Data Fusion through Synergy of Data Assimilation and Remote Sensing Techniques

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Outline

- **data fusion project overview**
  - *objectives*
  - *concept*
  - *framework*
- **science highlights**
  - *data assimilation enhancement*
  - *remote sensing integration*
  - *displacement correction*
  - *analysis improvements*
  - *data fusion product illustrations*
- **summary**

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why data fusion?

Data Fusion approach synergizes remote sensing and data assimilation

Algorithm/Product Attributes	Remote Sensing (sensor by sensor)	Traditional Blending or Merging (or morphing)	Data Assimilation	Data Fusion
User friendliness (data access) of multitude parameters	Multiple data streams (information overload)	Only for single parameters		
Reliability (accuracy, spatial/vertical placement)			Good for single parameters	
Time Frequency	Not regular intervals over same regions	Not regular intervals over same regions	Usually every 6 hours, at times more frequently	
Spatial & Vertical Resolutions	Depends on sensor			
Diversity of Geophysical Products	Depends on sensor	Single Parameters	Only Parameters important for forecast	Depends on enhancements to current systems
Consistency of Geophysical Products	Depends on algorithm	Single parameters, not cross-correlated through blending		
Consistency with Observations	Depends on algorithm	Depends on the algorithm	Removes good observations if they disagree with background	
Collocation of Observing Systems	Single platform	Only for set of sensors		
Combination of Conventional Data and Satellites	Sometimes used for correction			
Accounting for Observation Sources Errors	Depends on sensor and algorithm	Depends on blending technique		
Application to Prediction (NWP)				In theory, but not if observations and forecast are inconsistent
Application to Situational Awareness				

Optimal

Moderate

Poor

data fusion objectives

Data Assimilation is essentially a variational blending technique

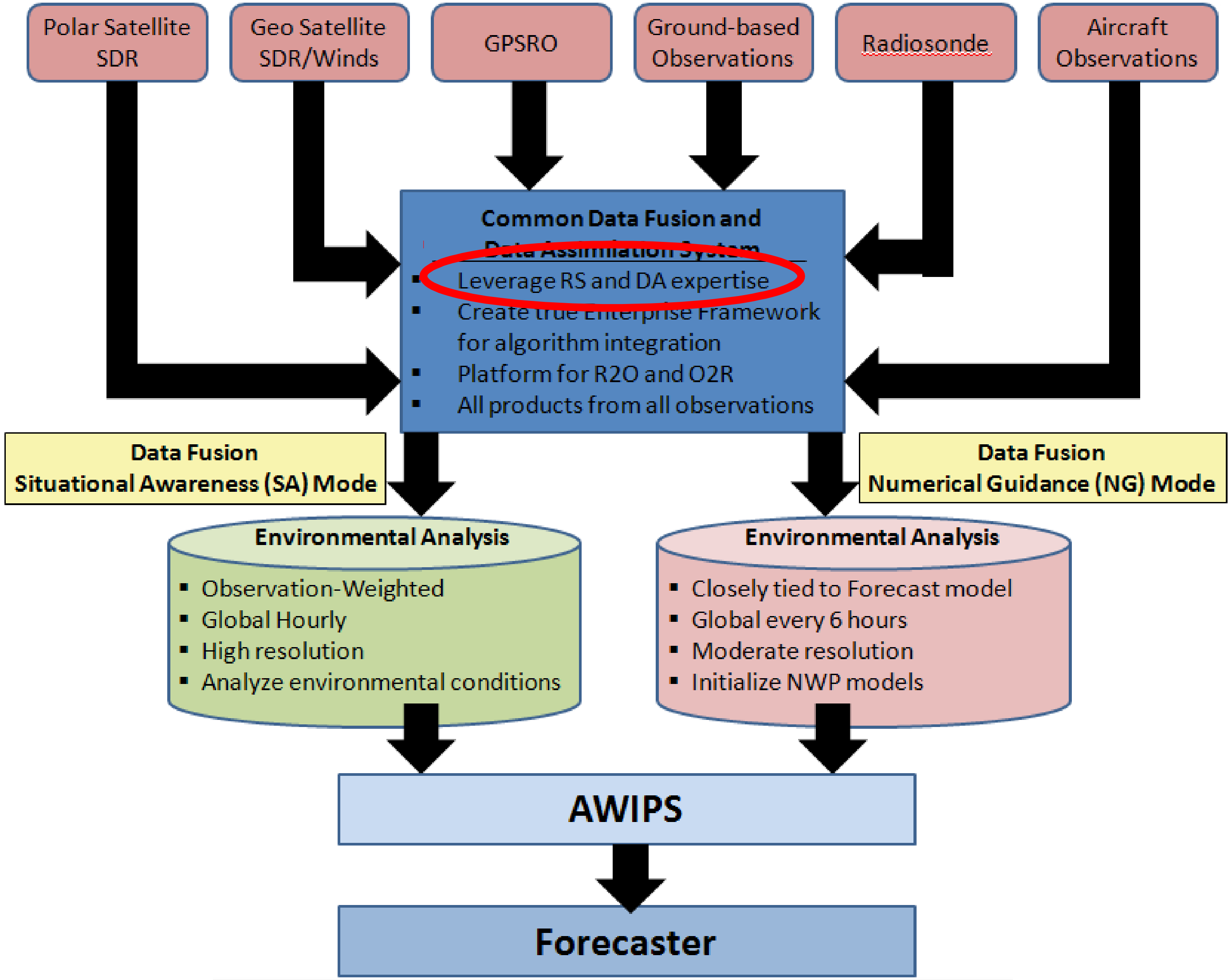
- **Develop an end-to-end framework to integrate remote sensing technology and data assimilation for a unified analysis.**
    - Use of remote sensing algorithms to compliment/improve data assimilation (improve guess, parameterizations, etc.)
    - Leverage 3D/4D, and balance constraints of variational data assimilation
- **Provide a comprehensive 4D cube, observation-weighted analysis (full suite of environmental parameters) to support operational short-term forecasting/nowcasting.**
    - Hourly or sub-hourly updates
    - Global analysis with high spatial resolution
    - Inclusion of both observation-driven and model-driven fields in analysis
    - Full suite of physically consistent products that fit the observations (blending done in observation space)
- **Demonstrate the added-value provided.**

data fusion concept

Enterprise science framework

Build a Data Fusion system which combines remote sensing and data assimilation to produce analyses tailored for:

