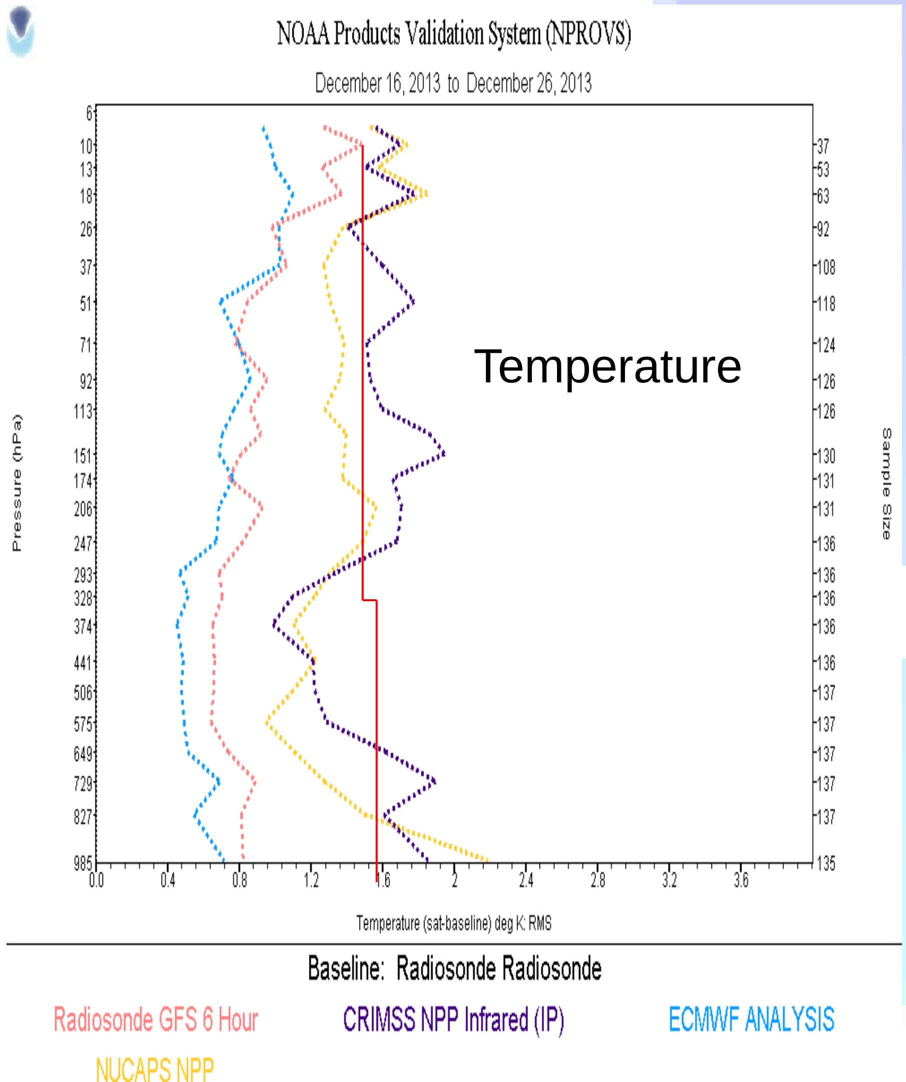


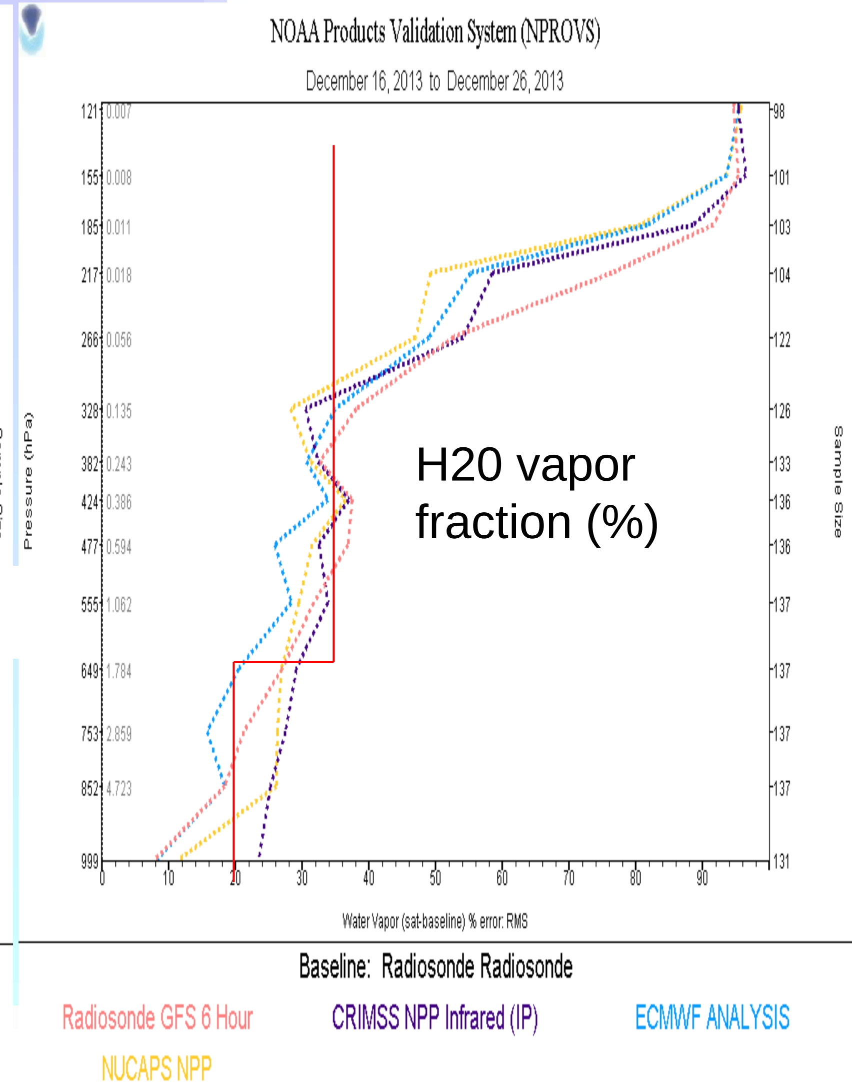


IR + MW Pass QC … AEROSE only

NPROVS+

SAT-minus-RAOB Vertical Statistic

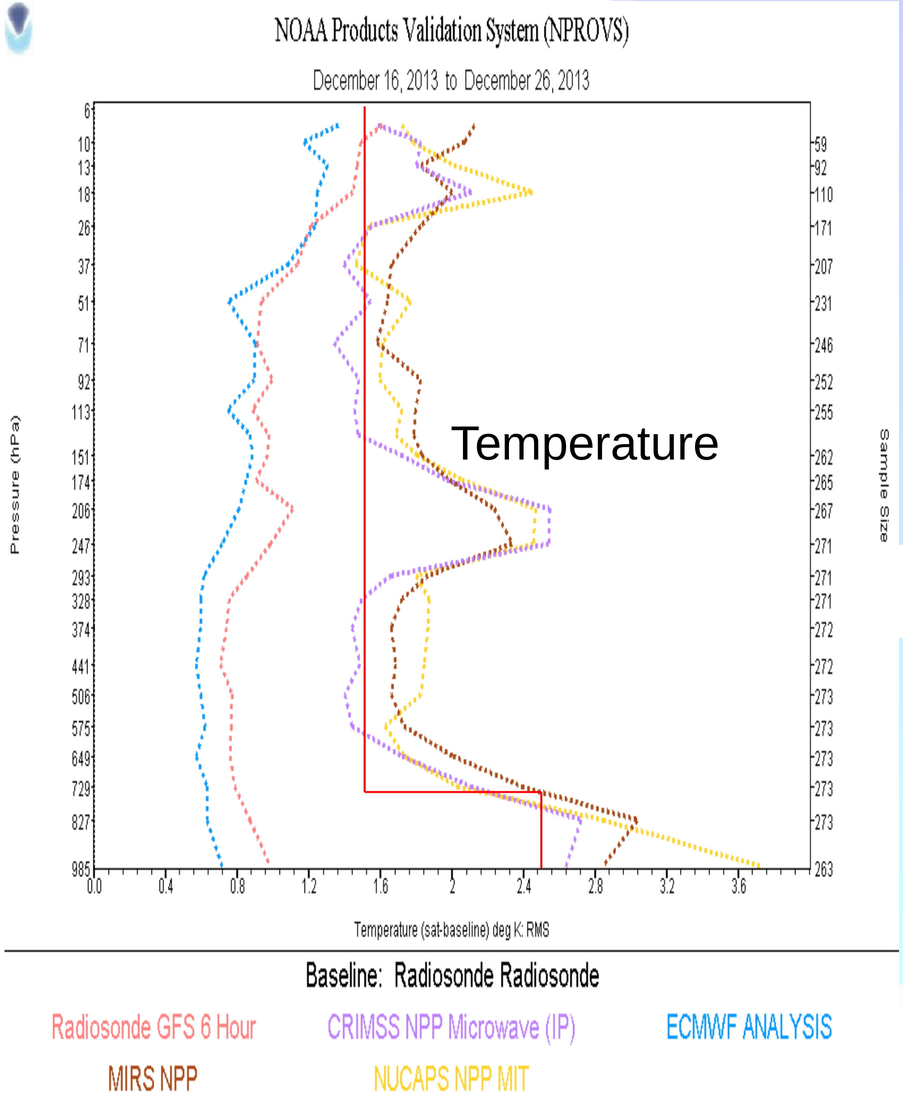


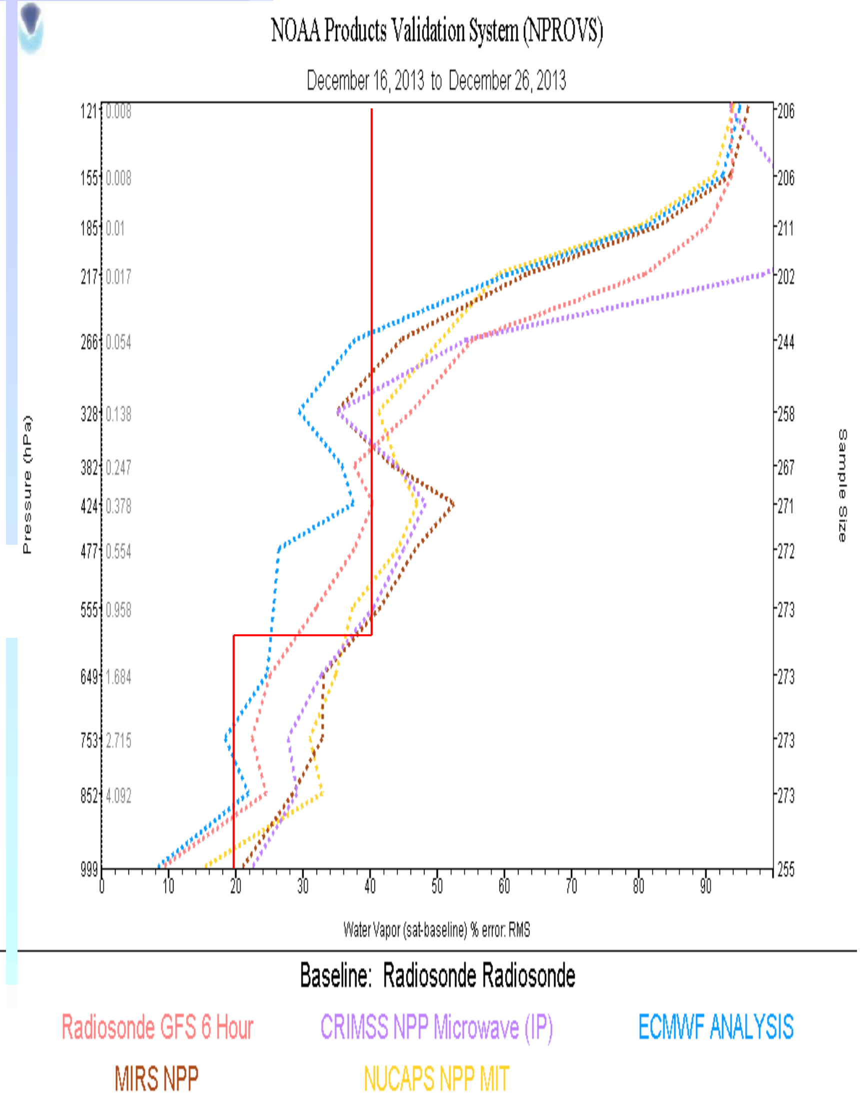


IR + MW pass QC, Maritime, +/- 3hr

NPROVS

SAT-minus-RAOB Vertical Statistic

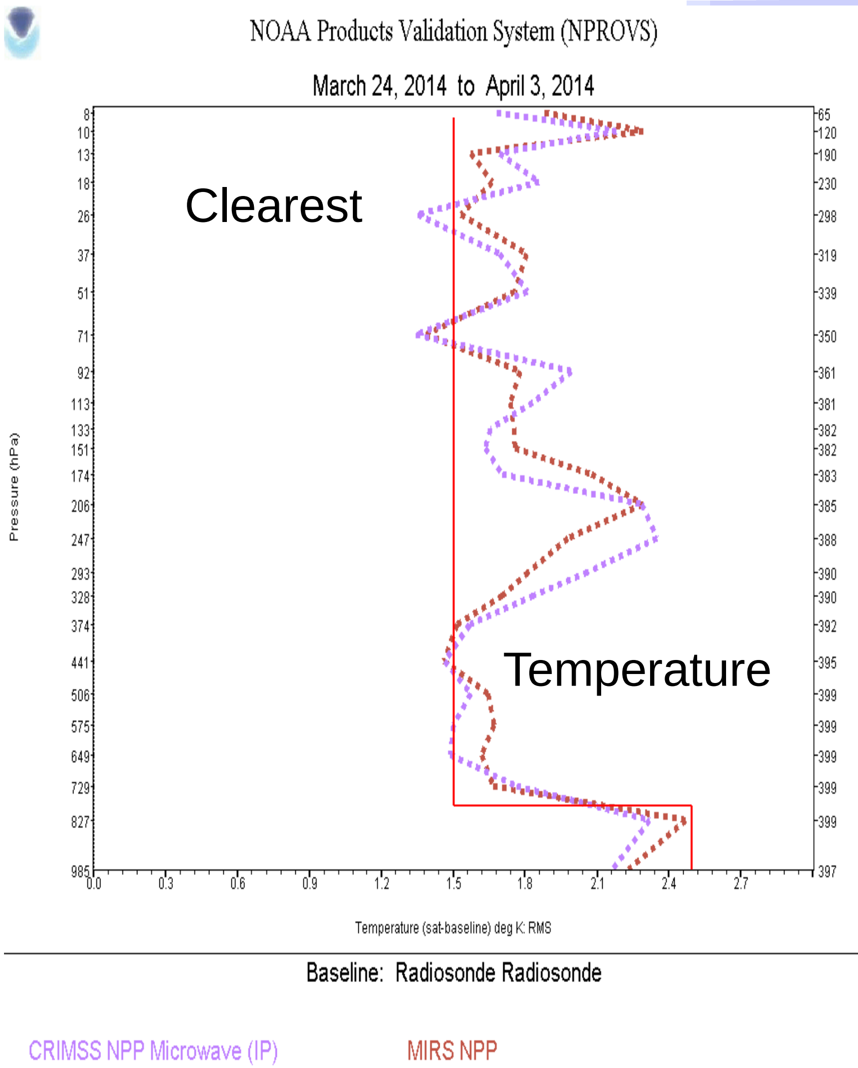


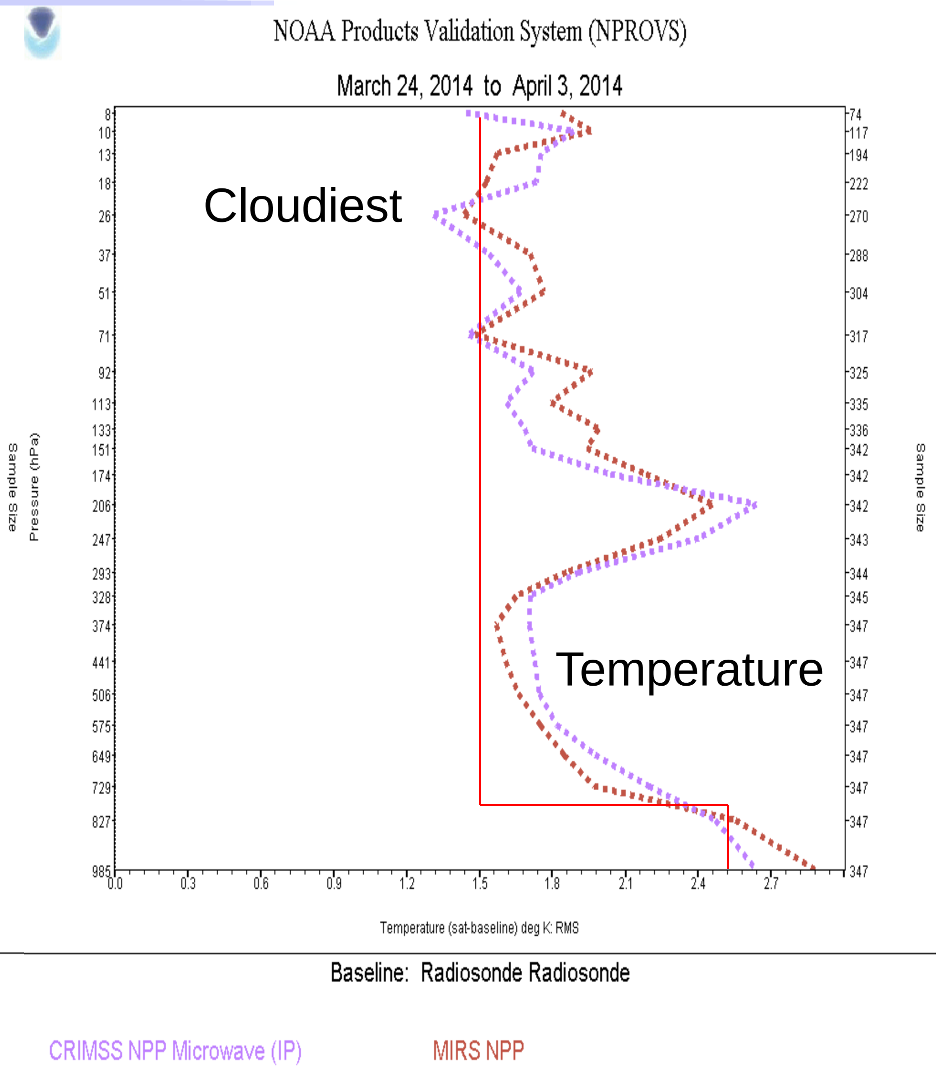


MW-only pass QC, Maritime (+/- 3hr)

NPROVS

SAT-minus-RAOB Vertical Statistic

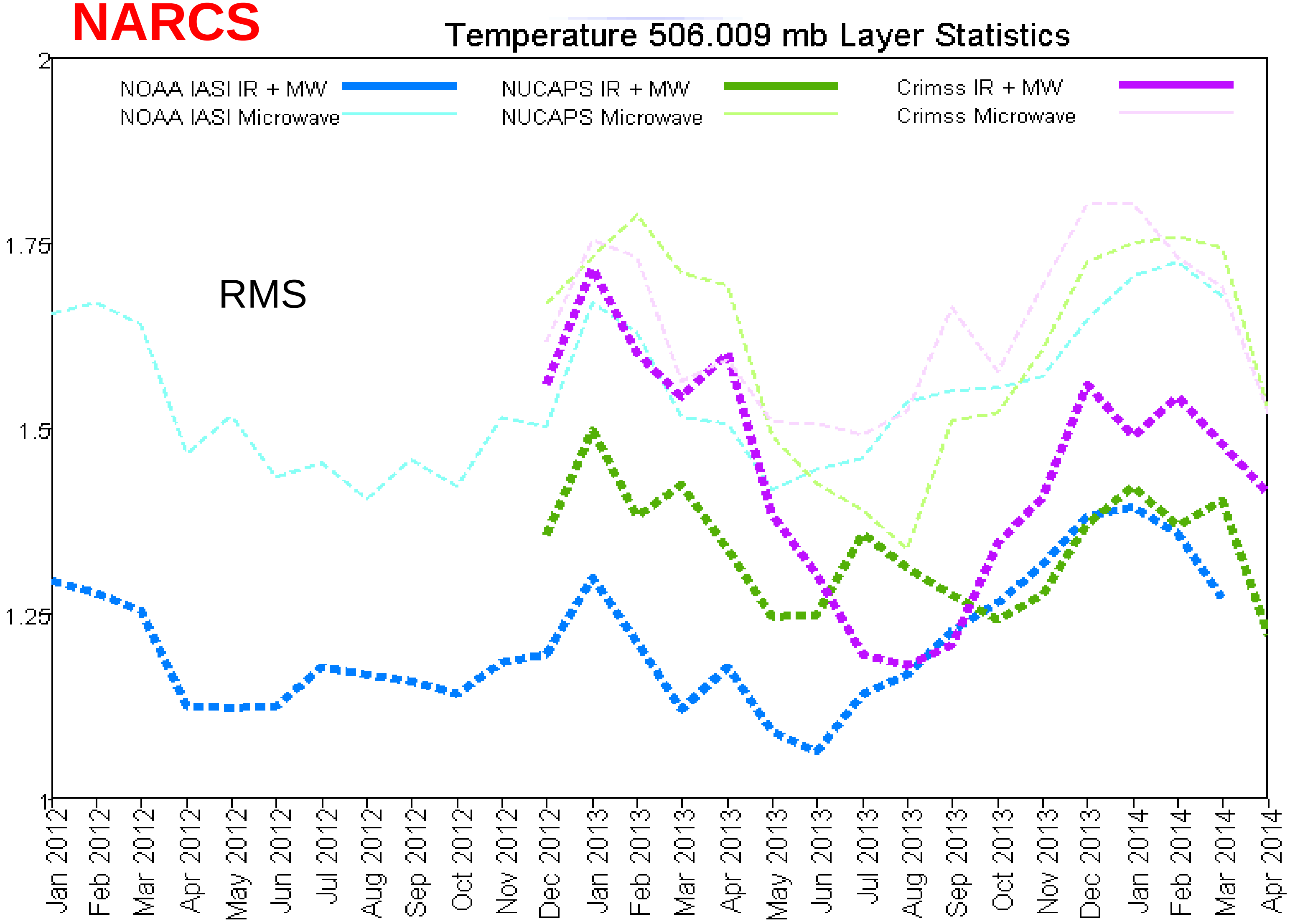




MW-only pass QC, Maritime (Sea-only retrieval)

NPROVS

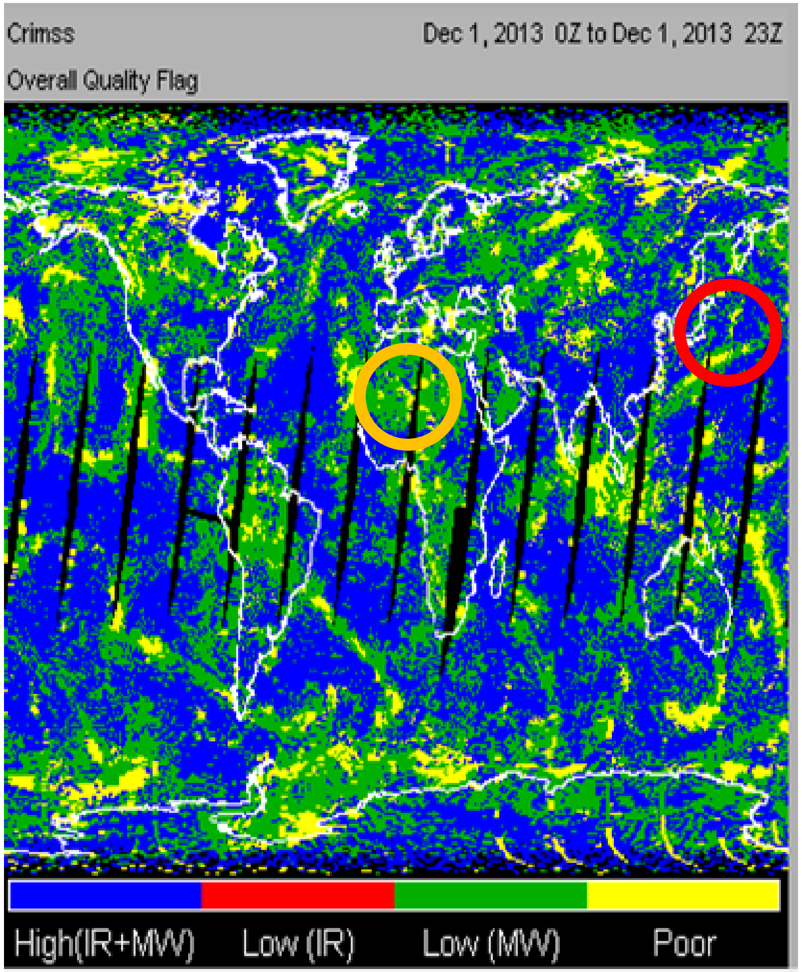
NARCS

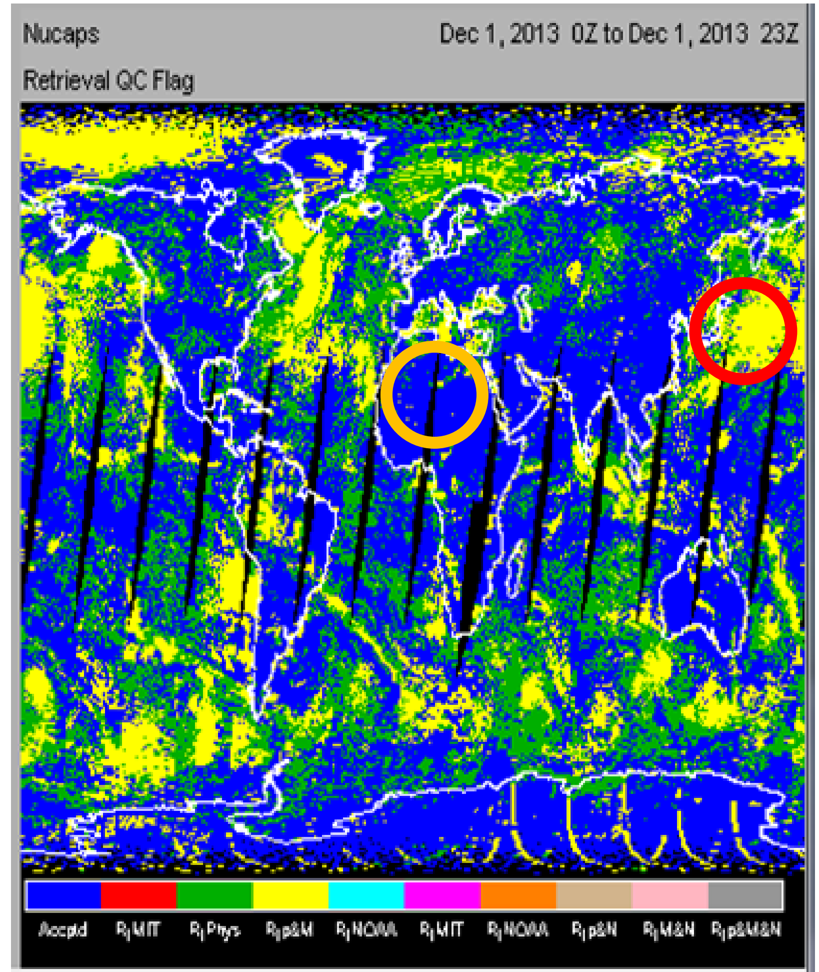


Global MARITIME: NPROVS

IDPS vs NUCAPS QC flag Analysis

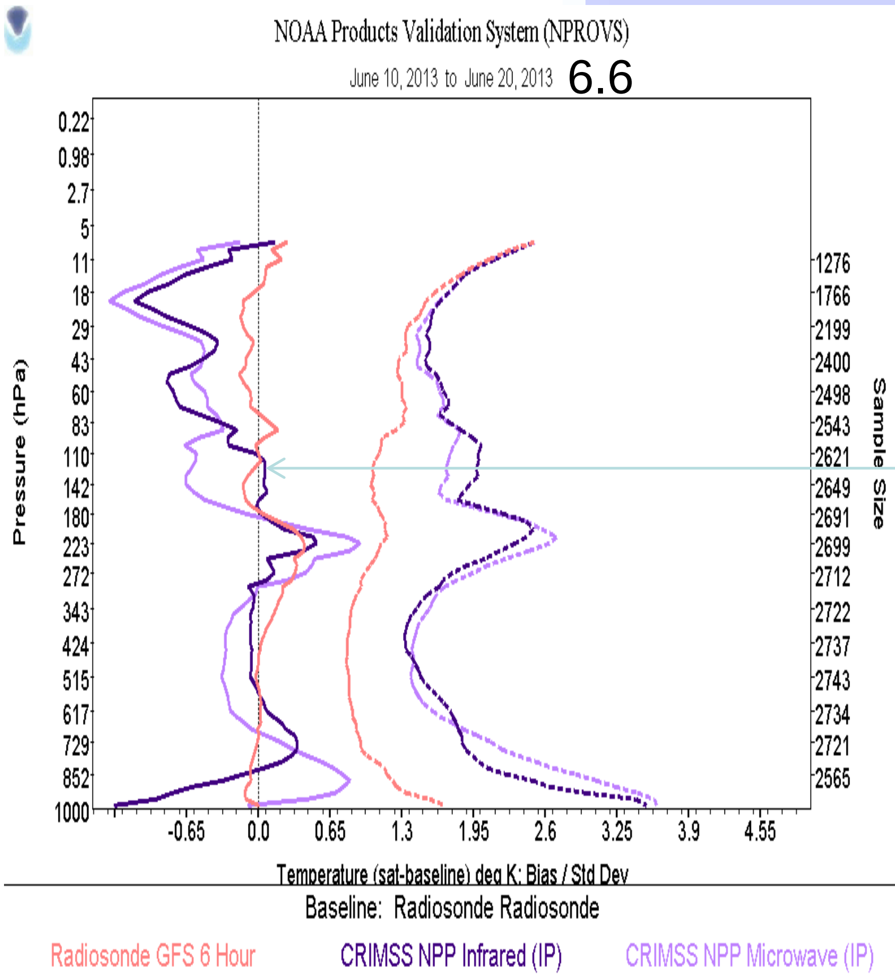
ODS

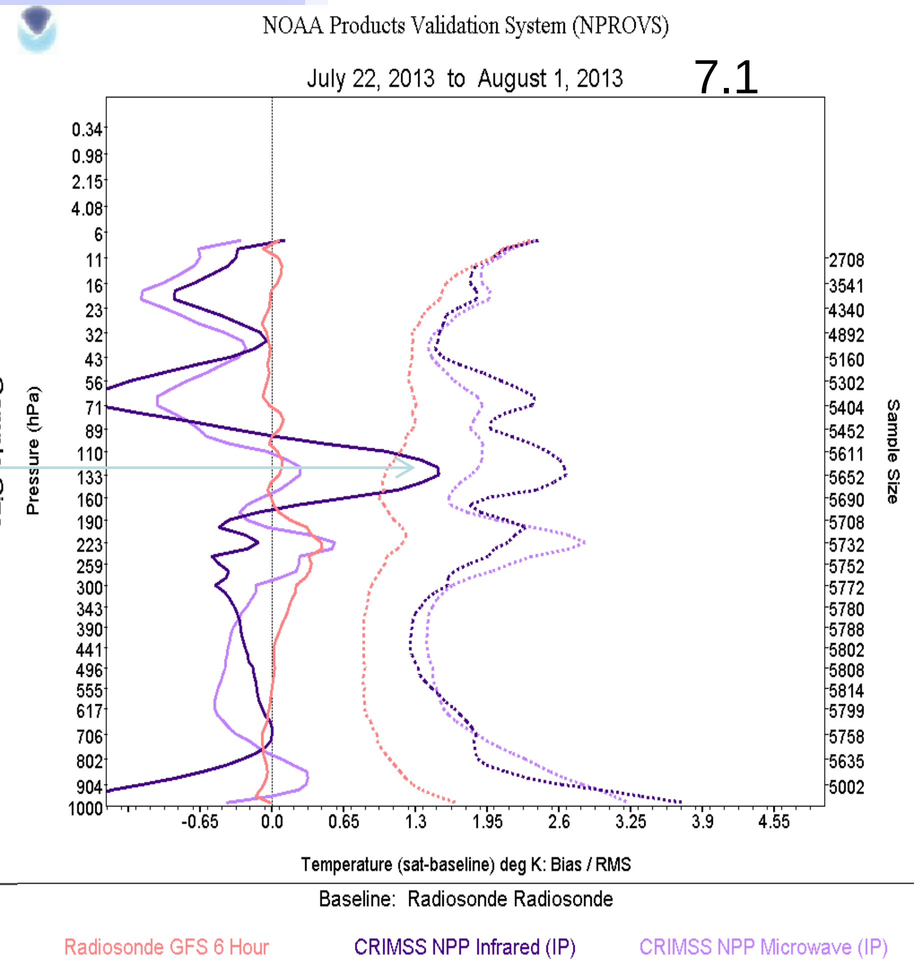




Blue: IR+MW pass **Green: MW-only pass** **Yellow: Both fail**

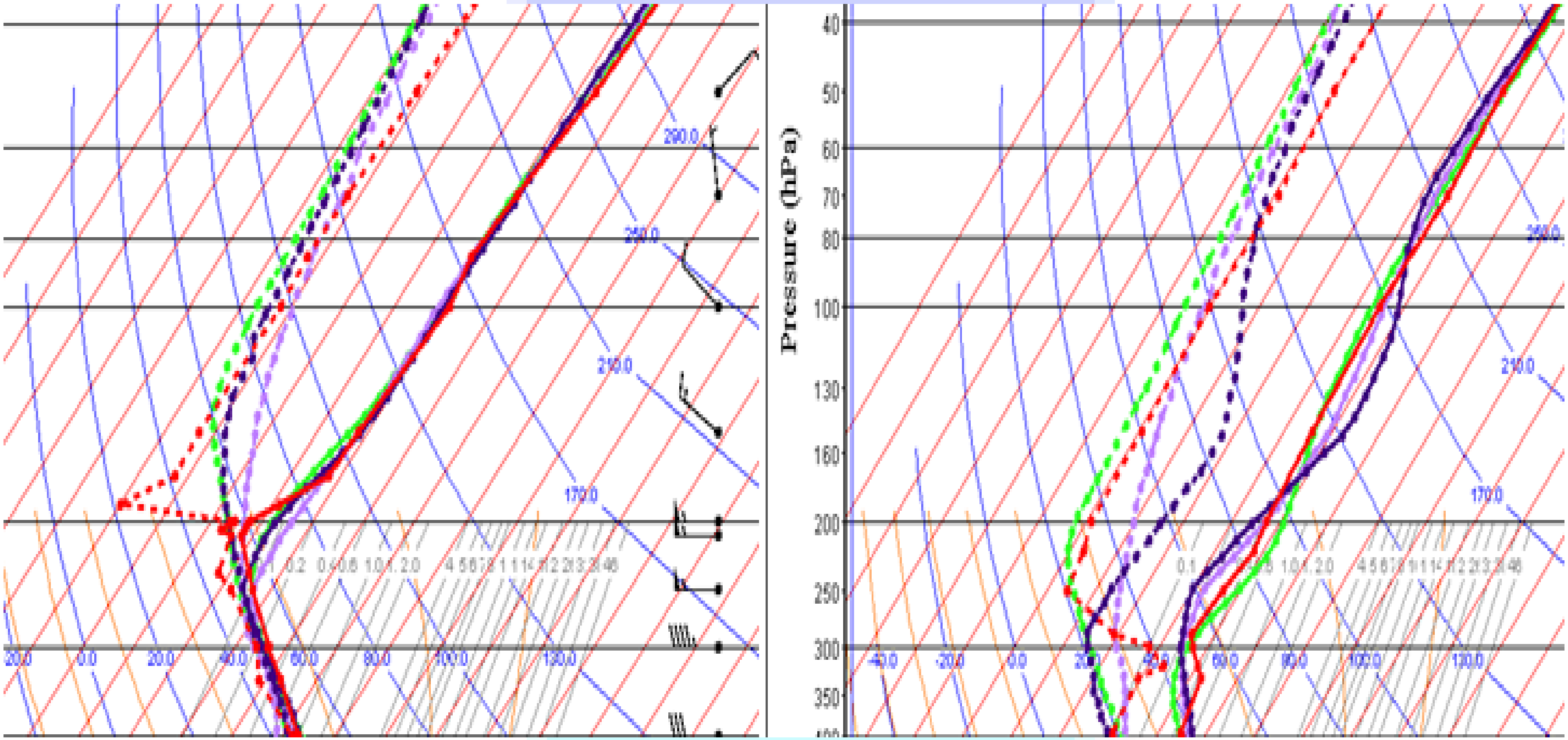
CrIMSS IDPS v7.1 IR+MW polar stratosphere problem





