Benefits of Using a Variational Preprocessing Approach for the Assimilation of Satellite Radiances:

An Application to Data Assimilation in Environmental Data Fusion

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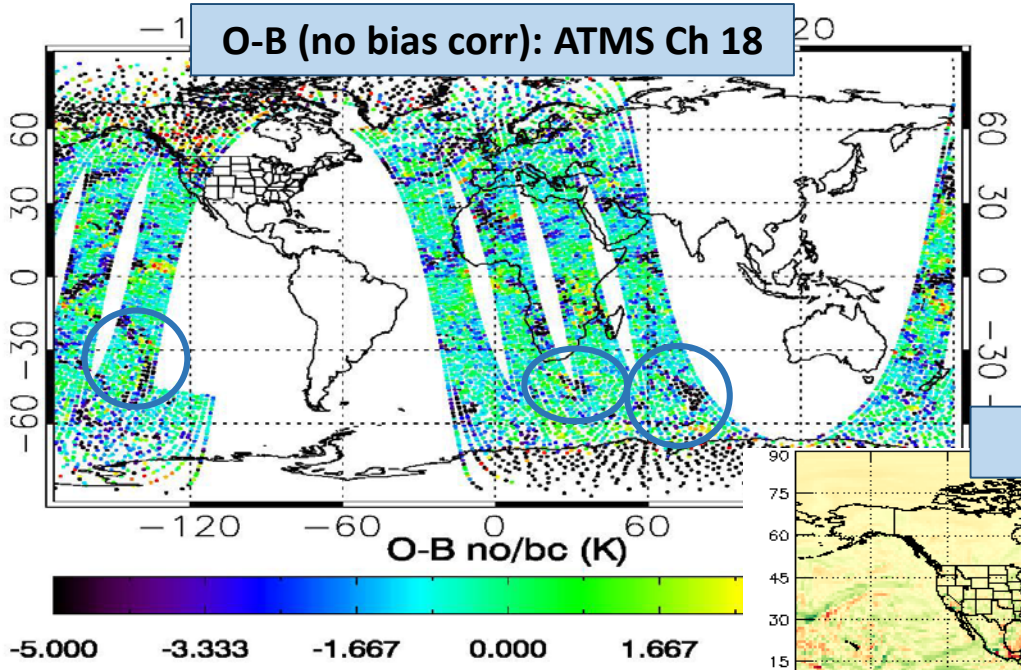
Objective and Motivation

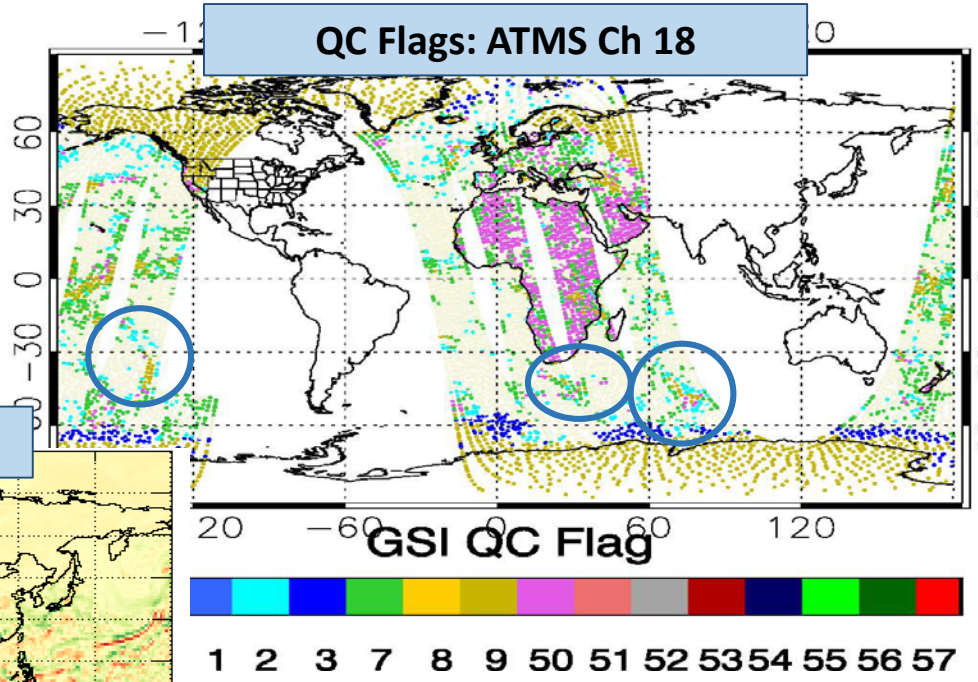
- The problem:
  - Satellite observations, especially those sensitive to moisture variables, tend not to be assimilated very well in data assimilation systems
    - Observations are often QC-ed out where the background differs too much from the observation, and/or in regions where observations tend not to be modeled well (e.g. cloudy or precipitating areas)
  - The result is an analysis that sticks to the background and contains displacements, especially in moisture fields

