Introducing NOAA's Microwave Integrated Retrieval System (MIRS)

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NOAA/NESDIS
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Contents

Overview

Stated Goals of MIRS

- State of the Art Algorithm: *For sounding, imaging, or combination thereof*
- Applicable to all Microwave Sensors
- Extend Applicability: *over non-oceanic surfaces and in all weather conditions*
- Operate independently from NWP models *(including surface pressure)*
- Robustness: *to channel(s) failure, instrument noise increase, etc*

Benefits

- Reduction of Time/Cost to Adapt to New Sensors
- Reduction of Time/Cost to Transition to Operations
- Potential Improvements in Severe Weather Forecasts
- Better Climate Data Records *(same algorithm for all sensors, independence from NWP models)*
- Make MIRS a publicly available package to benefit community

MIRS Concept

Variational Assimilation Retrieval (1DVAR)

- **Algorithm valid in all-weather conditions, over all-surface types**
  - CRTM as forward operator, validity-> clear, cloudy and precip conditions
  - Emissivity spectrum is part of the retrieved state vector
- **Cloud & Precip profiles retrieval (no cloud top, thickness, etc)**
  - EOF decomposition
- **Sensor-independent**
  - Highly Modular Design
- **Flexibility and Robustness**
  - Selection of Channels to use, parameters to retrieve
  - Modeling & Instrumental Errors are input to algorithm

Contents

Cost Function Minimization

- Cost Function to Minimize:

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

Jacobians & Radiance Simulation from Forward Operator: CRTM

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

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

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

More efficient (1 inversion)

Preferred when nChan << nParams (MW)

Quality Control of MIRS Outputs

- Convergence Metric: φ^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*.

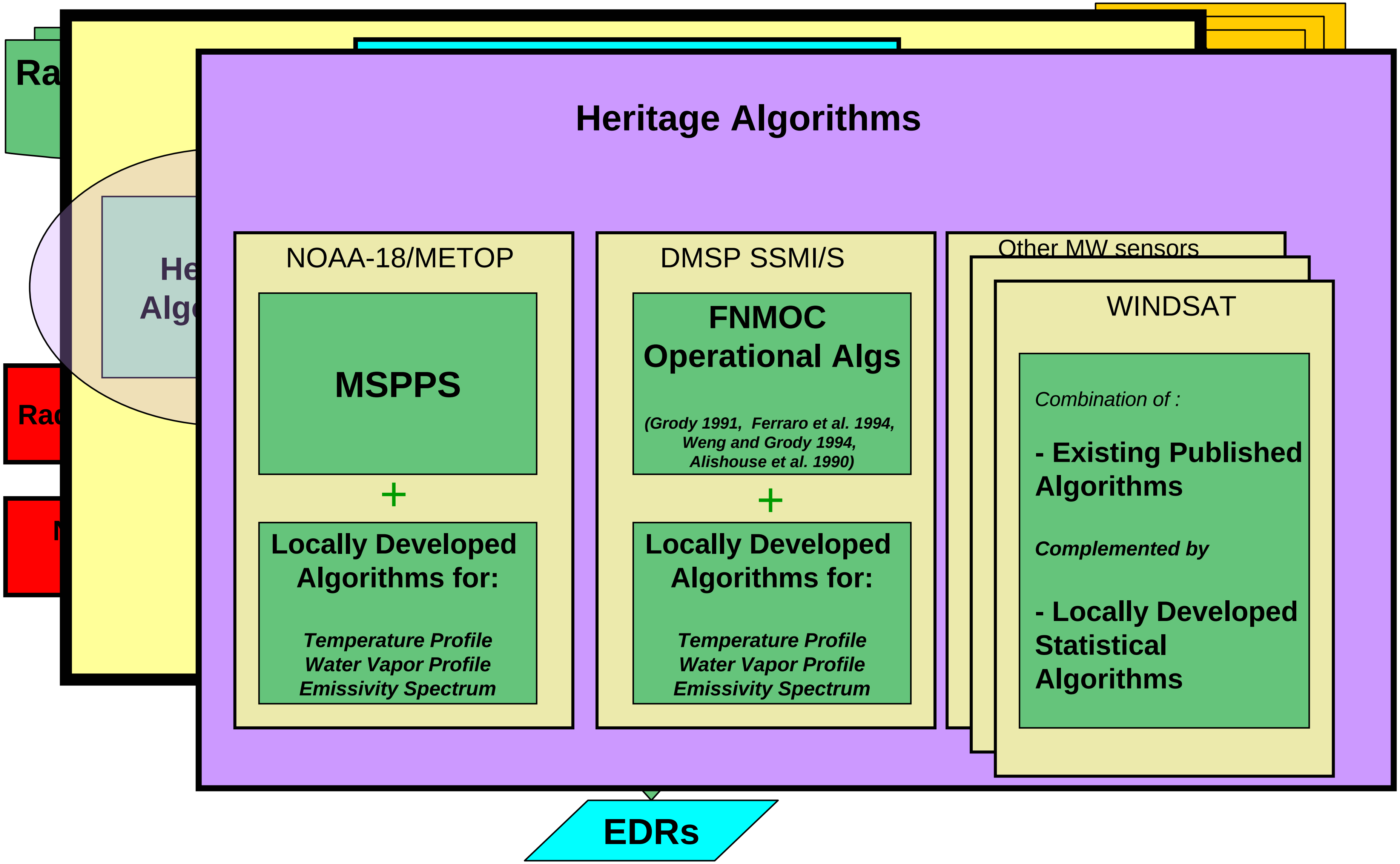
$$D = B \times K^T \left(K \times B \times K^T + E \right)^{-1} \times \left(Y(X) - K \times X_0 \right)$$

- Average kernel *A*:

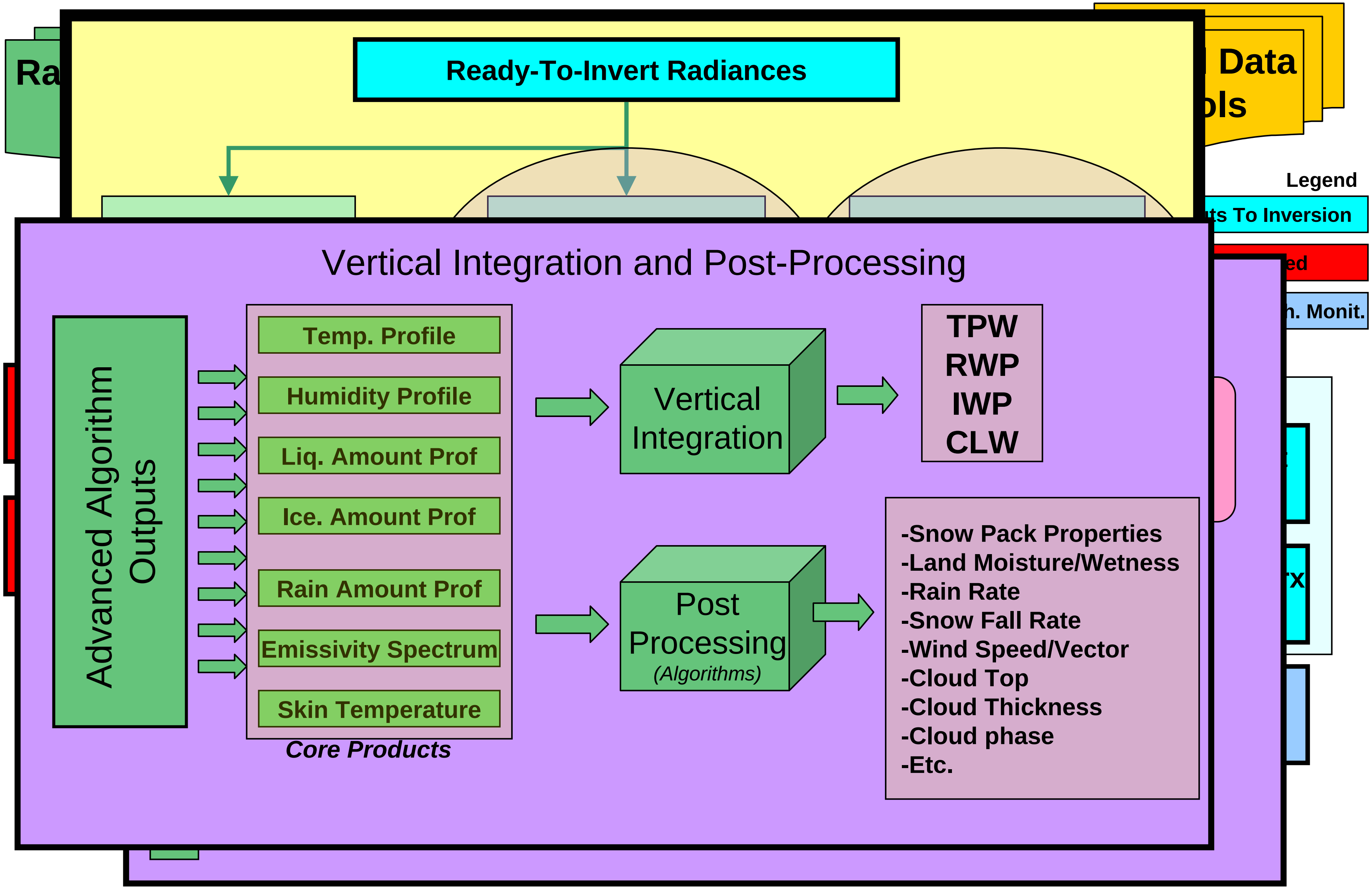
$$A = D \times K$$

  - If close to zero, retrieval coming essentially from background
  - If close to unity, retrieval coming from radiances: No artifacts from background

