Introducing NOAA's Microwave Integrated Retrieval System (MIRS)

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NOAA/NESDIS
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Overview

Stated Goals of MIRS

- Algorithm for sounding, imaging, or combination thereof
- Applicable to all Microwave Sensors
- Extend over non-oceanic surfaces & in all-weather conditions
- Operate independently from NWP model forecasts

Benefits

- Reduction of Time/Cost to Adapt to New Sensors
- Reduction of Time/Cost to Transition to Operations
- Improvements in Severe Weather Forecasts
- Better Climate Data Records

MIRS Concept

Variational Retrieval (1DVAR)

- **Algorithm valid in all-weather conditions, over all-surface types**
- **Cloud & Precip profiles retrieval (no cloud top, thickness, etc)**
- **Sensor-independent**
- **Flexibility and Robustness**

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

Emissivity spectrum is part of the retrieved state vector

EOF decomposition

Highly Modular Design

Selection of Channels to use, parameters to retrieve

Modeling & Instrumental Errors are input to algorithm

Contents

Cost Function Minimization

- Cost Function to Minimize:

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

Jacobians & Radiance Simulation from Forward Operator: CRTM

- To find the optimal solution, solve for: $\dfrac{\partial J(X)}{\partial X}=J'(X)=0$
- Assuming Linearity $y(x)=y(x_0)+K\left[x-x_0\right]$
- This leads to iterative solution:

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

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

More efficient (1 inversion)

Preferred when nChan << nParams (MW)

Quality Control of MIRS Outputs

- Convergence Metric: χ^2
- Uncertainty matrix *S*:

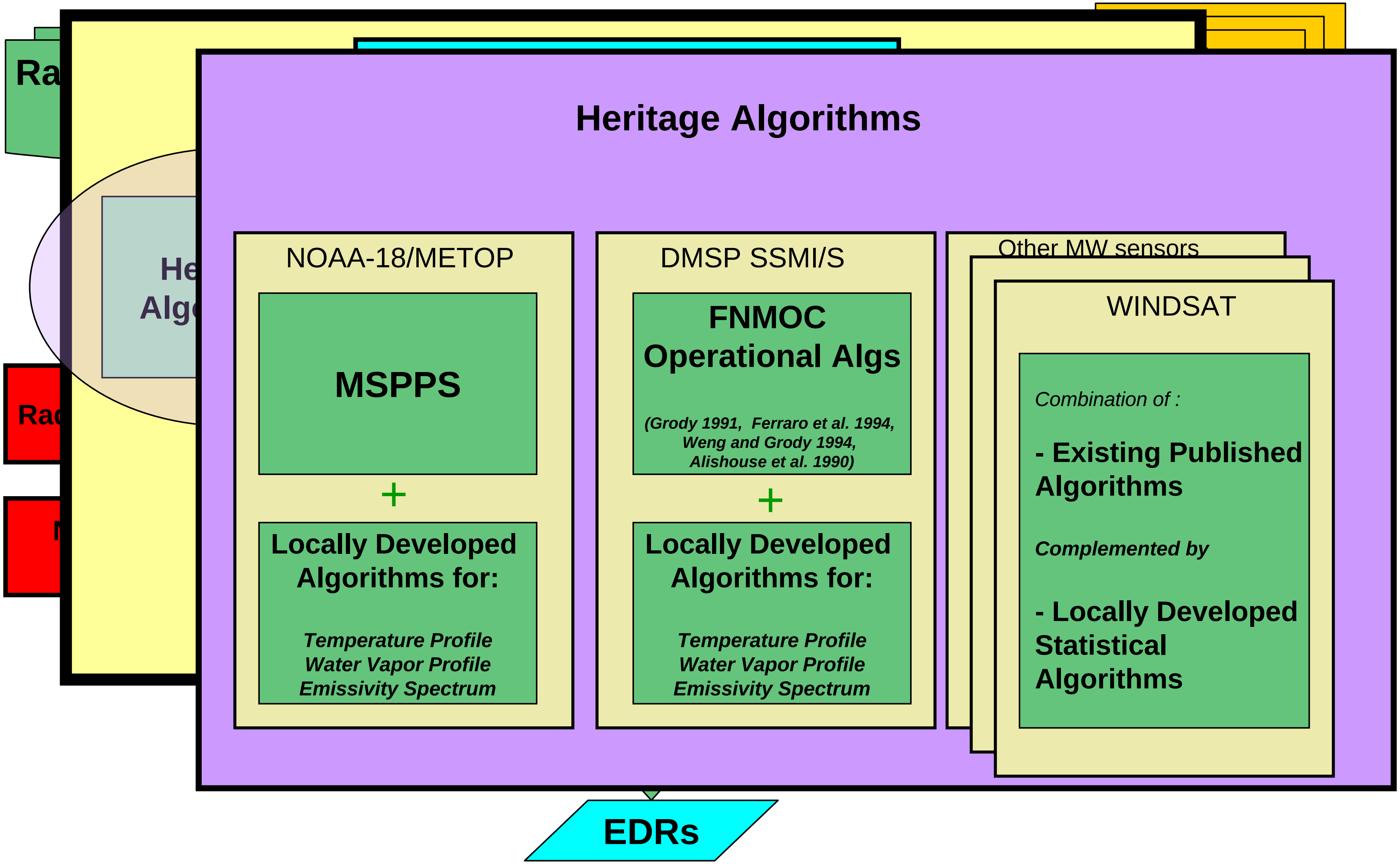
$$S = B - B \times K^T \left(K \times B \times K^T + E \right)^{-1} \times K \times B$$

- Contribution Functions *D*: *indicate amount of noise amplification happening for each parameter*.

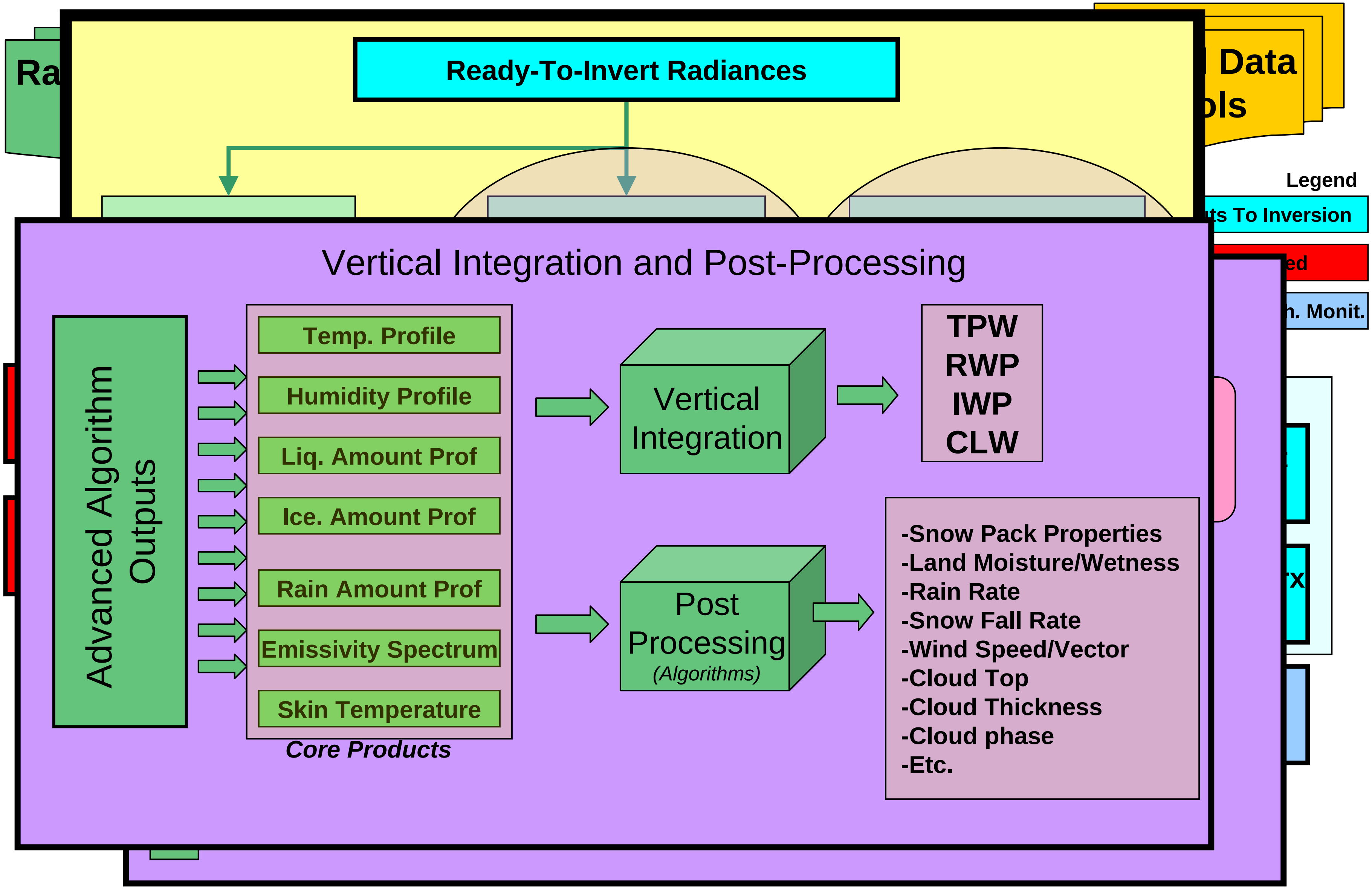
$$D = B \times K^T \left(K \times B \times K^T + E \right)^{-1} \times \left(Y(X) - K \times X_0 \right)$$

- Average kernel *A*: $A = D \times K$
  - If close to zero, retrieval coming essentially from background
  - If close to unity, retrieval coming from radiances: No artifacts from background

System Design & Architecture

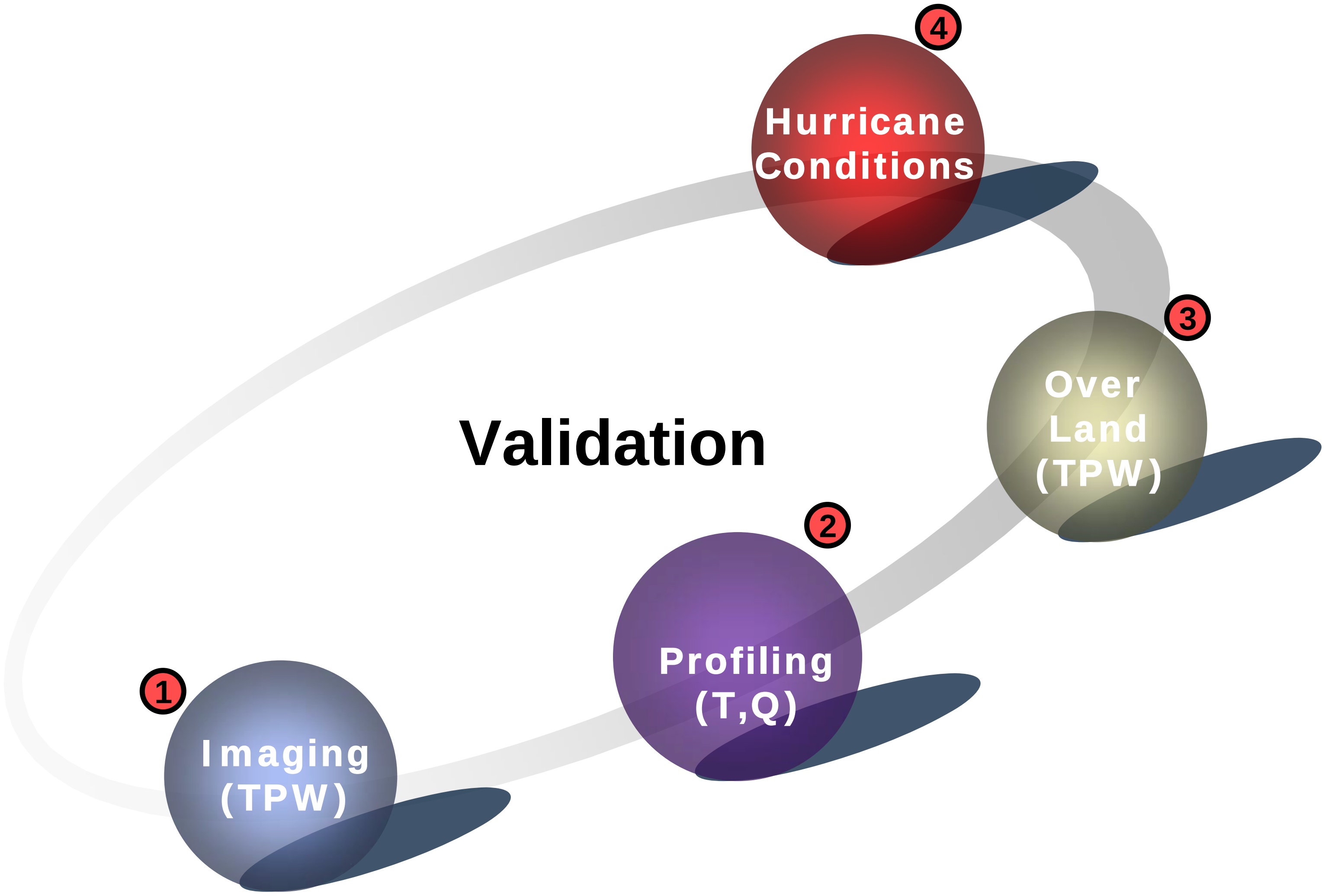


System Design & Architecture

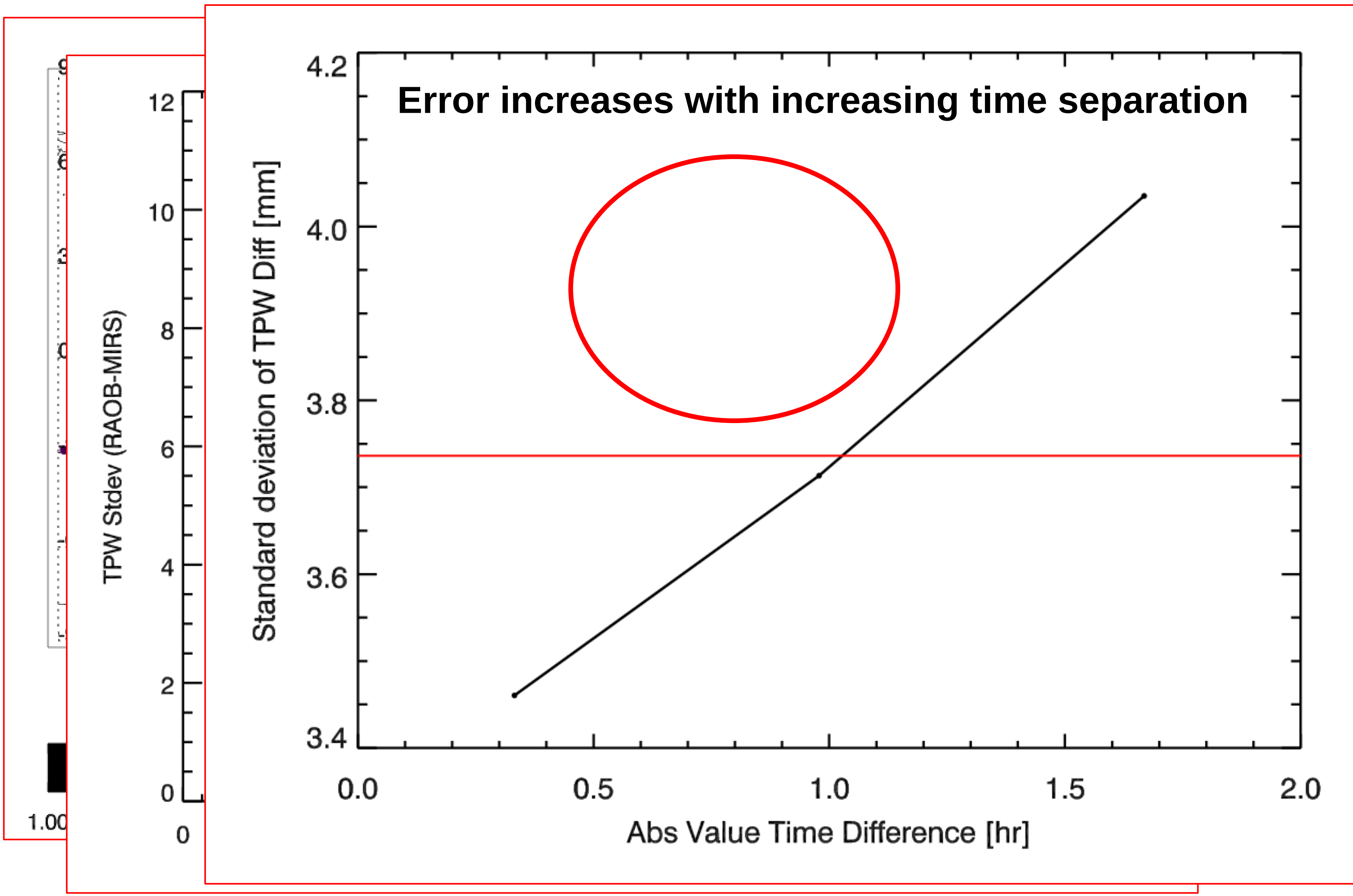


Contents

Performance Evaluation



QC of the Validation Set



Improvement Assessment (*wrt Heritage*)