O-B (no bias corr): ATMS Ch 18

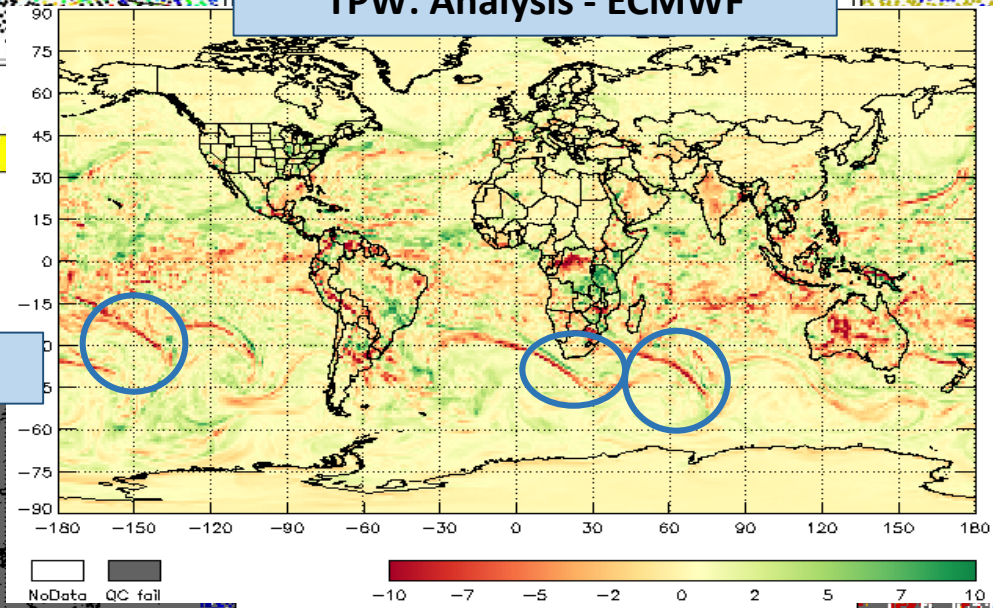


Standard Data Assimilation: GSI 4DEnsVar 20151223 12Z

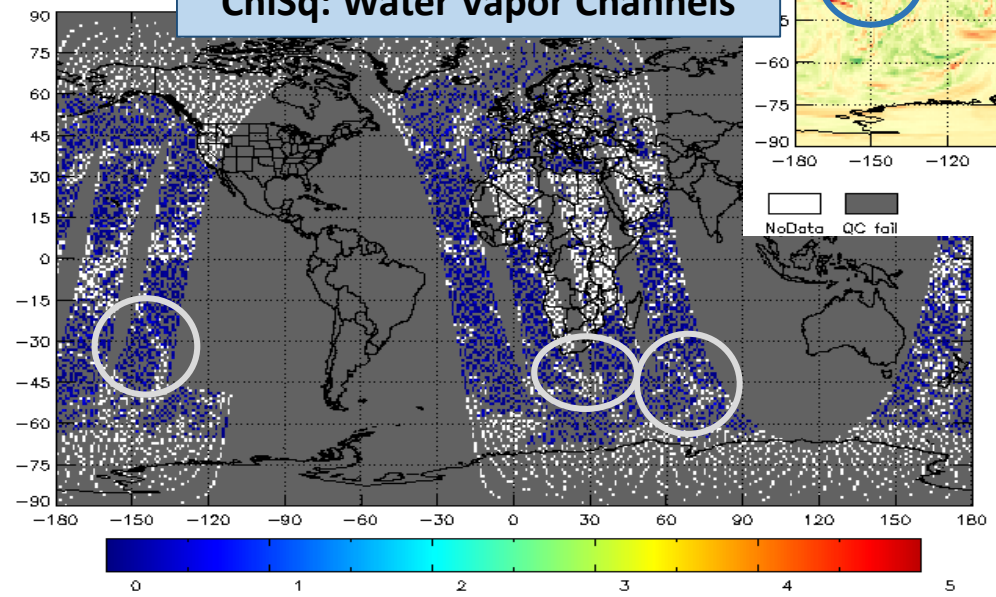
QC Flags: ATMS Ch 18



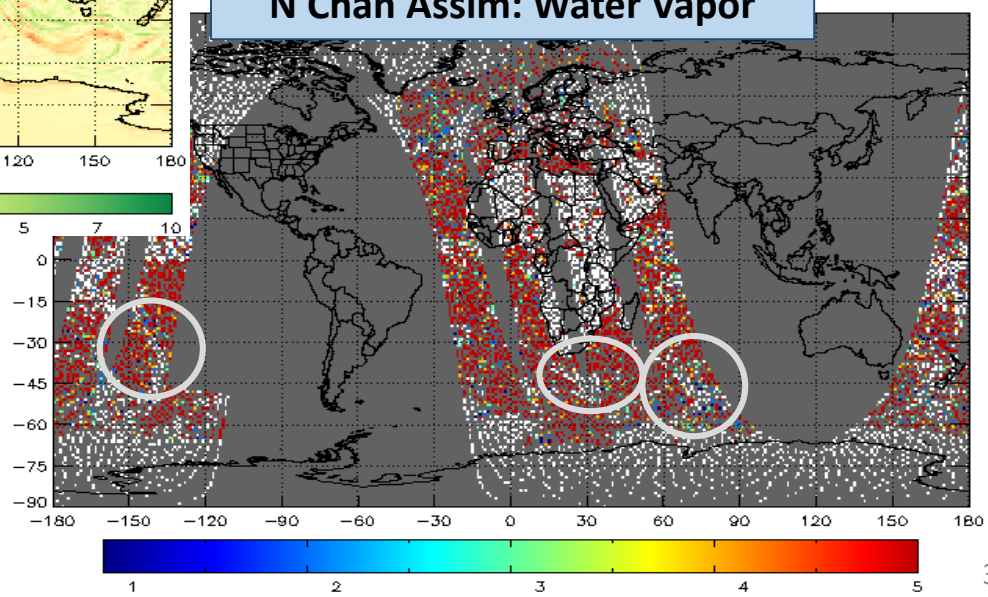
TPW: Analysis - ECMWF



ChiSq: Water Vapor Channels



N Chan Assim: Water Vapor



Large dipoles / displacements in TPW where obs failed QC (mostly for gross check, emissivity, and precip)

Objective and Motivation

- The problem:
  - Satellite observations, especially those sensitive to moisture variables, tend not to be assimilated very well in data assimilation systems
    - Observations are often QC-ed out where the background differs too much from the observation, and/or in regions where observations tend not to be modeled well (e.g. cloudy or precipitating areas)
  - The result is an analysis that sticks to the background and contains displacements, especially in moisture fields
- The goal:
  - Lessen dependence on the background in the analysis:
    - Create an analysis that is more informed by satellite observations, especially for moisture variables
    - Address the problem of displacements in the analysis fields
  - This can be achieved by putting satellite data through a preprocessor prior to assimilation: **MIIDAPS (The Multi-Instrument Inversion and Data Assimilation Preprocessing System)**

MIIDAPS Background

- MIIDAPS: The Multi Instrument Inversion and Data Assimilation Pre-Preprocessing System
  - 1DVar preprocessor based on the MiRS (Microwave Integrated Retrieval System) algorithm, which has been operational at NOAA since 2007:

Minimize the cost function:

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

Solve for:

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

Assume linearity:

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

This methodology can be applied to all parameters, including hydrometeors

Iterative solution:

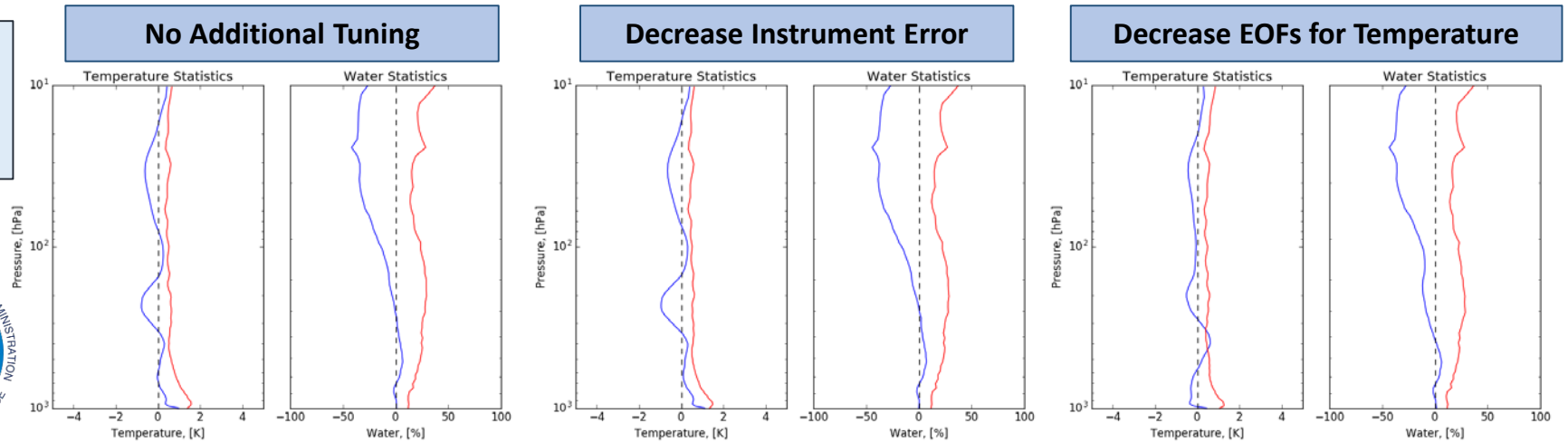
$$X_{n+1} = \left\{BK_n^T\left(K_n BK_n^T + E\right)^{-1}\right\}\left[\left(Y^m - Y(X_n)\right) + K_n X_n\right]$$

Forward and Jacobian operators from CRTM

MIIDAPS Background

- MIIDAPS: The Multi Instrument Inversion and Data Assimilation Pre-Preprocessing System
  - Methodology doesn't vary based on platform; approach could be extended to any sensor (microwave or infrared)
  - Approach is valid over all surfaces and in all-sky conditions
  - Can use climatology or an NWP field as a first guess/background to the 1DVar
  - Has several benefits, including:
    - Highly tunable retrievals
    - The potential to provide consistent quality control for a DA system
    - The ability to be run in a parallel in an HPC environment

ATMS in simulation, Verified against the Nature Run



MIIDAPS retrievals can be tuned independently for each sensor to optimize performance.

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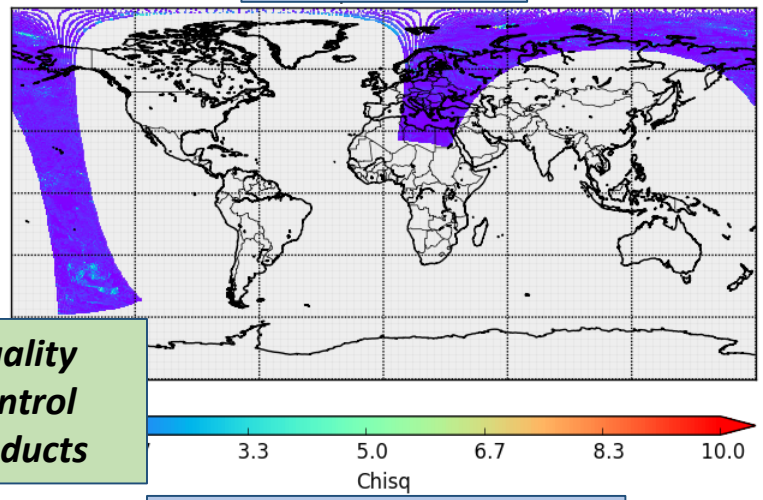
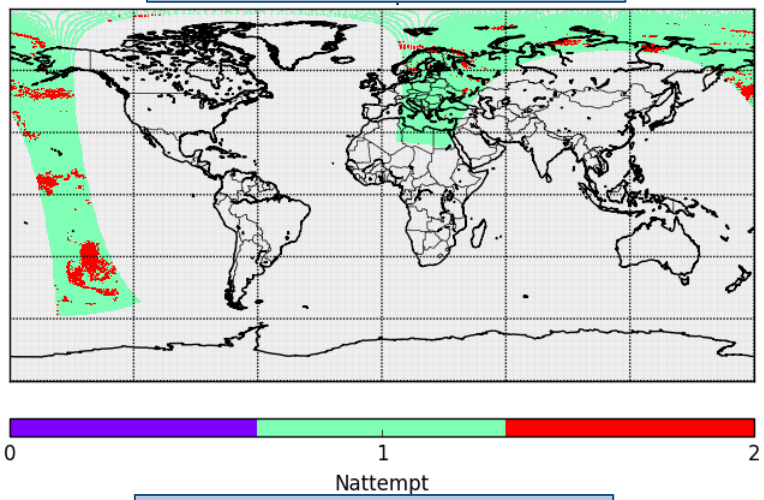
MIIDAPS Products and Performance