System Design & Architecture

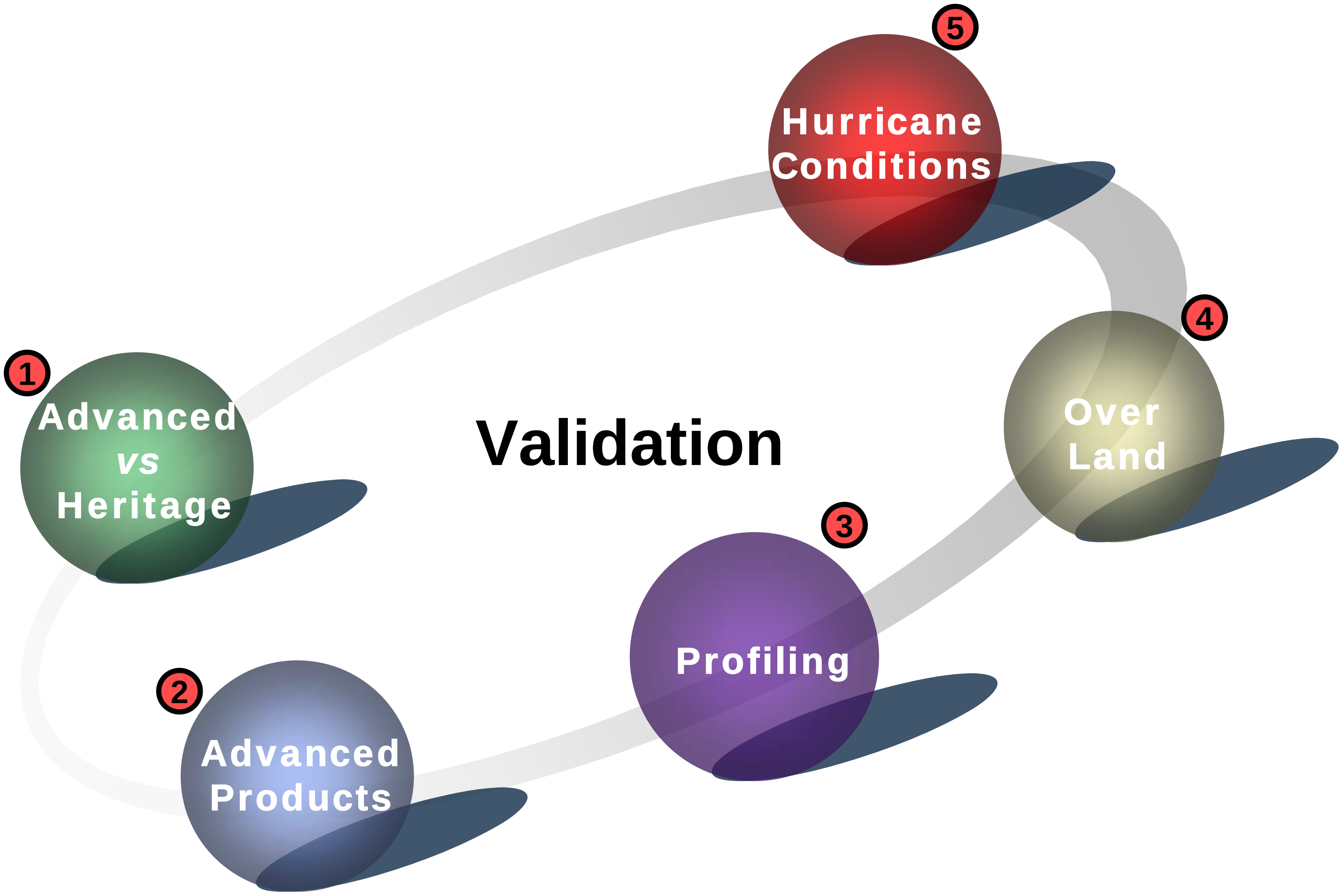


System Design & Architecture

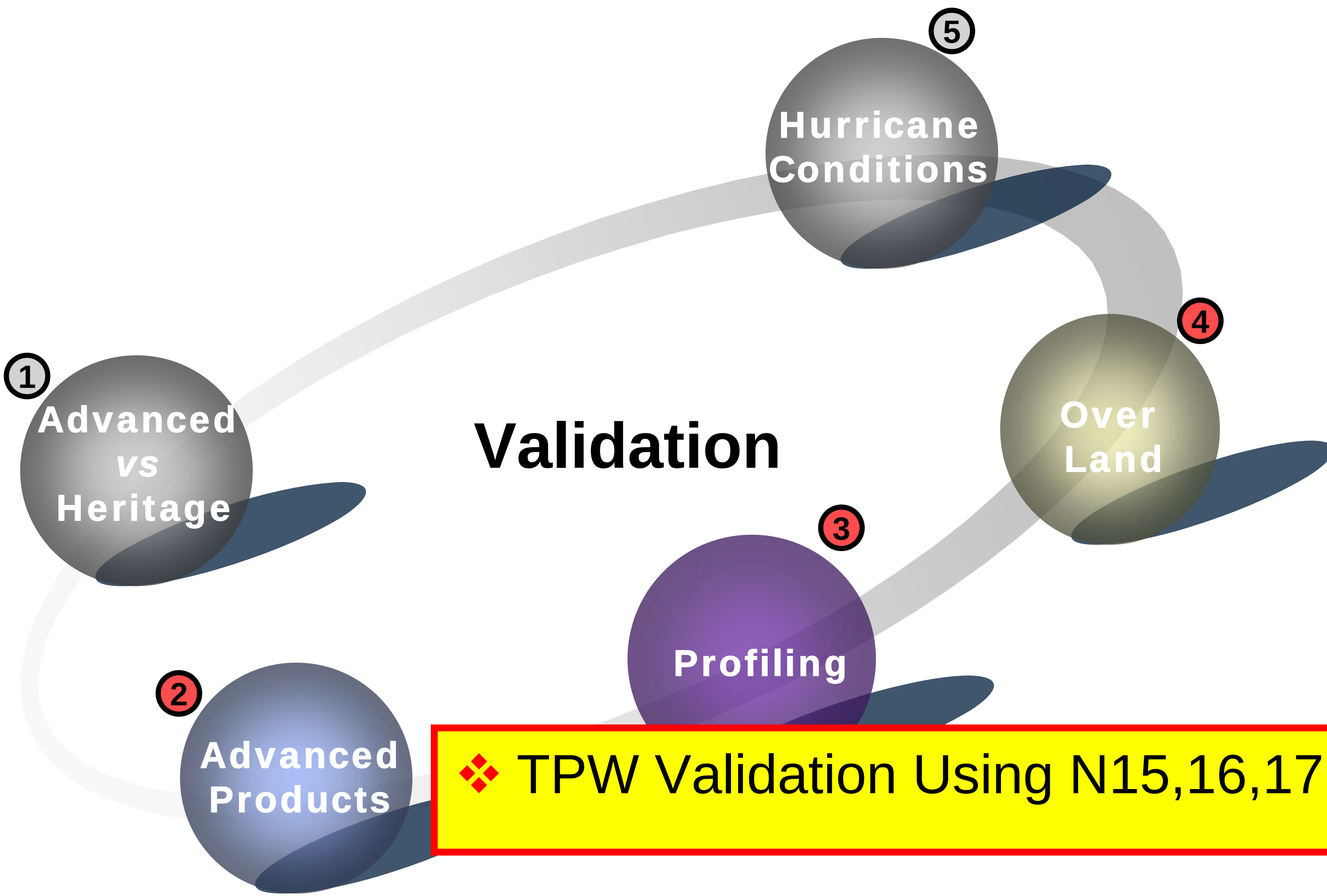


Contents

Performance Evaluation

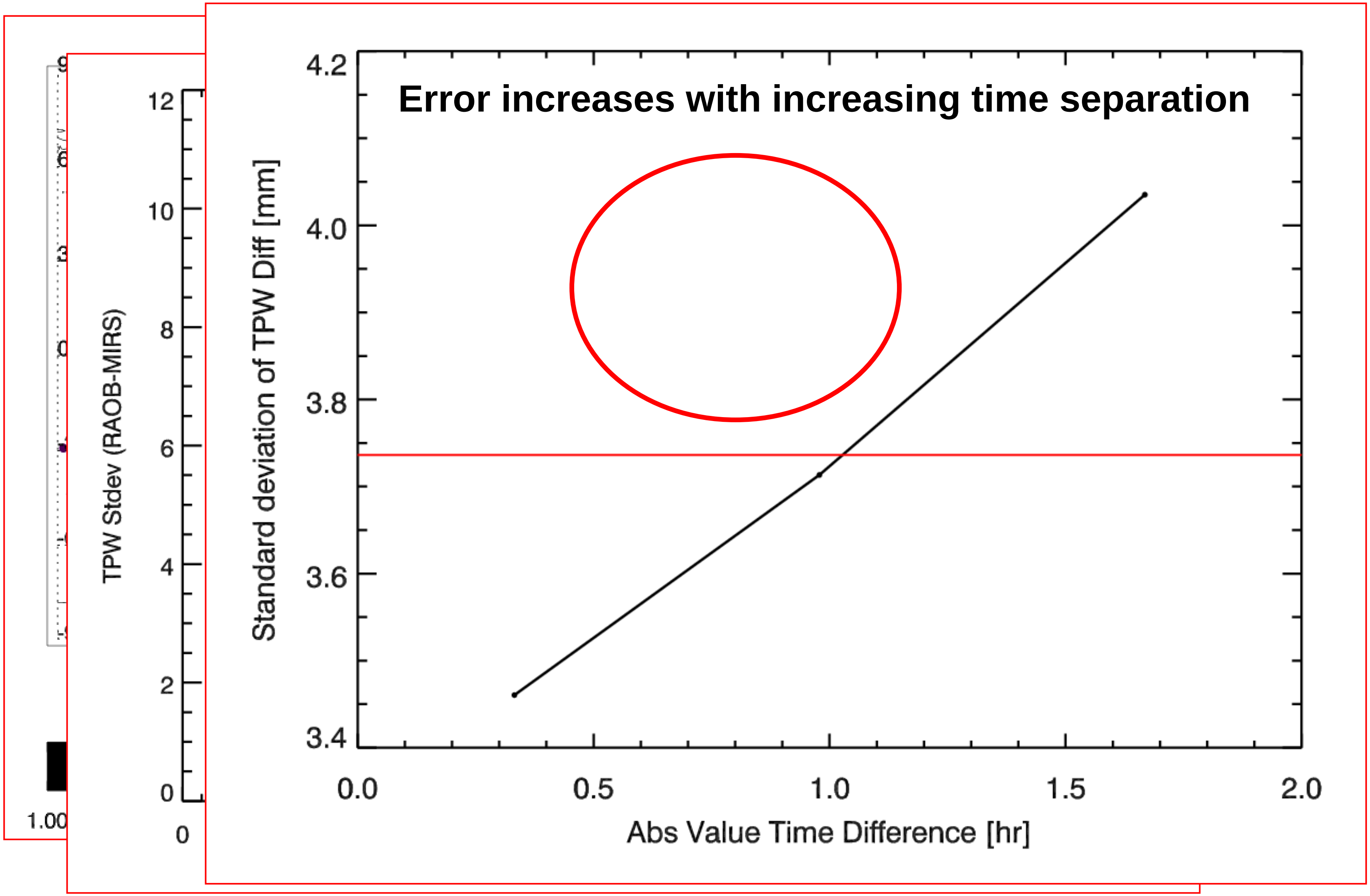


Performance Evaluation



❖ TPW Validation Using N15,16,17,18

QC of the Validation Set



Improvement Assessment (*wrt Heritage*)

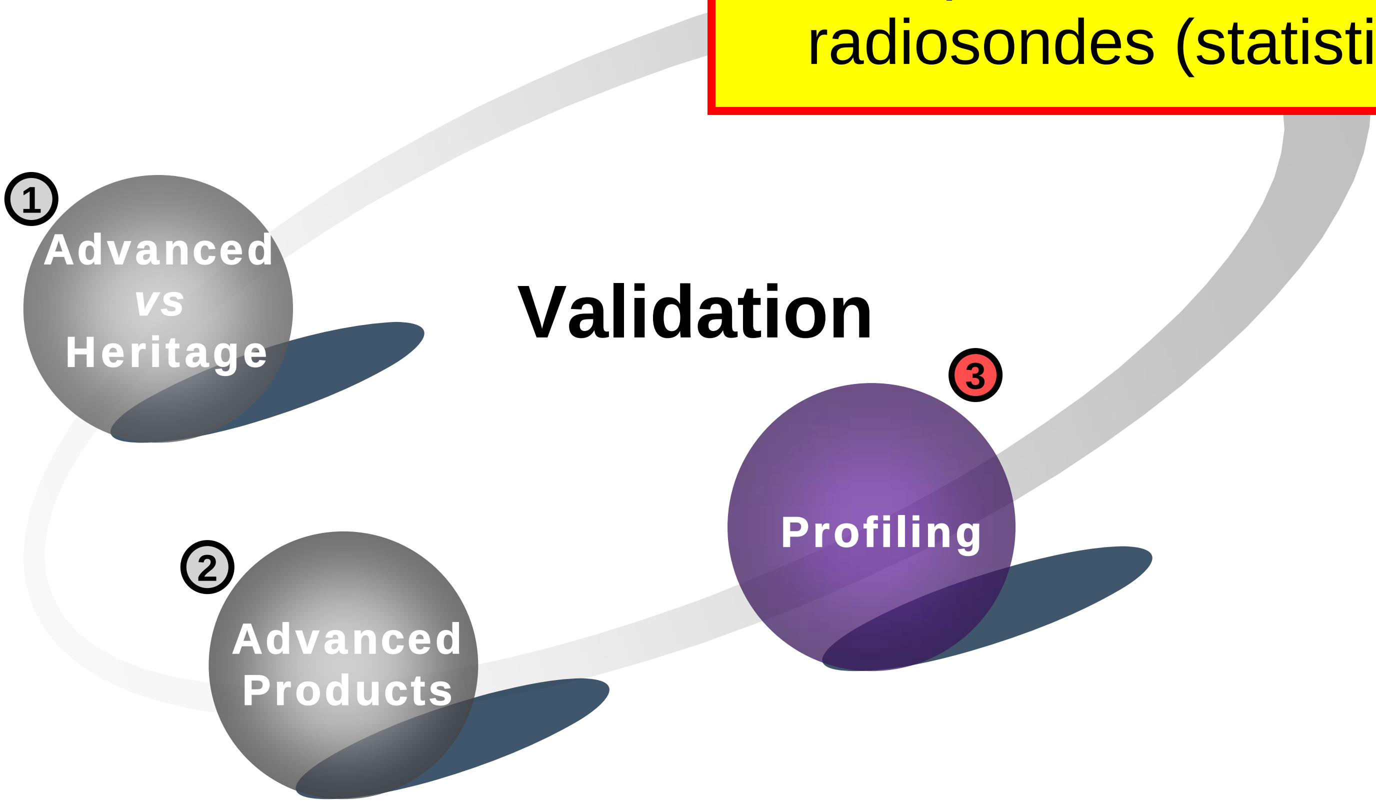
MSPPS: NOAA's operational system responsible for deriving microwave products

	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

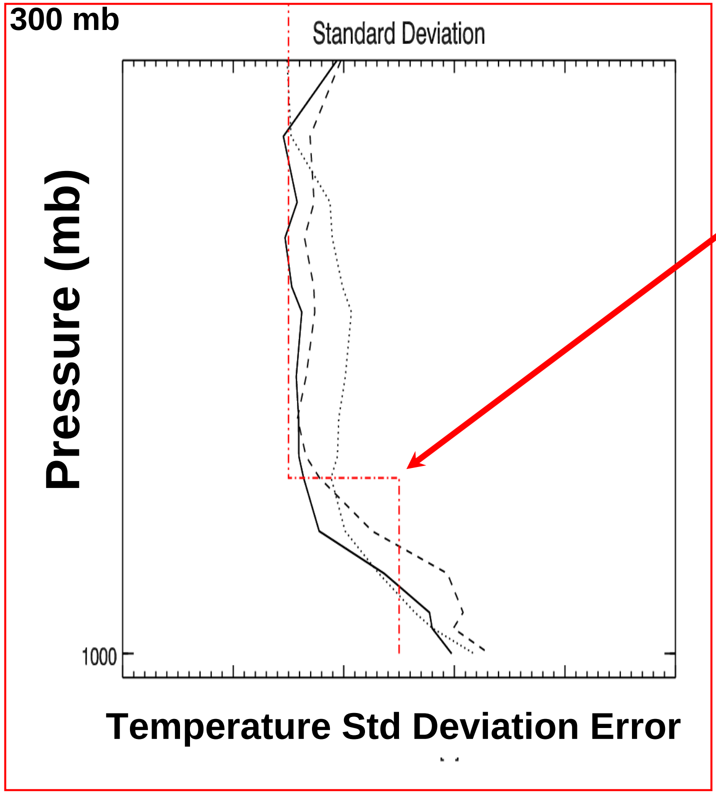
Performance Evaluation

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

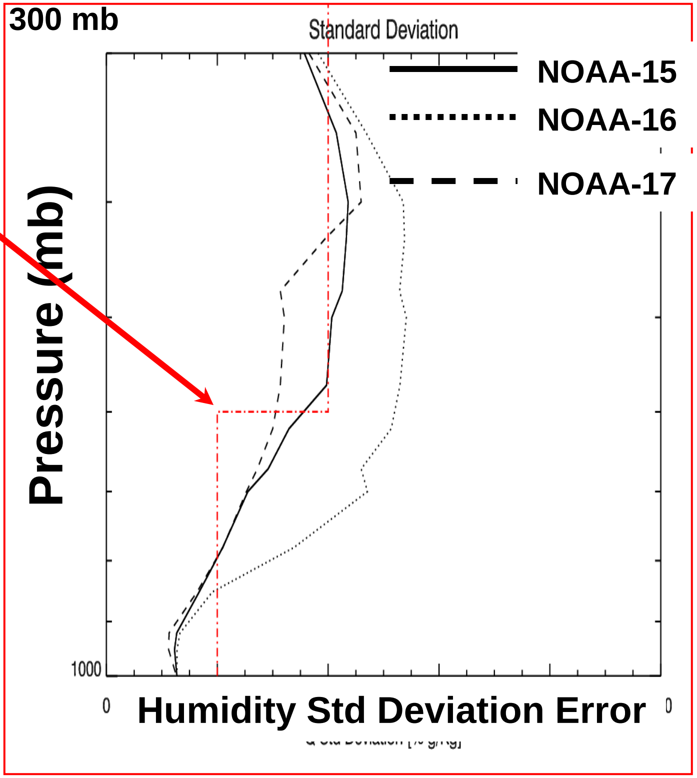


Temperature & Humidity Profiles

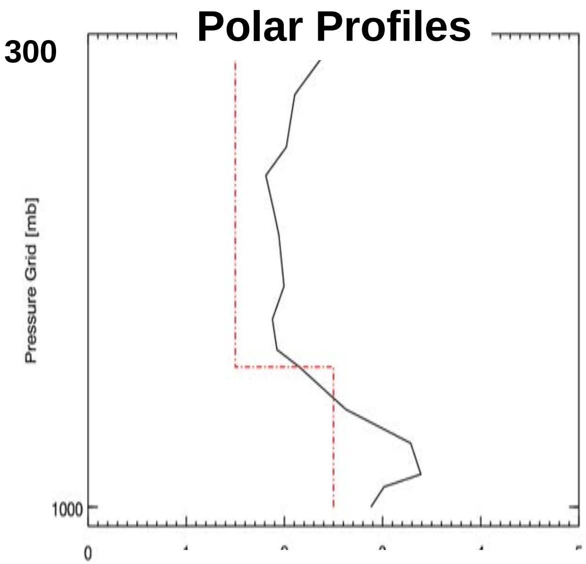
- Raob Profiles with at least 30 levels used. Ocean cases only. Retrievals up to 0.05 mbars. Assessment only up to 300 mbars.
- These are real data performances (stratified by sensor)
- Results shown here are cloudy (up to 0.15 mm from MIRS retrieval)
- Independent from NWP forecast information, including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

