A Comprehensive Variational Approach to Remote Sensing in All-Weather, All-Surface Conditions

-MiRS Algorithm-

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1 **General Overview and Mathematical Basis**

2 Performance Assessment

3 Summary & Conclusion

Introduction / Context

- Physical algorithm for microwave sensors (MiRS)
- Cost to extend to new sensors greatly reduced
- MiRS applies to imagers, sounders, combination
- MiRS uses the CRTM as forward operator (leverage)
- Applicable on all surfaces and in all-weather conditions
- Operational for N18,19,Metop-A and F16/F18 SSMI/S.
- **On-going / Future:**
  - Extension operations to Metop-B, NPP/ATMS and Megha-Tropiques (MADRAS and SAPHIR)
  - Get ready for the JPSS and GPM sensors.
  - **Extend to FY-3 MWTS, MWHS and imager**
  - **Extend applications of MiRS (hydrometeors profiling)**
  - **Extend MiRS to Infrared Remote Sensing (CRTM is already valid)**

All-Weather and All-Surfaces

Sounding Retrieval:

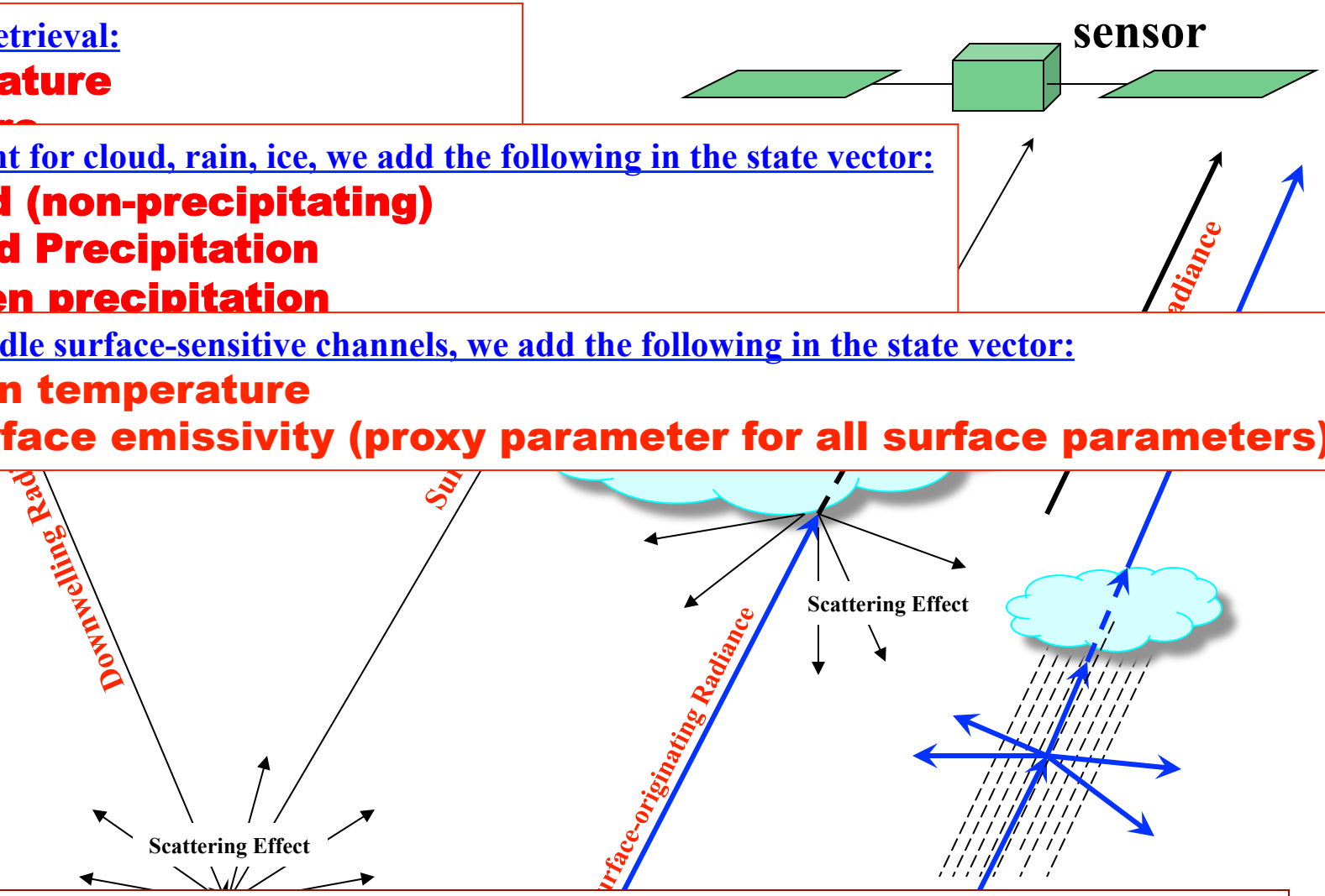
- **Temperature**
- **Moisture**

To account for cloud, rain, ice, we add the following in the state vector:

- **Cloud (non-precipitating)**
- **Liquid Precipitation**
- **Frozen precipitation**

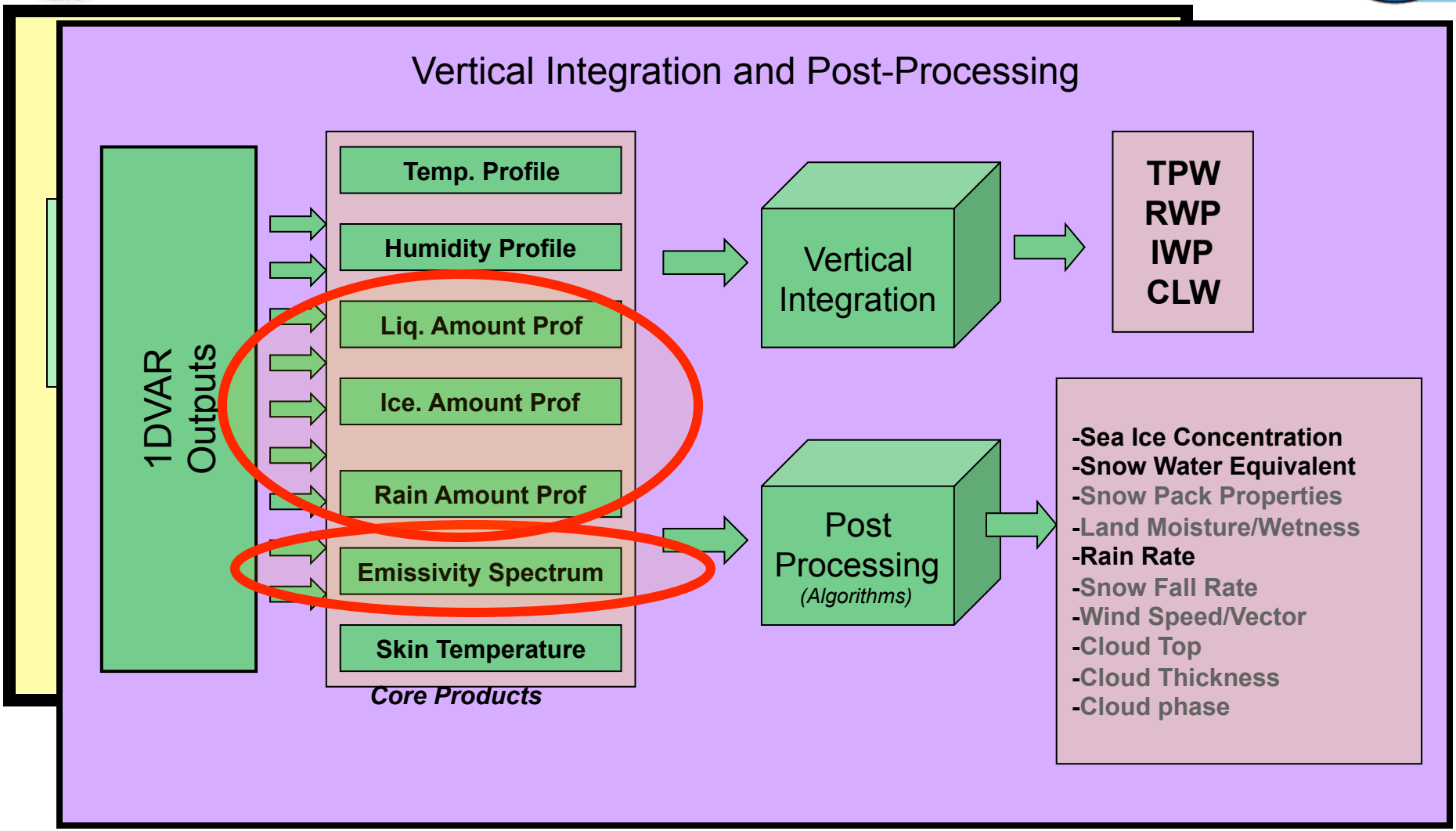
To handle surface-sensitive channels, we add the following in the state vector:

- **Skin temperature**
- **Surface emissivity (proxy parameter for all surface parameters)**