Quality Control Products

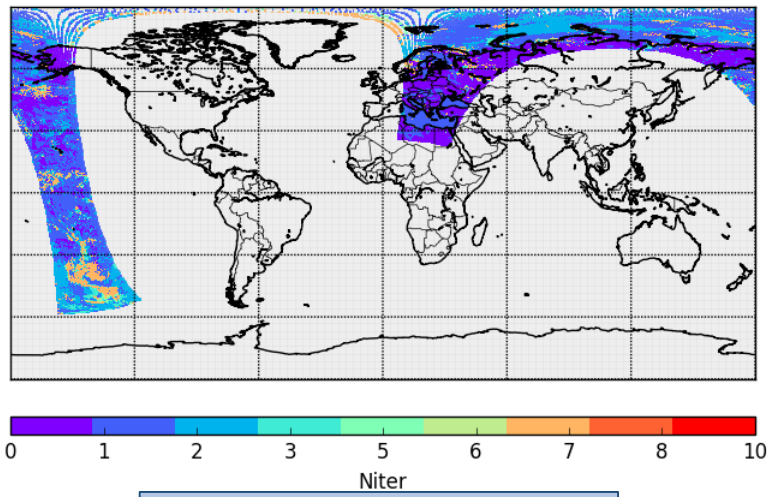
Chi Square



Number of Attempts

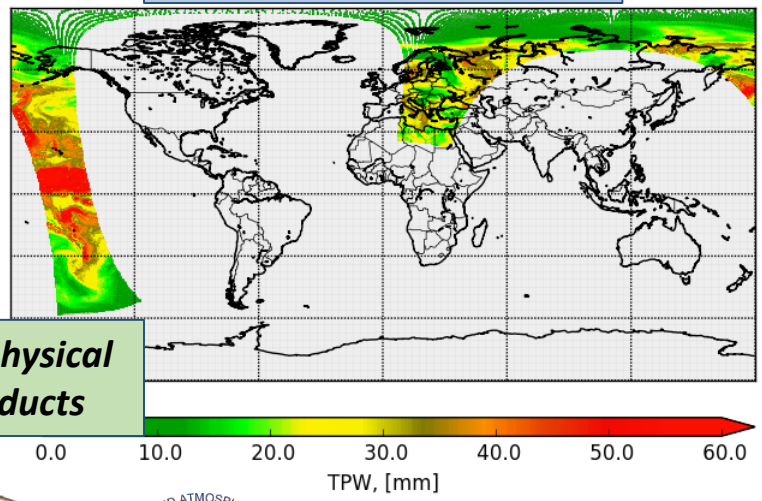


Number of Iterations

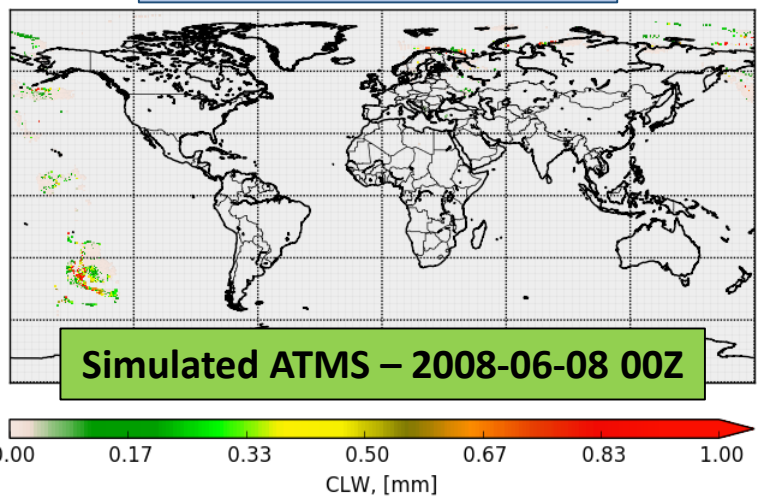


Geophysical Products

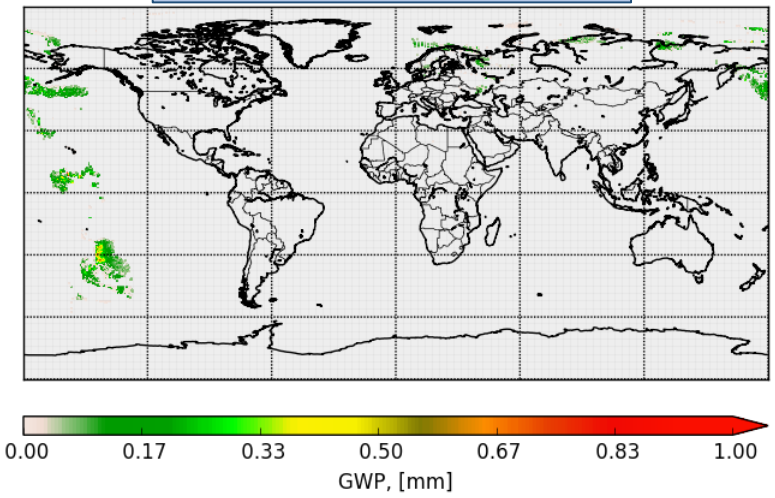
Precipitable Water



Cloud Liquid Water



Graupel Water Path



Simulated ATMS – 2008-06-08 00Z

Low chi square values indicate that MIIDAPS converged well. Cloud or precipitation is often present where chi square values are high; information that can be useful in informing QC.

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MIIDAPS Products and Performance

MIIDAPS Satellite Products											
	T(p)	Q(p)	SST/LST	TPW	Cloud & Ice Amt	Cld Type/Top	Precip	Sfc Emiss	SIC/SWE	Trace Gas	QC (ChiSq)
NOAA-18 AMSU/MHS											
NOAA-18 AVHRR											
NOAA-19 AMSU/MHS											
NOAA-19 AVHRR											
Metop-A AMSU/MHS											
Metop-A IASI											
Metop-B AMSU/MHS											
Metop-B IASI											
SNPP ATMS											
SNPP CrIS											
DMSP SSMI/S											
Aqua AMSU											
Aqua AIRS											
Megha-T SAPHIR											
GPM GMI											
GCOM-W1 AMSR2											
GOES-15 Sndr/Imgr											
Meteosat SEVIRI											
Himawari-8 AHI											
GOES-16 ABI											