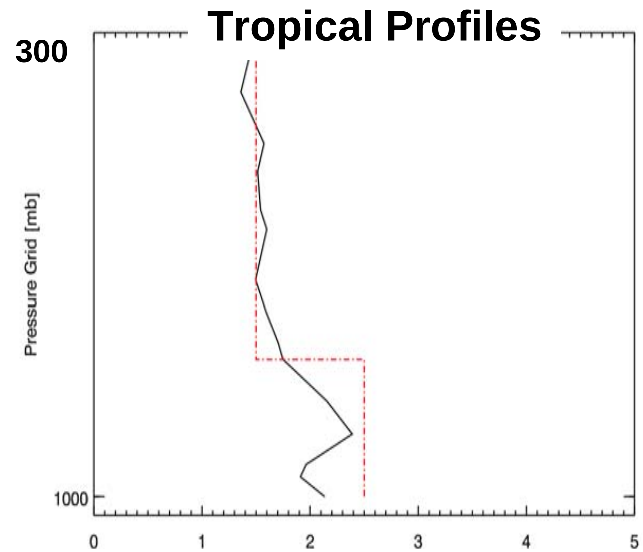


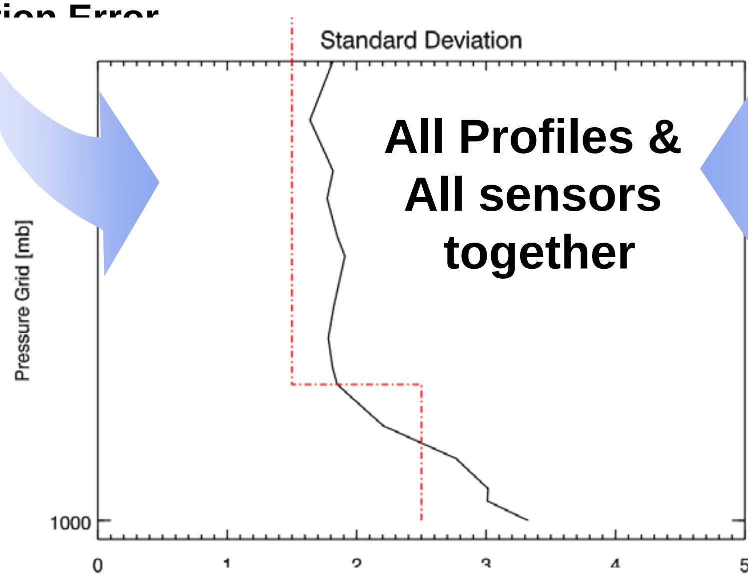
NPOESS IORD-II Requirements



Importance of the Evaluation Set







All Profiles & All sensors together

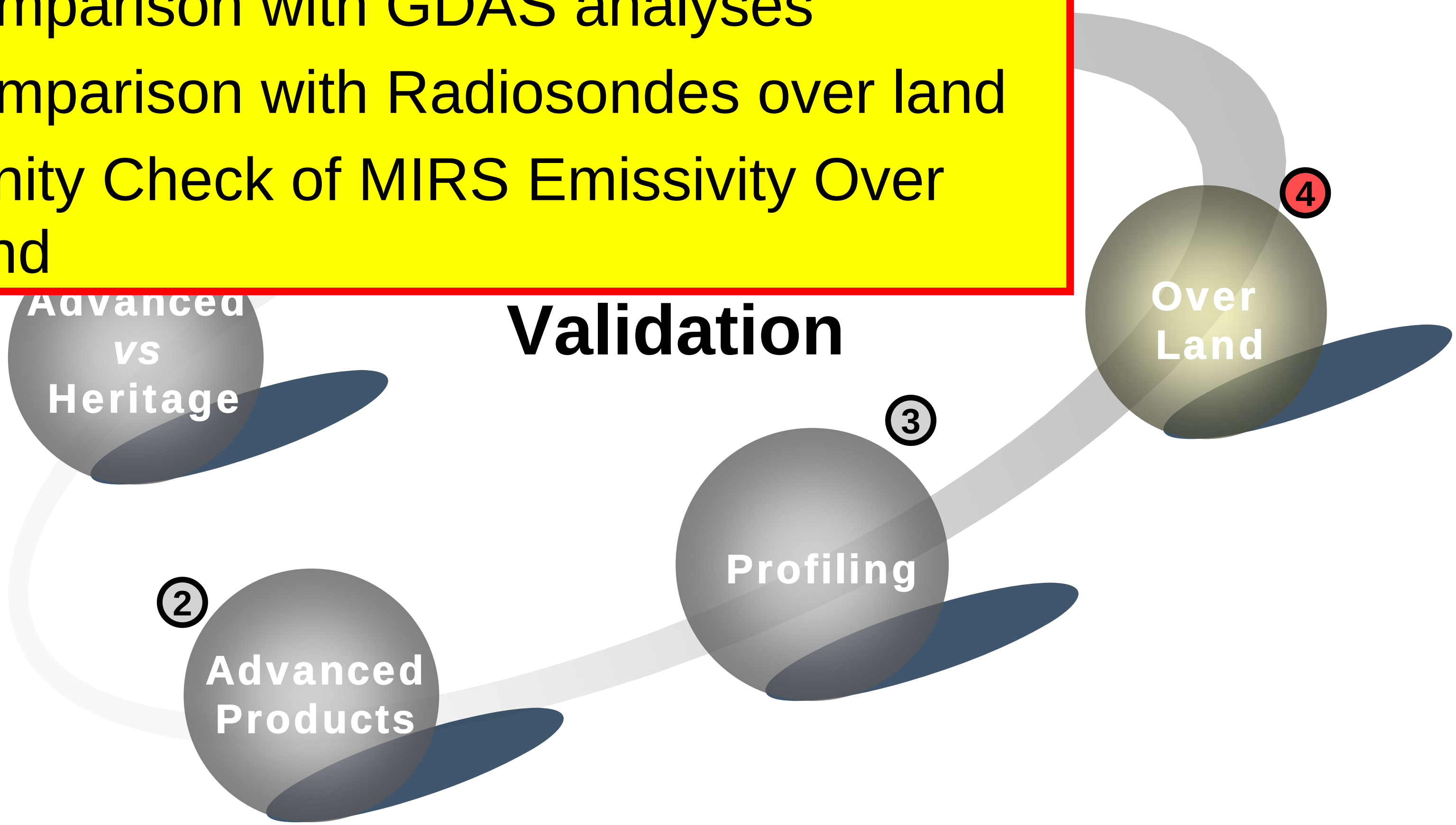
Focus of current efforts:

- **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).

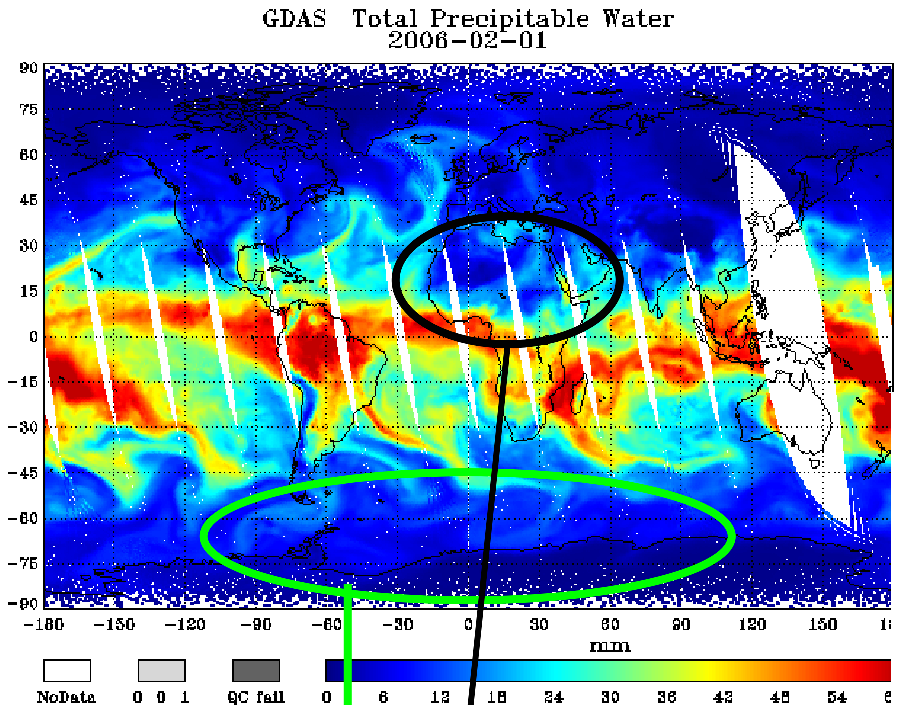
Performance Evaluation

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

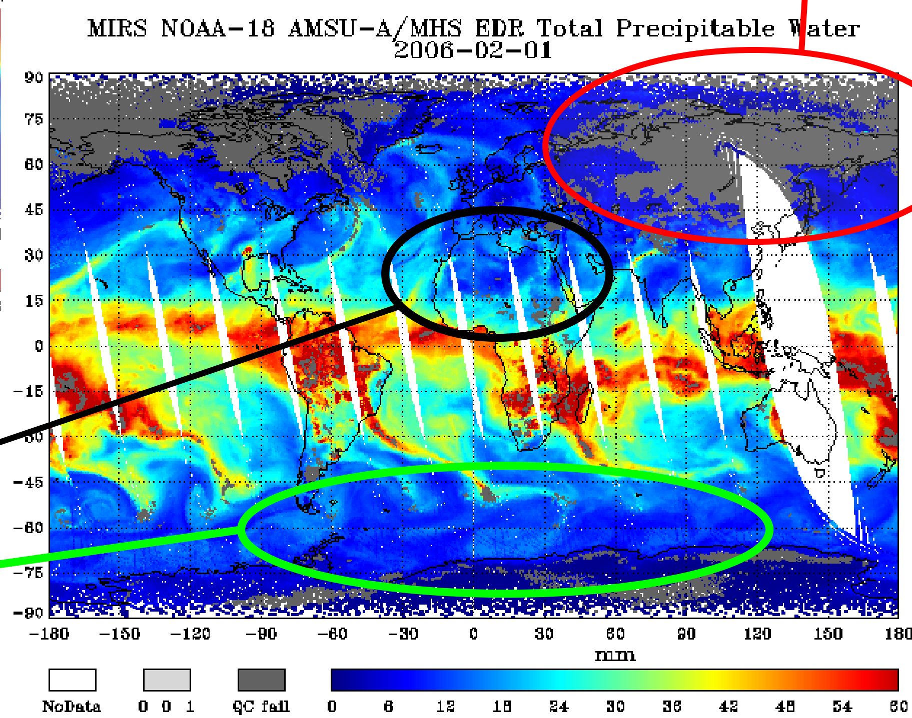


Microwave TPW Extended over Land

snow-covered surfaces need better handling



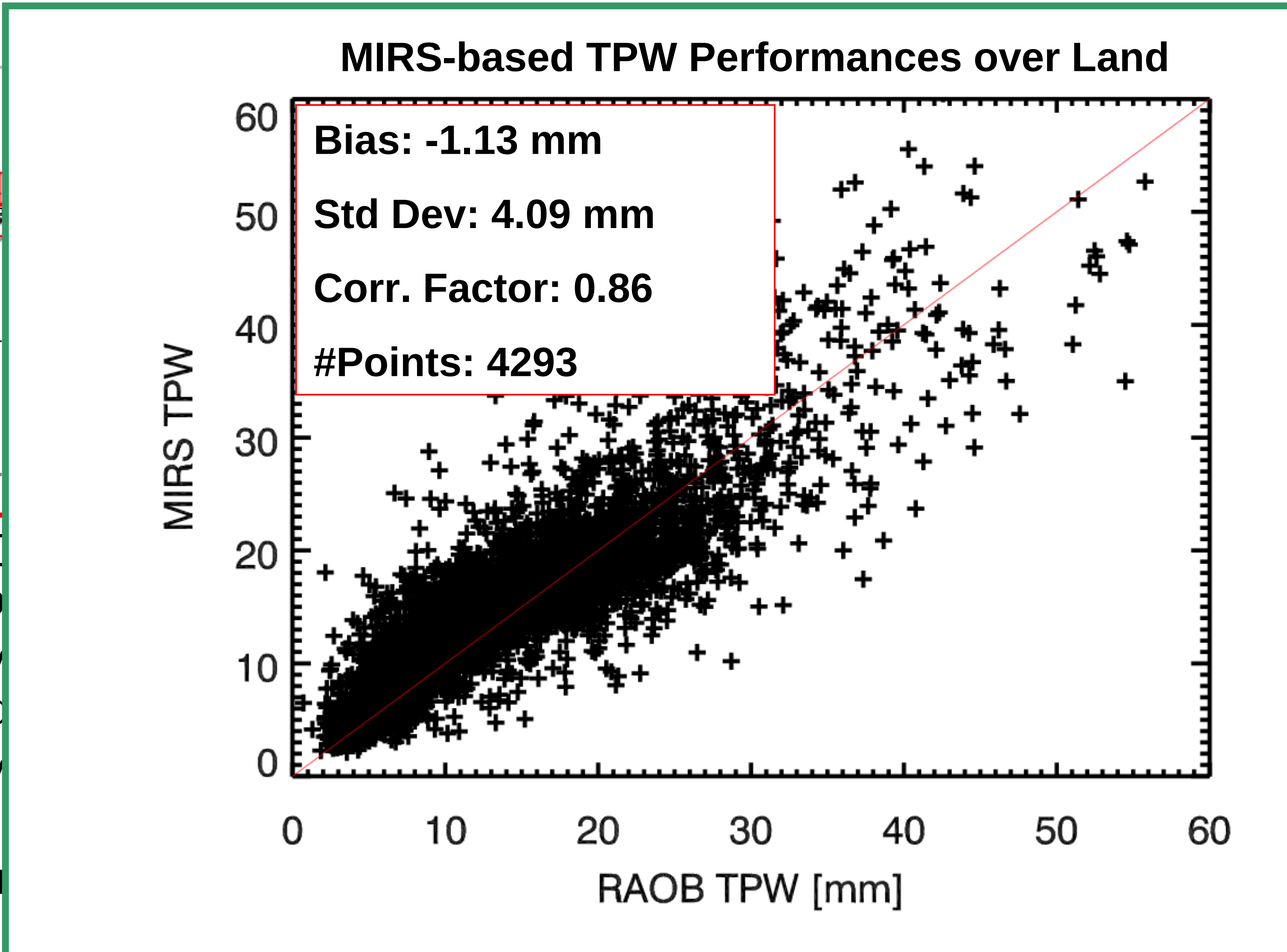
GDAS Analysis

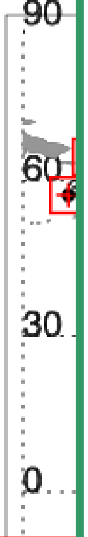


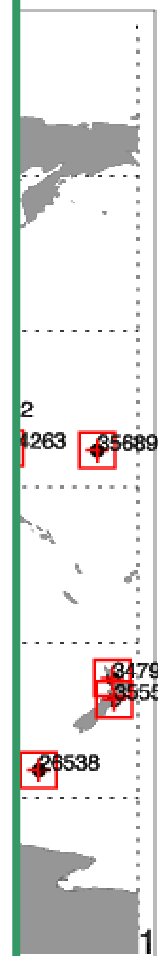
Retrieval over sea-ice and most land areas capturing same features as GDAS