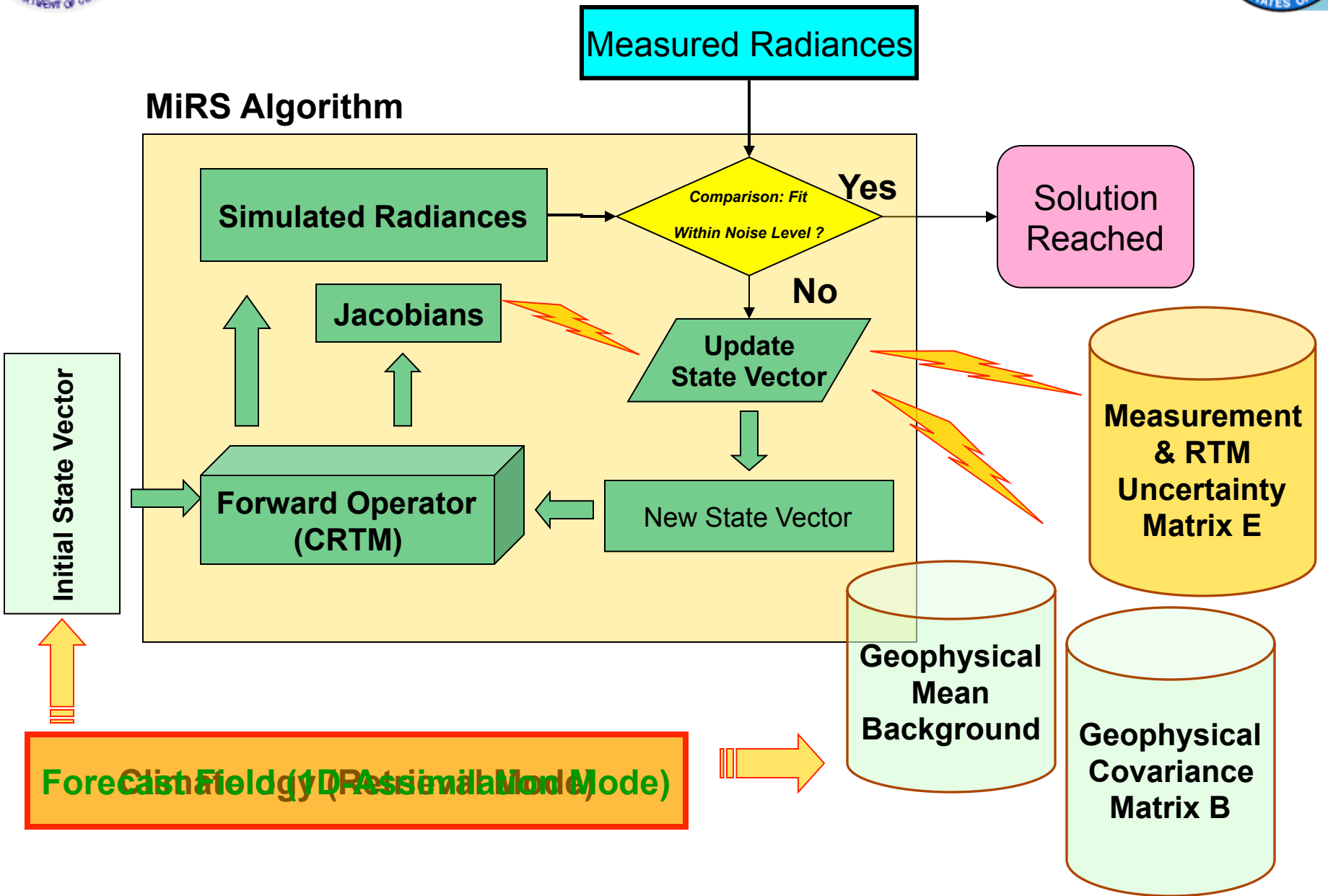


- Instead of guessing and then removing the impact of cloud and rain and ice on TBs (very hard), MiRS approach is to account for cloud, rain and ice within its state vector.
- It is highly non-linear way of using cloud/rain/ice-impacted radiances.

MiRS General Overview



1D-Variational Retrieval/Assimilation



Mathematical Basis: Cost Function Minimization

- Cost Function to Minimize:

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

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)

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

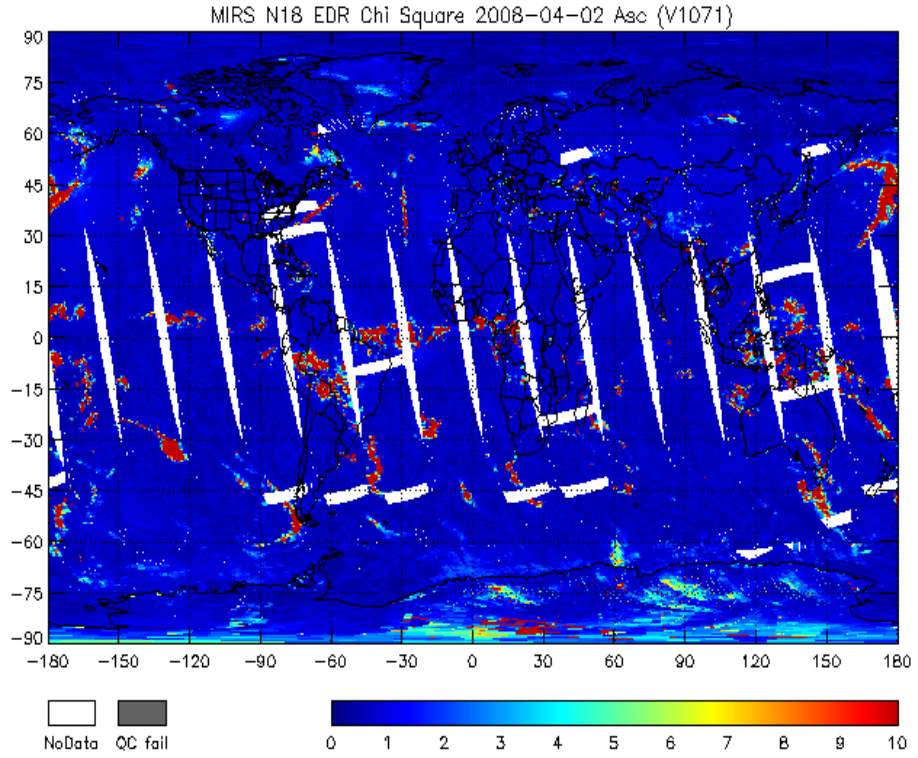
Solution-Reaching: Convergence

- 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.

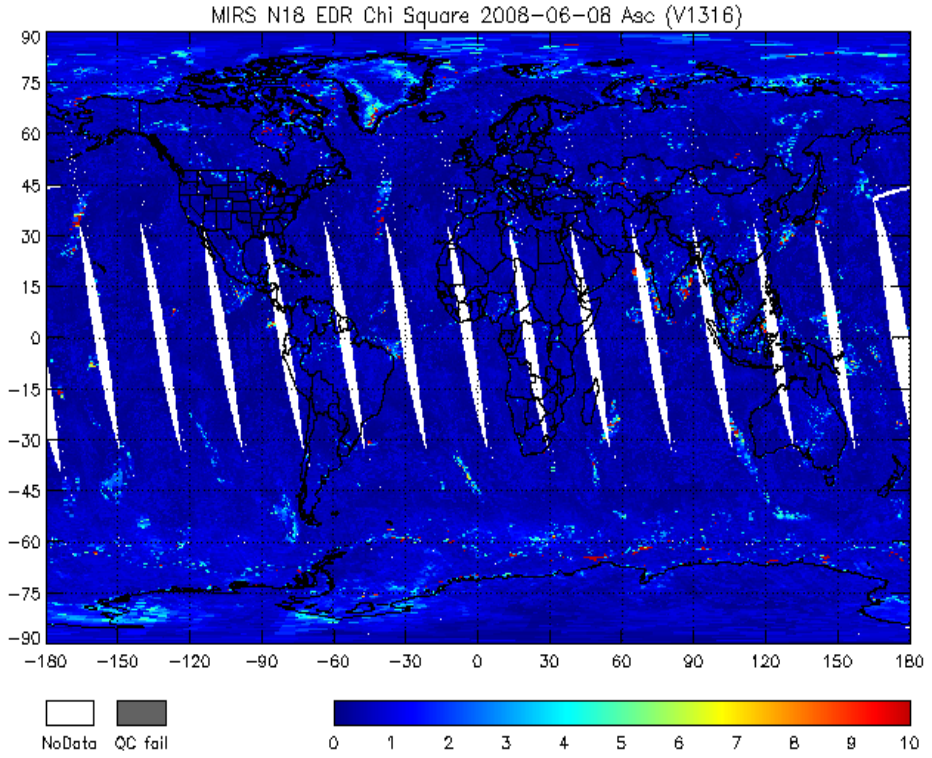
$$\varphi^2 = \left(\mathbf{Y}^m - \mathbf{Y}(\mathbf{X})\right)^T \times \mathbf{E}^{-1} \times \left(\mathbf{Y}^m - \mathbf{Y}(\mathbf{X})\right)$$

Previous version

(non convergence when precip/ice present)



Current version



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MiRS List of Products

Official Products

1. Temperature profile
2. Moisture profile
3. TPW (global coverage)
6. Surface Type *(sea, land, snow, sea-ice)*
7. Snow Water Equivalent (SWE)
8. Snow Cover Extent (SCE)
9. Sea Ice Concentration (SIC)
10. Cloud Liquid Water (CLW)
11. Ice Water Path (IWP)
12. Rain Water Path (RWP)

Products being investigated

1. Cloud Profile
2. Rain Profile
3. Atmospheric Ice Profile
6. Effective Snow grain size
7. Multi-Year (MY) Type SIC
8. First-Year (FY) Type SIC
9. Wind Speed
10. Soil Wetness Index

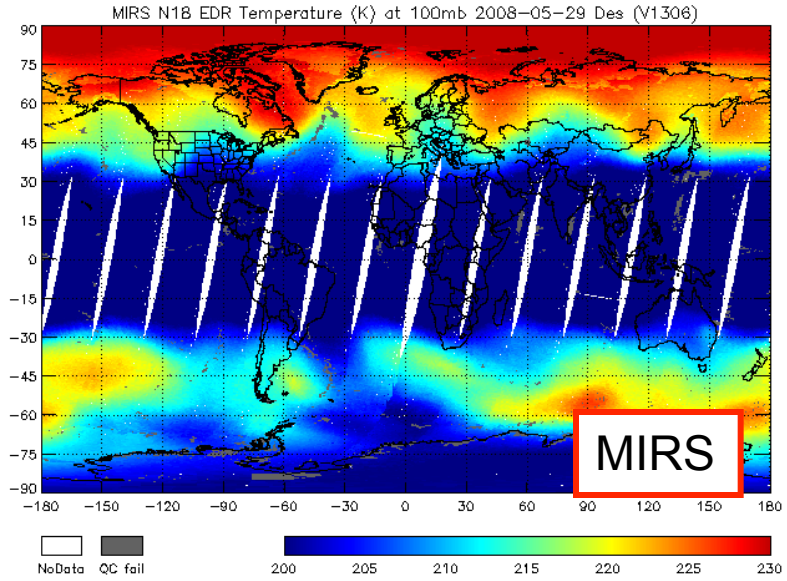
The following section about performance assessment is a snapshot (focused on sounding mainly).