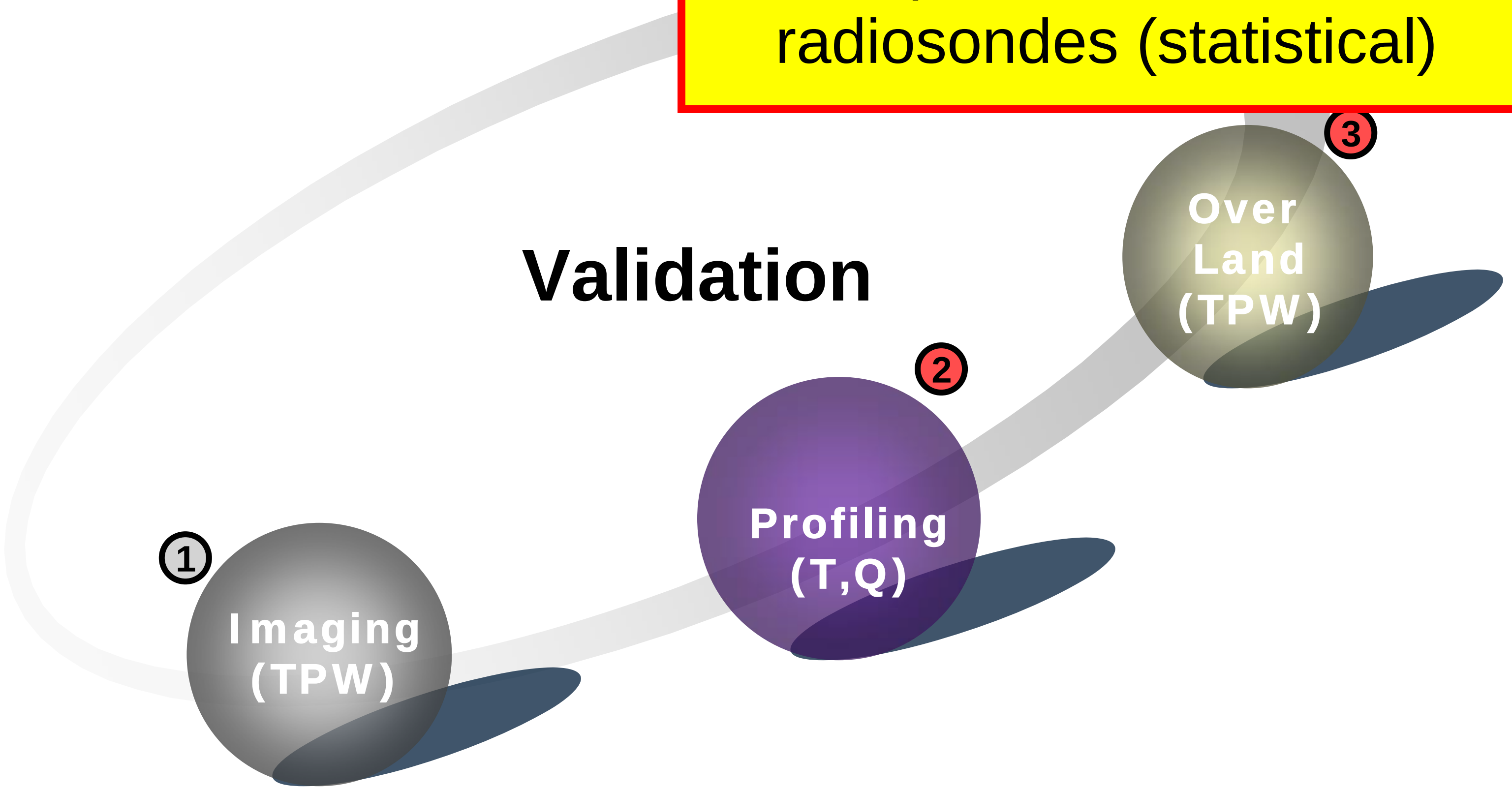
MSPPS: NOAA's operational system responsible for deriving microwave products

	MSPPS (bias)	MIRS (Bias)	MSPPS (Std)	MIRS (Std)	Improvement (%)
N15	1.87	0.49	4.57	3.85	16%
N16	1.31	-1.10	4.22	3.85	9%
N17	2.51	-0.2	4.26	3.30	23%

- Average TPW Standard Deviation Improvement is 16% over ocean
- Better scan angle handling
- Independence from NWP forecast outputs
- Capability extended over land

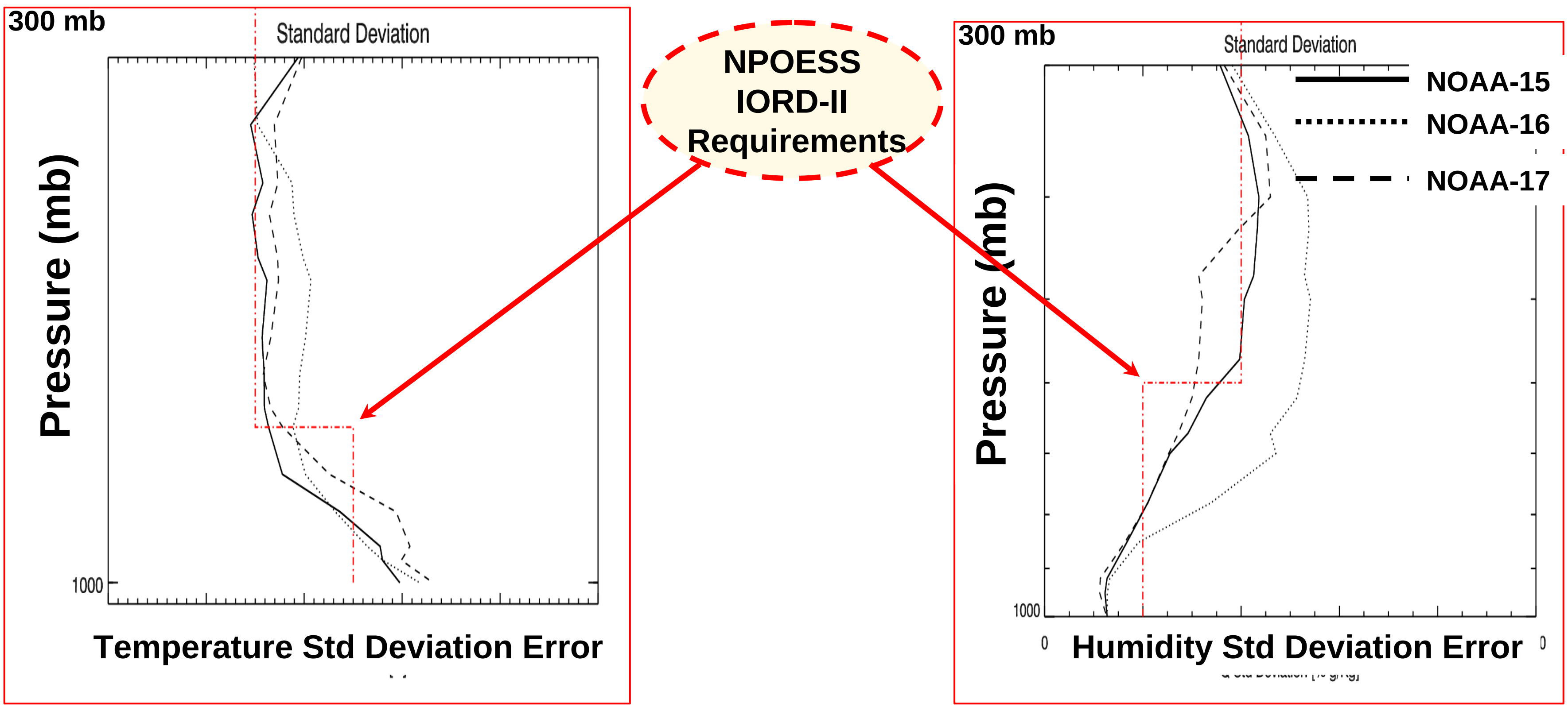
Performance Evaluation

- Temperature & Humidity profiles using N15,16,17,18
- Comparison with radiosondes (statistical)

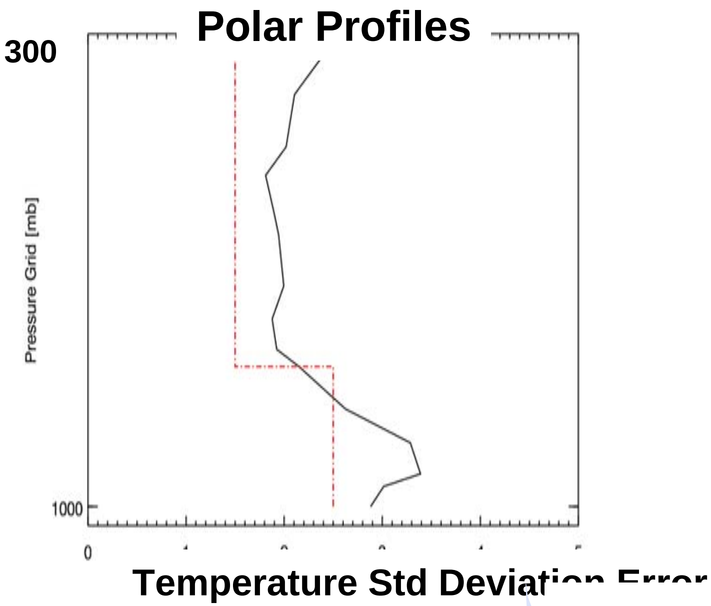


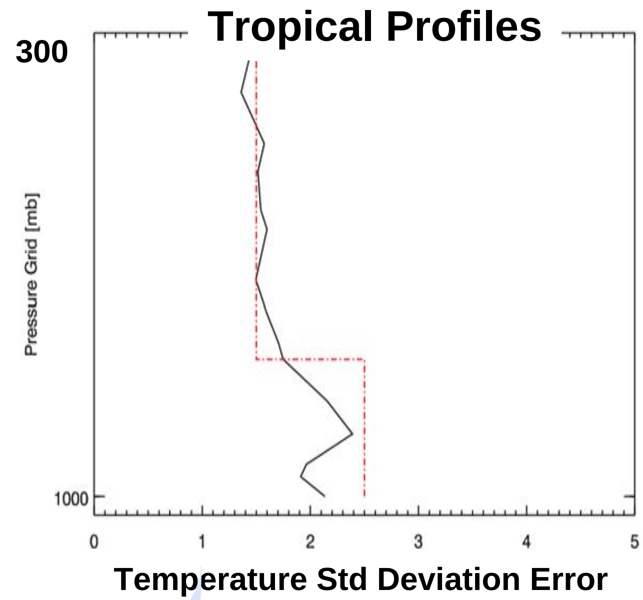
Temperature & Humidity Profiles

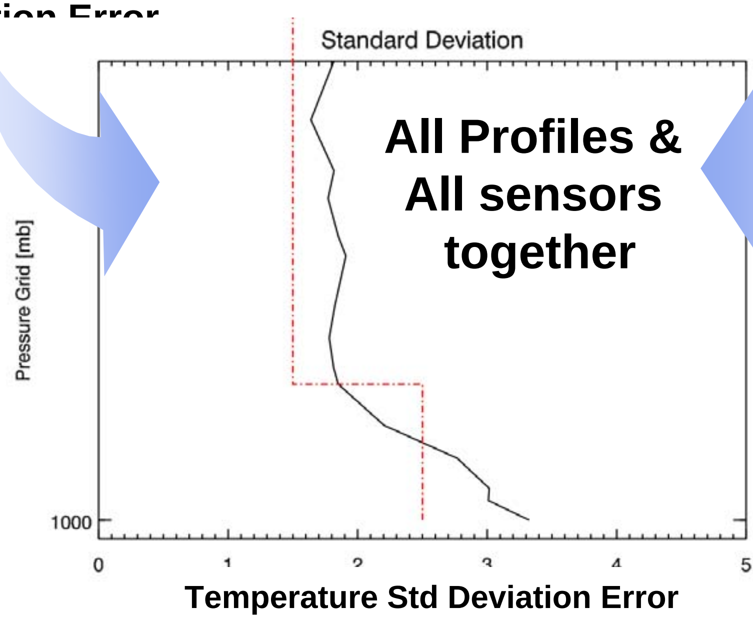
- Raob Profiles with at least 30 levels used. Ocean cases only. Retrievals up to 0.05 mbars. Assessment only up to 300 mbars.
- These are real data performances (stratified by sensor)
- Results shown here are cloudy (up to 0.15 mm from MIRS retrieval)
- Independent from NWP forecast information, including surface pressure
- Improvements in progress (scan-dependent covariance Matrix, air-mass pre-classification, etc)



