Variational Inversion of Hydrometeors Using Passive Microwave Sensors

-Application to AMSU/MHS, SSMIS and ATMS-

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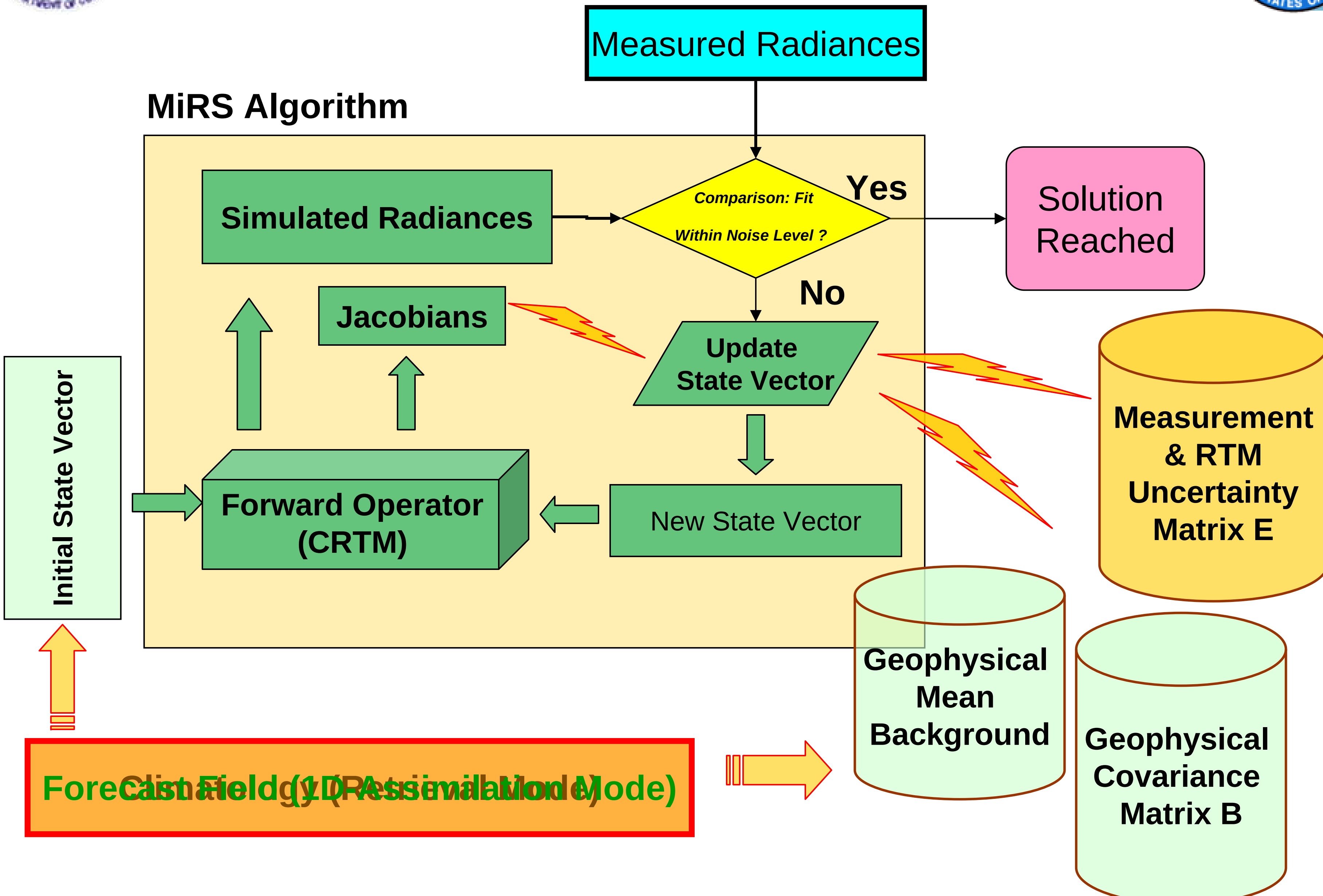
Contents

1D-Variational Retrieval/Assimilation



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

Parameters are Retrieved Simultaneously

If X is the set of parameters that impact the radiances Ym, and F the Fwd Operator

If 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

Suggests it is not recommended to use independent algorithms for different parameters, since they don't guarantee the fit to the radiances

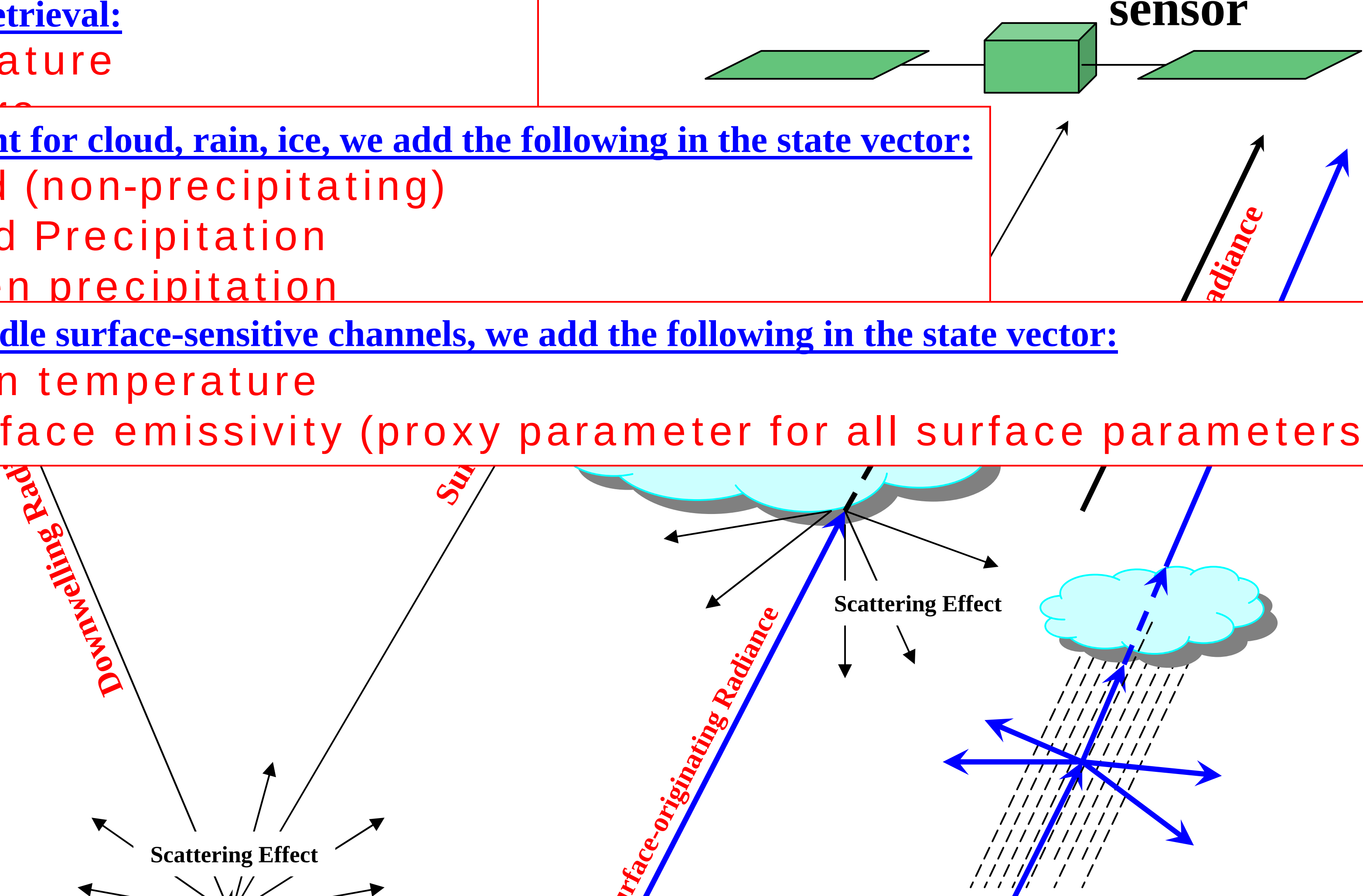
Contents

All-Weather and All-Surfaces

Sounding Retrieval:
- Temperature
- Moisture

To account for cloud, rain, ice, we add the following in the state vector:
- Cloud (non-precipitating)
- Liquid Precipitation
- Frozen precipitation