(Algorithms)

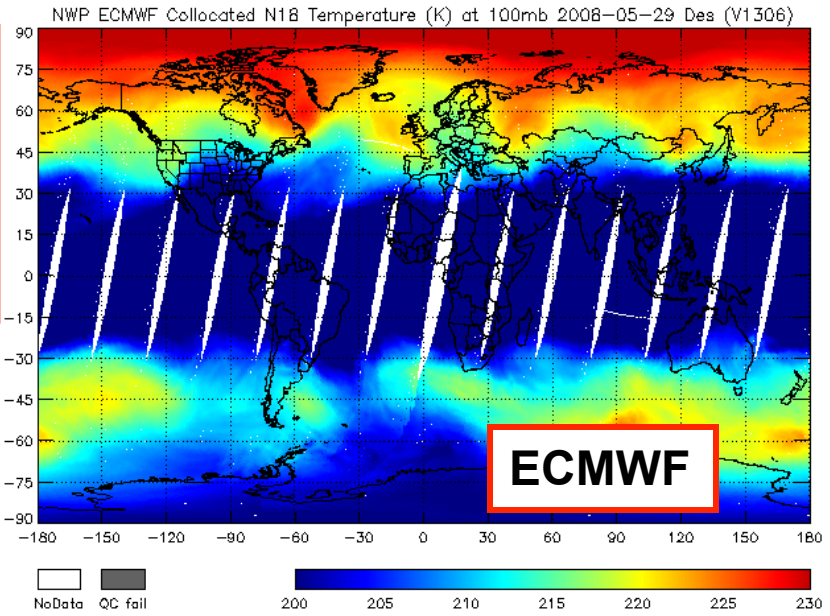
-Snow Fall Rate
-Wind Speed/Vector
-Cloud Top
-Cloud Thickness
-Cloud phase

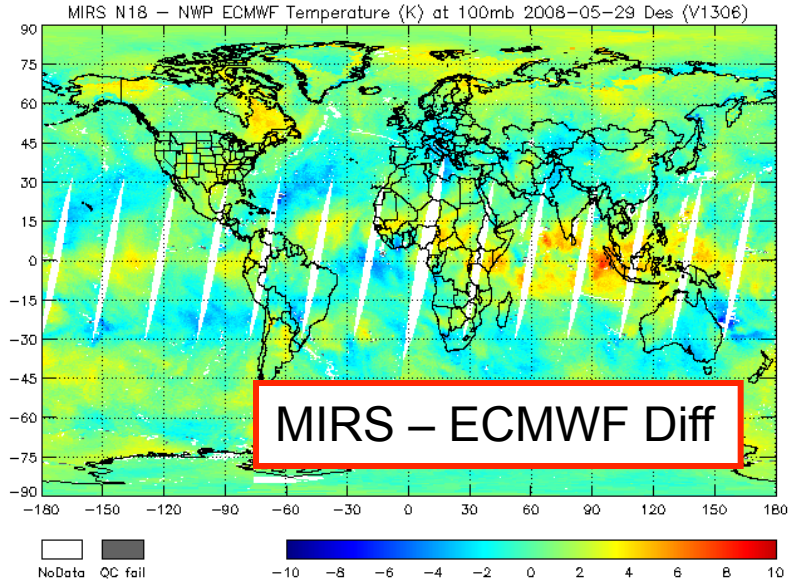
Temperature Profile Assessment

(against ECMWF)

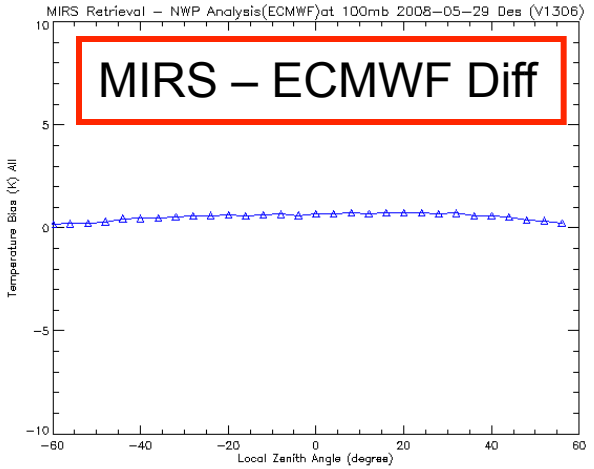


Angle dependence taken care of very well, without any limb correction



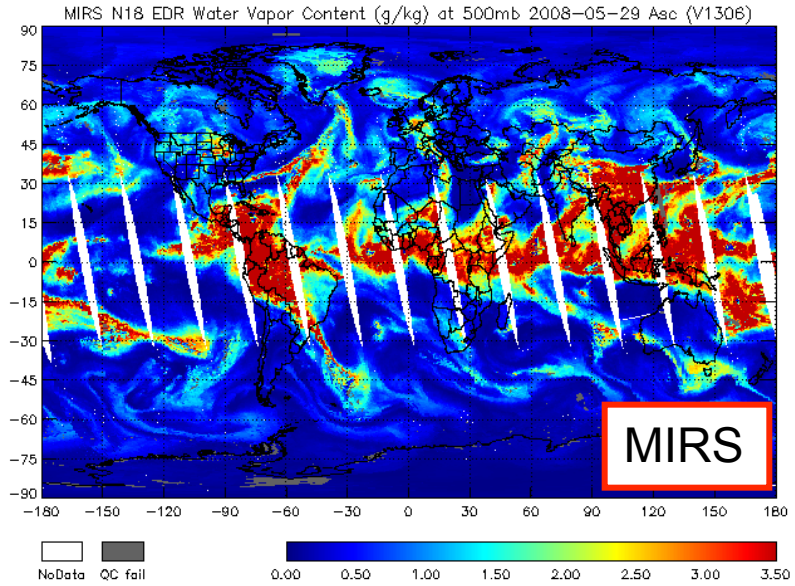


Note: Retrieval is done over all surface backgrounds but also in all weather conditions (clear, cloudy, rainy, ice)



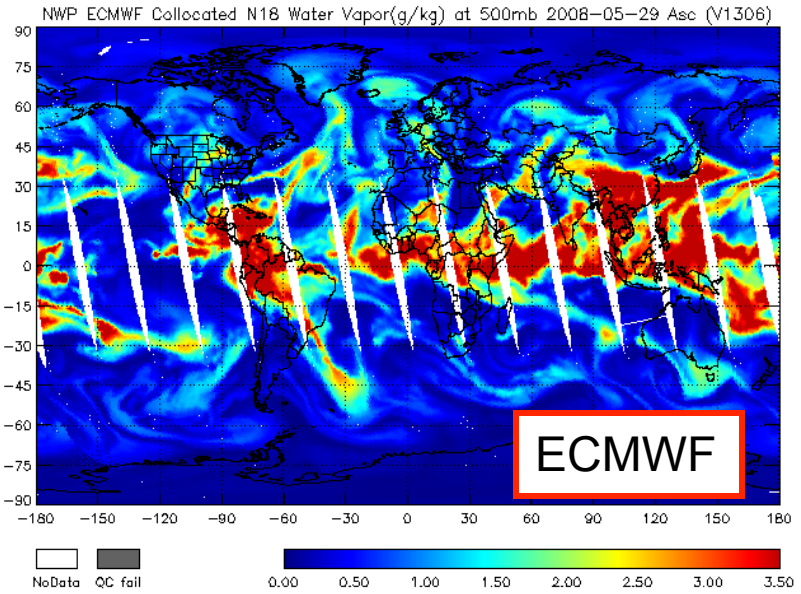
Moisture Profile

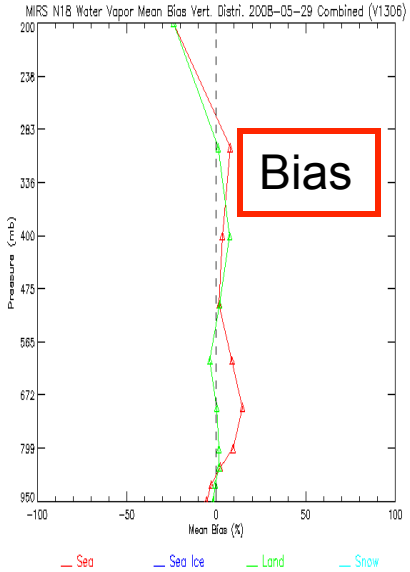
(against ECMWF)

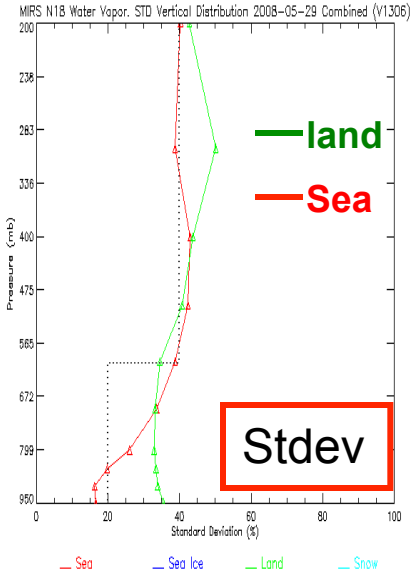


Validation of WV done by comparing to:

- **GDAS**
- **ECMWF**
- **RAOB**

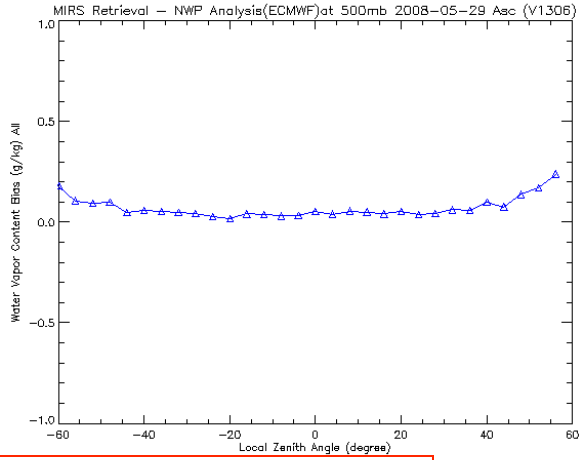






Assessment includes:

- **Angle dependence**
- **Statistics profiles**
- **Difference maps**

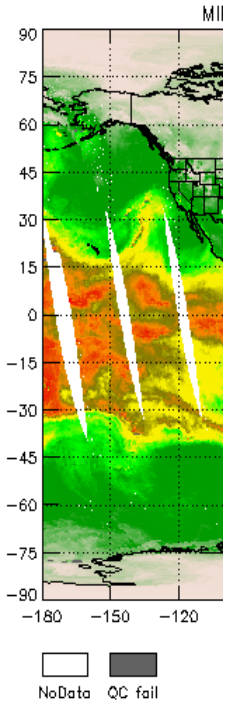


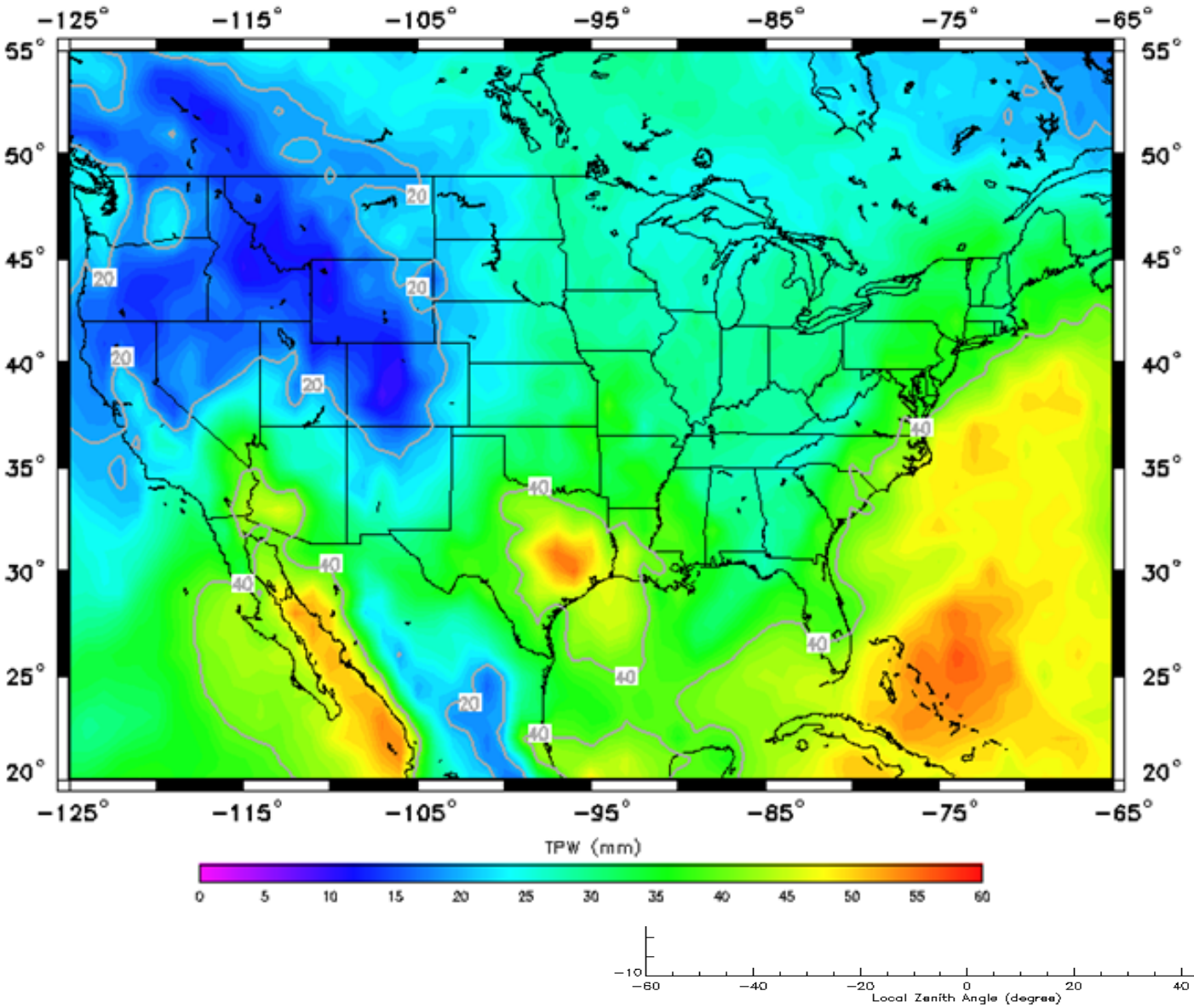
When assessing, keep in mind all ground truths (wrt GDAS, ECMWF, RAOB)

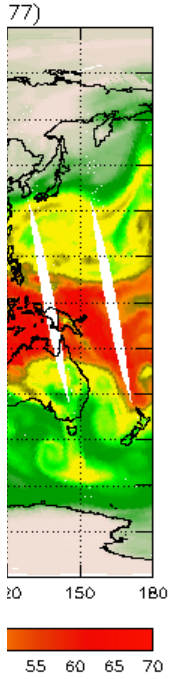
N18

TPW Global Coverage

MiRS TPW Retrieval (zoom over CONUS)



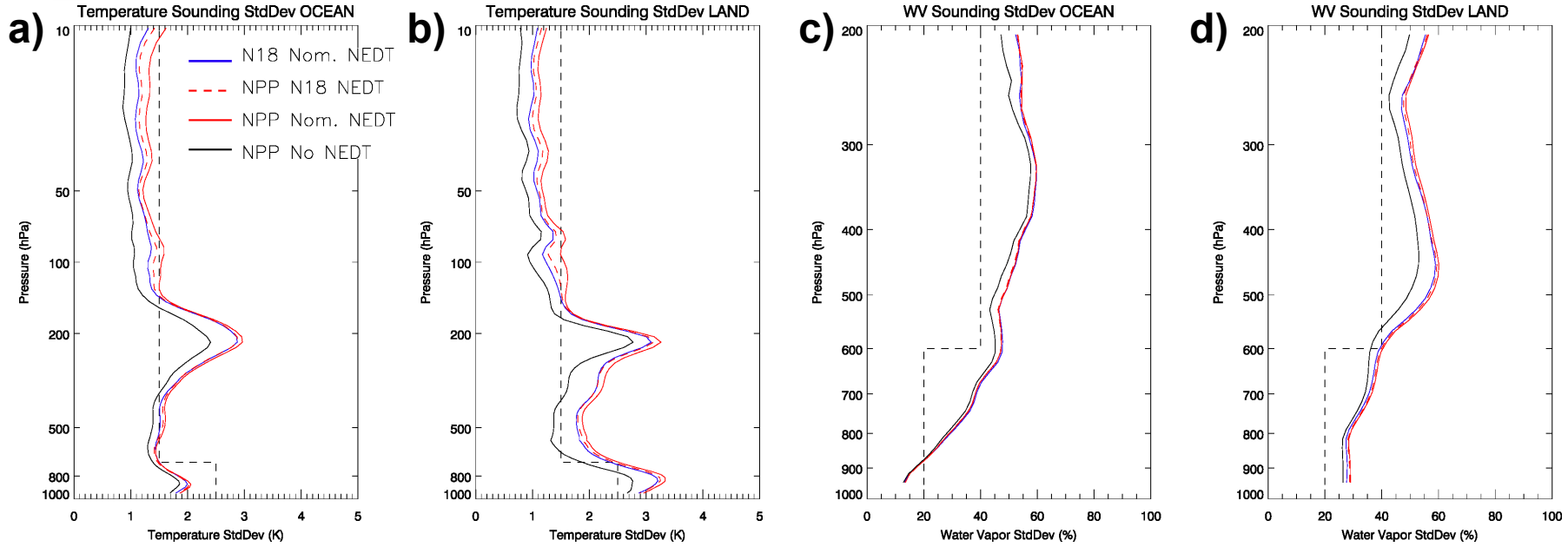




Very si

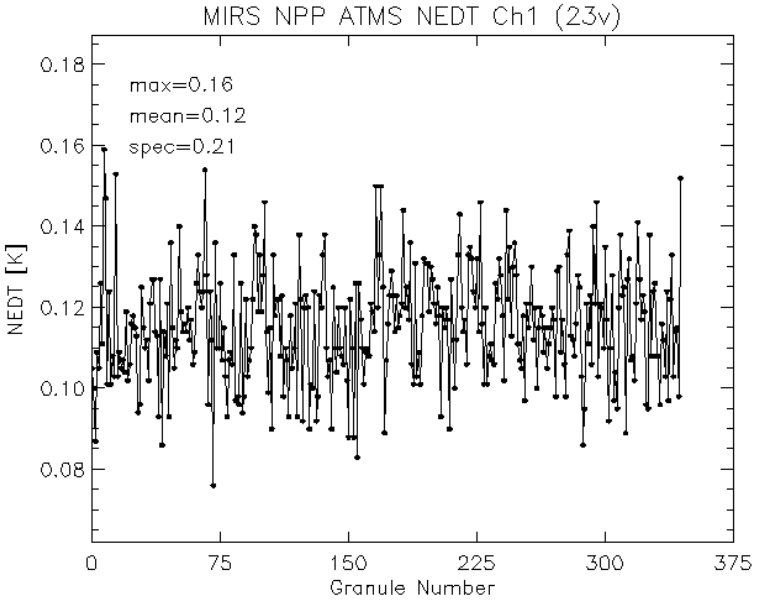
Smoot

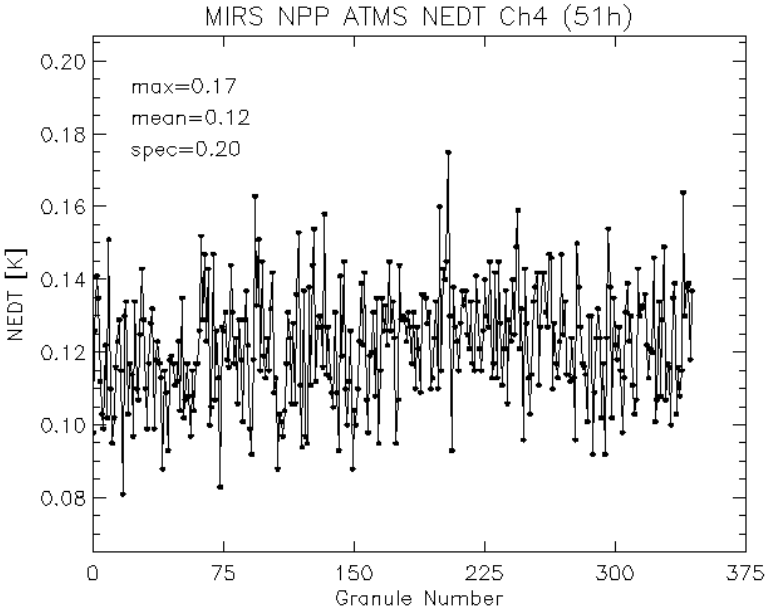
ATMS Expected Performances

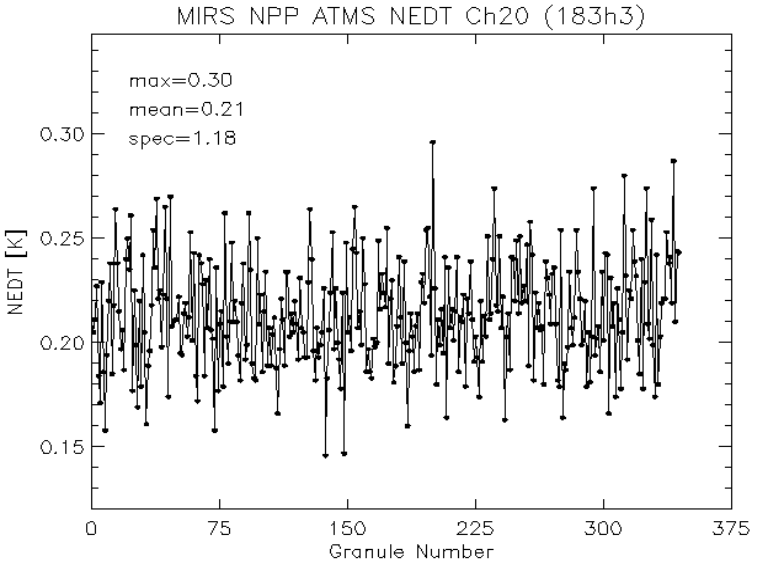


Theoretical performances for temperature sounding over ocean (a) and land (b) and water vapor sounding over ocean (c) and land (d). Simulations are performed in clear-sky for NPP with no noise added (black), N18 with noise (blue), NPP with N18-like noise (red dashed) and NPP expected noise (red).

