Microwave Sounding in All-Weather Conditions and Plans for NPP/ATMS

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Agenda

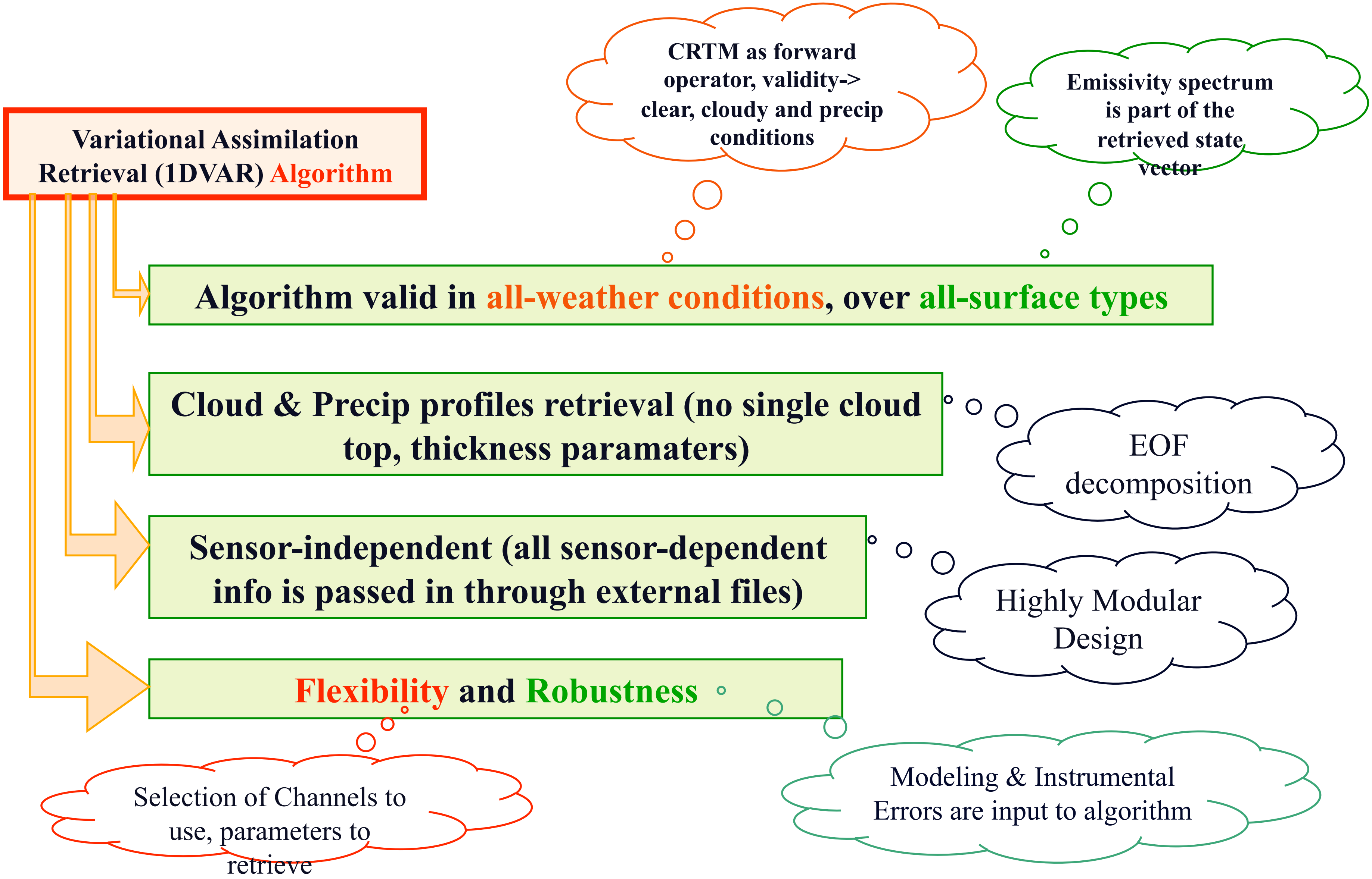
- Context
- Description of MiRS
- Results of MiRS for NOAA and Metop
- Plans for NPP ATMS

Context

- NOAA/NESDIS/STAR is developing a consistent, unique physical algorithm for all microwave sensors (called MiRS: Microwave Integrated Retrieval System)
- MiRS applies to imagers, sounders, combination
- MiRS uses the Community Radiative Transfer Model (CRTM) as the forward operator
- MiRS is applicable on all surfaces and in all-weather conditions (including in presence of cloud, rain, ice)
- MiRS is running operationally for NOAA-18, Metop-A and DMSP SSMI/S
- **Purpose:** Get ready for the NPP and NPOESS era. To use MiRS for ATMS and potentially for MIS.

Description of MiRS

MiRS Overall Concept



Variational Assimilation Retrieval (1DVAR) Algorithm

CRTM as forward operator, validity-> clear, cloudy and precip conditions

Emissivity spectrum is part of the retrieved state vector

Algorithm valid in all-weather conditions, over all-surface types

Cloud & Precip profiles retrieval (no single cloud top, thickness paramaters)

EOF decomposition

Sensor-independent (all sensor-dependent info is passed in through external files)

Highly Modular Design

Flexibility and Robustness

Selection of Channels to use, parameters to retrieve

Modeling & Instrumental Errors are input to algorithm

Mathematical Basis

- Cost Function to minimize:

$$\boxed{J(X) = \left[\frac{1}{2}\left(X - X_0\right)^T \times B^{-1} \times \left(X - X_0\right)\right] + \left[\frac{1}{2}\left(Y^m - Y(X)\right)^T \times E^{-1} \times \left(Y^m - Y(X)\right)\right]}$$

- To find the optimal solution, solve for:

$$\frac{\partial J(X)}{\partial X} = J'(X) = 0$$

- Assuming local Linearity

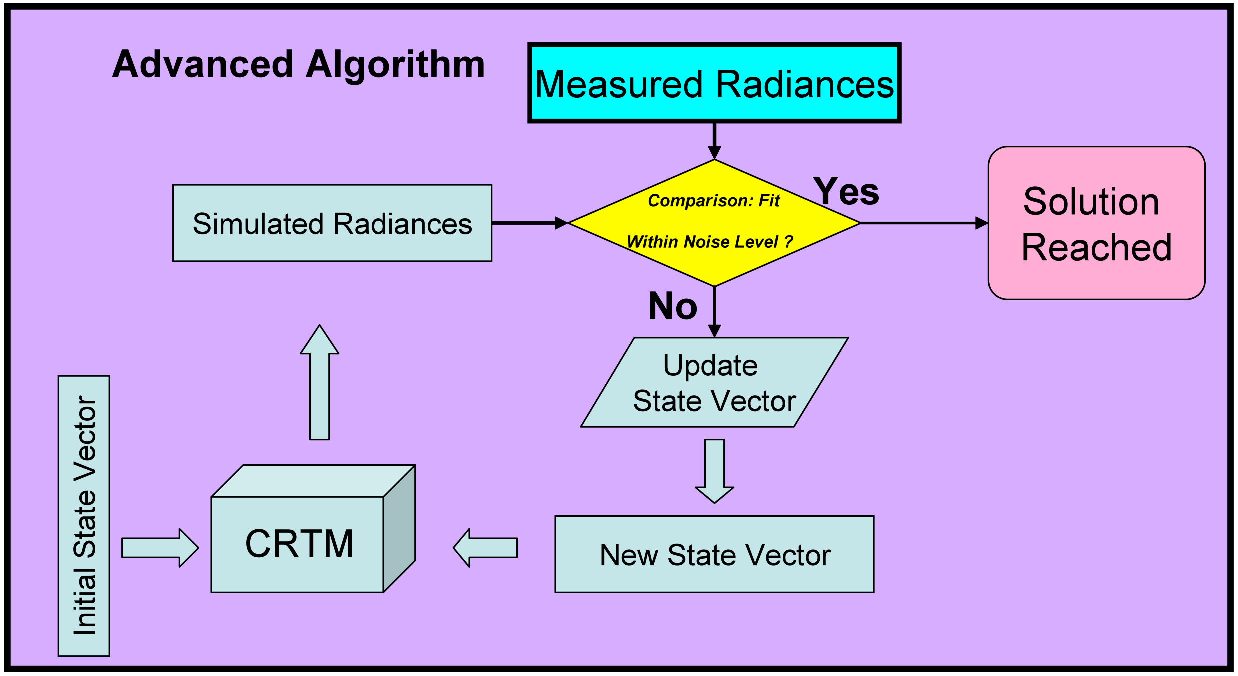
$$y(x) = y(x_0) + K\left[x - x_0\right]$$

- This leads to iterative solution:

$$\boxed{\Delta X_{n+1} = \left\{BK_n^T\left(K_n BK_n^T + E\right)^{-1}\right\}\left[\left(Y^m - Y(X_n)\right) + K_n \Delta X_n\right]}$$

More efficient
(1 inversion)

MiRS Algorithm (1DVAR)



Advanced Algorithm

Measured Radiances

Simulated Radiances

Comparison: Fit Within Noise Level ?

Yes

Solution Reached

No

Update State Vector

New State Vector

CRTM

Initial State Vector

The first retrieval attempt includes only clear and cloudy (non-precipitating) parameters

Convergence

Final solution (no precip)

Non-Convergence

2nd Attempt (liquid and ice rain turned ON along with all sounding/surface parameters)

MIRS State Vector

- Temperature & Water vapor profiles @ 100 layers
- Skin Temperature
- Surface Emissivity Spectrum
- Non-precipitating cloud amount vertical profile
- Liquid and frozen rain vertical profiles

Assumptions Made in Solution Derivation

- The PDF of X is assumed Gaussian
- Operator Y able to simulate measurements-like radiances
- Errors of the model and the instrumental noise combined are assumed (1) non-biased and (2) Normally distributed.
- Forward model assumed locally linear at each iteration.
- Independence of errors (instrumental and background)

Retrieval in Reduced Space
(EOF Decomposition)

- All retrieval is done in EOF space, which allows:
  - Retrieval of profiles (T,Q, RR, etc): using a limited number of EOFs
  - More stable inversion: smaller matrix but also quasi-diagonal
  - Time saving: smaller matrix to invert

- Mathematical Basis:
  - EOF decomposition *(or Eigenvalue Decomposition)*
    - By projecting back and forth Cov Matrx, Jacobians and X

$$\boxed{\Theta = L^{T} \times B \times L}$$

Diagonal Matrix
(used in reduced space retrieval)

Transf. Matrx
(computed offline)

Covariance matrix
(geophysical space)

Purpose(s) of Retrieving Precipitation Parameters

- #1: Be able to retrieve Temperature mainly (possibly water vapor as well) under precipitating conditions
- #2: Retrieve precipitation parameters themselves ONLY if enough information content present (not the case currently)

- Think of it as a ‘PRECIP- CLEARING’ but highly non-linear : Account for precip only to absorb extinction effects on radiances and allow retrieval of T/Q.

MIRS Convergence Criteria

- Convergence should check for minimal cost function J

$$J(X) = \underbrace{\left[\frac{1}{2}(X - X_0)^T \times B^{-1} \times (X - X_0)\right]}_{\substack{\uparrow \\ \text{Bkg-departure normalized by Bkg Error}}} + \underbrace{\left[\frac{1}{2}(Y^m - Y(X)\ )^T \times E^{-1} \times (Y^m - Y(X)\ )\right]}_{\substack{\uparrow \\ \text{Measurements-departure normalized by} \\ \text{Measurements+Modeling Errors}}}$$

- In practice, we use non-constrained cost Function: $\varphi^2 = (Y^m - Y(X))^T \times E^{-1} \times (Y^m - Y(X))$

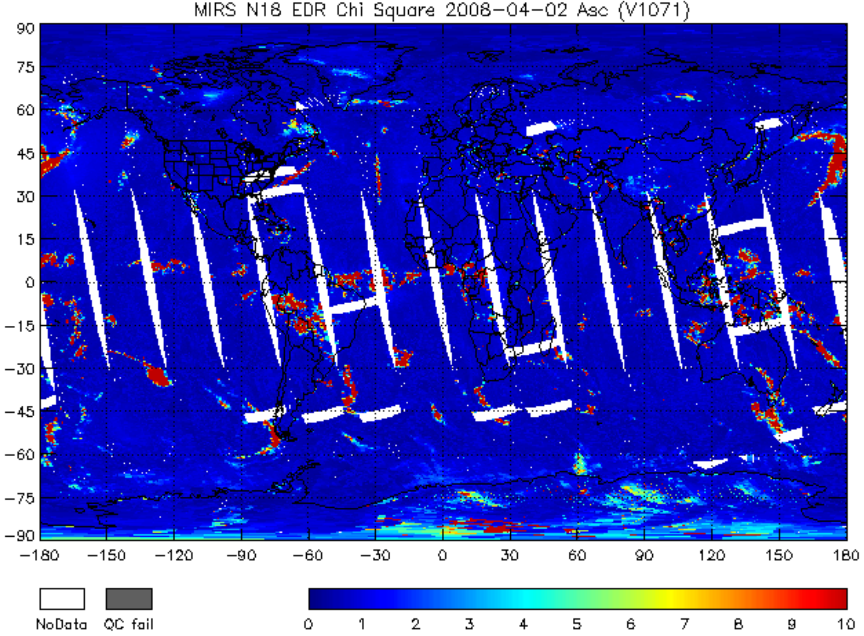
- Convergence threshold $\varphi^2 <= 1$

Convergence Example

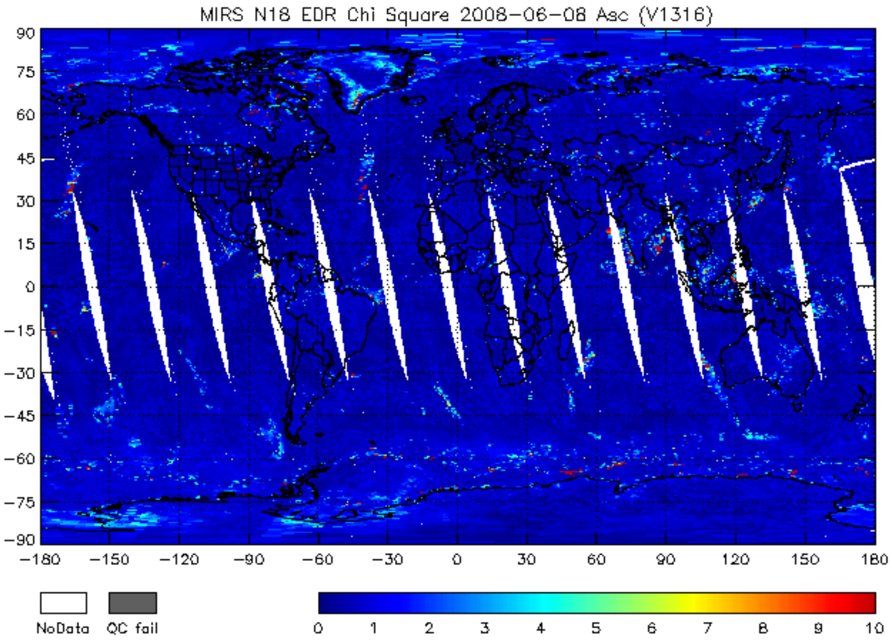
- Convergence is reached everywhere: all surfaces, all weather conditions including precipitating, icy conditions
- This is a major achievement: a radiometric solution is found even when precip/ice present. With CRTM physical constraints and covariance-based correlations.