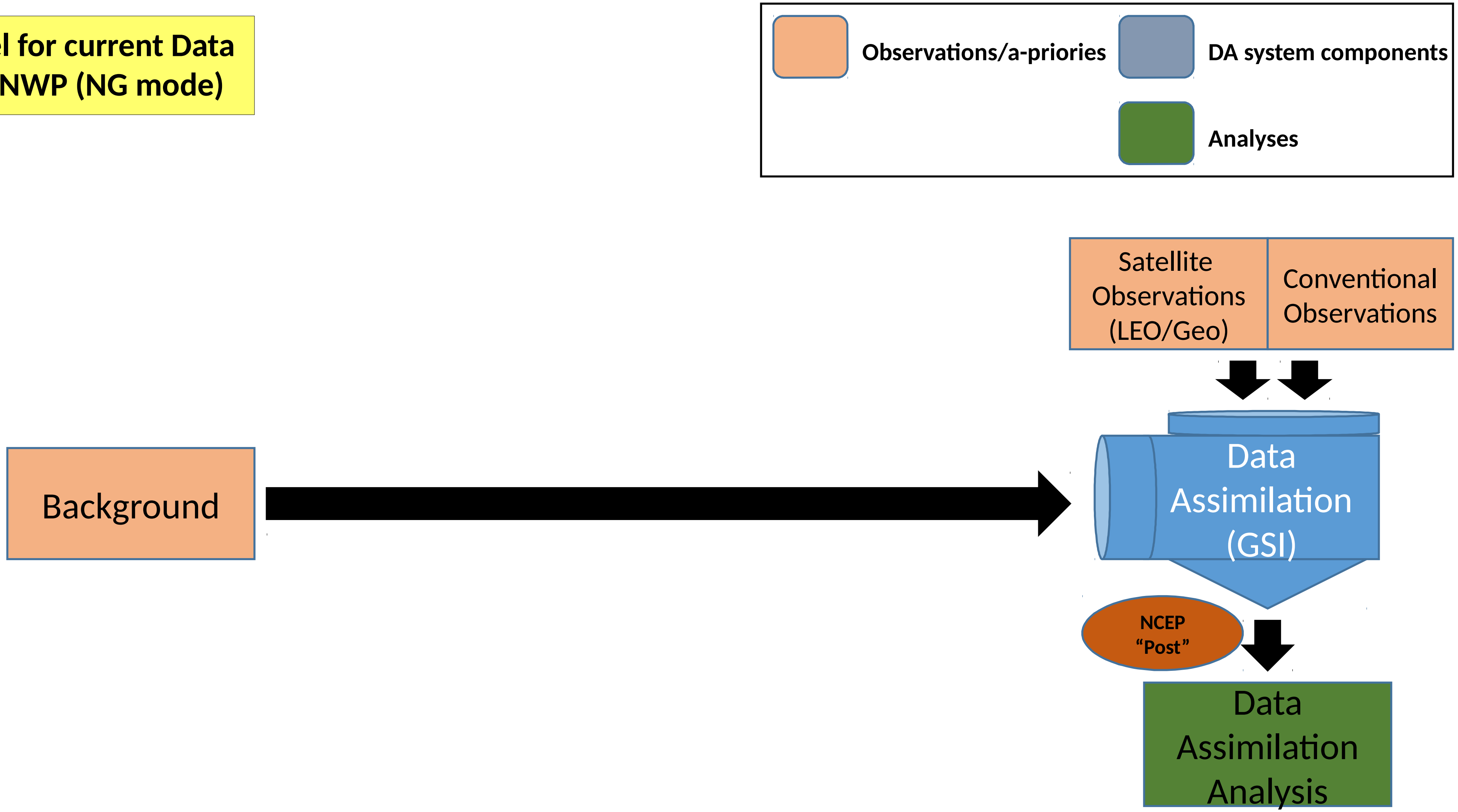
1) "Situational Awareness" (Observation-weighted)
or
2) "Numerical Guidance" (Background-weighted)



data fusion framework

Leverage current data assimilation

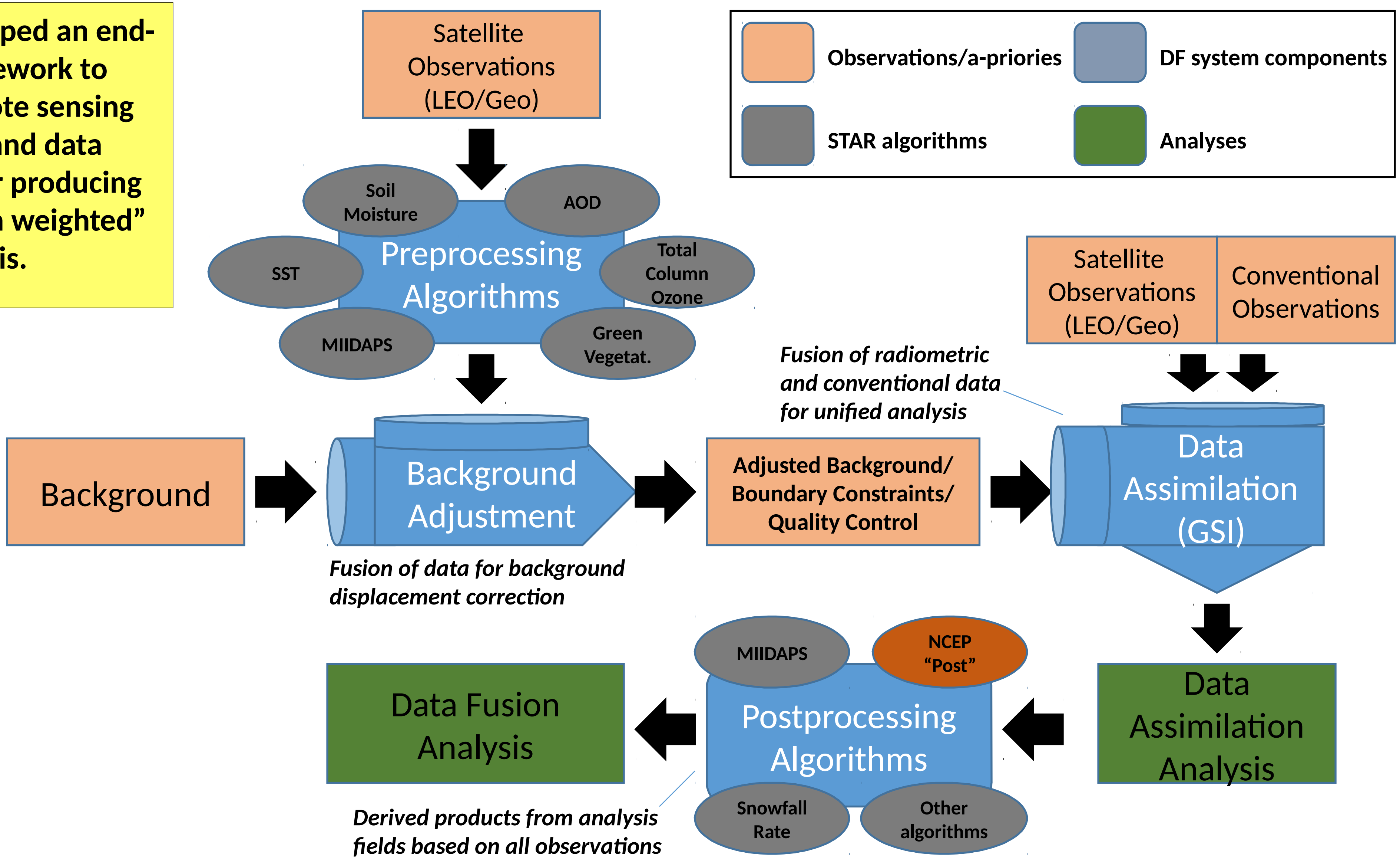
Simplified model for current Data Assimilation in NWP (NG mode)



data fusion framework

Practical implementation to synergize with remote sensing

STAR has developed an end-to-end framework to integrate remote sensing algorithms and data assimilation for producing an “observation weighted” analysis.



what does data fusion analysis contain?