Importance of the Evaluation Set







All Profiles & All sensors together

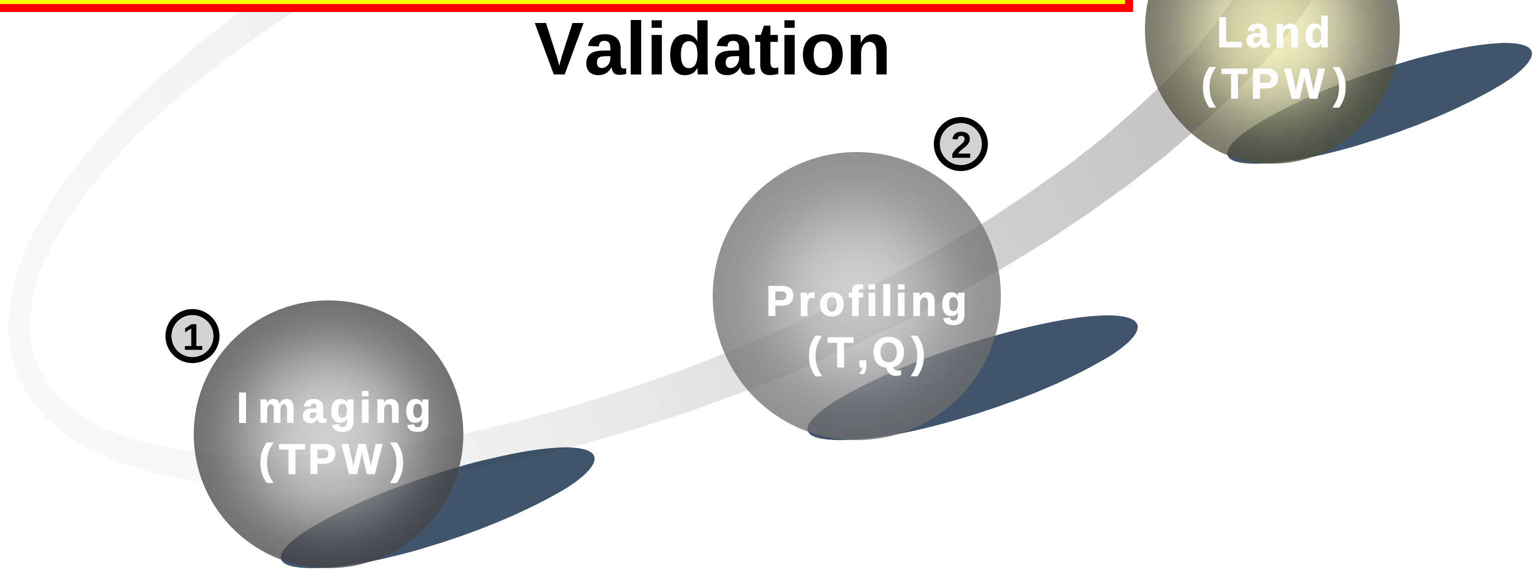
Focus of current efforts:

- **Air-mass preclassification of the background**
- **Improvement expected from first guess**

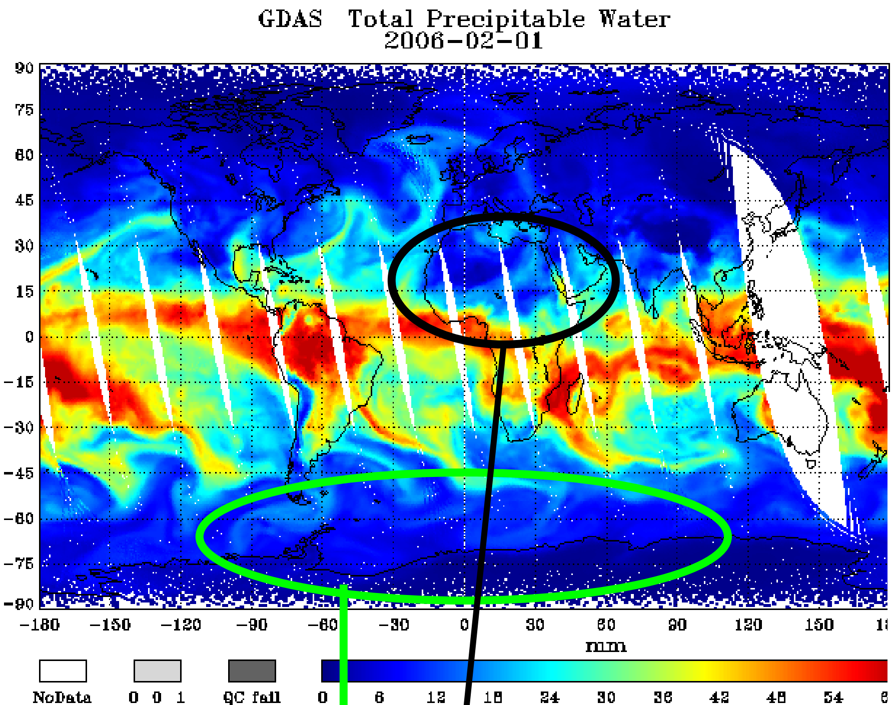
Caution must be exercised when comparing performances of algorithms on different sets. Types of sets are critical (tropical, polar, clear, cloudy, etc and their <u>relative percentage</u> in the set).

Performance Evaluation

- TPW retrieval extended over land
- Comparison with GDAS analyses
- Comparison with Radiosondes over land
- Sanity Check of MIRS Emissivity Over Land

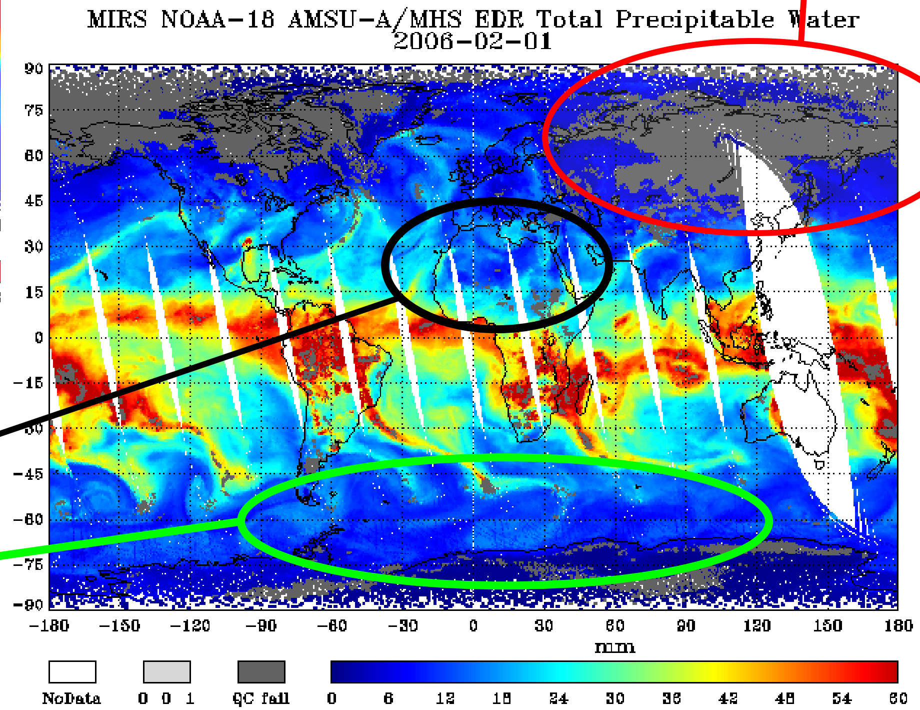


Microwave TPW Extended over Land



GDAS Analysis

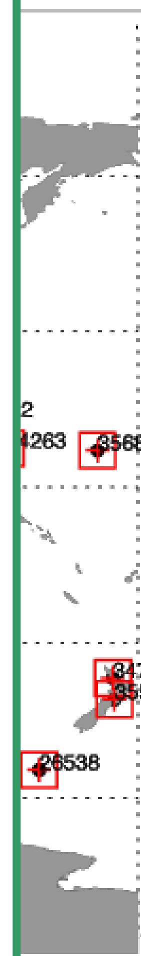
snow-covered surfaces need better handling

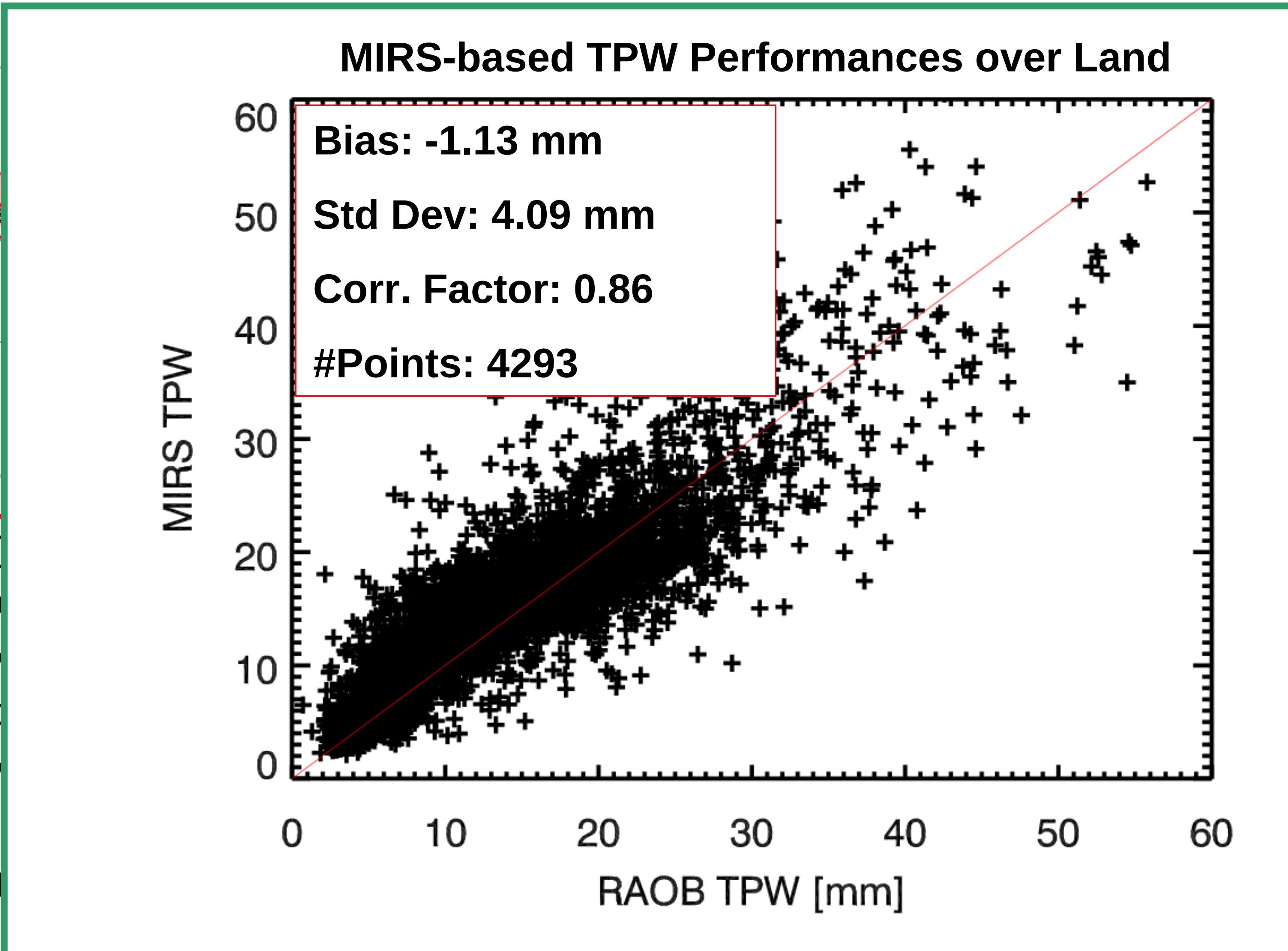


Retrieval over sea-ice and most land areas capturing same features as GDAS

MIRS Retrieval

Validation of TPW Retrieval over Land





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Extension of MIRS Validity Over Land

Same MIRS code used for retrieval over land and ocean.

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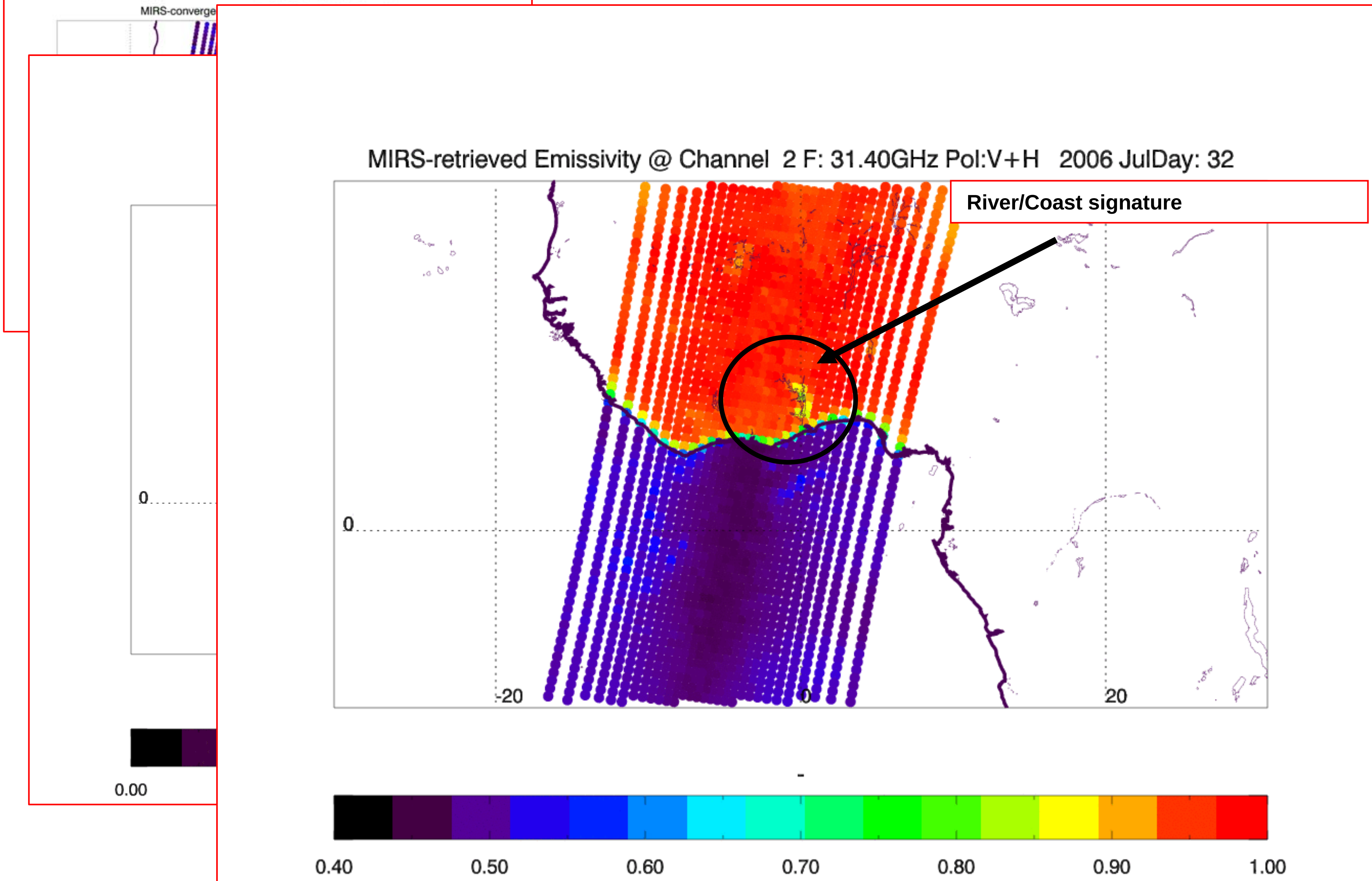
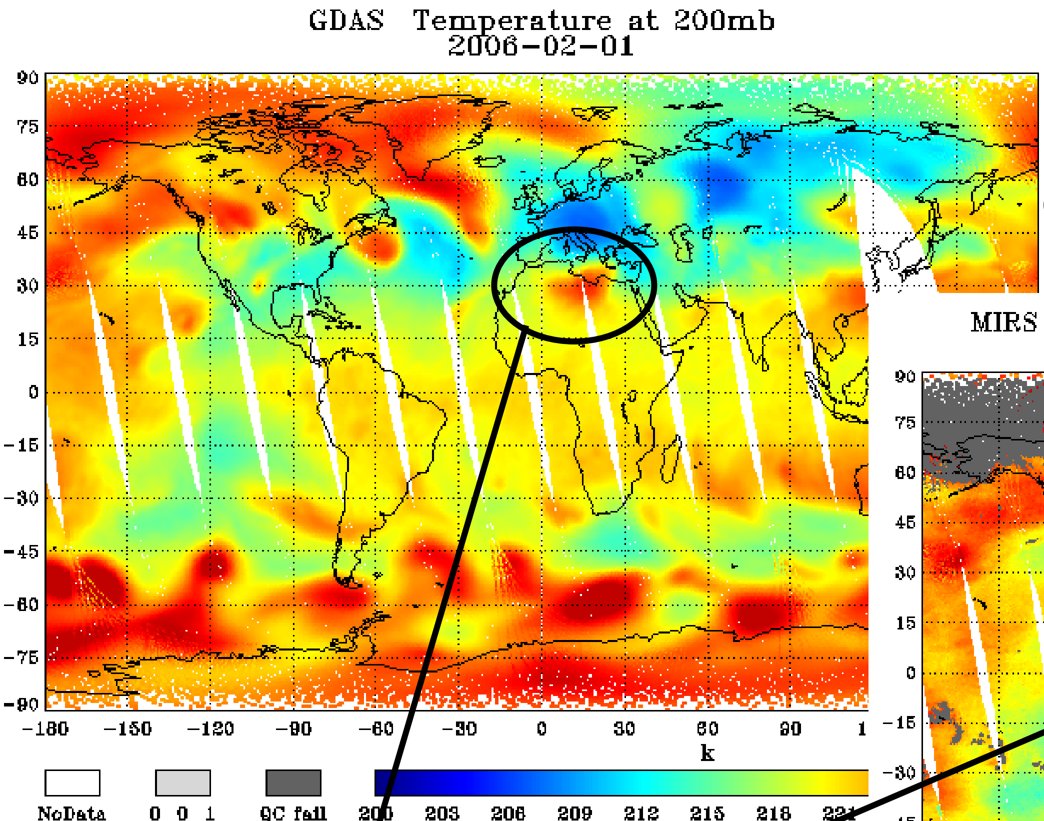
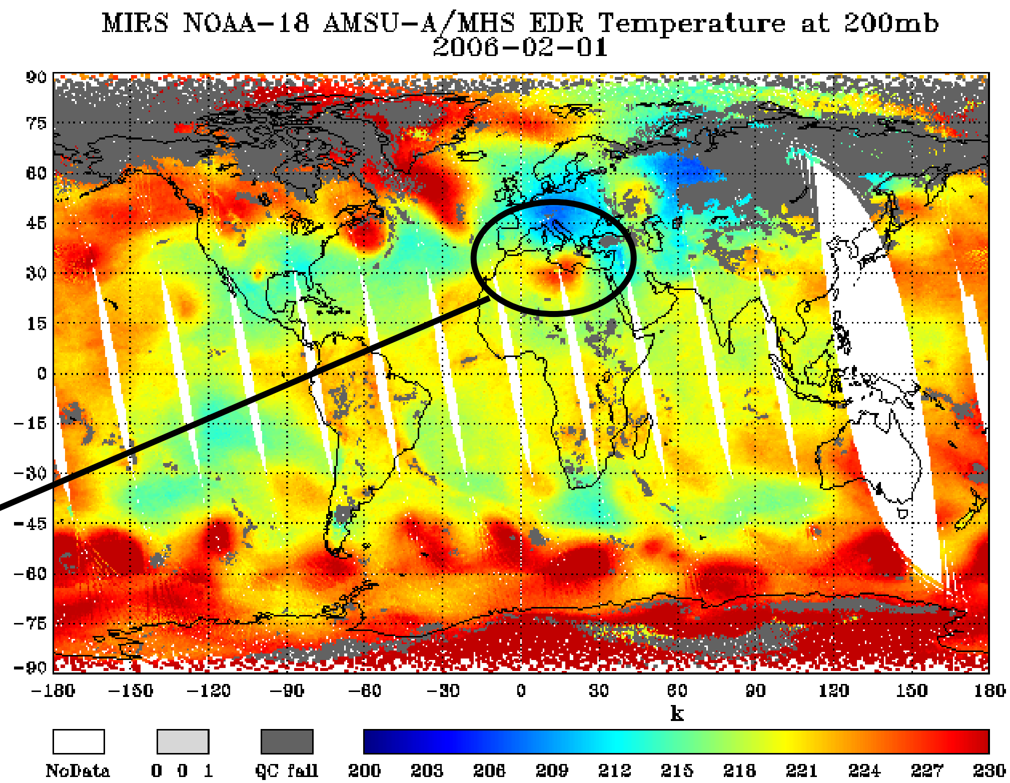