Moderate Information Content / Confidence

Good Information Content / Confidence

Not Enough Information Content for Retrieval

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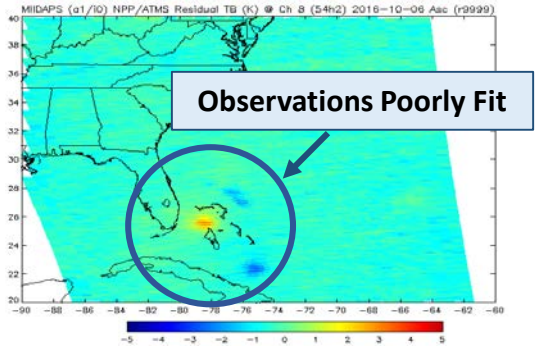
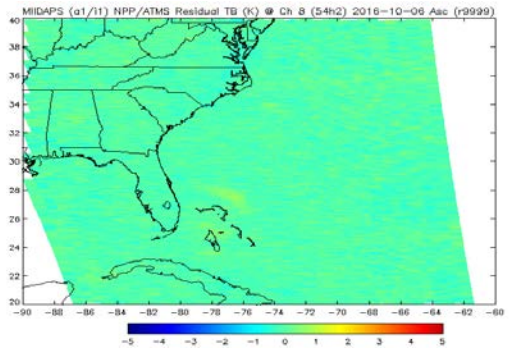
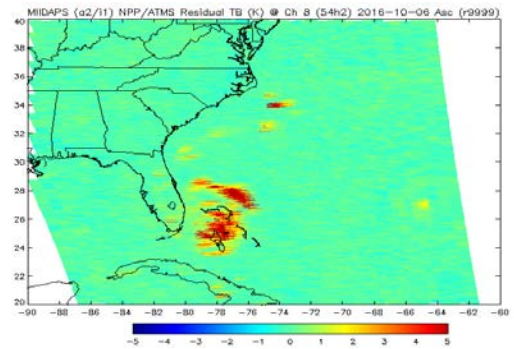
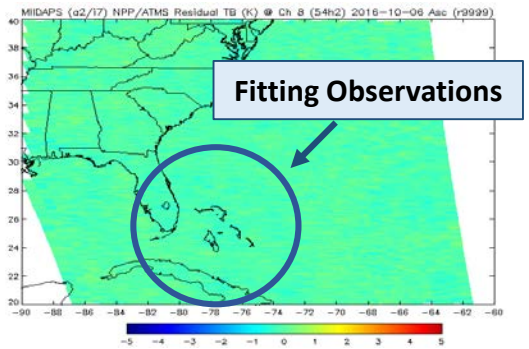
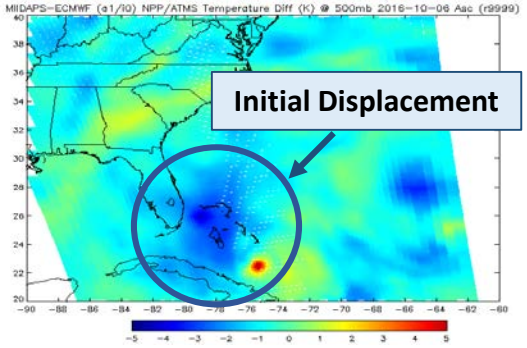
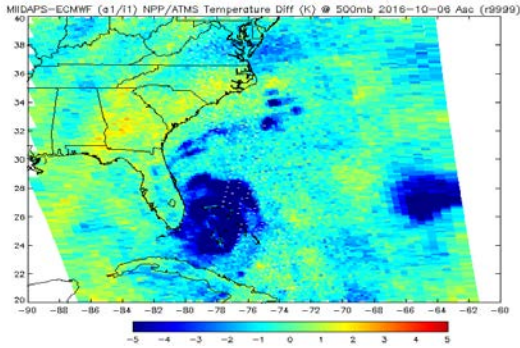
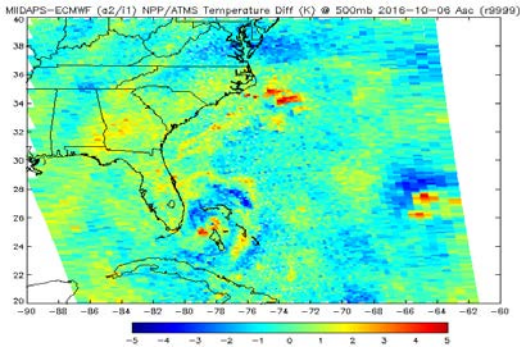
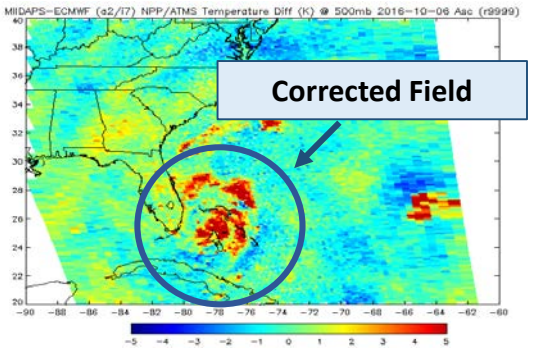
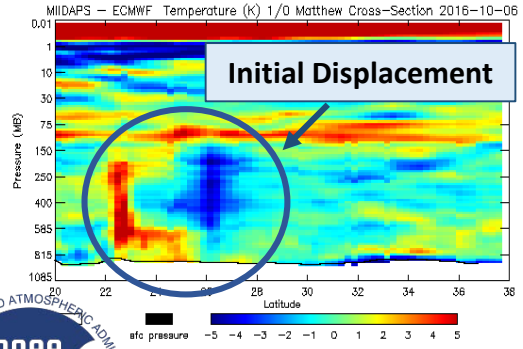
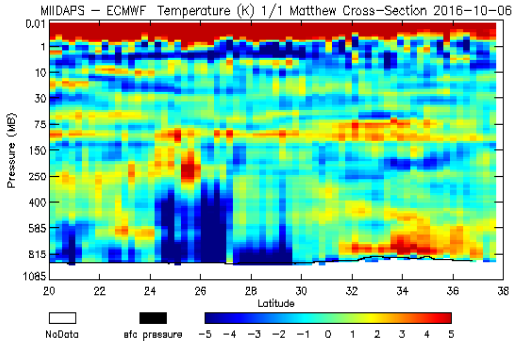
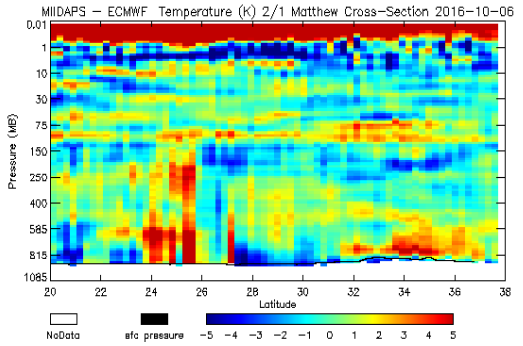
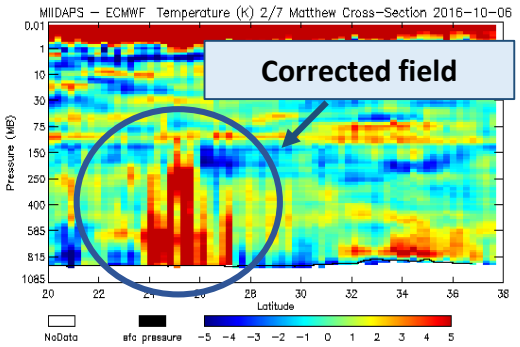
MIIDAPS Products and Performance