Data Fusion includes integration of observations from multiple observing systems at each stage of processing for an observation-weighted analysis

Satellite & Conventional Data

Traditional Satellite Products														
	T	Q	SST/ LST	TPW	Cloud Amt	Cloud Top	QPE	Sfc Emiss	SIC/ SWE	Wind	Trace Gas	AOD	Soil Moisture	Lightning
POES														
Metop														
SNPP														
DMSP														
Aqua														
Megha-T														
GPM														
GCOM-W1														
GOES-15														
Meteosat														
Himawari-8														
GOES-R														
GPSRO														
Radiosonde														

Added-Value Products (Derived)

Quality Control Products

Added Value Products		Quality Control Products
CAPE	Vertical Velocity (ω)	Observation Coverage
CIN	Divergence (D)	Observation Type
Lifted Index (LI)	Geopotential Height (Z)	Convergence (χ^2)
Surface Pressure	Freezing Level	Data Age
Stream Function (Ψ)	Parameter Trends	Summary QC Flags
Vorticity (ζ)		

Satellite Capability	Optimal	Marginal	Inadequate Signal

what does data fusion analysis contain?

In red are those parameters introduced thanks to the remote sensing: combining remote sensing algorithms to data assimilation.

Traditional Satellite Products														
	T	Q	SST/ LST	TPW	Cloud Amt	Cloud Top	QPE	Sfc Emiss	SIC/ SWE	Wind	Trace Gas	AOD	Soil Moisture	Lightning
POES	green	green	green	green	green		red	red	red					
Metop	green	green	green	green	green	green	red	red	red		red	red		
SNPP	green	green	green	green	green	green	red	red	red	green	red	red		
DMSP	green	green	green	green	green		red	red	red					
Aqua	green	green	green	green	green	green	red	red	red	green	red	red		
Megha-T		green		green	green		red	red						
GPM		green	green	green	green		red	red	red					
GCOM-W1		green	green	green	green		red	red	red	green			red	
GOES-15	green	green	green	green		green	red	red	red	green	red			
Meteosat		green	green	green		green	red	red	red	green	red			
Himawari-8		green	green	green		green	red	red	red	green	red	red		
GOES-R		green	green	green		green	red	red	red	green	red	red		red
GPSRO	green	green		green										
Radiosonde	green	green	green	green						green				

Added Value Products		Quality Control Products
CAPE CIN Lifted Index (LI) Surface Pressure Stream Function (Ψ) Vorticity (ζ)	Vertical Velocity (ω) Divergence (D) Geopotential Height (Z) Freezing Level Parameter Trends (red)	Observation Coverage Observation Type Convergence (χ^2) Data Age Summary QC Flags

Contributed by Data Assimilation and/ or Remote Sensing (green)

Contributed by Remote Sensing (red)

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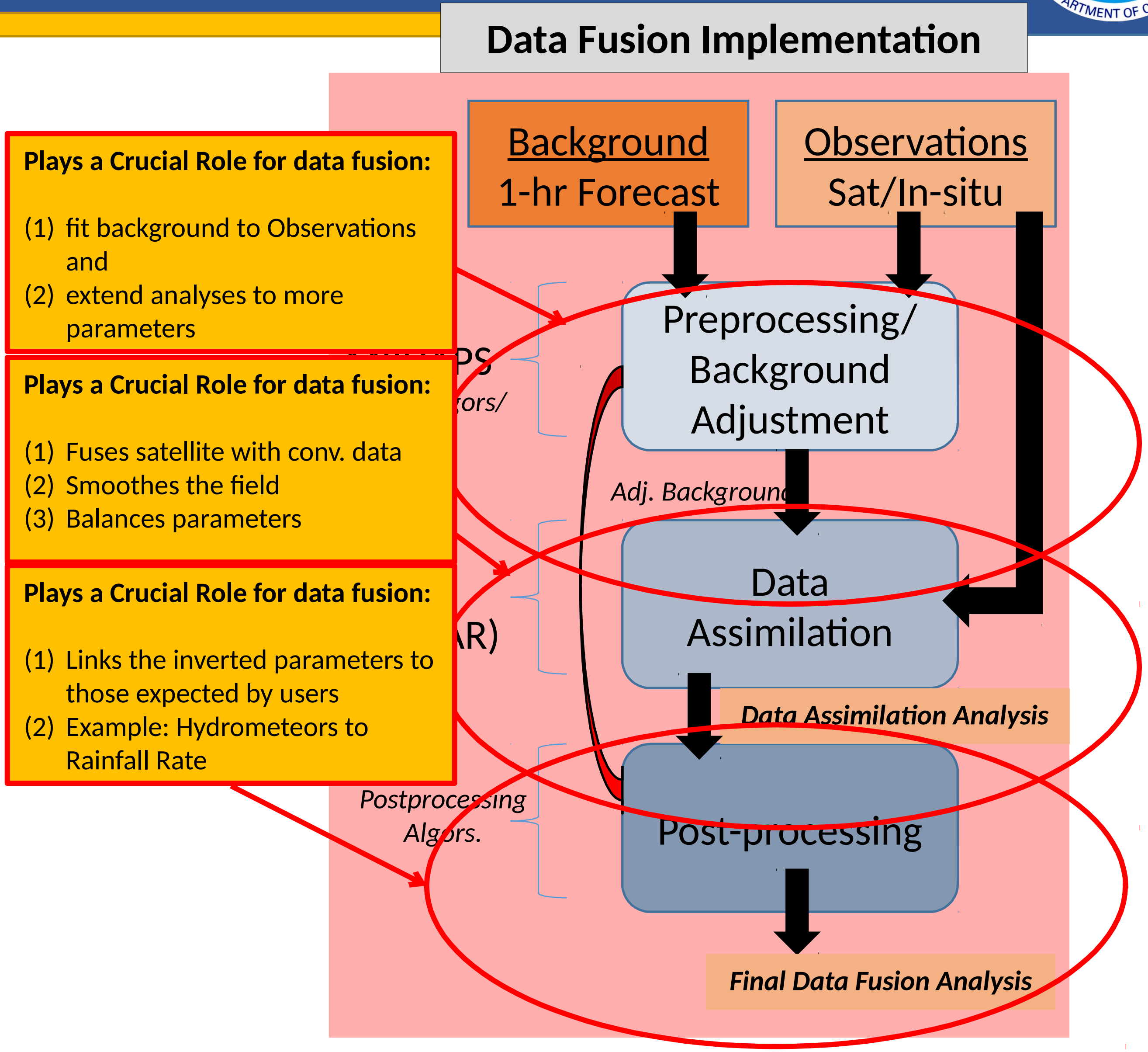
data fusion "SA" mode