Previous version

(non convergence when precip/ice present)



Current version



List of products (Official)

- **Metop-A and NOAA-18**
  1. Temperature profile (ocean)
  2. Moisture (ocean and non-costal land)
  3. Total Precipitable Water (TPW) (ocean and non-costal land)
  4. Land Surface Temperature (LST)
  5. Emissivity Spectrum (All surfaces)
  6. Surface Type (sea, land, snow, sea-ice)
  7. Emissivity-based Snow Water Equivalent (SWE)
  8. Emissivity-based Snow Cover Extent (SCE)
  9. Emissivity-based Sea Ice Concentration (SIC)
  10. Vertically Integrated Non-precipitating Cloud Liquid Water (CLW)
  11. Vertically Integrated Ice Water Path (IWP)
  12. Vertically Integrated Rain Water Path (RWP)

- **DMSP F16 SSMIS**
  1. Temperature profile (ocean)
  2. Moisture (ocean and non-costal land)
  3. Total Precipitable Water (TPW) (ocean and non-costal land)
  4. Land Surface Temperature (LST)
  5. Emissivity Spectrum (All surfaces)
  6. Surface Type (sea, land, snow, sea-ice)

Note: The hydrometeor profiles dropped from official list (lack of information content in radiances, see next slide)

Total: 30 products

List of unofficial products

(Delivered For Testing purposes)

Note: Cl[illegible] made availa[illegible]sting purposes (s[illegible]de)

- **Metop-A and NOAA-18**
  1. Cloud Liquid Water Profile (CLWP) over ocean
  2. Surface Temperature (skin) of snow-covered lan[illegible]
  3. Sea Surface Temperature (SST)
  4. Effective grain size of snow (over snow-co[illegible]nd surface)
  5. Multi-Year (MY) Type Sea Ice concentr[illegible]
  6. First-Year (FY) Type Sea Ice Conce[illegible]

- **DMSP F16 SSMIS**
  1. Extended Total Precipitabl[illegible] over non-coastal Land
  2. Emissivity-based Snow [illegible]quivalent (SWE)
  3. Emissivity-based Sn[illegible]r Extent (SCE)
  4. Emissivity-based [illegible] Concentration (SIC)
  5. Surface Temp[illegible] (skin) of snow-covered land
  6. Sea Surfac[illegible]erature (SST)
  7. Effective [illegible]ze of snow (over snow-covered land surface)
  8. Multi[illegible]Y) Type Sea Ice concentration
  9. Fi[illegible] (FY) Type Sea Ice Concentration

We will concentrate on the sounding aspect only.

Total: 21 test products

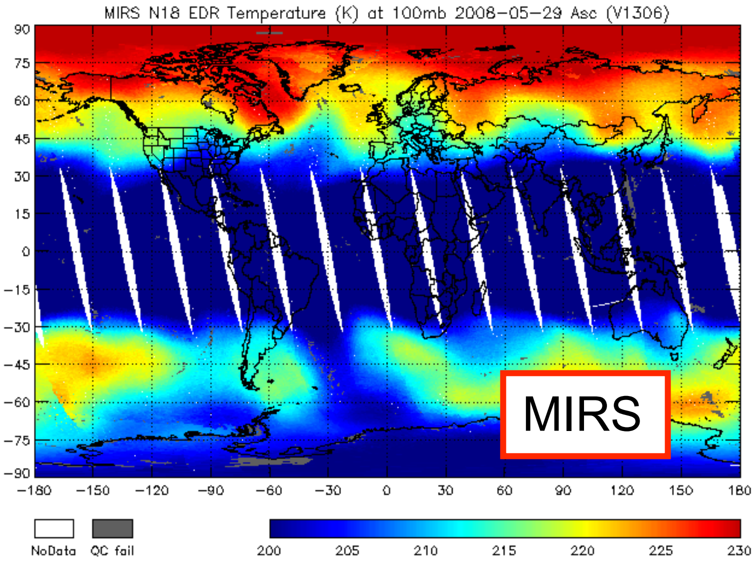
Results of MiRS for NOAA-18 and Metop-A

Assessment of Sounding Performances in Clear/Cloudy

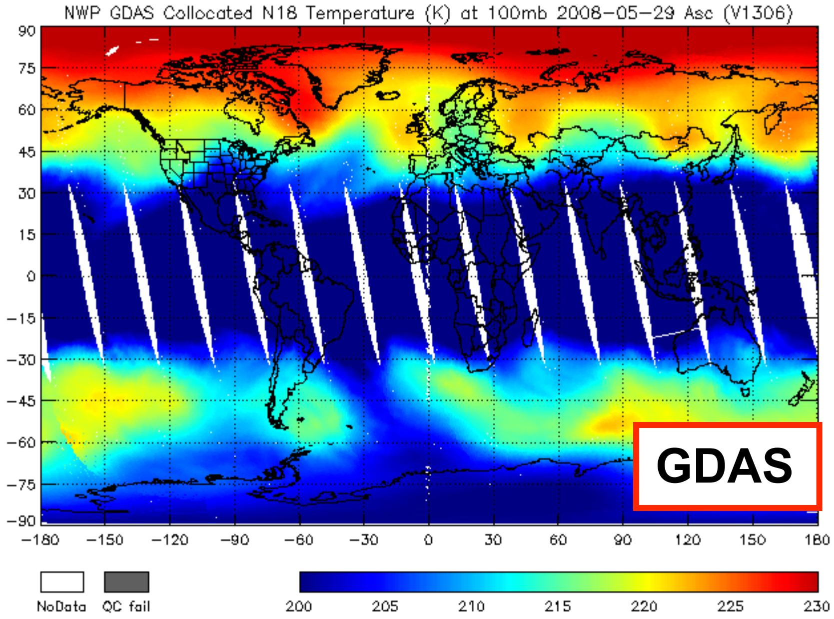
Comparisons made daily wrt:
- GDAS fields
- ECMWF fields
- COSMIC profiles
- Radiosondes profiles
- Heritage sounding algorithms (ATOVS)

Temperature Profile (1/4)

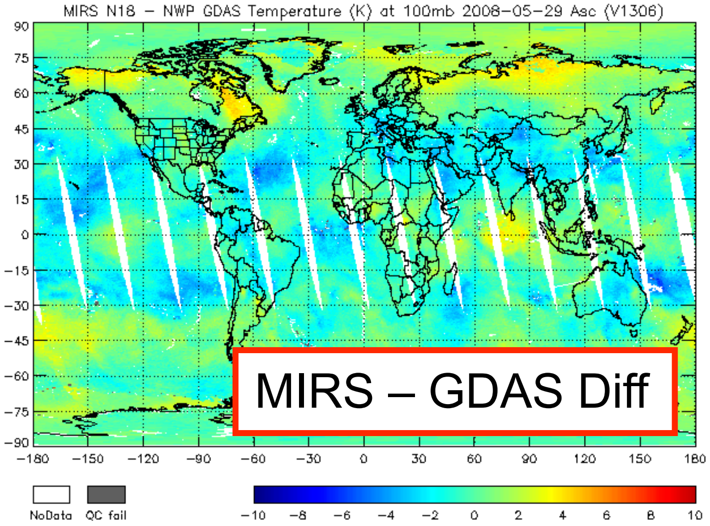
(over open water ocean, against GDAS)



MIRS N18 EDR Temperature (K) at 100mb 2008-05-29 Asc (V1306)



NWP GDAS Collocated N18 Temperature (K) at 100mb 2008-05-29 Asc (V1306)



MIRS N18 − NWP GDAS Temperature (K) at 100mb 2008-05-29 Asc (V1306)

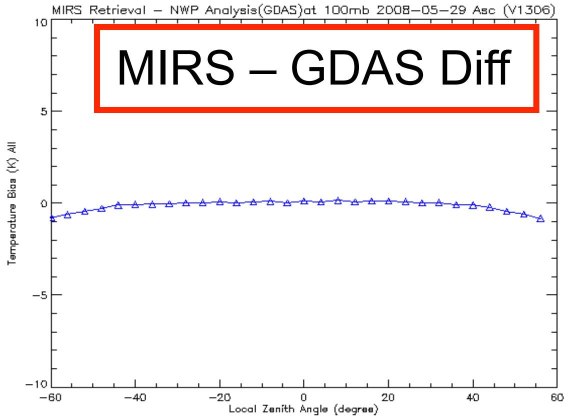
The temperature is officially delivered over ocean only. But over non-ocean (land, snow, sea ice), temperature is still valid.

Validation is performed by comparing to:

-GDAS

-ECMWF

-RAOB

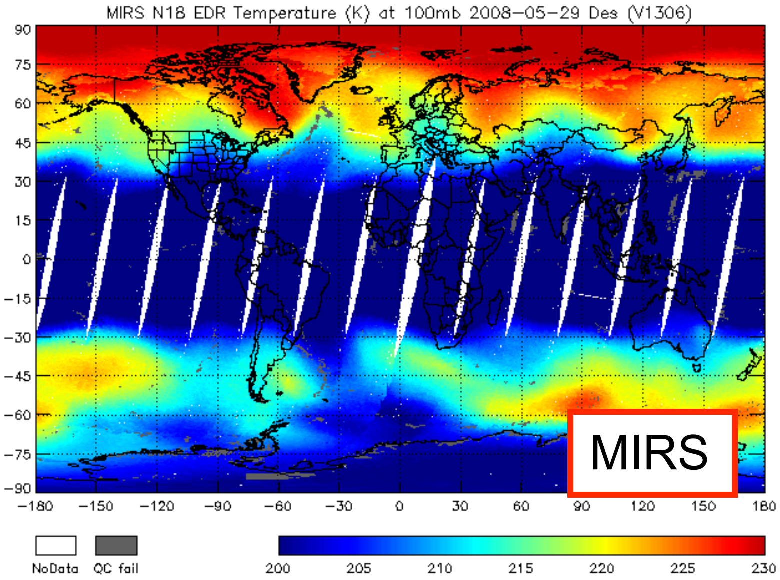


MIRS Retrieval − NWP Analysis(GDAS)at 100mb 2008-05-29 Asc (V1306)

N18

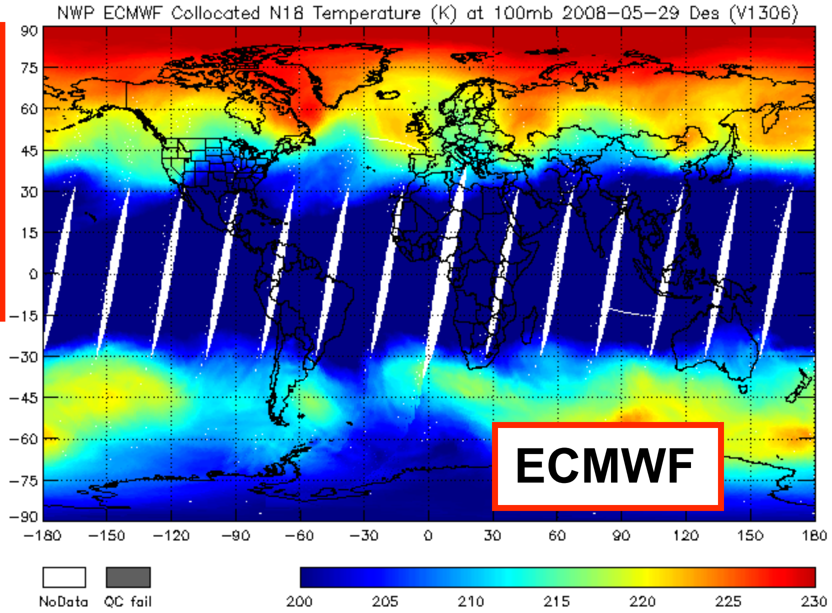
Temperature Profile (2/4)

(over open water ocean, against ECMWF)

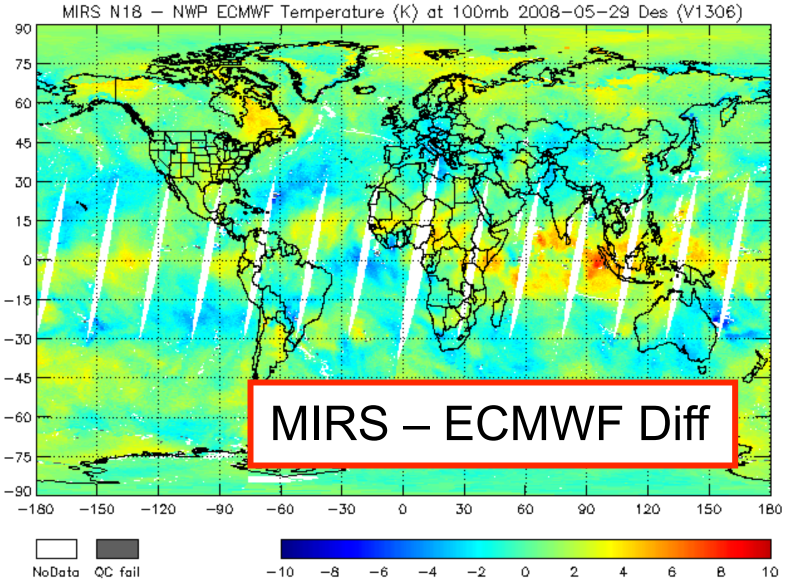


MIRS

Angle dependence taken care of very well, without any limb correction

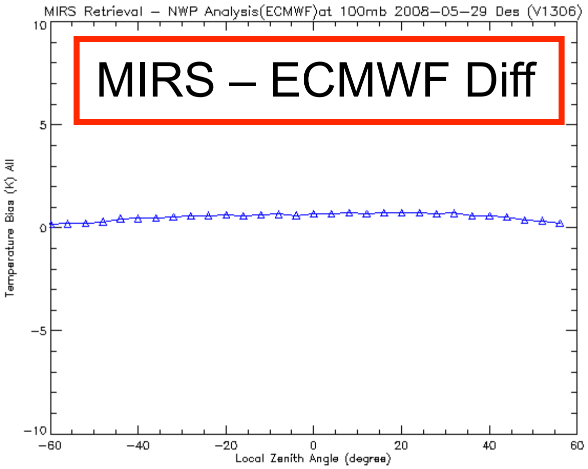


ECMWF



MIRS – ECMWF Diff

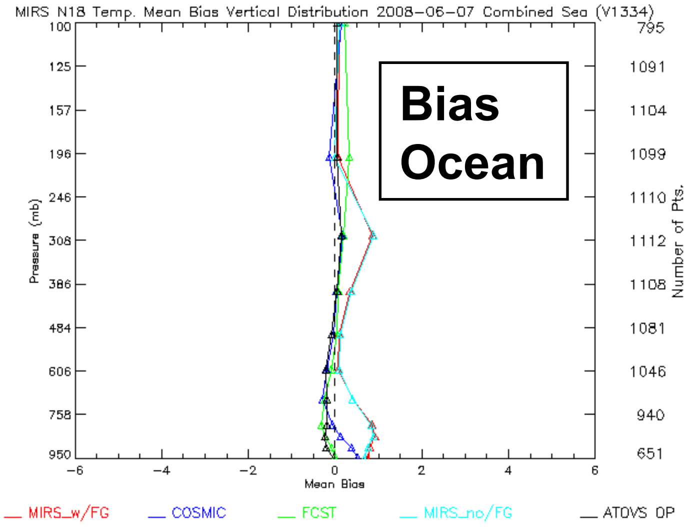
Note: Retrieval is done over all surface backgrounds but also in all weather conditions (clear, cloudy, rainy, ice)