Global Temperature Profiling



No Scan-Dependence in retrieval
Smooth Transition Land/Ocean

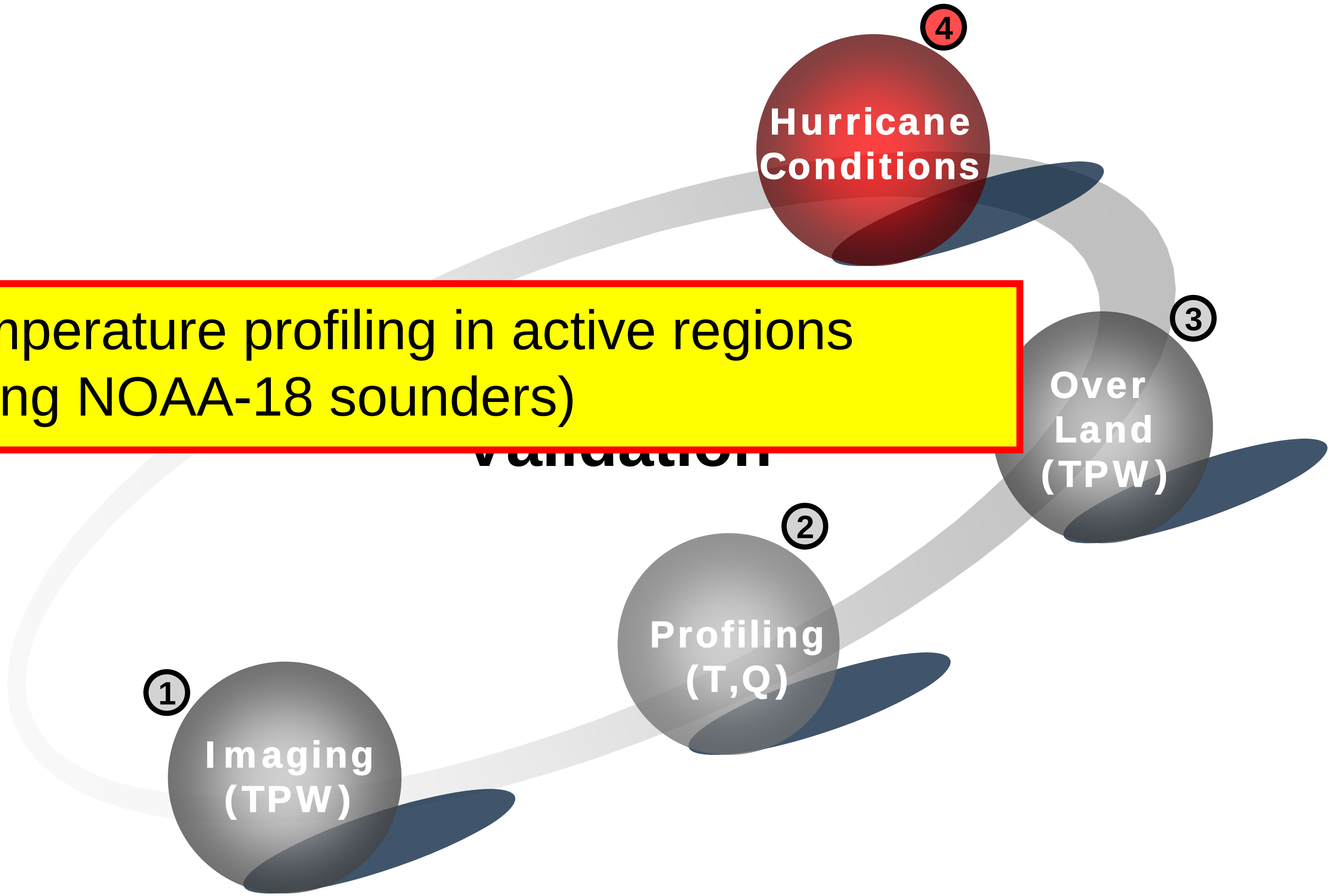
QC-failure is based on convergence:
Focus of on-going work



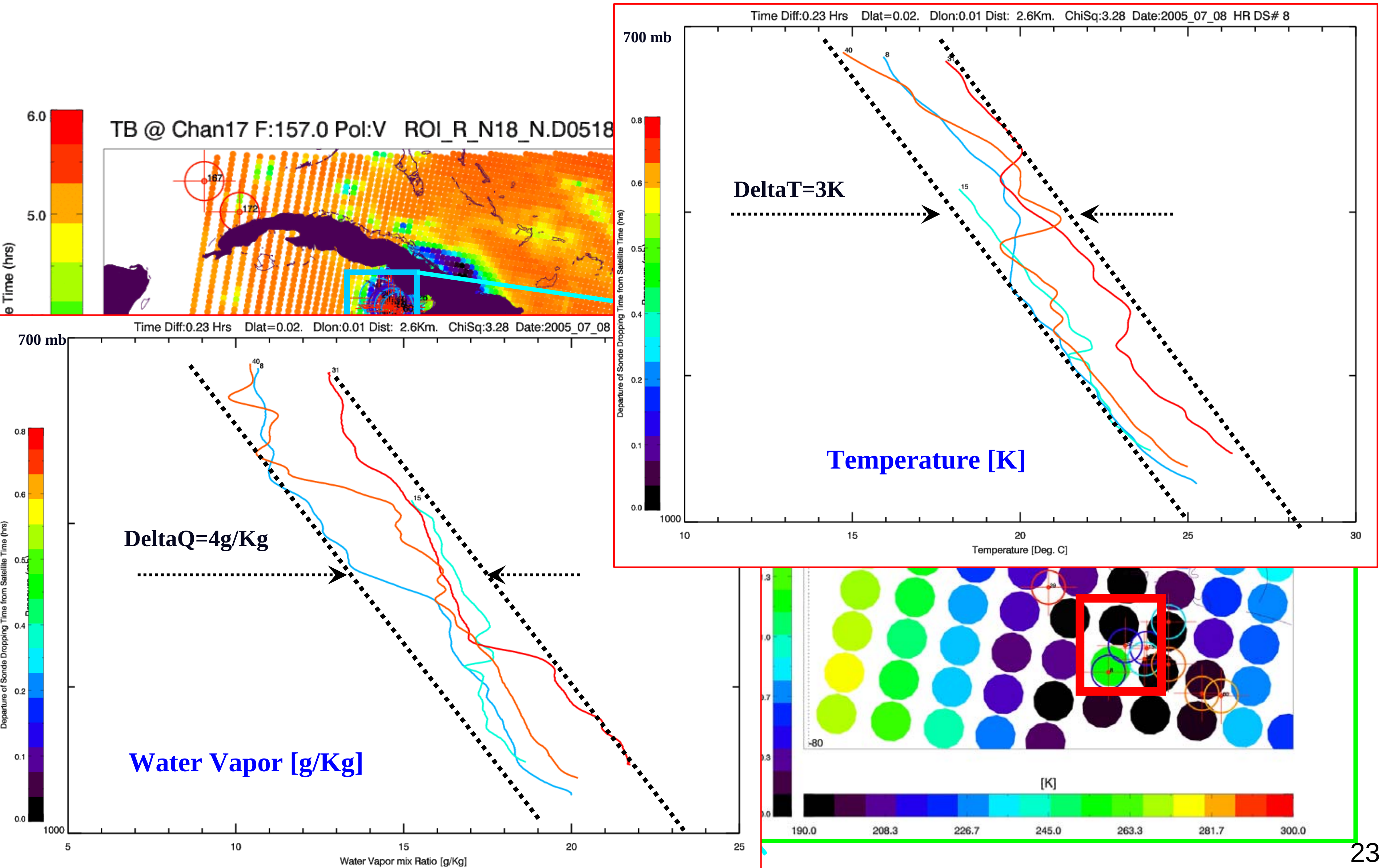
Similar Features Captured

Performance Evaluation

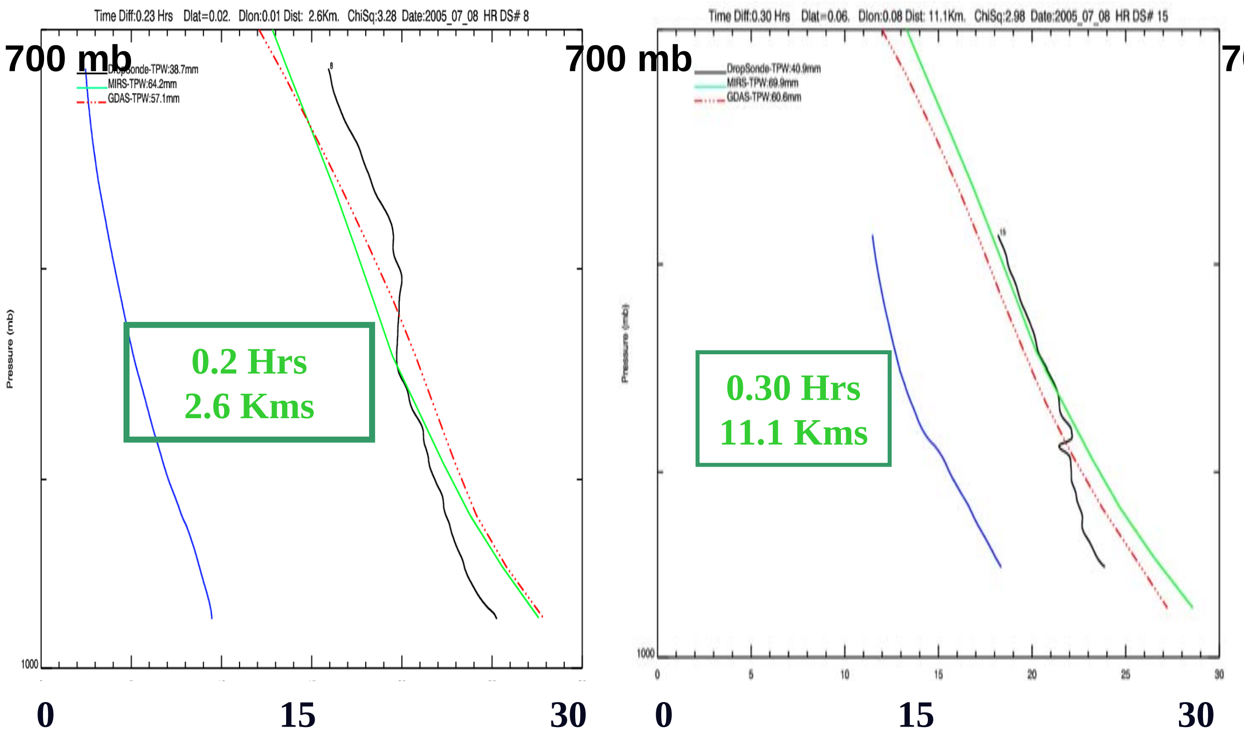
❖ Temperature profiling in active regions (using NOAA-18 sounders)



Challenges of Profiling in Active Areas



N-18 Profiling In Active Areas



[Deg. C]
[Kms]