Added value to data assimilation

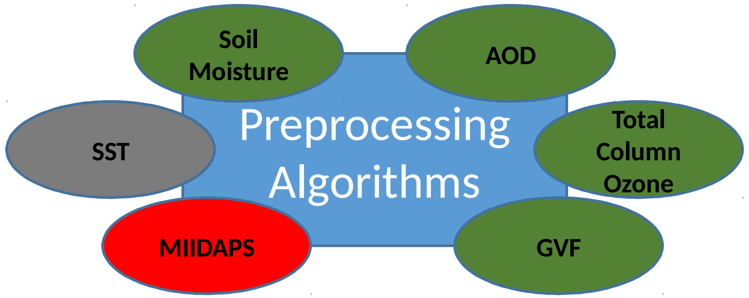
- Provides higher spatial resolution analysis (13-25 km)
- Provides analyses at hourly or sub-hourly intervals
- Reduces thinning of satellite data (more observations used)
- Observation-weighted analysis (less weight to background)
  - … *Needed to remove displacements in moisture fields*
- Leverages remote sensing algorithms to improve analysis
  - … *Use to specify unanalyzed variables which help constrain DA solution*
  - … *Increase number of observations assimilated (passing QC)*
- Post-processing algorithms incorporate inverted parameters from preprocessing into final DF analysis
  - … *Includes parameters, like rainfall rate, absent in DA analysis*



integration of STAR algorithms

Uses to synergize and improve data assimilation

MIIDAPS enables data fusion at the preprocessing stage by providing 1DVAR analyses for background adjustment and geophysical constraints in the Data Assimilation. MIIDAPS convergence metrics also provide Quality Control information to the assimilation system.



Cumulative Use

Geophysical Constraints
+
Background Adjustment
+
Quality Control

The Multi-Instrument Inversion and Data Assimilation Preprocessing System (MIIDAPS)

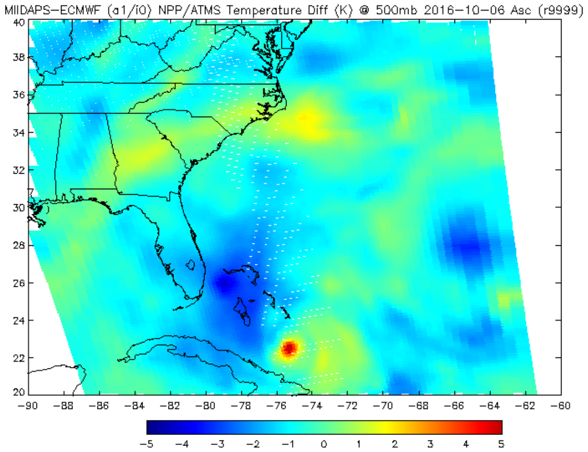
MIIDAPS is based on the Microwave Integrated Retrieval System (MiRS).

Data Fusion effort focused on:

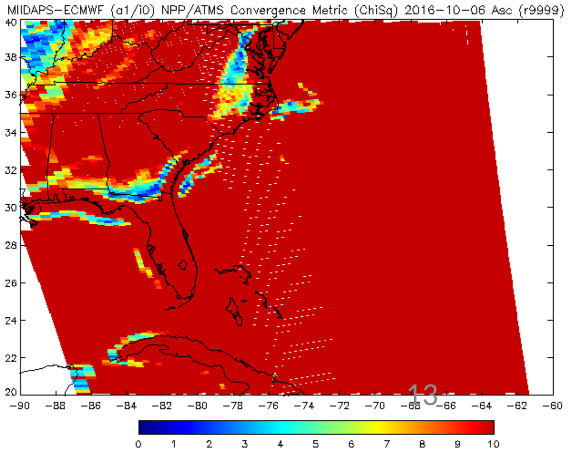
- Extension to research PMW sensors (e.g.GMI)
- Extension to Geostationary IR sensors (e.g. AHI)
- Extension to polar IR sensors (e.g. CrIS)
- Exploiting sounding, surface (incl. cryospheric), hydrological, trace gas, and QC information

MIIDAPS example: 1DVAR algorithm applied to SNPP-ATMS observations over Hurricane Matthew October 6, 2016 18Z

MIIDAPS-ECMWF 500hPa Temp Iterations 1-14



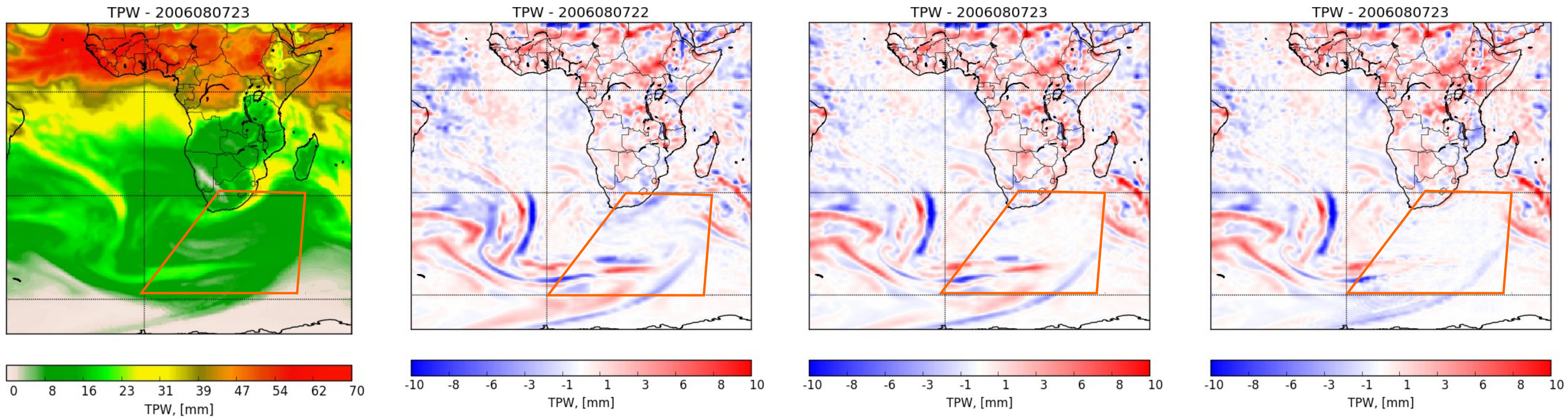
MIIDAPS Convergence Metric Iterations 1-14