NPP/ATMS REAL DATA
Initial Assessment of Noise levels







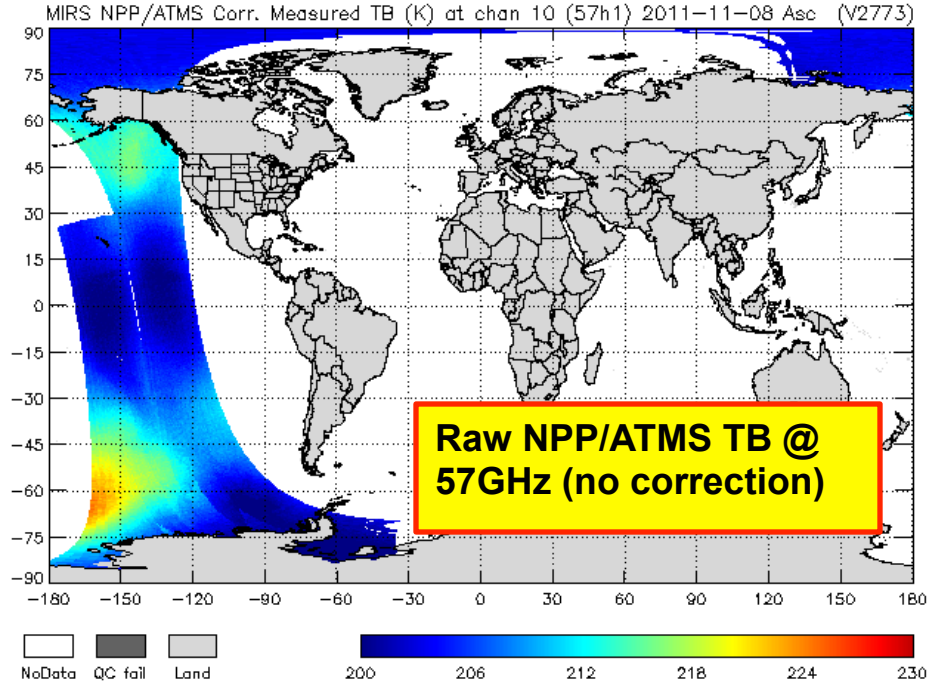
Noise levels for NPP/ATMS seem all to be within spec, and even lower (for some channels, significantly) than spec.

To be monitored further with time.

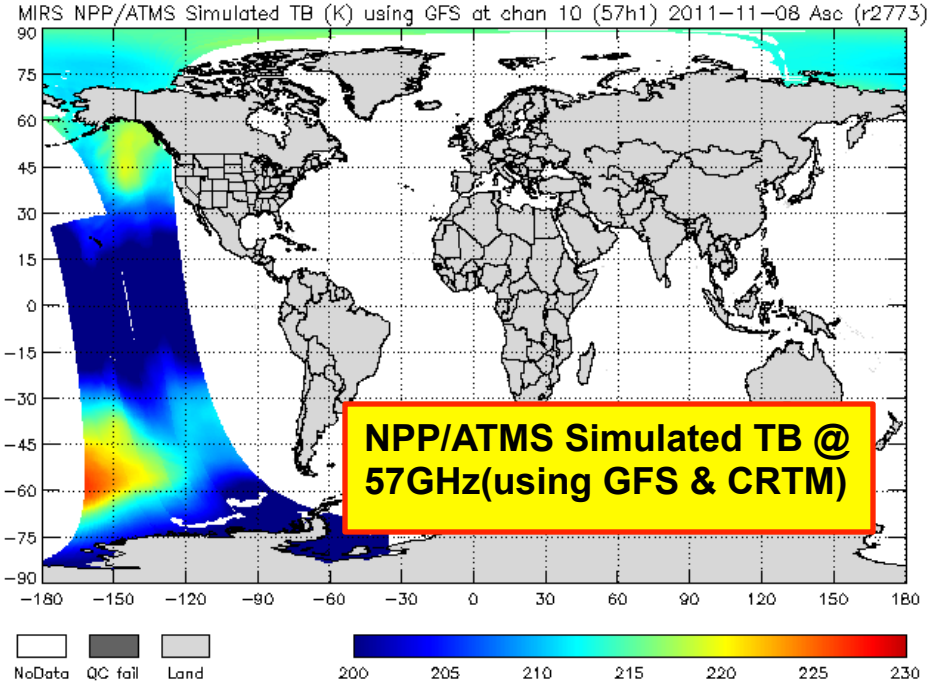
NPP/ATMS Real Data

(Initial Radiometric Assessment)

NPP/ATMS data started flowing Nov 8th 2011



Raw NPP/ATMS TB @ 57GHz (no correction)

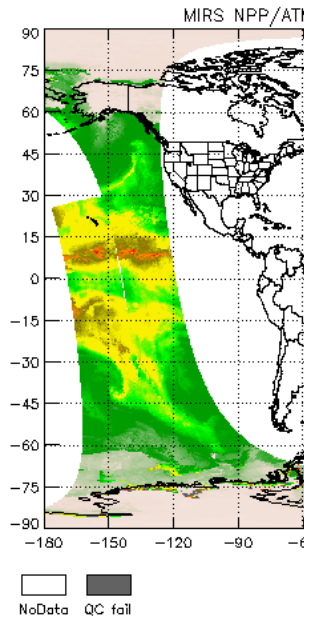


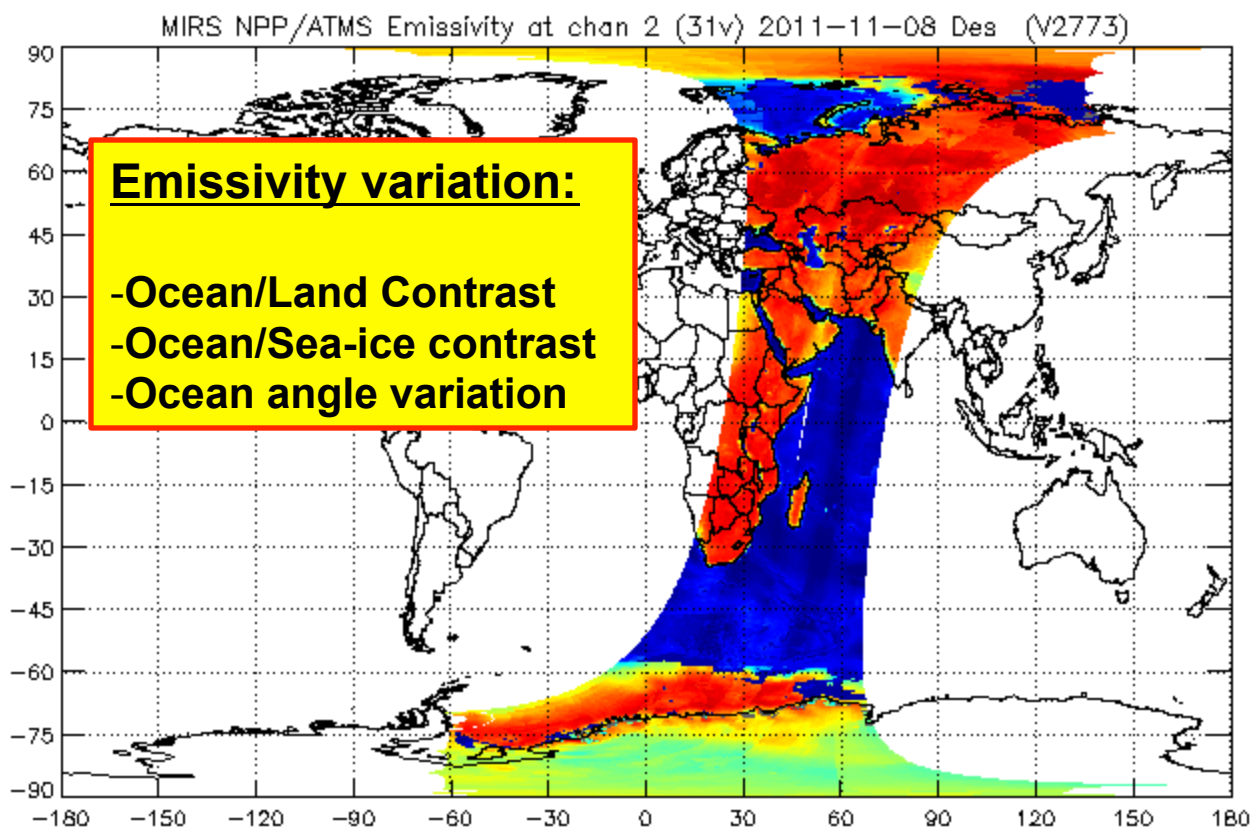
NPP/ATMS Simulated TB @ 57GHz(using GFS & CRTM)

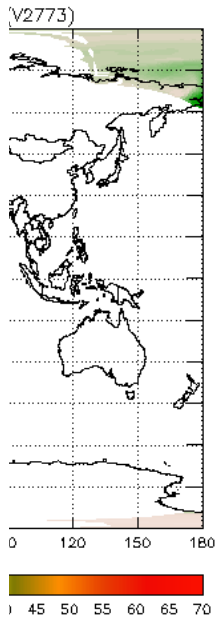
Hot off the press results.