MIRS – ECMWF Diff

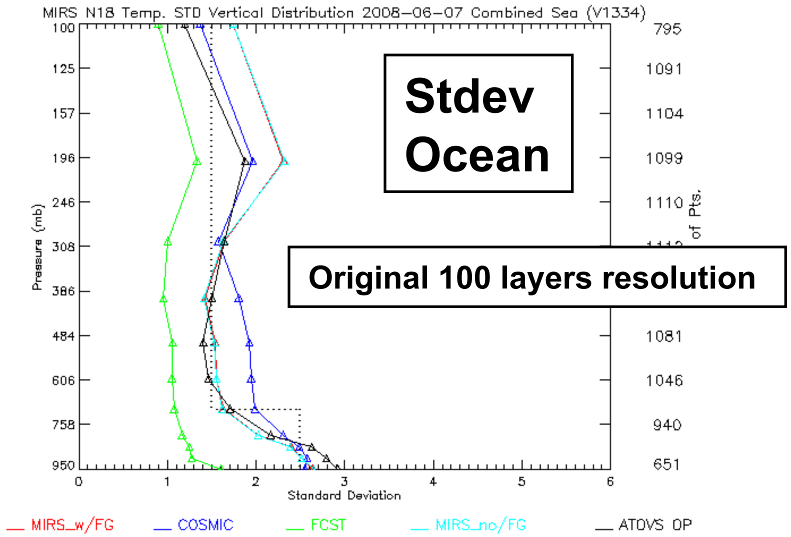
Temperature Profile (3/4)

(over open water ocean, against RAOBs, COSMIC, ATOVS, Forecast)



MIRS N18 Temp. Mean Bias Vertical Distribution 2008–06–07 Combined Sea (V1334)

Bias Ocean



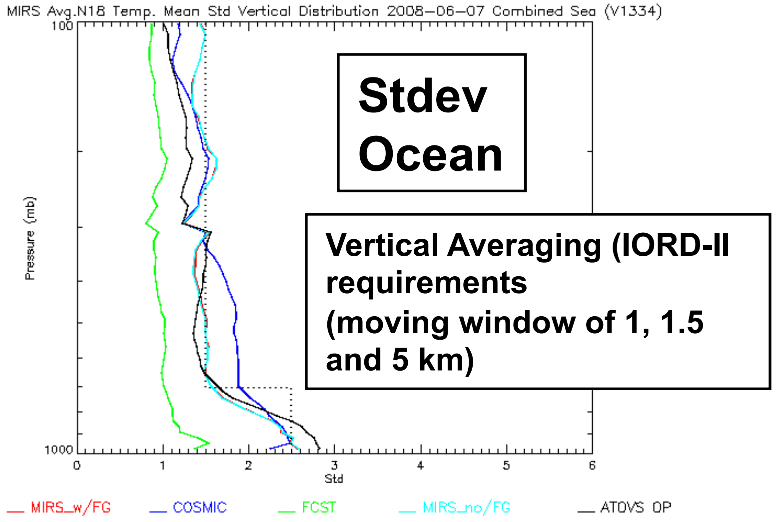
MIRS N18 Temp. STD Vertical Distribution 2008–06–07 Combined Sea (V1334)

Stdev Ocean

Original 100 layers resolution

Bias of roughly 1 K noticed at the surface

Collocation criteria (COSMIC, ATOVS, SSMIS, RAOB):
+/- 5 hours, +/- 100 Kms
Data spanning 42 days



MIRS Avg.N18 Temp. Mean Std Vertical Distribution 2008–06–07 Combined Sea (V1334)

Stdev Ocean

Vertical Averaging (IORD-II requirements (moving window of 1, 1.5 and 5 km)

N18

Temperature Profile (4/4)

(Performances)

		Ocean		Land	
	Layer	Bias (K)	Std (K)	Bias (K)	Std (K)
MIRS vs ECMWF	100 mb	0.281	1.883	1.019	1.787
	300 mb	0.273	1.504	0.548	1.701
	500 mb	0.059	1.311	0.241	1.806
	800 mb	1.169	1.823	1.157	3.410
	950 mb	1.727	2.736	0.860	4.480
MIRS vs GDAS	100 mb	-0.0485	1.541	0.017	1.708
	300 mb	0.183	1.589	0.151	1.801
	500 mb	-0.197	1.401	0.245	1.847
	800 mb	1.152	1.711	1.277	3.826
	950 mb	1.107	2.808	0.881	4.826
MIRS vs RAOB	100 mb	0.080	1.739	0.259	2.085
	300 mb	0.851	1.858	0.489	1.774
	500 mb	0.123	1.578	-0.062	1.811
	800 mb	0.681	2.082	1.501	2.789
	950 mb	0.810	2.882	1.702	3.146

Note*: IORD-II requirements for temperature in cloudy:

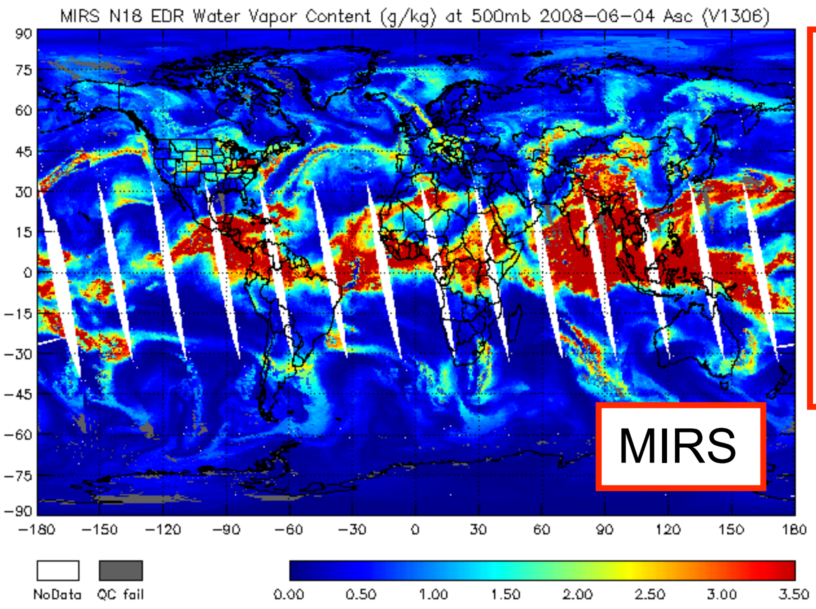
-Uncertainty (surface to 700 mb: 2.5K per 1km layer, 700 mb to 300 mb: 1.5K per 1 km layer, 300 to 30 mb: 1.5K per 3km layer, 30 to 1mb: 1.5K per 5km layer)

*These requirements are for CrIS and ATMS, which have more channels and higher sensing skills in general than AMSU, MHS or SSMIS

N18

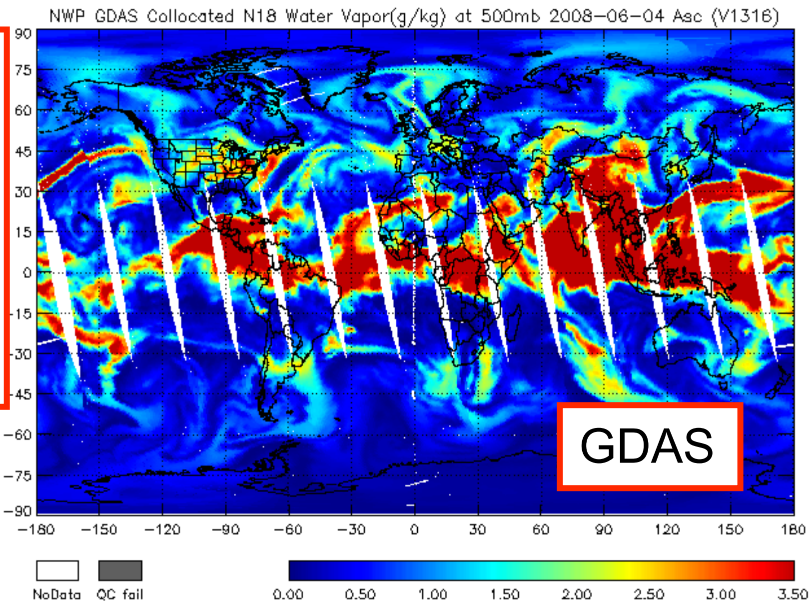
Moisture Profile (1/4)

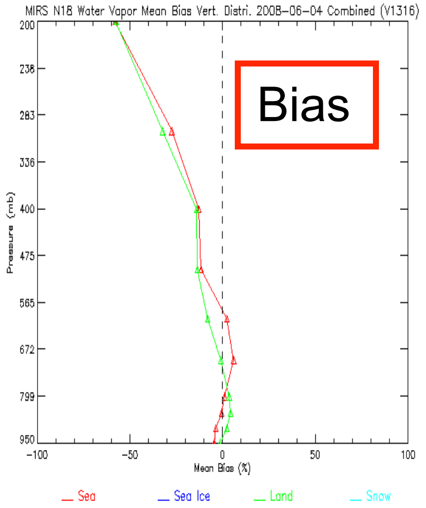
(over open water and land, against GDAS)

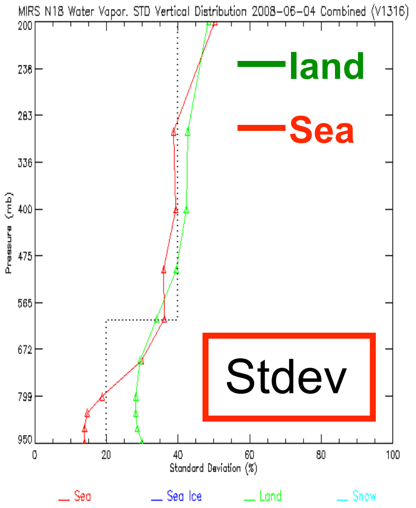


Validation of WV done by comparing to:
- -GDAS
- -ECMWF
- -RAOB

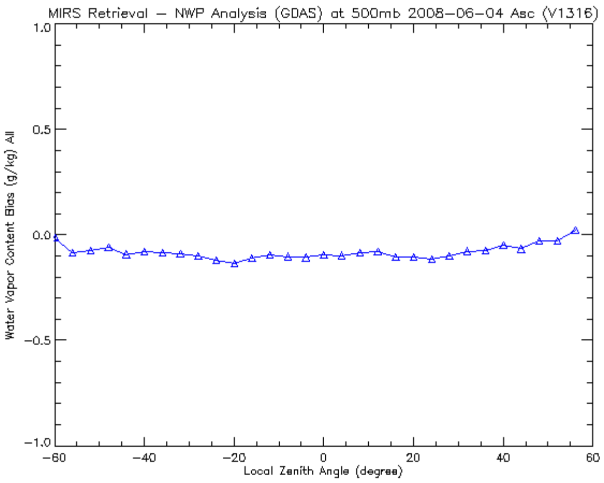
Retrieval done over all surfaces in all weather conditions







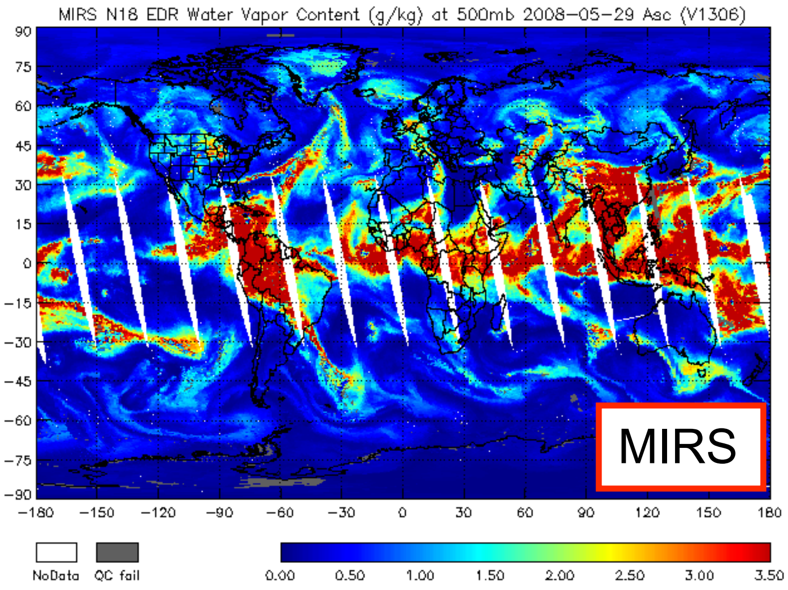
Assessment includes:
- -Angle dependence
- -Statistics profiles
- -Difference maps



N18

Moisture Profile (2/4)

(over open water and land, against ECMWF)



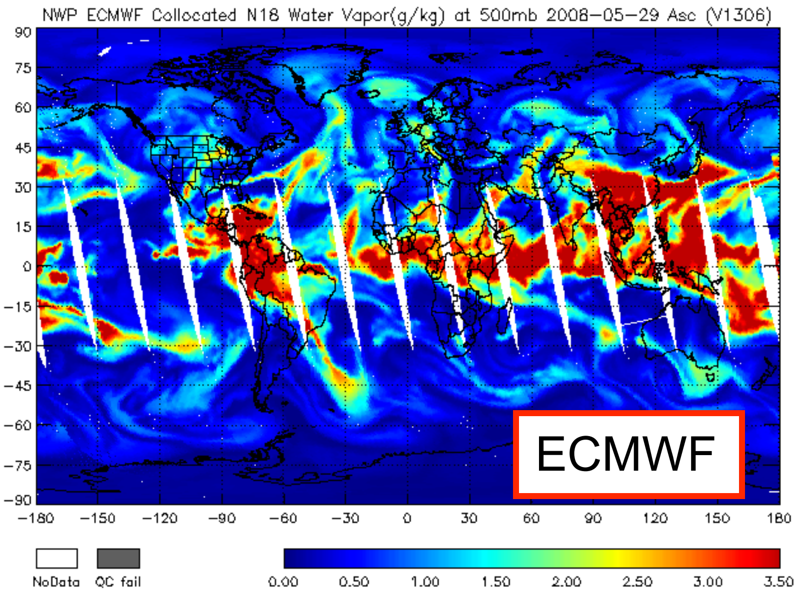
Validation of WV done by comparing to:

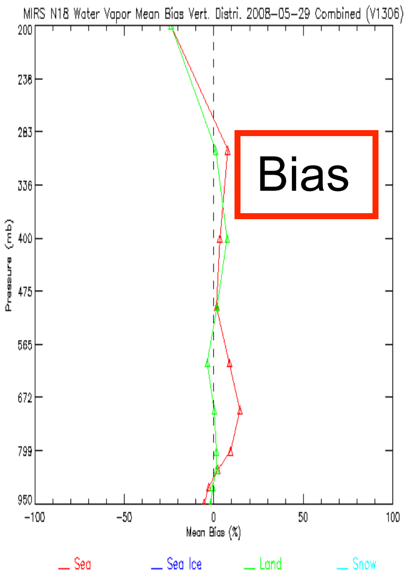
-GDAS

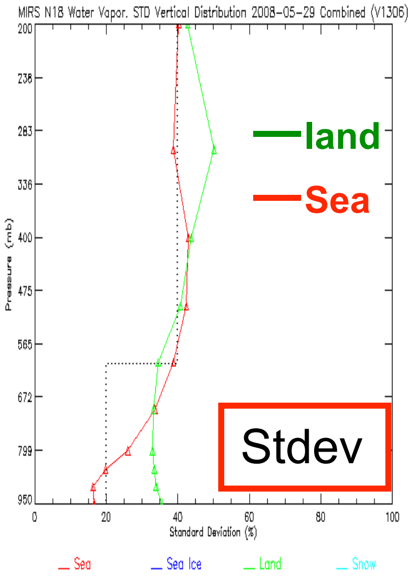
-ECMWF

-RAOB

Retrieval done over all surfaces in all weather conditions





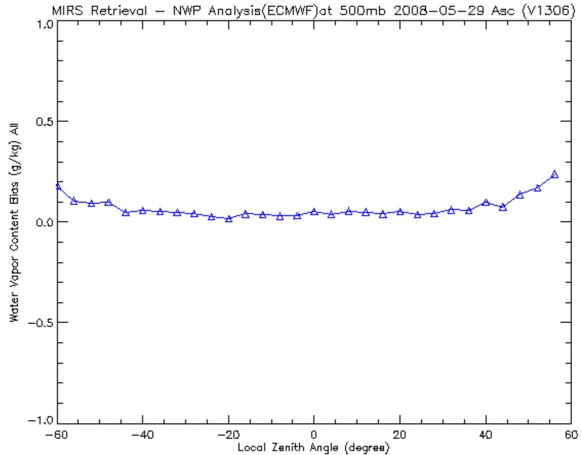


Assessment includes:

-Angle dependence

-Statistics profiles

-Difference maps



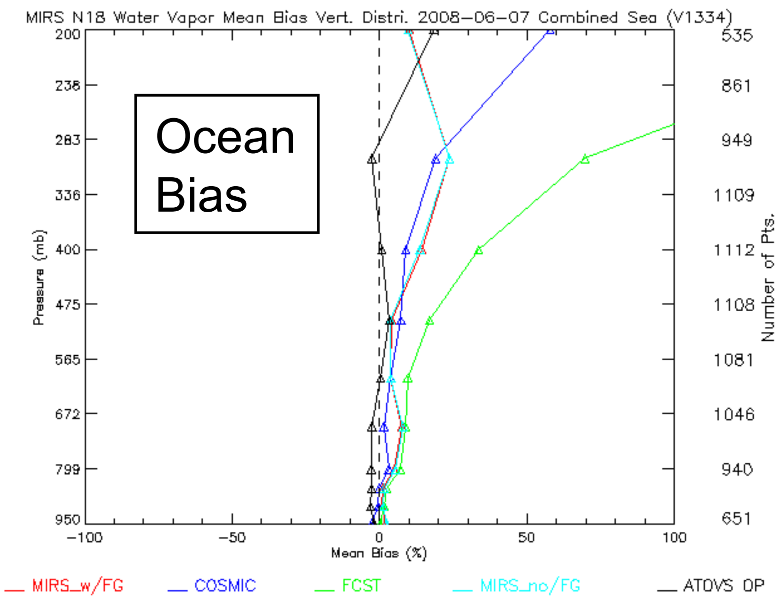
When assessing, keep in mind all ground truths (wrt GDAS, ECMWF, RAOB)

N18

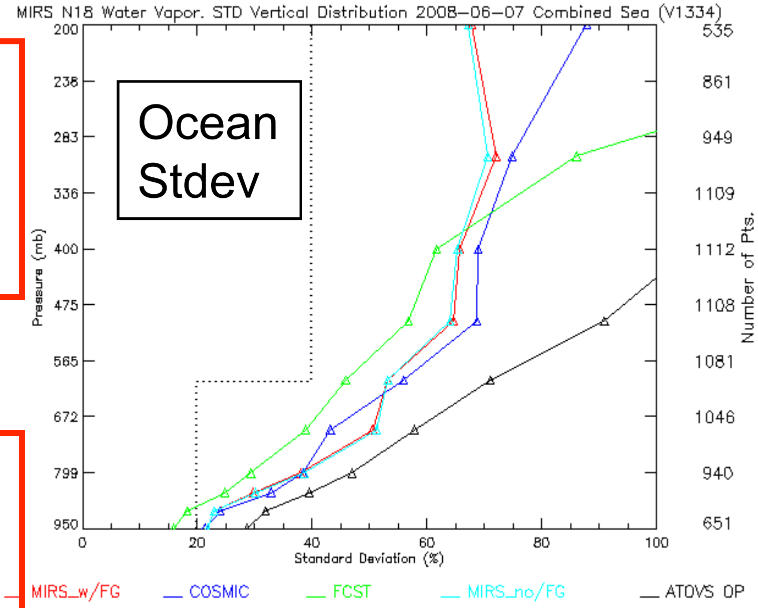
Moisture Profile (3/4)

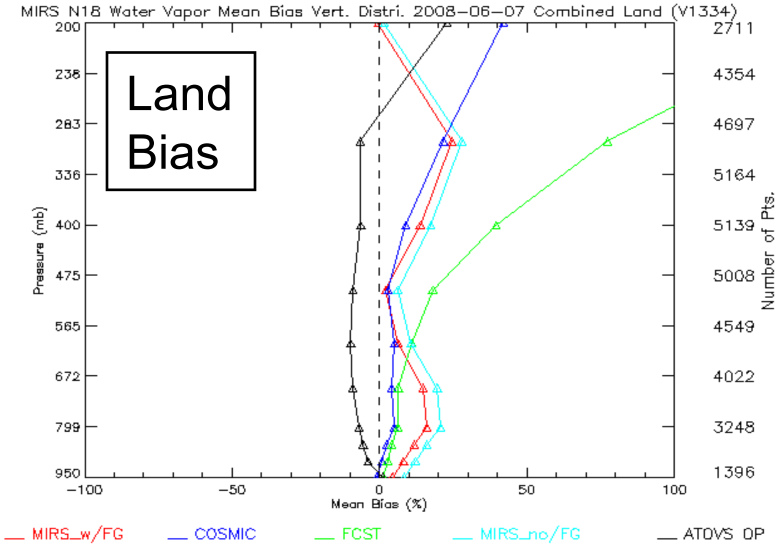
N18

(over open water and land, against RAOB, COSMIC, Forecast, ATOVS)


MIRS N18 Water Vapor Mean Bias Vert. Distri. 2008–06–07 Combined Sea (V1334)

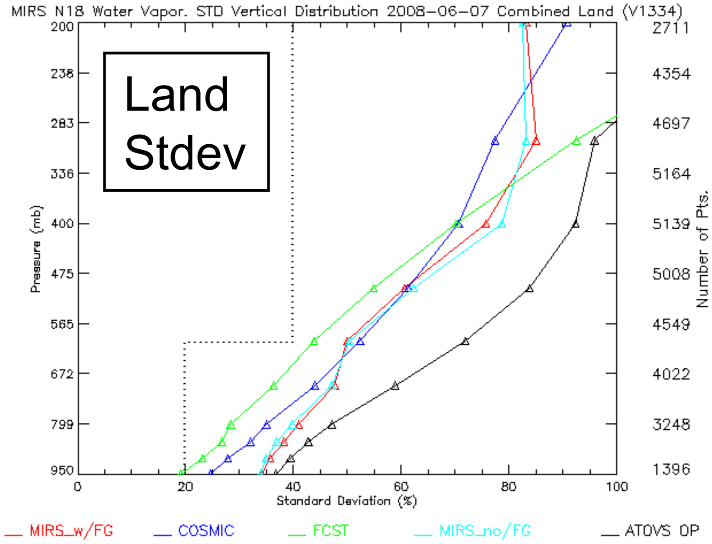
Stdev is found very good over land and ocean


MIRS N18 Water Vapor. STD Vertical Distribution 2008–06–07 Combined Sea (V1334)


MIRS N18 Water Vapor Mean Bias Vert. Distri. 2008–06–07 Combined Land (V1334)

MIRS is compared to Raob (along with COSMIC, ATOVS and Forecast)

Bias wrt RAOB (over land) not consistent with ECMWF and GDAS


MIRS N18 Water Vapor. STD Vertical Distribution 2008–06–07 Combined Land (V1334)

Moisture Profile (4/4)

(Performances)

		Ocean		Land	
	Layer	Bias (%)	Std (%)	Bias (%)	Std (%)
MIRS vs ECMWF	100 mb				
	300 mb	8.0	41.0	1.5	54.0
	500 mb	-0.5	42.5	-1.5	41.0
	800 mb	11.0	28.0	-1.0	32.5
	950 mb	-5.0	17.0	-5.5	32.0
MIRS vs GDAS	100 mb				
	300 mb	-29	40.5	-30.0	53.0
	500 mb	-10.0	39.5	-15.0	38.5
	800 mb	2.0	22.0	8.0	30.0
	950 mb	-5.5	13.5	3.0	30.0
MIRS vs RAOB	100 mb				
	300 mb	21.5	75.0	21.0	83.0
	500 mb	2.0	65.0	1.0	60.0
	800 mb	2.0	38.0	7.0	41.0
	950 mb	0.5	21.5	4.0	30.0

Note*: IORD-II requirements for Water Vapor Mixing Ratio (in g/Kg), for cloudy:

-Uncertainty (surface to 600 mb: greater of 20% or 0.2 g/Kg, 600 mb to 100 mb: greater of 40% or 0.1 g/Kg) [expressed as percent error of average mixing ratio in 2km layers]

- No measurement precision

***These requirements are for CrIS and ATMS, which have more channels and higher sensing skills in general than AMSU, MHS or SSMIS**

N18

Assessment of Sounding Performances in Hurricane conditions

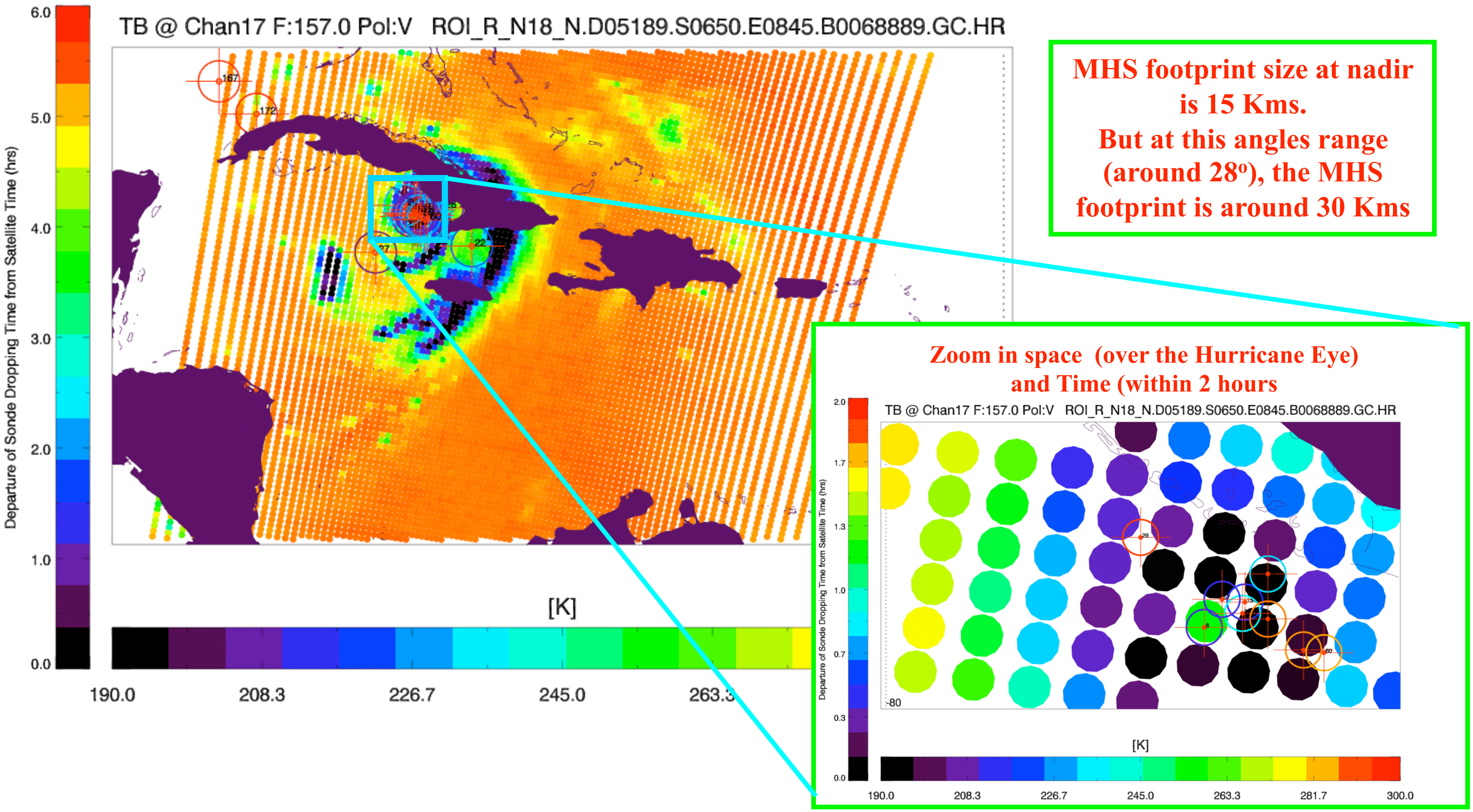
A tricky issue to say the least because of:

- *Highly variable meteorological conditions (in time and space)*
- *Collocation errors*
- *Moving target (sondes sample different parts of the atmosphere while dropping/ascending)*
- *Representativeness errors (spot vs footprint)*
- *Intra variability of ground truth measurements*
- *3D effects on TBs*

Assessment of Sounding in Hurricane Conditions

Collocation with GPS-Dropsondes

- **Case of July 8th 2005 (descending pass)**



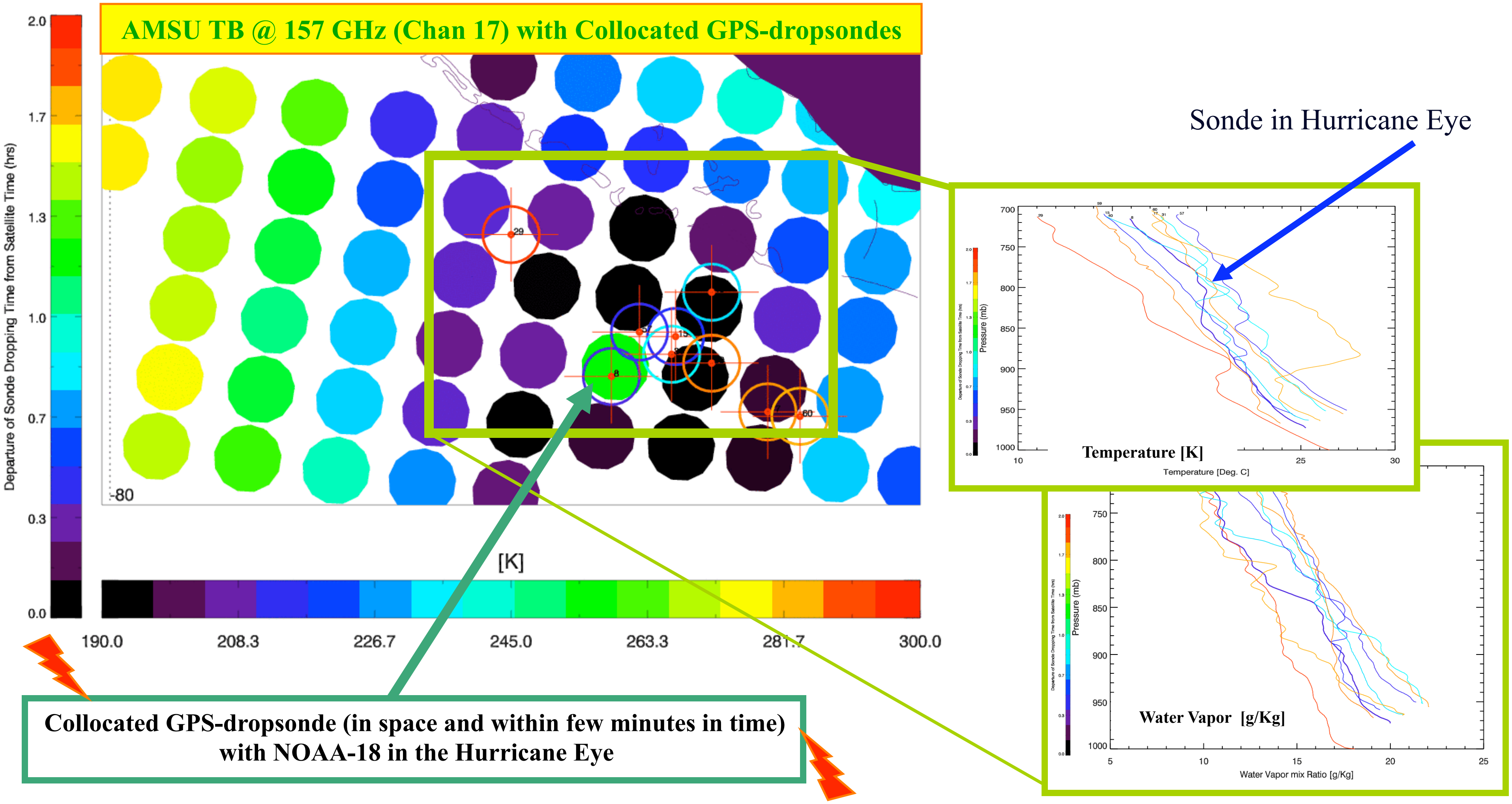
MHS footprint size at nadir is 15 Kms. But at this angles range (around 28º), the MHS footprint is around 30 Kms