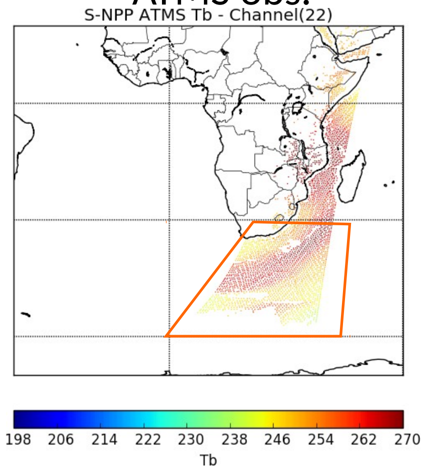
impact of adjustment

Remove displacements before assimilation

G5NR TPW | a) Background – G5NR | b) GSI analysis – G5NR | c) EDF analysis – G5NR



Location of assimilated ATMS obs.



<u>Example Analysis Cycle at 2006-08-07 23Z</u>

a) Background-G5NR (GEOS-5 Nature Run) shows large displacements (dipoles) in TPW field

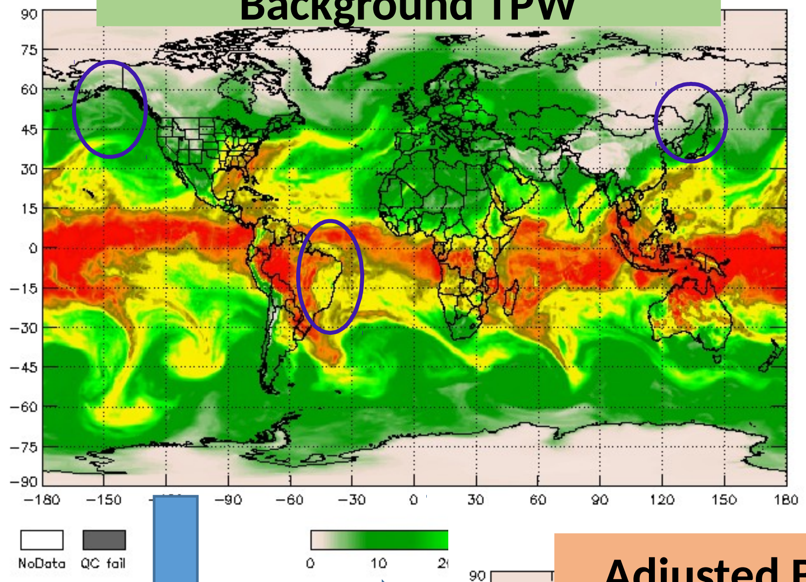
b) GSI analysis-G5NR reduces magnitude of dipoles slightly where SNPP ATMS data exists (red trapezoid)

c) EDF analysis through MIIDAPS-based background adjustment removes most of dipole feature and reduces TPW differences where SNPP ATMS data exists (red trapezoid)

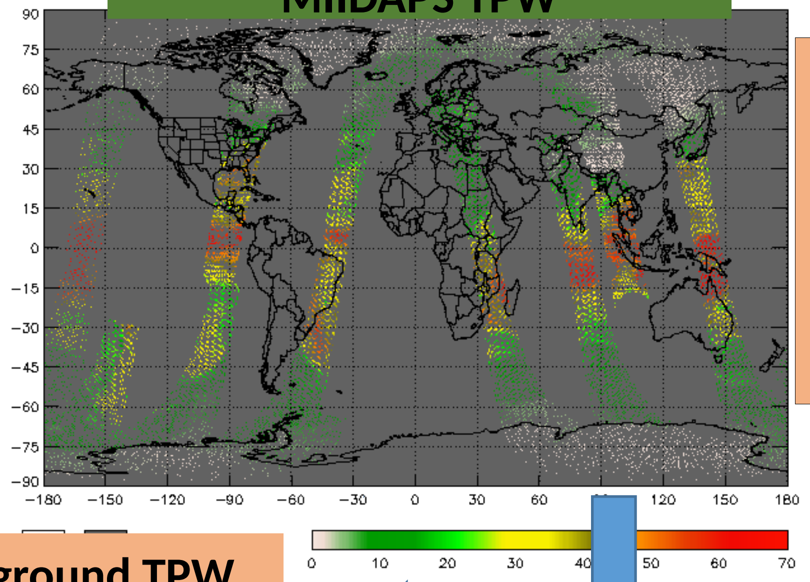
illustration of data fusion preprocessing

Practical example using just 1 hour of POES/NPP/Metop data

Background TPW

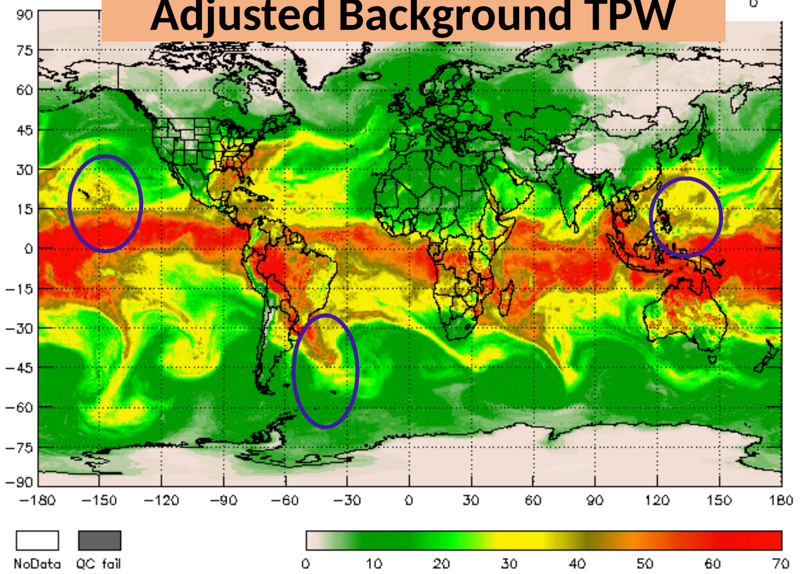


MIIDAPS TPW



Background adjustment only TPW but can be extended to Temperature, CLW, SST/LST, etc.

Adjusted Background TPW



Background field (a prior forecast valid at the analysis time or a prior analysis) kept for continuity where satellite data aren't available.

Preprocessed satellite data (e.g. retrievals from remote sensing algorithms like MIIDAPS) replace background information with information consistent with observations.