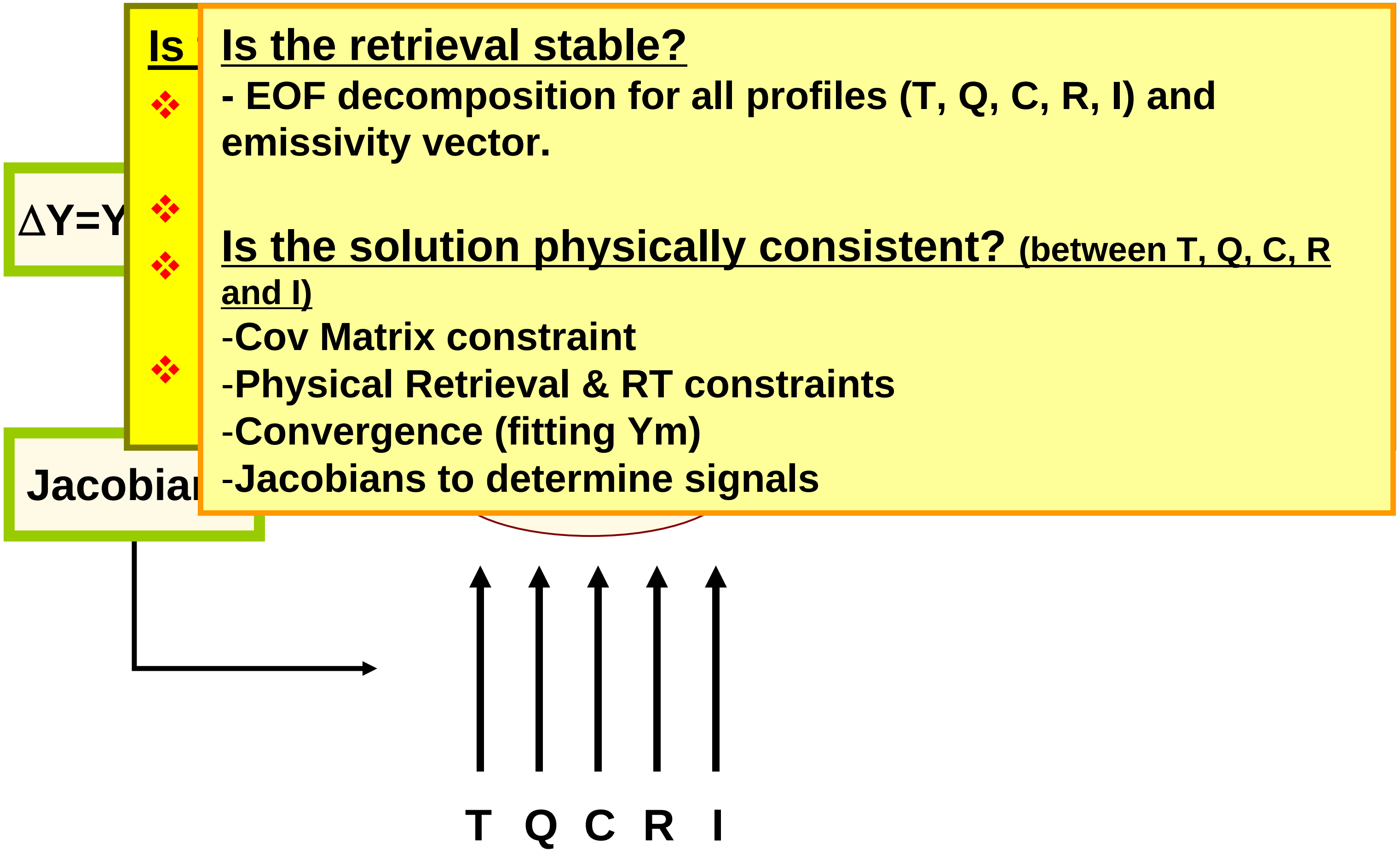
To handle surface-sensitive channels, we add the following in the state vector:
- Skin temperature
- Surface emissivity (proxy parameter for all surface parameters)



- ❖ **Instead of guessing and then removing the impact of cloud and rain and ice on TBs (very hard), MiRS approach is to account for cloud, rain and ice within its state vector.**
- ❖ **It is highly non-linear way of using cloud/rain/ice-impacted radiances.**

All-Weather: Cloud/Precip-Clearing

- Instead of guessing impact of cloud and rain and ice on TBs (very hard), MiRS approach is to account for cloud, rain and ice within its state vector.
- Advantages:
  - It is highly non-linear way of using cloud/rain/ice-impacted radiances
  - Does not rely on cloud or rain uniform distribution
  - Does not rely on cloud resolving models (added uncertainty, need to linearize, speed cost, etc)
- Disadvantage:
  - Results depend on assumptions made in RT (particle size, distribution, etc)
  - Greater reliance on a robust, valid covariance matrix (flow dependent matrix becomes necessary: see poster by K. Garrett).



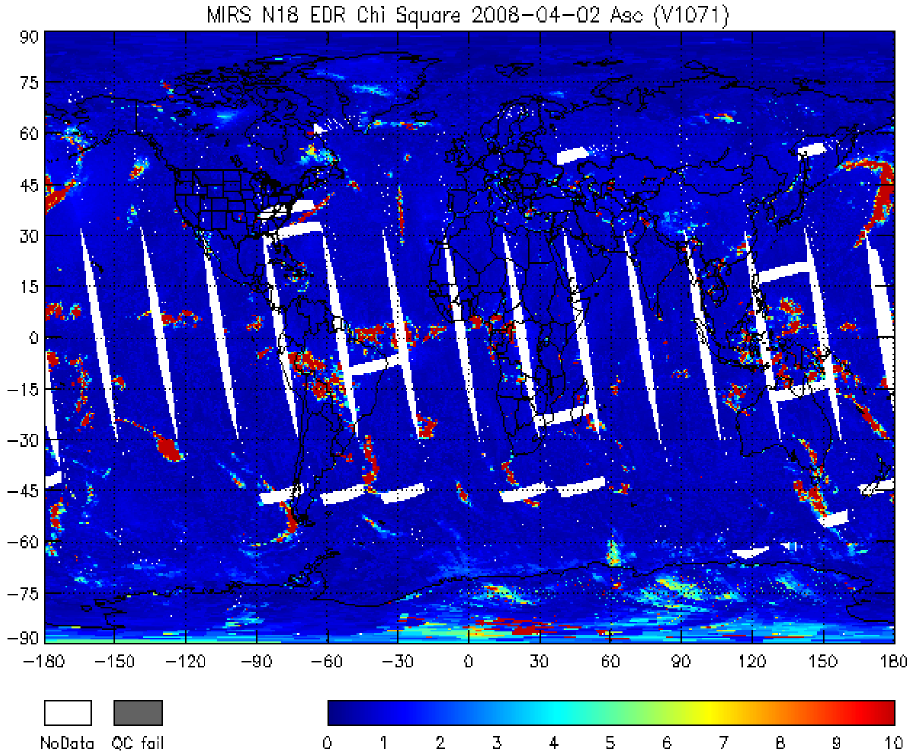
Solution-Reaching: Convergence

- Convergence is reached everywhere: all surfaces, all weather conditions including precipitating, icy conditions
- A radiometric solution (whole state vector) is found even when precip/ice present. With CRTM physical constraints.

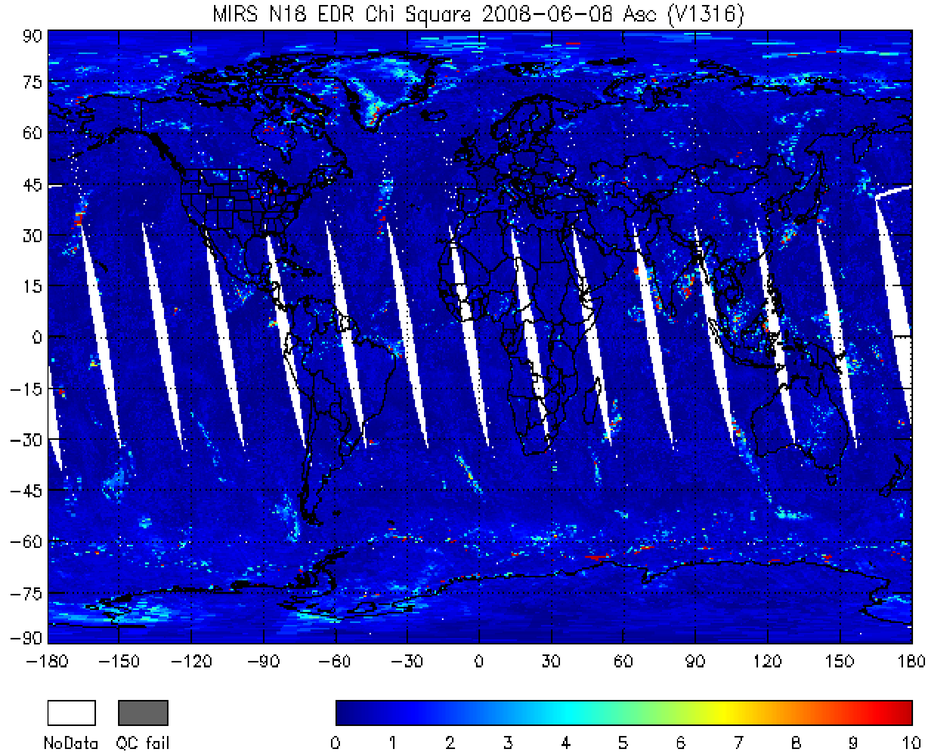
$$\varphi^2 = \left(Y^m - Y(X)\right)^T \times E^{-1} \times \left(Y^m - Y(X)\right)$$