IR + MW pass, global, NPROVS

CrIMSS IDPS v7.1 IR+MW polar stratosphere problem



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

GRUAN Reference Measurement Principles

Given RAOB uncertainty (u_2) and product uncertainty (u_1)

Given the variability (σ) of a variables (m) in time and space from measurement (RAOB) or model (Retrl),then

Two observations on different platforms are **consistent** if:

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

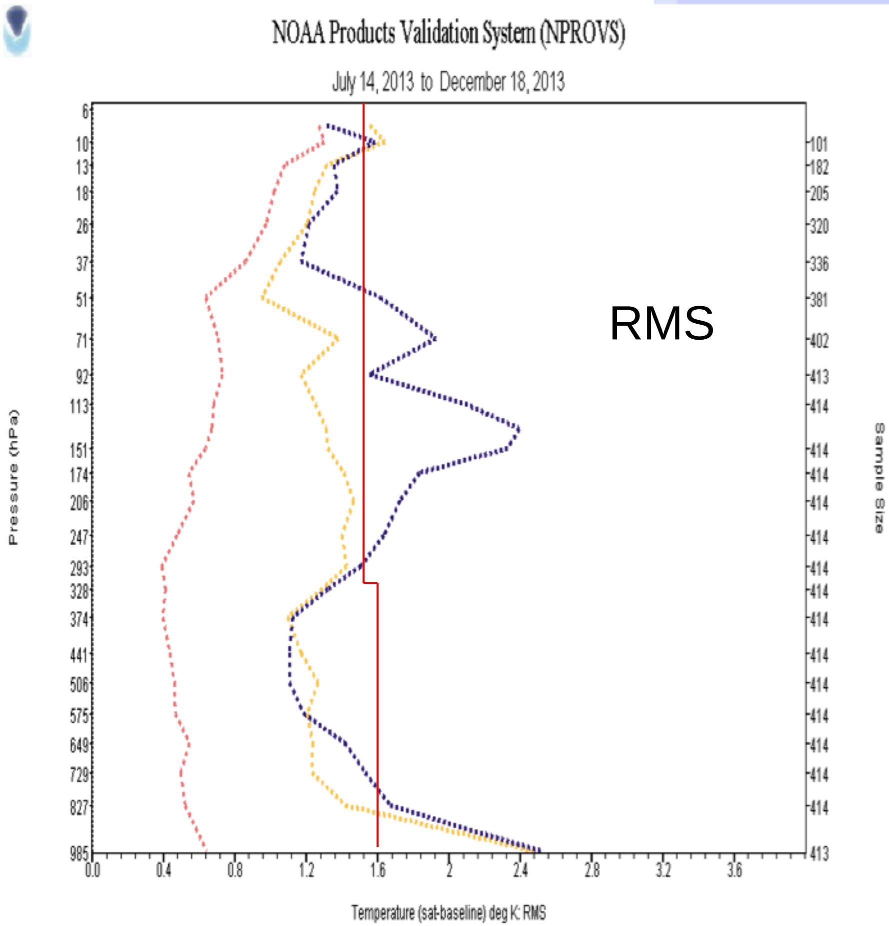
… at this preliminary stage:

K = ABS(X – GRUAN) / u2

where "X" either SAT or NWP

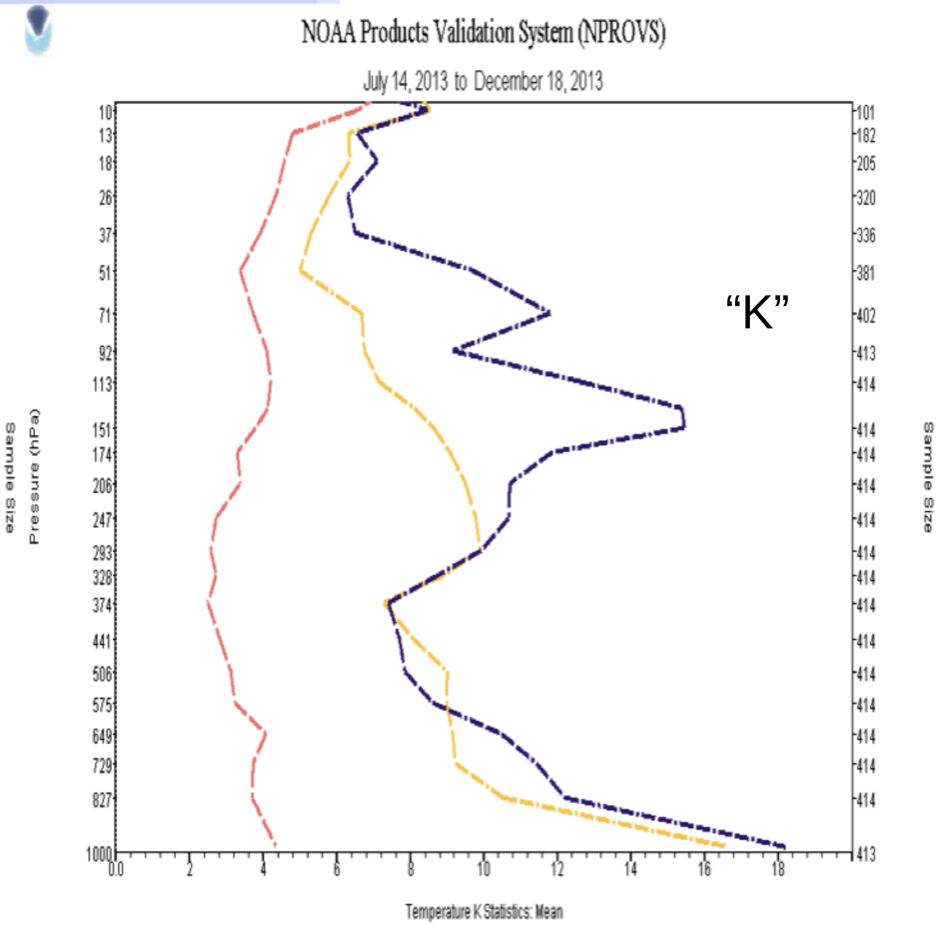
"need uncertainty estimates for EDR" !!

PDISP – NPROVS+



Baseline: REFERENCE SONDE GRUAN RAOB

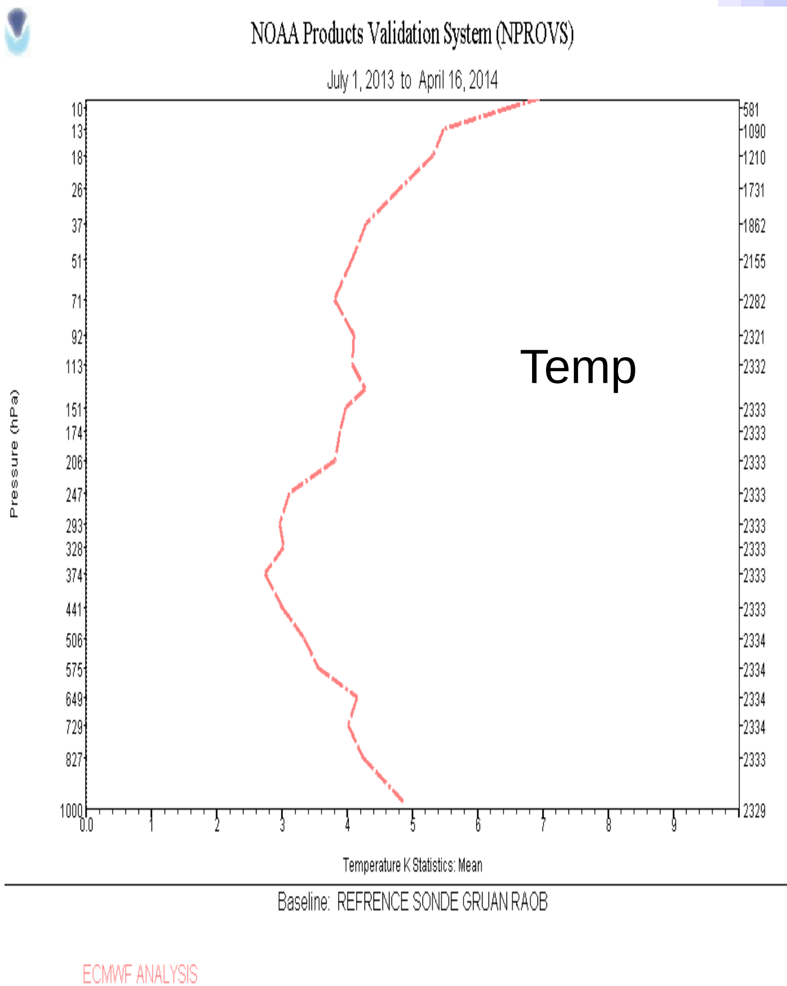
CRIMSS NPP Infrared (IP) ECMWF ANALYSIS NUCAPS NPP TEST

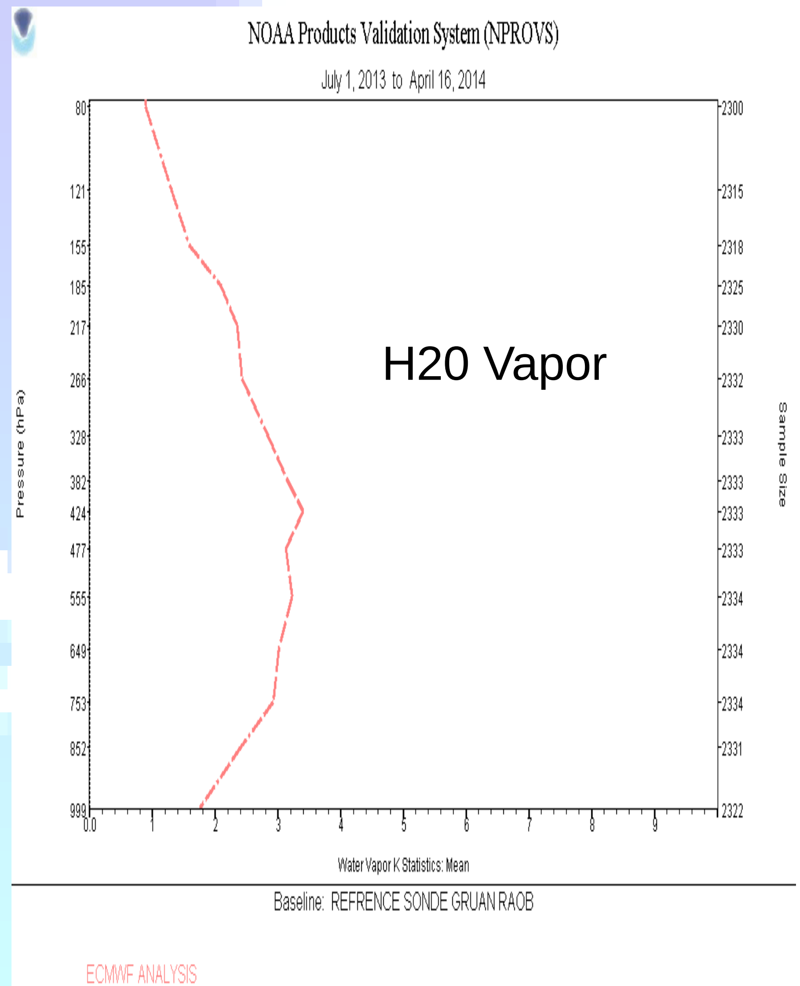


Baseline: REFERENCE SONDE GRUAN RAOB

CRIMSS NPP Infrared (IP) ECMWF ANALYSIS NUCAPS NPP TEST

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





K analysis

Raobs better at measuring Temp than Moisture

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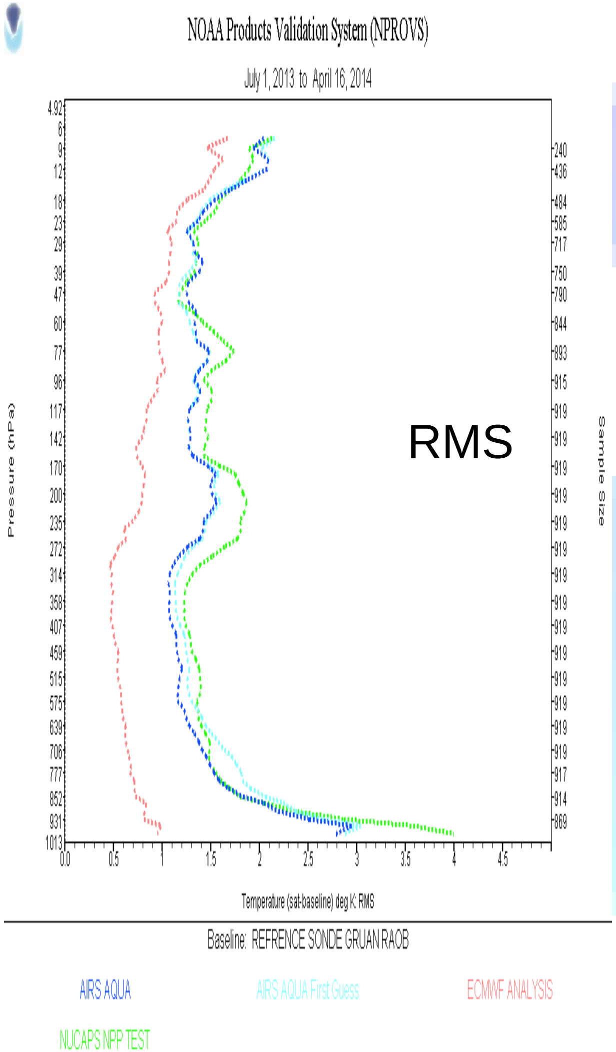
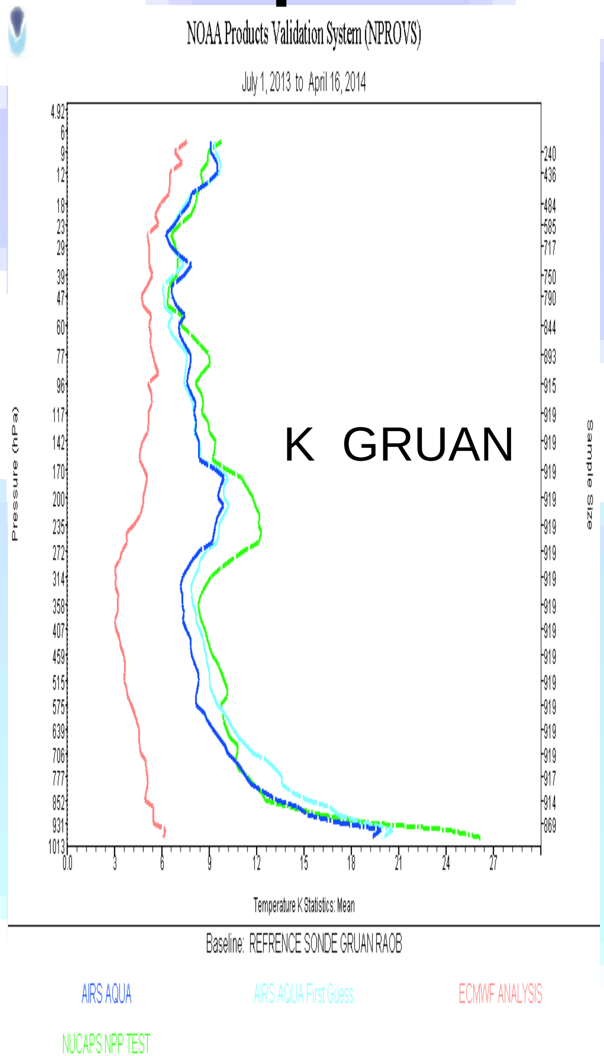
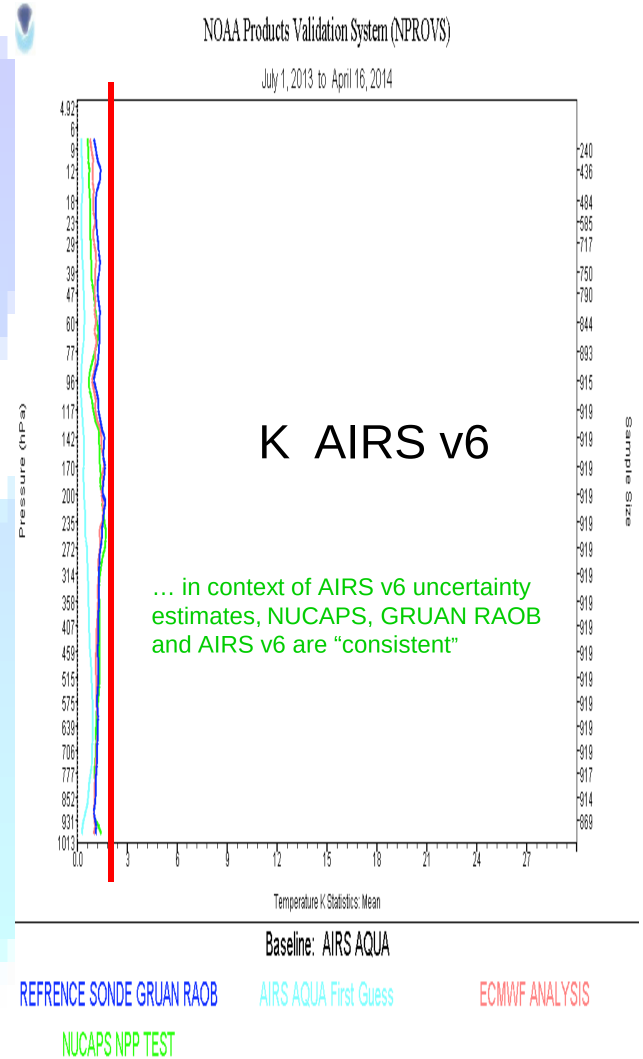
Temperature







AIRS AIRS FG NUCAPS ECMWF (GRUAN RAOB)

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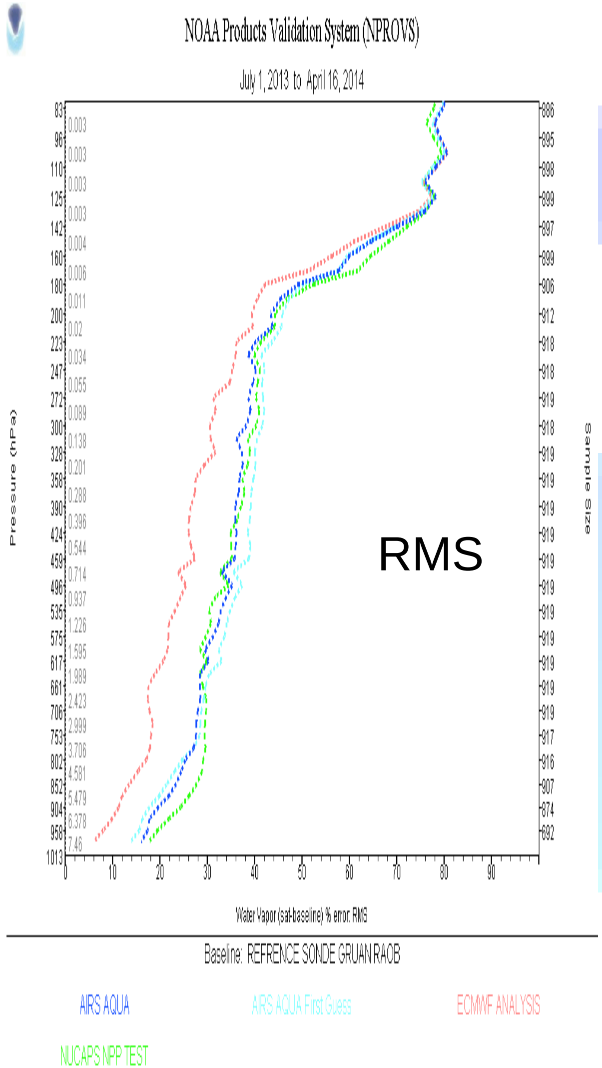
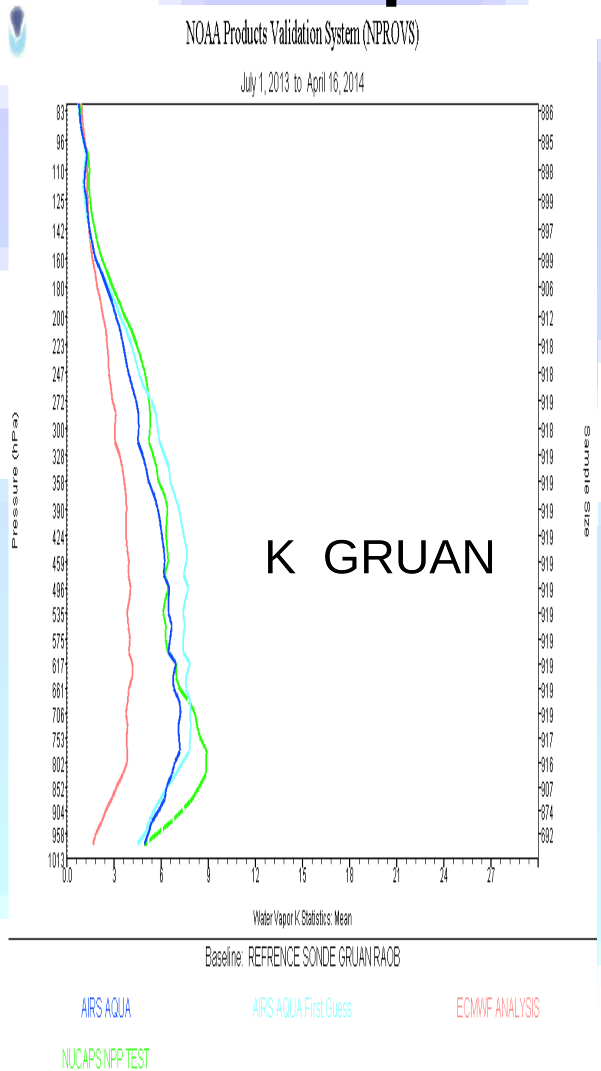
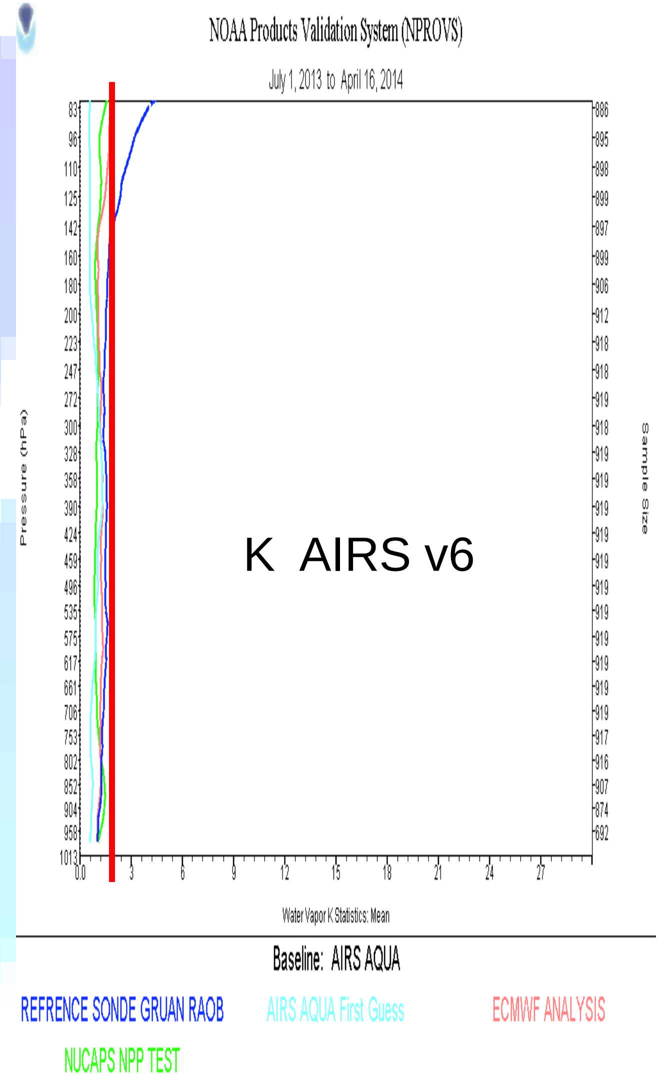
H20 Vapor







AIRS AIRS FG NUCAPS ECMWF (GRUAN RAOB)

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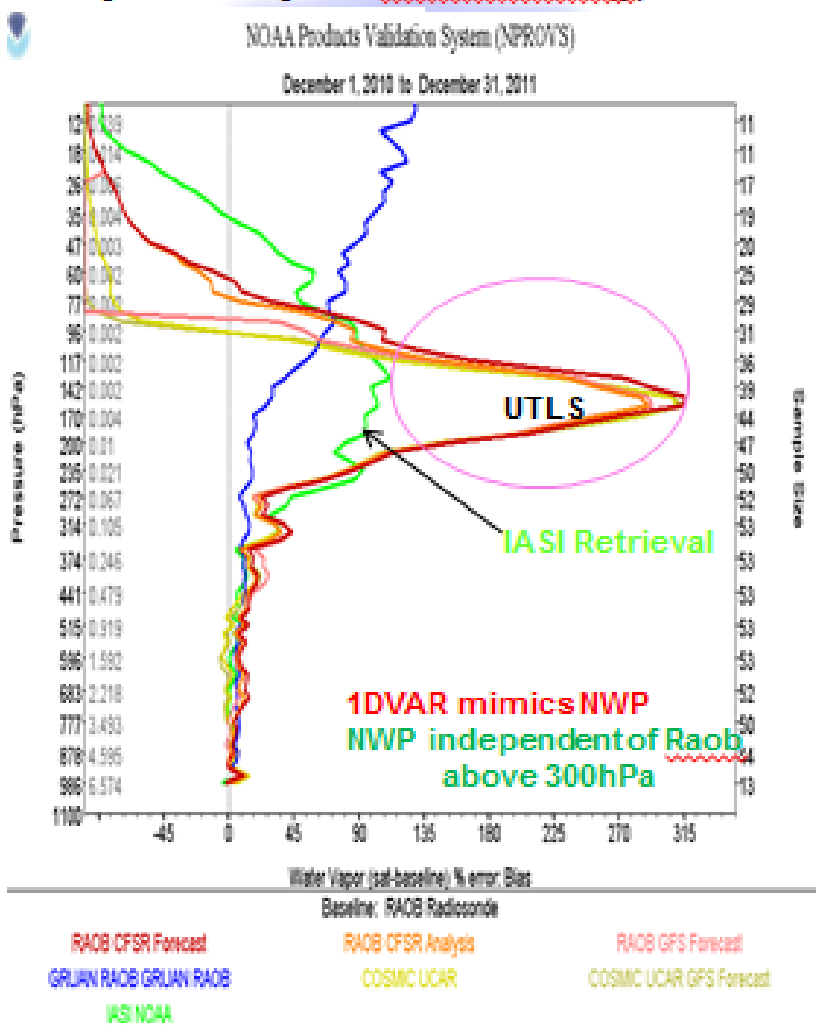
Mainly Vicinity of Lindenberg, Germany

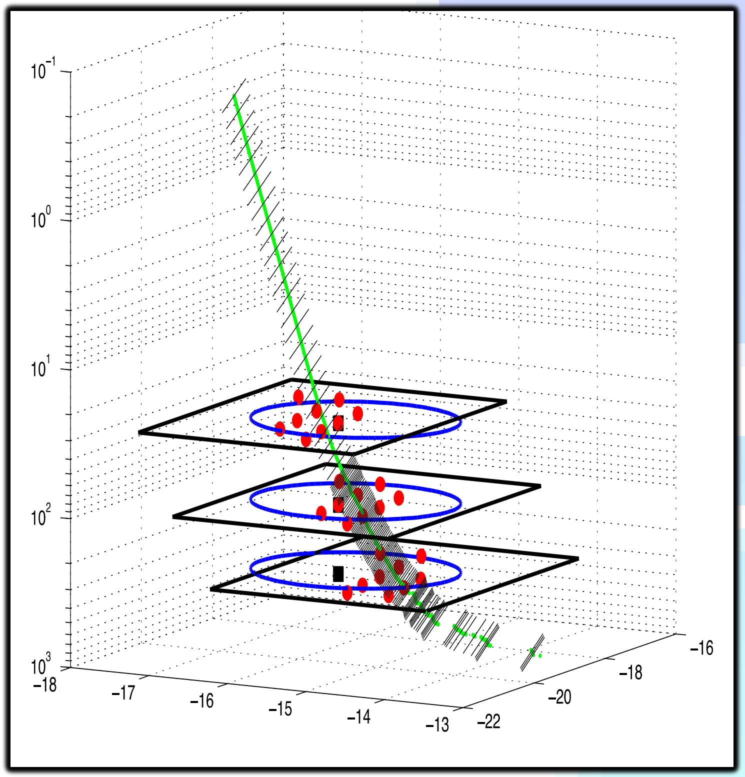


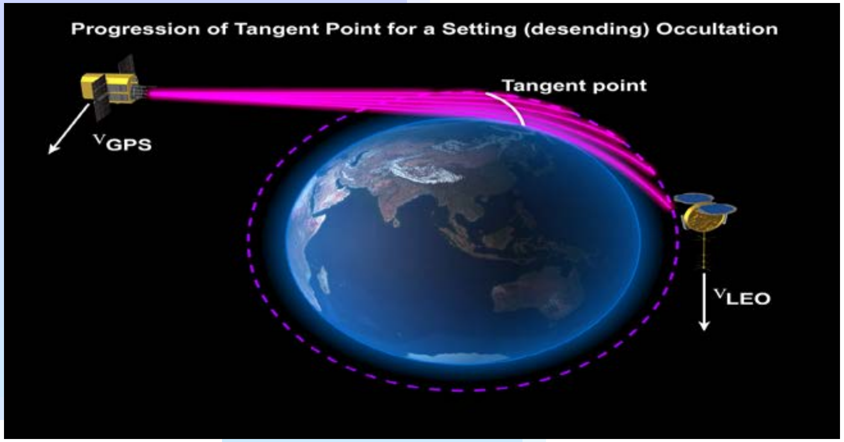
GRUAN Sonde, NWP and COSMIC, respectively, -minus-GTS Sonde

NPROVS+

COSMIC / GRAS

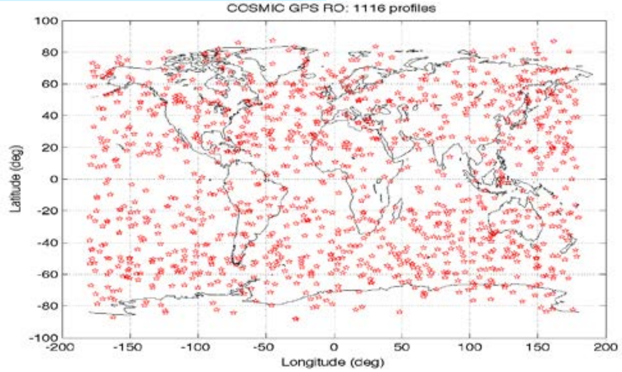
(Stratosphere Reference Temp from Space …)





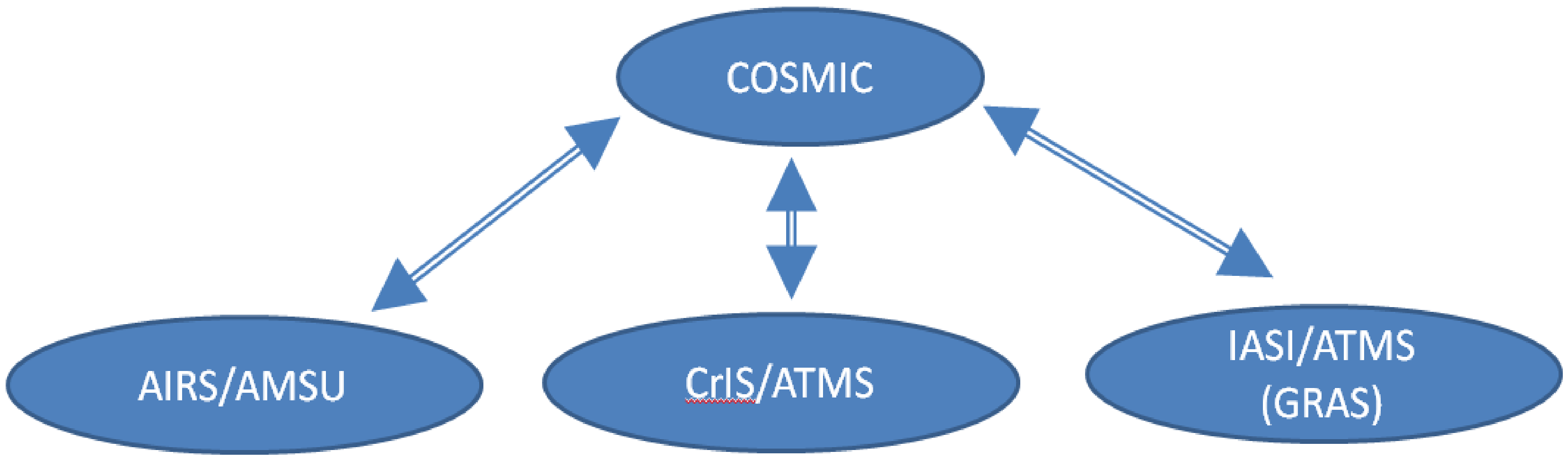
http://www.cosmic.ucar.edu/launch/GPS_RO_cartoon.jpg