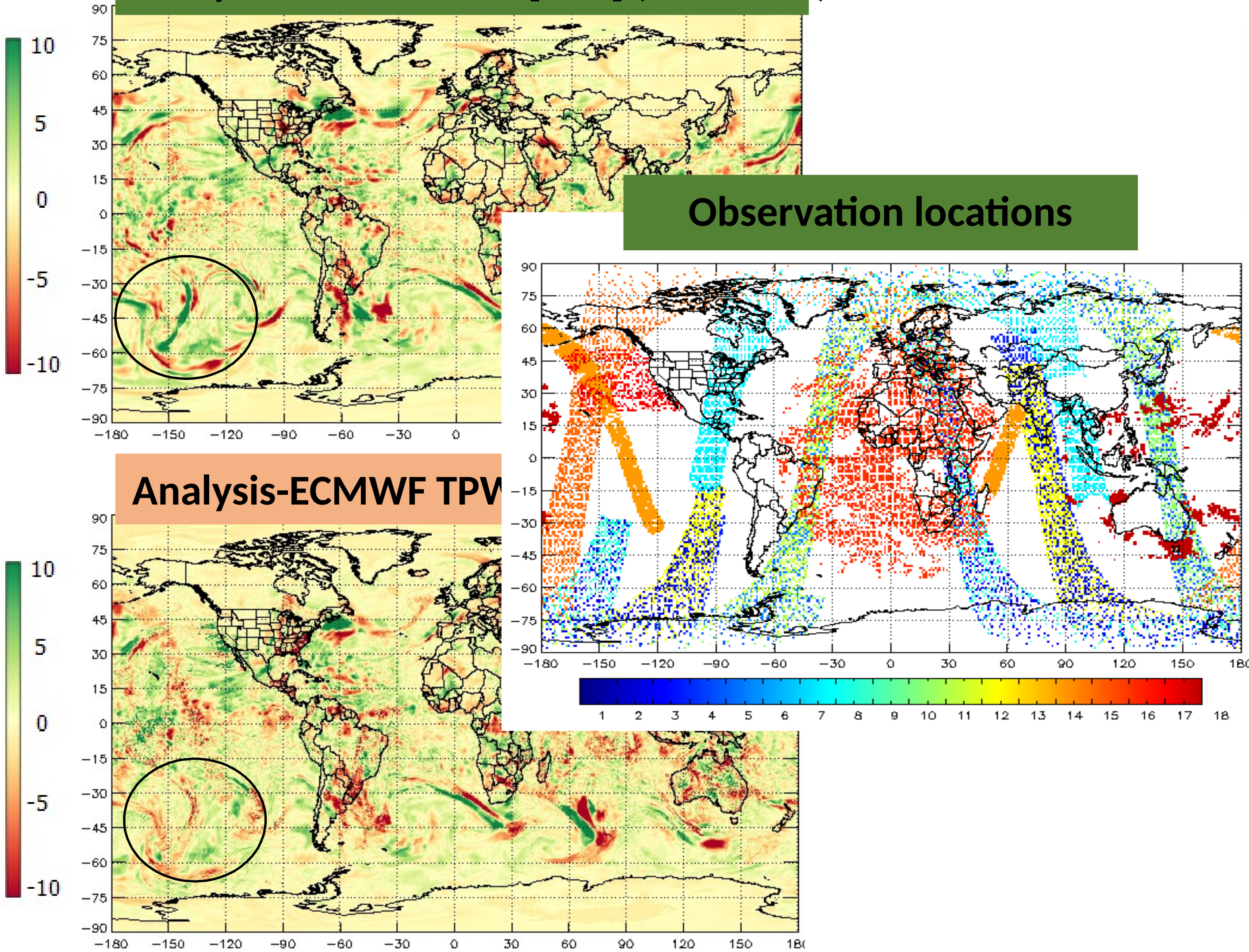
data assimilation analysis (TPW) vs ECMWF

Adjustment of TPW only: 2015-12-23 12Z

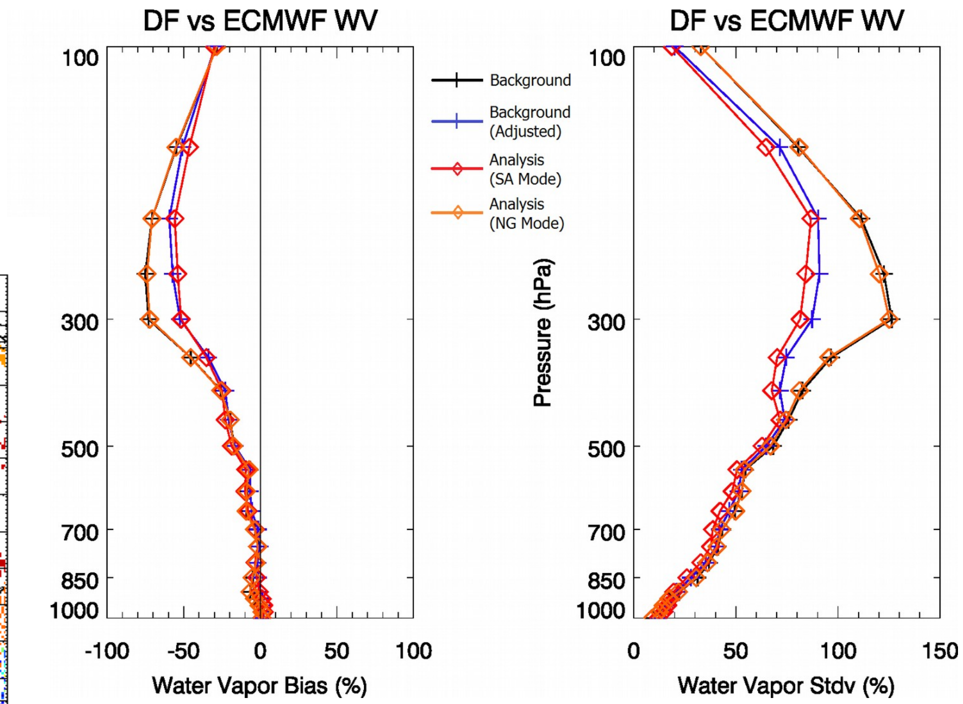
Analysis-ECMWF TPW [mm] (NG Mode)