Previous version

(non convergence when precip/ice present)

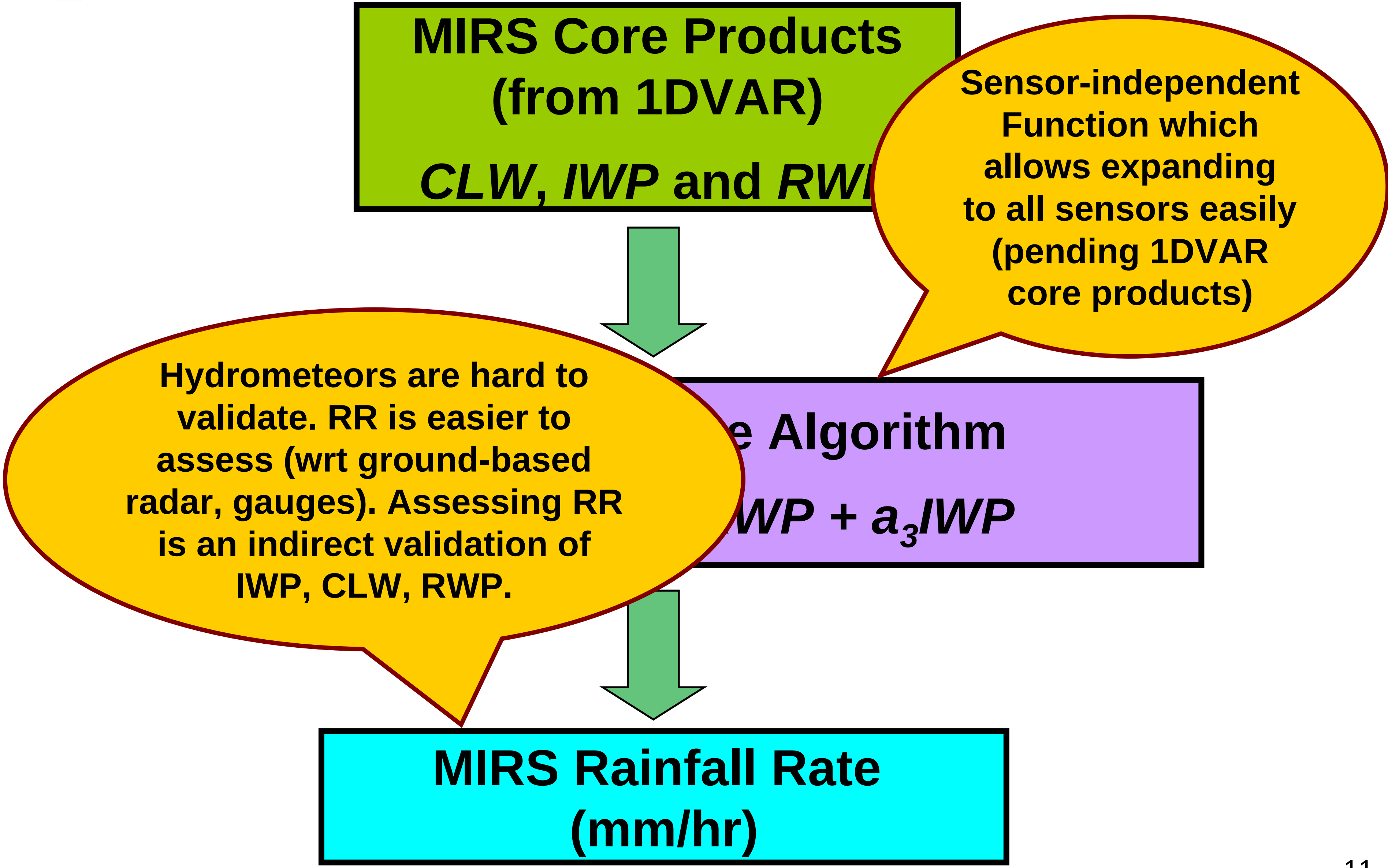


Current version



Contents

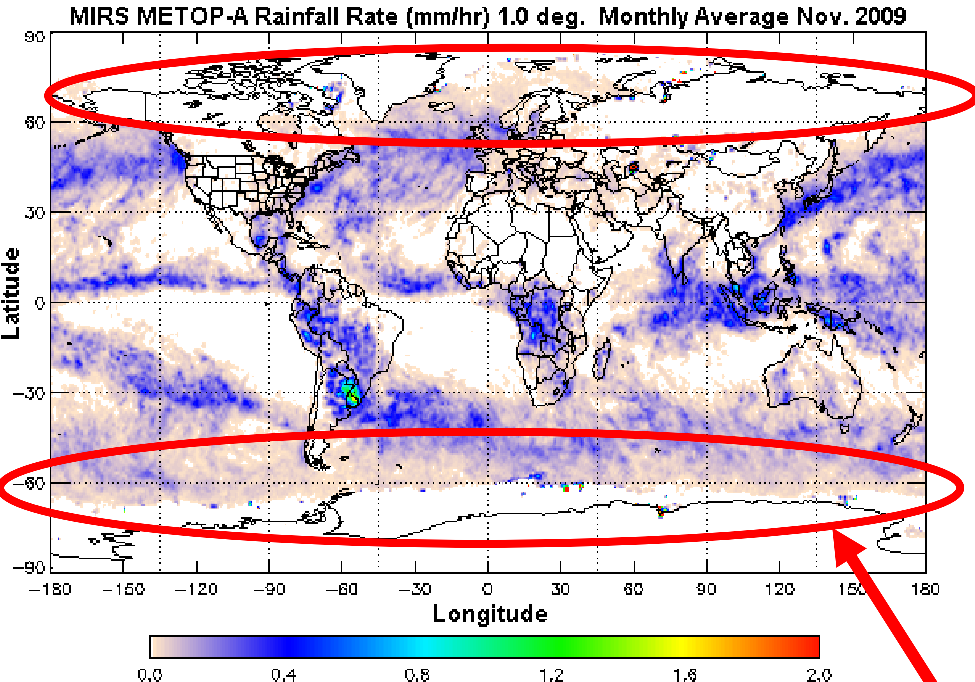
Hydrometeors Inversion Approach



Rainfall Rate Assessment

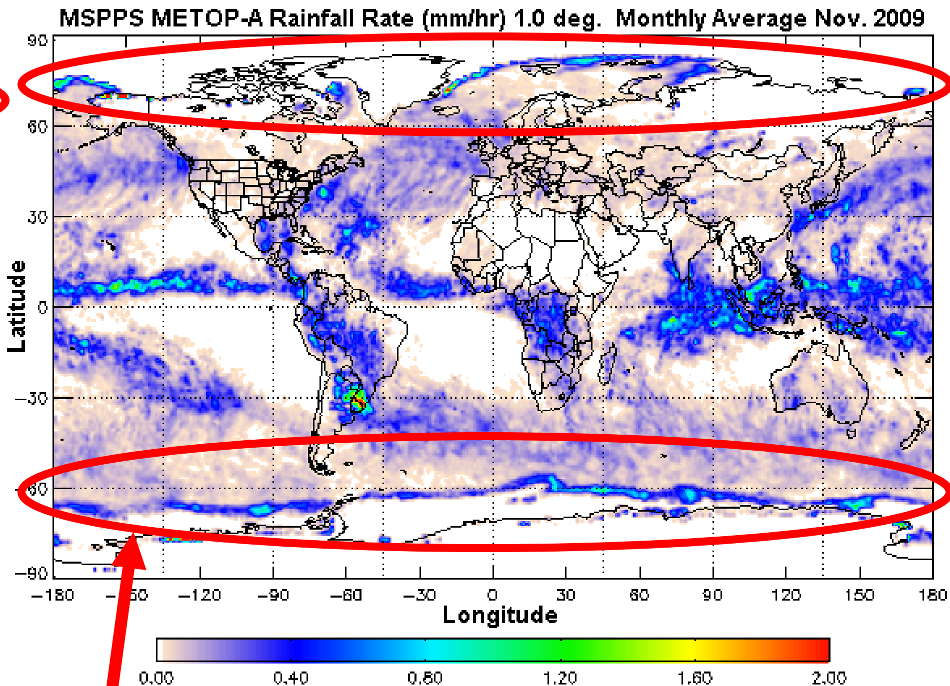
MiRS Monthly composite (Metop-A)