Zoom in space (over the Hurricane Eye) and Time (within 2 hours

Collocation AMSU/MHS with GPS-Dropsondes (2nd case)

A peak at the vertical profiles measured by the dropsondes

- **Case of July 8th 2005 (descending pass)**


AMSU TB @ 157 GHz (Chan 17) with Collocated GPS-dropsondes

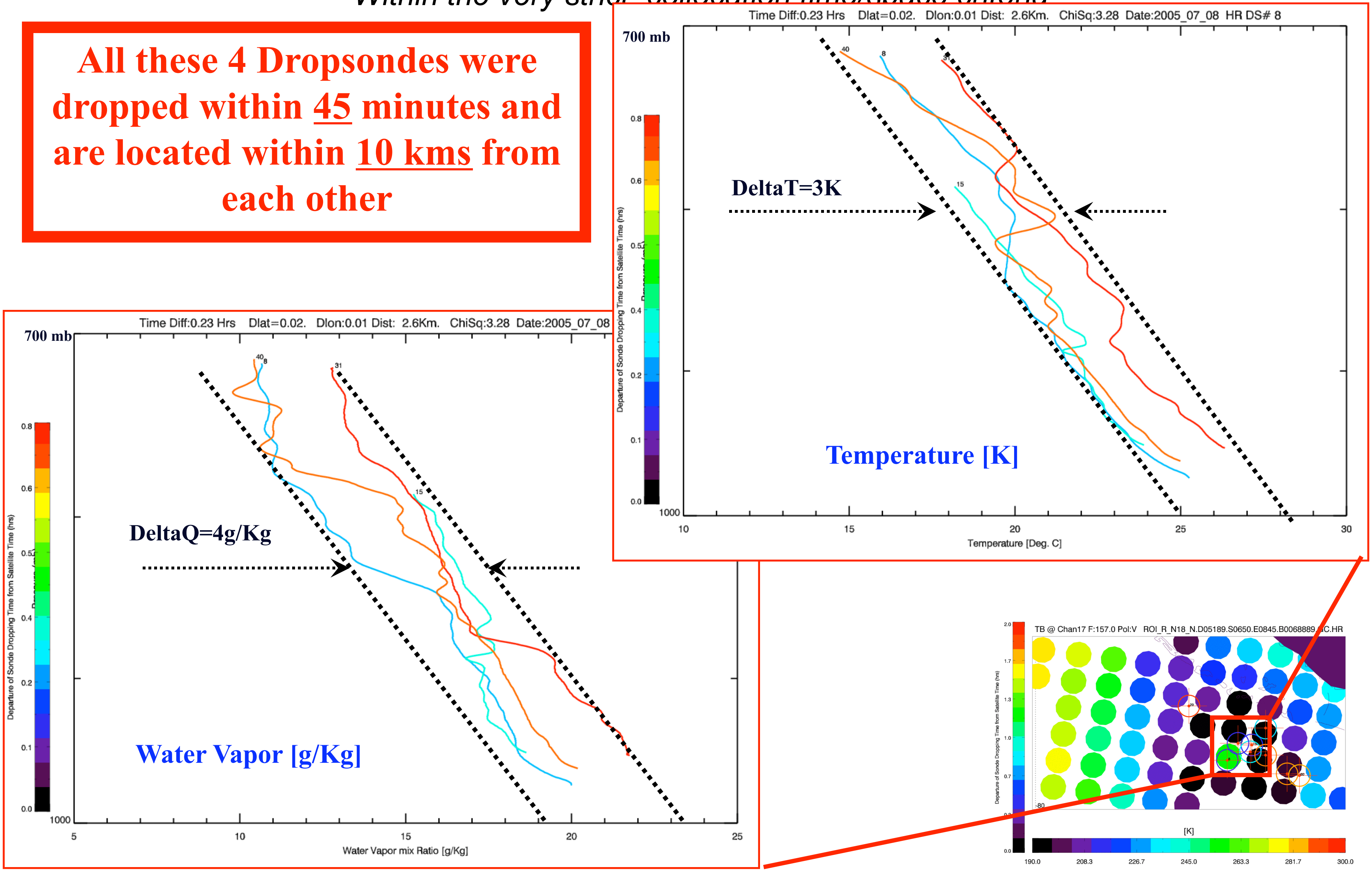
Sonde in Hurricane Eye

Collocated GPS-dropsonde (in space and within few minutes in time) with NOAA-18 in the Hurricane Eye

Natural/Dropsondes Intra-variability

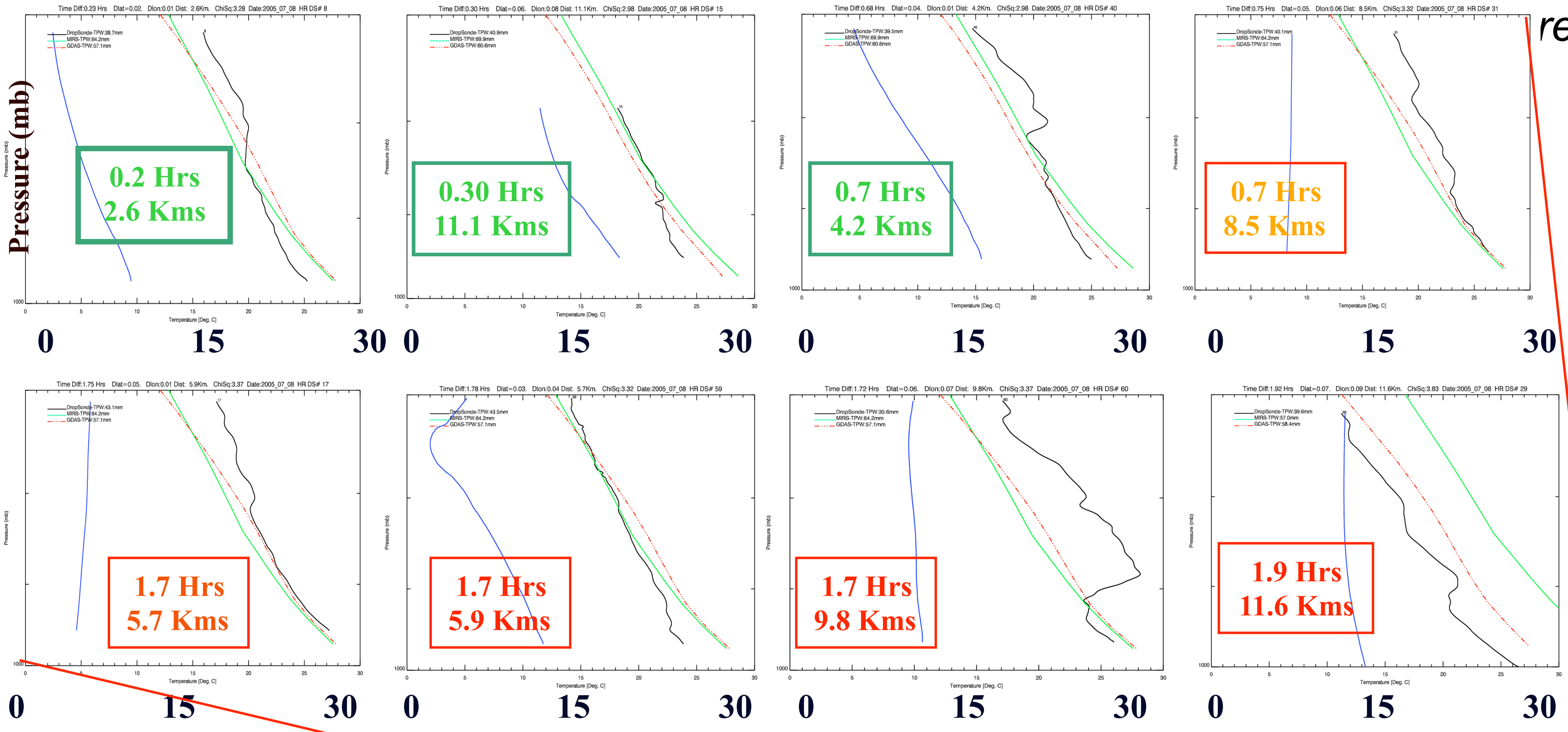
Within the very strict collocation time/space criteria

All these 4 Dropsondes were dropped within <u>45</u> minutes and are located within <u>10 kms</u> from each other



Case-By-Case Comparison with Dropsondes Measurements (Case#2)

region)



[Deg. C]

[Kms]

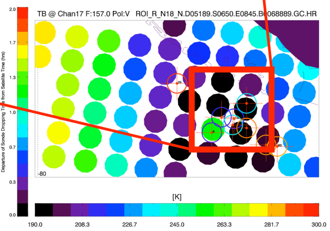
The more distant (in time and space) the DS are from the measurements, the worse the performances are.

Retrieval

GDAS

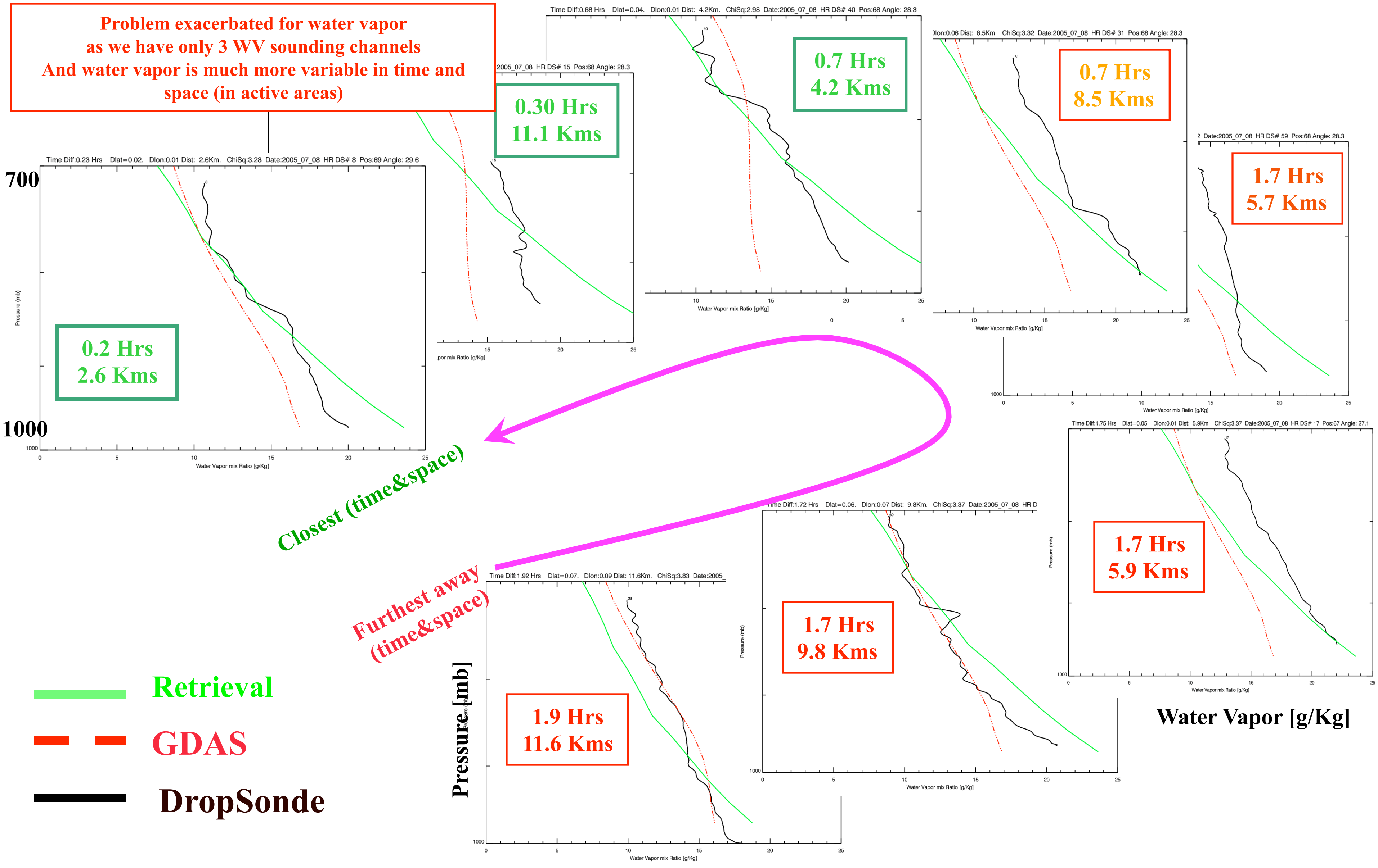
DropSonde

Profile of DS Distance Departure



Case-By-Case Comparison with Dropsondes Measurements (Case#2)

-Dennis Hurricane- WATER VAPOR PROFILE (Zoom over 700-1000 mb region)



Problem exacerbated for water vapor as we have only 3 WV sounding channels And water vapor is much more variable in time and space (in active areas)

0.2 Hrs
2.6 Kms

0.30 Hrs
11.1 Kms

0.7 Hrs
4.2 Kms

0.7 Hrs
8.5 Kms

1.7 Hrs
5.7 Kms

1.7 Hrs
5.9 Kms

1.7 Hrs
9.8 Kms

1.9 Hrs
11.6 Kms

Closest (time&space)

Furthest away (time&space)