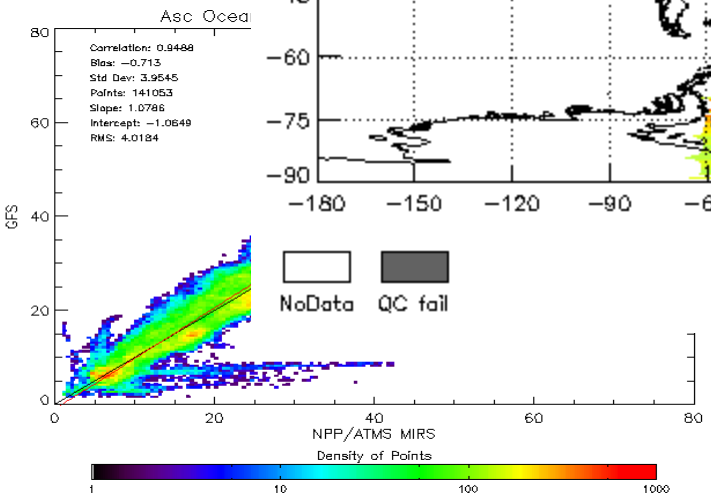
Non-corrected TBs fed to MiRS.

NPP/ATMS Real Data
(Initial EDRs Assessment)









no bias correction

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Summary & Conclusion

- MiRS is a generic retrieval/assimilation system (N18, N19, Metop-A, DMSP F16/18 SSMIS).
- Immediate efforts focus on NPP/ATMS extension (encouraging results with first day of data)
- Efforts also aim at extending MiRS to NPP/ATMS , TRMM/TMI and GPM/ Mega-Tropiques
- In MiRS, parameters impacting TBs are retrieved simultaneously including sounding, emissivity, skin temperature, cloud, rain, ice, etc.
- Final solution suite fits measurements (satisfying a necessary but often overlooked requirement).
- Inclusion of the emissivity in the retrieval allows the handling of surface-sensitive channels
- Inclusion of rain, ice and cloud in the retrieval allows to process cloud/rainy – impacted radiances.
- Thorough assessment performed using many references:
  - In clear/cloudy conditions, results are good.
  - In rainy conditions, task is much tougher (on-going).
- For more detailed information about the MiRS project, visit: mirs.nesdis.noaa.gov *(more validation data, publication list and software package)*

BACKUP SLIDES

All-Weather Handling: *Cloud/Precip-Clearing*

- **MiRS approach to account for rain/cloud/ice-sensitive channels is by accounting for rain/ cloud/ice vector within state vector.**
- **Adva**
  - **It is radi**
  - **It is radi**
  - **Doe**
  - **Doe nee**

Is the retrieval stable?

- EOF decomposition for all profiles (T, Q, C, R, I) and emissivity vector.

Is the solution physically consistent? (between T, Q, C, R and I)

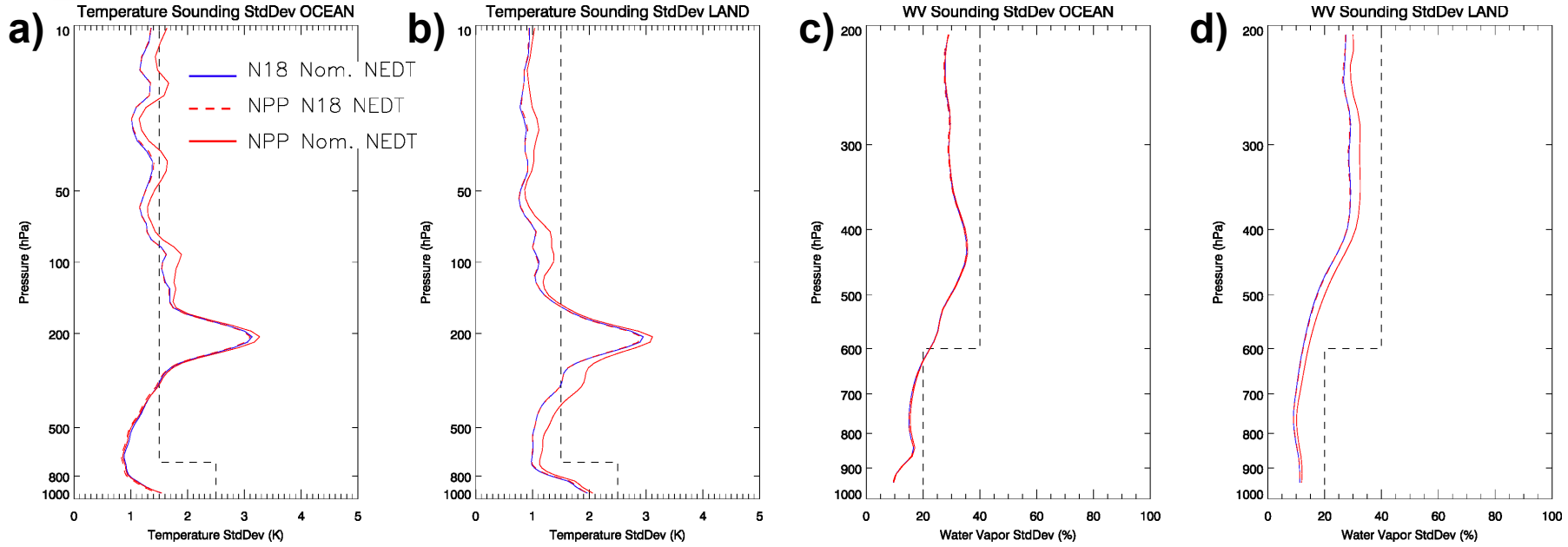
-Cov Matrix constraint
-Physical Retrieval & RT constraints
-Convergence (fitting Ym)
-Jacobians to determine signals

- **Disadvantages:**
  - **Results depend on assumptions made in RT (particle size, distribution, etc**
  - **Greater reliance on a robust, valid covariance matrix (flow dependent matrix becomes necessary)**

Surface-Sensitive Channels Handling

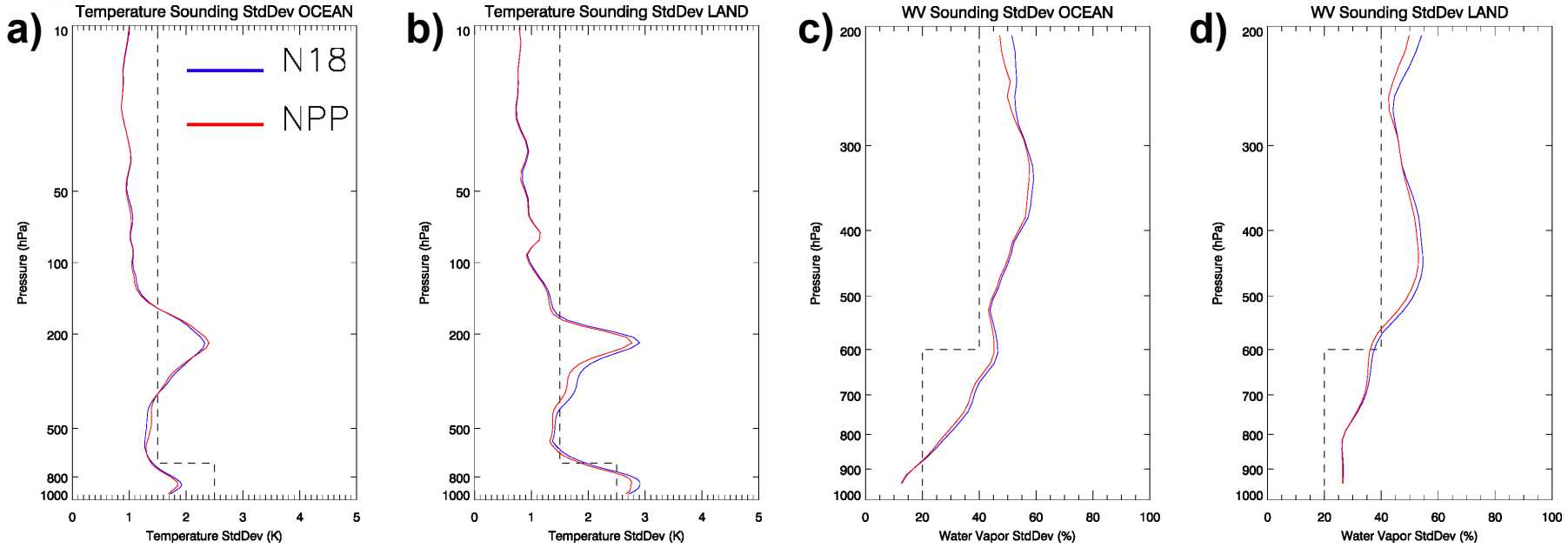
- **MiRS approach to account for surface-sensitive channels is by accounting for emissivity vector within state vector.**
- **Advantages:**
  - Extend retrieval to all surfaces (only difference is background covariance and mean used). *Example: TPW over land.*
  - Generating an emissivity vector product, 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

ATMS Expected Performances



Theoretical performances for temperature sounding over ocean (a) and land (b) and water vapor sounding over ocean (c) and land (d). Simulations are performed in precipitating atmospheres for N18 with noise (blue), NPP with N18-like noise (red dashed) and NPP expected noise (red).

ATMS Expected Performances

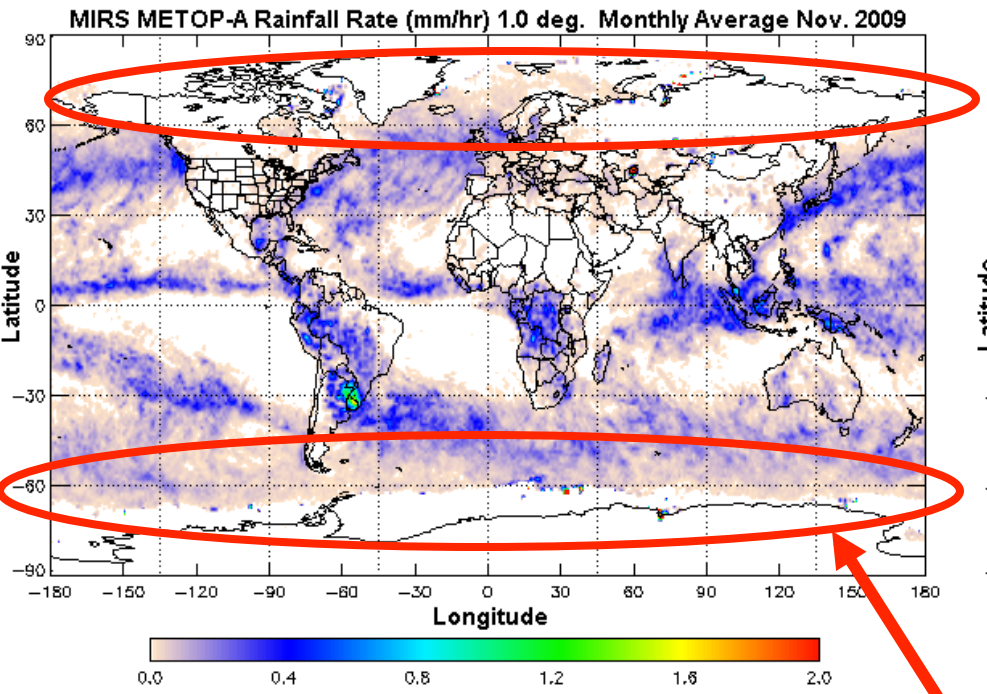


Theoretical performances in clear-sky for temperature sounding over ocean (a) and land (b) and water vapor sounding over ocean (c) and land (d). Simulations are performed with no instrument noise added.