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



One Day of COSMIC Profiles

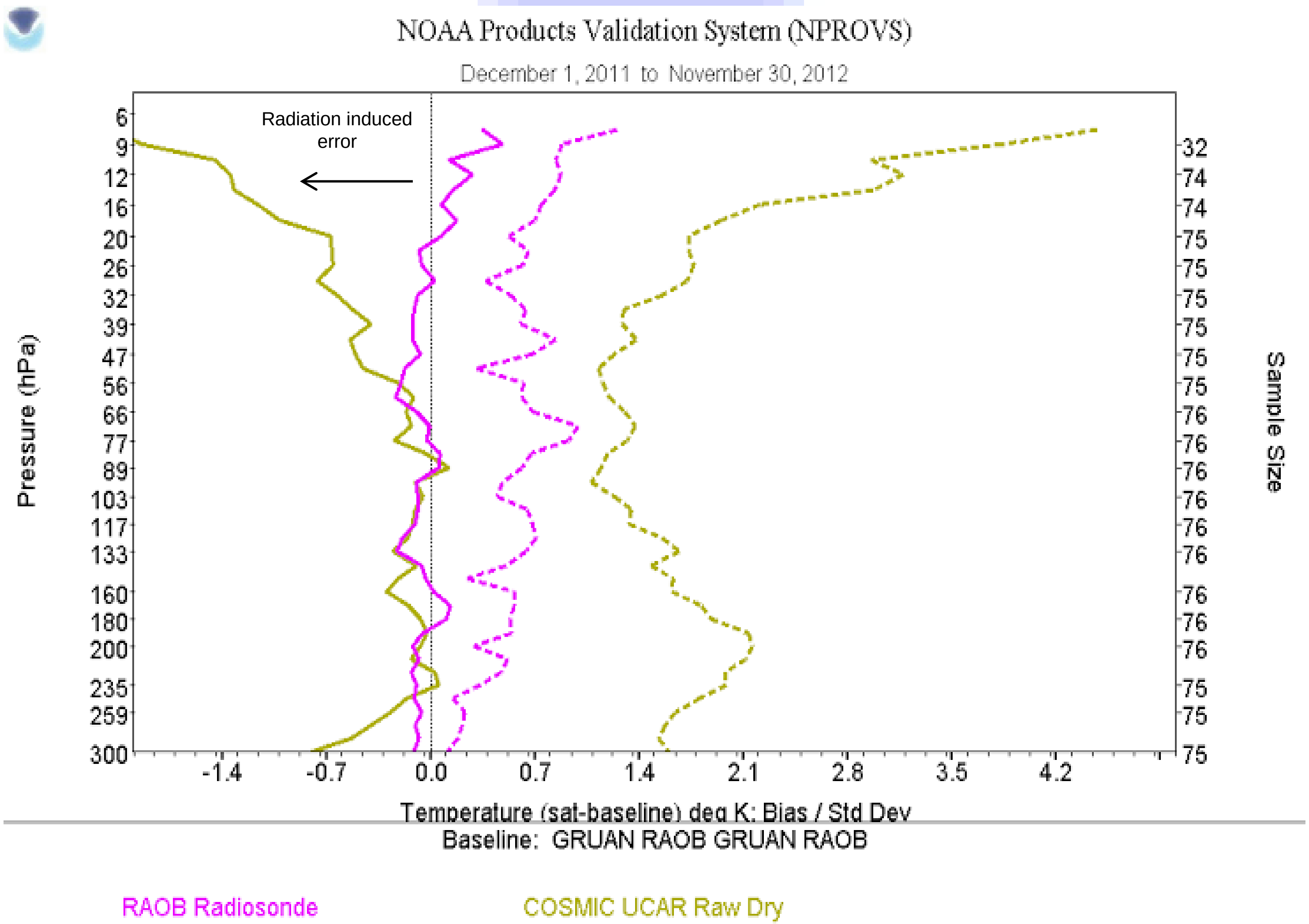
courtesy Knuteson / Feltz CIMSS



GPSRO Anchored Collocation

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

Lindenberg, Germany; 12Z (daytime)



(COSMIC Tdry)-minus-(GRUAN RAOB) … NPROVS+

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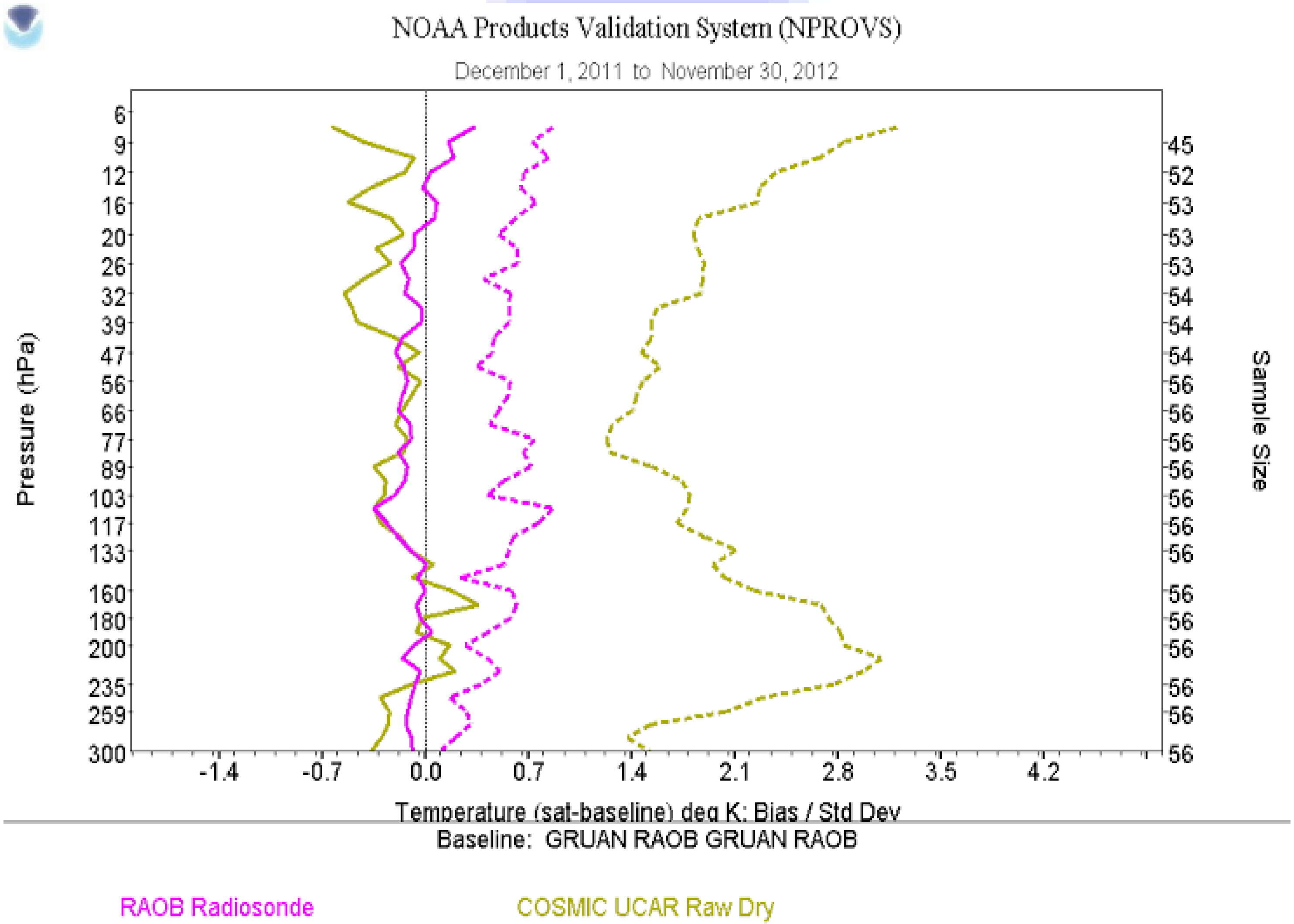
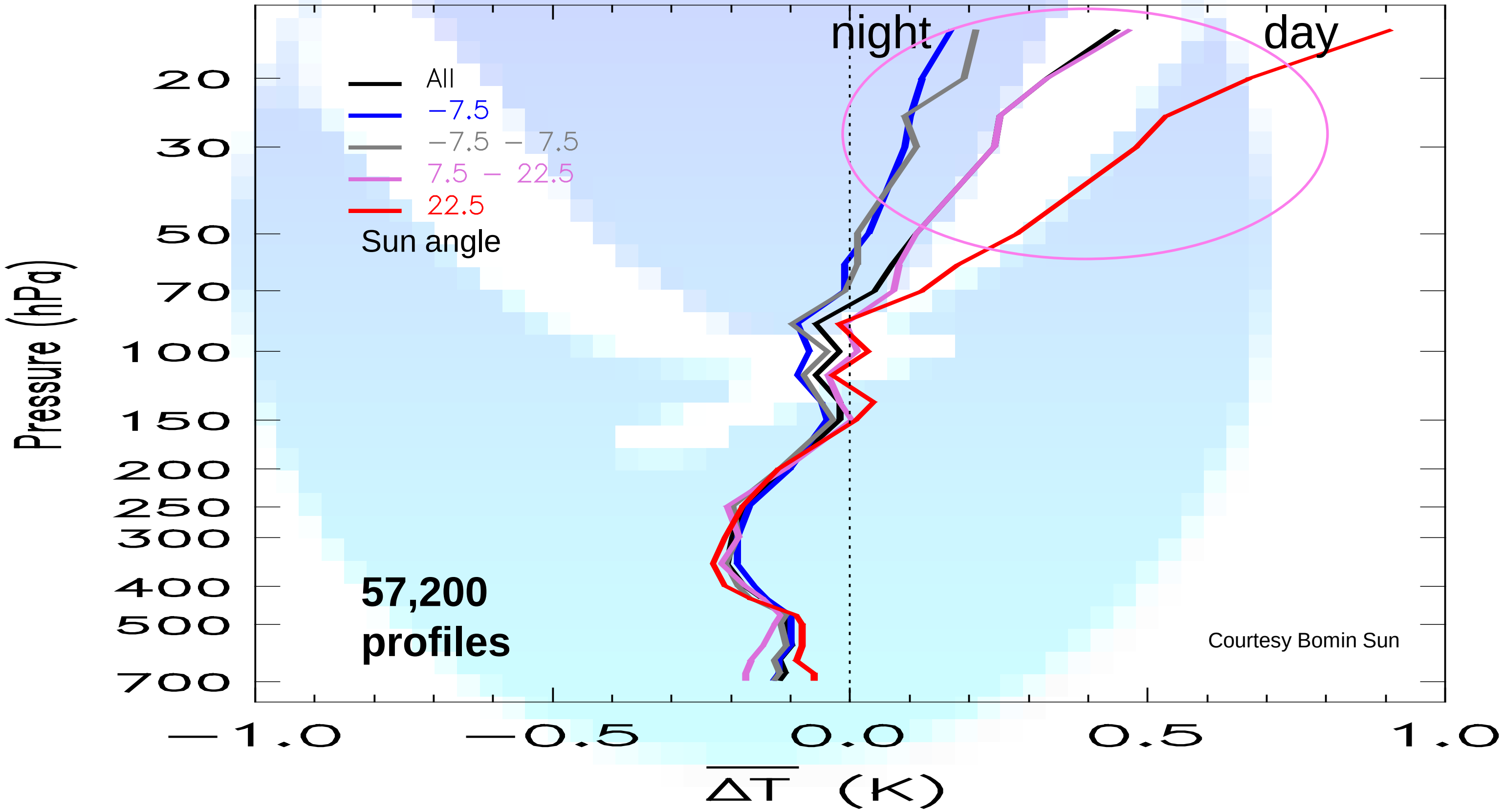
Lindenberg, Germany; 00Z (night)



COSMIC Tdry-minus-GRUAN RAOB … NPROVS+

Vaisala RS92
(radiation induced error)

(Conv Raob)-minus-(COSMIC Tdry) … NPROVS



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

OUTREACH (NPROVS+):

- Copernicus, European Earth Observation Program (3.8 billion, 6 yrs)
- GEWEX Water Vapor Assessment (G-VAP)
- GCOS Reference Upper Air Network (GRUAN)
- GSICS/GRUAN/GNSSRO WIGOS Workshop (May, 2014, Geneva)

Summary

- NPROVS and NPROVS+ (to) provide standardized EDR sounding product validation *and oversight at STAR*
- JPSS funded dedicated RAOB sustained through March 2015 …
- NUCAPS troubleshooting and deployment of NESDIS Unique Retrieval across CrIS, IASI and AIRS (and AMSU/ATMS) main goals
- Integration of GRUAN Uncertainty (K) analysis … *requires sounding EDR uncertainty estimates (recommended for all EDR's)*
- GPSRO as a reference from space
- Validation datasets routinely available and recommended for distribution and use internal, external and international

Extras

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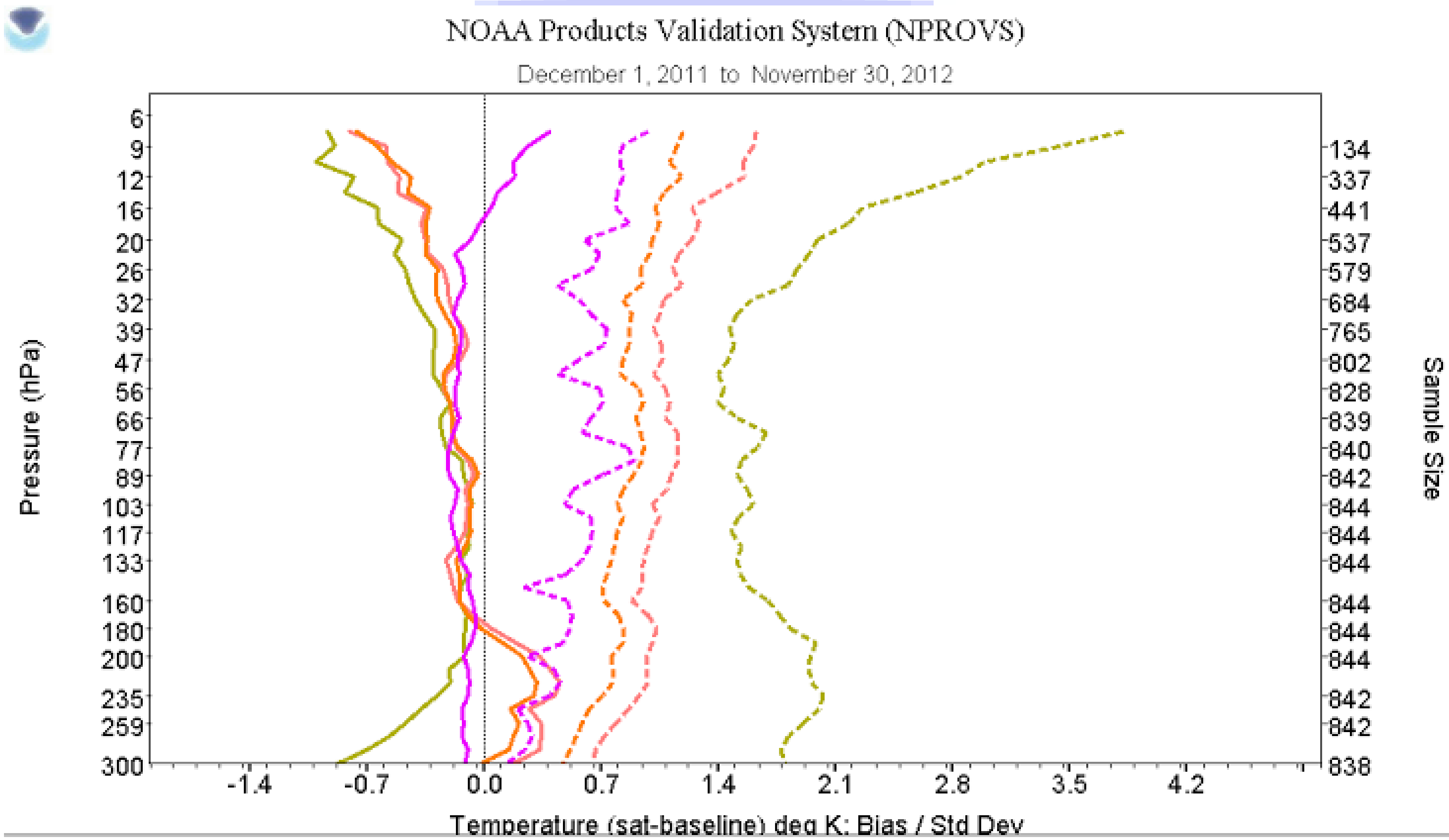
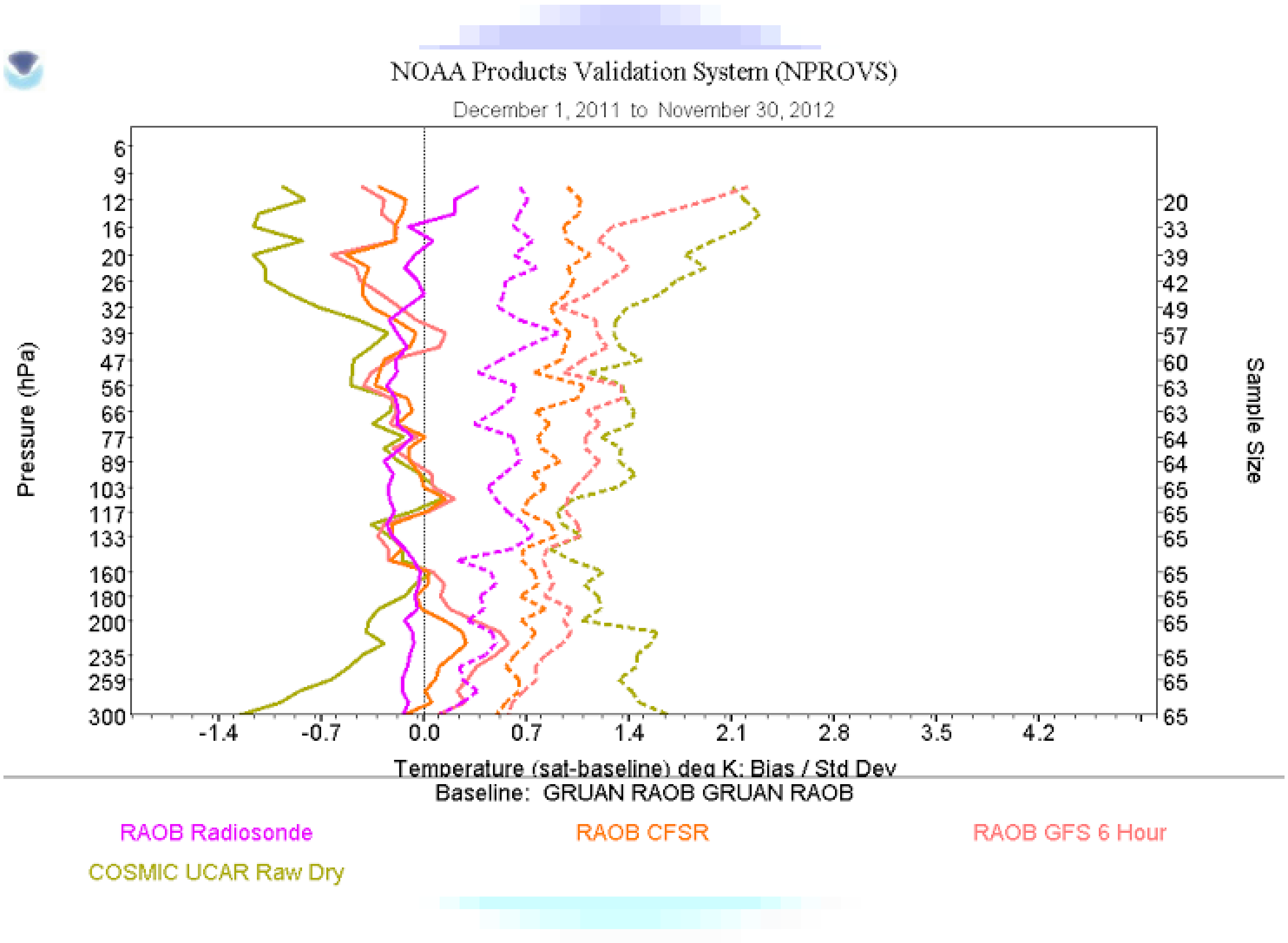


Baseline: GRUAN RAOB GRUAN RAOB

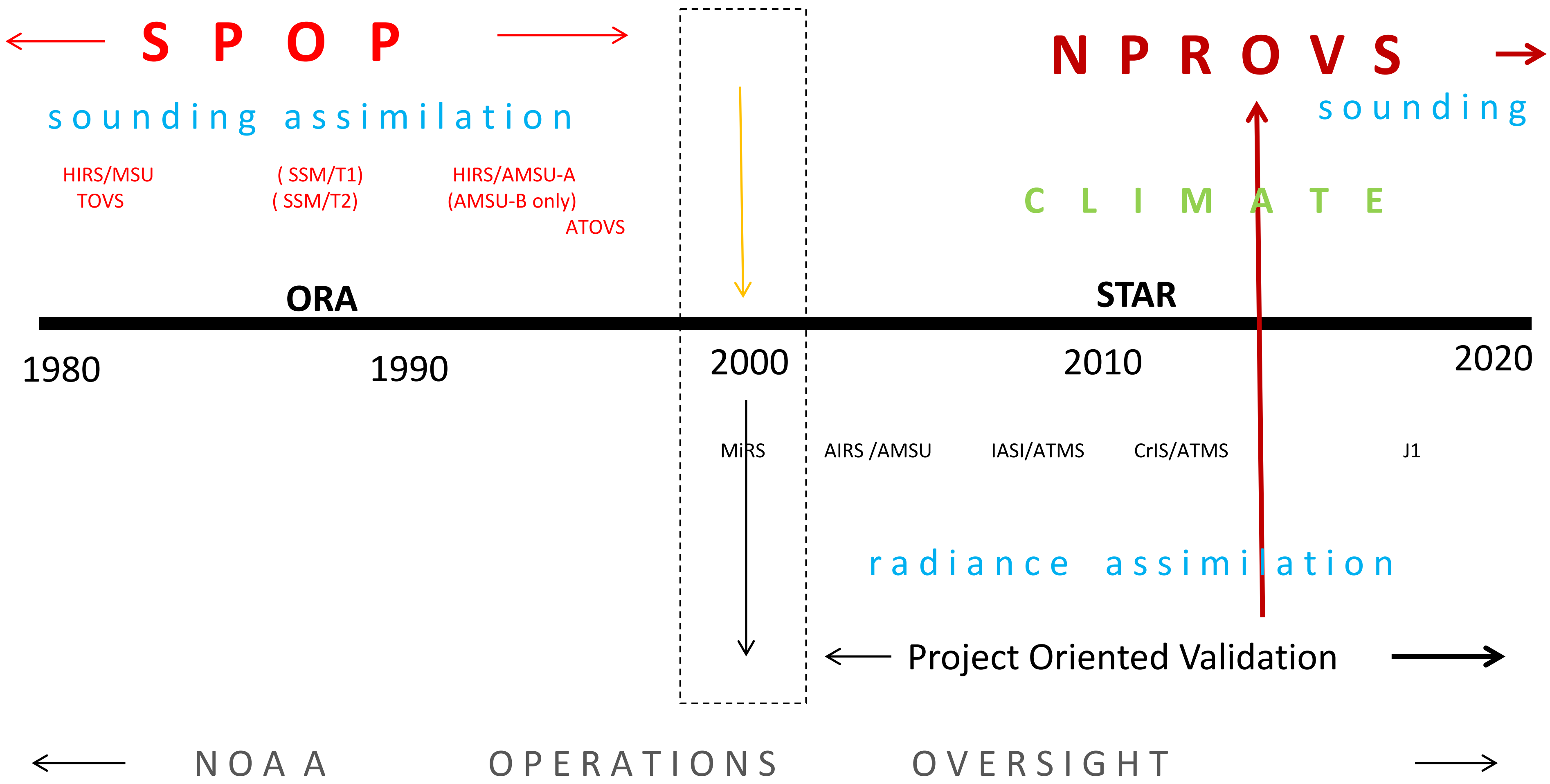
RAOB Radiosonde | RAOB CFSR | RAOB GFS 6 Hour

COSMIC UCAR Raw Dry

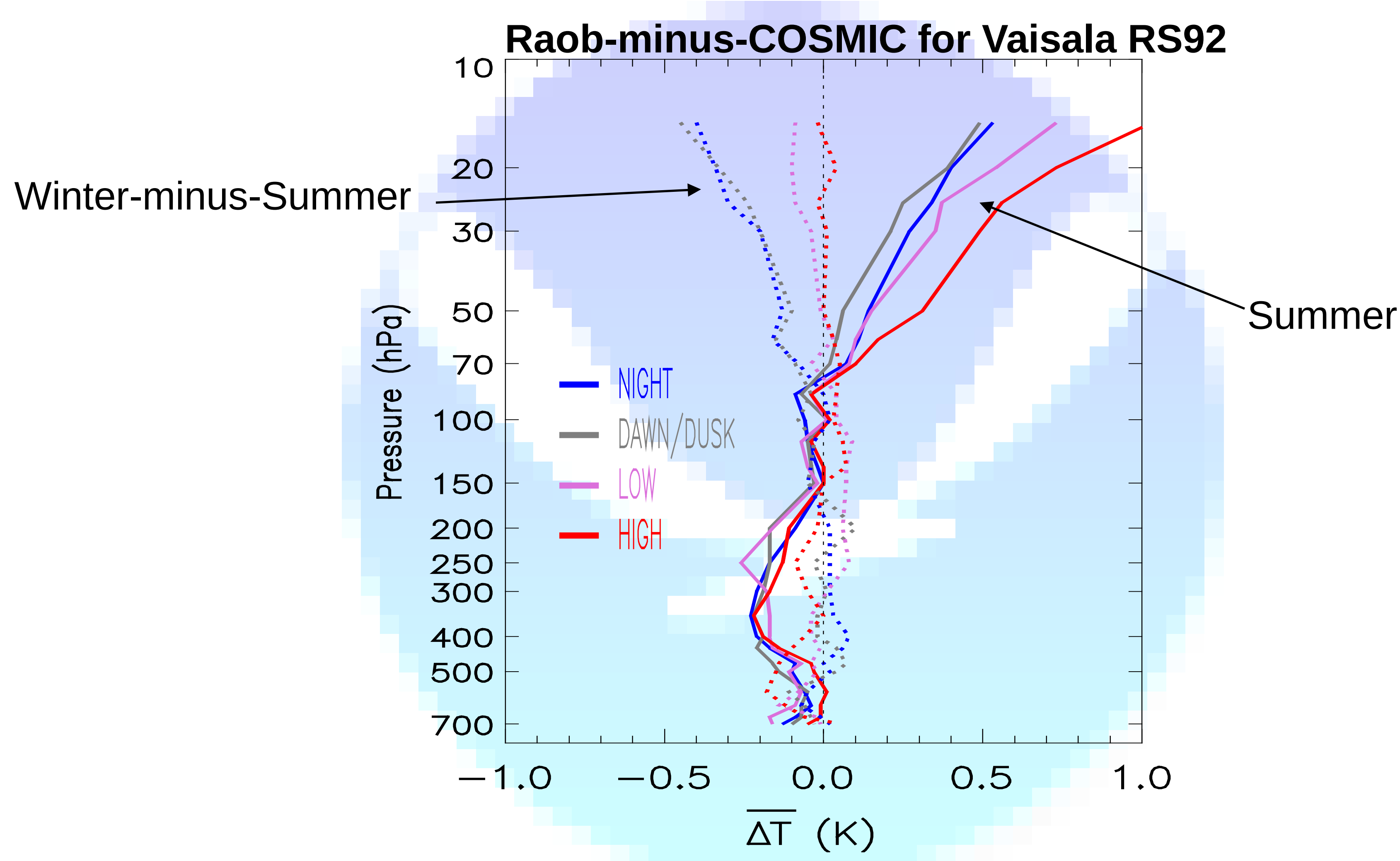

NOAA Products Validation System (NPROVS)
December 1, 2011 to November 30, 2012
Pressure (hPa)
6
9
12
16
20
26
32
39
47
56
66
77
89
103
117
133
160
180
200
235
259
300
Sample Size
20
33
39
42
49
57
60
63
63
64
64
65
65
65
65
65
65
65
65
65
-1.4
-0.7
0.0
0.7
1.4
2.1
2.8
3.5
4.2
Temperature (sat-baseline) deg K: Bias / Std Dev
Baseline: GRUAN RAOB GRUAN RAOB
RAOB Radiosonde
RAOB CFSR
RAOB GFS 6 Hour
COSMIC UCAR Raw Dry

+/- 3 hr / 150km

Brief History NOAA Program for Soundings



Restore Project Independent **NOAA PRO**duct **O**ver**S**ight



Seasonal variation in bias is bigger at nighttime: Summer relatively warmer than winter at night (NPROVS)

Applications using Satellite Sounder Products at the NASA SPoRT Center

Emily Berndt[1], Bradley Zavodsky[2], Gary Jedlovec[2], Clay Blankenship[3]

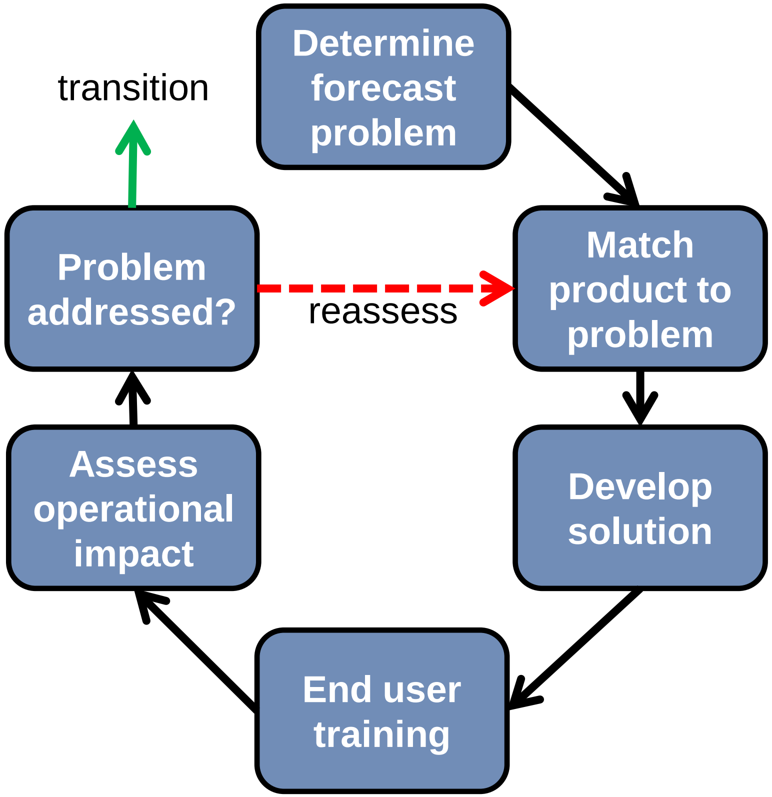
[1]NASA Postdoctoral Program Marshall Space Flight Center, Huntsville, Alabama
[2]Short-term Prediction Research and Transition Center NASA/MSFC, Huntsville, Alabama
[3]Universities Space Research Association, Huntsville, Alabama

STAR JPSS Annual Science Team Meeting
Soundings EDR Breakout Session 5d
14 May 2014

Outline

- SPoRT Paradigm/Overview
- Situational Awareness Activities
- Data Assimilation Activities

SPoRT Mission and Paradigm



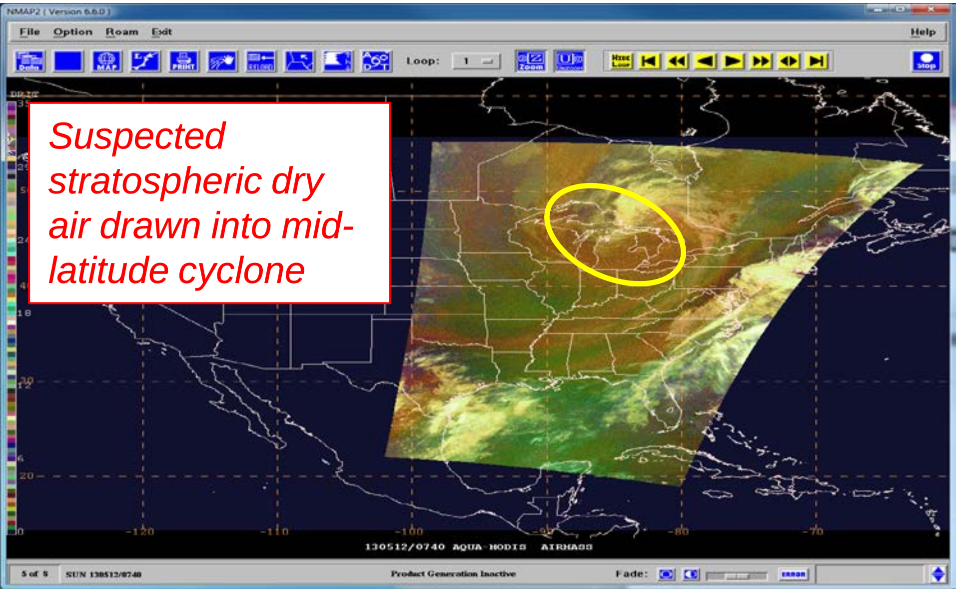
Test-Bed Environment

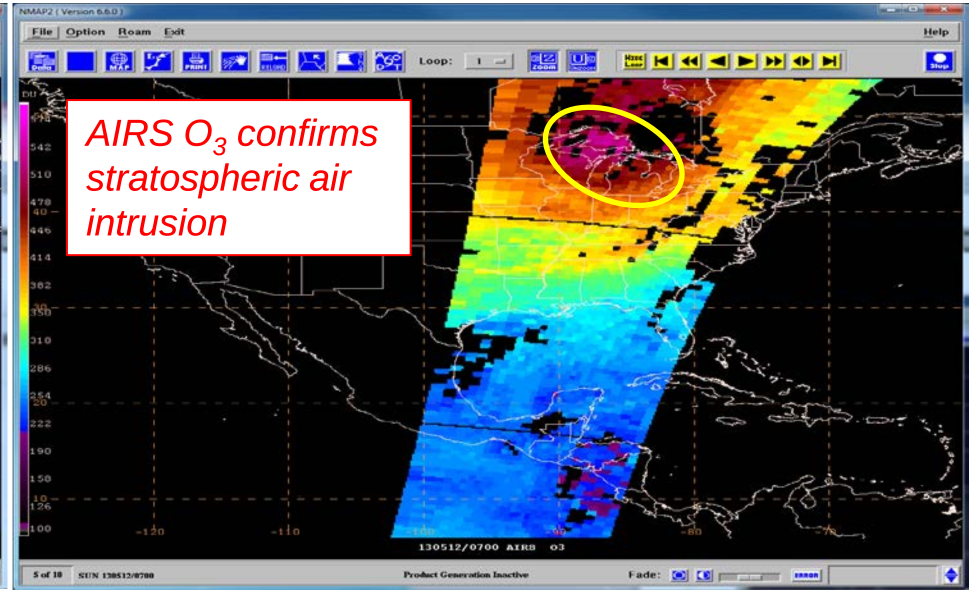
- *Apply satellite measurement systems and unique Earth science research to improve the accuracy of short-term weather prediction at the regional and local scale*
- Bridge the "Valley of Death"
- Can't just "throw data over the fence"
  - Maintain interactive partnerships with help of specific advocates or "satellite champions"
  - Integrate into user decision support tools
  - Create forecaster training on product utility
  - Perform targeted product assessments with close collaborating partners
- Concept has been used to successfully transition a variety of satellite datasets to operational users for nearly 10 years