1DVAR



MSPPS Monthly composite (Metop-A)

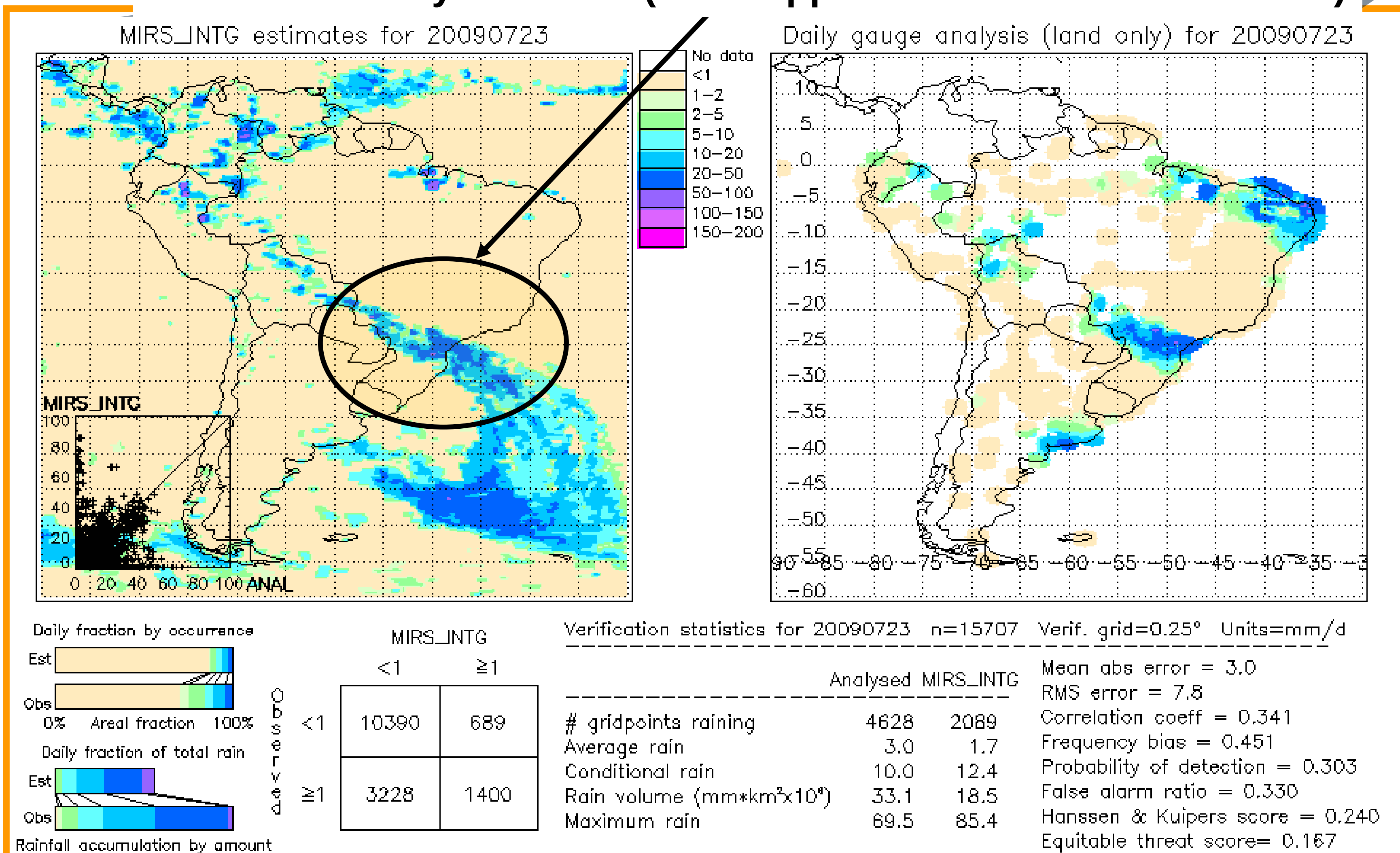
Heritage algorithm: based on physical regression



Significant reduction in Rain false alarm using MiRS, at surface transitions and edges

MiRS RR part of IPWG Intercomparison
(N. America, S. America and Australia sites)

No discontinuity at coasts (MiRS applies to both land and ocean)



RR

es

Image taken from IPWG web site: credit to Daniel Villa

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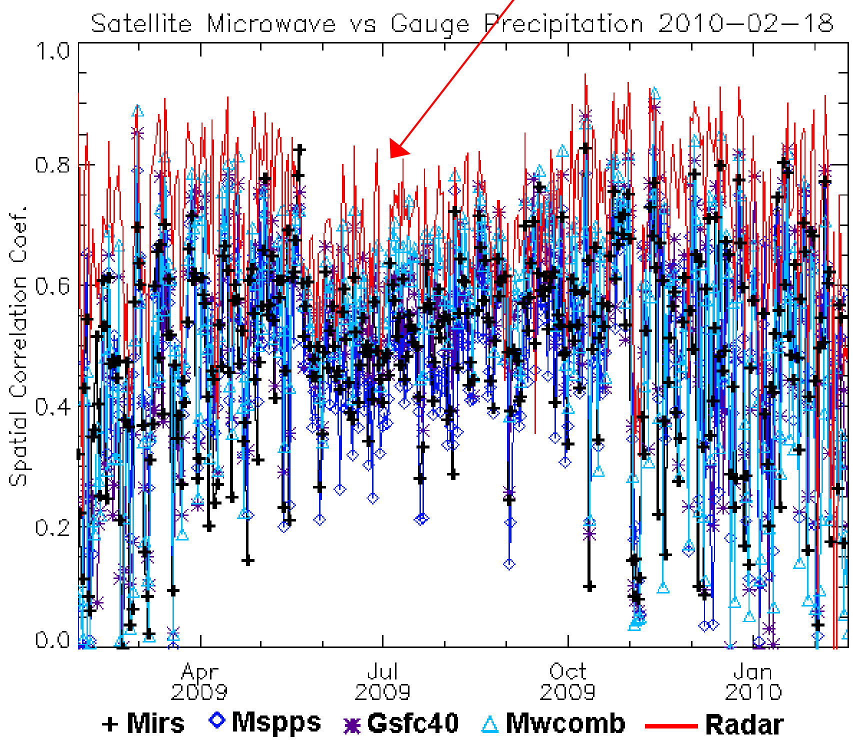
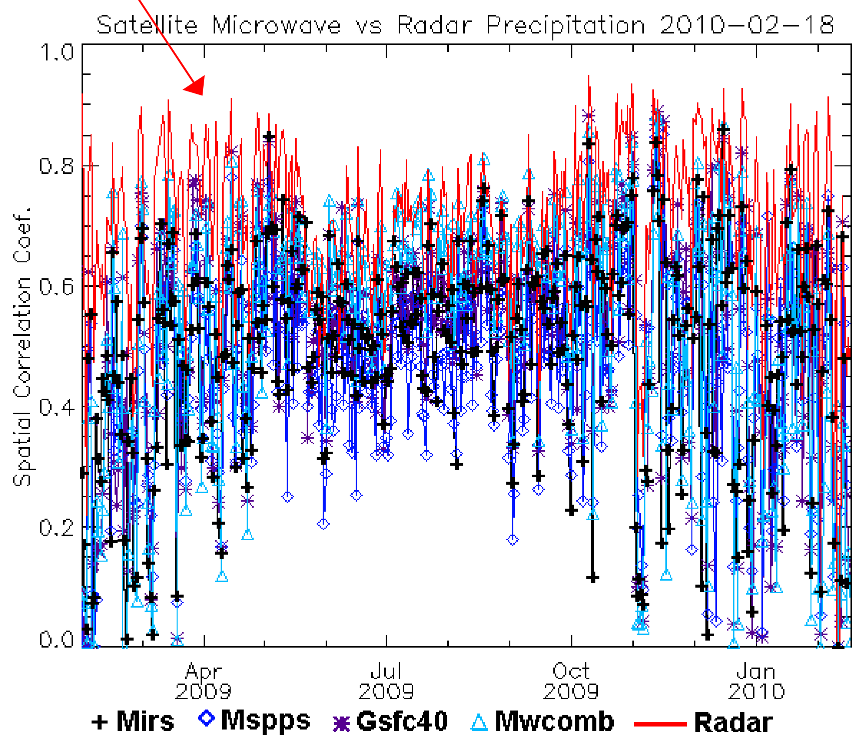
MiRS RR Comparison to Gauges & Radar