MIRS Retrieval

Validation of TPW Retrieval over Land







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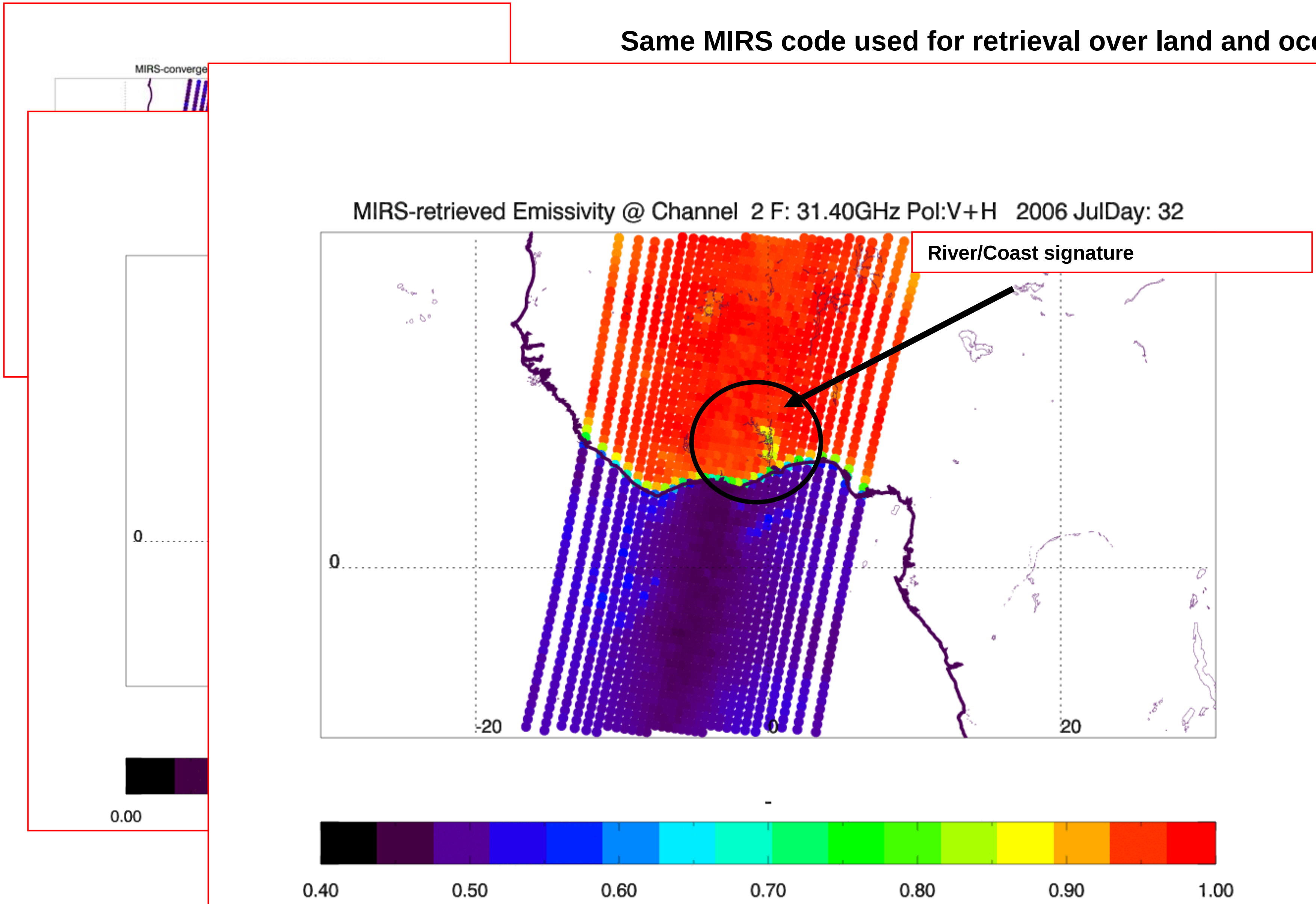
Extension of MIRS Validity Over Land

Same MIRS code used for retrieval over land and ocean.



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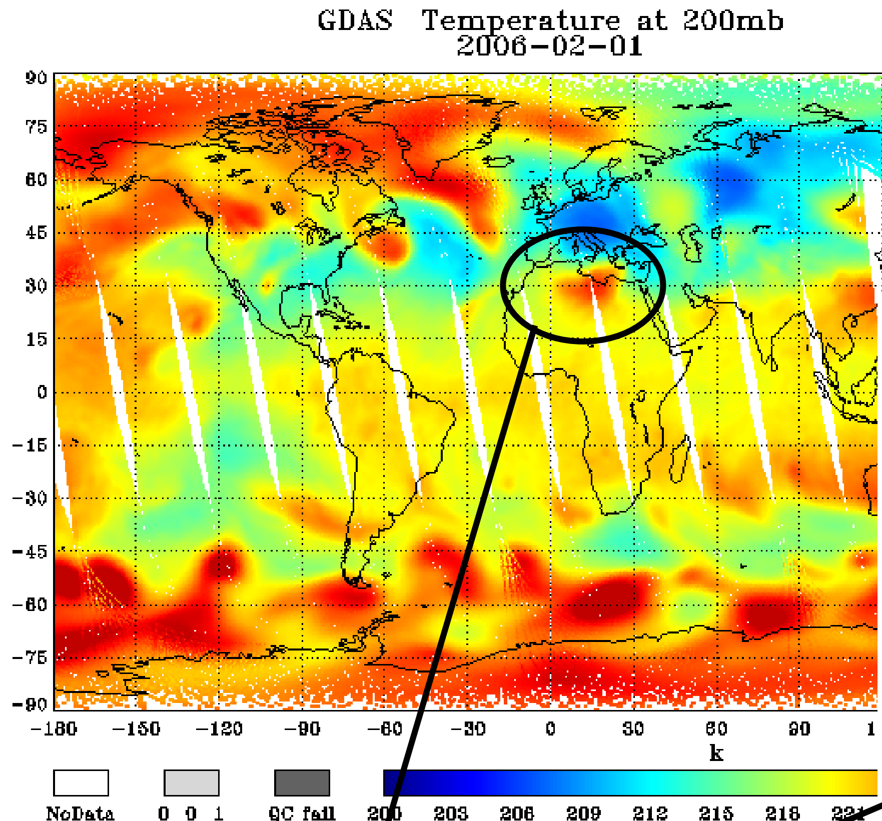
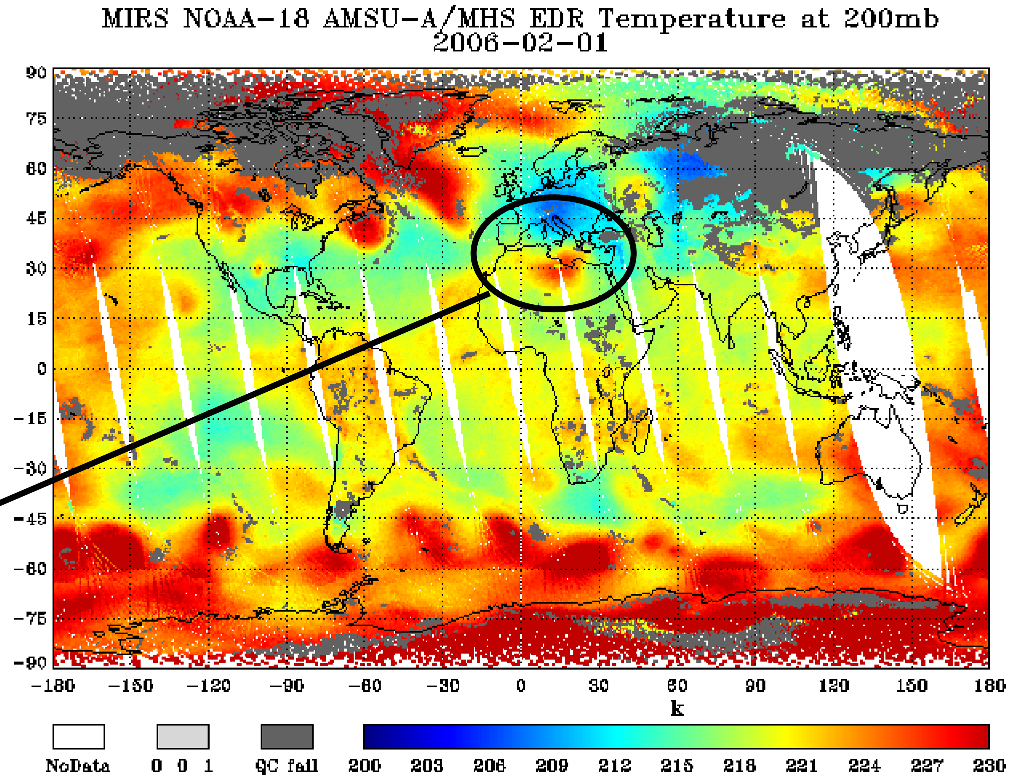
Global Temperature Profiling



No Scan-Dependence in retrieval
Smooth Transition Land/Ocean

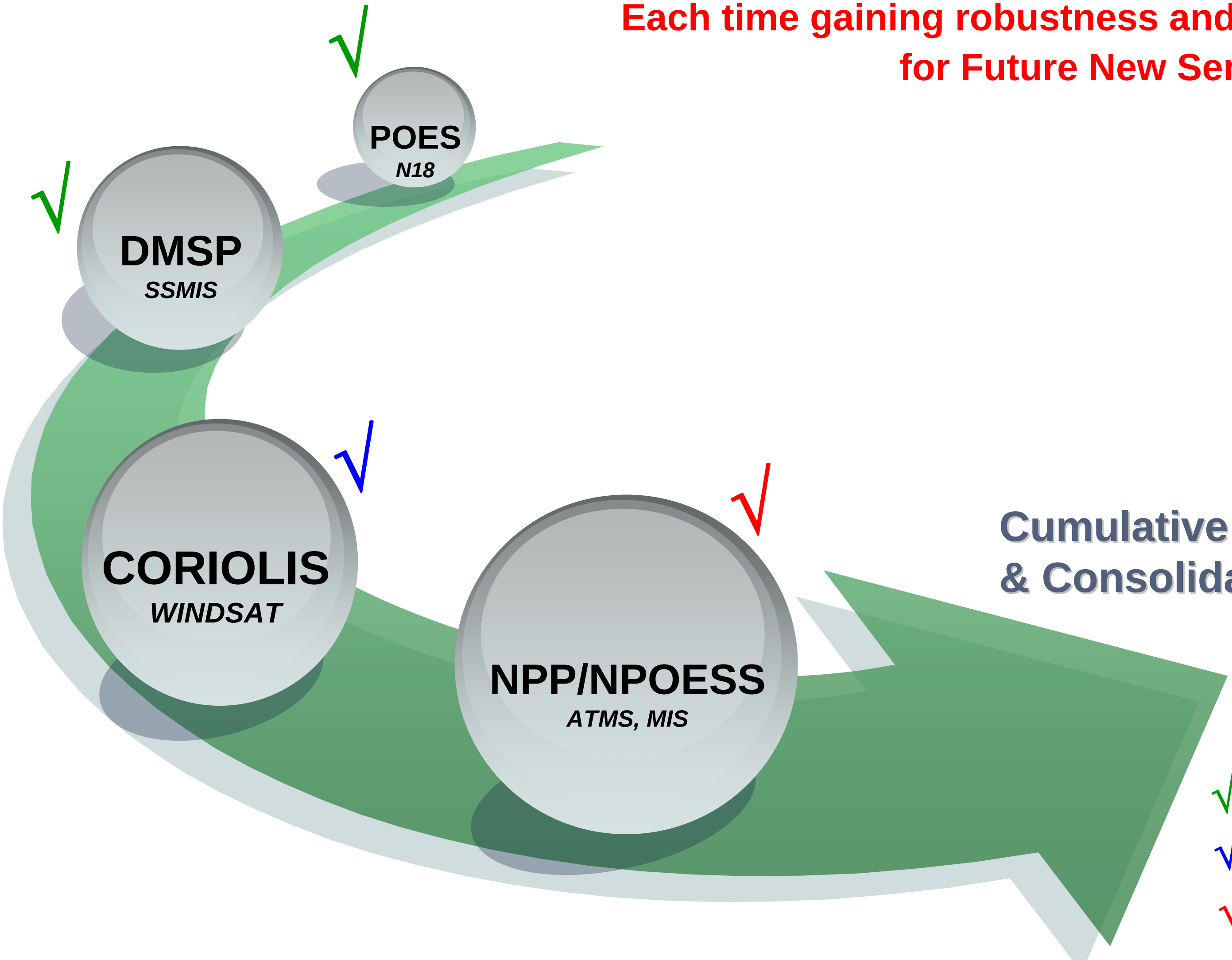
QC-failure is based on convergence:
Focus of on-going work