Outline

- SPoRT Paradigm/Overview
- Situational Awareness Activities
- Data Assimilation Activities

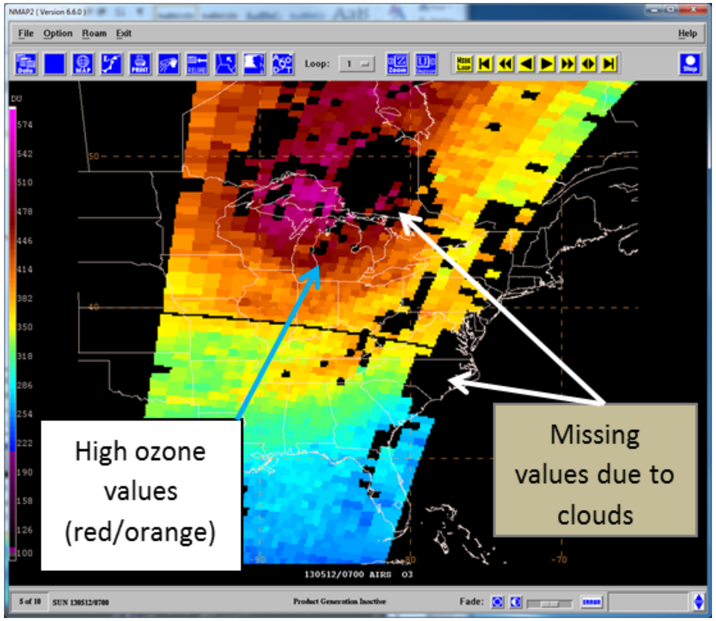
AIRS Total Ozone at WPC/OPC

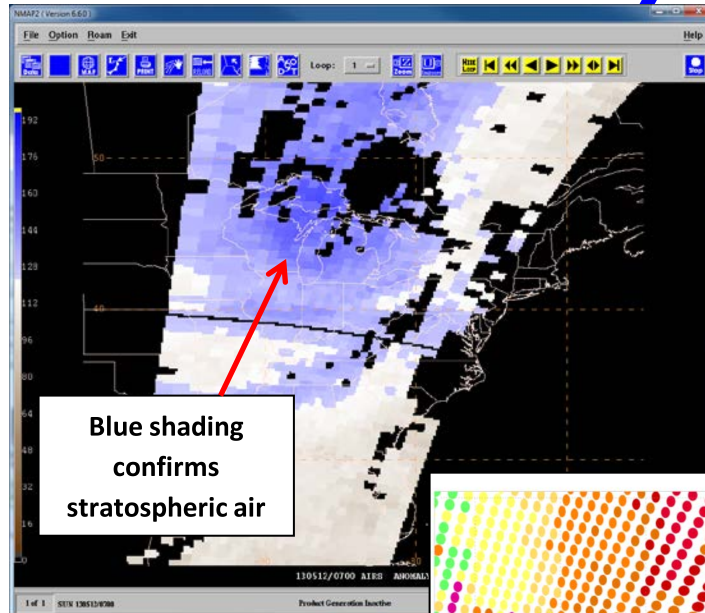


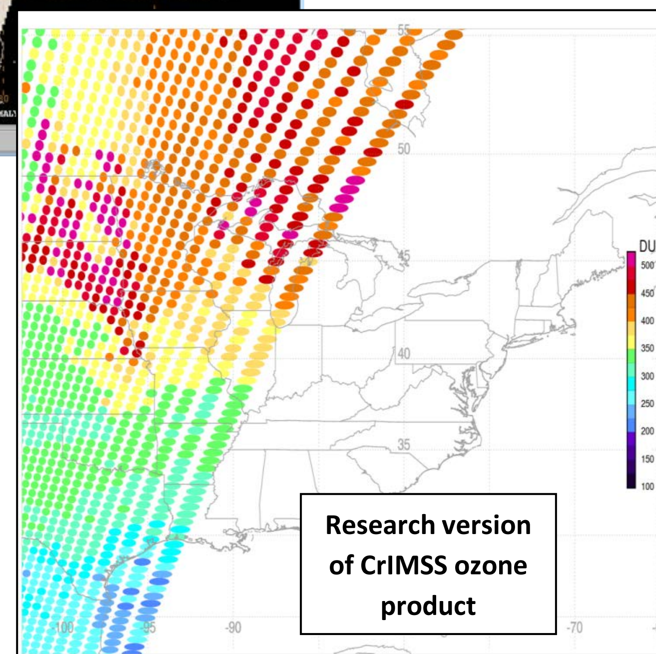


- AIRS helps determine stratospheric intrusions associated with mid-latitude and extratropical cyclone strengthening and damaging non-convective winds
- Enhances interpretation of RGB products
- Full transition of product to Weather Predication Center (WPC) and Ocean Prediction Center (OPC) in N-AWIPS decision support system
- Numerous posts on SPoRT and NOAA Proving Ground blogs related to product
- Journal of Operational Meteorology paper on use at WPC/OPC

AIRS Total Ozone at WPC/OPC



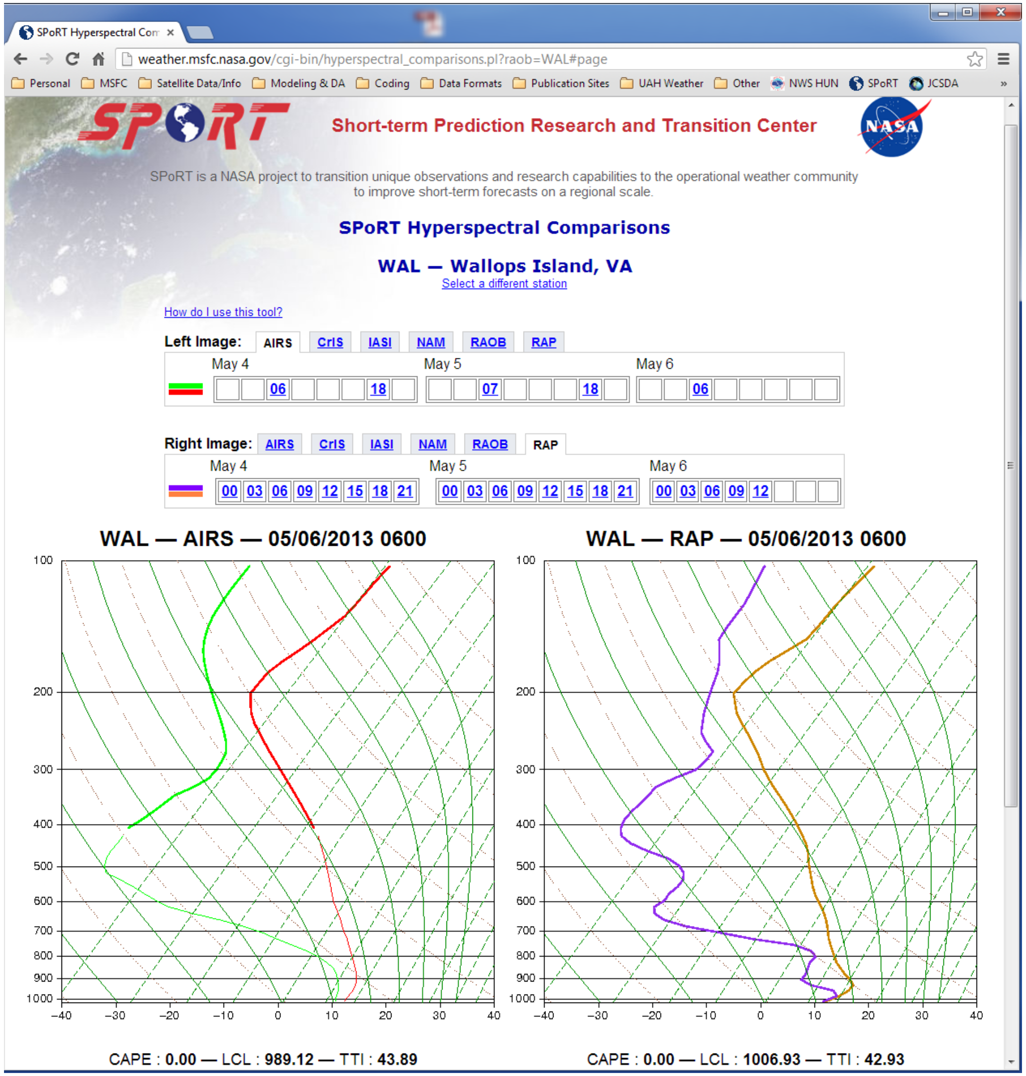




- Paper on development, application, and transition of SPoRT ozone products in draft for IEEE Transactions in Geoscience and Remote Sensing
- Anomaly product developed to confirm high ozone values are stratospheric and not just within the climatological range
- Similar CrIMSS product in development in anticipation of the release of NUCAPS

Profiles for convective initiation

- SPoRT is actively working to engage NWS forecasters in the use of soundings from AIRS for situational awareness of CI
- Mid-level moisture and above PBL lapse rates may be valuable for gaining confidence in regional models where other verifying observations are not available
- Currently developing training to communicate strengths and limitations of hyperspectral IR sounder profiles
- Plan to come up with a strategy for ingesting into AWIPS II
- Development of IASI and NUCAPS CrIS profiles will yield better comparison of AIRS, IASI, CrIS soundings and the potential for ~6 sondes per day locally



Outline

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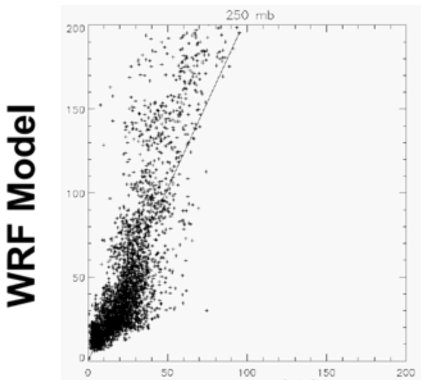
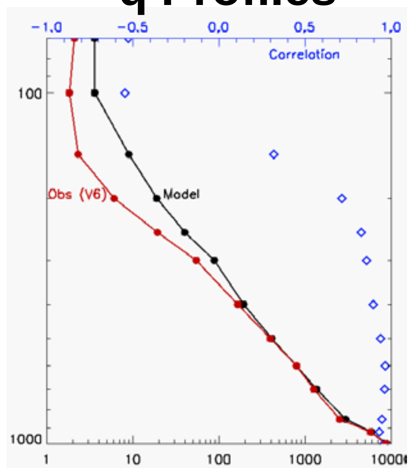
Assimilation of Bias-Corrected AIRS Profiles

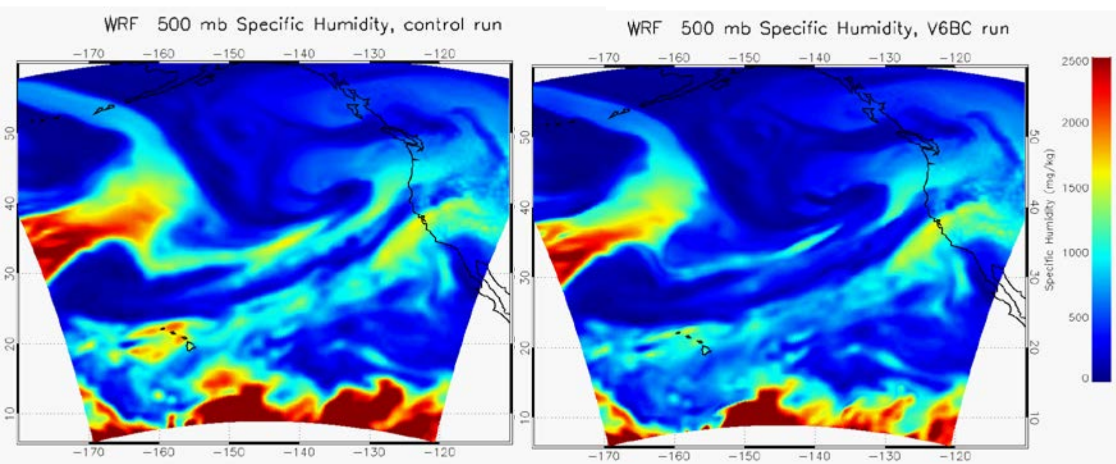
250 mb Spec. Hum. [g/kg]



Uncorrected AIRS V6

Mean Model/Obs q Profiles

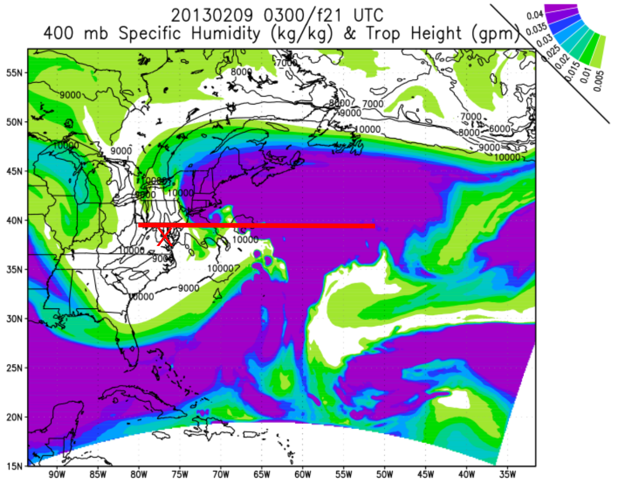




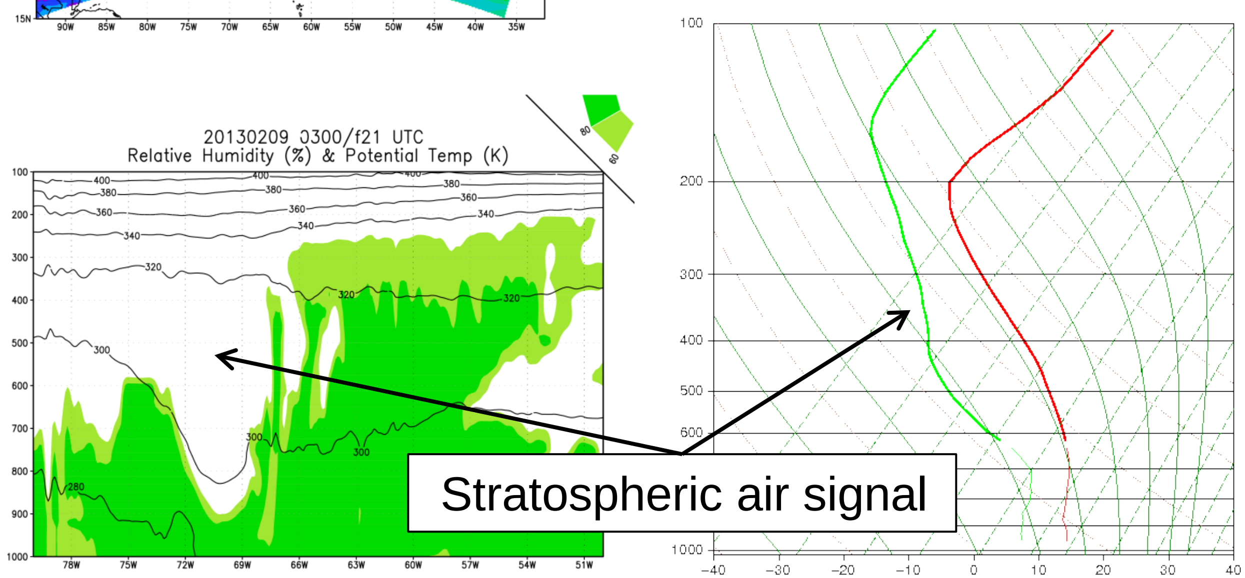
Goal: improve WRF forecasts by assimilating retrieved AIRS T/q profiles

- In areas where radiance observations are rejected due to cloud contamination, we can use retrieved profiles above the cloud level
- One problem is the systematic humidity bias between model and observations in middle/upper troposphere (obs are drier).
- q bias is removed by a simple linear correction at each layer (T bias is near zero)
- Atmospheric river features are narrower after assimilating AIRS profiles
- Use of bias correction means this is not just a result of the observations drying the model everywhere (since mean innovation is now near zero)

Improving Mid-Latitude Cyclone and Non-Convective Wind Forecasts



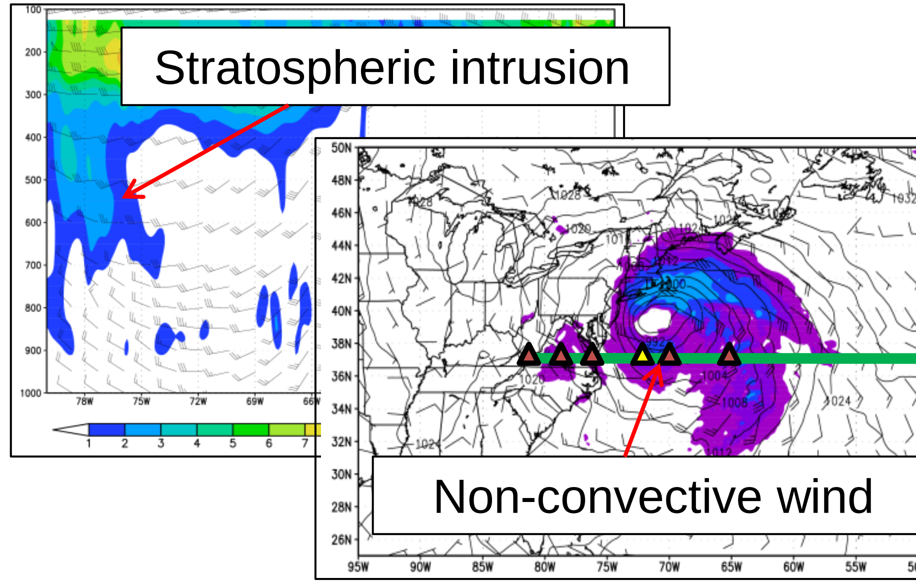
- Ongoing research includes the assimilation of AIRS, IASI and CrIMSS T and q profiles into the WRF model to address stratospheric intrusions and non-convective wind events
- Will addition of profiles improve the model representation of T and q and better resolve warm, dry stratospheric air intrusions?

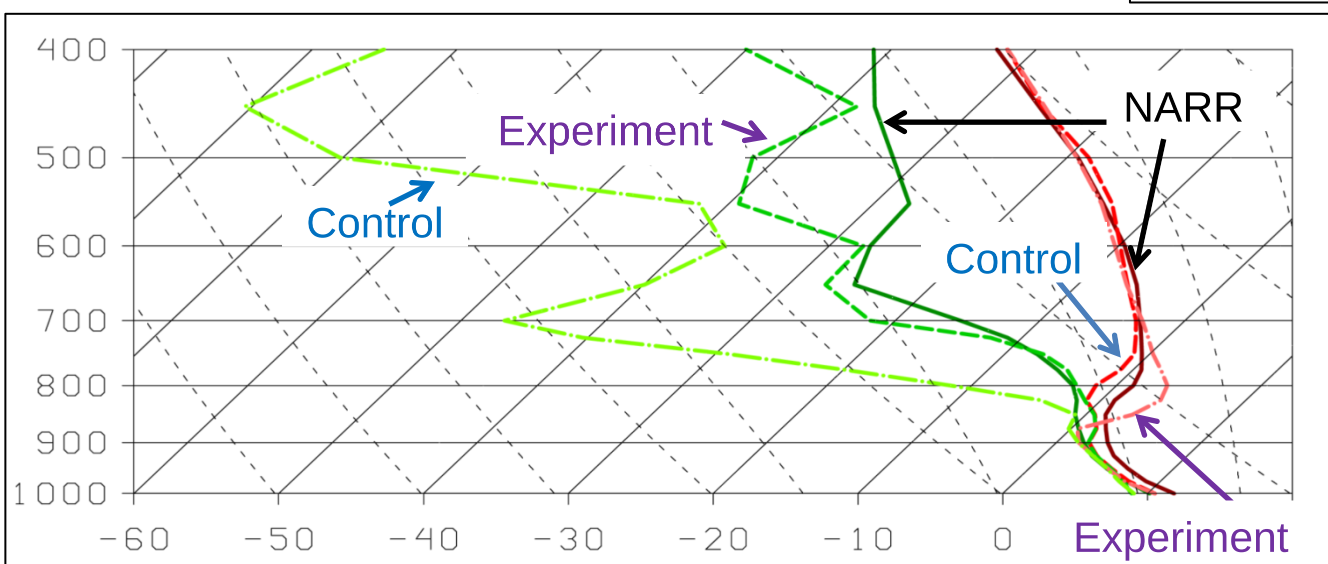


- If stratospheric intrusions are better resolved, will model representation of near-surface non-convective winds improve?

Improving Mid-Latitude Cyclone and Non-Convective Wind Forecasts

- Results show modeling low-level stability is more important than correctly modeling the stratospheric intrusion
- Modeling low-level stability could be improved by:
  - using NUCAPS CrIS instead of CrIMSS
  - developing a GSI Module to assimilate profiles with appropriate Error values





Modeling low-level inversion important for resulting wind forecast

Summary

- SPoRT is a proven community leader for transitioning satellite products to operational end users and is working to bring data from hyperspectral infrared sounders to forecasters
- SPoRT products using AIRS data are currently or will soon be evaluated at WFOs and National Centers
  - Ozone profiles
  - Sounder profiles for convective initiation
- SPoRT also assimilates AIRS, CrIMSS, and IASI into regional models to address specific forecast issues
  - Atmospheric rivers
  - Mid-latitude cyclones/non-convective winds
- We continue to develop similar capabilities with IASI and CrIS profiles as well, especially as NUCAPS becomes available

Please contact me if you have an idea for an AIRS, CrIS, or IASI -related product that might benefit operational forecasters

emily.b.berndt@nasa.gov

http://weather.msfc.nasa.gov/sport/ http://nasasport.wordpress.com/

Validation of the NOAA Unique CrIS/ATMS Processing System (NUCAPS) Operational Retrieval Products

Nicholas R. Nalli[1,2], A. Gambacorta[1,2], T. Reale[3], B. Sun[1,3], Q. Liu[2], C. Barnet[4], T. S. King[1,2], W. W. Wolf[2], F. Iturbide-Sanchez[1,2], C. Tan[1,2], D. Tobin[5], L. Borg[5], E. Joseph[6], V. R. Morris[6], A. K. Mollner[7], F. Tilley[1,2], X. Xiong[1,2], M. Wilson[1,2], *et al.*

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2014 STAR JPSS Annual Meeting
College Park, Maryland, USA
14 May 2014

Outline

- **Introduction and Background**
- **Validation Methodology**
  - NWP Global Comparisons
  - Satellite EDR Intercomparisons
  - Conventional RAOB Matchup Assessments
  - Dedicated/Reference RAOB Matchup Assessments
  - Intensive Field Campaign "Dissections"
- **Assessment Methodology**
  - Reducing Correlative Measurements to layers
  - Statistical Metrics for Sounder EDR Validation
  - Use of Averaging Kernels
- **STAR Validation Archive (VALAR)**
  - VALAR Concept and Objectives
  - VALAR Data
- **Preliminary NUCAPS Validation**
  - AVTP and AVMP
  - Ozone Profile
- **Future Work**

The Importance of Validating Sounder EDRs

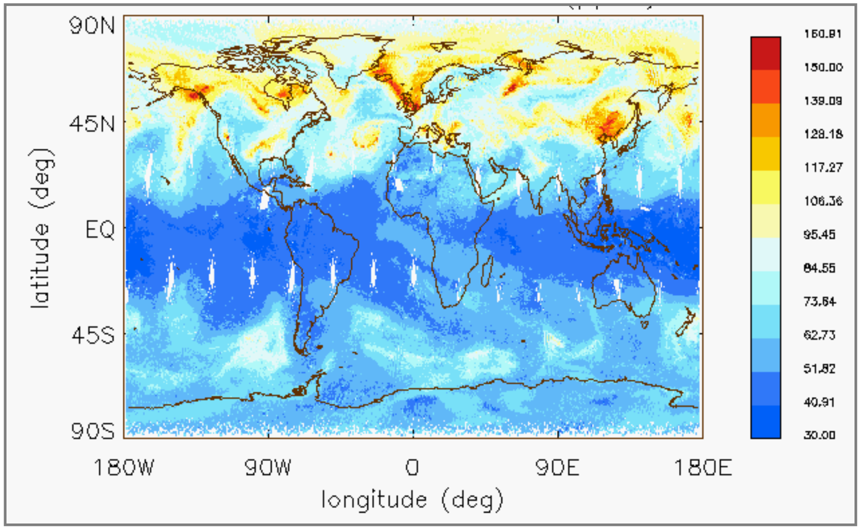
- **Validation** is "the process of ascribing uncertainties to these radiances and retrieved quantities through comparison with correlative observations" (*Fetzer et al.,* 2003).
  - EDR validation provides implicit validation of SDRs
- EDR validation enables development/improvement of algorithms
- Includes validation of the cloud-cleared radiances (a Level 2 product shown to have positive impact on NWP; e.g., *Le Marshall et al.,* 2008)
- Users of sounder EDR observations (AVTP, AVMP and trace gas) include
  - Weather Forecast Offices (AWIPS)
    - Nowcasting / severe weather
  - NOAA Data Centers (e.g., NGDC, CLASS)
  - Basic and applied science research/investigation (e.g., *Pagano et al.,* 2013)

CrIMSS Operational EDR Algorithms

- **NOAA Unique CrIS/ATMS Processing System (NUCAPS)**
  - Exact line-for-line modular implementation of the iterative, multistep AIRS Science Team retrieval algorithm
  - Non-precipitating conditions (cloudy, partly cloudy, clear)
  - AVTP, AVMP and trace gas profiles (O_3, CO, CO_2, CH_4, etc.)
  - Operational algorithm starting Sep 2013
- **Original IDPS Algorithm**
  - Optimal Estimation (OE) algorithm originally developed by AER
  - CrIMSS operational product (MX7.1) validated through Beta and Provisional maturities (*Divakarla et al.,* 2014)
  - Replaced by NUCAPS in Sep 2013; validation transition to NUCAPS

NUCAPS Ozone retrieval 450 hPa

15 May 2013



JPSS Cal/Val Program

- **JPSS Cal/Val Phases**
  - Pre-Launch / Early Orbit Checkout (EOC)
  - **Intensive Cal/Val (ICV)**
    - Validation of EDRs against multiple correlative datasets
  - **Long-Term Monitoring (LTM)**
    - Characterization of all EDR products and long-term demonstration of performance
- In accordance with the JPSS phased schedule, the **SNPP CrIMSS EDR cal/val plan** was devised to ensure the EDR would meet the mission Level 1 requirements (*Barnet,* 2009)
- The **EDR validation methodology** draws upon previous work with AIRS and IASI (*Nalli et al.,* 2013, *JGR Special Section on SNPP Cal/Val*)

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

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

Validation of NUCAPS Operational Retrieval Products

VALIDATION METHODOLOGY

Validation Methodology Hierarchy (1/2)

1. **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

2. **Satellite EDR (e.g., AIRS, ATOVS, COSMIC) *Intercomparisons***
   - Global samples acquired from Focus Days (e.g., AIRS)
   - 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)

3. **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
     - Non-uniform, less-accurate and poorly characterized radiosonde types used in data sample

Validation Methodology Hierarchy (2/2)

4. **Dedicated/Reference RAOB Matchup *Assessments***
   - Dedicated sondes: Vaisala RS92-SGP dedicated for the purpose of satellite validation
     - Well-specified error characteristics and optimal accuracy
     - Minimal mismatch errors
     - Include atmospheric state best estimates (*Tobin et al.,* 2006), merged soundings (e.g., lidar) and uncertainty estimates (dual launches)
   - Reference sondes: CFH, GRUAN-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, PMRF, BCCSO, AEROSE, GRUAN

5. **Intensive Field Campaign *Dissections***
   - Include dedicated RAOBs, especially those *not* assimilated into 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)
   - Detailed performance specification; state specification; SDR cal/val; EDR "dissections"
   - E.g., AEROSE, JAIVEX, WAVES, AWEX-G, EAQUATE

Validation of NUCAPS Operational Retrieval Products

ASSESSMENT METHODOLOGY

Assessment Methodology: Reducing Truth to Correlative Layers

- The **measurement equation** (e.g., *Taylor and Kuyatt,* 1994) for retrieval includes forward and inverse operators (*Rodgers*, 1990) to estimate the measurand, $\mathbf{x}$, on forward model layers:

$$\hat{\mathbf{x}} = I[F(\mathbf{x}, \mathbf{b}), \mathbf{b}, \mathbf{c}]$$

- **Rigorous validation** therefore requires high-resolution truth measurements (e.g., dedicated RAOB) be **reduced to correlative RTA layers** (*Nalli et al.,* 2013, *JGR Special Section on SNPP Cal/Val*)
- **Radiative transfer approach** is to integrate quantities over the atmospheric path (e.g., number densities → column abundances), interpolate to RTA (arbitrary) levels, then compute then RTA layer quantities, e.g.,

$$\Sigma_x(z) = \int_{z_t}^{z} N_x(z')\, dz'$$

Assessment Methodology: Statistical Metrics

- Level 1 AVTP and AVMP accuracy requirements are defined over **coarse layers**, roughly 1–5 km for tropospheric AVTP and 2 km for AVMP (e.g., Q. Liu's presentation).

AVTP

$$\mathrm{RMS}(\Delta T_{\mathfrak{L}}) = \sqrt{\frac{1}{n_j}\sum_{j=1}^{n_j}(\Delta T_{\mathfrak{L},j})^2} \qquad \mathrm{BIAS}(\Delta T_{\mathfrak{L}}) \equiv \overline{\Delta T_{\mathfrak{L}}} = \frac{1}{n_j}\sum_{j=1}^{n_j}\Delta T_{\mathfrak{L},j}$$

$$\mathrm{STD}(\Delta T_{\mathfrak{L}}) \equiv \sigma(\Delta T_{\mathfrak{L}}) = \sqrt{[\mathrm{RMS}(\Delta T_{\mathfrak{L}})]^2 - [\mathrm{BIAS}(\Delta T_{\mathfrak{L}})]^2}$$

AVMP and O_3

- W2 weighting was used in determining Level 1 Requirements
- To allow compatible STD calculation, W2 weighting should be consistently used for both RMS and BIAS

$$\mathrm{RMS}(\Delta q_{\mathfrak{L}}) = \sqrt{\frac{\sum_{j=1}^{n_j} W_{\mathfrak{L},j}(\Delta q_{\mathfrak{L},j})^2}{\sum_{j=1}^{n_j} W_{\mathfrak{L},j}}}, \qquad \text{water vapor weighting factor, } W_{\mathfrak{L},j},$$

$$\mathrm{BIAS}(\Delta q_{\mathfrak{L}}) = \frac{\sum_{j=1}^{n_j} W_{\mathfrak{L},j}\,\Delta q_{\mathfrak{L},j}}{\sum_{j=1}^{n_j} W_{\mathfrak{L},j}}, \qquad W_{\mathfrak{L},j} = \begin{cases} 1 & ,\ \mathrm{W}^0 \\ q_{\mathfrak{L},j} & ,\ \mathrm{W}^1 \\ (q_{\mathfrak{L},j})^2 & ,\ \mathrm{W}^2 \end{cases}$$

$$\mathrm{STD}(\Delta q_{\mathfrak{L}}) = \sqrt{[\mathrm{RMS}(\Delta q_{\mathfrak{L}})]^2 - [\mathrm{BIAS}(\Delta q_{\mathfrak{L}})]^2}$$

Assessment Methodology: Use of Averaging Kernels (AKs)

- **AKs** define the **vertical sensitivity** of the sounder measurement system

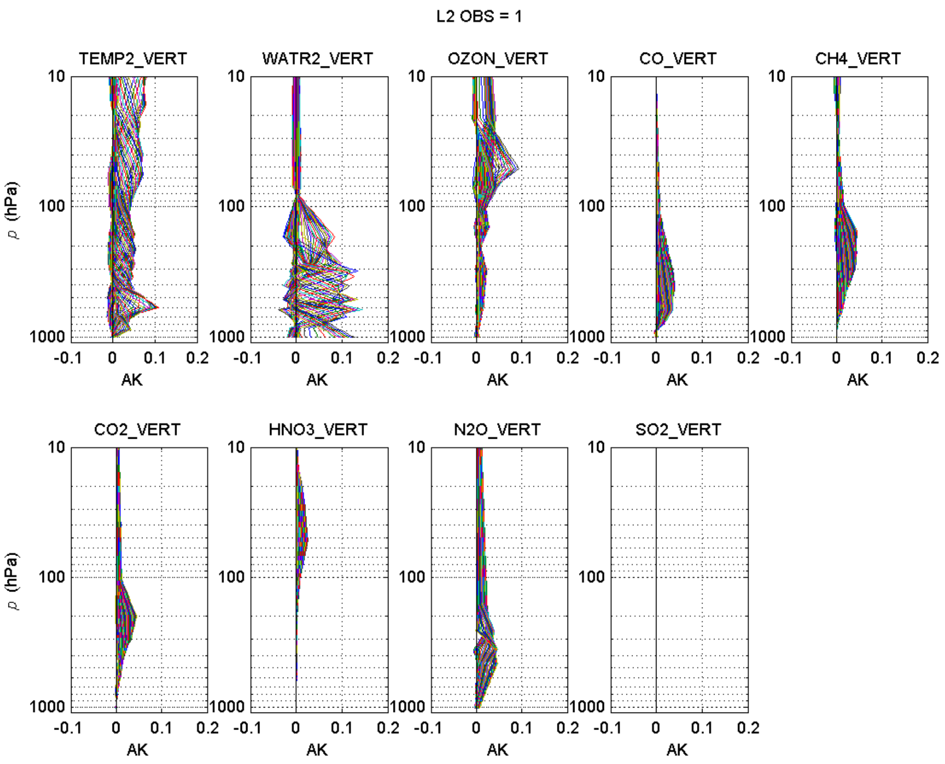
$$\mathbf{A} \equiv \frac{\partial \hat{\mathbf{x}}}{\partial \mathbf{x}}$$

- Facilitates intercomparisons of profiles obtained by two different observing systems

- Retrieval AKs can be used to "smooth" correlative truth (RAOBs reduced to RTA layers), thereby **removing null-space errors** otherwise present

$$\mathbf{x}_s = \mathbf{A}(\mathbf{x} - \mathbf{x}_0) + \mathbf{x}_0$$

NOAA-Unique IASI Averaging Kernels



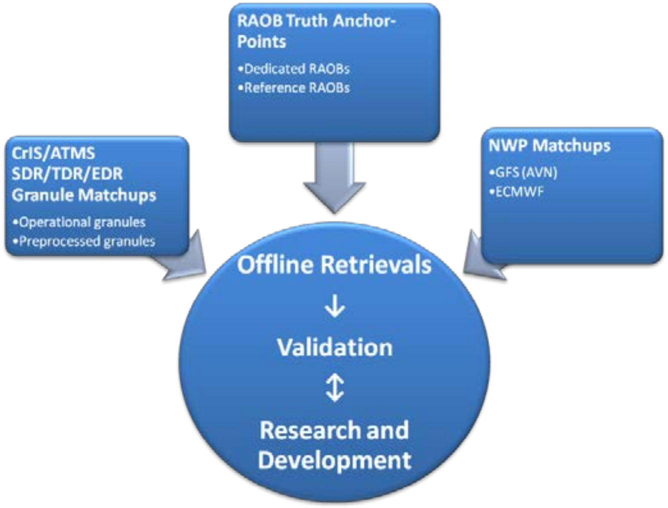
Validation of NUCAPS Operational Retrieval Products