🟩 **Retrieval**

🟥 🟥 **GDAS**

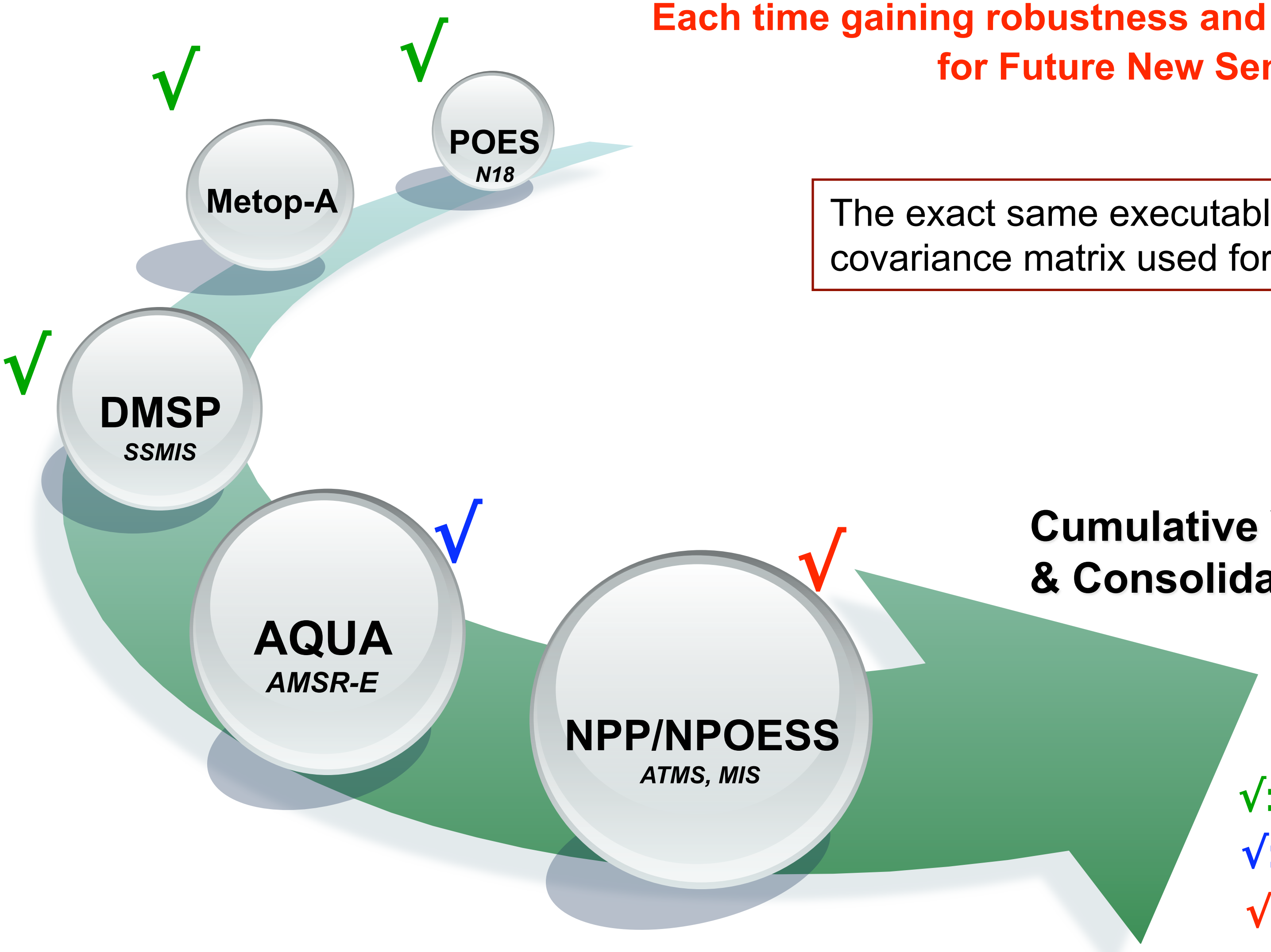
⬛ **DropSonde**

Plans for ATMS

Getting ready for NPP and NPOESS

**MIRS is applied to a number of microwave sensors,
Each time gaining robustness and improving validation
for Future New Sensors**

The exact same executable, forward operator, covariance matrix used for all sensors



√ **POES** *N18*

√ **Metop-A**

√ **DMSP** *SSMIS*

√ **AQUA** *AMSR-E*

√ **NPP/NPOESS** *ATMS, MIS*

**Cumulative Validation
& Consolidation of MIRS**

√: Applied Daily

√: Applied occasionally

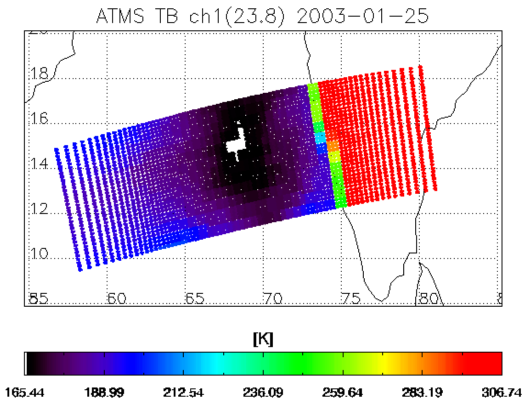
√: Tested in Simulation

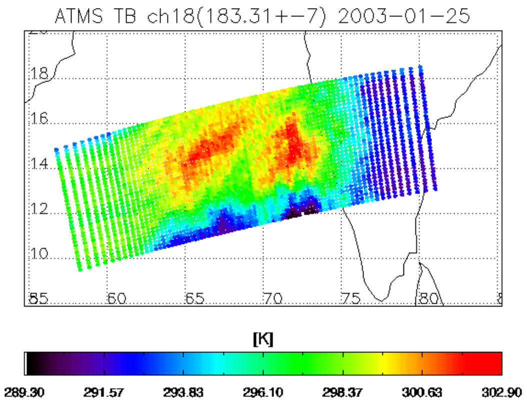
Running MiRS for ATMS

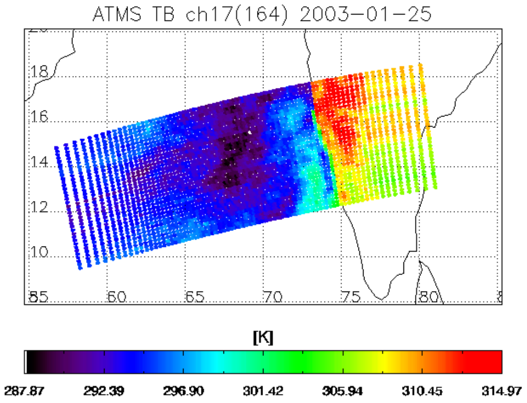
- Same code used for ATMS (leverage a lot of effort performed for N18, Metop-A, DMSP,AMSR-E, etc)
- External files needed:
  - Noise file (both instrument and RTM uncertainty)
  - Emissivity Covariance Matrix
  - CRTM Look-Up-Tables
- Data access: through NDE NPOESS Data Exploitation (NDE): MiRS will run on NDE
- Work accomplished:
  - Reader of HDF-5 files ready to process data

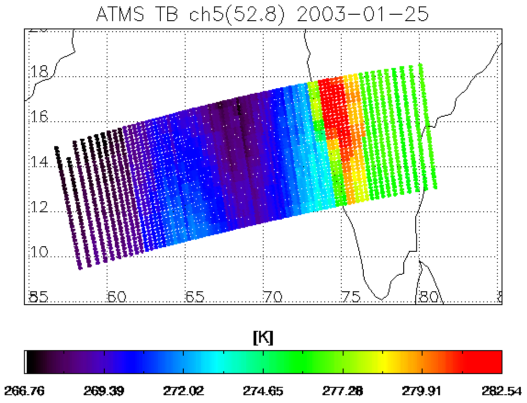
ATMS Radiances

- ATMS SDR sample files provided through NDE (by NGST) in HDF-5 format.
- Decoder/encoder ready.
- Plan: simulate ATMS radiances on a daily basis to generate proxy ATMS data to test MiRS on


ATMS TB ch1(23.8) 2003−01−25


ATMS TB ch18(183.31+−7) 2003−01−25


ATMS TB ch17(164) 2003−01−25


ATMS TB ch5(52.8) 2003−01−25

Conclusions & Talking Points

Discussion (1/2)

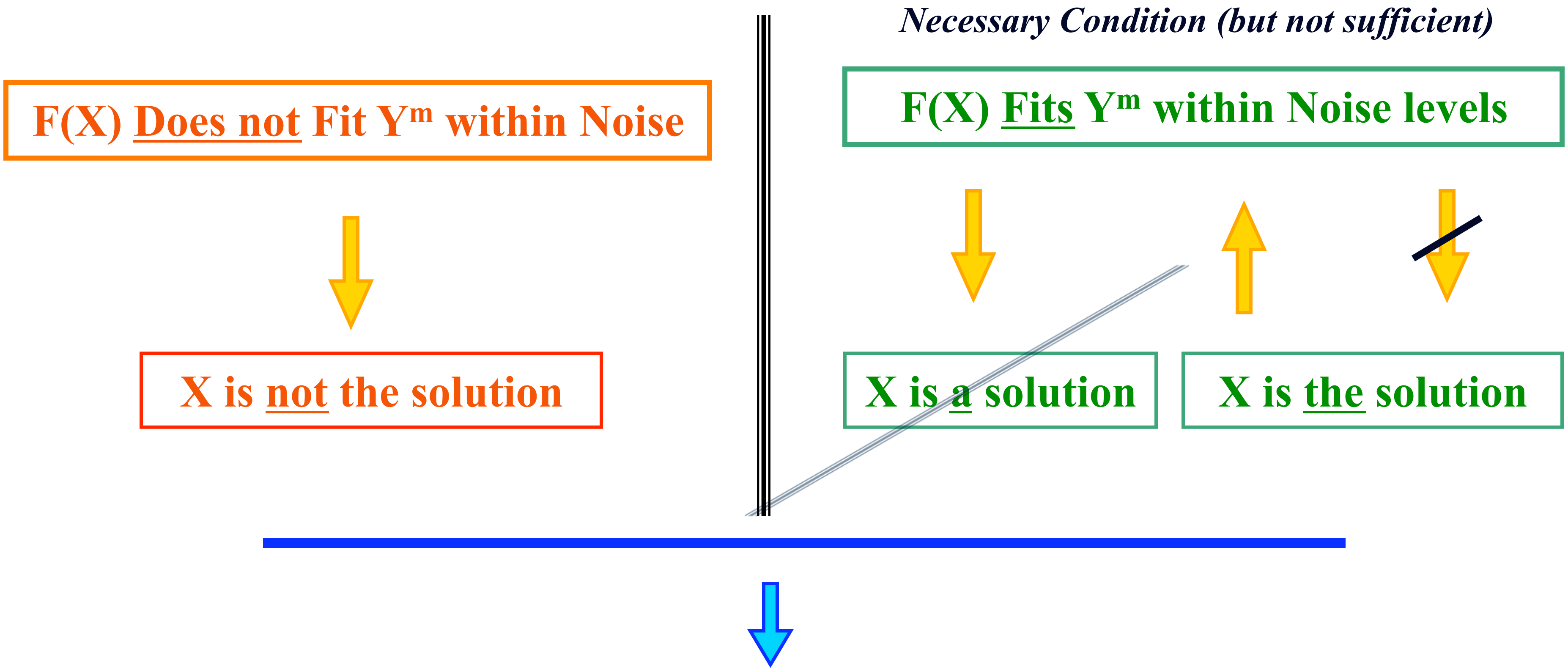
- MiRS sounding Performances were assessed using different sources. Sometimes results are different, reflecting inter-truth variability.
- When consistent behavior is noticed, assumed that MIRS is the likely reason
- SSMIS is found, as expected from radiances noisiness, to have slightly more degraded performances (than N18) –*Not shown here-*
- N18 and Metop-A running at AMSUA resolution
- SSMIS running at UAS resolution
- TPW is extended to all surfaces [Ocean, Land, Sea ice and Snow] operationally for NOAA-18 and Metop-A, for the first time.
- Retrieval is performed (and convergence reached) in cloudy, rainy, ice-impacted scenes

Discussion (2/2)

- MiRS is ready to be applied to ATMS (NPP): No issues expected
- Leverage of previous work for N18, MetopA and DMSP SSMIS will have direct positive impact on ATMS readiness (and likely validity)
- MiRS will assimilate (retrieve) all ATMS data (over all surfaces and in all-weather conditions)
- Assessment in clear/cloudy conditions pretty good.
- Assessment in all-weather conditions much tougher.
- <u>Suggested further work:</u>
  - Use ATMS retrievals as first guess to CrIS/ATMS?
  - Given that CRTM is valid in IR/MW and MiRS technology is not spectrum-dependent, Use MiRS for IR/MW synergy?

BACKUP SLIDES

Nominal approach: Simultaneous Retrieval



Necessary Condition (but not sufficient)

F(X) Does not Fit Y^m within Noise

X is not the solution

F(X) Fits Y^m within Noise levels

X is a solution

X is the solution

All parameters are retrieved simultaneously to fit all radiances together

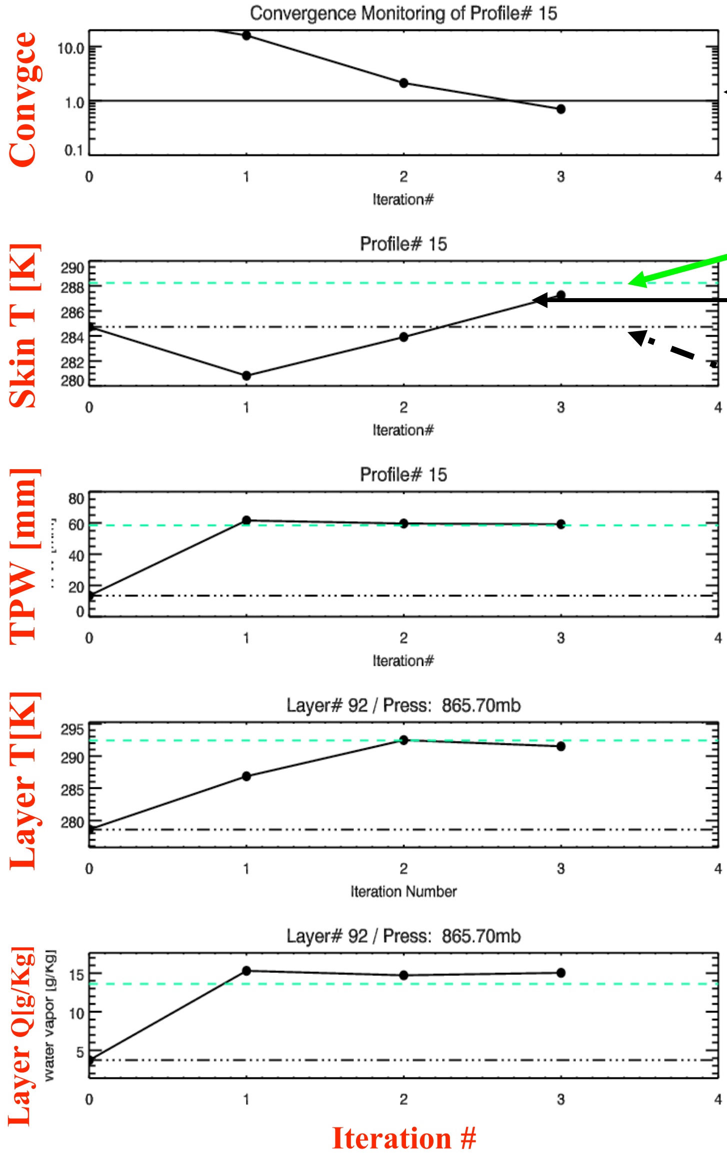
Handling Channel Degradation / Failure

- Instrument NEDT (AMSU/MHS) is computed dynamically from Level1B data, then fed to retrieval, along with RTM uncertainty
- If a channel' NEDT is high, channel will have less weight in retrieval
- Similarly, if RTM precision for a channel is low, it will have less weight in retrieval
- If channel is declared *failed*, MIRS has ability to turn it OFF by a switch

MIRS 1DVAR Algorithm is still valid (by concept) even if:
-Noise becomes higher,
- If channel fails