Similar Features Captured

MIRS Applications

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

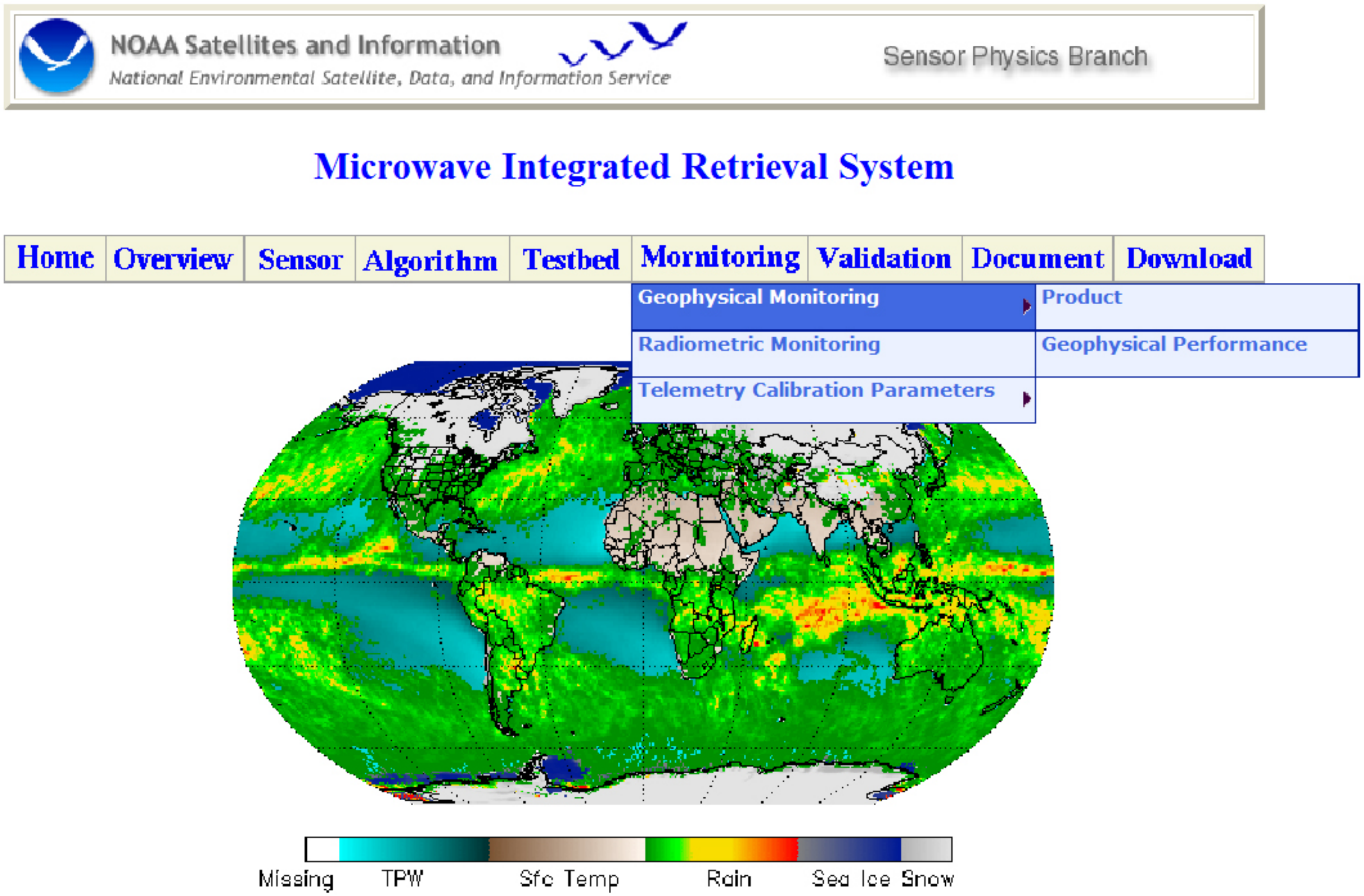


**Cumulative Validation
& Consolidation of MIRS**

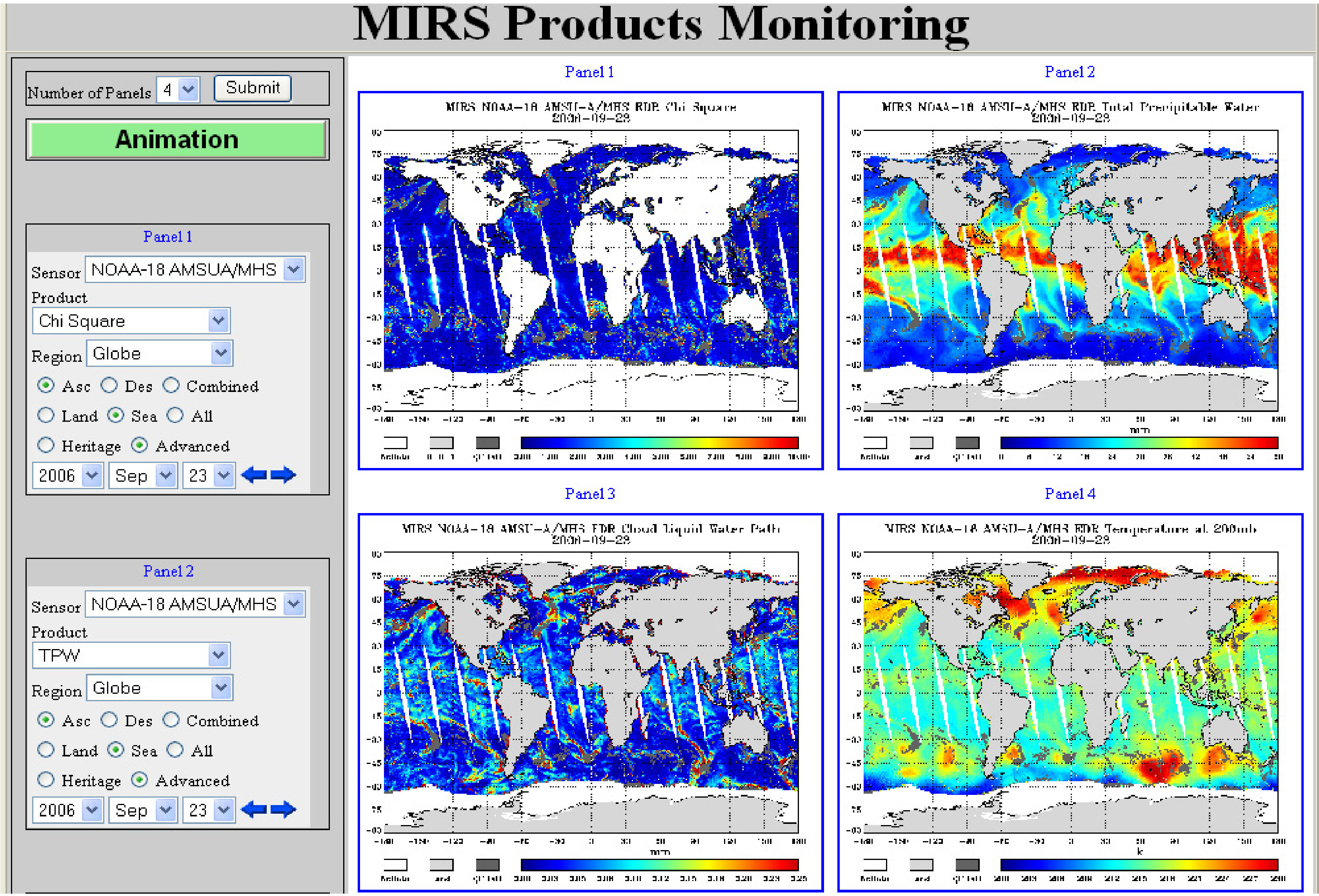
- √: Applied Daily
- √: Applied occasionally
- √: Tested in Simulation

Performance Monitoring – Functionalities

❖ Online Scrolling Menus



Products Performance Monitoring – Functionalities (cont'd)



Thank You !

Questions?

BACKUP SLIDES

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Bayes Theorem (of Joint probabilities)

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

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

=1

I ector X:

Core Retrieval Mathematical Basis

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

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

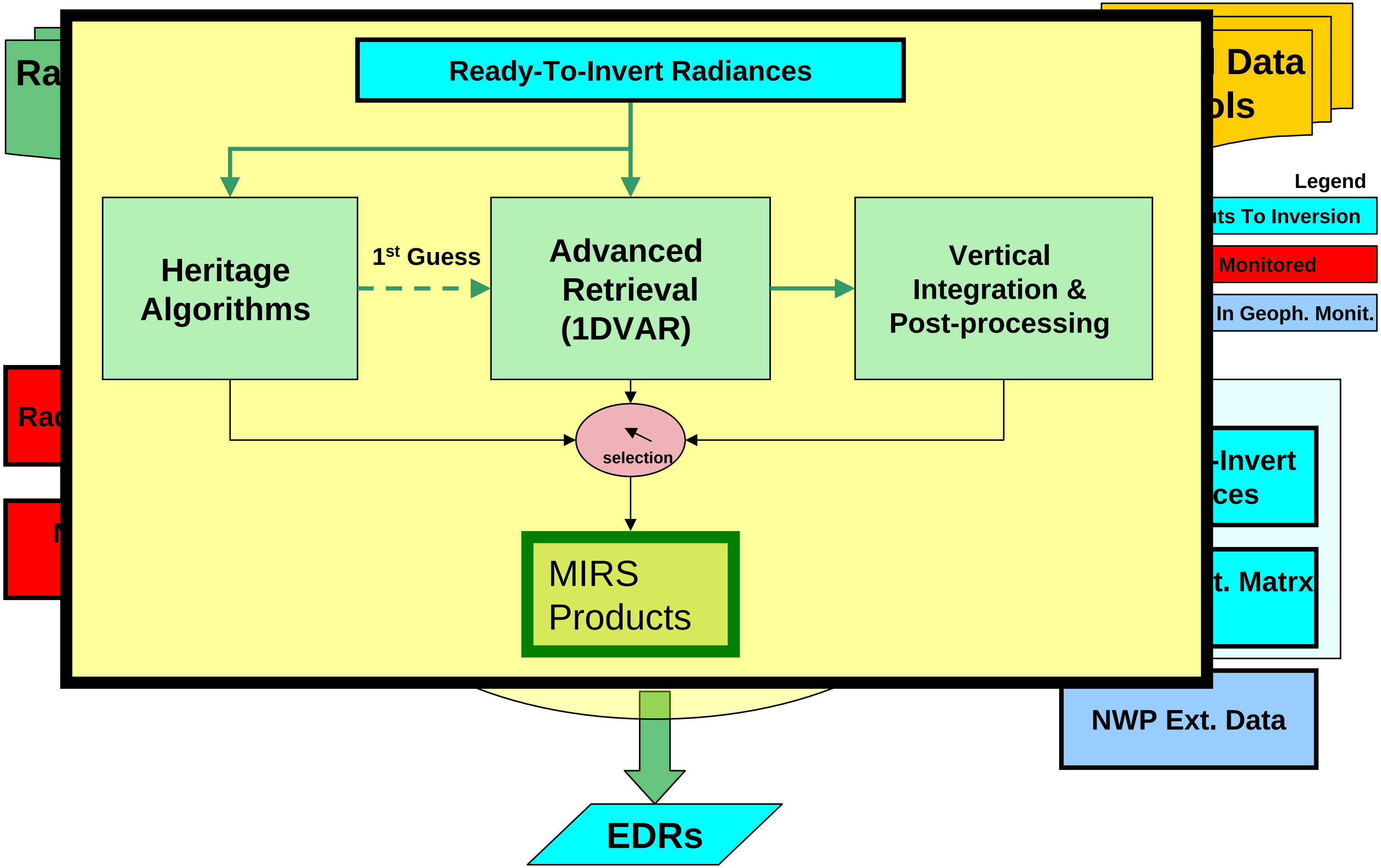
Is Equivalent to Minimizing

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

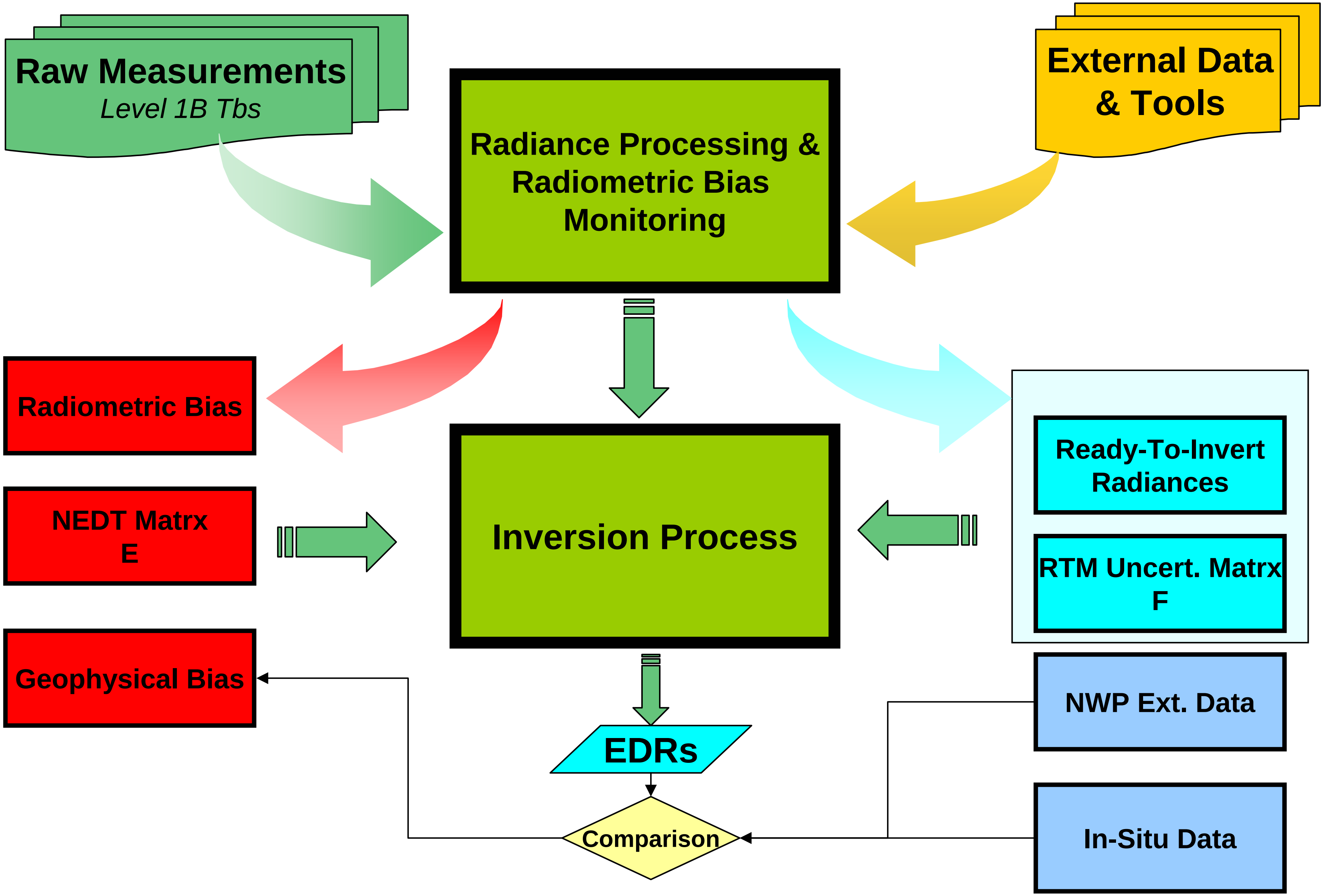
Which amounts to Minimizing J(X) *–also called COST FUNCTION –*
Same cost Function used in 1DVAR Data Assimilation System

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

System Design & Architecture



System Design & Architecture



Nominal approach: Simultaneous Retrieval

F(X) <u>Does not</u> Fit Y^m within Noise

X is <u>not</u> the solution

Necessary Condition (but not sufficient)