STAR VALIDATION ARCHIVE (VALAR)

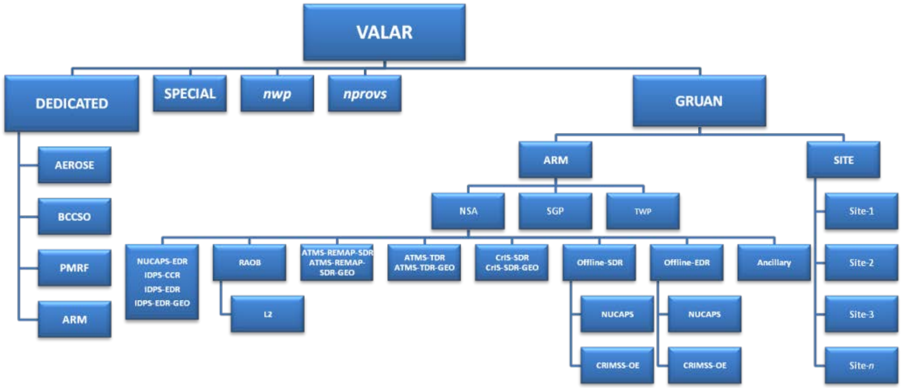
Validation Archive (VALAR)

- We are in the process of building a **Validation Archive (VALAR)** for satellite sounder research (viz., CrIS/ATMS, IASI)
- **VALAR** is intended to serve as a go-to archive for the life of the SNPP mission to **directly support validation and development**

VALAR Concept and Objectives

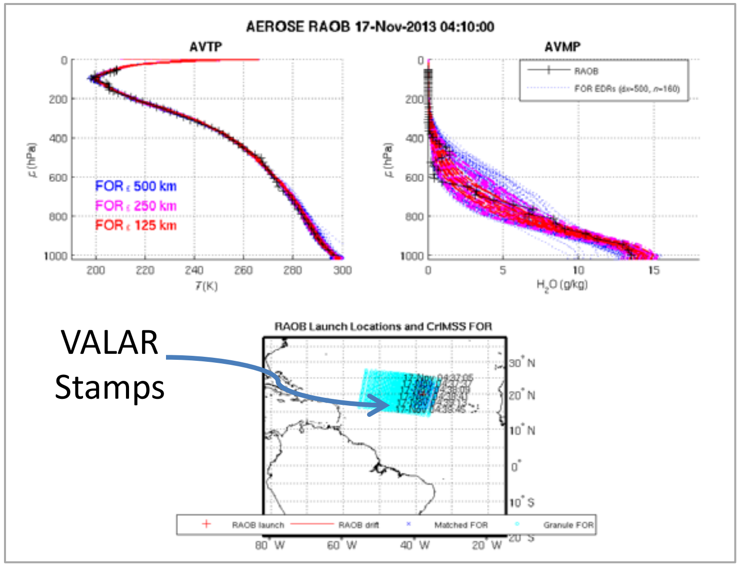


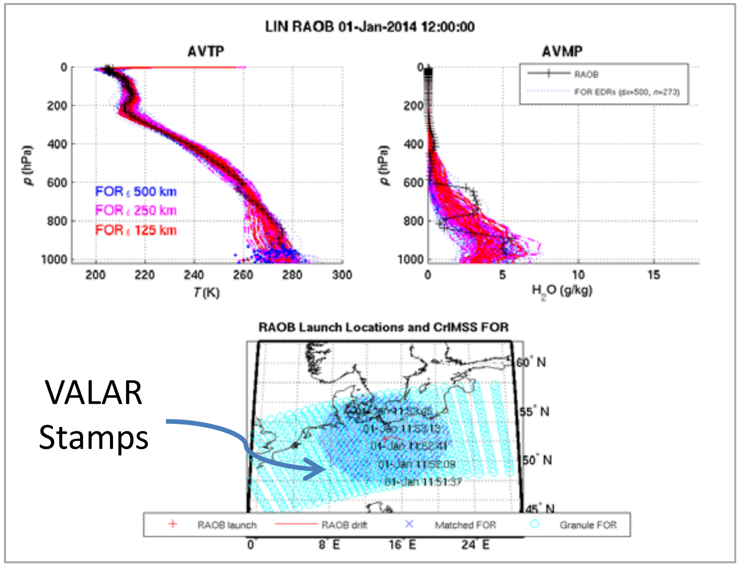
VALAR Data Organization



VALAR Data

- **High-quality RAOB Anchor Points** (dedicated and reference sondes)
  - Original native files “untouched” at full resolution
  - Reduced 100 RTA layers (i.e., **correlative truth**)
- **CrIS/ATMS SDR/TDR/EDR Granule “Stamps”**
  - A VALAR “stamp” is roughly defined as a granule file matched with a RAOB anchor point needed for offline retrievals and validation
  - SDR/TDR/EDR stamps consist of 4-scan line granules within ±1 minute of overpass (≈500 km radius, usually 4-5 granules centered on RAOB)

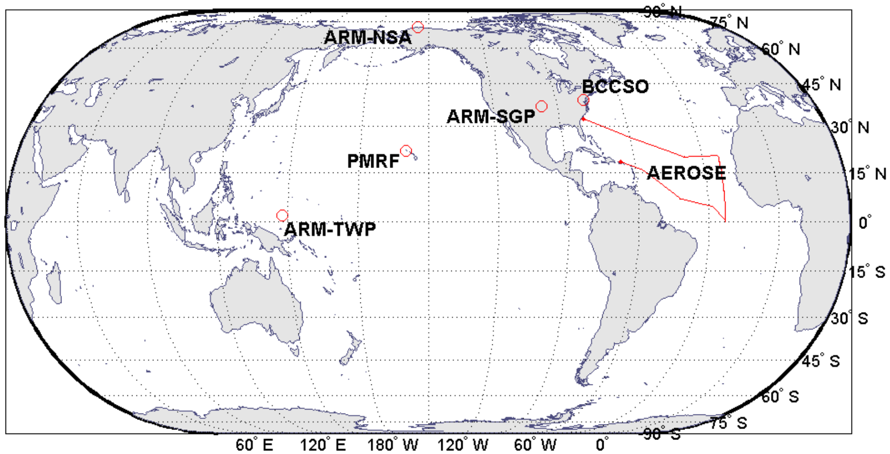




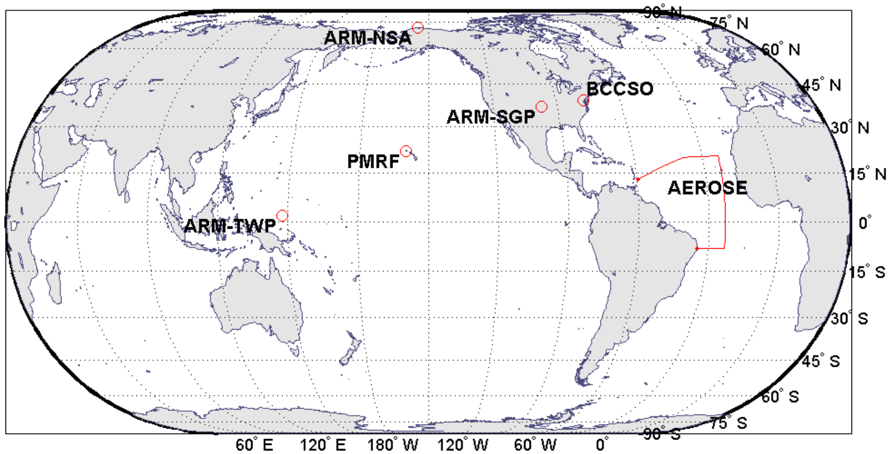
JPSS SNPP Dedicated RAOB Truth

- **PMRF** (Kauai, Hawaii)
  - 2012 SNPP testbed site
- **BCCSO** (Beltsville, MD)
  - Howard University
  - Continent, urban
- **ARM Sites** (*Tobin et al.,* 2006)
  - TWP (Manus Island)
  - SGP (Oklahoma)
  - NSA (Alaska)
- **AEROSE Campaigns** (*Nalli et al.,* 2006, 2011)
  - Tropical Atlantic Ocean
  - Dust/smoke aerosols, Saharan air layers
  - Dedicated Ozonesondes
  - Truly independent dataset

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

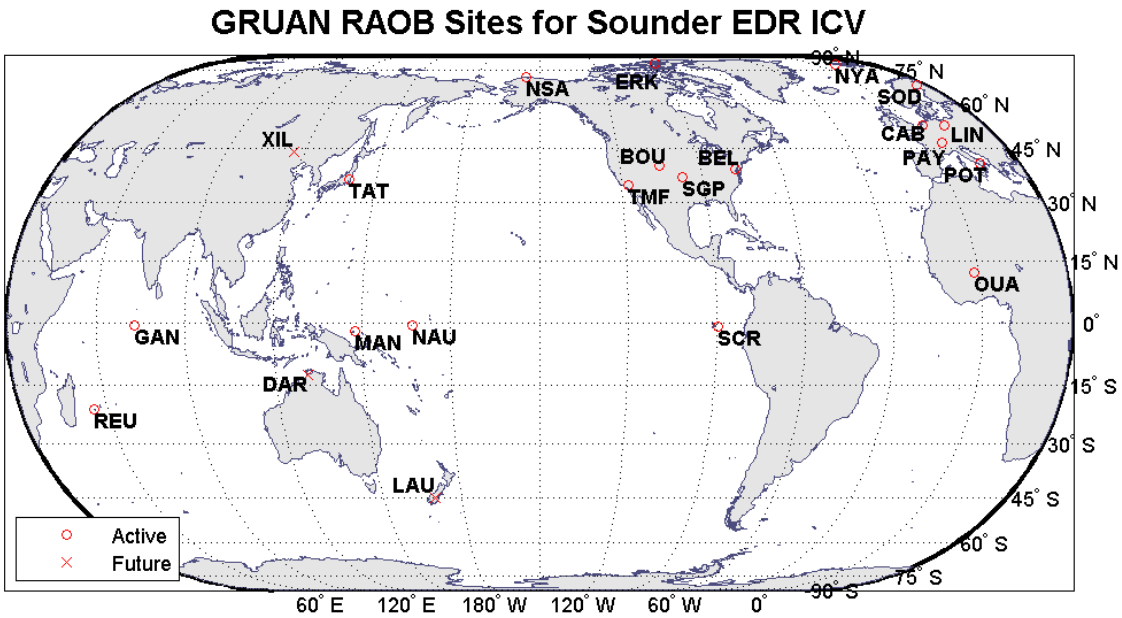


S-NPP CrIMSS EDR ICV Dedicated RAOB Sites (Year 2)



Reference RAOB Truth

- GRUAN reference RAOB (*Seidel et al.*, 2009) collocations (00:00 and 12:00 UTC) are currently being acquired via the **NPROVS+** system (e.g., *Reale et al.*, 2012)
  - Traceable reference measurements
- NPROVS+ collocations support development of the **STAR Validation Archive (VALAR)**



VALAR and NPROVS+

NPROVS+

- 7-day delay GRUAN and dedicated RAOB collocation
- Nearest-FOR Operational-EDR Collocation Files
- Nearest-FOR Reprocessed-EDR Collocation Files
- User Interface Tools: PDISP, NARCS and ODS
- **Routine ICV and LTM**

↔

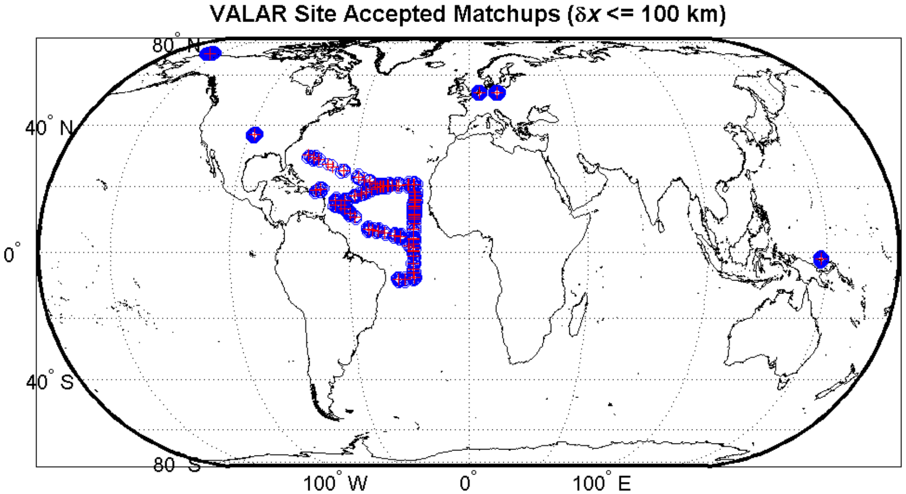
VALAR

- Reduced 100 layer collocated RAOB
- SDR/TDR/EDR Granule Stamps
- Host Offline Retrievals
- Reprocessed EDR Granule Stamps
- **Research ICV and LTM**
- Facilitate Algorithm Research/Development

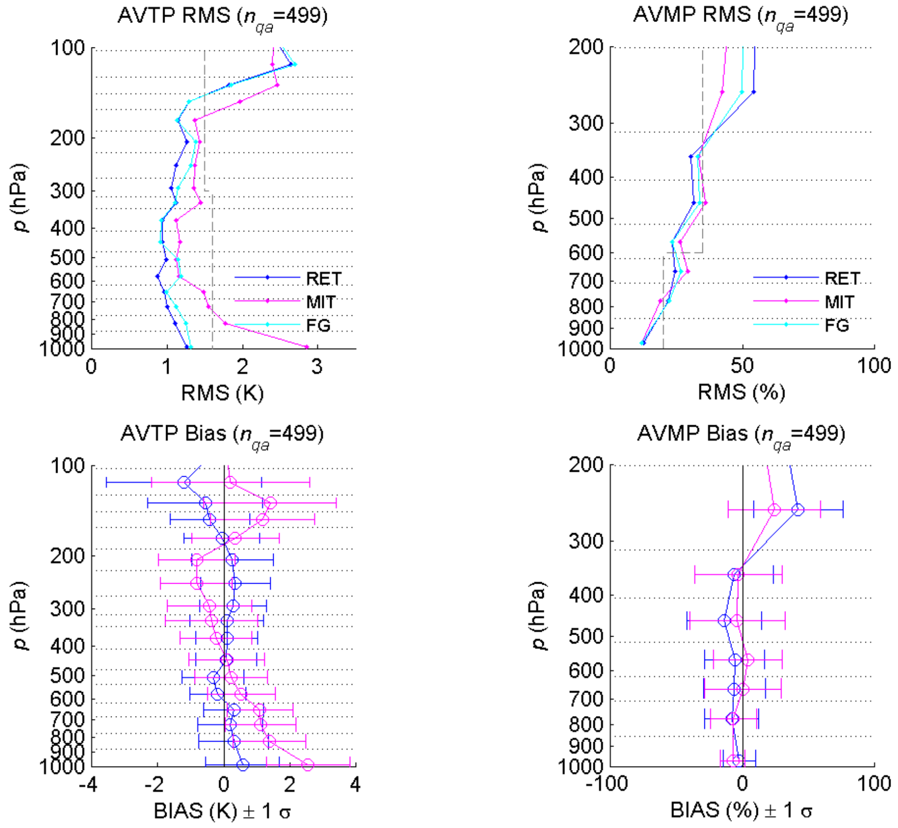
Validation of NUCAPS Operational Retrieval Products

NUCAPS VALIDATION

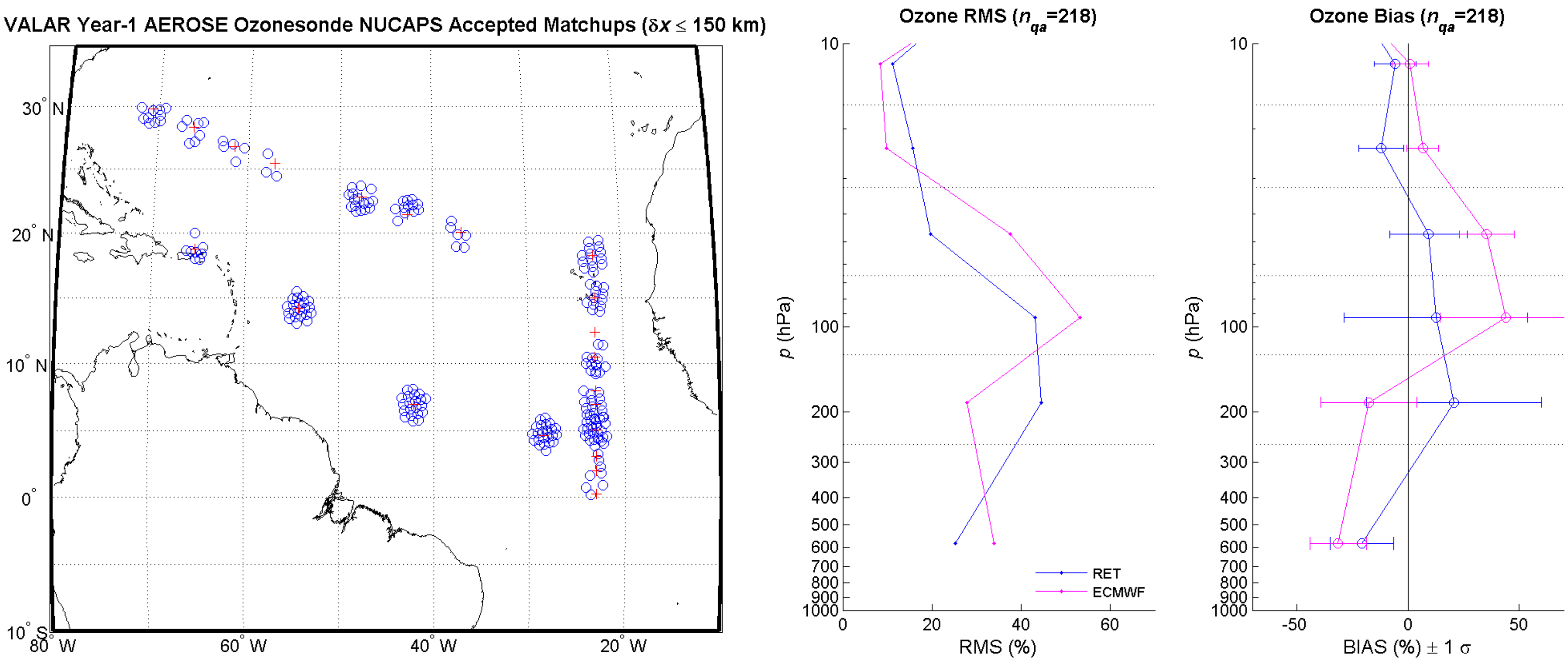
NUCAPS AVTP/AVMP – VALAR Tropics



Tropics



NUCAPS Ozone – VALAR AEROSE Year-1
Dedicated Ozonesondes



Future Work

- **SNPP NUCAPS Stages 1-3 Validated Maturities**
  - Support short-term NUCAPS algorithm updates/improvements

- **Intensive Cal/Val (ICV)** and **Long Term Monitoring (LTM)** of **NUCAPS EDRs**
  - VALAR growth, development and enhancements
  - **Operational and offline AVTP and AVMP validation**
    - Coarse-layer ensemble statistical analyses versus dedicated and reference RAOB truth
  - **Trace gas profile EDR (e.g., O_3, CO) validation**
    - Ozonesondes (e.g., AEROSE, SHADOZ)
    - WRF-CHEM modeling (e.g., *Smith and Nalli,* 2014)
  - **GRUAN reprocessing** of RS92 RAOB data (e.g., **AEROSE**)
  - **Apply averaging kernels** in NUCAPS error analyses
  - **calc – obs** (e.g., CCR) analyses
  - Skin SST EDR validation
  - Support long-term NUCAPS EDR algorithm development
    - A priori
    - AVTP/AVMP uncertainty estimates

Acknowledgments

- The **NOAA Joint Polar Satellite System Office** (M. D. Goldberg, L. Zhou, et al.).
- The STAR Satellite Meteorology and Climatology Division (F. Weng and I. Csiszar).
- AEROSE works in collaboration with the NOAA PIRATA Northeast Extension (PNE) project (R. Lumpkin, G. Foltz and C. Schmid) and is supported by the NOAA Educational Partnership Program grant NA17AE1625, NOAA grant NA17AE1623, JPSS and NOAA/NESDIS/STAR.
- Ruud Dirksen and the GRUAN Lead Center
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- Contributions to the S-NPP validation data collection effort: B. Demoz and M. Oyola (Howard University); D. Wolfe (NOAA/ESRL); J. E. Wessel (Aerospace).
- D. Holdridge and J. Mather and the U.S. DOE ARM Climate Research Facility for its support of the satellite overpass radiosonde efforts.

GPS Antennas in the South Pacific

Bill Ward

PACIFIC REGION

5/14/14

Outline

- PR Observing Program/GPS Information
- Location of sensors
- Programmatic areas/Data Uses
- Severe Weather in the Pacific
- Tropical Cyclone data
  - TCs across the Pacific Region
- Summary
  - Key Opportunities/Challenges

PR Observing Program

- NWS PR supports numerous islands throughout Hawaii, American Samoa, Guam, CNMI and Micronesia via Weather Surface & Upper air Observations, Satellite Ground Stations, GPS Sensors, Buoys, Ships, Planes, etc.,….
  - Invaluable support for our Watch, Warning and Advisory programs
  - Provides verification and forensic support
  - Used day to day in our forecasts

Background

What is GPS-Met?

- GPS-Met is a ***ground-based*** system that measures the delay in the GPS radio signal caused by ***water vapor*** above the surface station
- System uses ***low cost COTS GPS receivers***
  - collocated with surface meteorological sensors
- Accurate, all-weather, requires no external calibration
- Improvements demonstrated in satellite calibration/validation (Cal/Val), weather forecasting, climate monitoring, and in situ (e.g., rawinsonde) QC

Programmatic Areas

- Local Forecasts and Warnings
  - Supports model validation
  - Tropical and mid latitude forecasting
  - Atmospheric Rivers
- Tsunami information
  - Ground displacement
    - Possible TWC support
- Elevation Datum
- Climate information
  - Ground truth/elevation
  - Tide station data

Mission Applications

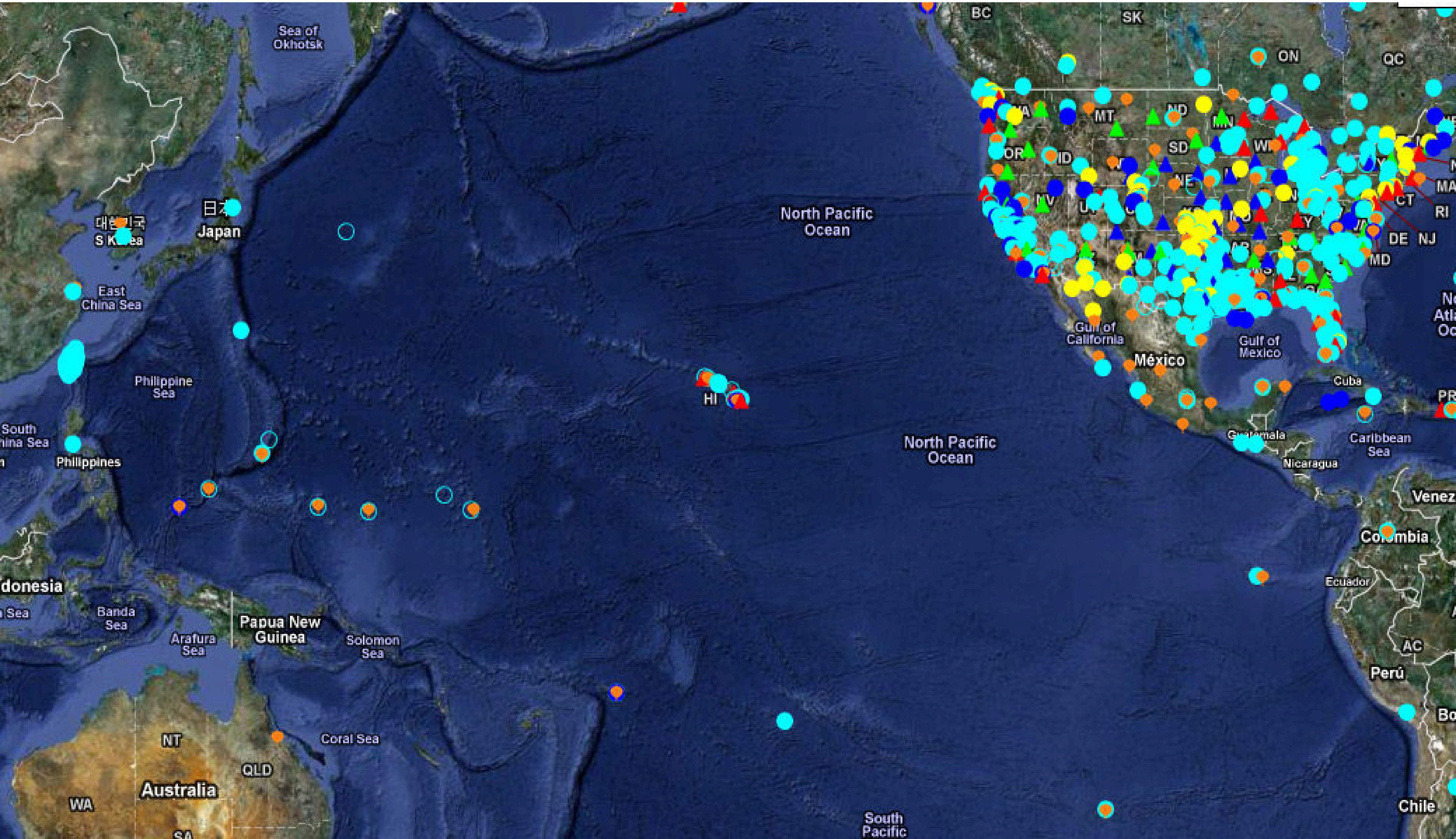
- GPS-Met currently adds value to a wide range of meteorological applications
  - Satellite calibration and validation (IPW)
  - Radiosonde and aviation (TAMDAR & WVSS-2 water vapor QC)
  - NWP performance (assimilated into GFS, HRRR and others)
  - Climate reference/GRUAN (observations do not drift over time)
  - Input into other water vapor products (e.g., Blended Precip)
  - All-weather capability (during high impact events)
  - Future value in "initiation of convection", tropical, hydrologic, aviation, and marine applications, as well as part of National Mesonet
- Importance to NOAA
  - Partnerships with many other organization
    - Seismic
    - Geodetic
    - Climatology
    - Laboratories
    - Universities

GPSMet Units in PR

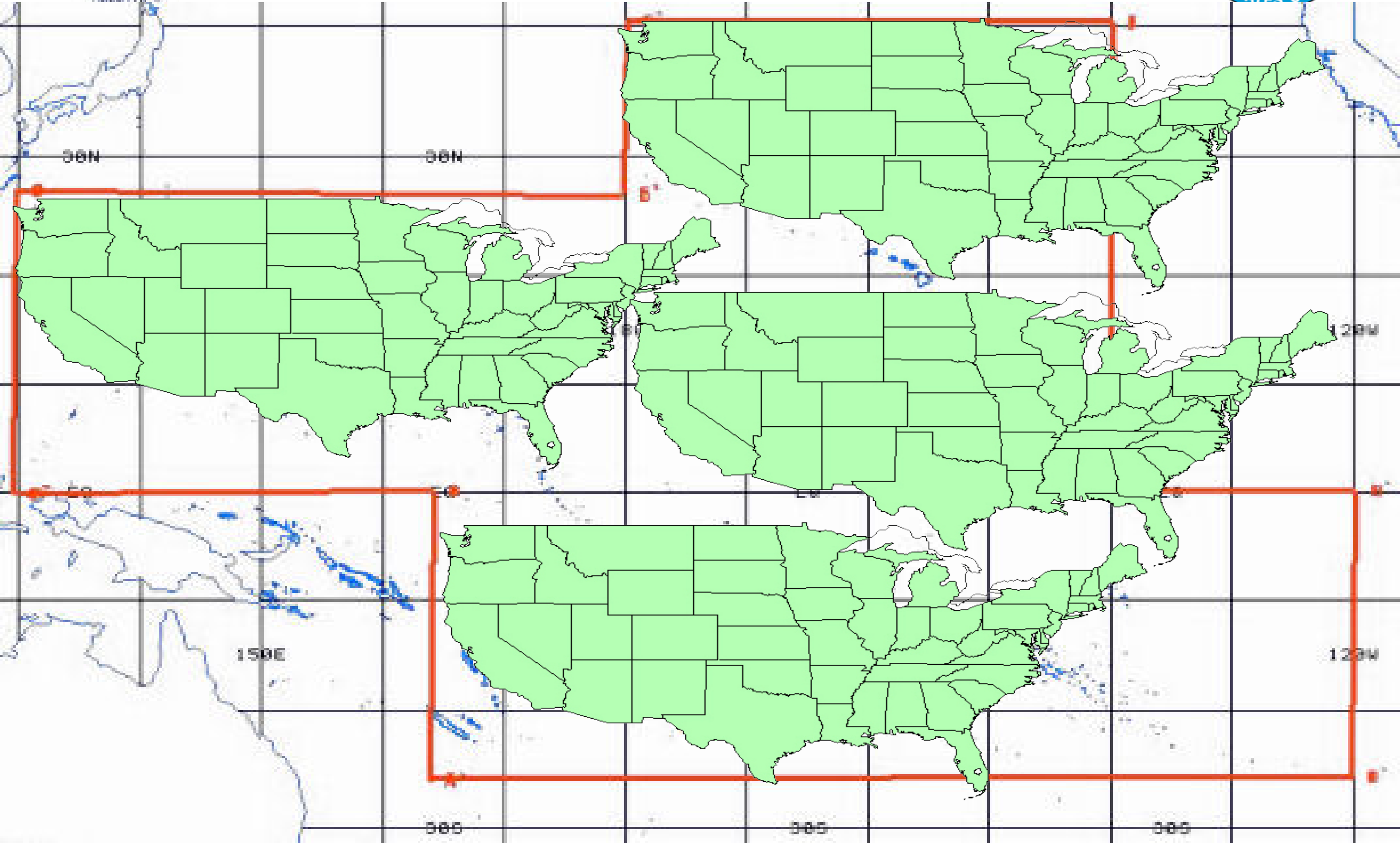
- Guam √
- Saipan √
- Majuro √
- Pohnpei √
- Chuuk √
- Yap √
- Palau √
- American Samoa √

Kwajalein (2014)
Lihue √ (2014)
Hilo √
Midway (2014?)
Rose Atoll (?)
Wake Island √ (2014?)