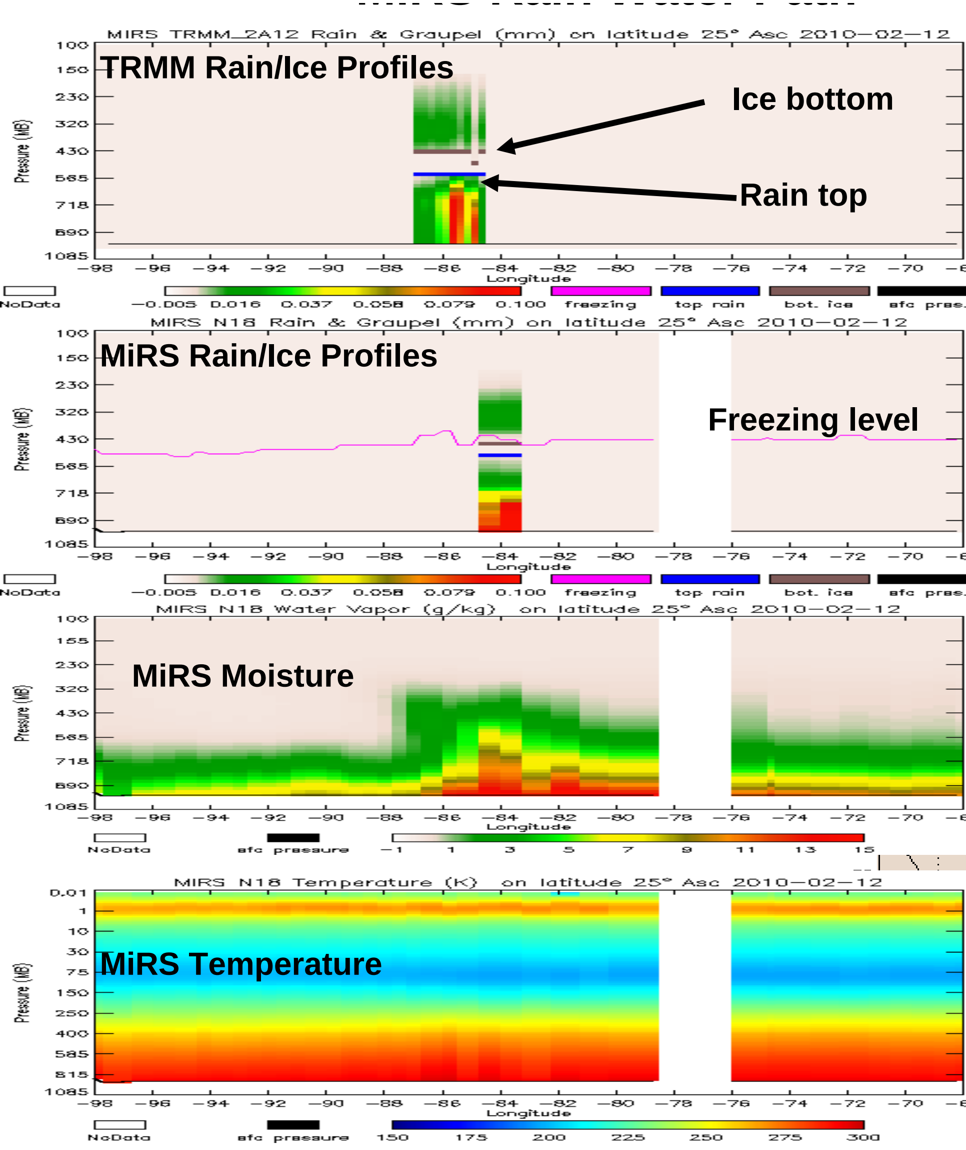
Upper Limit set by the Rain Gauge to Rain Radar Comparison





Qualitative check of the Cloudy/Rainy radiance handling

Cross-sections of both TRMM and MiRS products at 25 degrees North



Notes:

-Generally, consistent features between TRMM and MiRS (except for expected shift)

- Ice is found on top of liquid rain

-Transition between frozen and liquid is delineated by the freezing level determined from the temperature profile.

-Moisture increases in and around the rain event

- Suggests that these products are reasonably constrained within physical inversion

Contents

Summary & Conclusion

- MiRS is a generic retrieval/assimilation system (N18, N19, Metop-A, DMSP F16/18 SSMIS). Being extended to NPP/ATMS, TRMM/TMI and GPM/Mega-Tropiques
- All parameters impacting TBs are retrieved simultaneously: sounding, emissivity, skin temperature, cloud, rain, ice, allowing point-to-point variation of emissivity over land
- Final solution fits measurements (a necessary requirement).
- Inclusion of hydrometeors in retrieval allows processing cloud/rain –impacted radiances. Non-linear cloud-precip clearing.
- Physical Constraints are included through Covariance.
- Assessment of hydrometeors performed using RR as proxy.
- Results show that MiRS RR is consistent with established algorithms perfs, with the added value of a physically consistent solution.

BACKUP SECTION

Cost Function Minimization

- Cost Function to Minimize:

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

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 $y(x) = y(x_0) + K[x - x_0]$
- This leads to iterative solution:

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

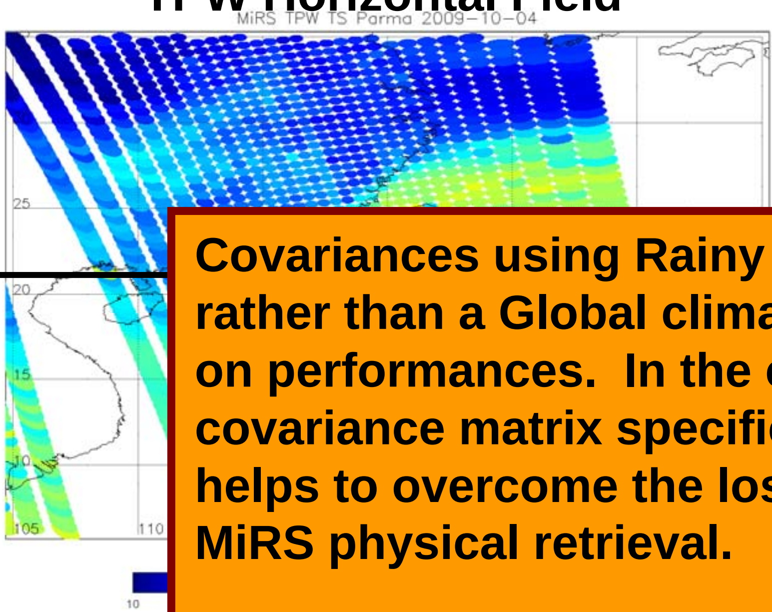
$$\Delta X_{n+1} = \left\{B K_n^T \left(K_n B K_n^T + E\right)^{-1}\right\}\left[\left(Y^m - Y(X_n)\right) + K_n \Delta X_n\right]$$

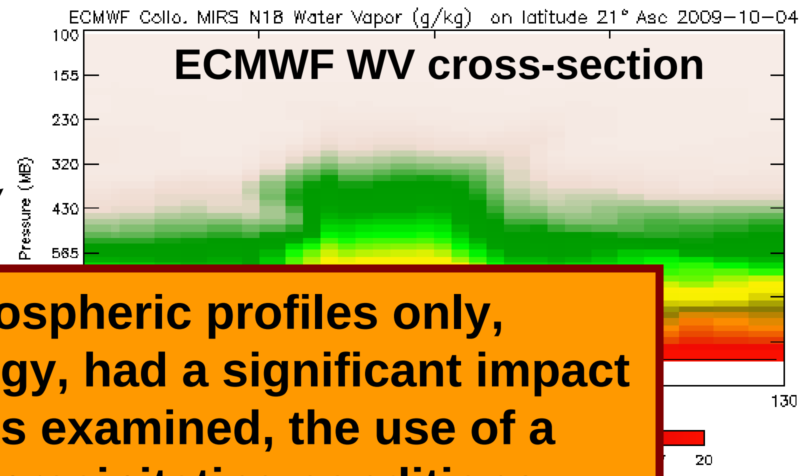
More efficient (1 inversion)

Preferred when nChan << nParams (MW)