RainFall Rate Assessment

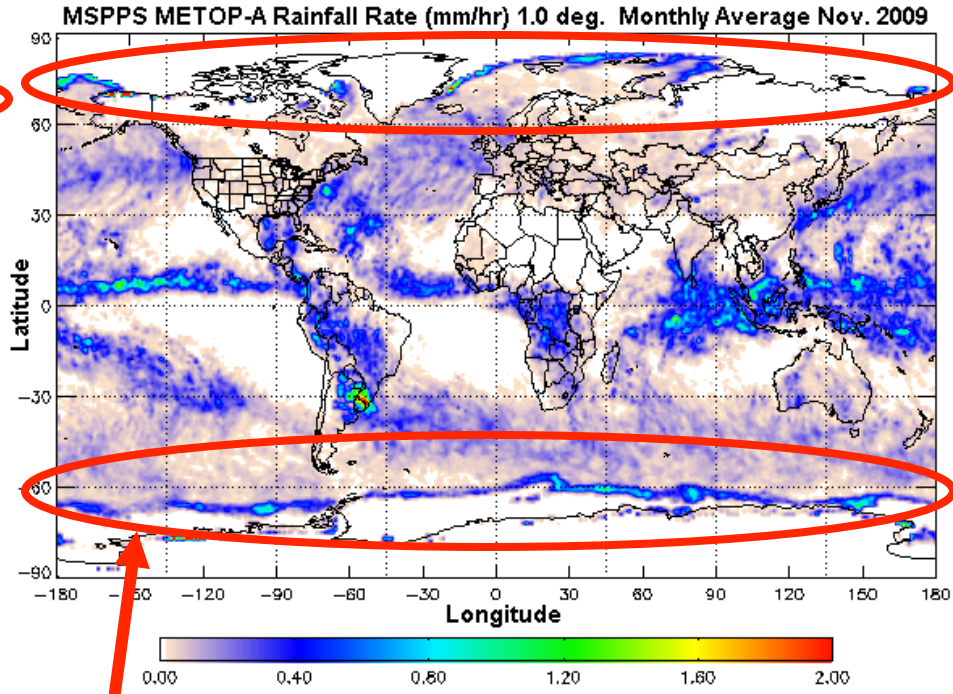
MiRS Monthly composite (Metop-A)

1DVAR



MSPPS Monthly composite (Metop-A)

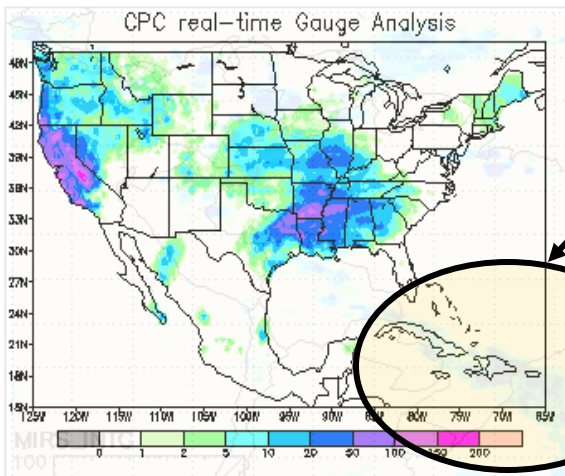
Heritage algorithm: based on physical regression



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)



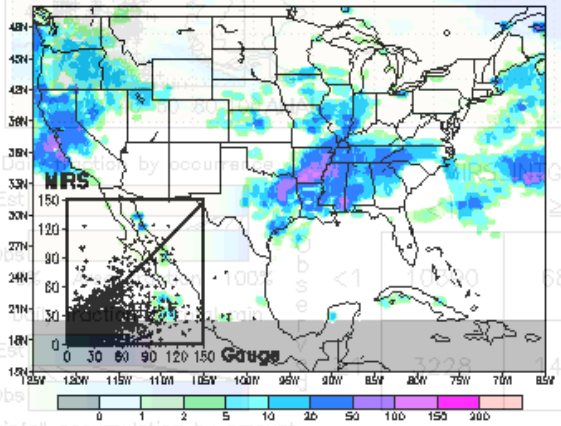
	(G) gauge	(S) MIRS	(R) radar
Number of points:	11699.	11699.	11699.
# points w/rain:	6719.	4409.	5754.
Mean rain rate:	8.51	5.99	5.67
Cond. rain rate:	14.68	15.86	11.36
Max. rain rate:	184.07	123.81	143.01
	G–S	G–R	R–S
Correlation:	0.663	0.834	0.716
Mean Absolute Error:	5.76	4.72	4.42
RMSE (mm/day):	12.76	10.84	8.84
RMSE (normalized):	1.50	1.21	1.55
Probability of Detection:	0.599	0.737	0.572
False Alarm Ratio:	0.087	0.141	0.144
Bias Ratio (rain:no rain):	0.656	0.858	0.668
Heidke Skill Score:	0.493	0.560	0.497
Hanssen–Kuipers Score:	0.522	0.574	0.487
Equitable Threat Score:	0.327	0.389	0.330

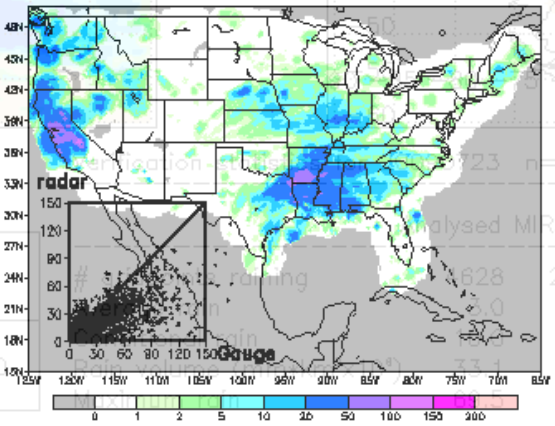
MIRS

gauge	< 1	≥ 1
< 1	4597.	383.
≥ 1	2693.	4026.

radar

gauge	< 1	≥ 1
< 1	4179.	813.
≥ 1	1766.	4941.



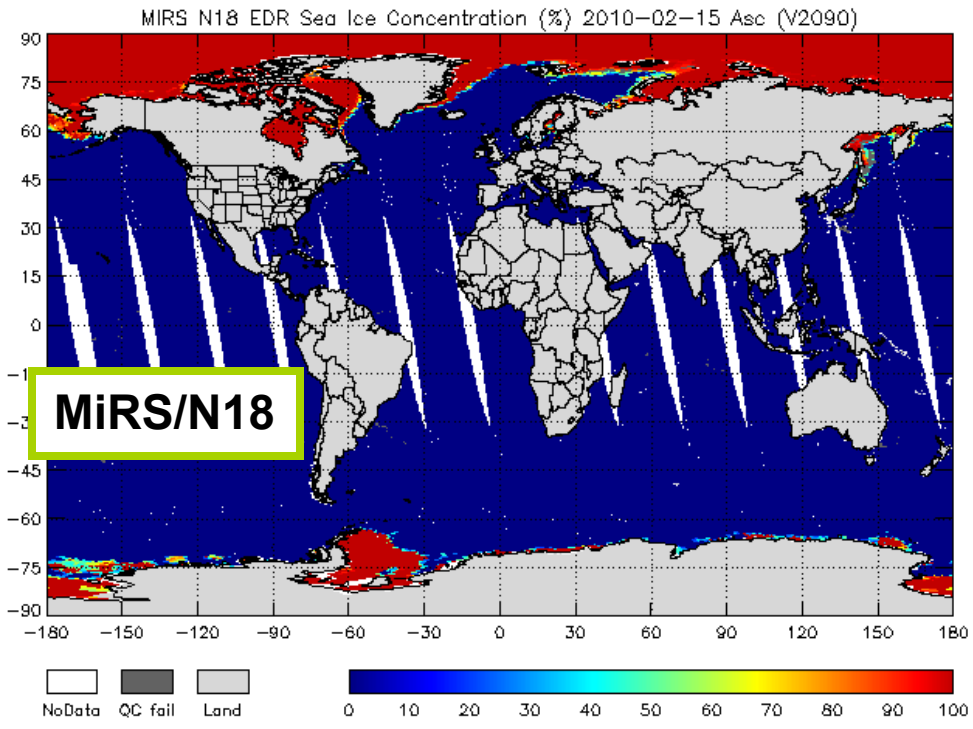


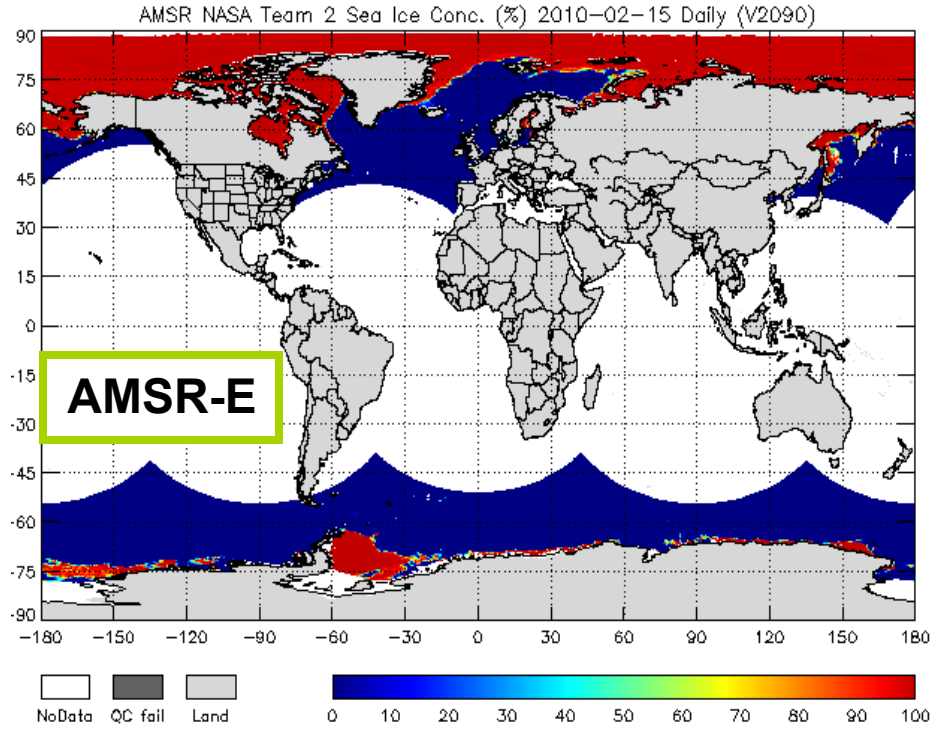
This is an independent assessment where comparisons of MiRS RR composites are made against radar and gauges data.