GPSMet Sites

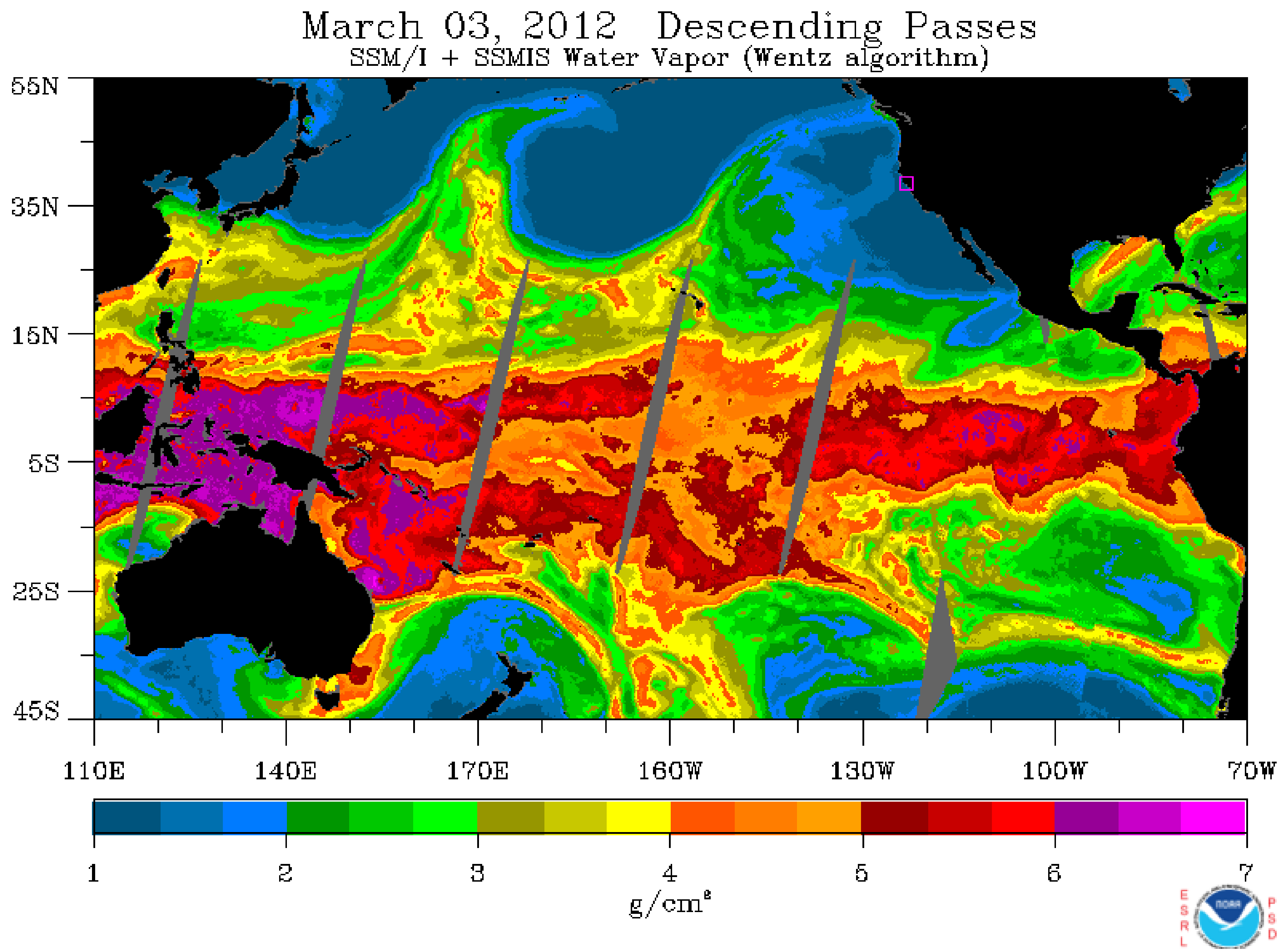


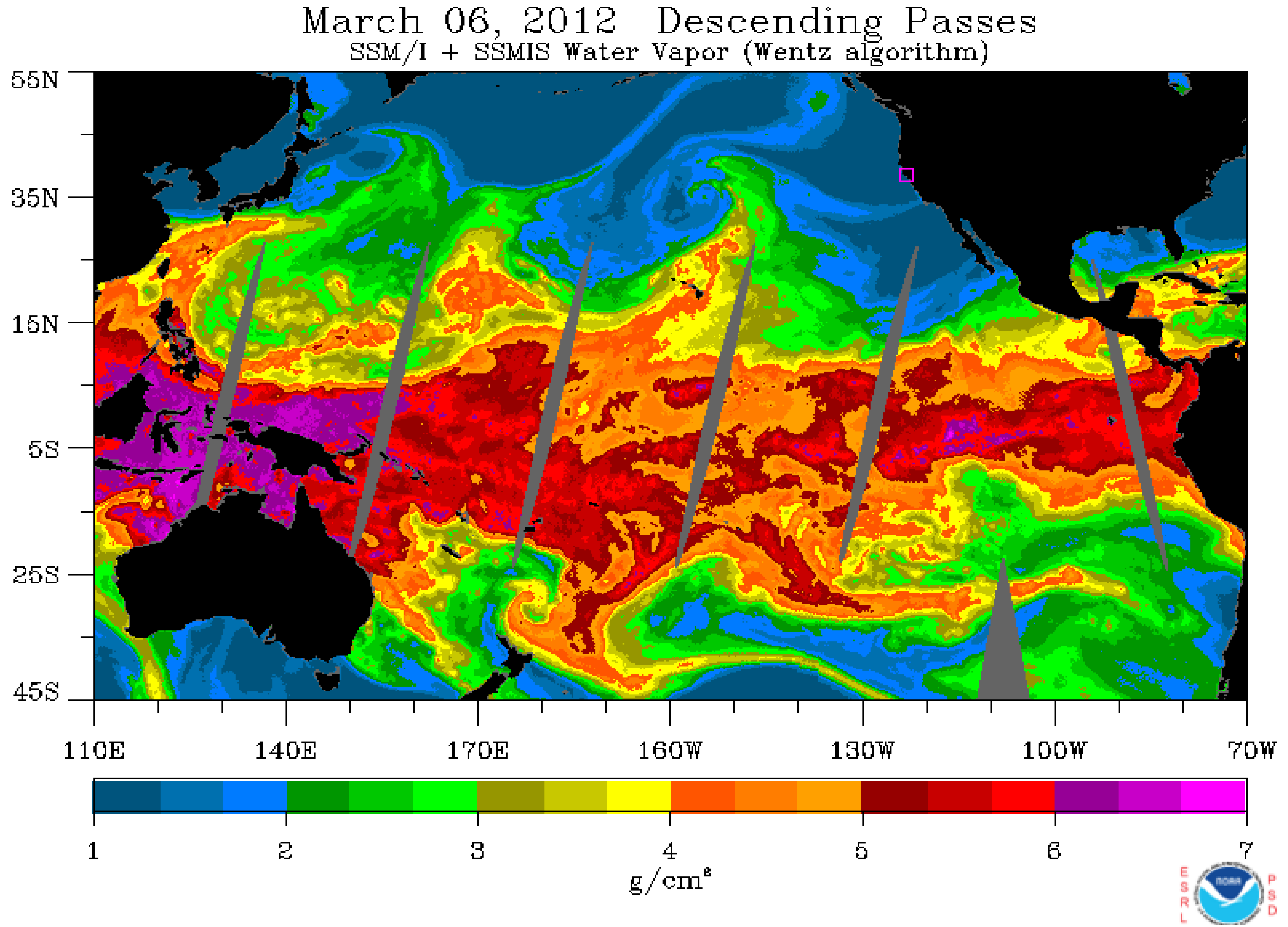
Area of Responsibility



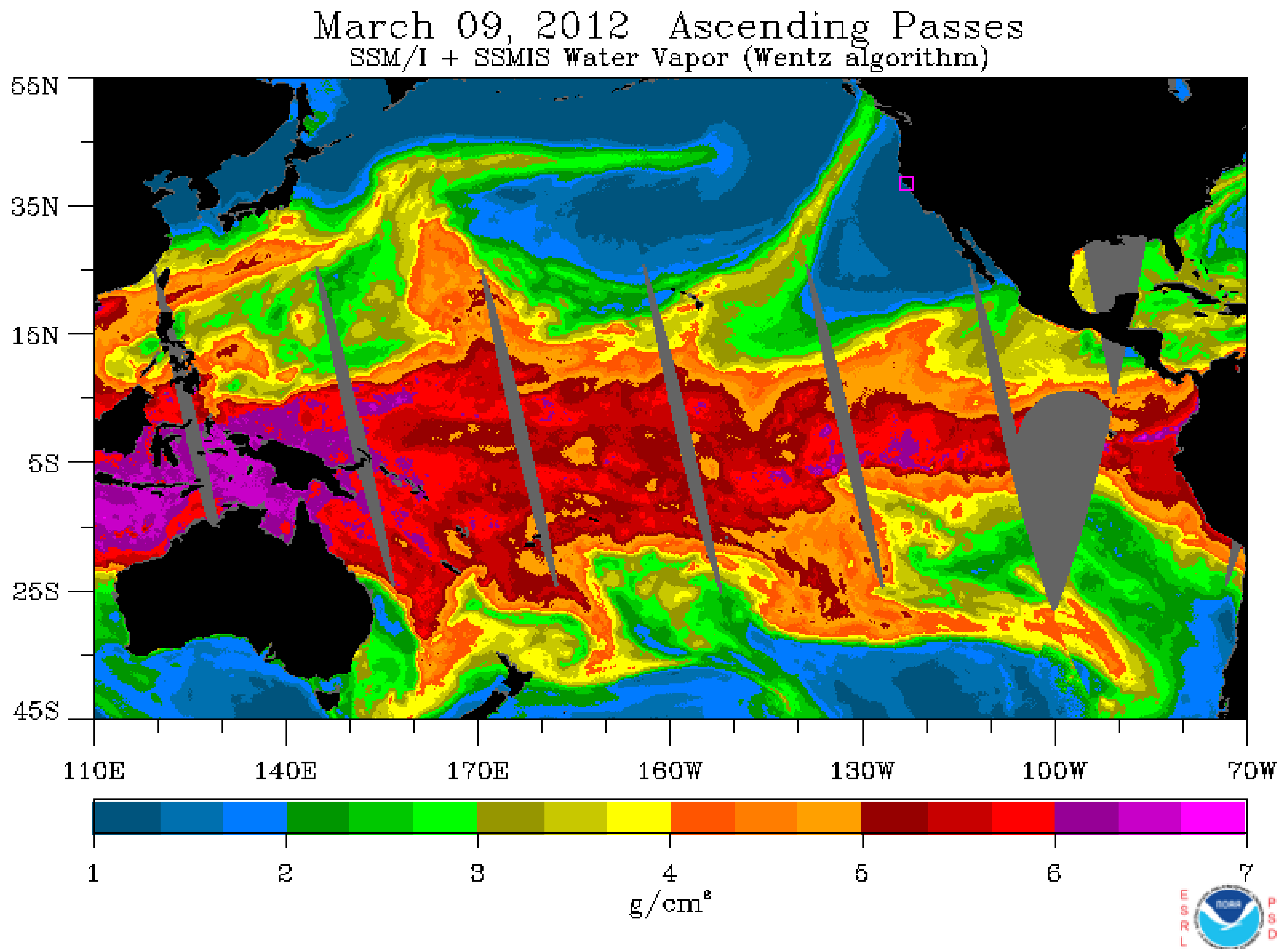
Hawaii SVR Wx & Flooding Summary March 3rd – 11th, 2012

- **Event Summary:**
  - During the period of March 3rd through 11th, 2012 heavy rainfall led to a period of significant flooding for much of the state of Hawaii.
  - In addition to flooding, severe weather spawning waterspouts, a tornado, and very large hail impacted some or all of Kaua'i, Oahu, Maui, and the Big Island.
- Rainfall rates were very intense
  - exceeding more than 3 inches per hour.
  - More than 45 inches on Kauai
- The intense instability led to a period of severe thunderstorms
  - Waterspouts
  - One confirmed tornado,
  - Hail up to 4 and ¼ inches in diameter. (new Hawaii state record)


March 03, 2012 Descending Passes
SSM/I + SSMIS Water Vapor (Wentz algorithm)
55N
35N
15N
5S
25S
45S
110E
140E
170E
160W
130W
100W
70W
1
2
3
4
5
6
7
g/cm²
ESRL
PSD
NOAA



March 06, 2012 Descending Passes
SSM/I + SSMIS Water Vapor (Wentz algorithm)
55N
35N
15N
5S
25S
45S
110E
140E
170E
160W
130W
100W
70W
1
2
3
4
5
6
7
g/cm²
ESRL
PSD



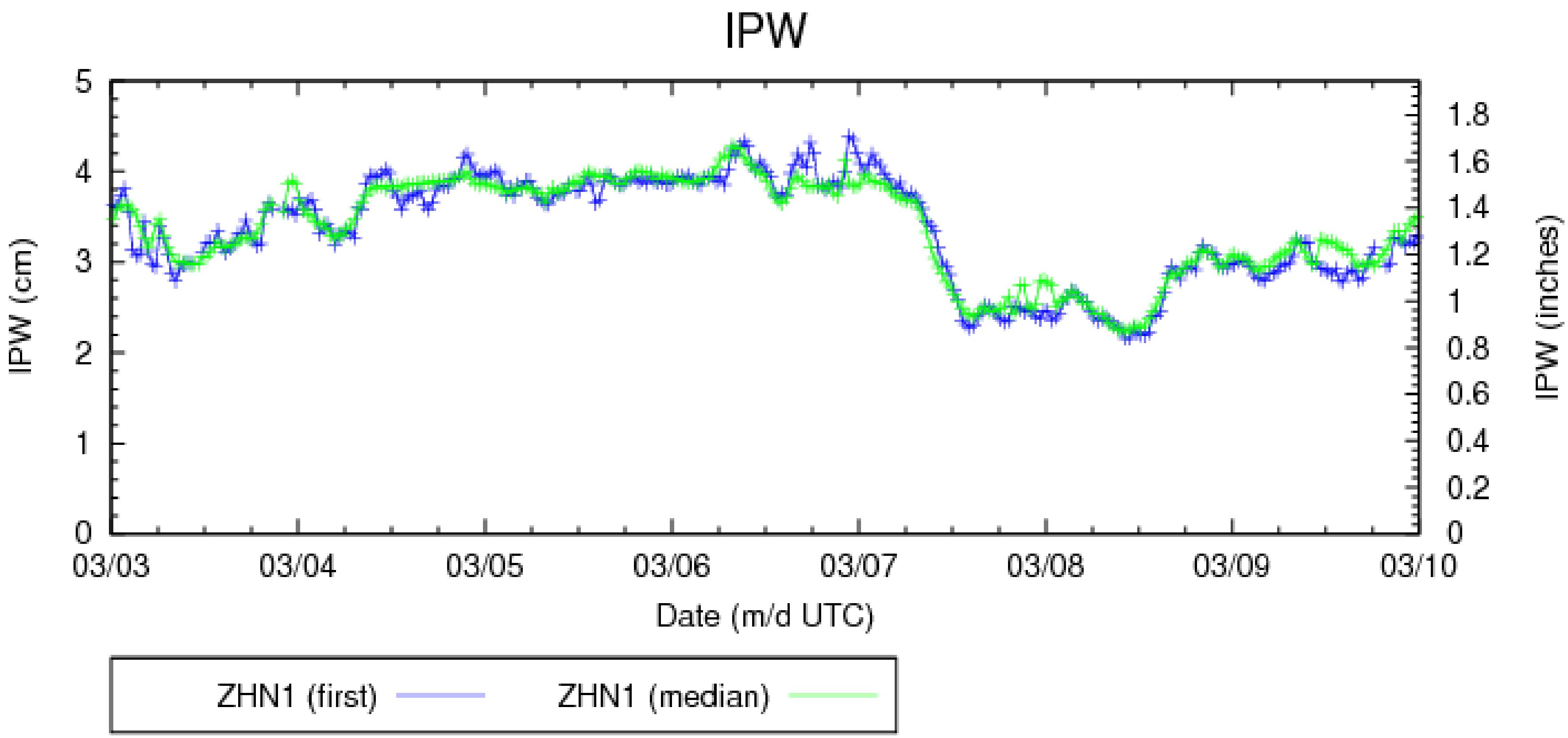
March 09, 2012 Ascending Passes
SSM/I + SSMIS Water Vapor (Wentz algorithm)
55N
35N
15N
5S
25S
45S
110E
140E
170E
160W
130W
100W
70W
1
2
3
4
5
6
7
g/cm²
ESRL
PSD

NOAA/GSD Ground-Based GPS Meteorology (GPS-MET)

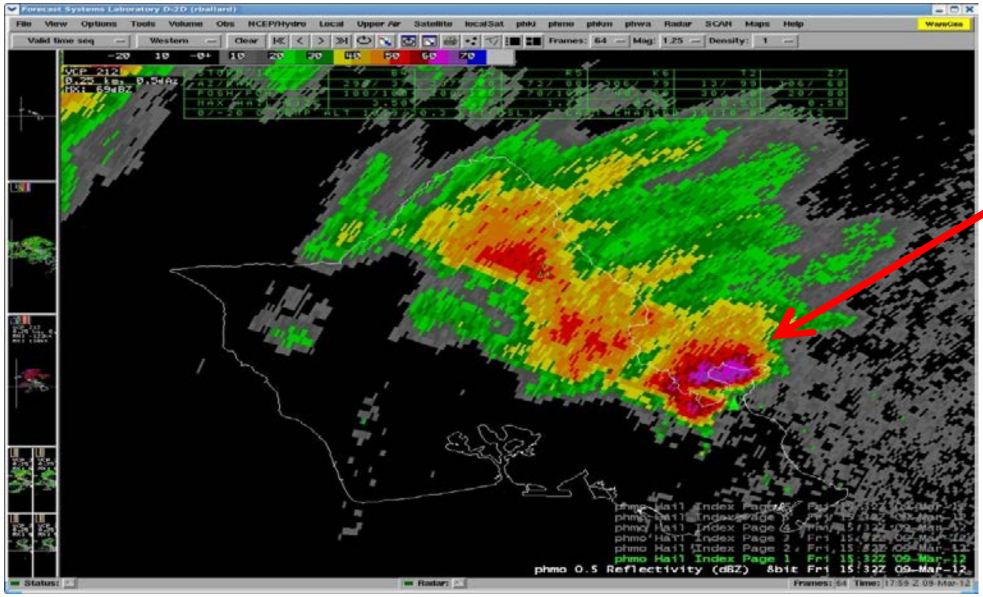
March 03, 2012 to March 10, 2012 (12063 to 12070)

Honolulu WAAS, HI (ZHN1)

Download Text | Print Format

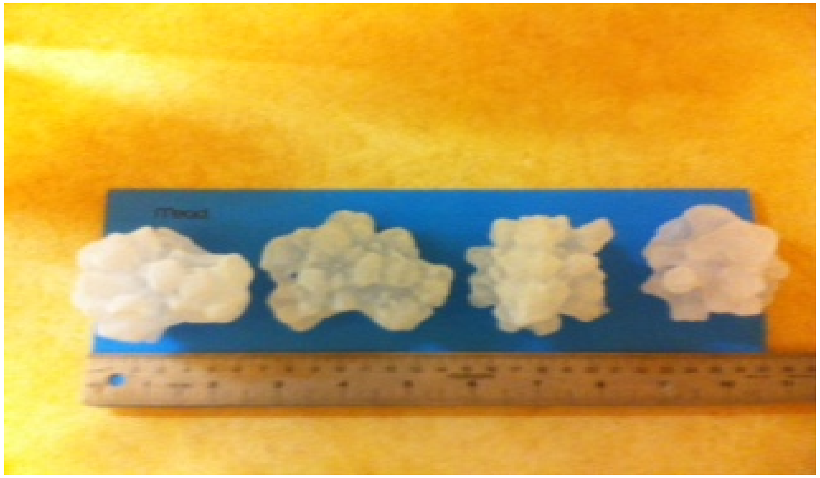


Honolulu WAAS, HI (ZHN1) site info

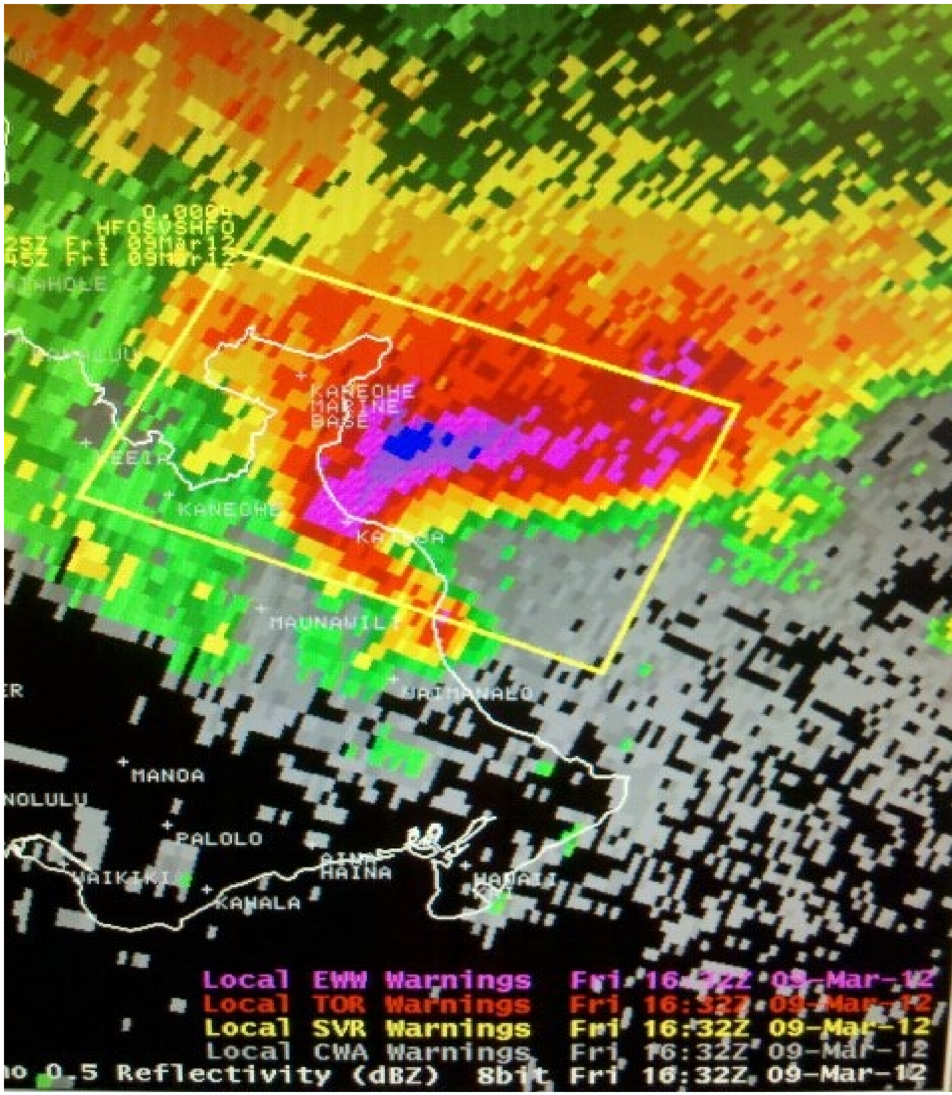


An image of thunderstorms impacting the windward coast of Oahu on the morning of March 9th. Supercell thunderstorms such as these also impacted portions of eastern Maui.

Dimensions:
Length - 4 1/4 inches
Height - 2 1/4 inches
Wide - 2 inches
Date - March 9th, 2012
Time - @6:05am
Location - Kaneohe, HI



Radar Signature with Waterspout



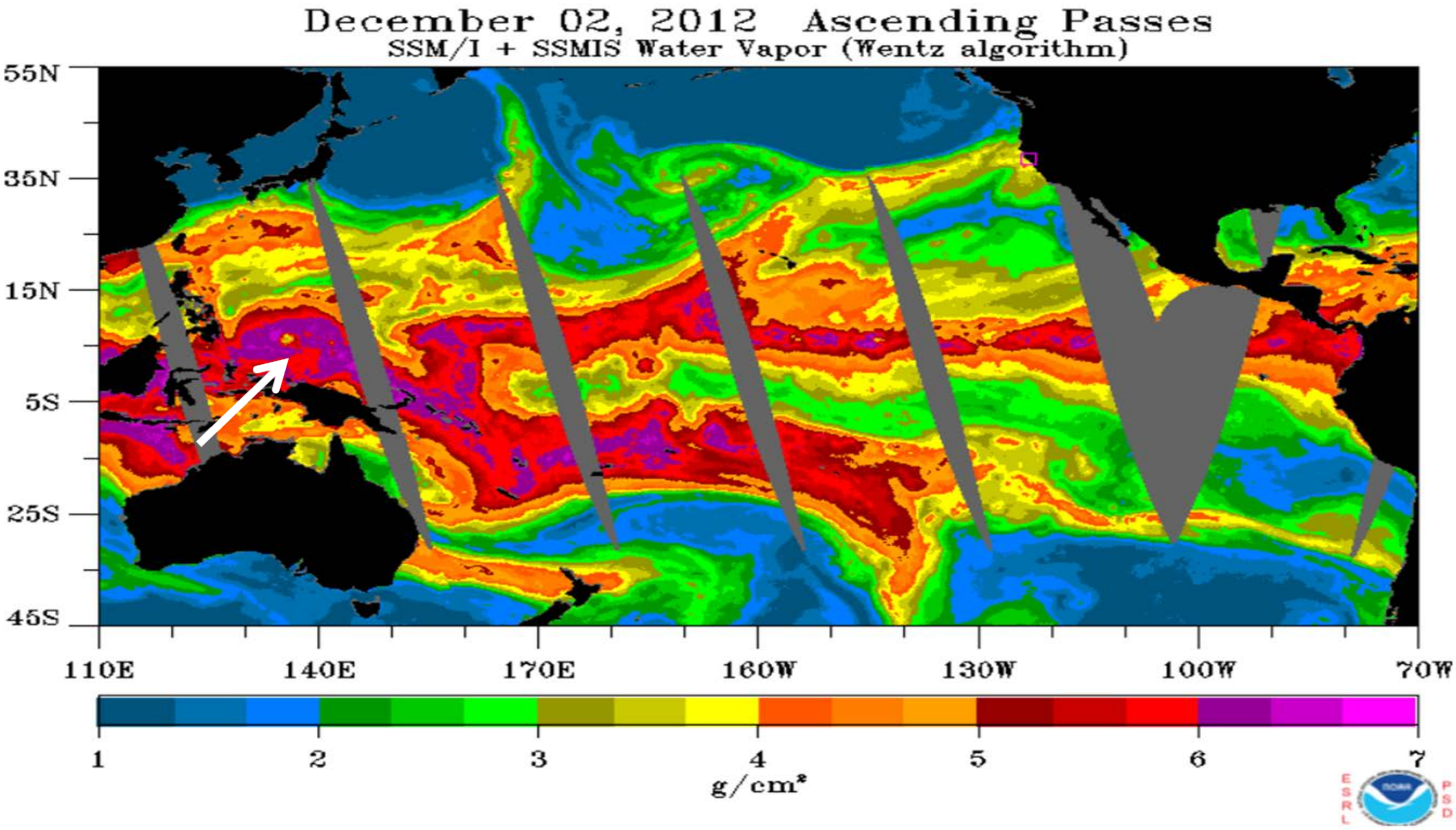
Loop Road, Wailua, Kauai
courtesy of www.hawaiinewsnow.com

Flooding on Kauai on March 8th.

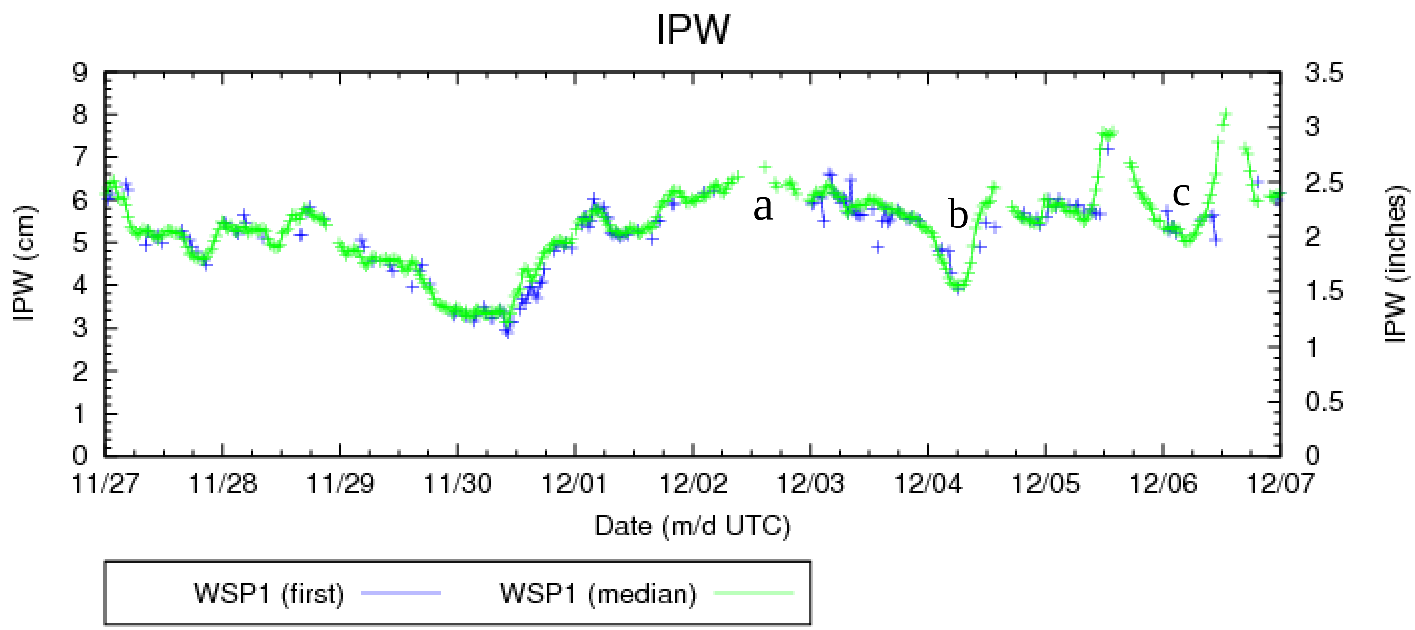
Photo Courtesy of Jay Armstrong.

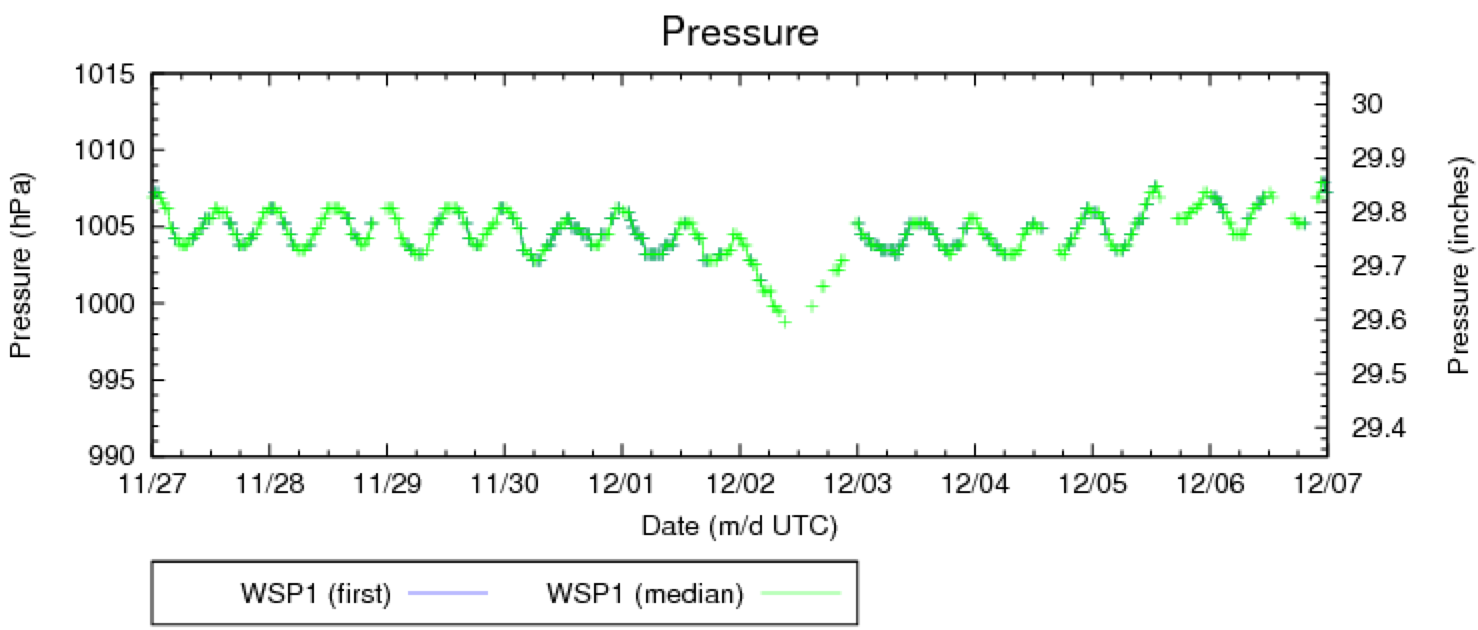
Hana Highway between Nahiku and Hana, Maui

Super Typhoon Bopha

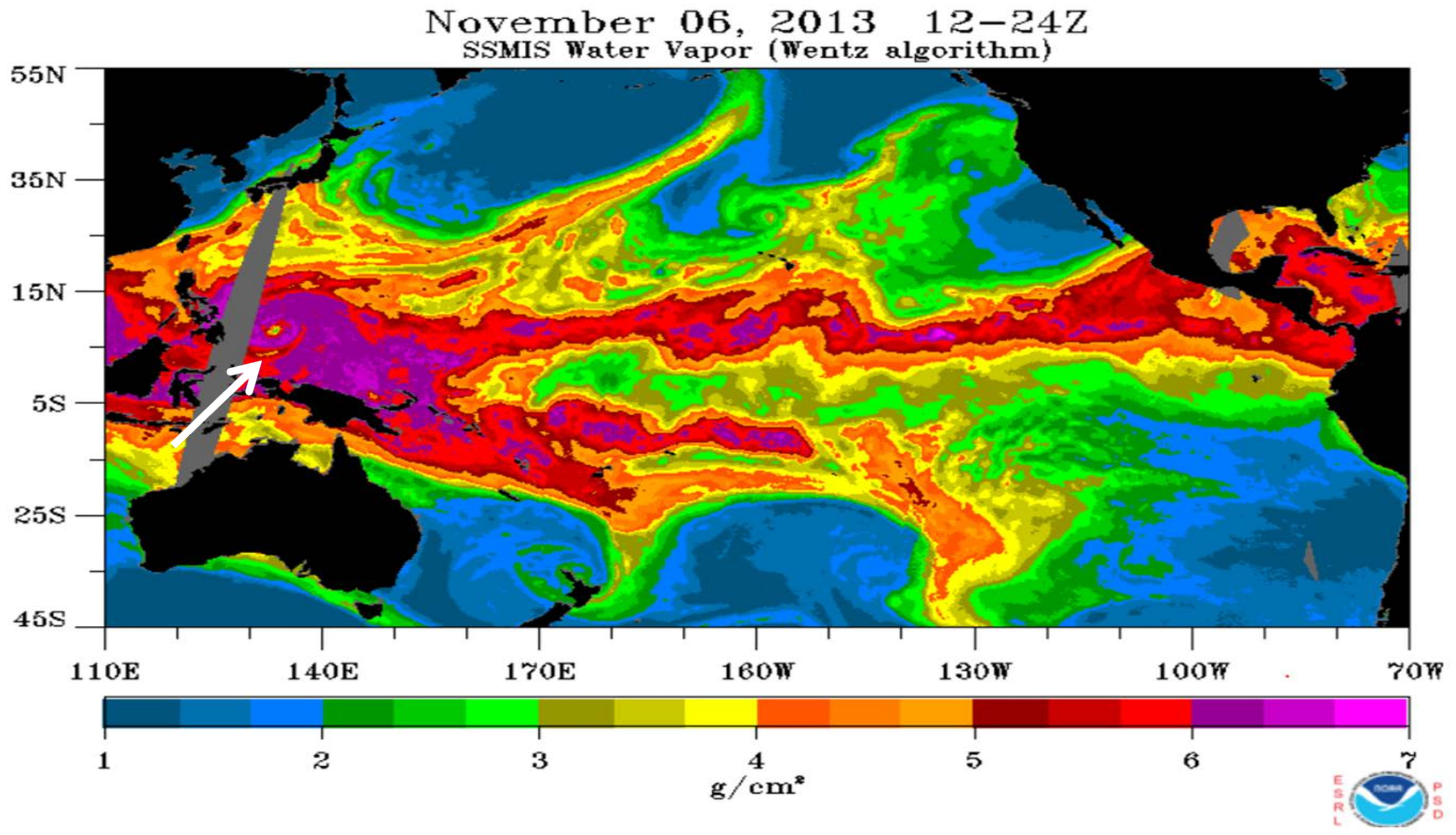


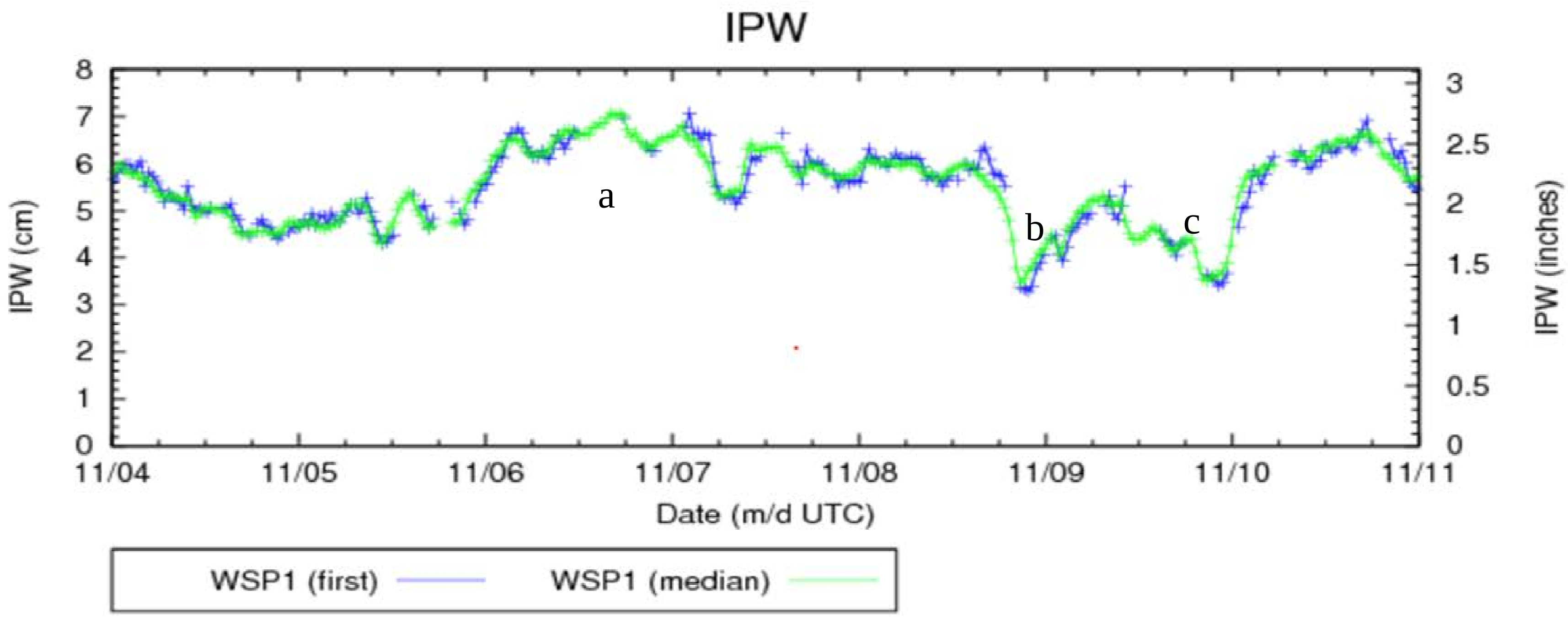
November 27, 2012 to December 07, 2012
Koror, PW (WSP1) STY Bopha