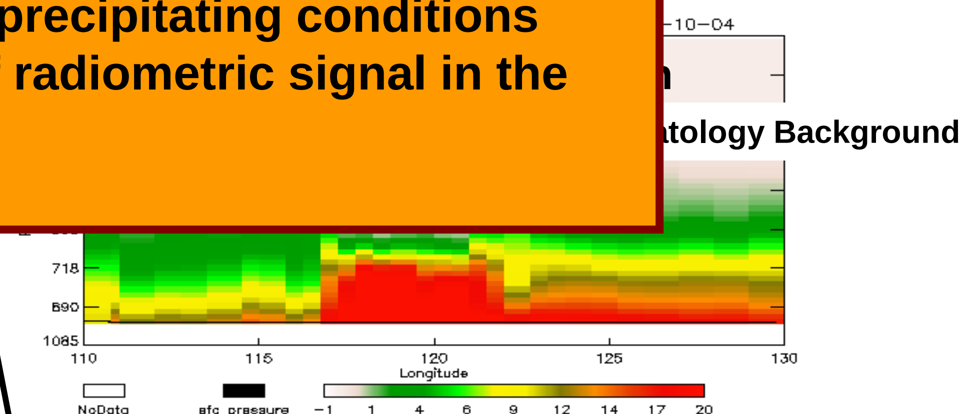
Importance of the Covariance Matrix

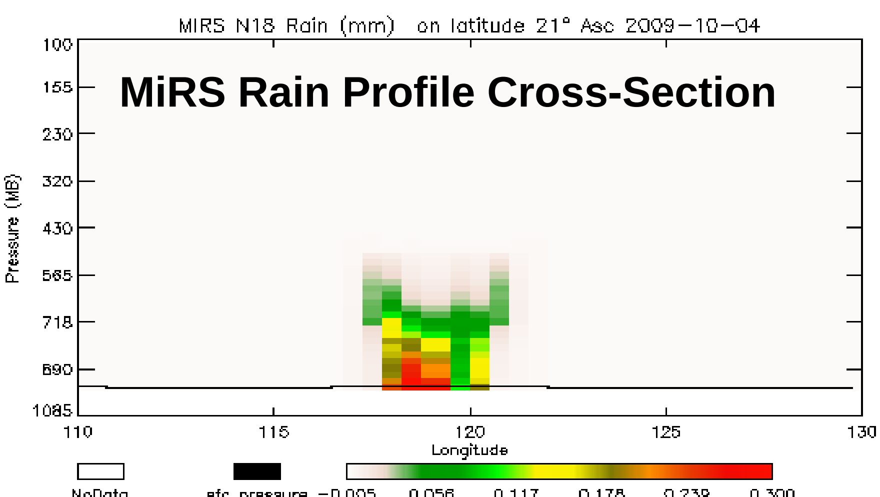
TPW Horizontal Field

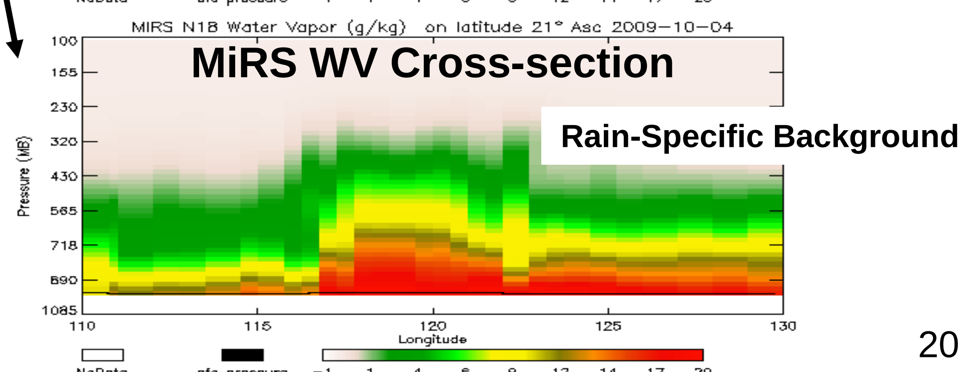




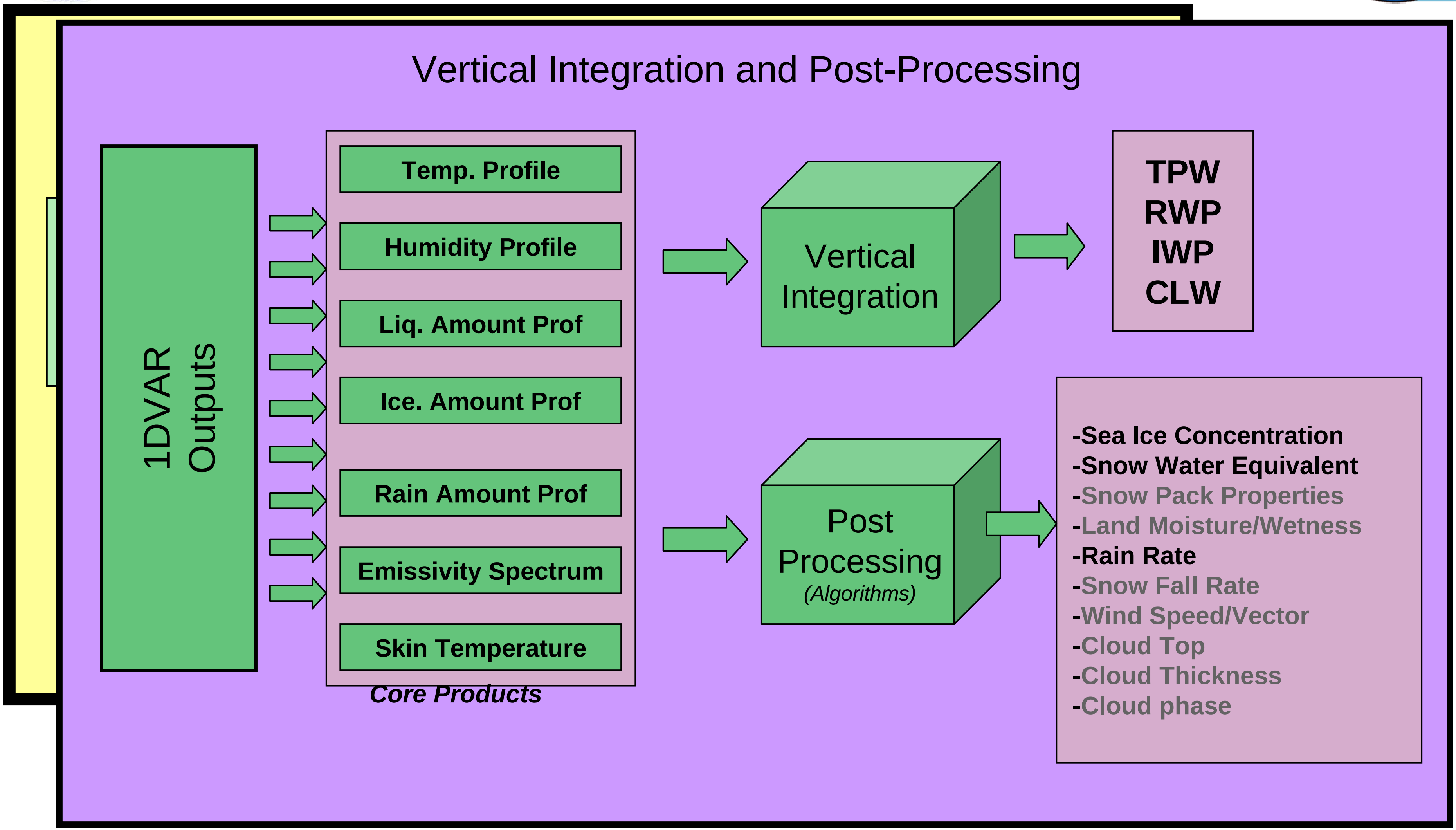
Covariances using Rainy atmospheric profiles only, rather than a Global climatology, had a significant impact on performances. In the cases examined, the use of a covariance matrix specific to precipitating conditions helps to overcome the loss of radiometric signal in the MiRS physical retrieval.







MiRS General Overview



All-surfaces: Variational Handling of Surface-Sensitive Channels

- Similar to handling cloud and hydrometeors, MiRS approach to account for surface-sensitivity of channels is by accounting for emissivity vector within state vector.