Observation locations

Analysis-ECMWF TPW



Performance at observation locations

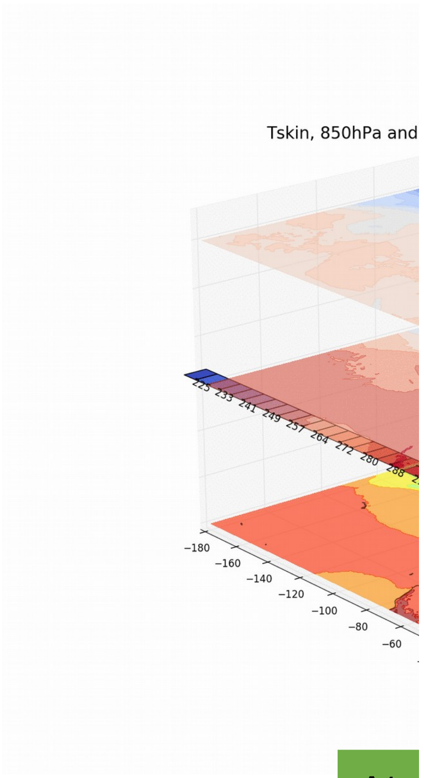


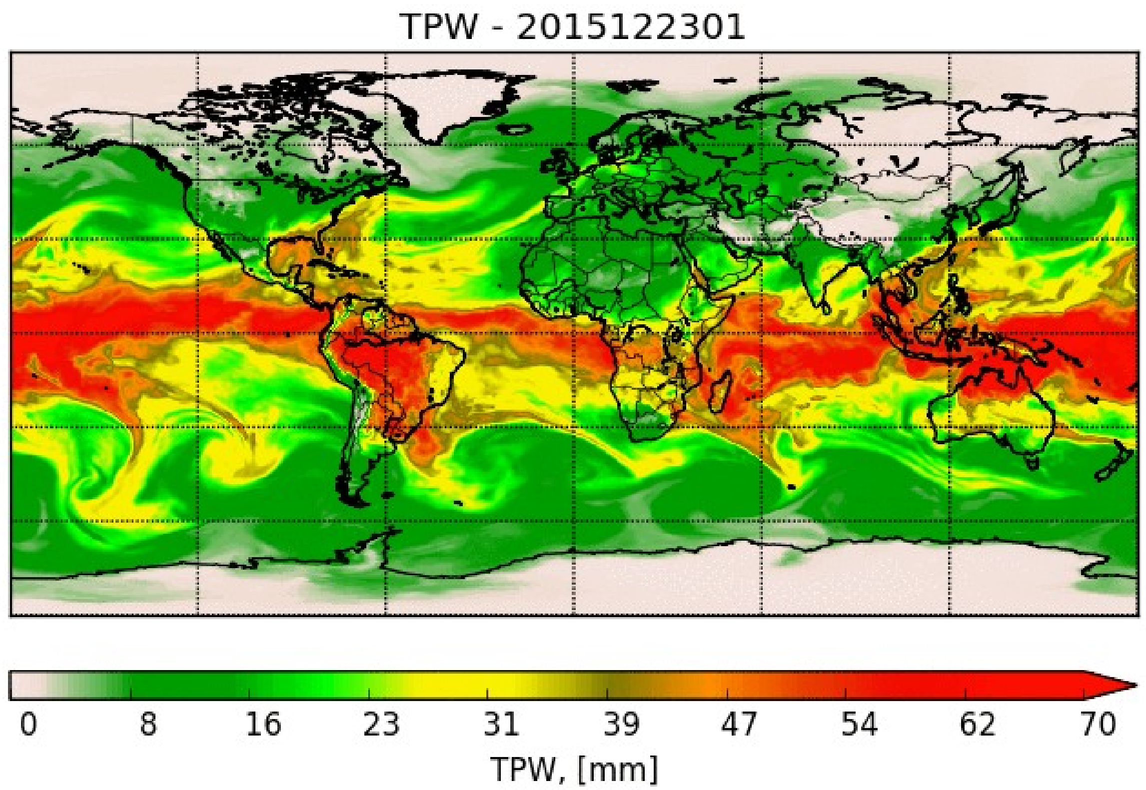
- **Background Adjustment provides displacement correction not attained in NG Mode.**
- **DA using Adjusted Background refines analysis (smoothing, balance)**

illustration of data fusion analysis

Snapshot of products

4D Cul **modynamic**





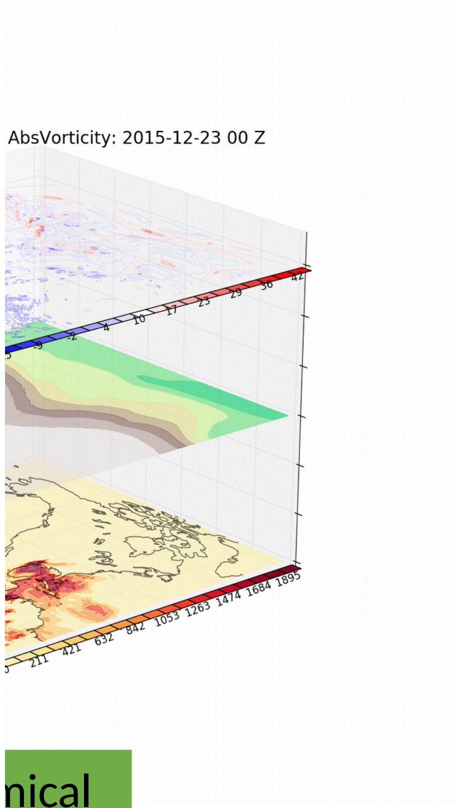


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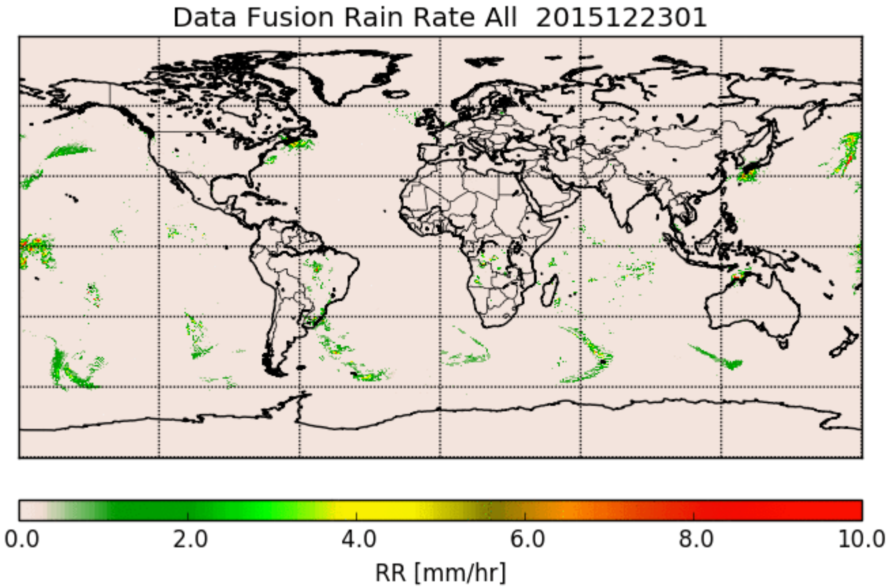
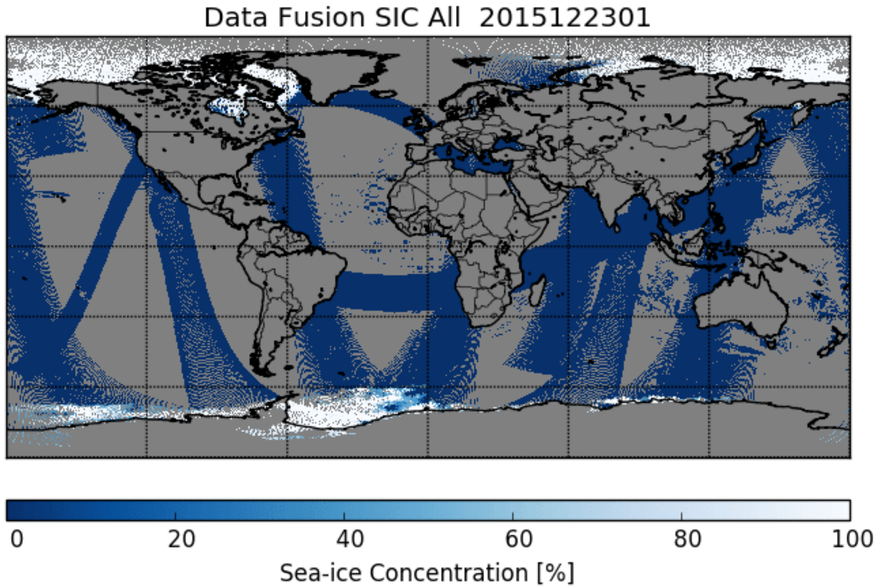
illustration of data fusion analysis