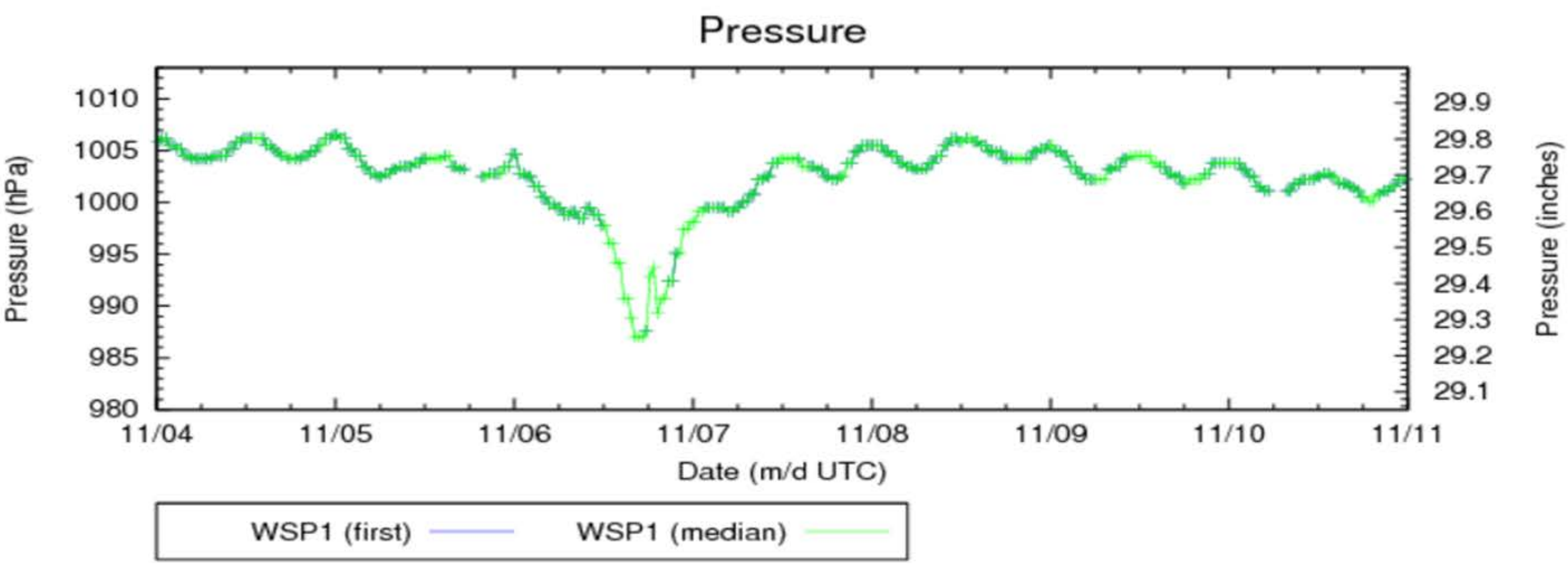


Super Typhoon Haiyan





IPW
IPW (cm)
IPW (inches)
a
b
c
Date (m/d UTC)
WSP1 (first)
WSP1 (median)



Pressure
Pressure (hPa)
Pressure (inches)
Date (m/d UTC)
WSP1 (first)
WSP1 (median)

Summary

- Pacific Region is data sparse
  – GPS sensors (Additional locations)
  – Automated data sites
  – Wind Profilers (Continuous winds aloft)
  – Satellite IPW (Future algorithms)
- Importance of Synoptic Features, MJO, TUTT, Tropical Regimes, Subtropical & Mid Latitude Phenomena
  – Vertical transport of moisture
  – Meridional transport
  – Mid latitude and tropical systems

Summary

- Pacific Region covers a vast area of responsibility
- Unique region in the NWS in diversity of comms and variety of offices/services
- Resource needs reflect a customized and innovative approach to meeting mission requirements

Questions

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The need for atmospheric chemistry products from CrIS

Ask not what CrIS can do for the country, but what the country expects from CrIS

Monika Kopacz and Kenneth Mooney

NOAA, Climate Program Office

May 14, 2014

Atmospheric composition data from space: facts and questions

- Data available since 1999. How much more data can we expect from current instruments?
- Is the data accurate and useful? How can we tell?
- Do we need more data and for what applications?
- Early products from CrIS

What (CO) data is available and how much more can we expect?

Launched in 1999

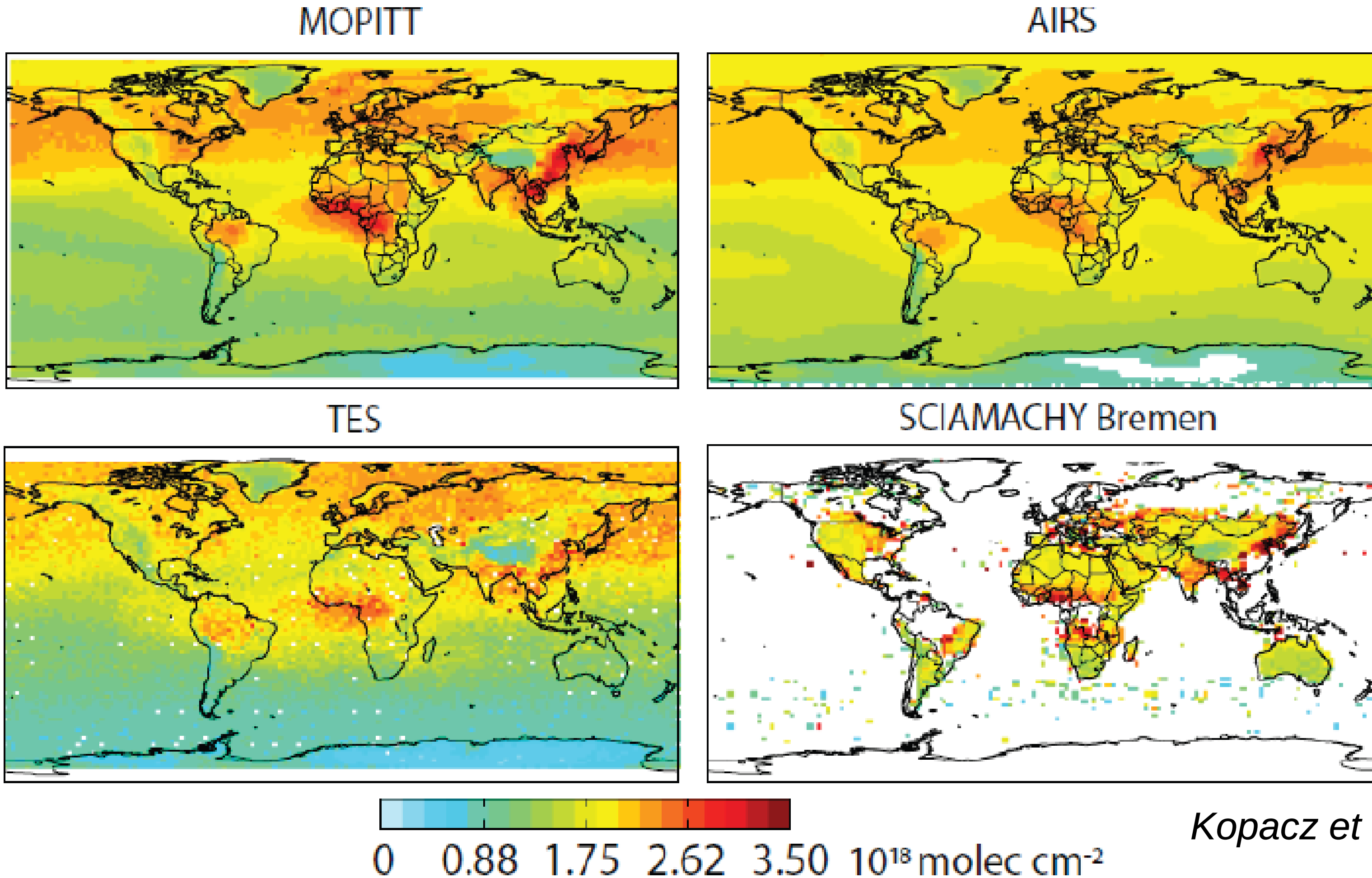
Launched in 2002, stopped working ~ 2006/2013

Launched in 2002

Launched in 2004

Launched in 2006 and 2012 (3rd one in 2016)

CO data from space: is it accurate?



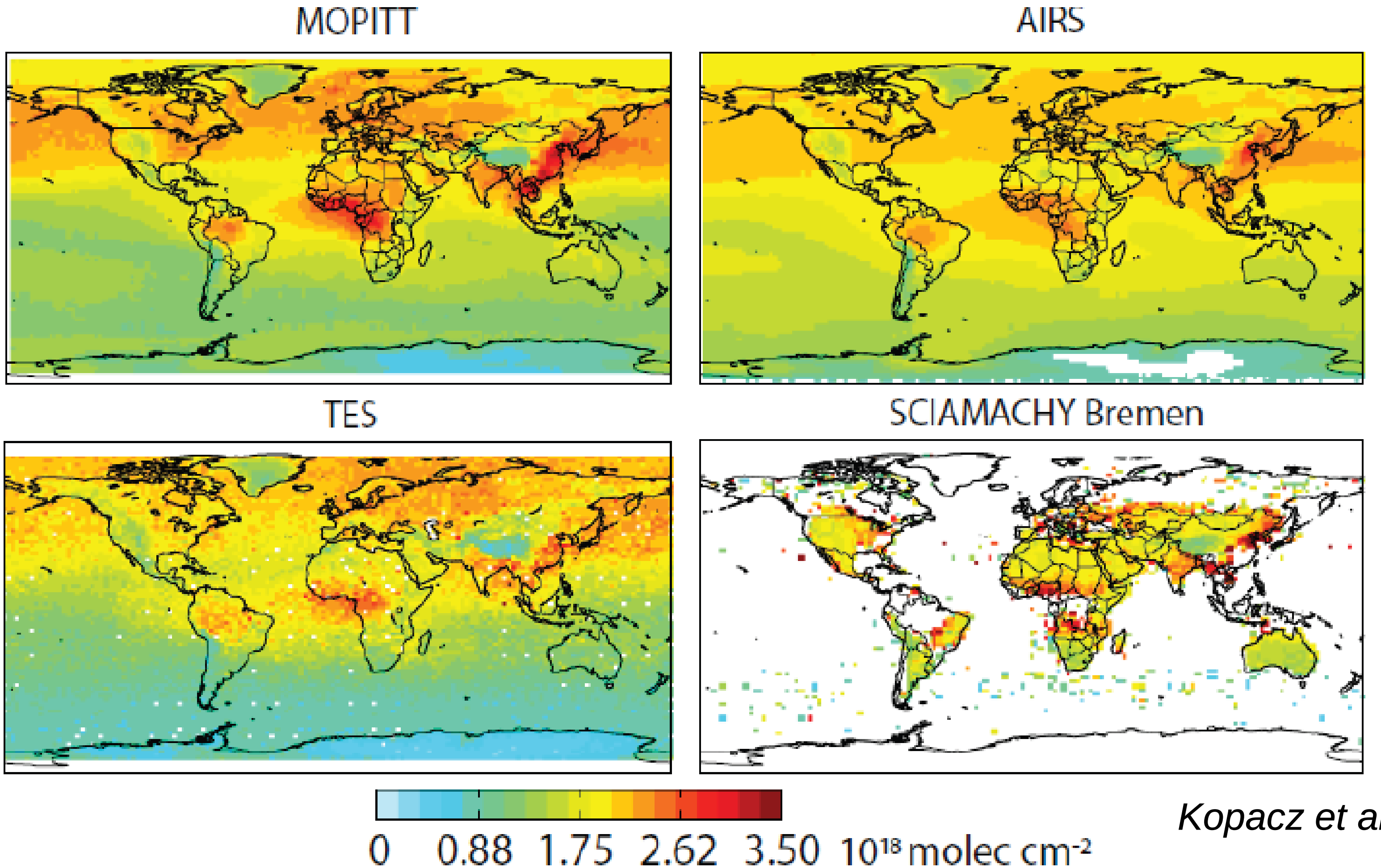
Kopacz et al. 2010

Which one of these is "the best"?

Long term record? MOPITT
High accuracy? TES

Dense global coverage? AIRS
Sensitivity near the surface? SCIAMACHY

CO data from space: is it accurate?



Kopacz et al. 2010

Which one of these is "the best"?

Long term record? MOPITT

High accuracy? TES

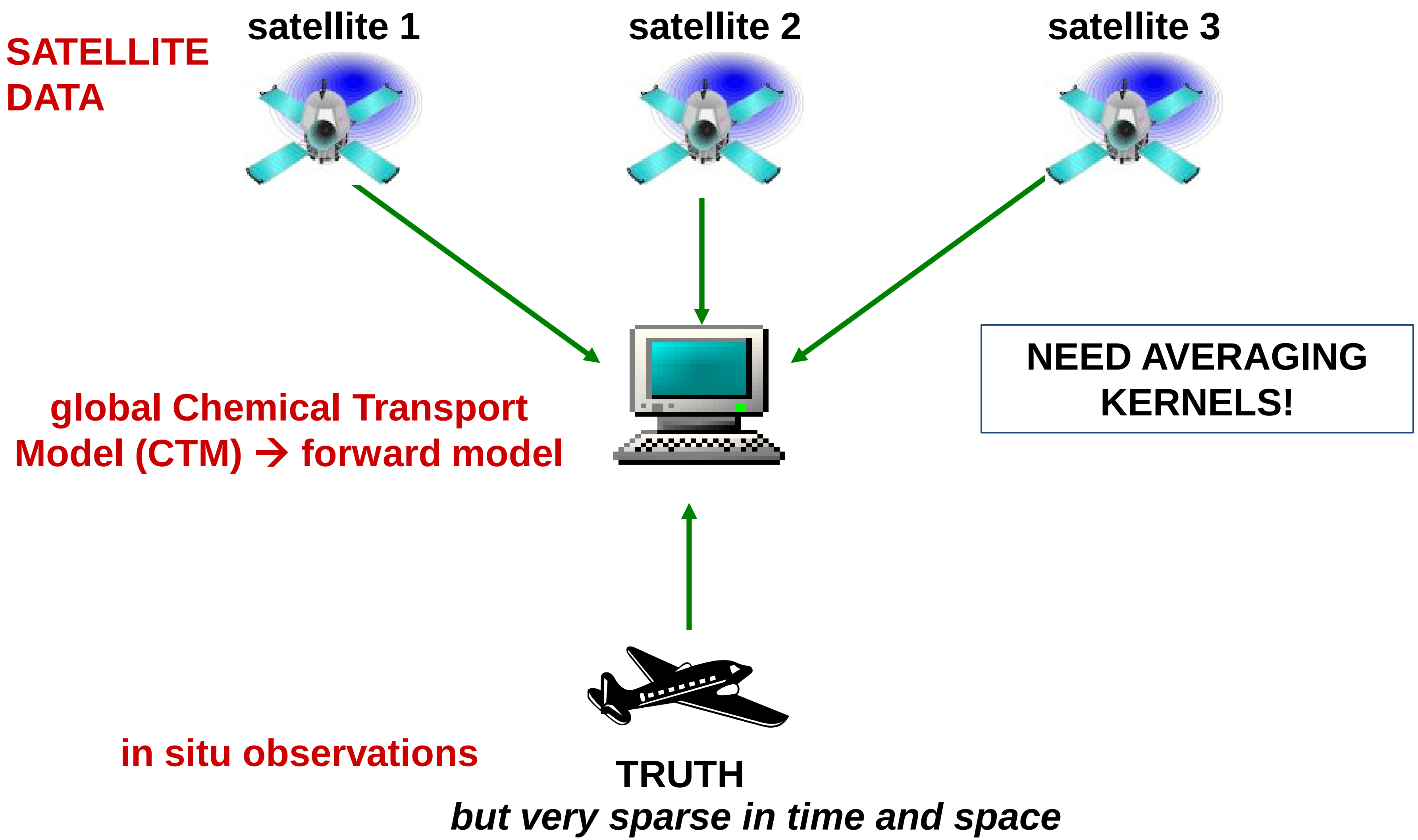
Dense global coverage? AIRS

Sensitivity near the surface? SCIAMACHY

CrIS

Is the data accurate? How can we tell?

Chemical Transport Model (CTM) as a comparison platform



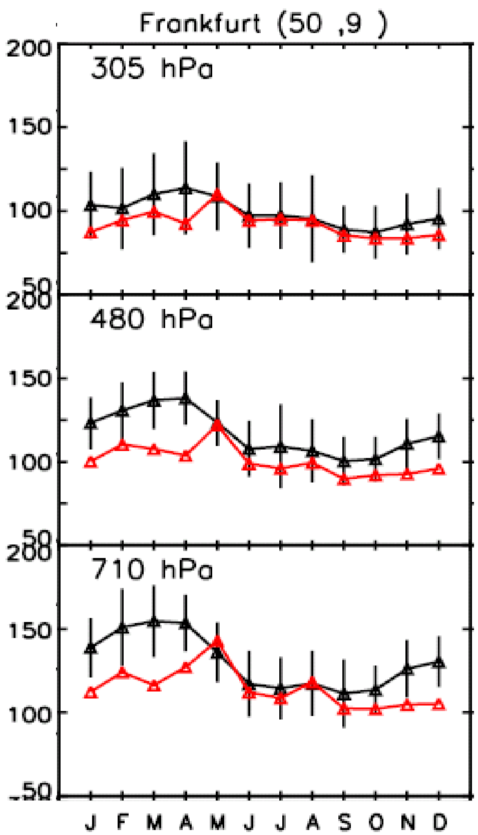
GEOS-Chem Chemical Transport Model (CTM): the comparison platform

EMISSIONS → **CTM** → **CONCENTRATIONS**

Compare with in situ data

aircraft

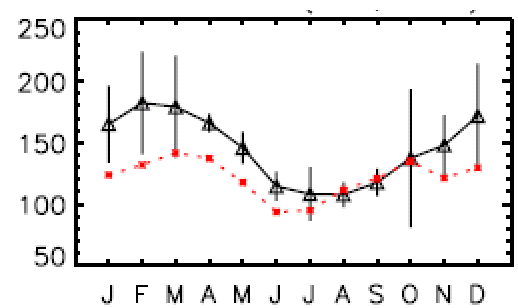
MOZAIC



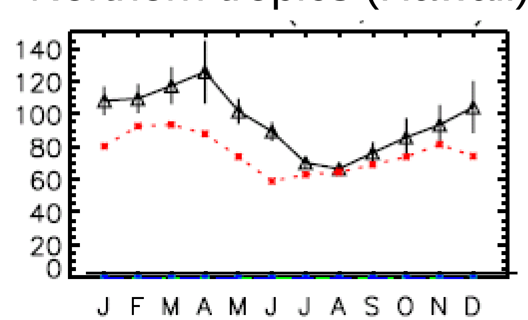
surface

GMD

Northern midlatitudes (Ireland)



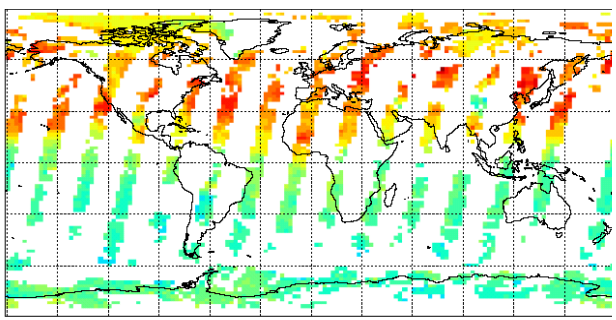
Northern tropics (Hawaii)



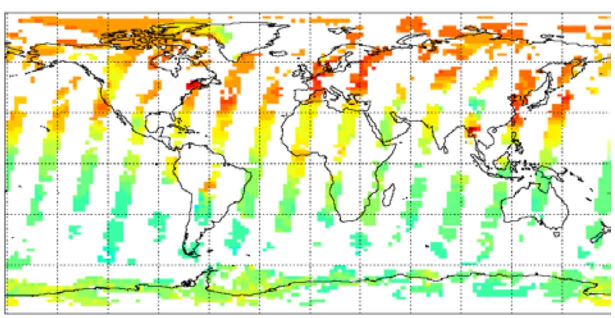
Compare with satellite data

$$\hat{\mathbf{y}} = \mathbf{y}_a + \mathbf{A}(\mathbf{y} - \mathbf{y}_a)$$

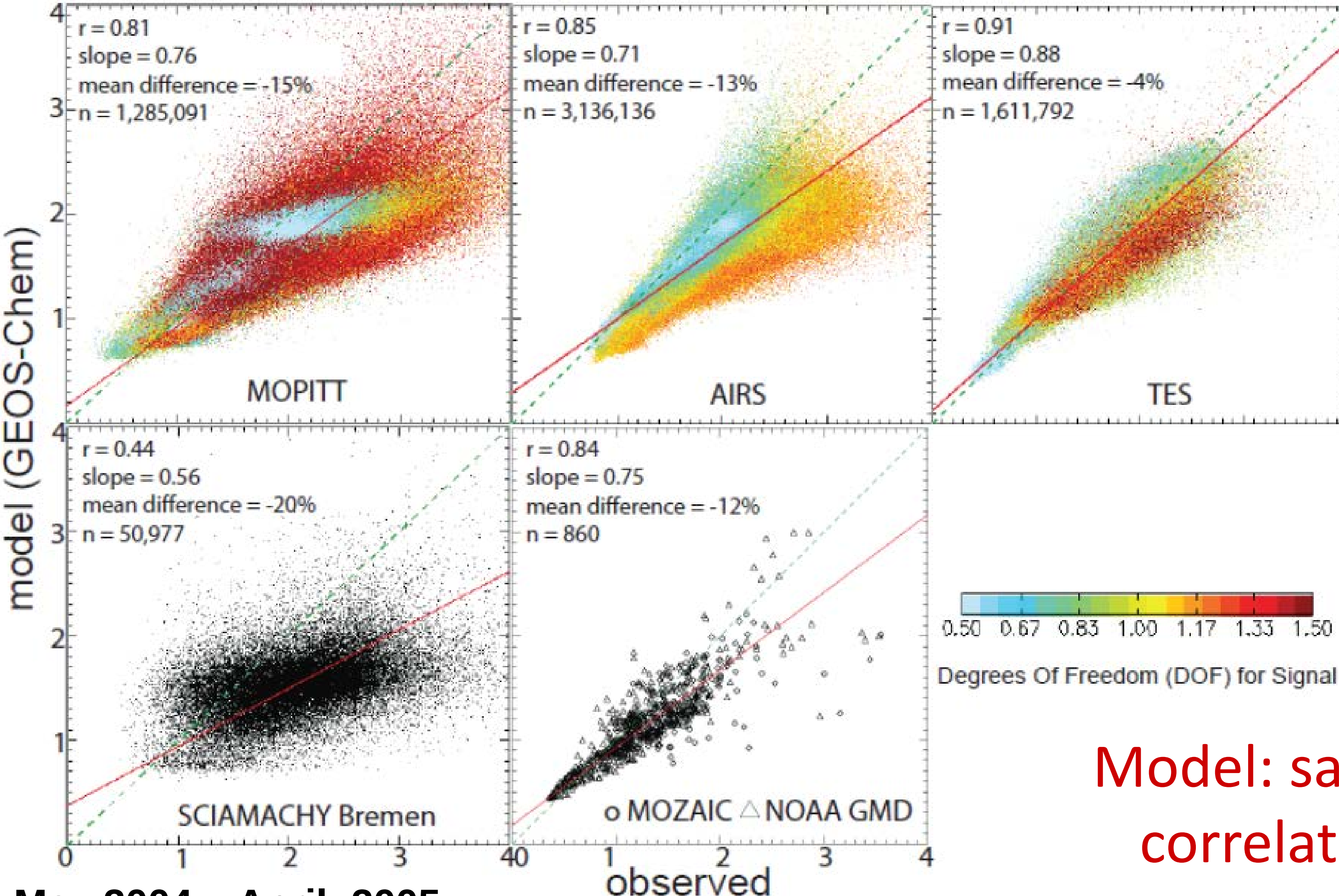
MOPITT CO columns



GEOS-Chem+ MOPITT AK



Model: satellite correlations



May 2004 – April 2005 global daytime columns (averaged on 2°x2.5° resolution of GEOS-Chem)

**TES data for 2005-2006*

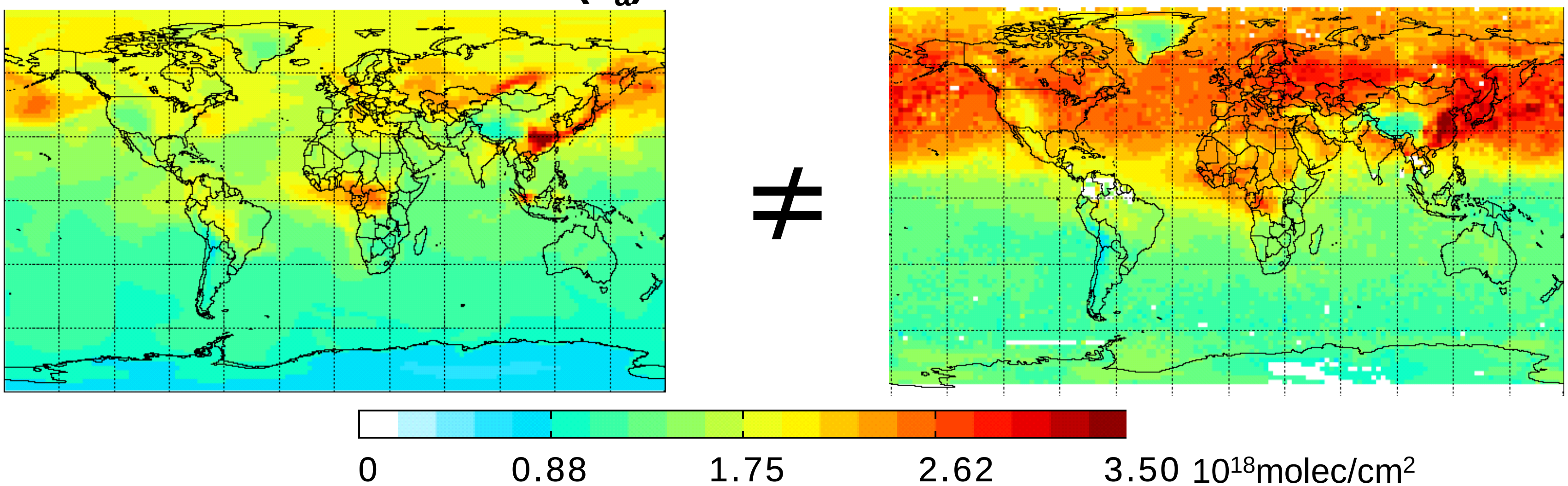
Measure of information content: degrees of freedom (DOFs) ← color dimension

Unit: 10^{18} molec/cm^2

Kopacz et al. *2010*

Is the data useful?
Inverse estimates of CO sources

GEOS-Chem CO column: $F(x_a)$ **satellite CO column: y**



***a priori* sources:** $x_a + \varepsilon_a$

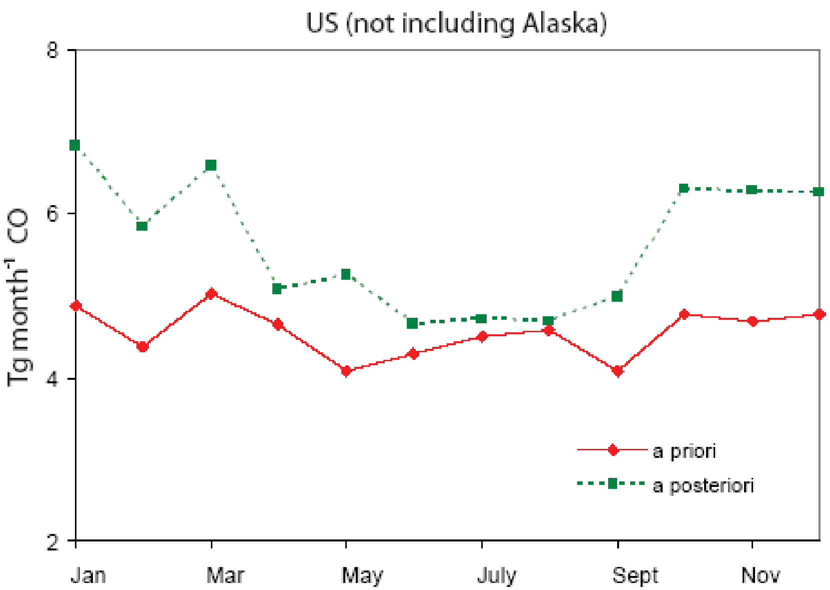
satellite data (MOPITT, AIRS, SCIAMACHY Bremen) : $y + \varepsilon_o$

model concentrations: $F(x) + \varepsilon_m$

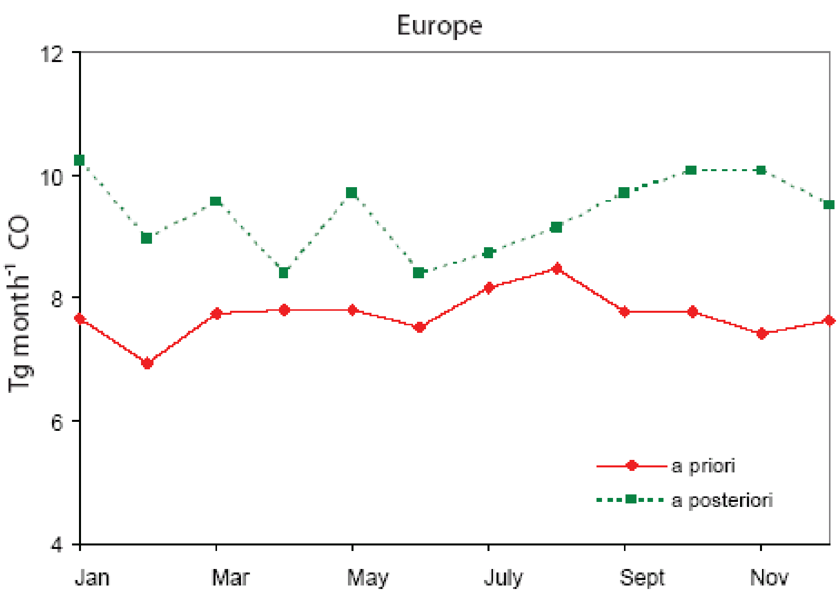
observation error: $\varepsilon_e = \varepsilon_o + \varepsilon_m + \varepsilon_r$

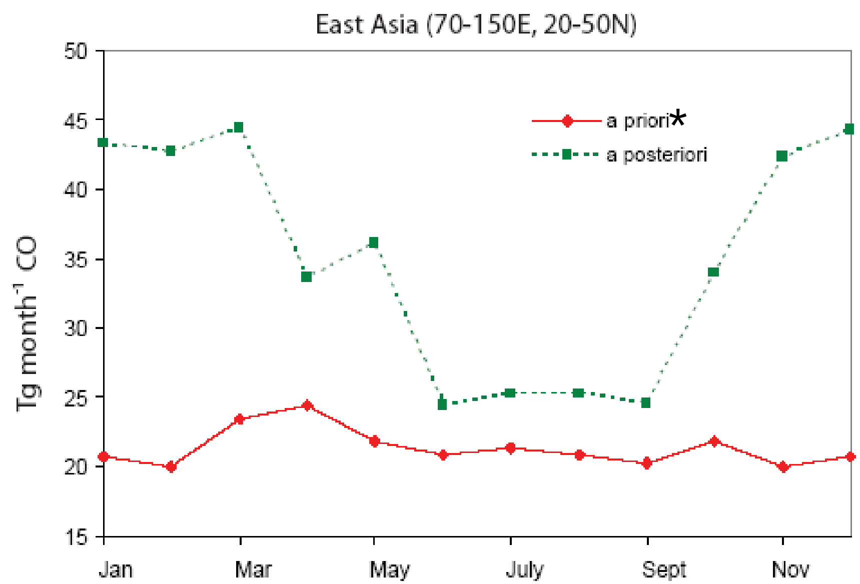
$$\min \; J(\mathbf{x}) = (\mathbf{F}(\mathbf{x}) - \mathbf{y})^T \mathbf{S}_\varepsilon^{-1} (\mathbf{F}(\mathbf{x}) - \mathbf{y}) + (\mathbf{x} - \mathbf{x}_a)^T \mathbf{S}_a^{-1} (\mathbf{x} - \mathbf{x}_a)$$