F(X) <u>Fits</u> Y^m within Noise levels

X is <u>a</u> solution

X is <u>the</u> 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

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

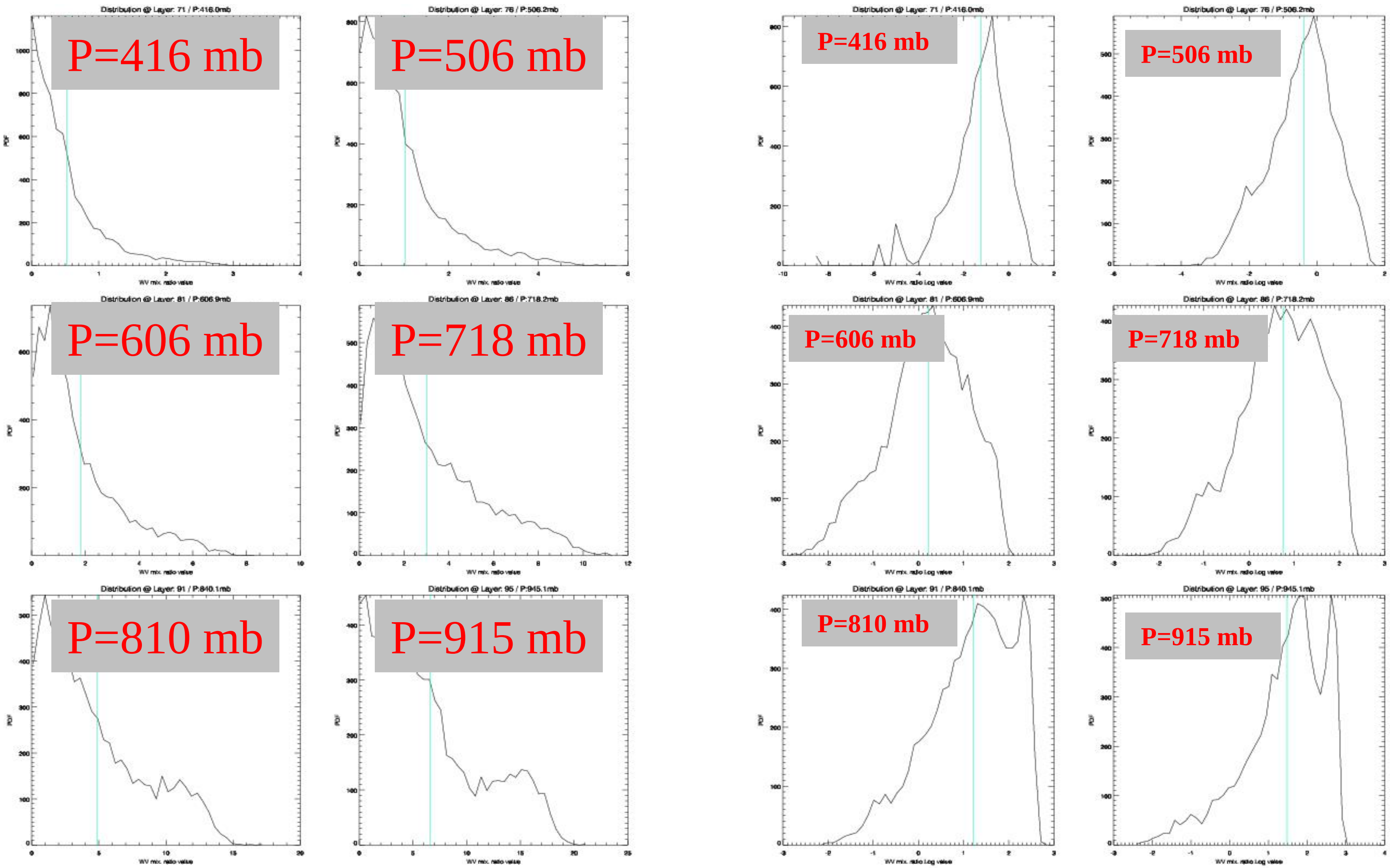
Diagonal Matrix
(used in reduced space retrieval)

Transf. Matrx
(computed offline)

Covariance matrix
(geophysical space)

Retrieval in Logarithm Space

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



Applied to WV, Cloud and precip

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

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

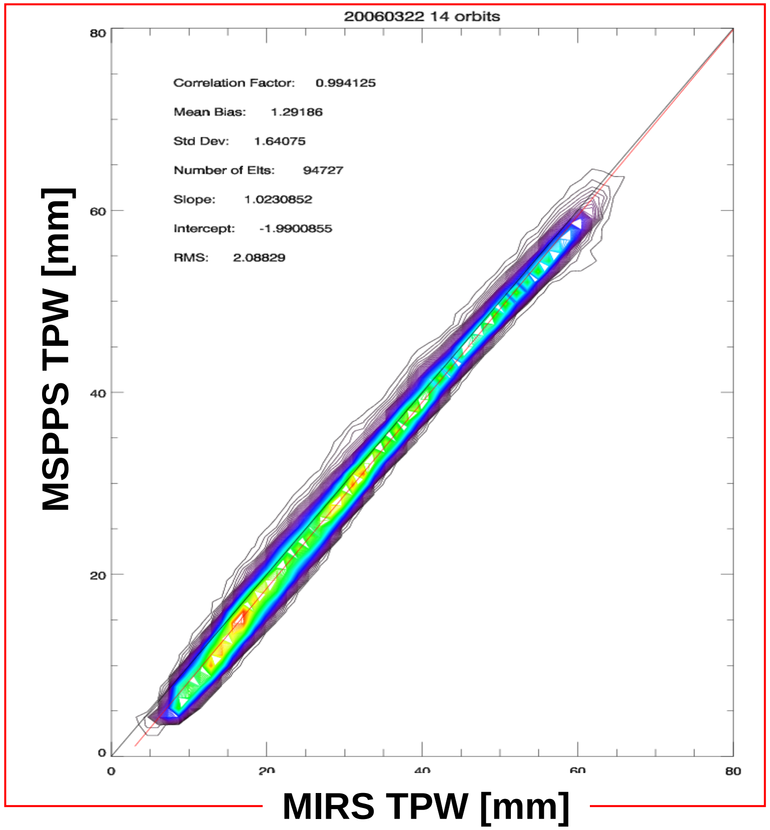
Two Types of Validation, depending on parameter

- 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

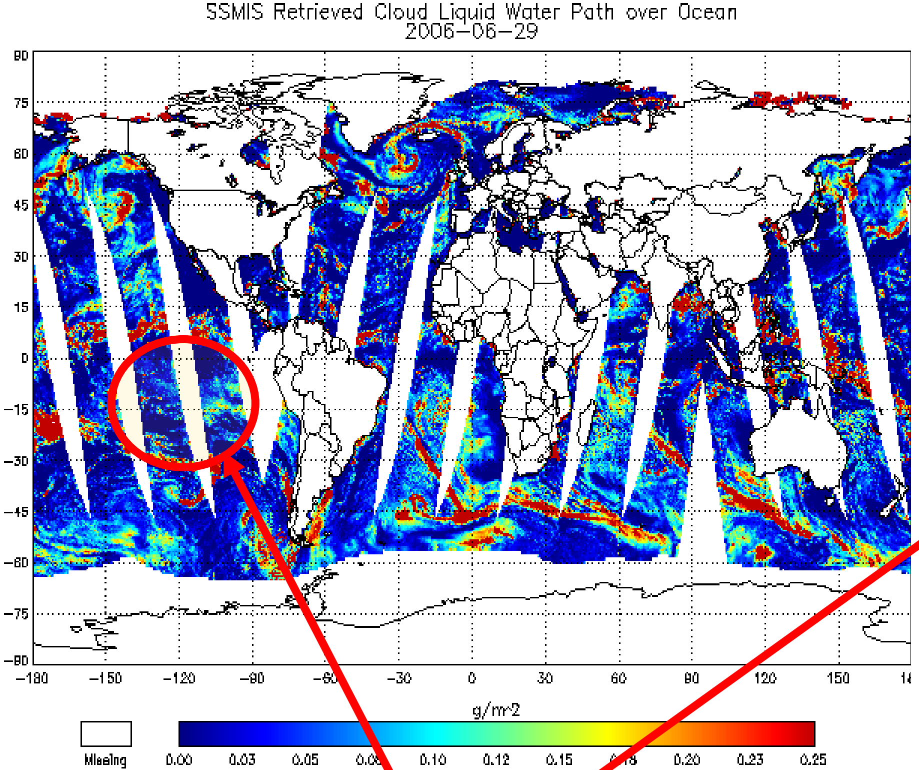
- MIRS retrieves the humidity profile. The TPW is integrated in post-processing stage.

- MSPPS relies on NWP forecast for both SST and Wind (emissivity).

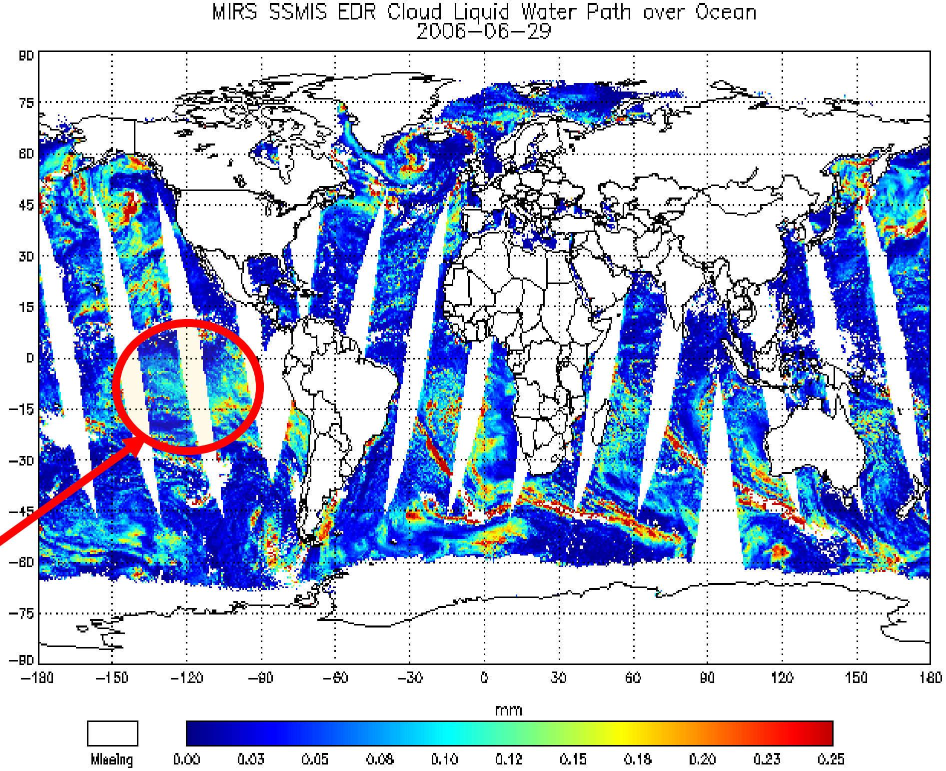
- MIRS is independent of NWP data (even from surface pressure).

Cloud Retrieval Using SSMI/S

FNMOC Operational Algorithm



MIRS Algorithm

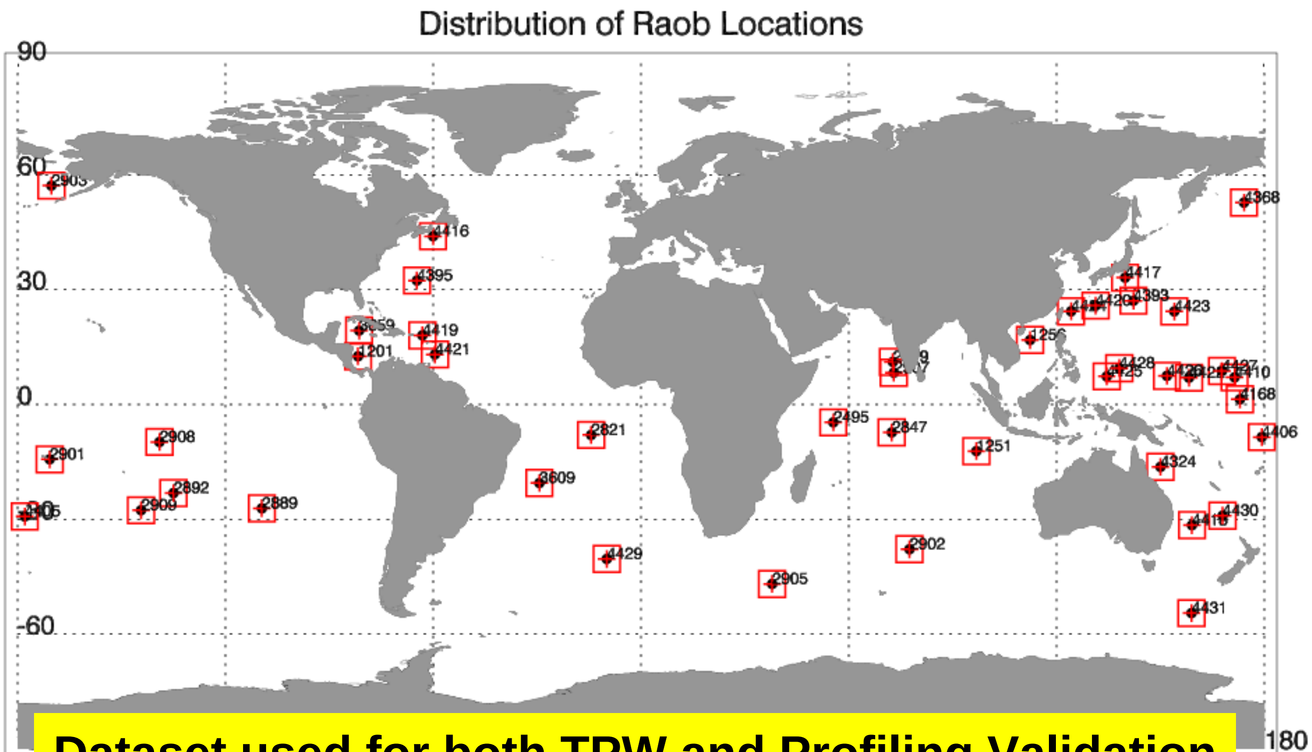


MIRS is more sensitive to small values (due to use of higher frequency channels)

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



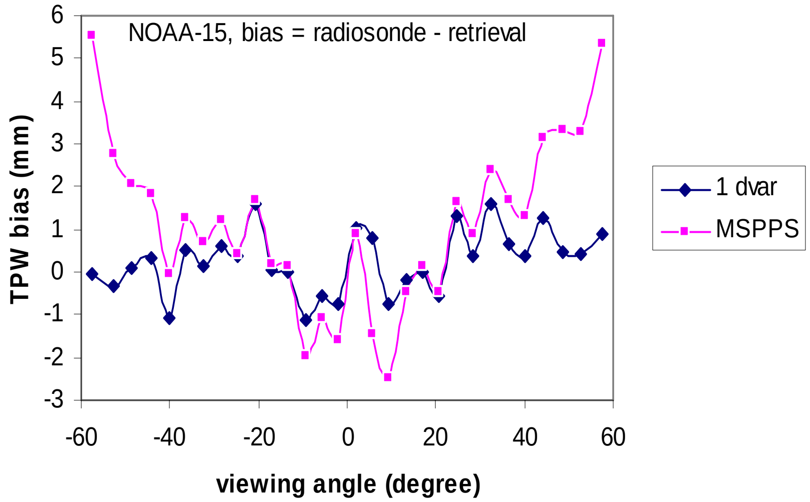
Dataset used for both TPW and Profiling Validation

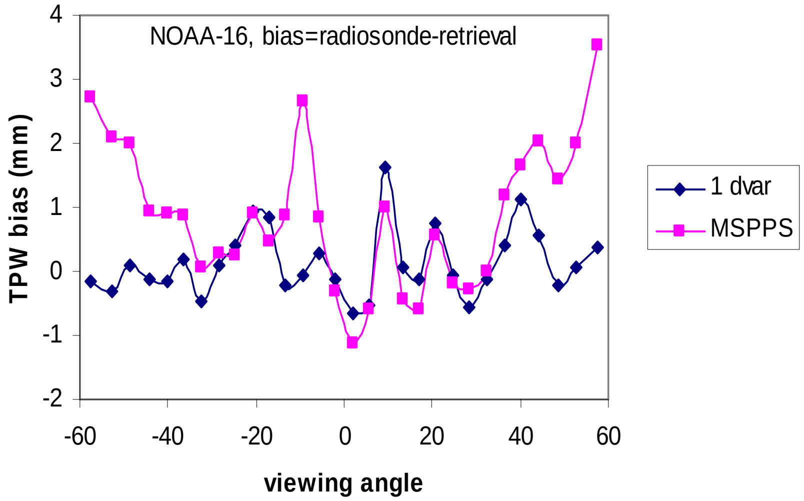
Retrieval Bias vs. Viewing Angles

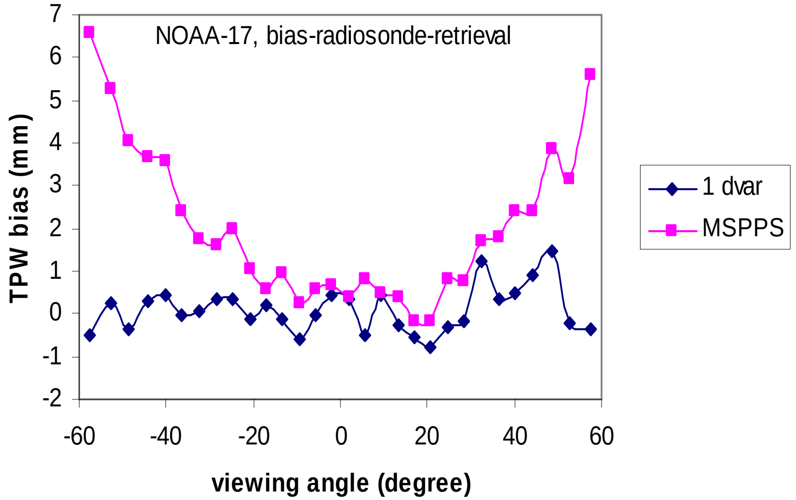
Match-up TPW from radiosondes and AMSU retrieval in 2002.