Image taken from IPWG web site: credit to Daniel Villa

MiRS/N18 Sea-Ice Concentration Assessment

Comparison with AMSR-E

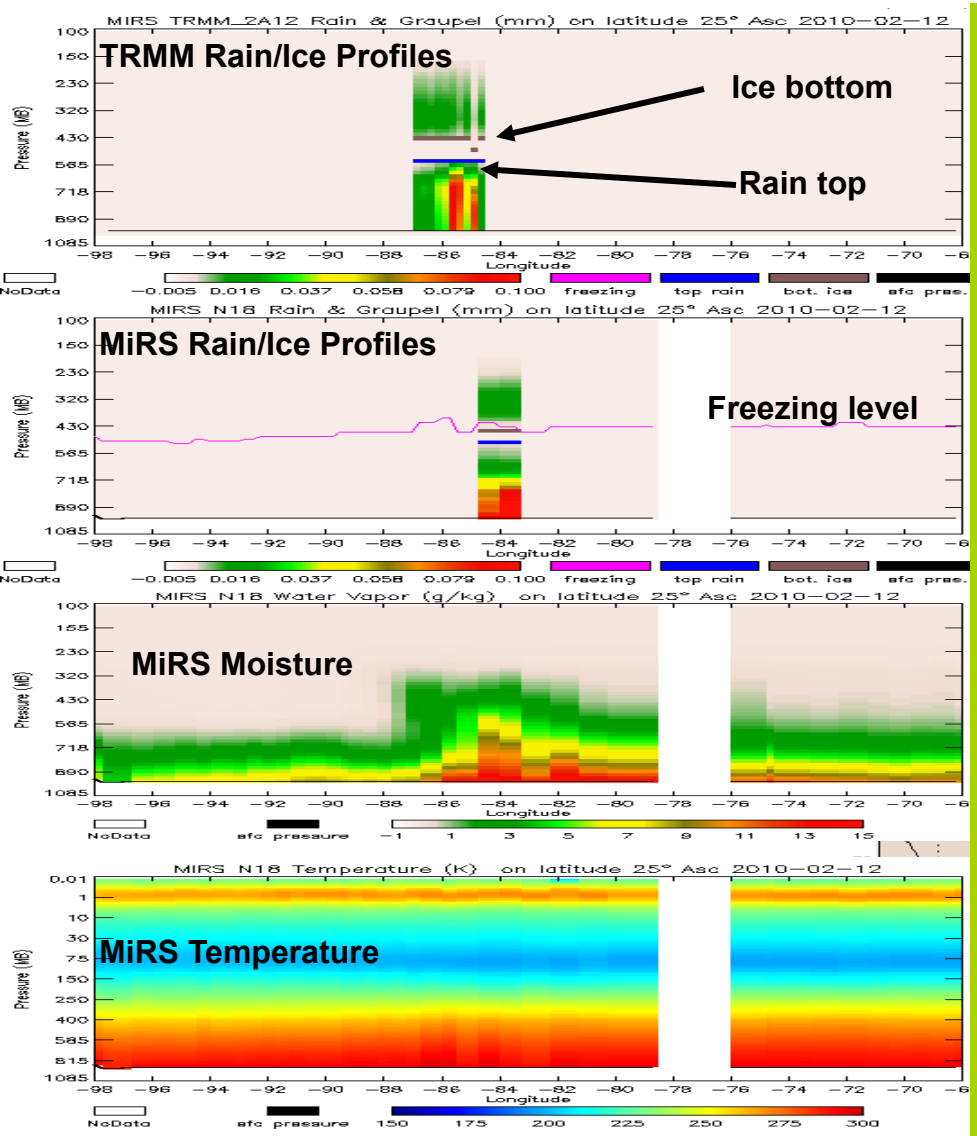




All MiRS surface parameters are obtained from emissivity, not TBs (so the validation of these products is an indirect validation of emissivity itself)

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

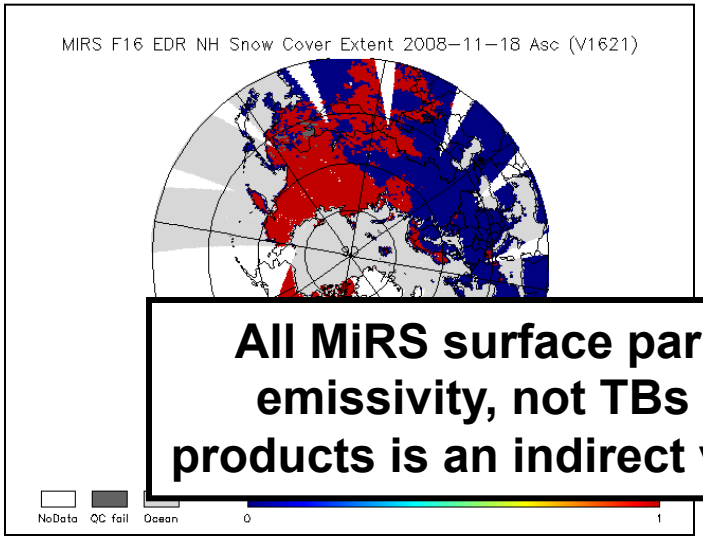
- Suggests that these products are reasonably constrained within physical inversion

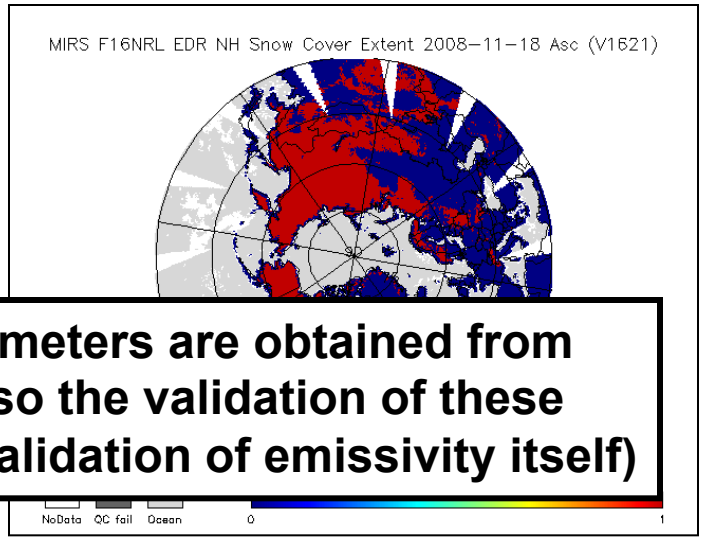
MiRS/F16 SSMIS Snow Cover Extent (SCE)

Comparison with IMS & AMSR-E

2008-11-18

F16 MIRS





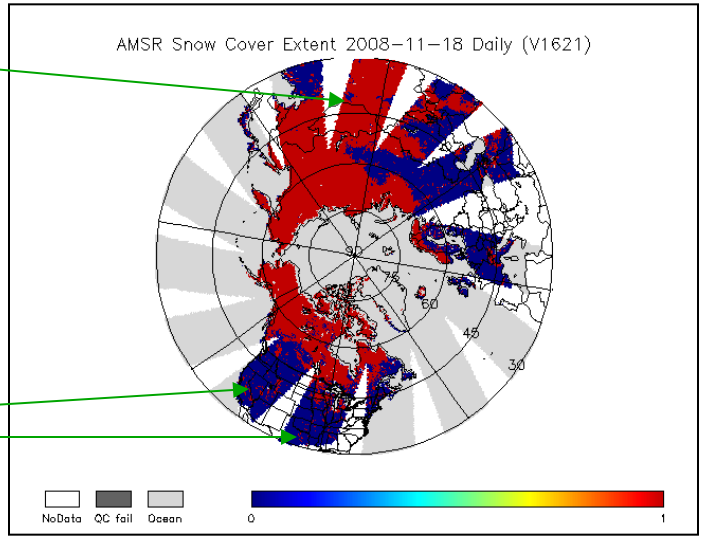
F16 NRL

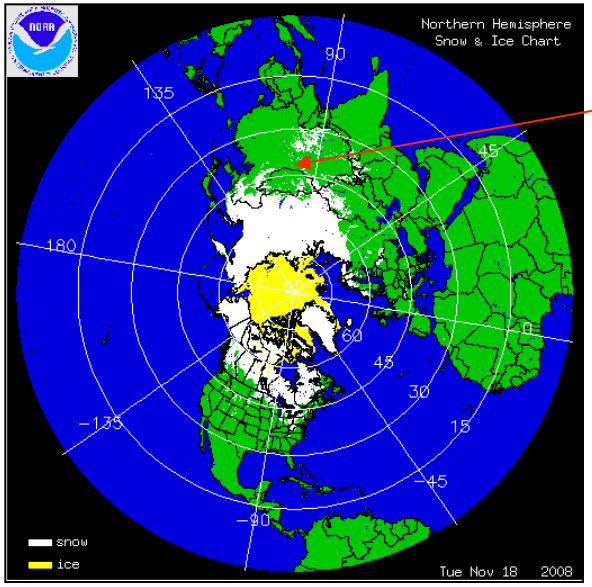
All MiRS surface parameters are obtained from emissivity, not TBs (so the validation of these products is an indirect validation of emissivity itself)

Extensive snow cover

AMSRE

False alarms





Less Extensive snow cover

IMS