RESULT: monthly CO source estimates at 4º x 5º resolution



Seasonal variability of emissions: largely missing in *a priori* estimates





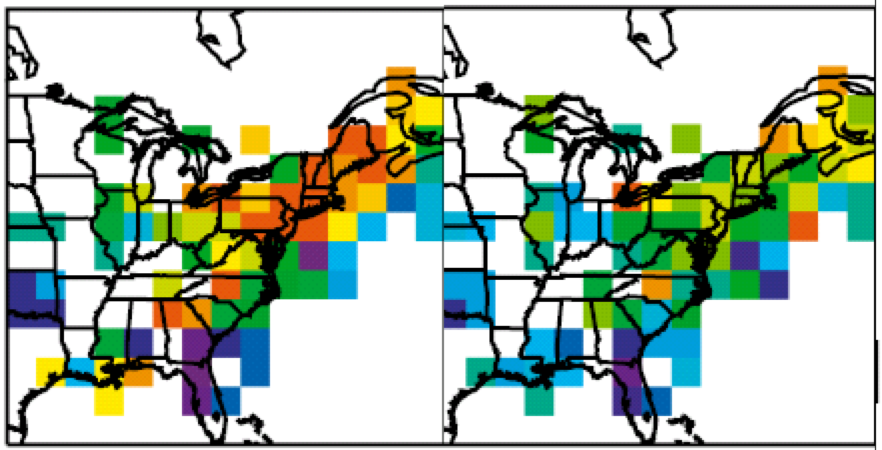
Includes regional inhomogeneity

* *Streets et al.* [2006] did not include *Streets et al.* [2003] seasonality

Regional CO source estimates: N. America

Previous study

GEOS-Chem w/ NEI99 emission inventory **>** INTEX-A observations

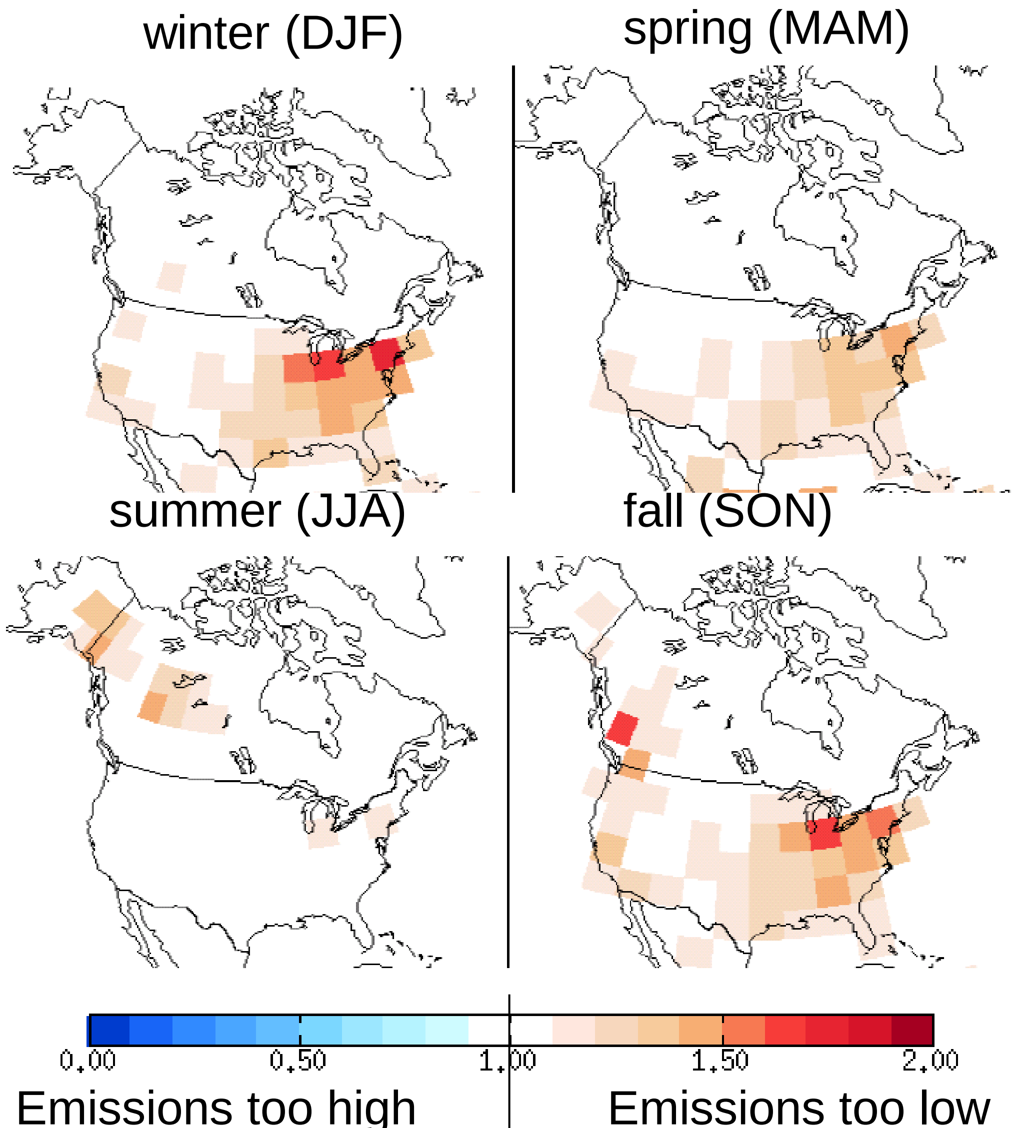


Hudman et al. [2008]

NEI99 60% too high (in the summer)

Conclusion: *Hudman et al.* [2007] correction to NEI99 inventory ok in the summer, not in fall-winter

Current study w/ 60% correction

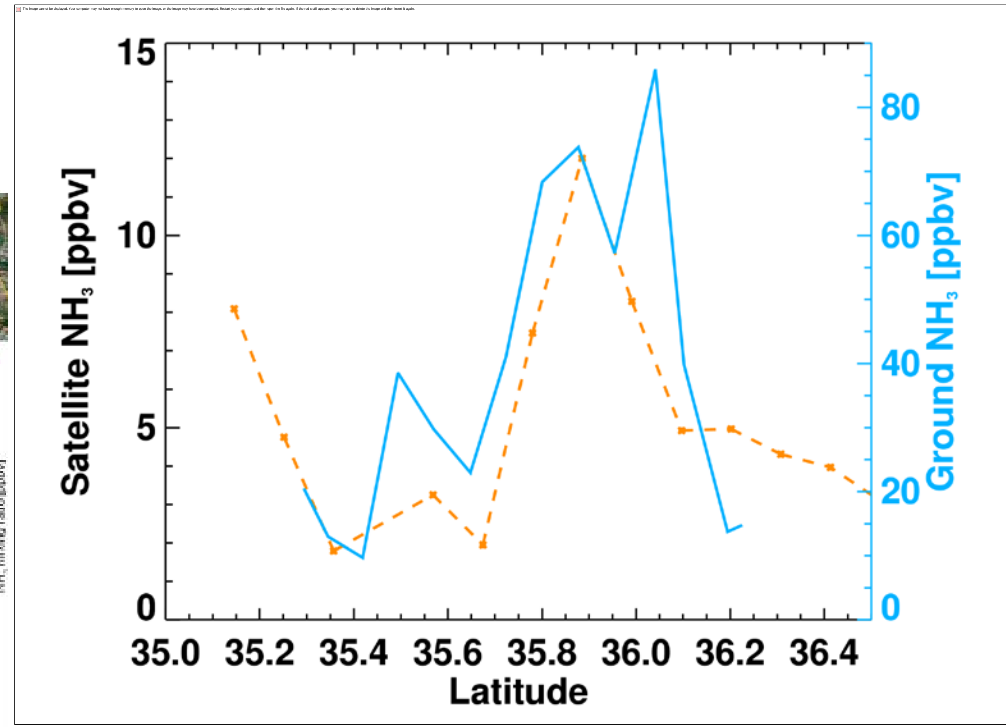


CrIS product (being) developed with AC4 support

Surface and **CrIS NH_3** in DISCOVER-AQ 2013

- Open path Quantum Cascade Laser (QCL) on a moving platform collected data almost directly under TES transect (red symbols) in the San Joaquin Valley on January 28, 2013

- Hotspot measured near Tipton



- Satellite and QCL NH_3 measured in January 2013 are spatially well correlated

Credit: Matt Alvarado and Karen Cady-Pereira

Conclusions

- CrIS needs to provide long term high quality CO retrieval to continue CO monitoring from space, and to continue addressing a large array of air pollution transport, source and chemistry problems
- CrIS should and will provide NH_3 retrievals
- CrIS can and does provide a range of species that are currently being retrieved from TES, AIRS and IASI
- CrIS products need to be developed with averaging kernels for comparison with other data and for validation purposes
- CrIS products need to be and can be validated with future NOAA and other field campaigns

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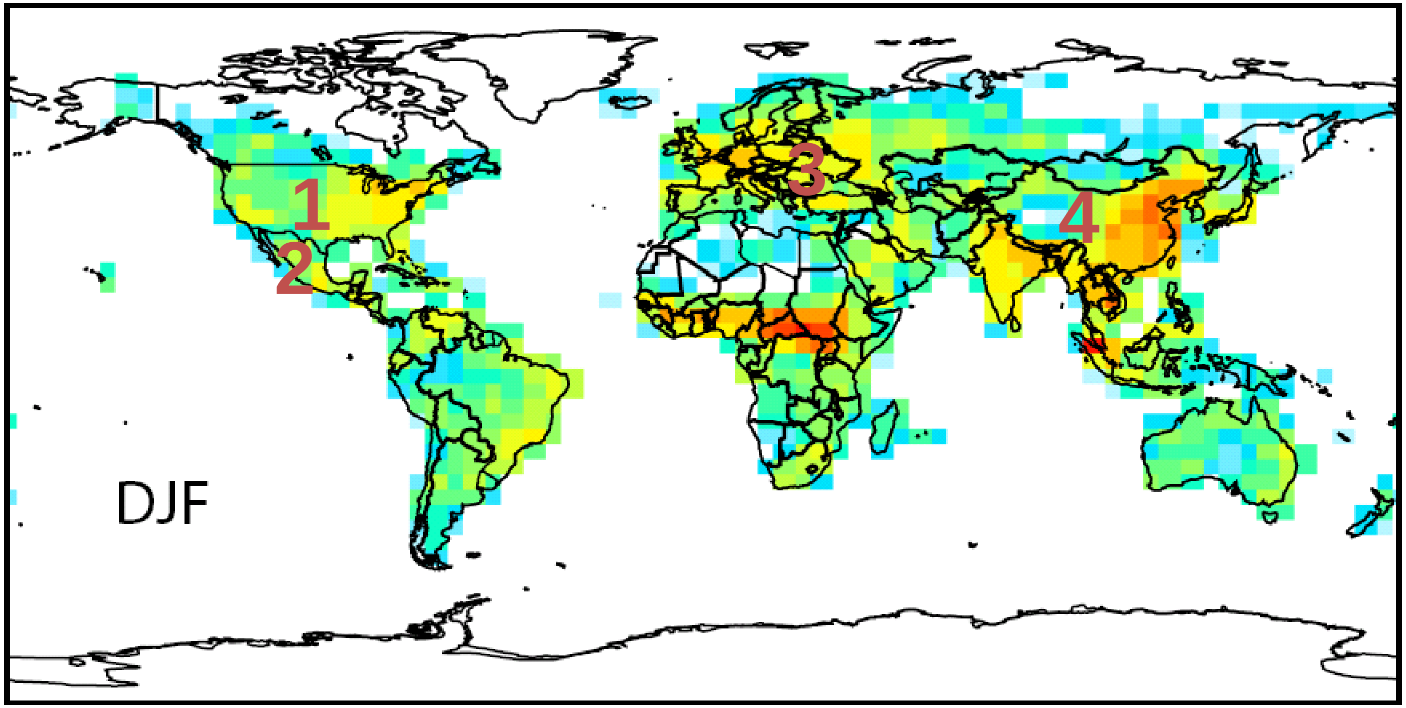
Atmospheric Chemistry, Carbon Cycle, and Climate (**AC4**) program
(under Earth System Science)
NOAA/OAR Climate Program Office
www.climate.noaa.gov

http://cpo.noaa.gov/ClimatePrograms/EarthSystemScience/AtmosphericChemistryCarbonCycleandClimate.aspx

A priori emissions ($\mathbf{x}_a$): fossil fuel, biofuel and biomass burning



Global inventories:

Fossil fuel EDGAR 3.2 (global)

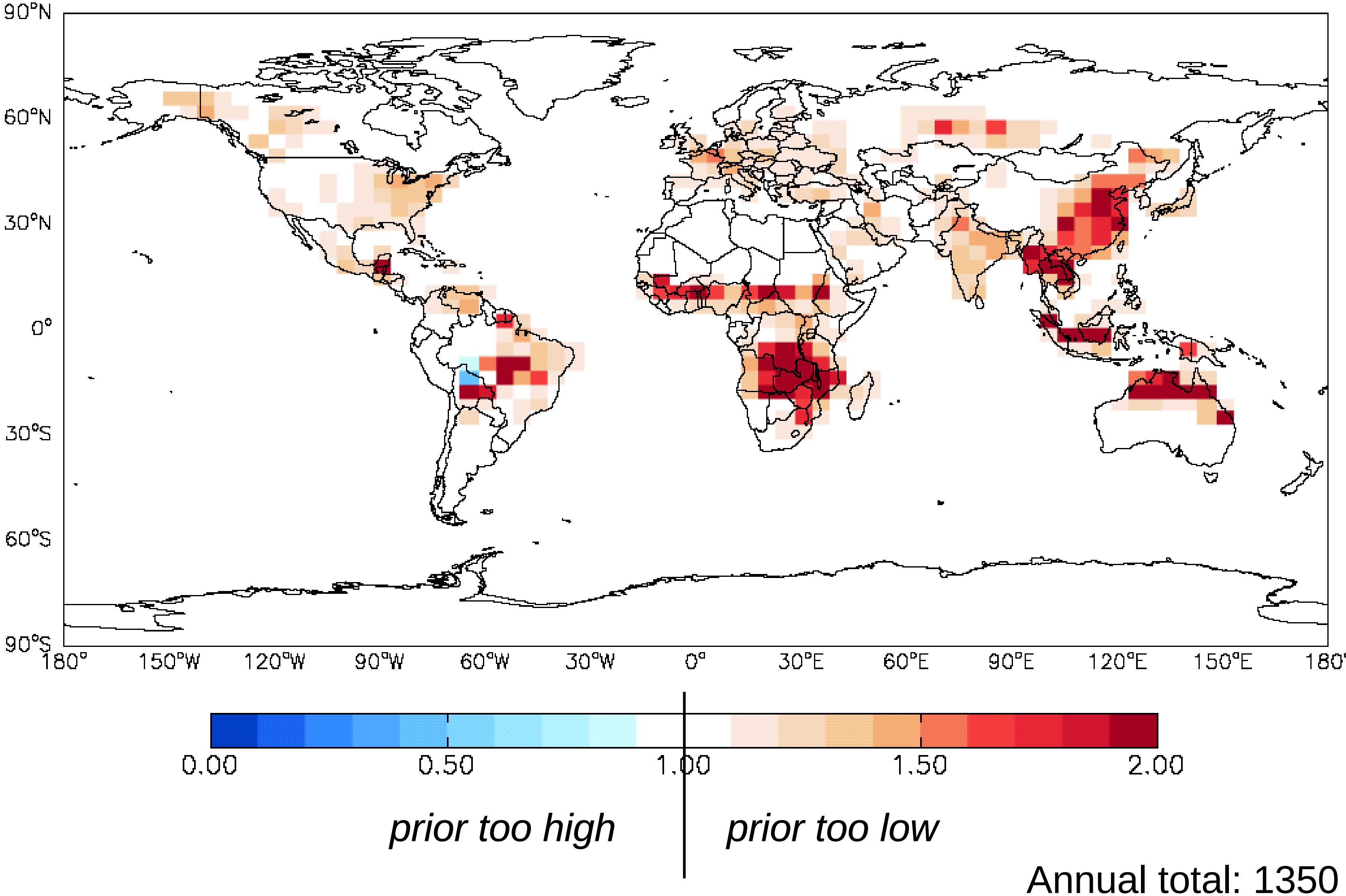
Biomass burning GFED2 (global)

Regional inventories:

1. US fossil fuel: NEI99 – 60%
2. Mexico fossil fuel: BRAVO
3. Europe fossil fuel: EMEP
4. Asia fossil fuel: *Streets et al.* 2006 for China and *Streets et al.* 2003 elsewhere

A posteriori estimates of CO sources: emissions too low

Annual mean *a posteriori/a priori* emission ratio

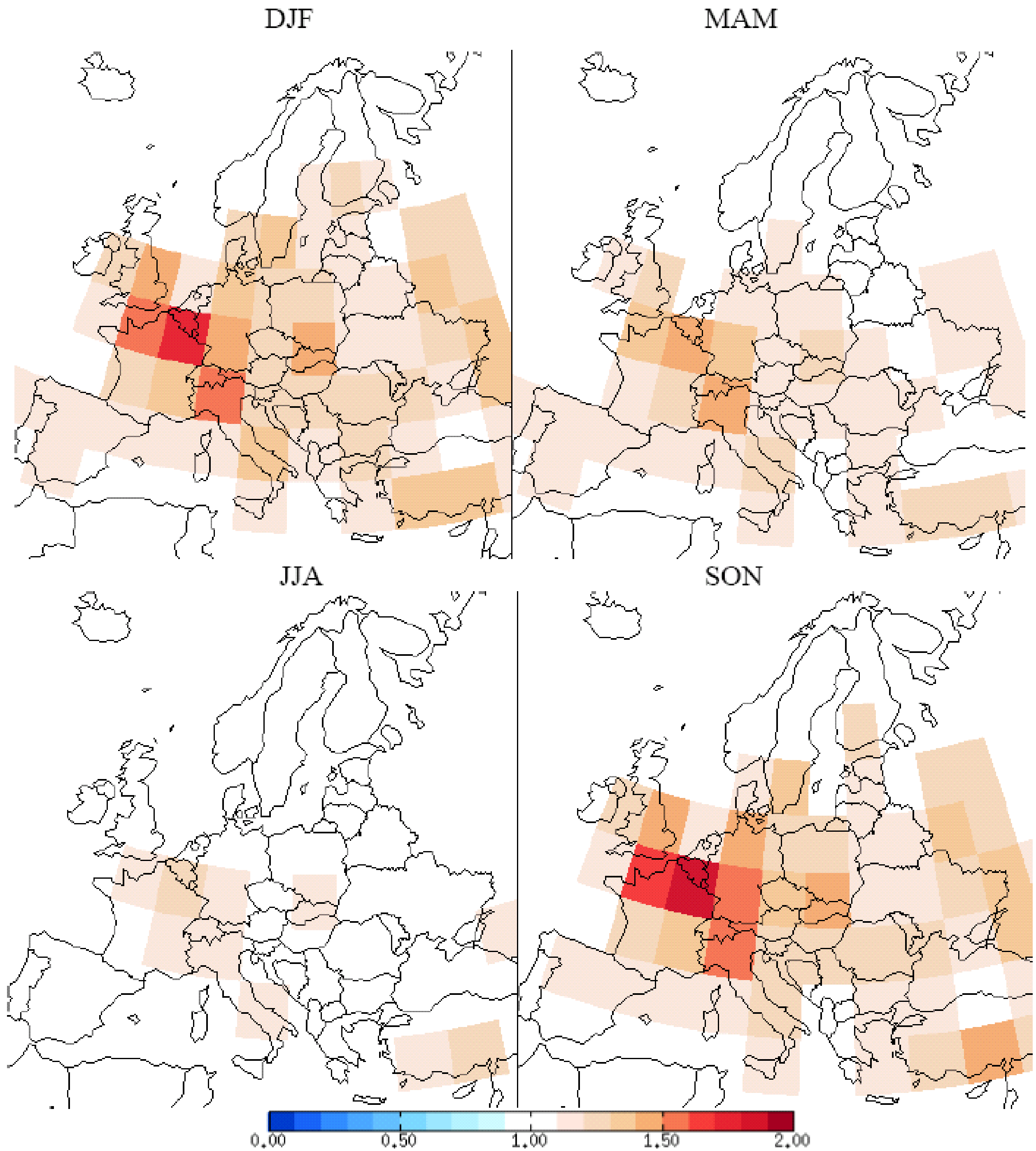


Annual total: 1350 Tg

Regional CO source estimates: Europe

Findings: Similar seasonality and spatial inhomogeneity as in N. America

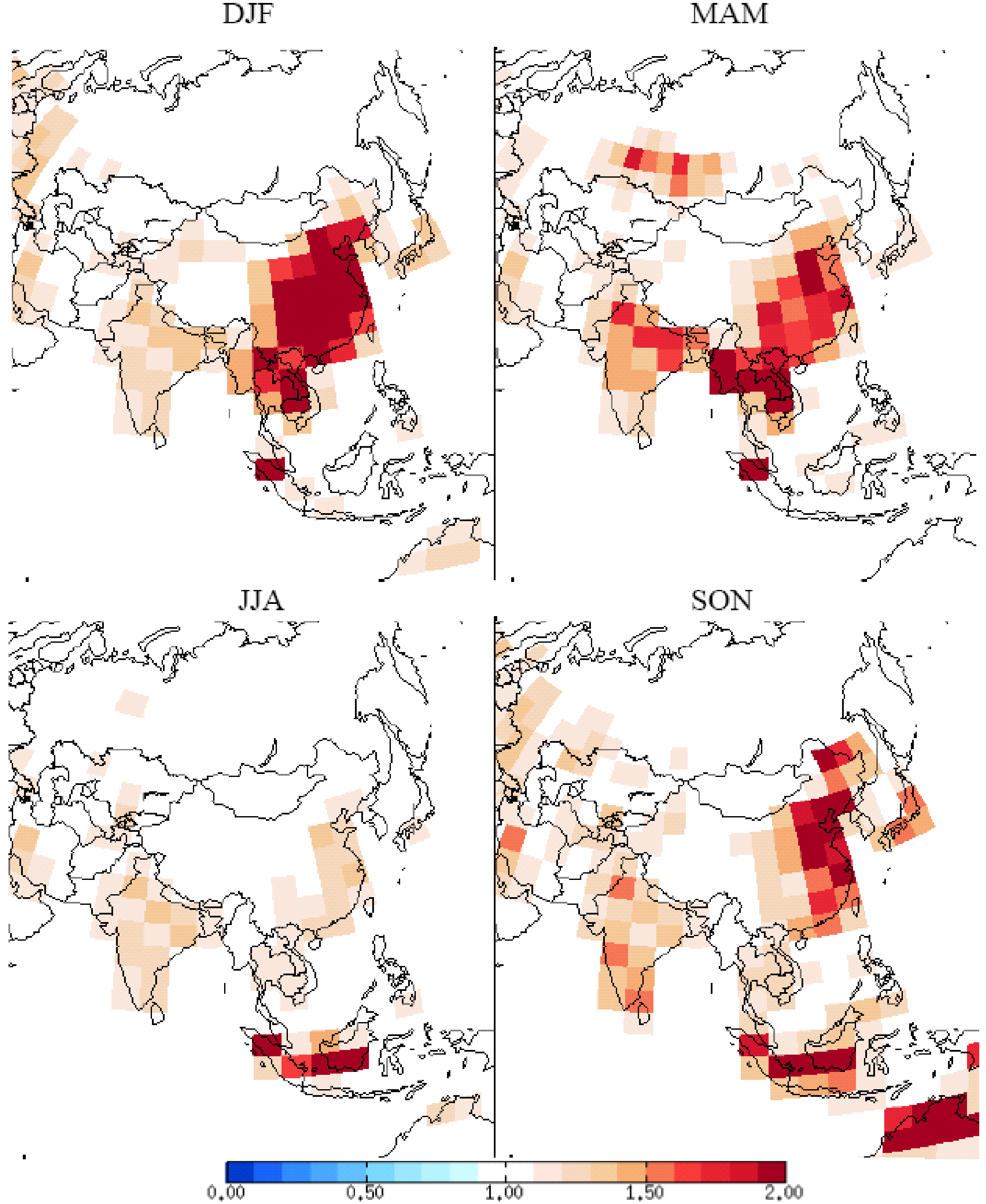
Possible **reasons** for underestimate: residential heating, “cold starts”



Regional CO source estimates: Asia

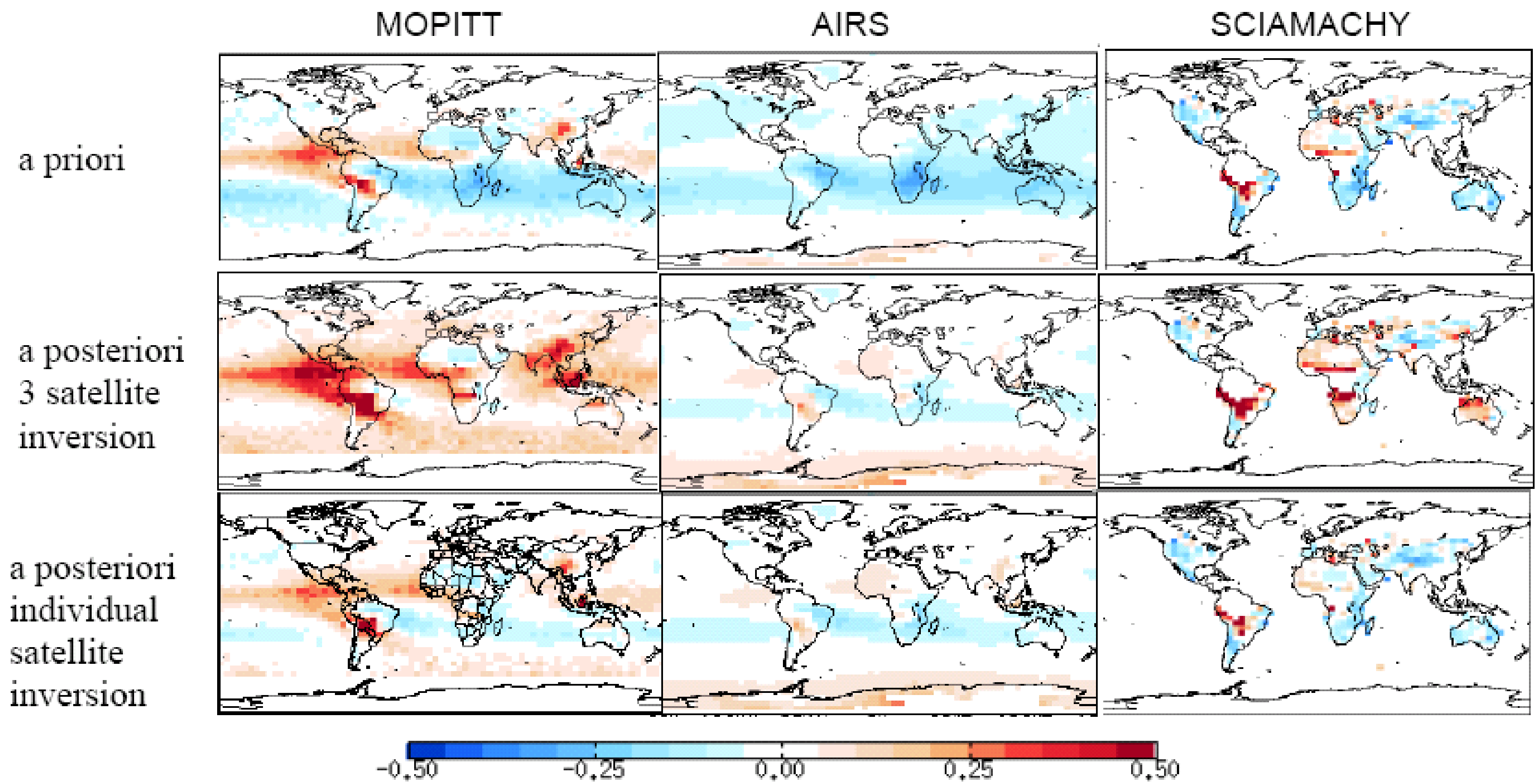
Findings:
Stronger seasonality in China than in N. America, no considerable seasonality in India

Possible **reasons** for underestimate: residential heating, "cold starts"



Improvement in model-data agreement from source inversion

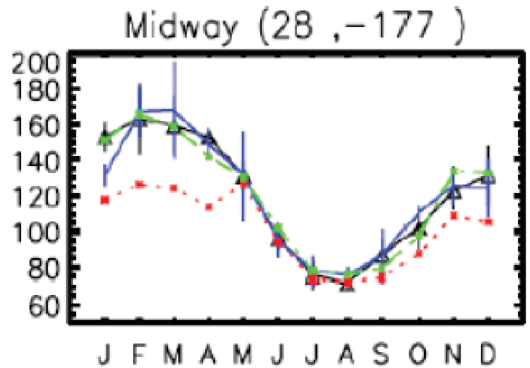
Fractional model bias: **(model-data)/data** during sample period: Sept-Oct-Nov 2004

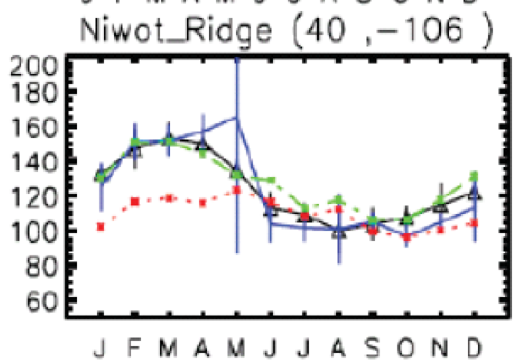


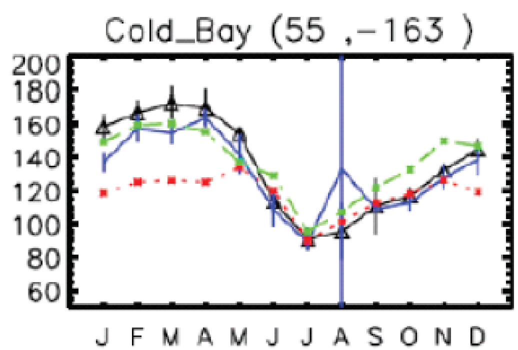
<u>Conclusion:</u> a balance of information, but AIRS dominates due to data density AND regional instrument inconsistencies

Comparison with independent surface measurements (GMD network)

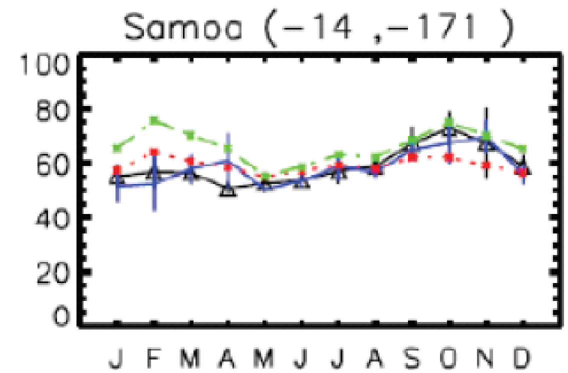
Northern Hemisphere:
great improvement

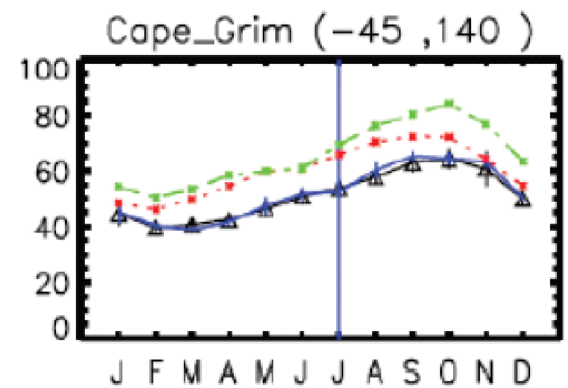






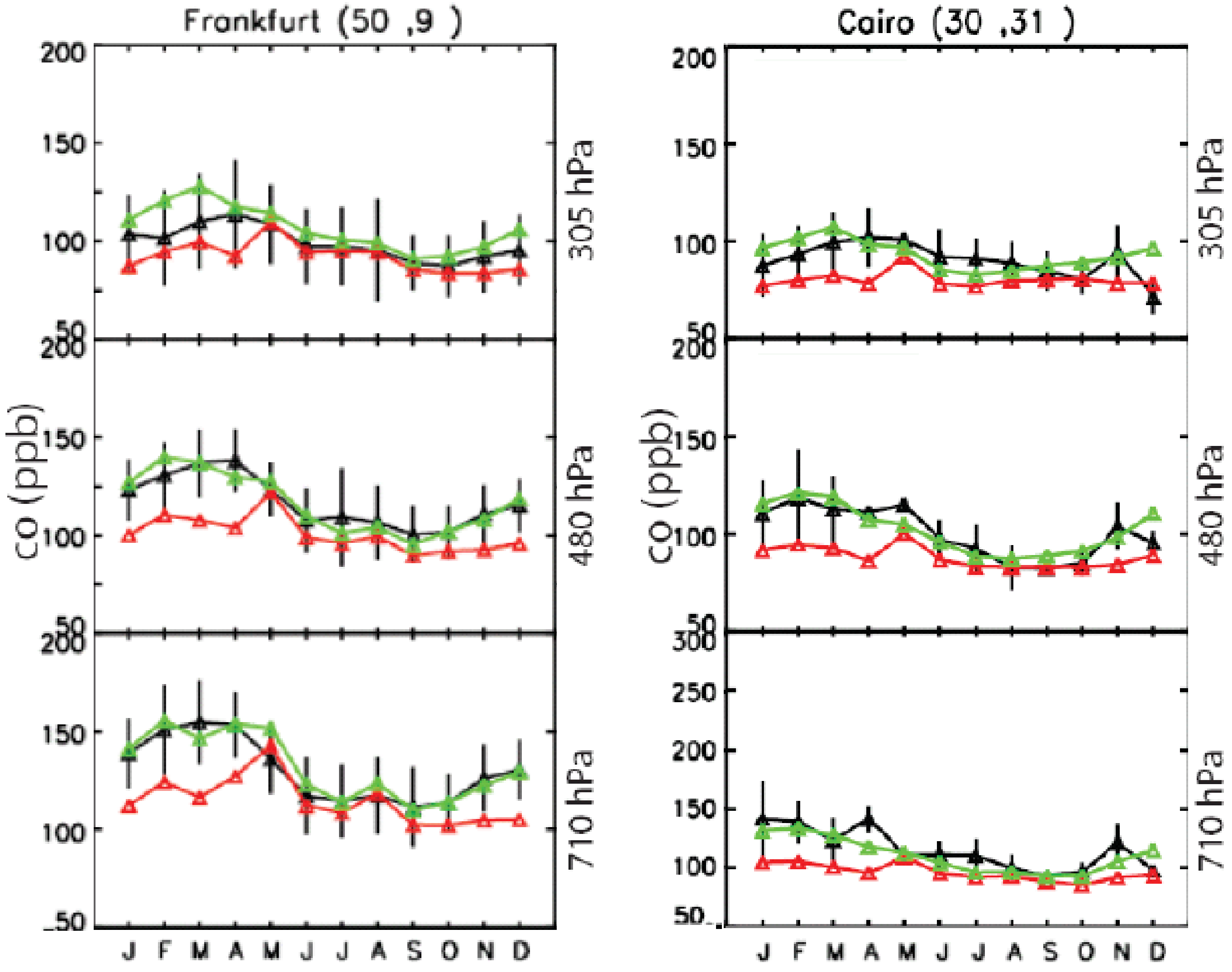
Southern Hemisphere:
still a challenge to match obs.





Model *a priori*	Model *a posteriori*
Obs (2004-2005)	Obs (climatology)

Comparison with independent aircraft measurements (MOZAIC)



Model *a priori* Model *a posteriori* Obs (climatology)

Major conclusions

1. GEOS-Chem CTM is a useful intercomparison platform for analyzing satellite data consistency
2. MOPITT, AIRS, TES and SCIAMACHY CO concentrations are generally consistent, especially in the northern hemisphere
3. Global annual CO emissions are found to be 1350 Tg
4. CO emissions in N. America, Europe and China exhibit strong seasonality, consistent with surface and aircraft observations
5. Tropical (mostly biomass burning) sources in S. America and Africa are estimated to be 183 and 343 Tg, mostly driven by AIRS data (larger than MOPITT or SCIAMACHY in southern hemisphere)
6. Regional satellite inconsistencies in southern hemisphere result in overestimated sources → motivation for more accurate data

Amount of *a priori* information in model-satellite correlations

Measure of information content: degrees of freedom (DOFs)

Note: DOFs not available for SCIA; reprocessing with MOPITT a priori does not change SCIA correlations