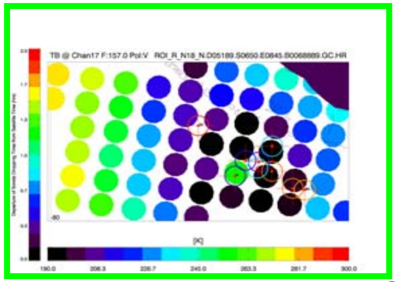
Deg C

Retrieval

GDAS

DropSonde

Profile of DS Distance Departure



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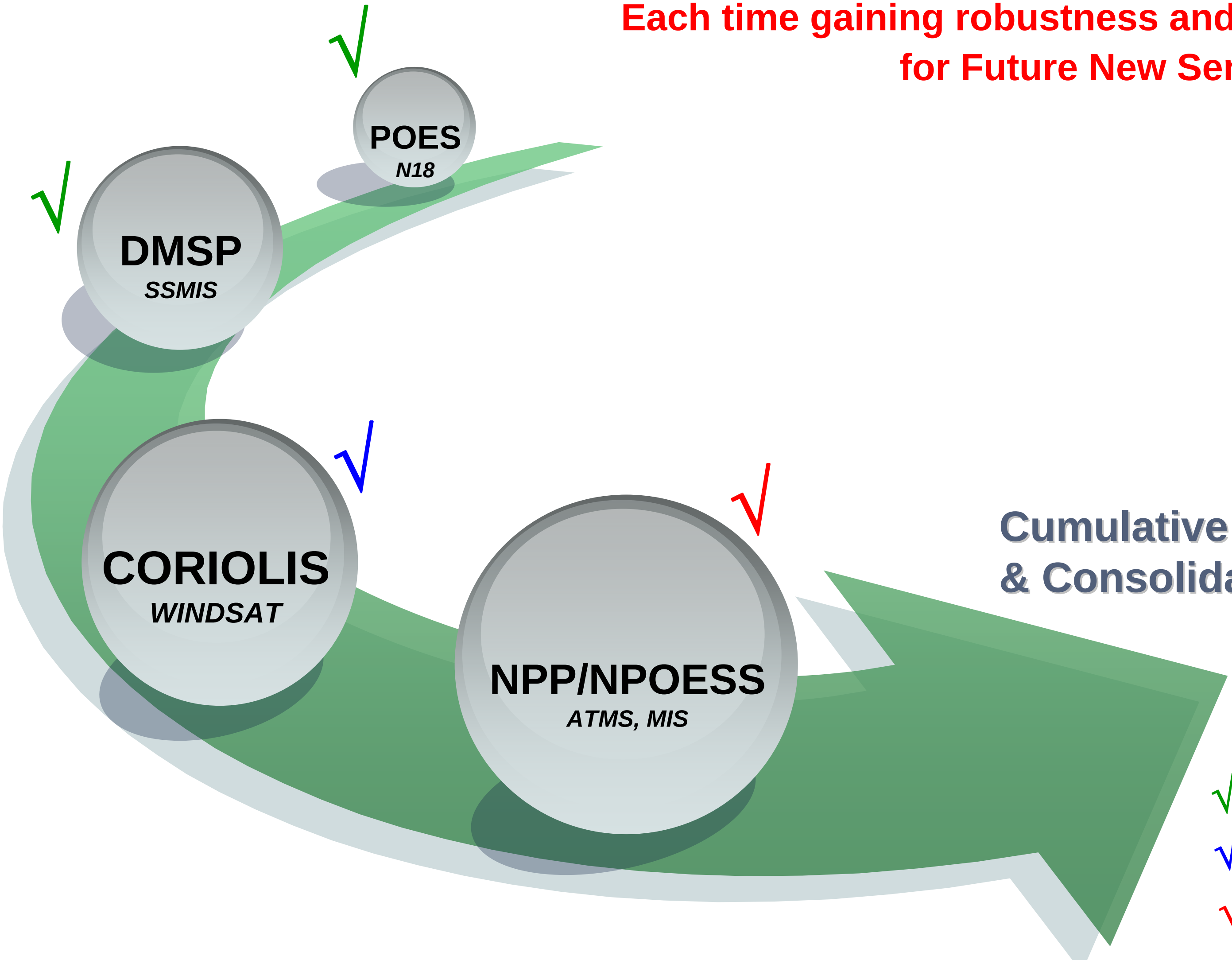
MIRS Applications

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

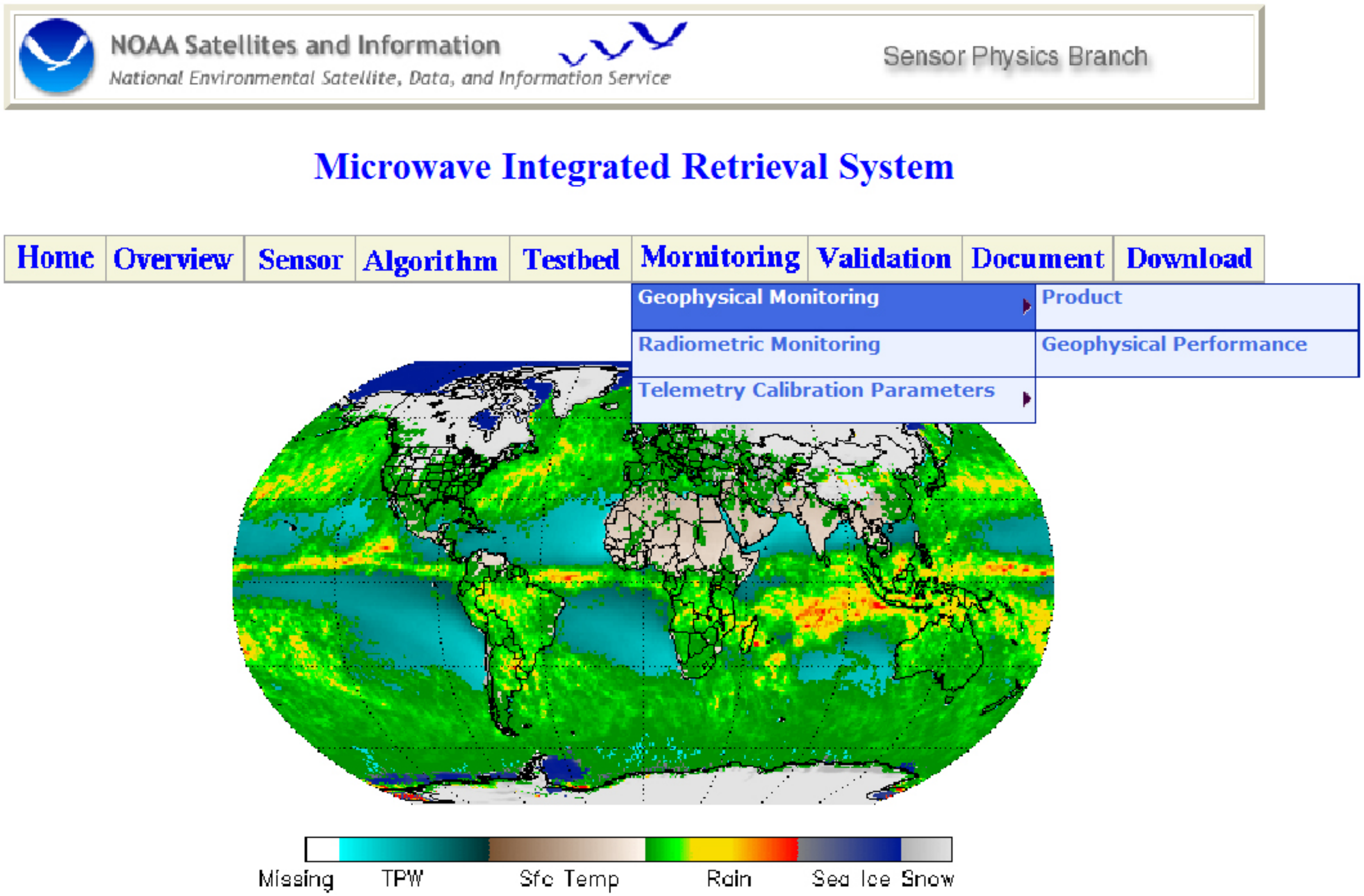


**Cumulative Validation
& Consolidation of MIRS**

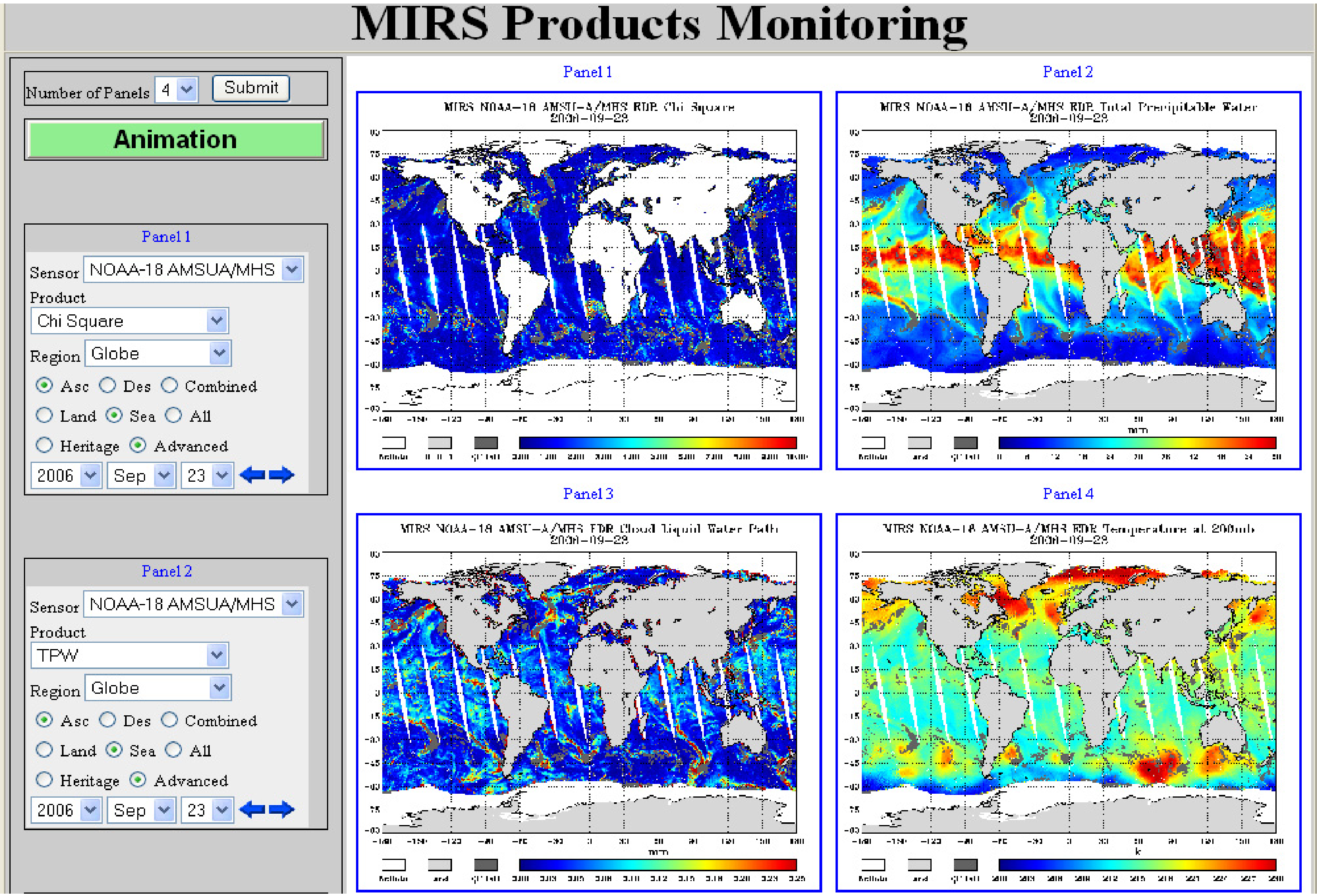
√: Applied Daily
√: Applied occasionally
√: Tested in Simulation

Online Access

❖ Online Scrolling Menus



Products Performance Monitoring – Functionalities (cont'd)



Thank You !

Questions?

BACKUP SLIDES

Core Retrieval Mathematical Basis

Ir

Bayes Theorem (of Joint probabilities)

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$$P(X,Y) = P(Y|X) \times P(X) = P(X|Y) \times P(Y)$$

$$P(X|Y^m) = \frac{P(Y^m|X) \times P(X)}{P(Y^m)}$$

I ... ector X:

=1

Core Retrieval Mathematical Basis

Maximizing $P(X \mid Y^m) =$

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

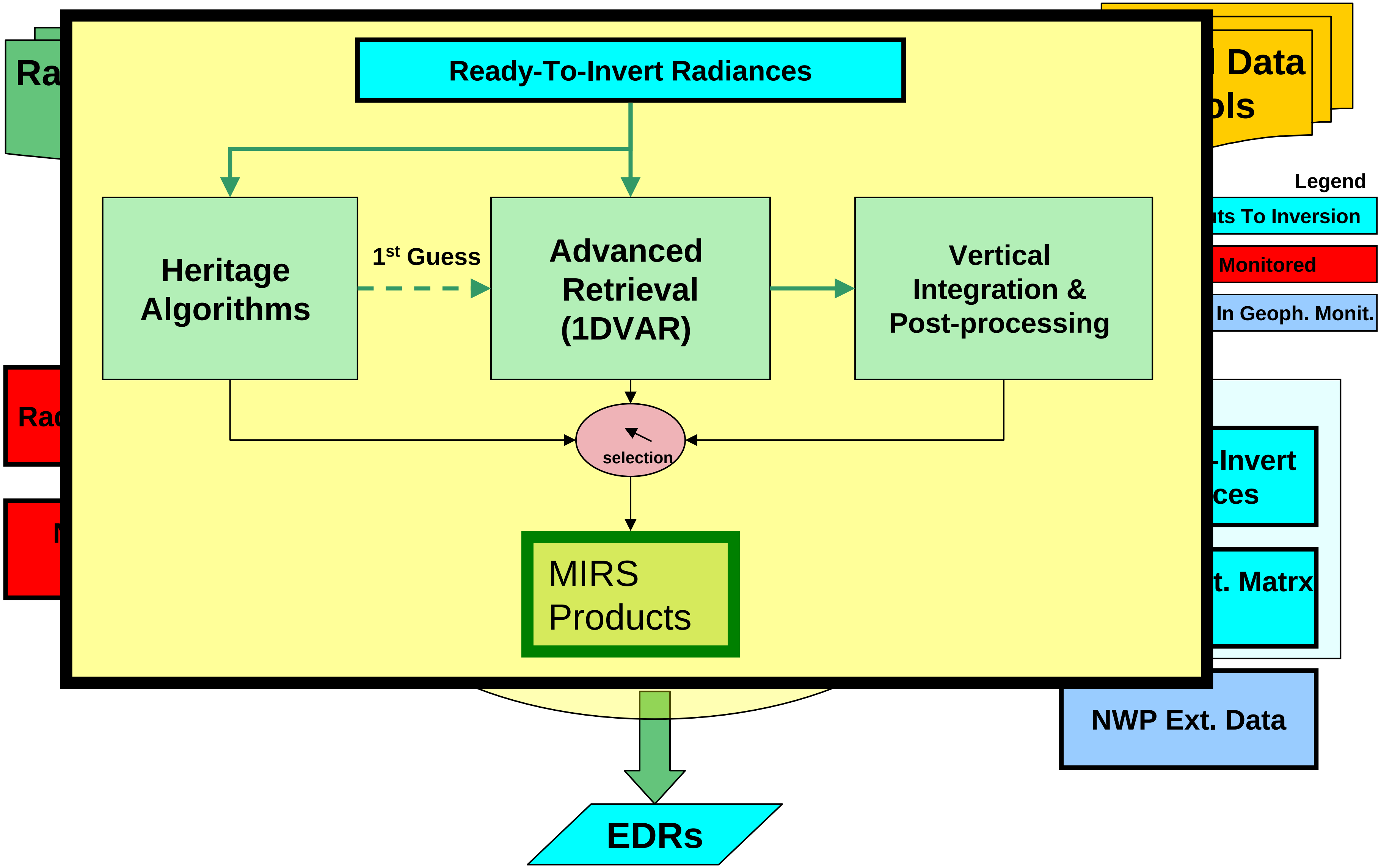
Is Equivalent to Minimizing

$$-\ln\left(P(X \mid Y^m) \right)$$

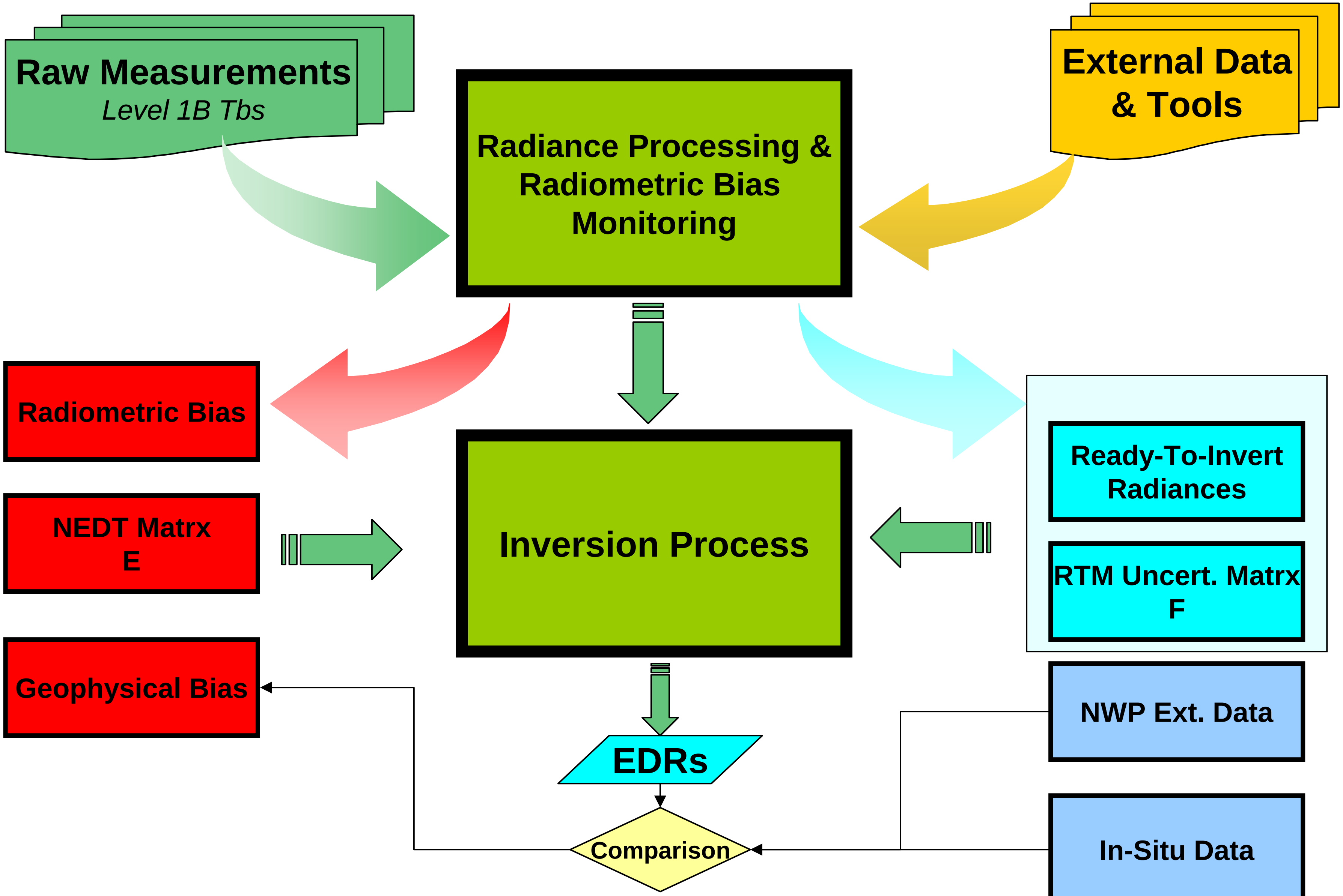
Which amounts to Minimizing J(X) *–also called COST FUNCTION – Same cost Function used in 1DVAR Data Assimilation System*

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

System Design & Architecture



System Design & Architecture



Nominal approach: Simultaneous Retrieval

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

X is **not** the solution

Necessary Condition (but not sufficient)

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

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.

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

$$\Theta = L^T \times B \times L$$

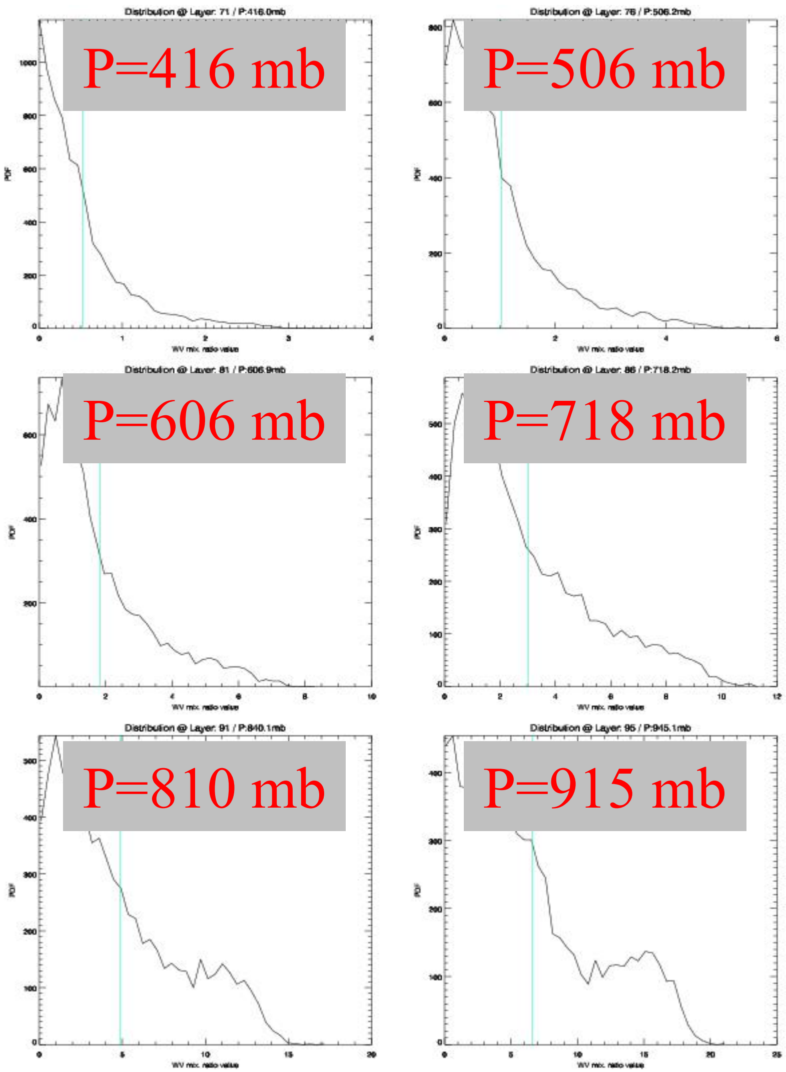
Diagonal Matrix *(used in reduced space retrieval)*

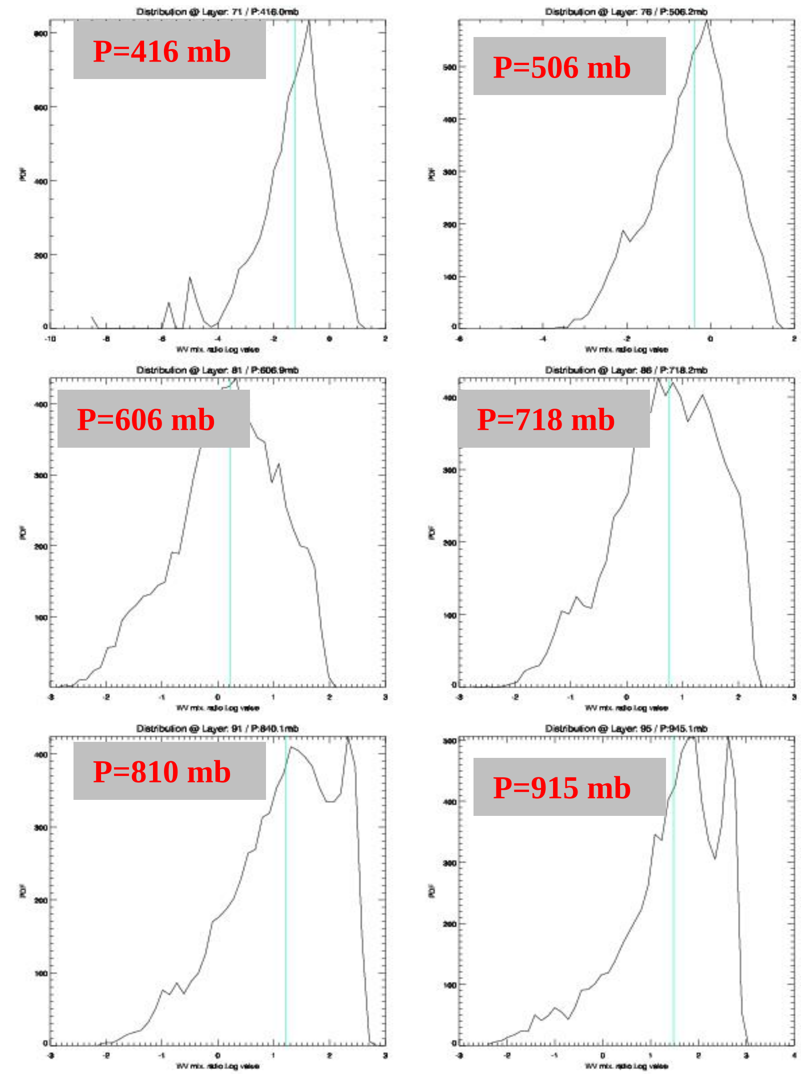
Transf. Matrx *(computed offline)*

Covariance matrix *(geophysical space)*

Retrieval in Logarithm Space

<u>Advantages:</u> (1) Distributions made more Gaussian & (2) No risk of having unphysical negative values





Applied to WV, Cloud and precip

$$J_1 = \frac{\partial R}{\partial \mathrm{Log}(x)} = \frac{\partial R}{\partial x} \times \frac{\partial x}{\partial \mathrm{Log}(x)} = J \times x$$

Validation Approach

Use of Multiple Microwave Sensors:

- AMSU A/B (or MHS) onboard NOAA-15-16-17-18
- WINDSAT onboard CORIOLIS
- SSMI/S onboard DMSP F-16

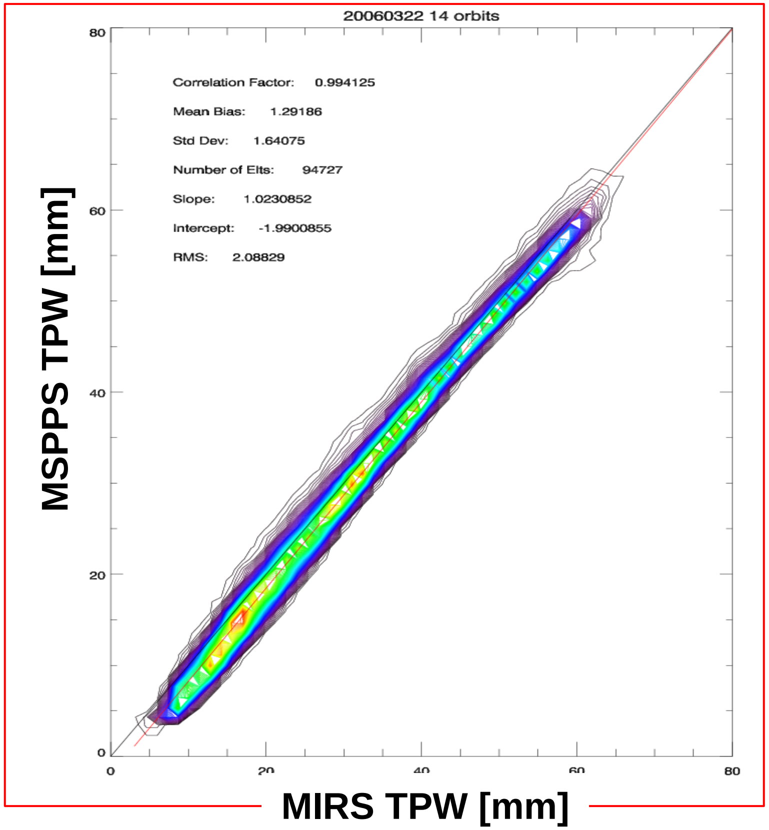
Two Types of Validation, depending on parameter

- Quantitative Validation
  - NWP Data (GDAS)
  - Heritage Algorithms (MSPPS)
  - Conventional Radiosondes (from NCEP and from NCDC)
  - GPS-DropSondes
- Qualitative Validation
  - Science Constraints in Retrieval System
  - Capture of known meteorological phenomena

Metrics:

- Standard statistical metrics Bias/RMS/StdV/Correlation
- Case By Case Evaluation (especially for active areas)