- Advantages:
  - Extend retrieval to all surfaces (only difference is background covariance and mean used). *Example: TPW over land.*
  - Generating an emissivity vector product, clear from atmospheric effects (used for a more accurate estimate of surface parameters)
  - Consistent treatment of all parameters globally (same methodology). *Example: RR is retrieved over ocean and land using the same code.*
  - Greater physical distinction between Tskin and Emissivity (based on physical Jacobians and different spectral signatures)
  - Allows a point to point variation of emissivity (useful for coasts, after rain, etc)
- Disadvantages:
  - Great emphasis must be given to the balance between different parameters (so that emissivity does not become a sink hole for variability due to other parameters such as cloud: hard)
  - Great constraint is put on the accuracy of emissivity

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

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

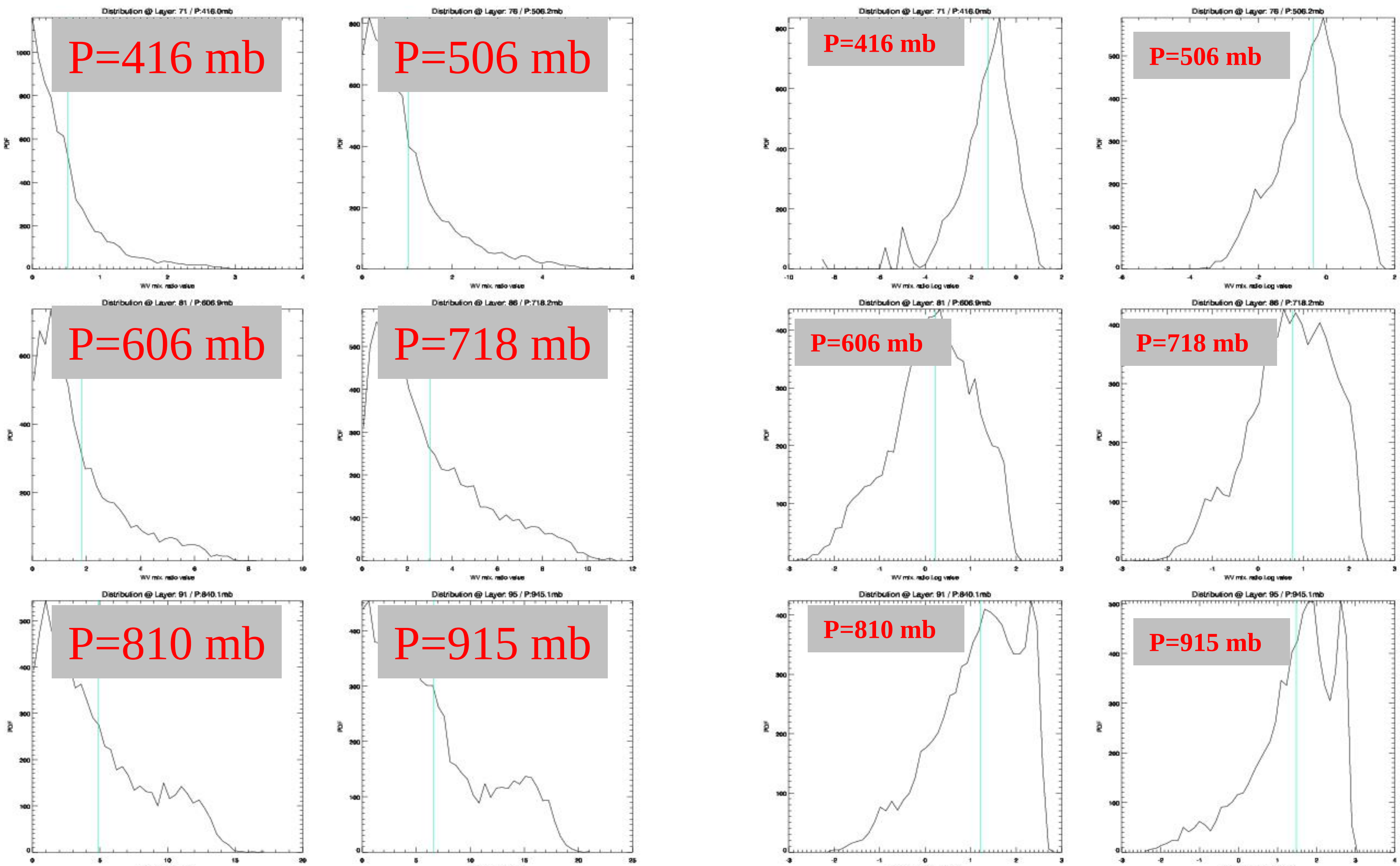
Diagonal Matrix
(used in reduced space retrieval)

Transf. Matrx
(computed offline)

Covariance matrix
(geophysical space)

Retrieval in Logarithm Space

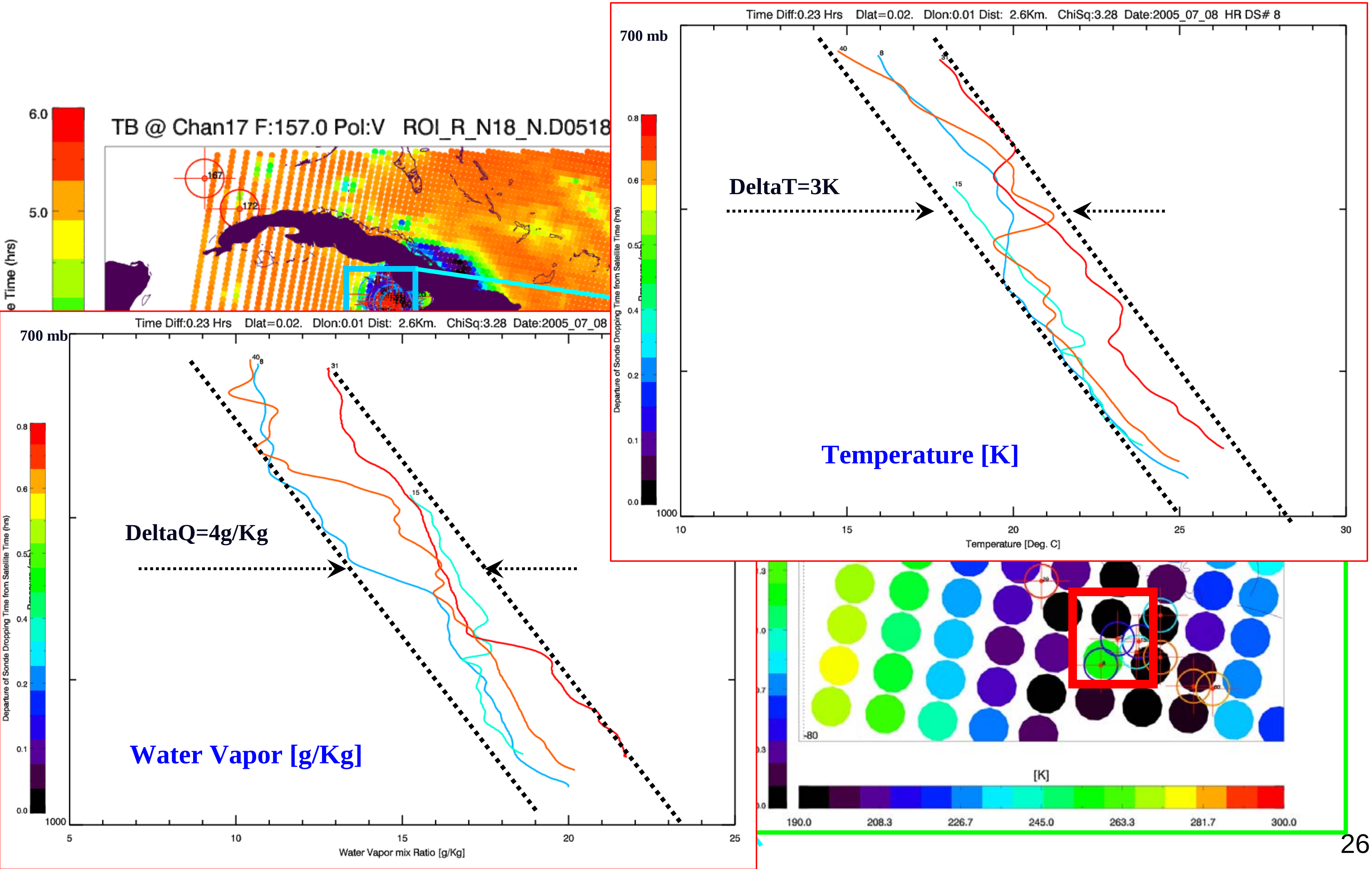
Advantages: (1) Distributions made more Gaussian & (2) No risk of having unphysical negative values