Note: This does not prevent performances from degrading

Illustration of the System Functionality

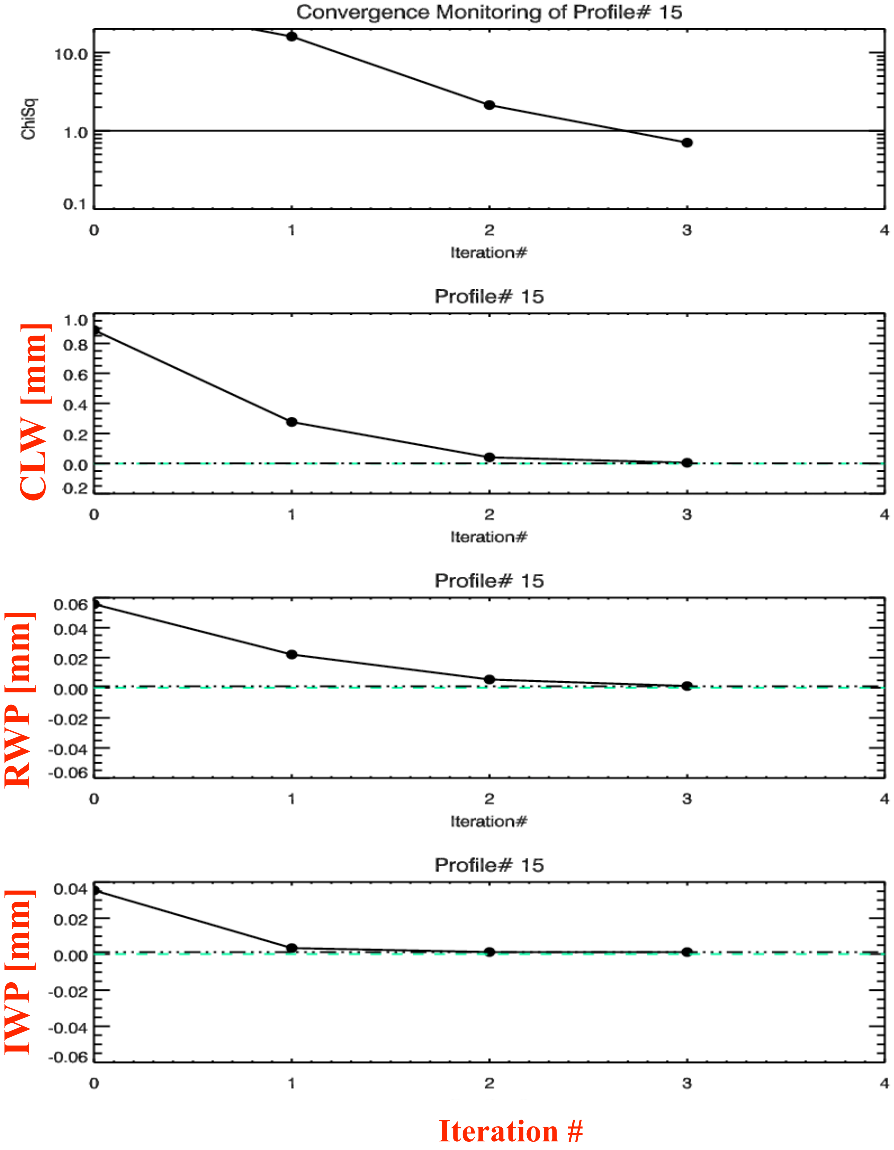


Convergce threshold

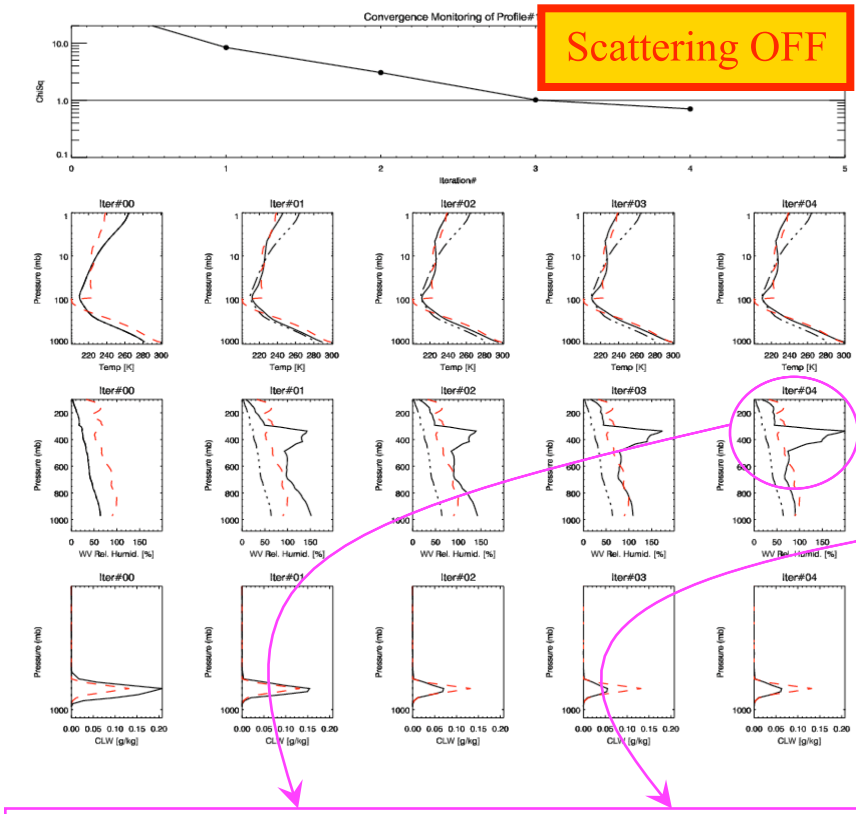
Truth

Retrieval

BackGrd

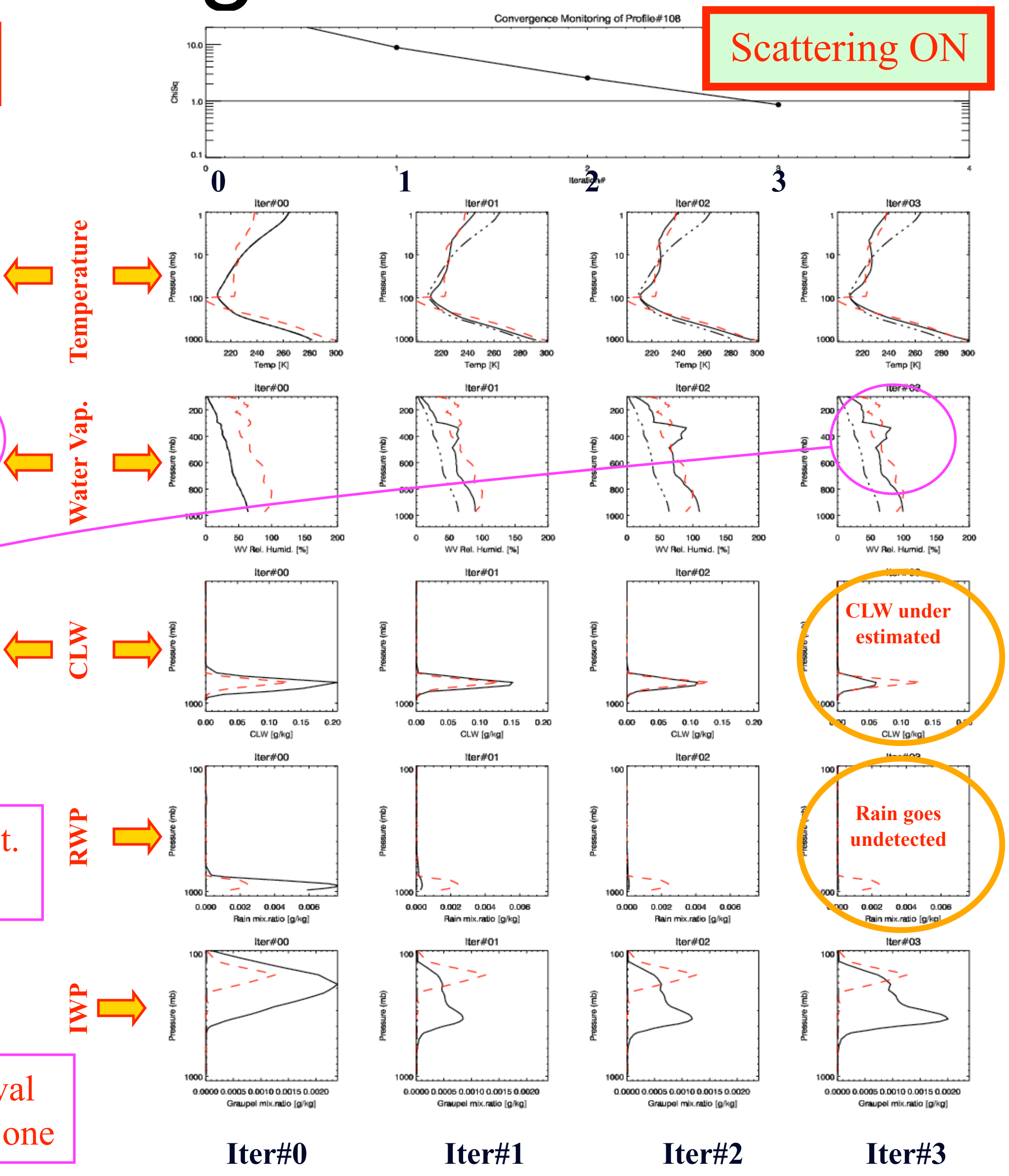


Assessment in a Precipitating Case



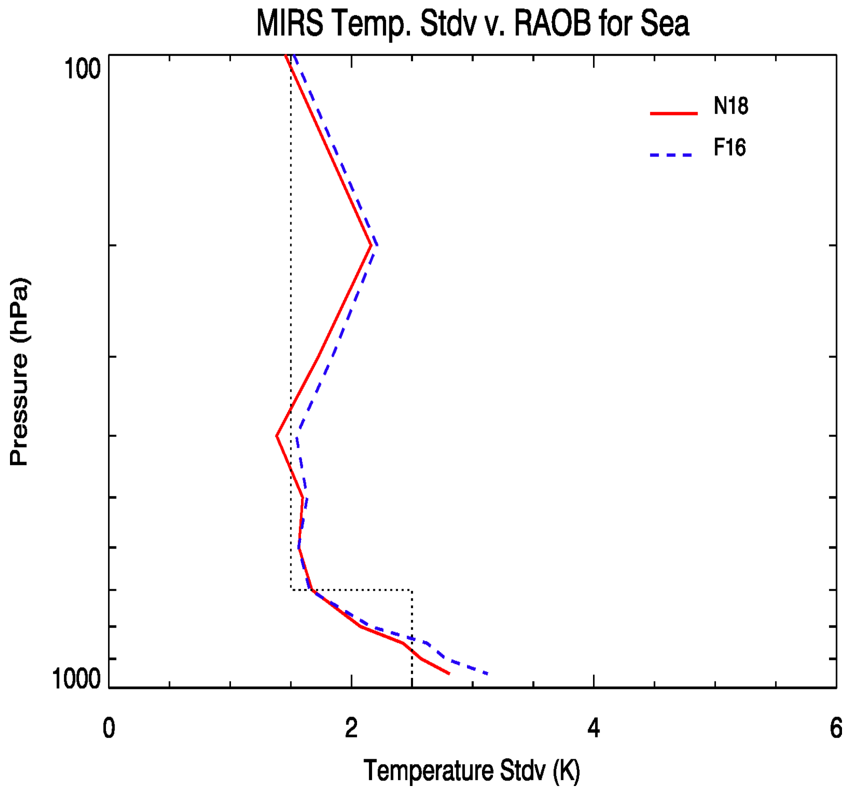
When scattering is OFF, Water vapor performance is hit.
When ON, '**precip-clearing'** takes place

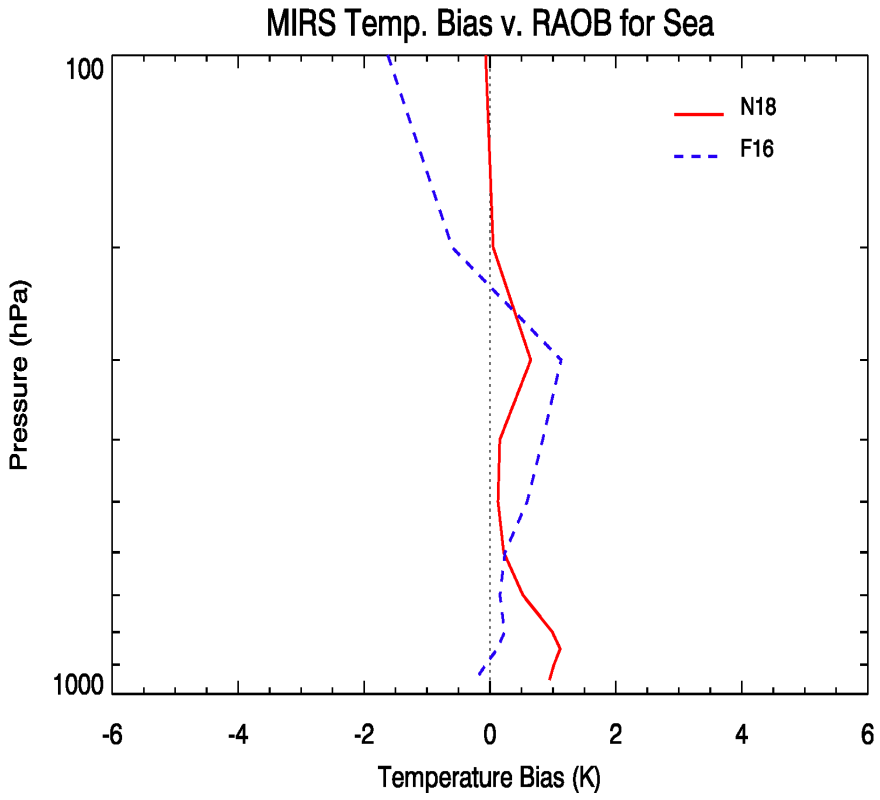
In precipitation, cross-compensation is affecting retrieval
Radiometric solution reached but is not the geophysical one



Comparison of Performances (N18 vs SSMIS)

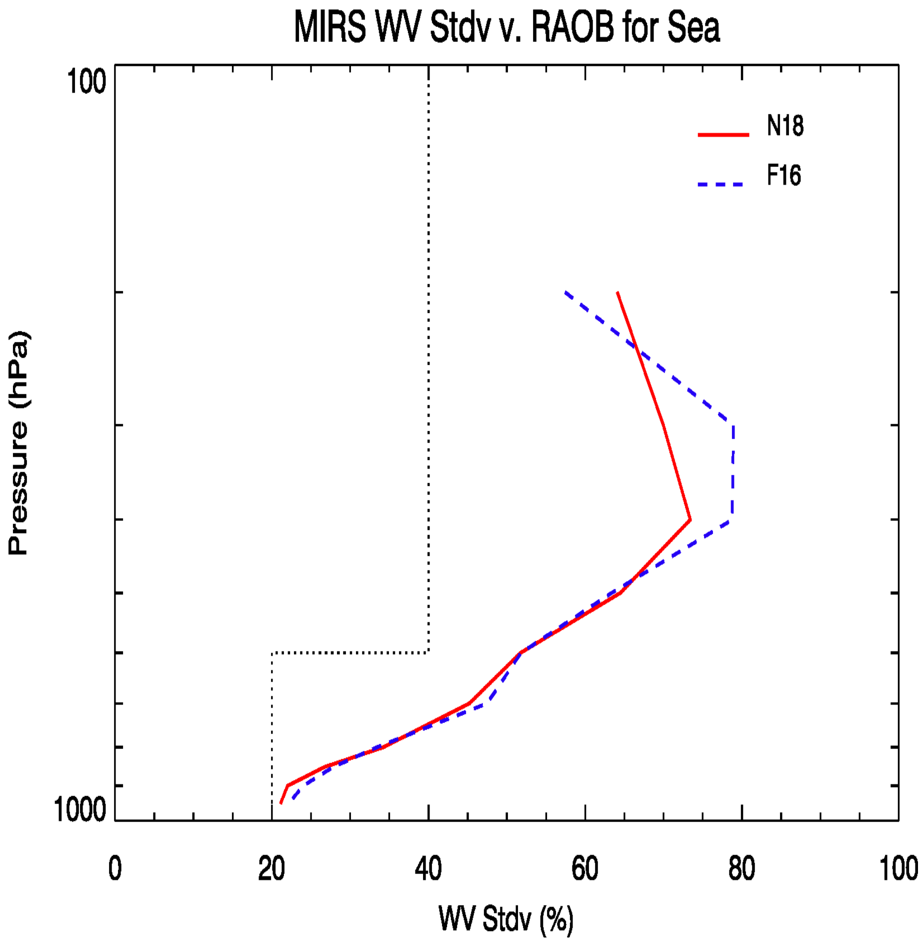
Temperature Performances (Sea)