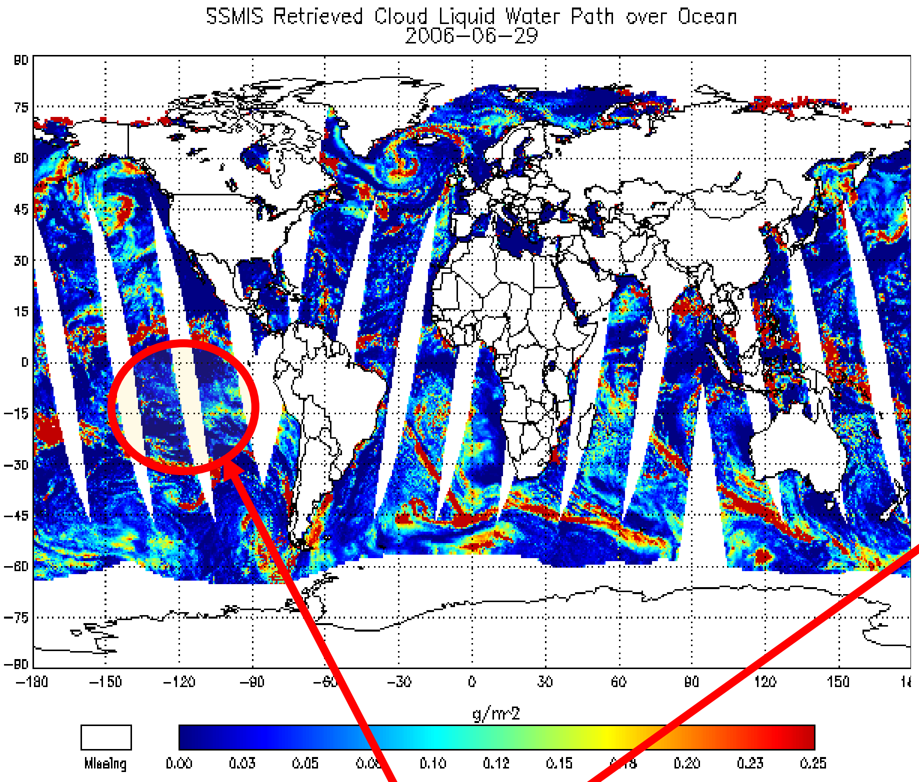
TPW Comparison MIRS vs MSPPS



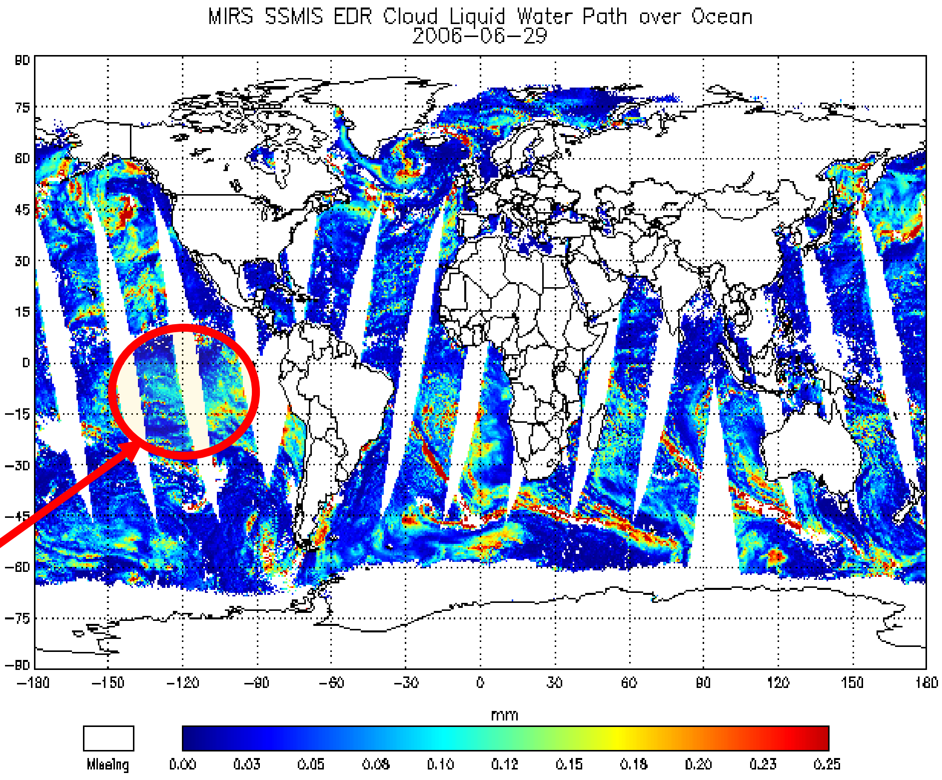
- MSPPS TPW used as reference
- MIRS retrieves the humidity profile. The TPW is integrated in post-processing stage.
- MSPPS relies on NWP forecast for both SST and Wind (emissivity).
- MIRS is independent of NWP data (even from surface pressure).

Cloud Retrieval Using SSMI/S

FNMOC Operational Algorithm



MIRS Algorithm

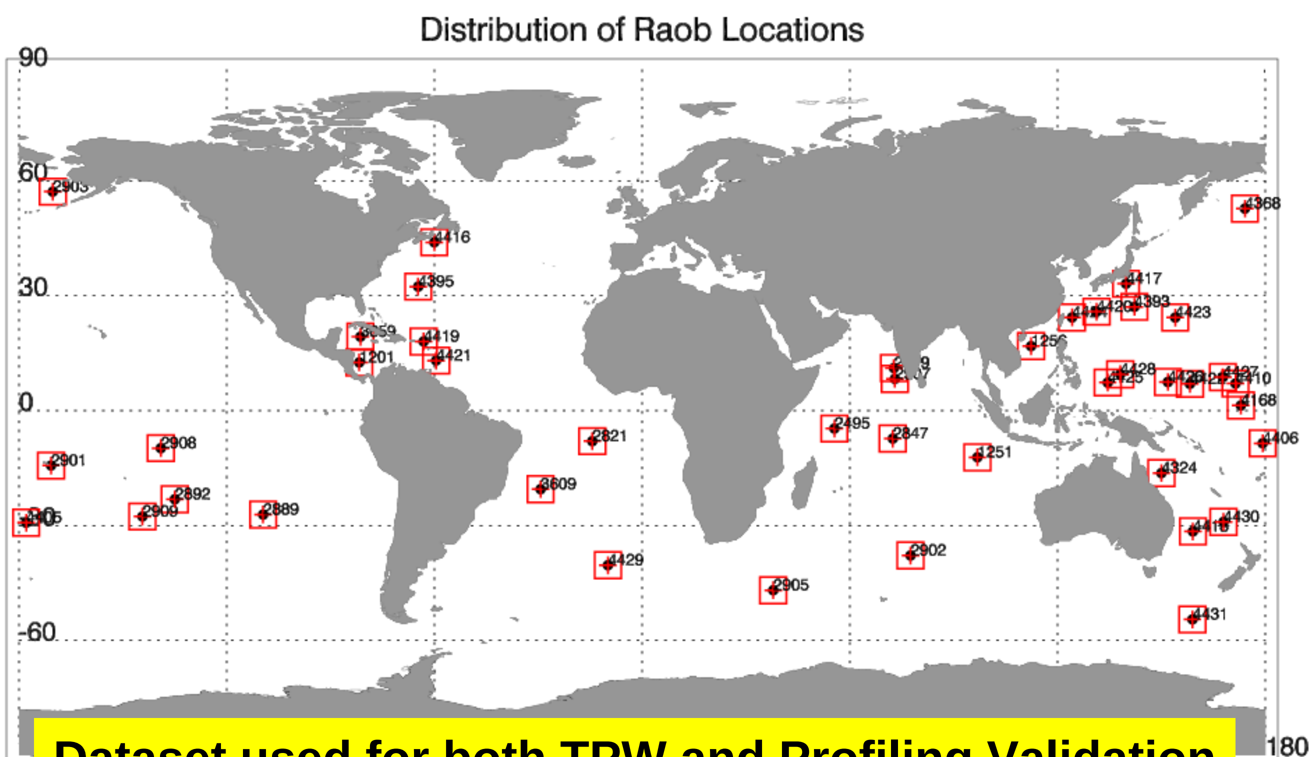


MIRS is more sensitive to small values (due to use of higher frequency channels)

Retrieval using DMSP F16 SSMI/S

In-Situ Global Distribution

	Source	Period	Coverage	# of Points	Ref.
POES NOAA15	NCEP	2002-2004	Ocean	1255	Liu & Weng 2004
POES NOAA16	NCEP	2002-2004	Ocean	1655	Liu & Weng 2004
POES NOAA17	NCEP	2002-2004	Ocean	1522	Liu & Weng 2004
POES NOAA18	NCDC-IGRA	2005-2006	Land	~8,000	Durre et al. 2006



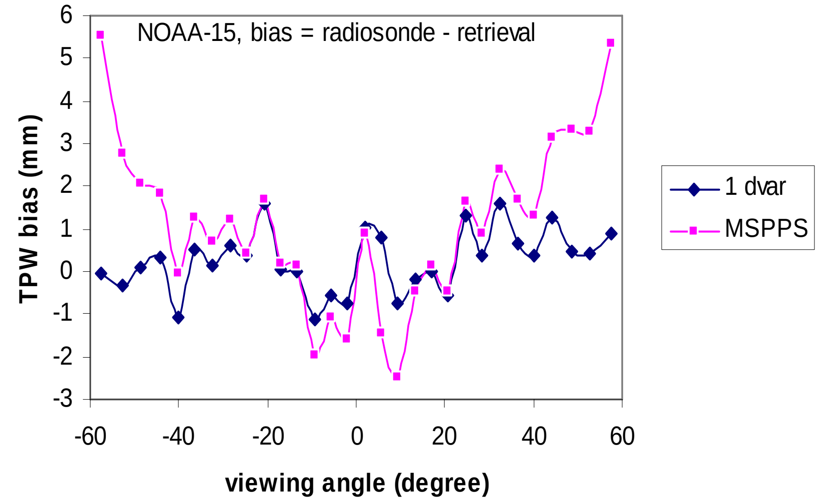
Dataset used for both TPW and Profiling Validation

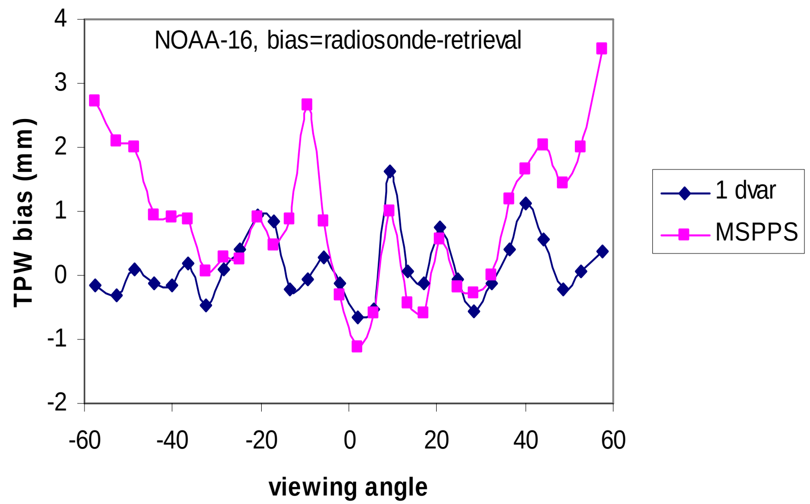
Retrieval Bias vs. Viewing Angles

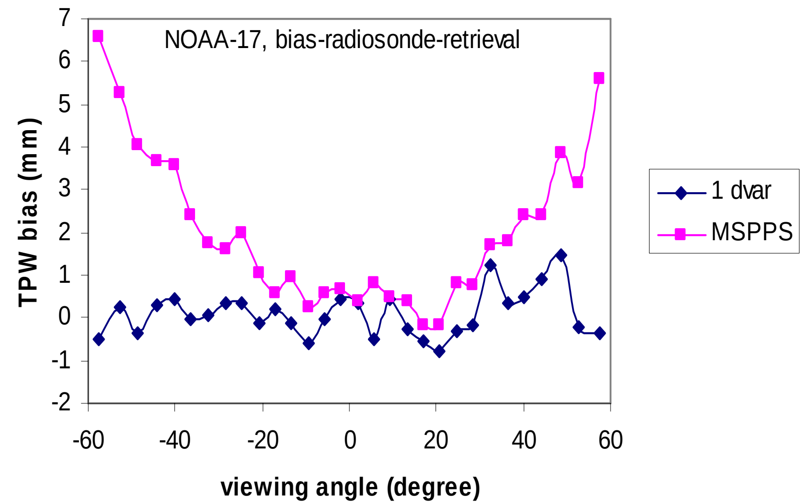
Match-up TPW from radiosondes and AMSU retrieval in 2002.

Bias variation to viewing angles.