Bias variation to viewing angles.

Bias = radiosonde – AMSU

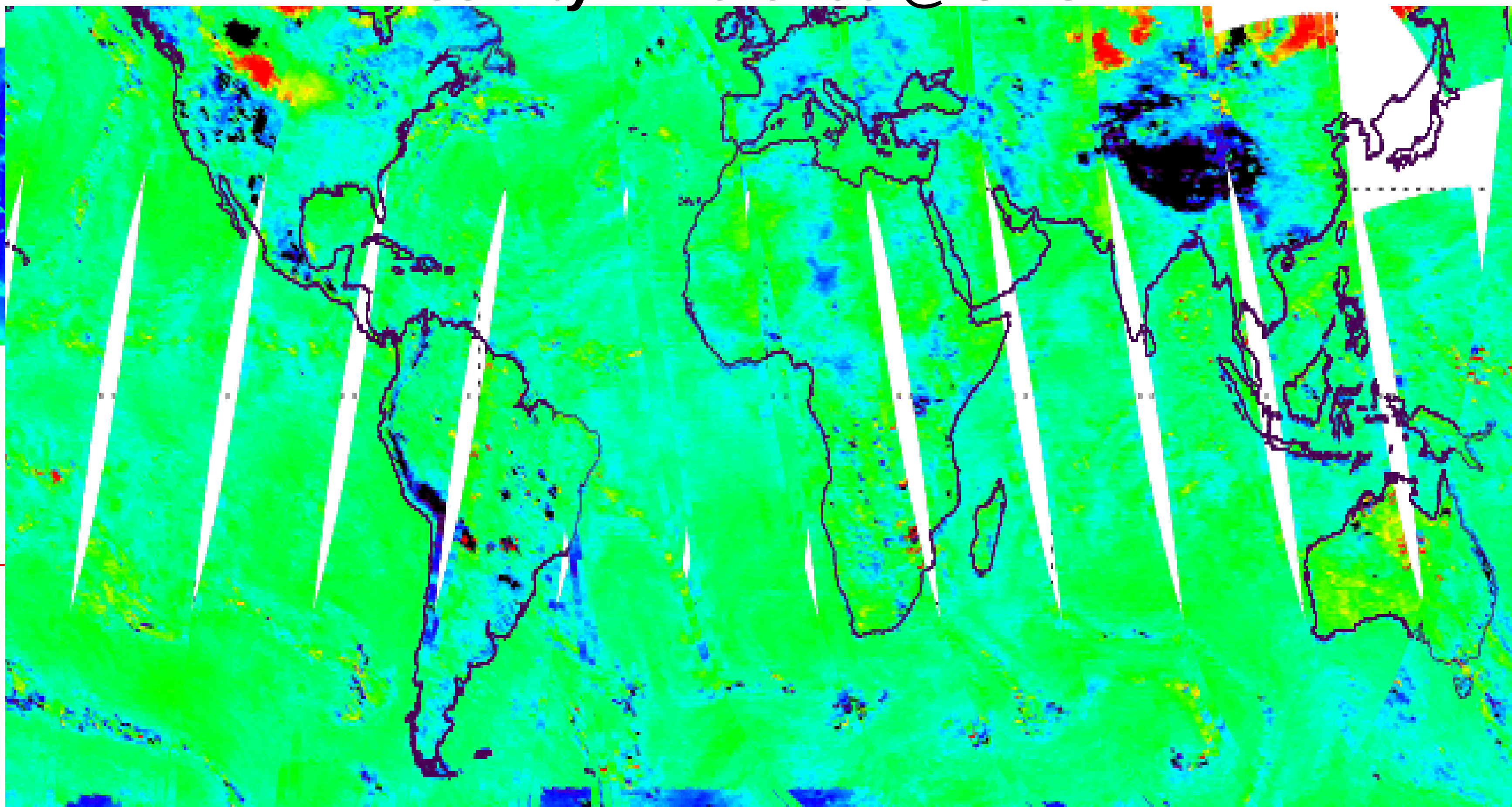






Emissivity Qualitative Validation

Emissivity Difference @ 31 GHz



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

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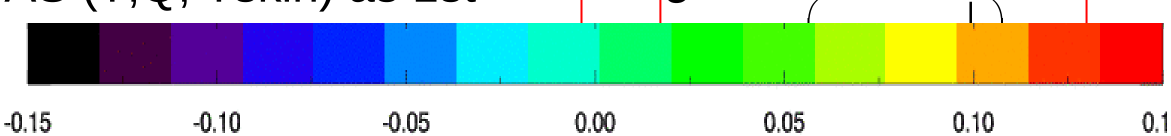

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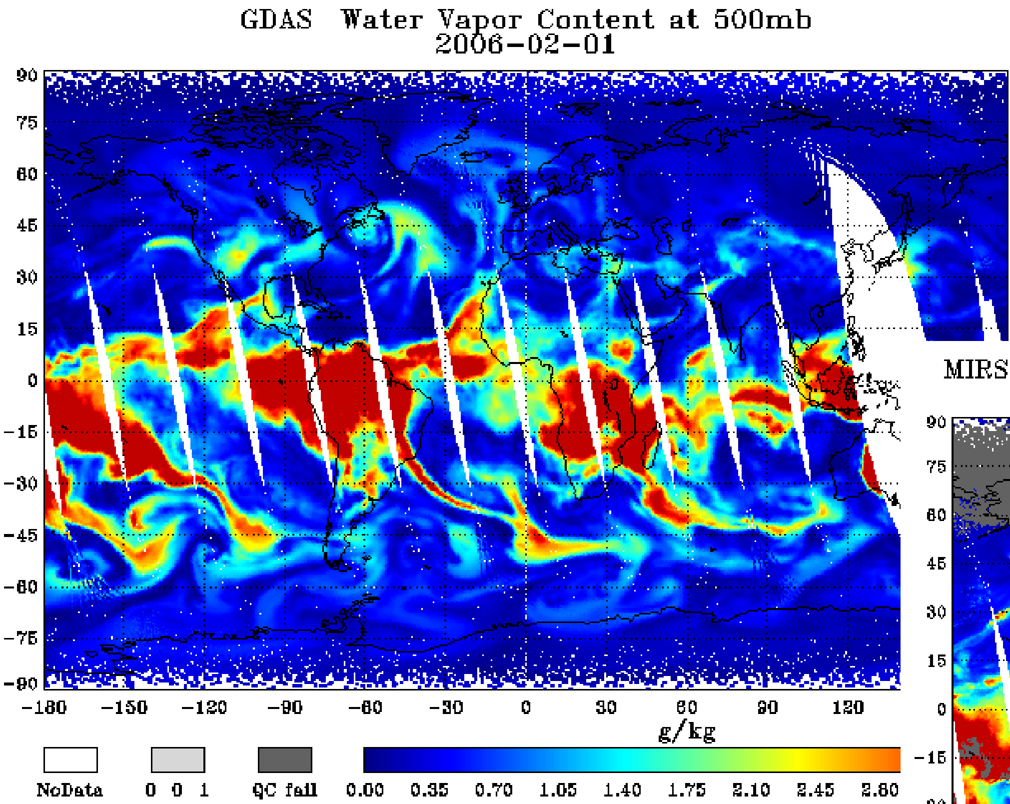
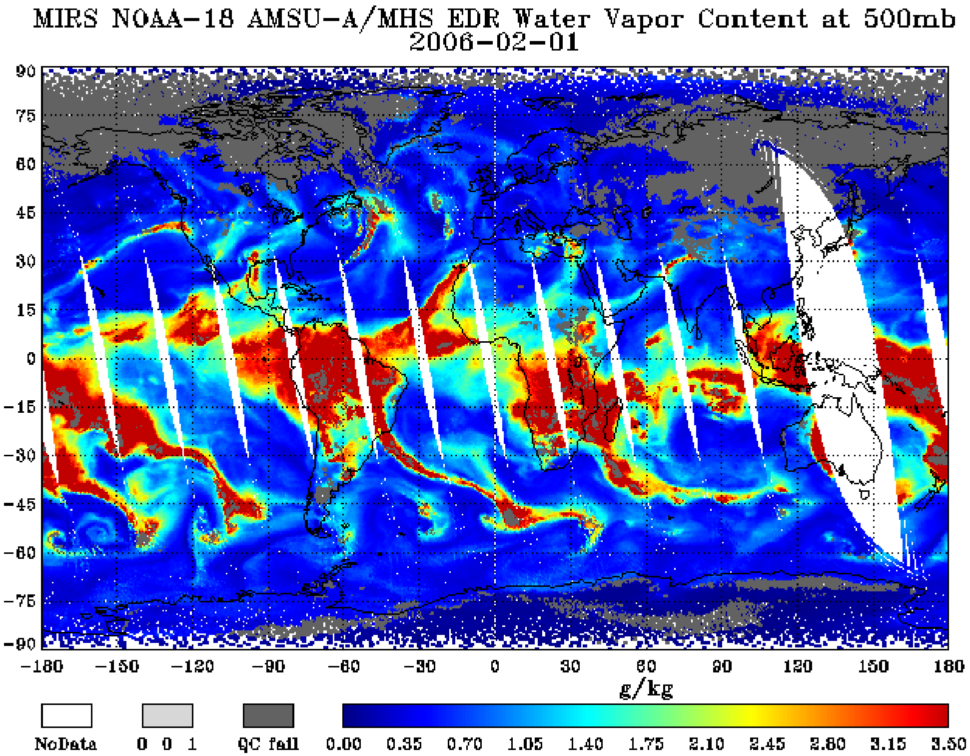
Global Humidity Profiling

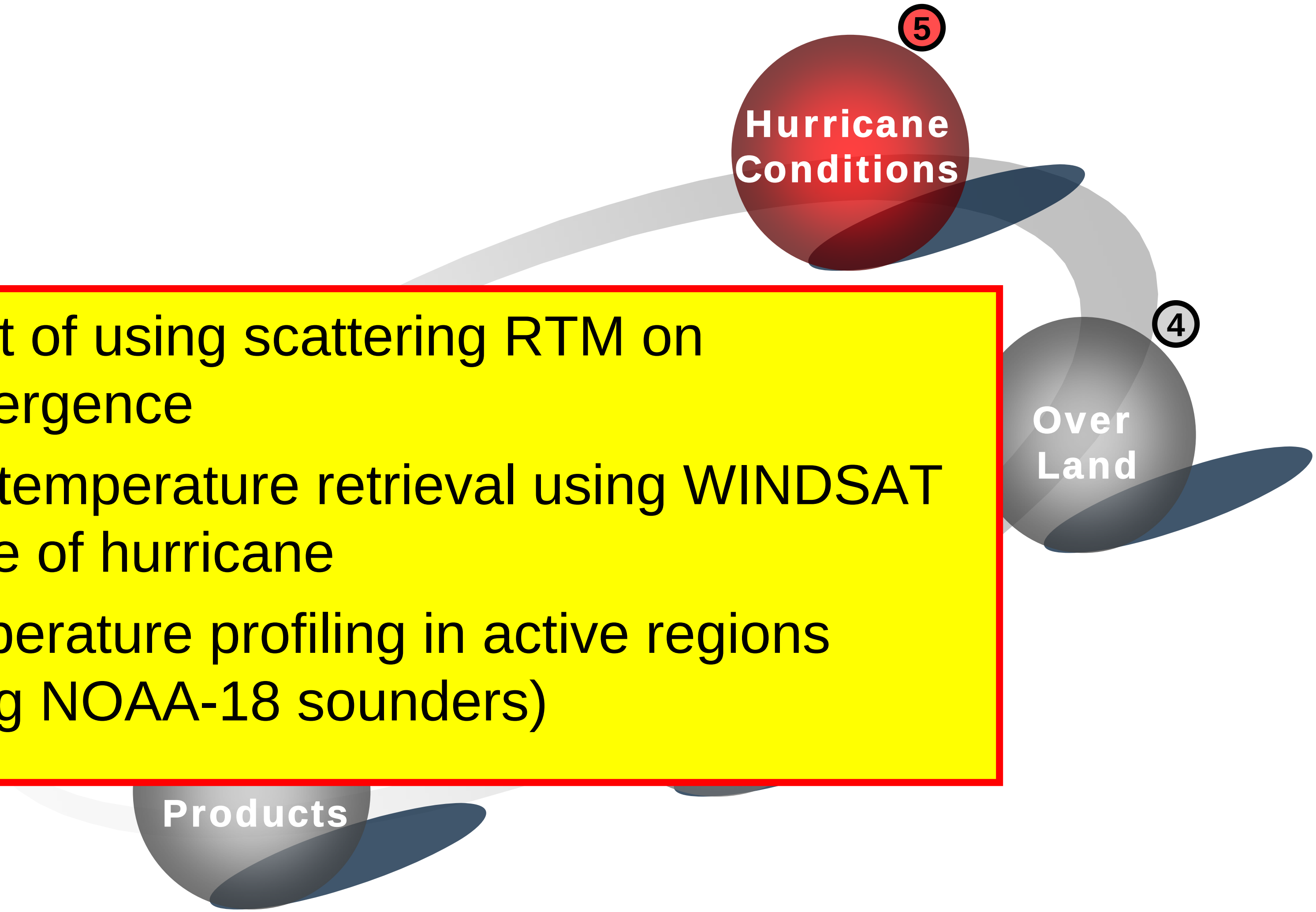


No Scan-dependence noticed: Angle dependence properly accounted for



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)