Hurricane Matthew

	Background (Forecast)	1st Iteration	8th Iteration	14th Iteration
ATMS 54 GHz Residual T_b				
500 mb Temp: MIIDAPS - ECMWF				
Temp Profile: MIIDAPS - ECMWF				

Observations Poorly Fit

Fitting Observations

Initial Displacement

Corrected Field

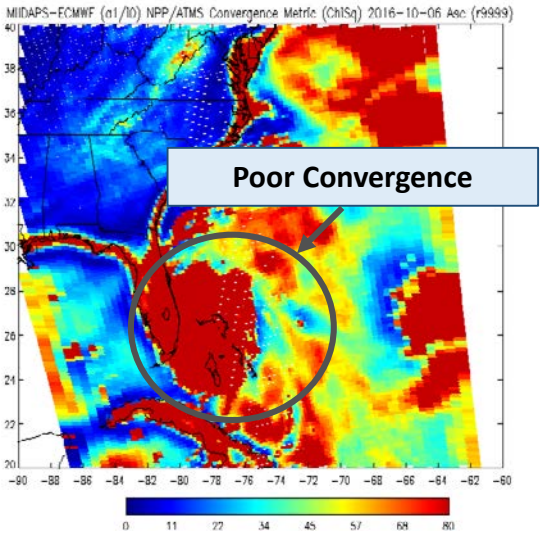
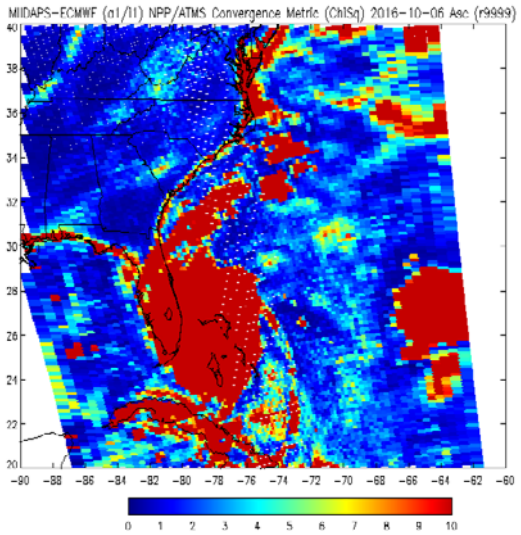
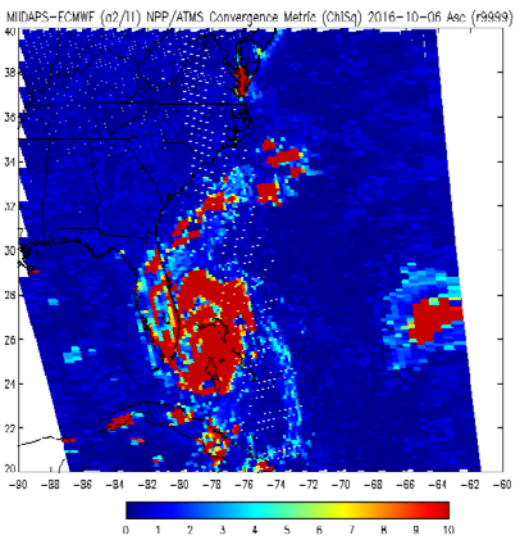
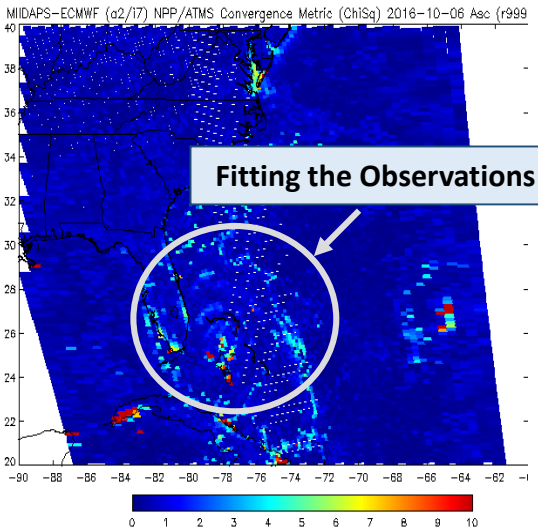
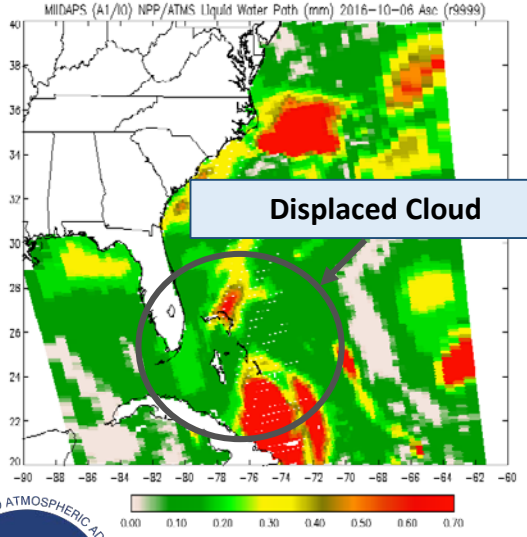
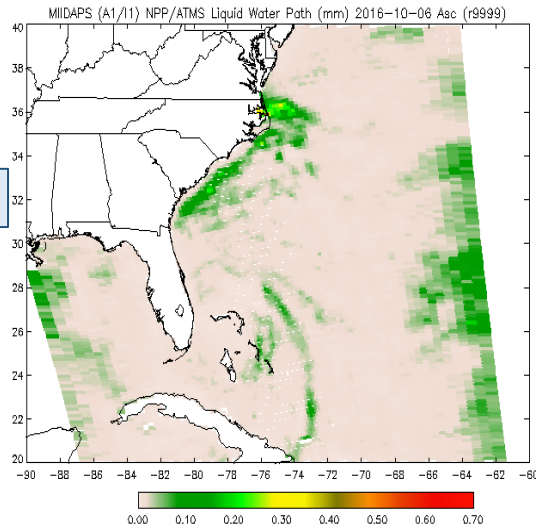
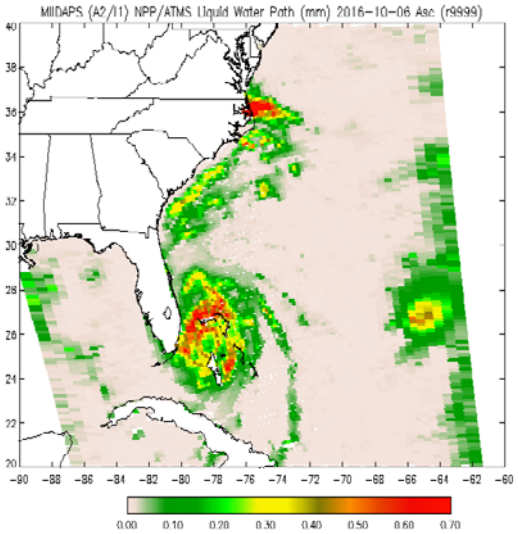
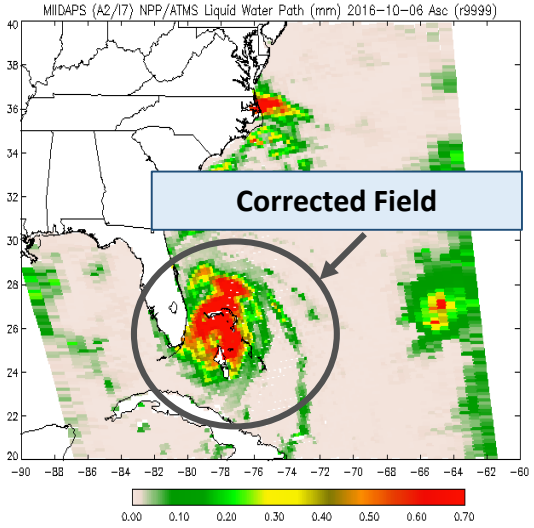
Initial Displacement