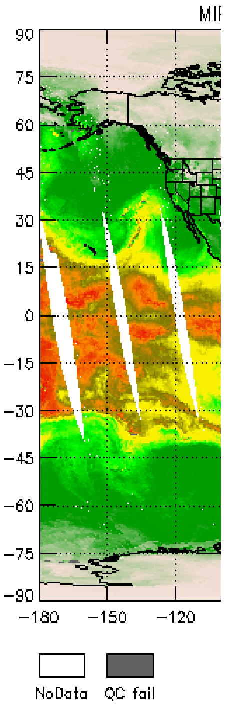
Applied to WV, Cloud and precip

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

Challenges of Profiling in Active Areas



TPW Global Coverage



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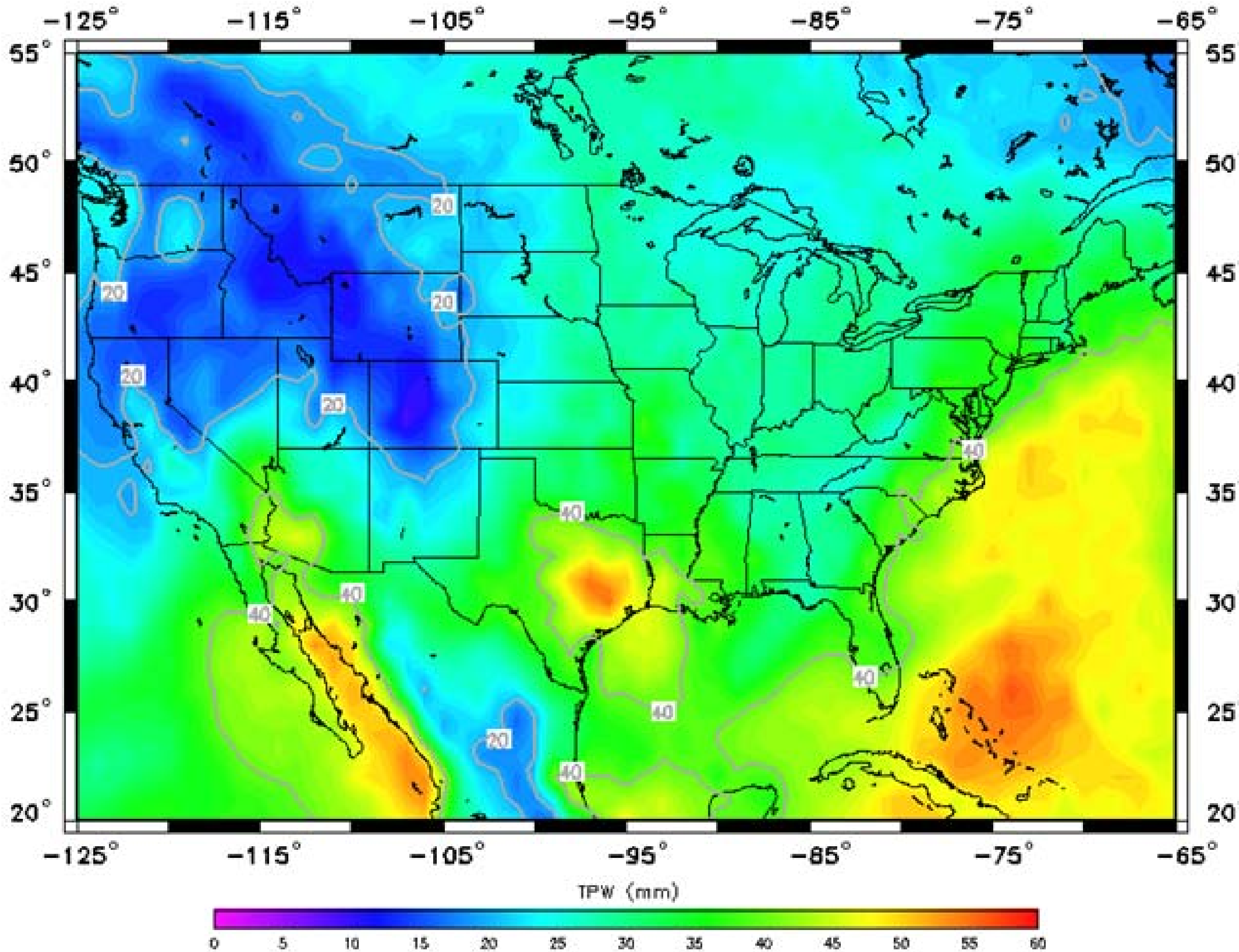
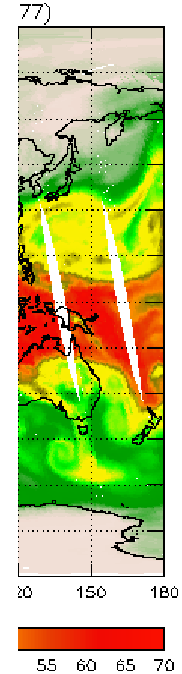
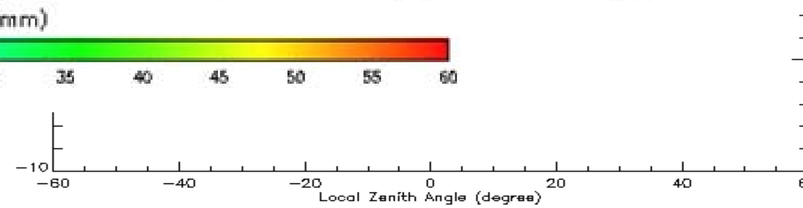
Smootl

MiRS TPW Retrieval (zoom over CONUS)



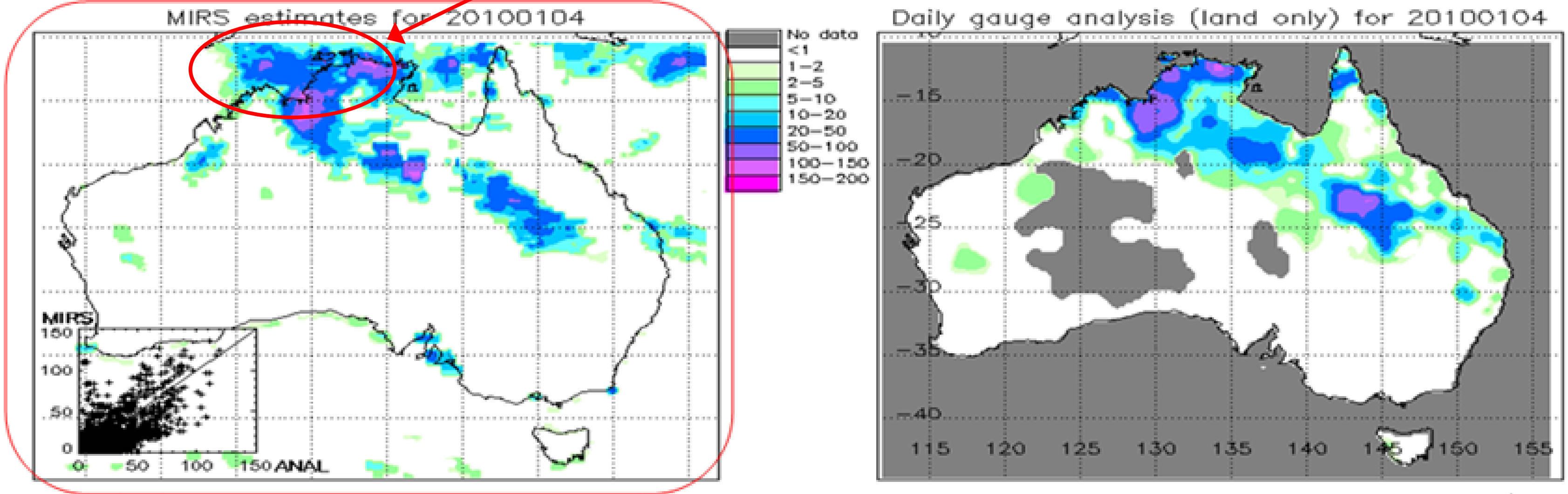


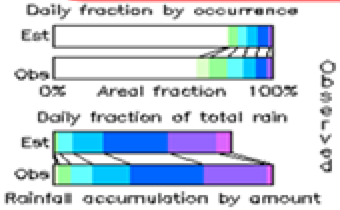


No Discontinuities at Coast

Validation over *Australia*

Rain Gauge





Observed	MIRS <1	MIRS ≥1
<1	6116	363
≥1	1675	1681

Verification statistics for 20100104 n=9835 Verif. grid=0.25° Units=mm/d

	Analysed	MIRS
# gridpoints raining	3356	2044
Average rain	5.0	4.1
Conditional rain	14.7	19.7
Rain volume (mm*km²x10⁶)	33.7	27.5
Maximum rain	118.7	135.8

Mean abs error = 3.6
RMS error = 9.0
Correlation coeff = 0.756
Frequency bias = 0.609
Probability of detection = 0.501
False alarm ratio = 0.178
Hanssen & Kuipers score = 0.445
Equitable threat score= 0.326

Courtesy of Elizabeth E. Ebert, Bureau of Meteorology, Australia