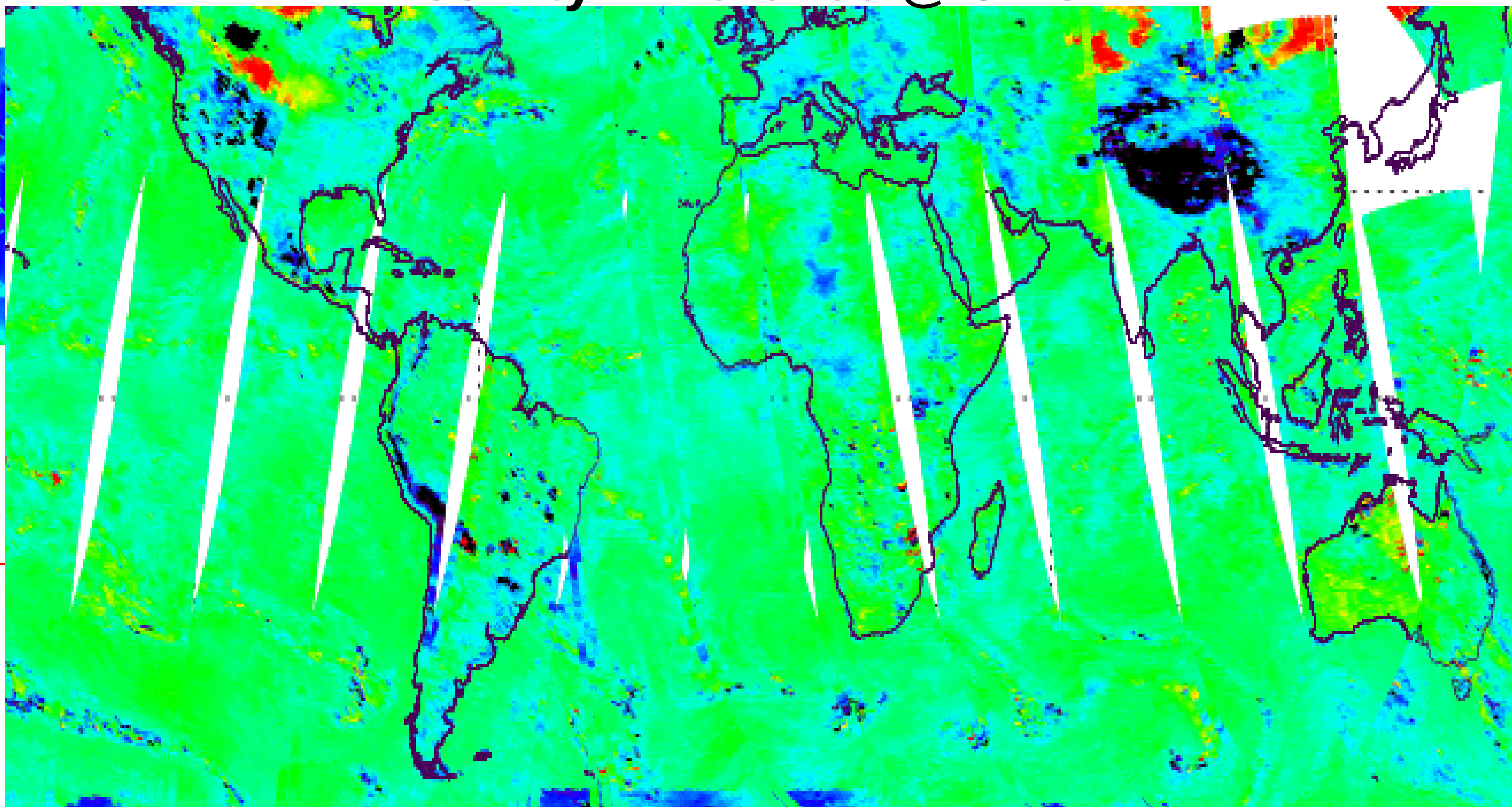
Bias = radiosonde – AMSU



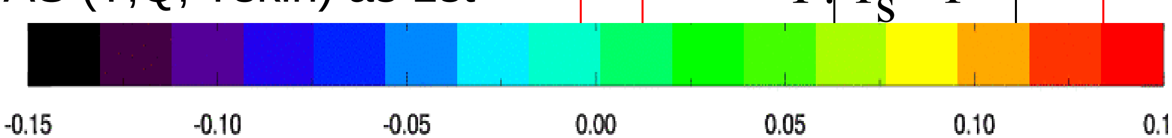




Emissivity Difference @ 31 GHz



❖Use of GDAS (T,Q, Tskin) as 1st guess & Ba
move

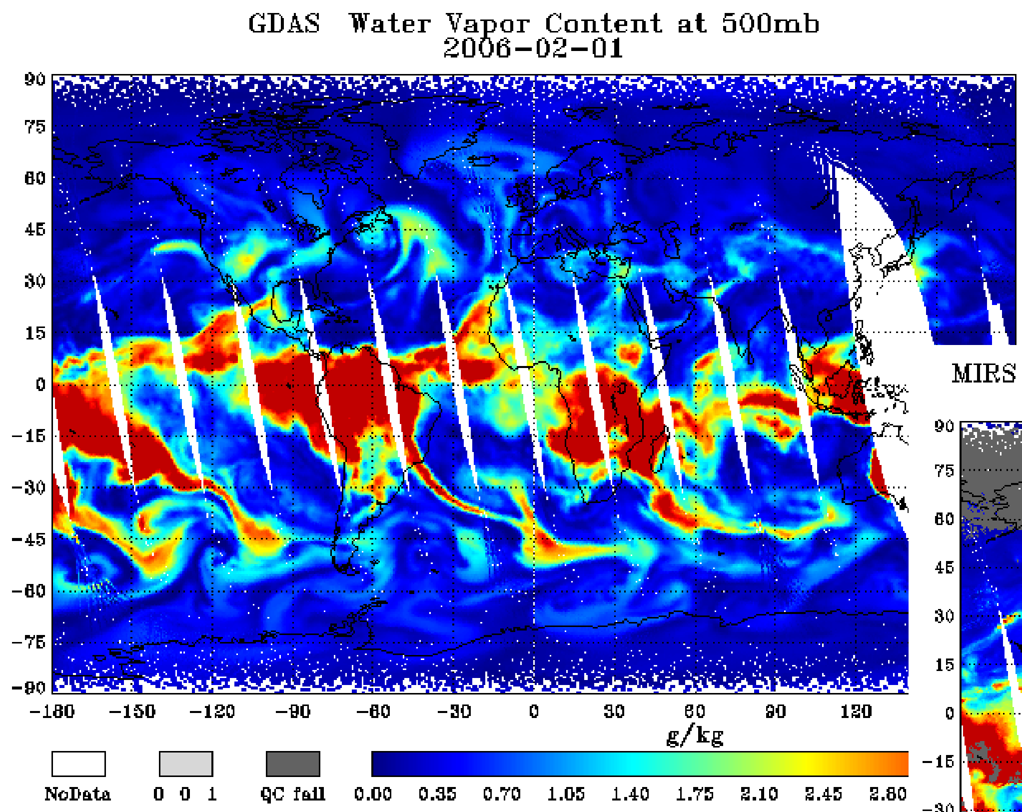


ons:

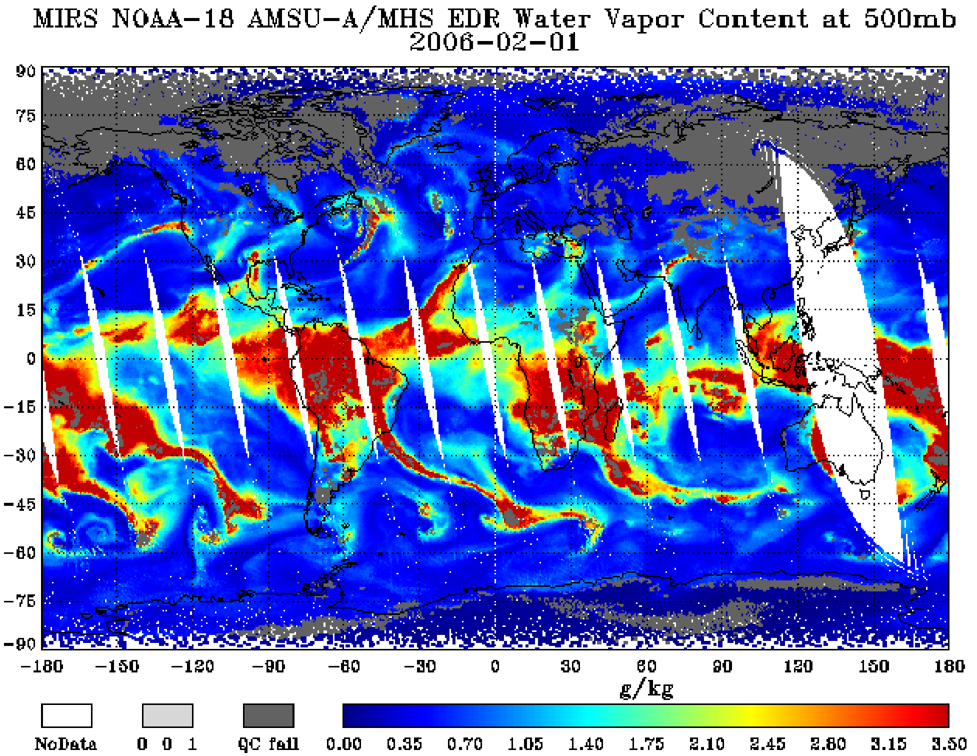
$\Gamma.\left(T_s - T\downarrow\right)$

$\Gamma \neq 0$

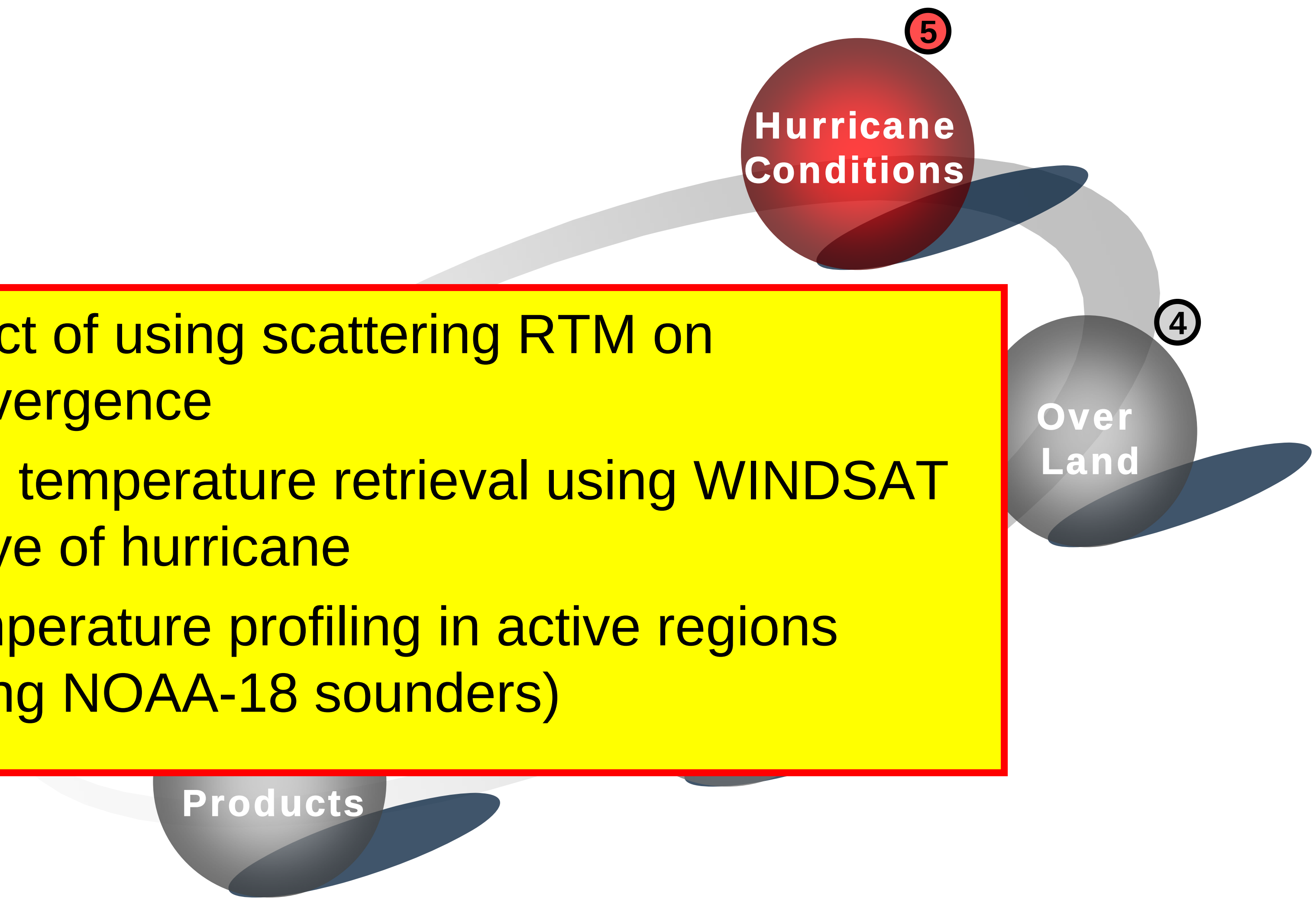
Global Humidity Profiling



No Scan-dependence noticed: Angle dependence properly accounted for



Performance Evaluation



- Effect of using scattering RTM on convergence
- Skin temperature retrieval using WINDSAT in eye of hurricane
- Temperature profiling in active regions (using NOAA-18 sounders)

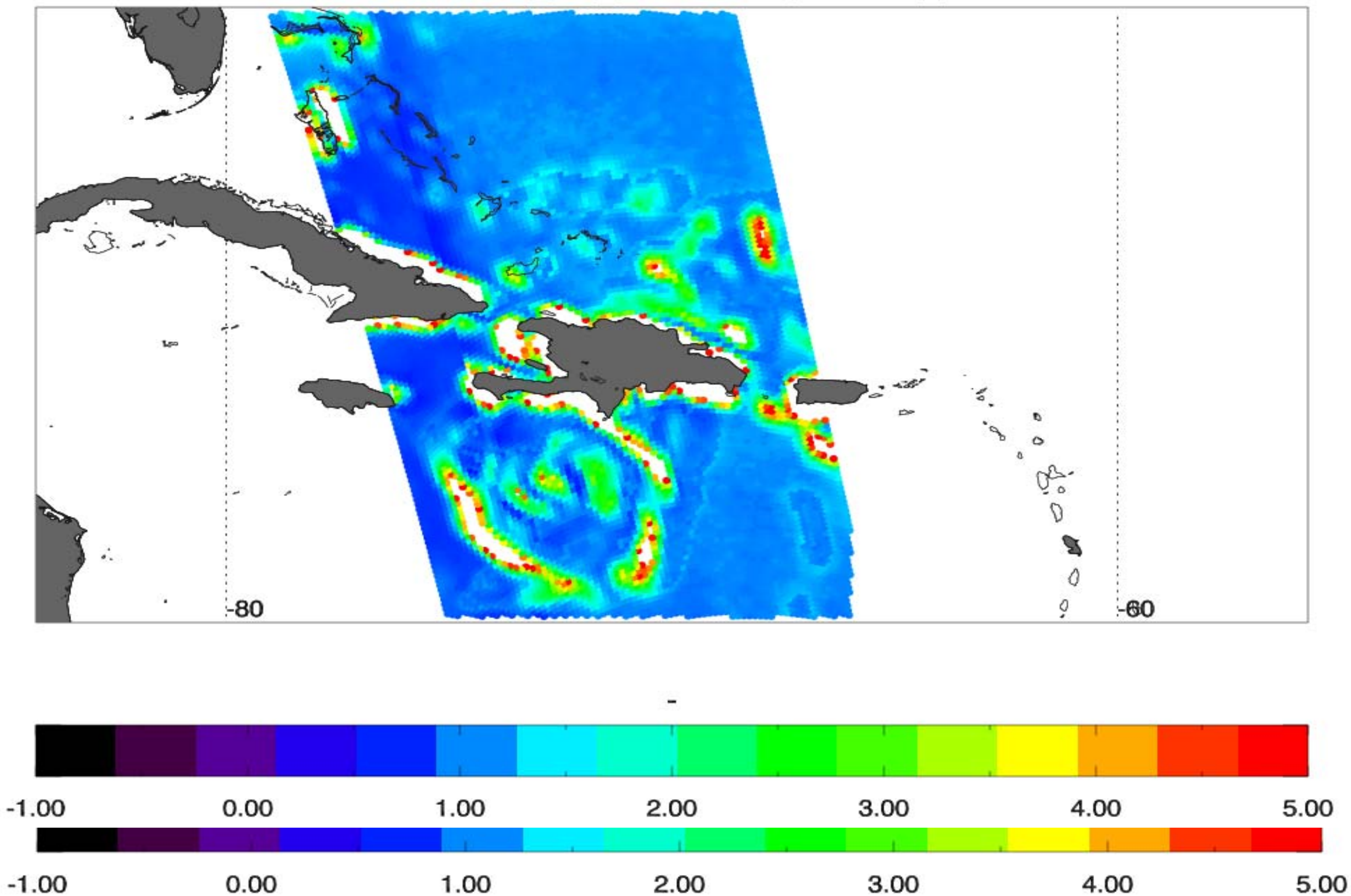
WINDSAT Retrieval (Chi Square)

Rain Model OFF

Rain Model ON

Retrieval using Windsat data (sdr68)
Spatial resolution of 6.8 GHz (50 kms)
But with a lot of oversampling

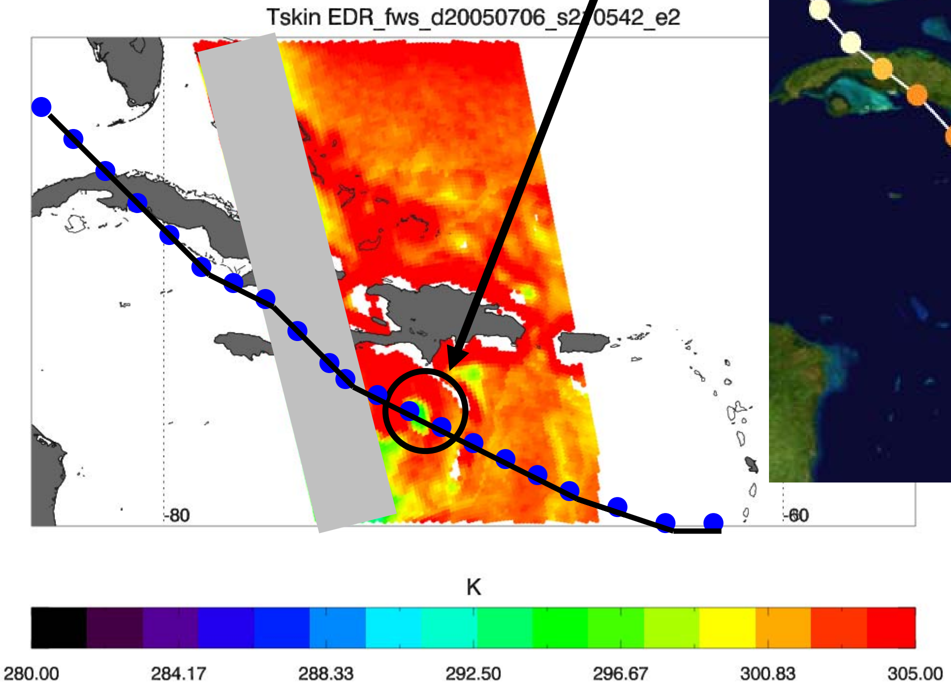
ChiSq EDR_fws_d20050706_s210542_e2



SST Retrieval In Hurricane Conditions

During Hurricane Dennis on July 6th 2005, WINDSAT Data captured Skin Temperature Cooling inside Eye of Hurricane

MIRS SST Retrieval Using WINDSAT (Frq 6 to



Dennis Hurricane Track, Courtesy of National Hurricane Center