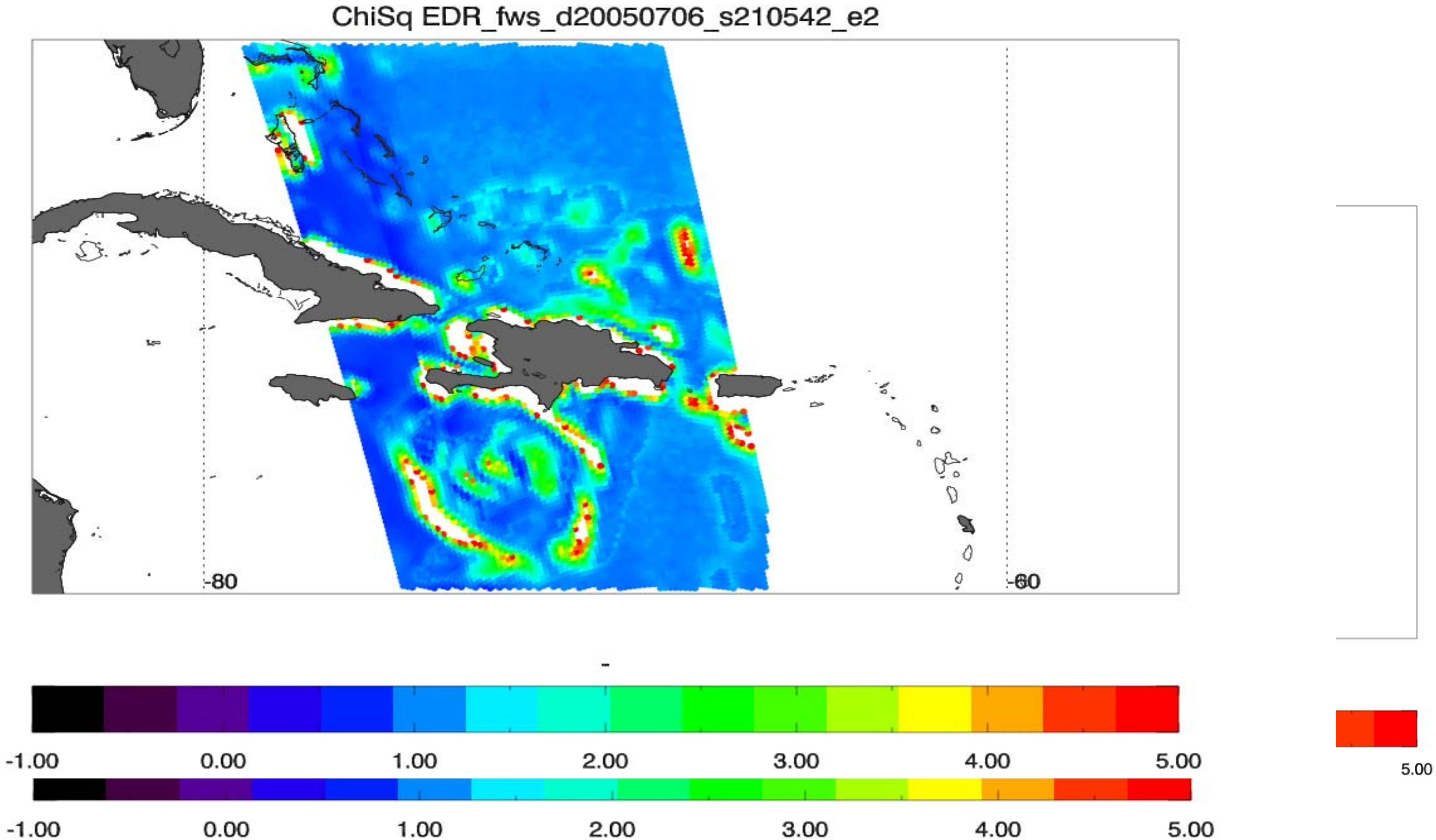


WINDSAT Retrieval (Chi Square)

Rain Model OFF

Rain Model ON

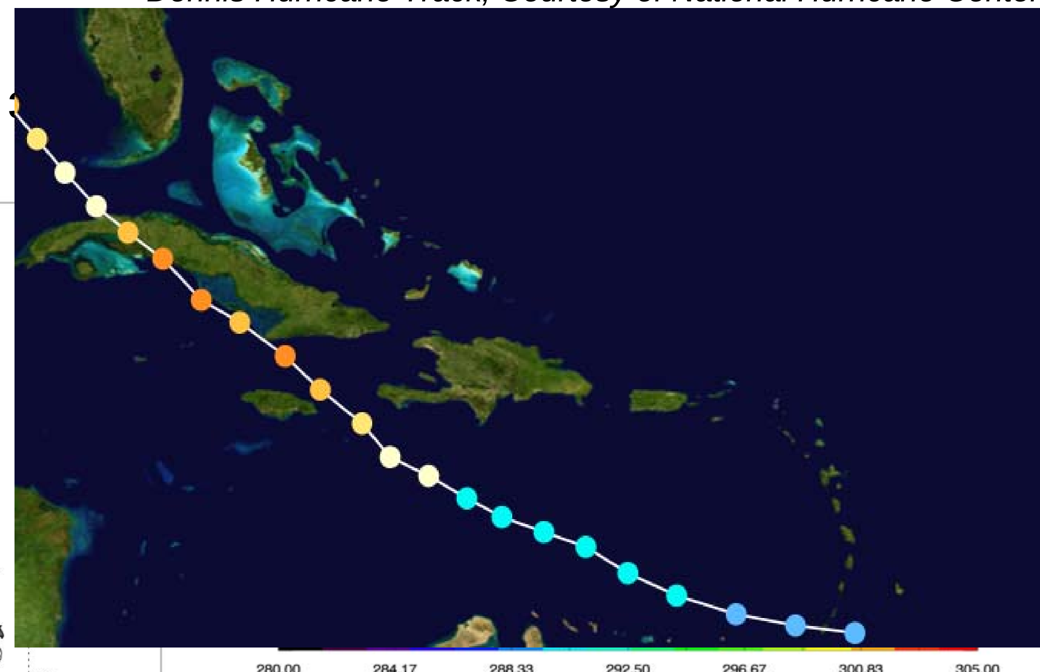
Retrieval using Windsat data (sdr68)
Spatial resolution of 6.8 GHz (50 kms)
But with a lot of oversampling



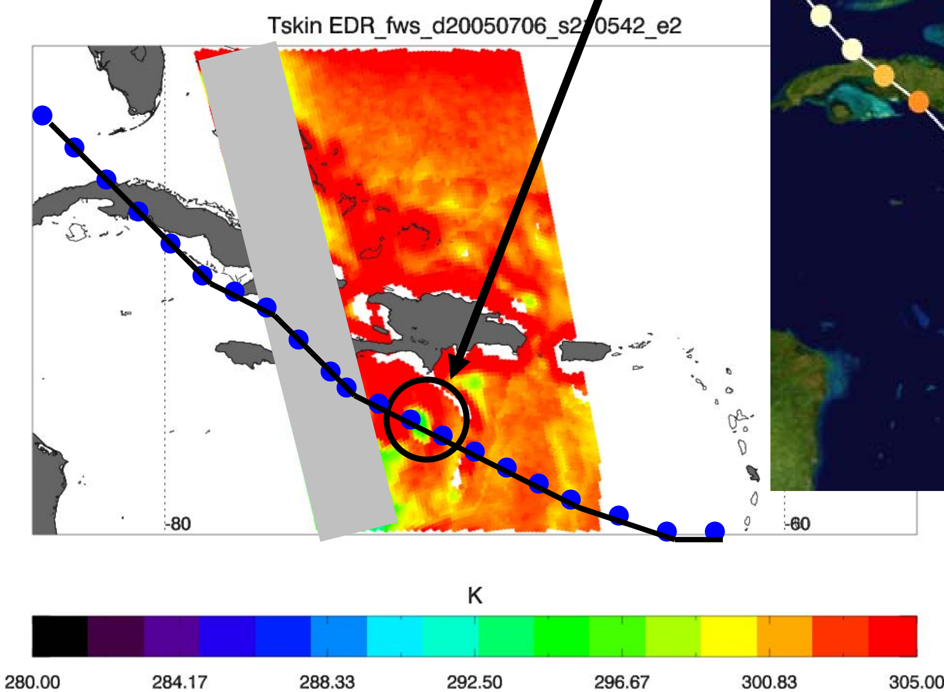
SST Retrieval In Hurricane Conditions

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

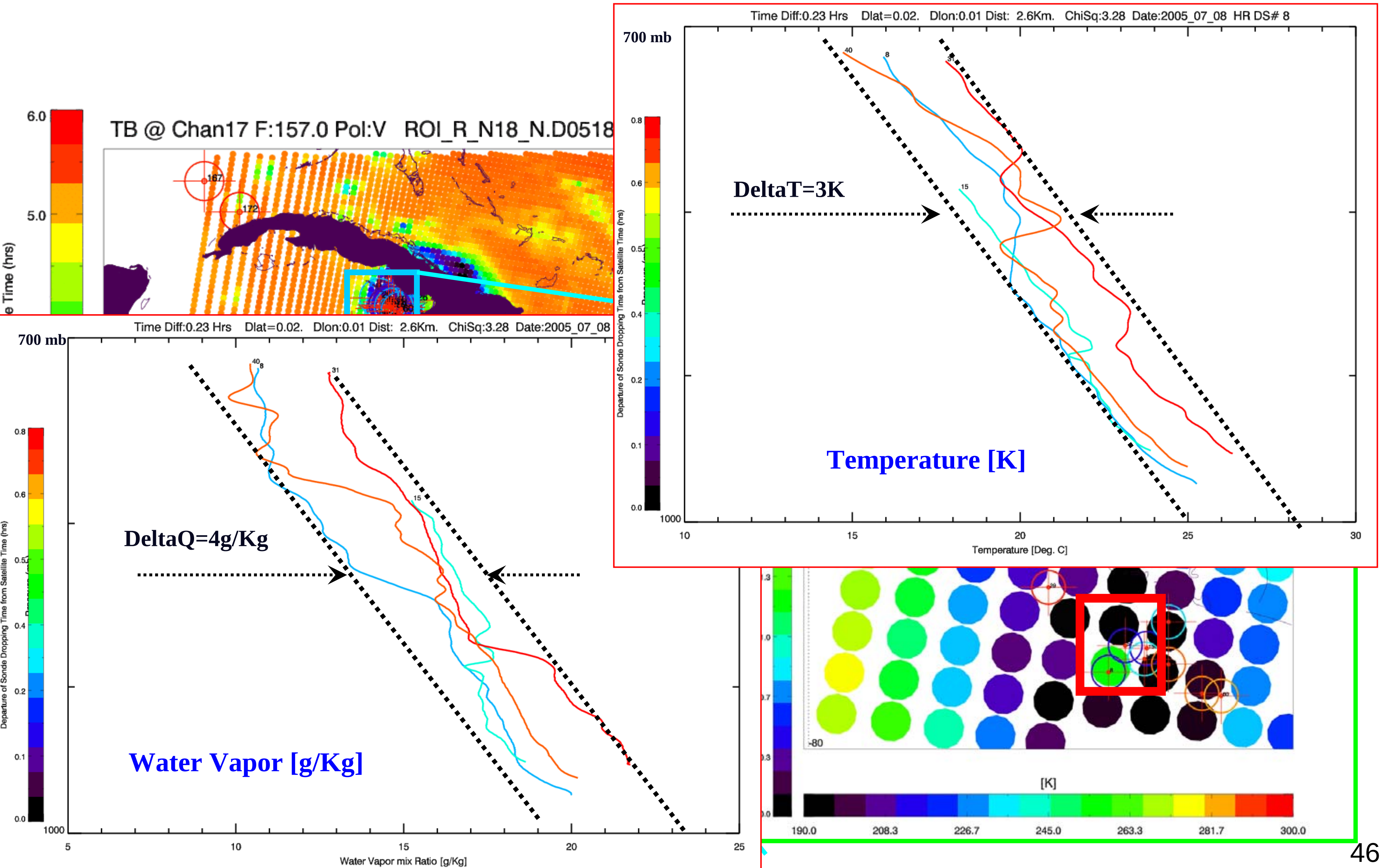
Dennis Hurricane Track, Courtesy of National Hurricane Center



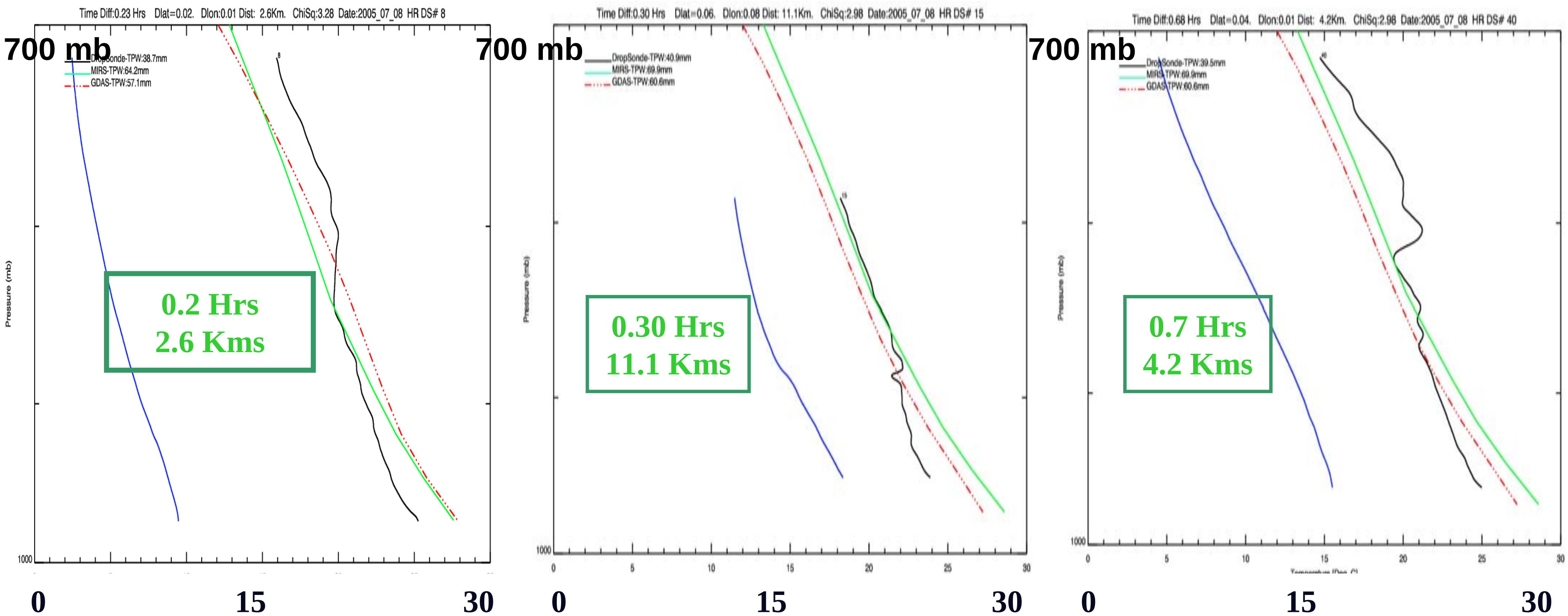
MIRS SST Retrieval Using WINDSAT (Frq 6 to 3



Challenges of Profiling in Active Areas



N-18 Profiling In Active Areas



[Deg. C]
[Kms]

Retrieval
GDAS
DropSonde
Profile of DS Distance Departure