Corrected field

MIIDAPS removes horizontal and vertical displacements in model background temperature fields to fit them more closely to observations.

MIIDAPS Products and Performance

Hurricane Matthew

	Background (Forecast)	1st Iteration	8th Iteration	14th Iteration
Convergence Metric (Chi Square)				
Liquid Water Path (LWP)				

MIIDAPS moves background moisture fields closer to moisture fields retrieved from observed data.

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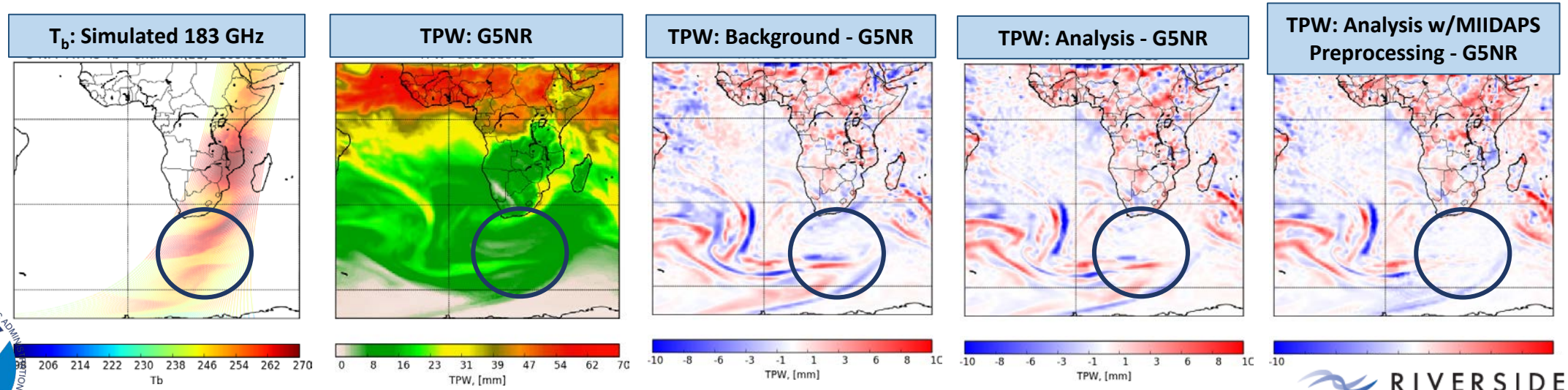
MIIDAPS Applications

- MIIDAPS as a preprocessor for satellite data assimilation:
  - Retrieved products (e.g. temperature, moisture profiles) can be used to adjust the model background prior to assimilation
    - Tunable, depending on the sensor
  - Retrieved products can be used to inform/constrain unanalyzed variables (not part of the state vector, but impact radiance simulation) in the assimilation system
  - Convergence metrics and other products can be used for universal quality control in the assimilation system
    - More accurate quality control and more observations assimilated

MIIDAPS as a Preprocessor: Background Adjustment with Simulated ATMS



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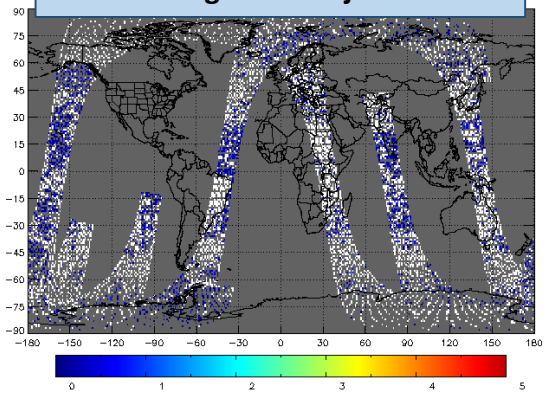
MIIDAPS Applications

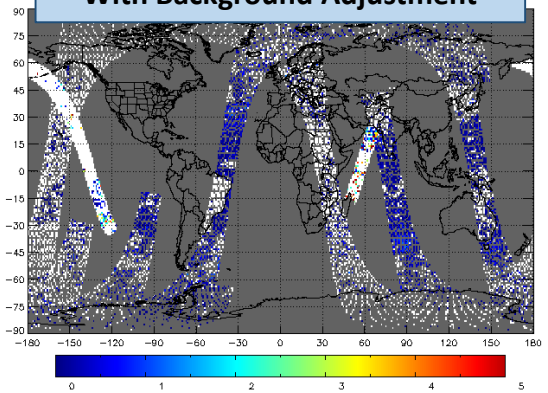
MIIDAPS as a Preprocessor in Data Fusion