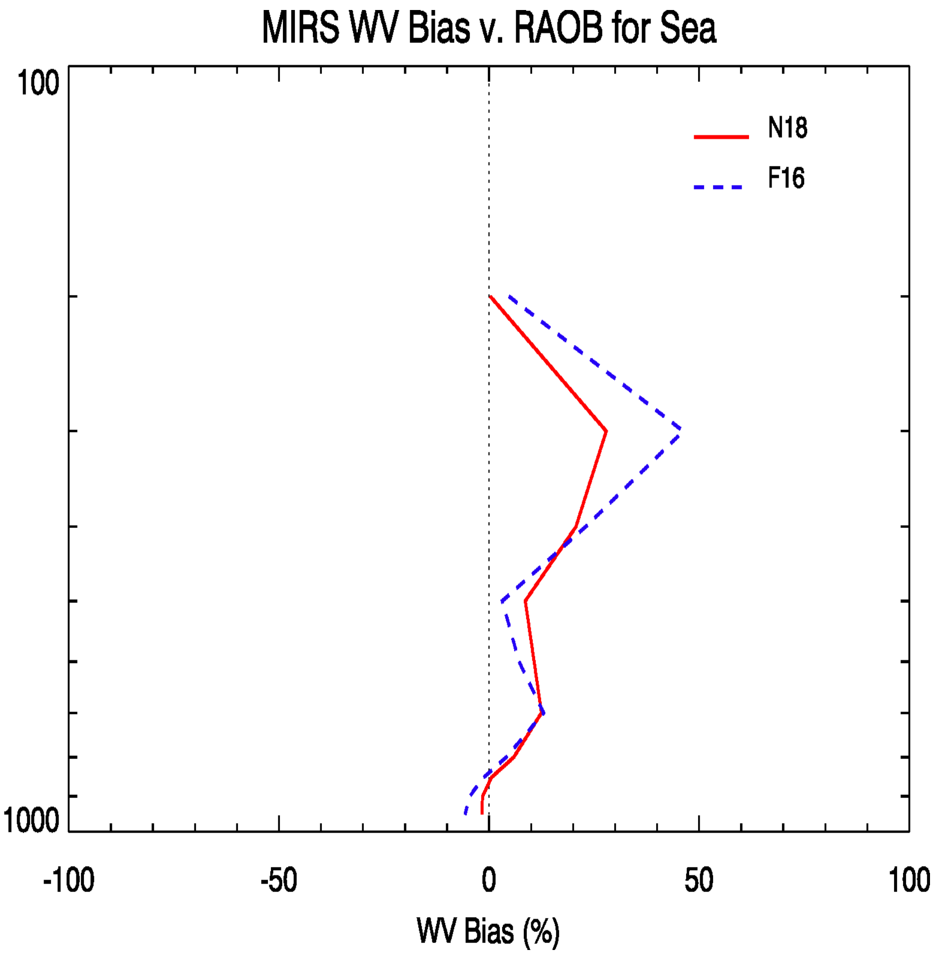




RAOBs used as a reference. Several months worth of data used.

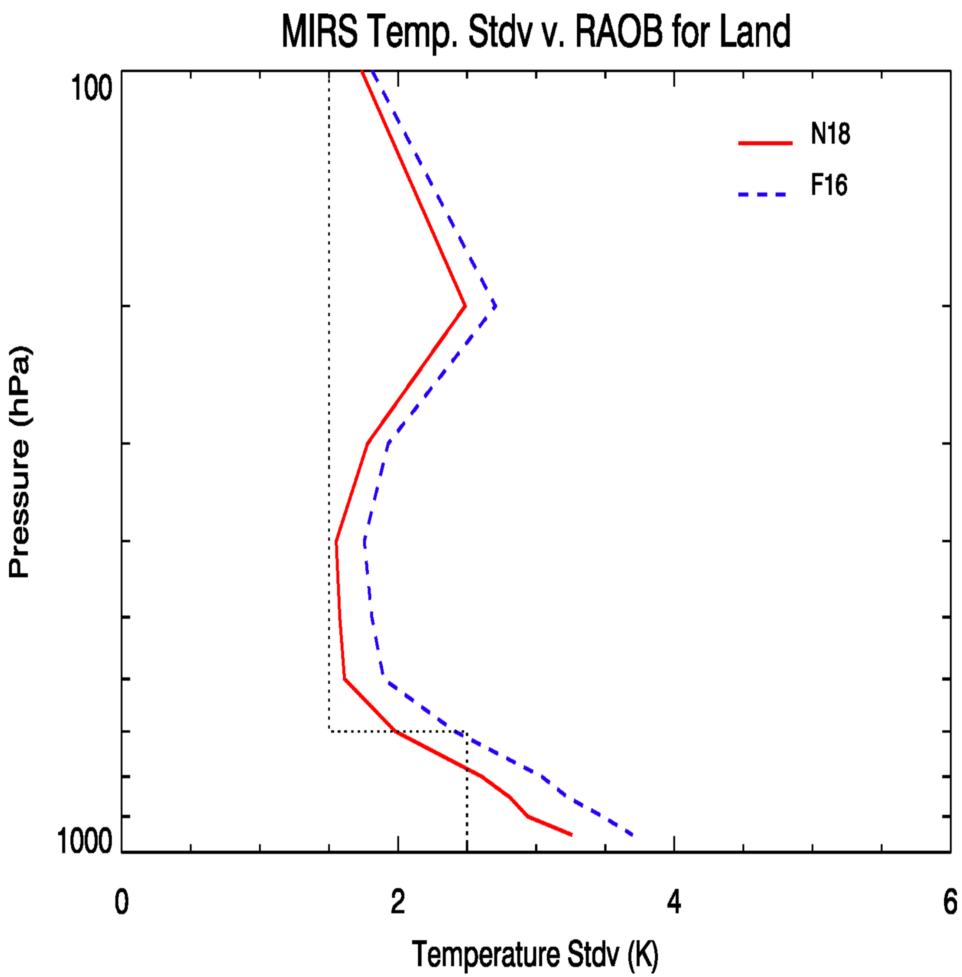
Moisture Performances (Sea)

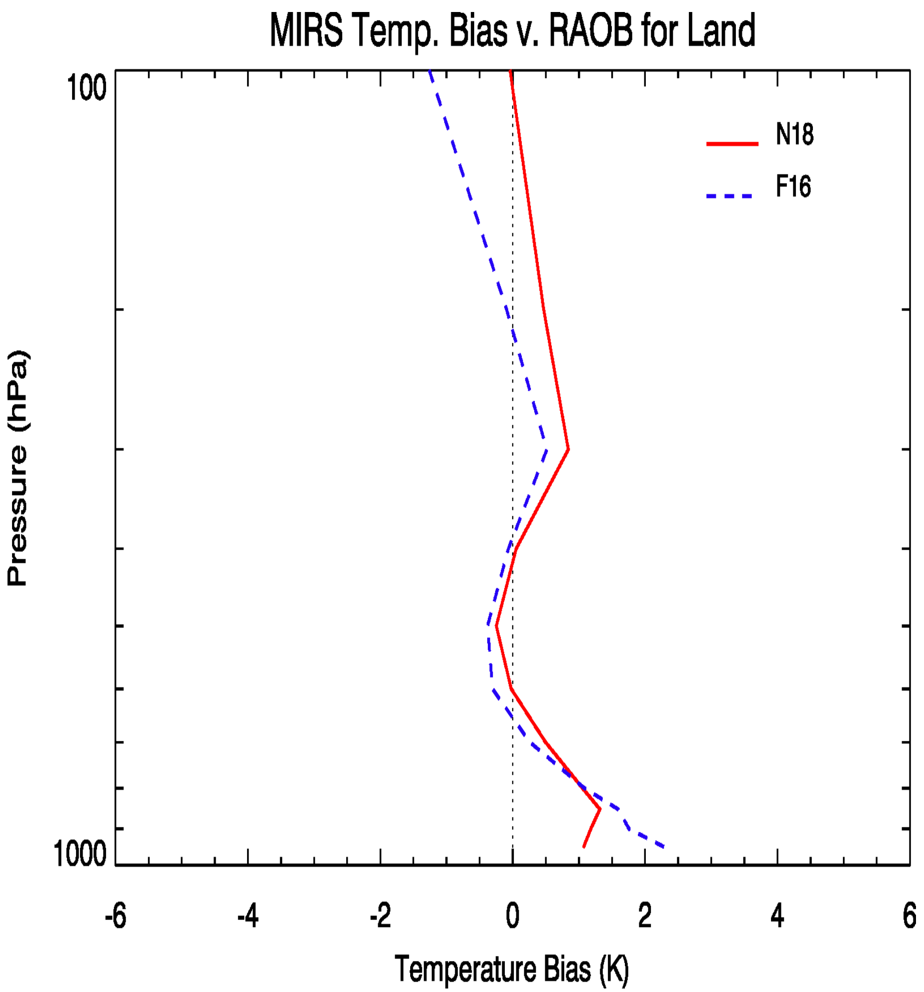

MIRS WV Stdv v. RAOB for Sea


MIRS WV Bias v. RAOB for Sea

RAOBs used as a reference. Several months worth of data used.

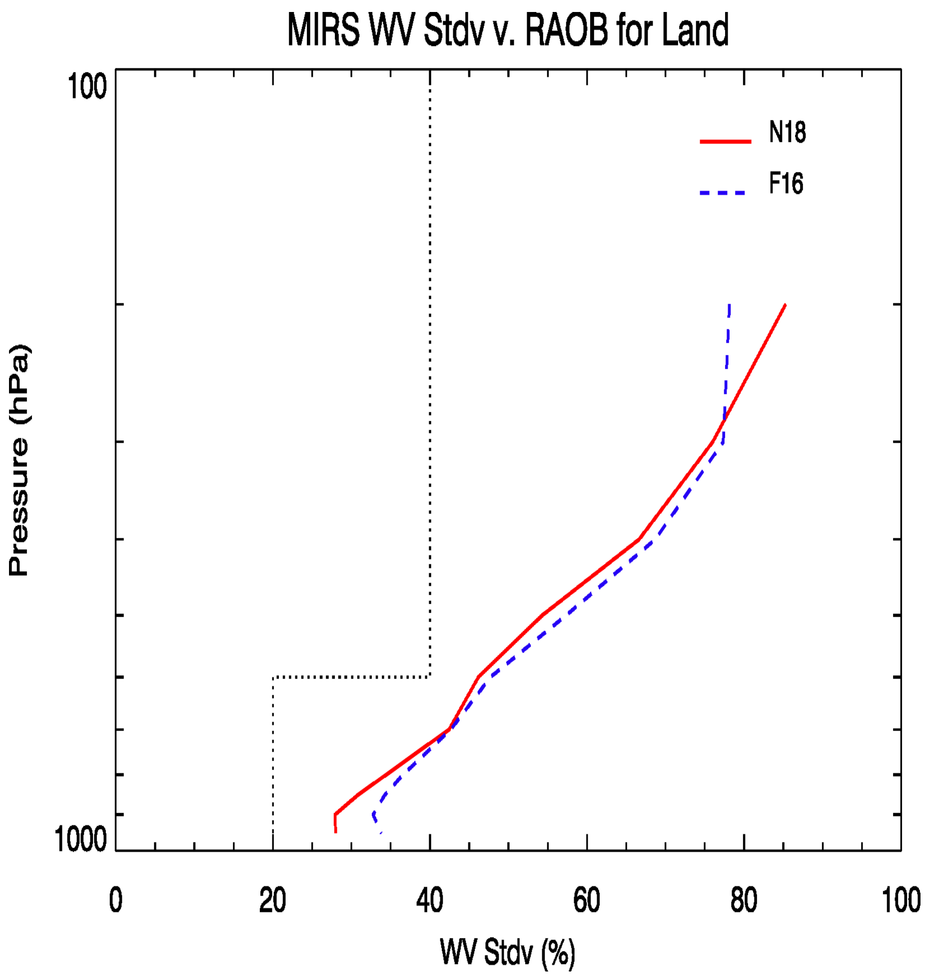
Temperature Performances (Land)

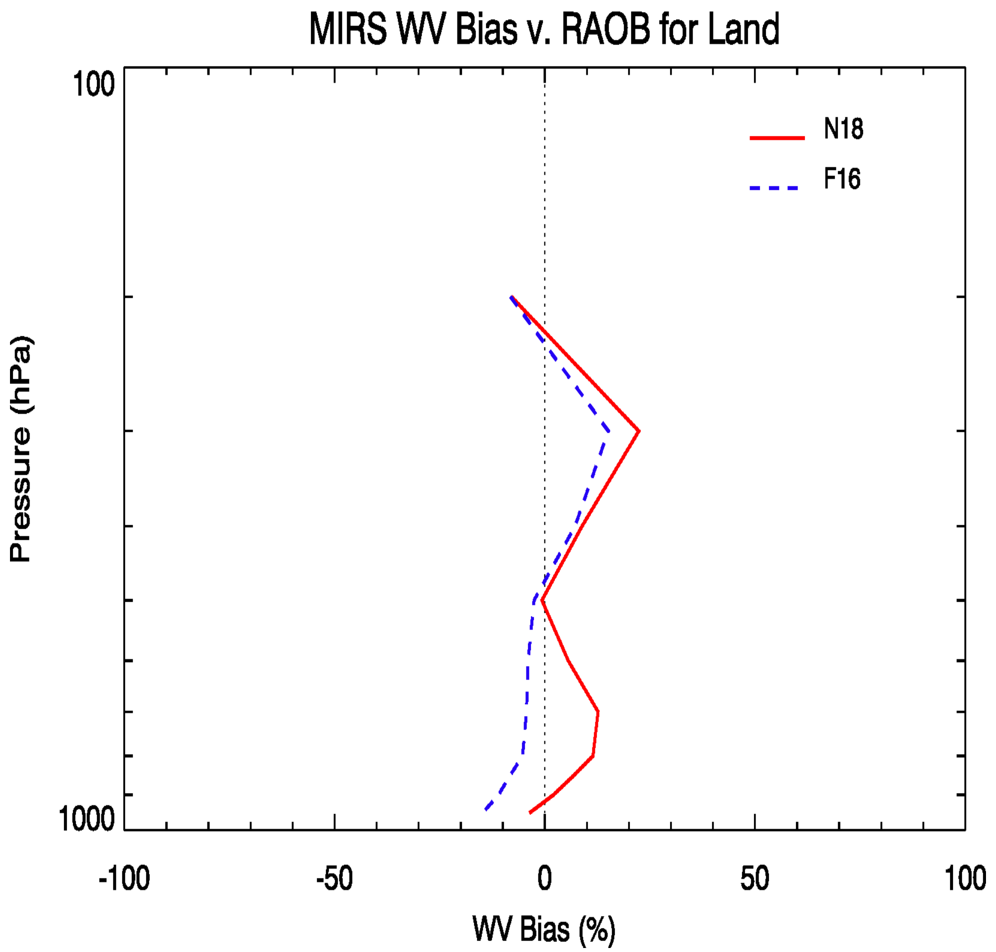

MIRS Temp. Stdv v. RAOB for Land


MIRS Temp. Bias v. RAOB for Land

RAOBs used as a reference. Several months worth of data used.

Moisture Performances (Land)





RAOBs used as a reference. Several months worth of data used.