- Data Fusion:
  - Can use MIIDAPS as a preprocessor for data assimilation, with options to use background adjustment, MIIDAPS QC, and variable constraints
  - High resolution (25km) global hourly analysis informed by satellite data over the atmospheric column; useful for situational awareness

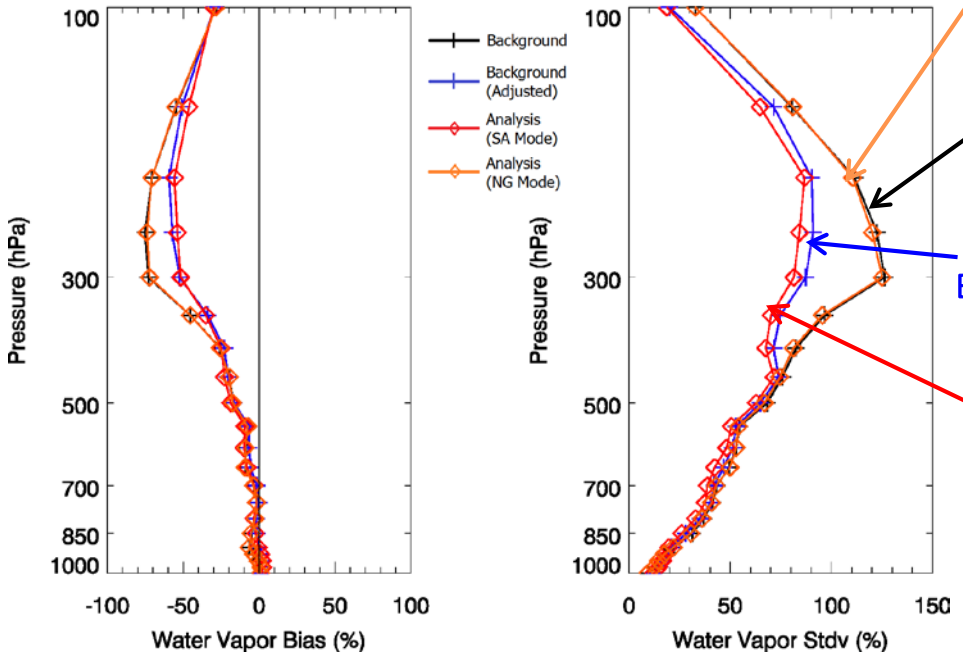
ChiSq: Water Vapor Channels No Background Adjustment



ChiSq: Water Vapor Channels With Background Adjustment



Water Vapor Statistics : DA/DF versus ECMWF



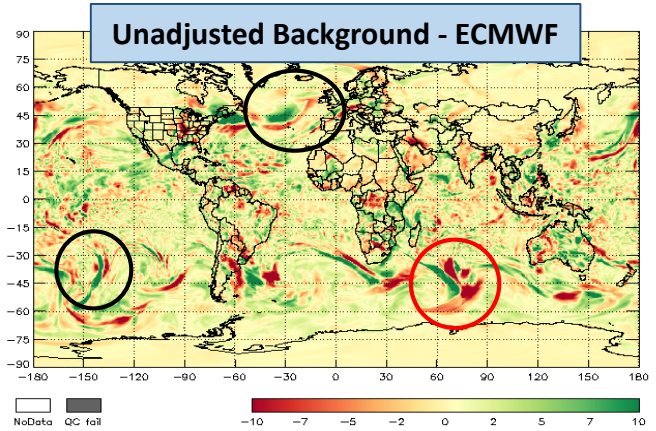
Data Assimilation Analysis

Data Assimilation Background

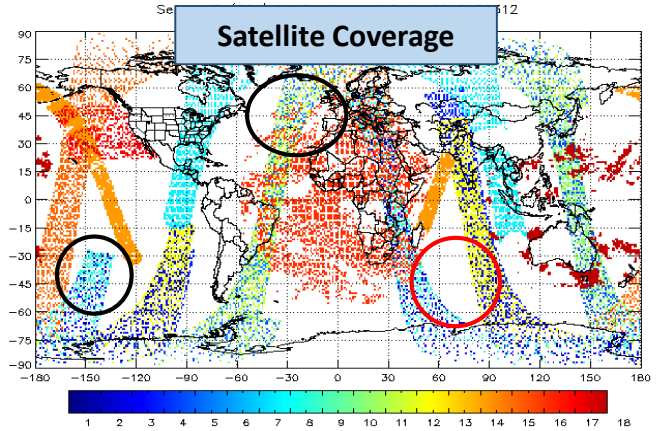
Data Fusion Adjusted Background (MIIDAPS pre-processing)

Data Fusion Analysis

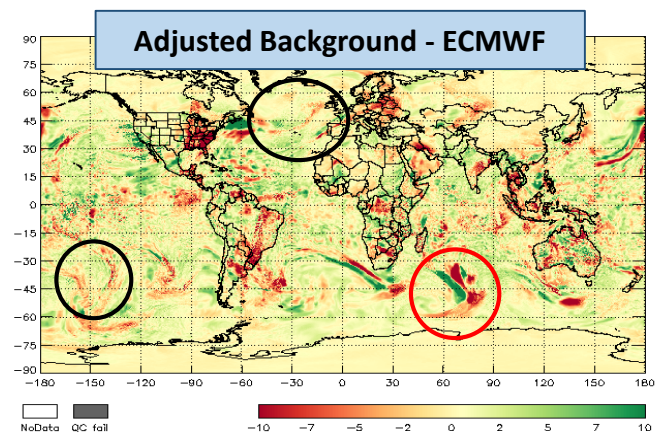
Unadjusted Background - ECMWF



Satellite Coverage



Adjusted Background - ECMWF



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Conclusions and Future Work

- MIIDAPS is a sensor-agnostic tool:
  - Capable of retrieving geophysical parameters from satellite data; retrievals are highly tunable
  - Can serve as a preprocessor in data assimilation
  - Valid for use with both microwave and IR sensors
- MIIDAPS results are valid over all surface types, and in all-sky conditions
- MIIDAPS has been shown to correct displacements in modeled fields
  - Able to adjust a data assimilation background to more closely fit the observations
- Work is ongoing to validate MIIDAPS as a preprocessor in the Data Fusion system
- Work is planned to test analyses produced using MIIDAPS as initial background for NWP