- **Developed framework to integrate remote sensing algorithms to derive products from analysis fields or unanalyzed variables provided by preprocessing algorithms**
  - Integrated NOAA Microwave Integrated Retrieval System (MiRS) for Rainfall Rate, Sea-ice Concentration, and Snow-Water Equivalent



Global Hourly Rainfall Rate

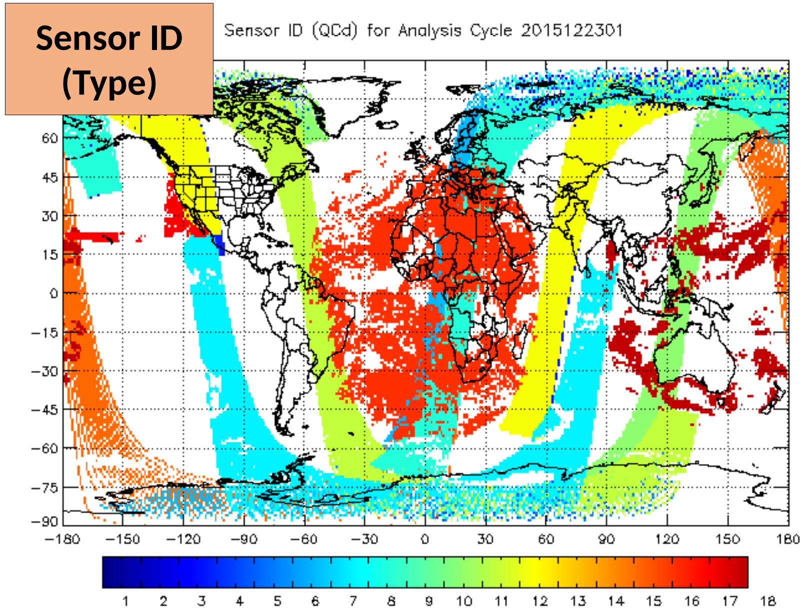


Global Hourly Sea-ice Products

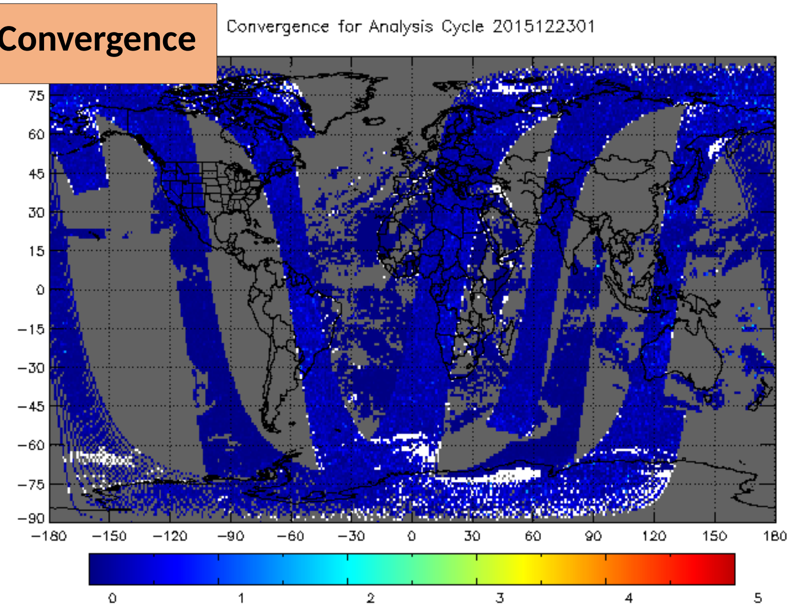
illustration of data fusion quality control

Global, hourly quality control

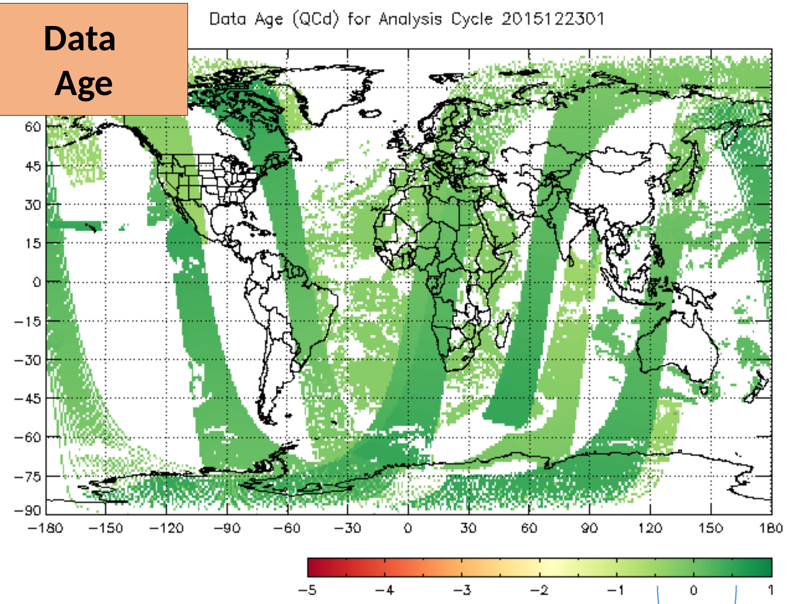
Sensor ID (Type)



Convergence



Data Age



N-18
N-19
METOP-A
METOP-B
SNPP
Meteosat-10
GOES-15
Himawari-8

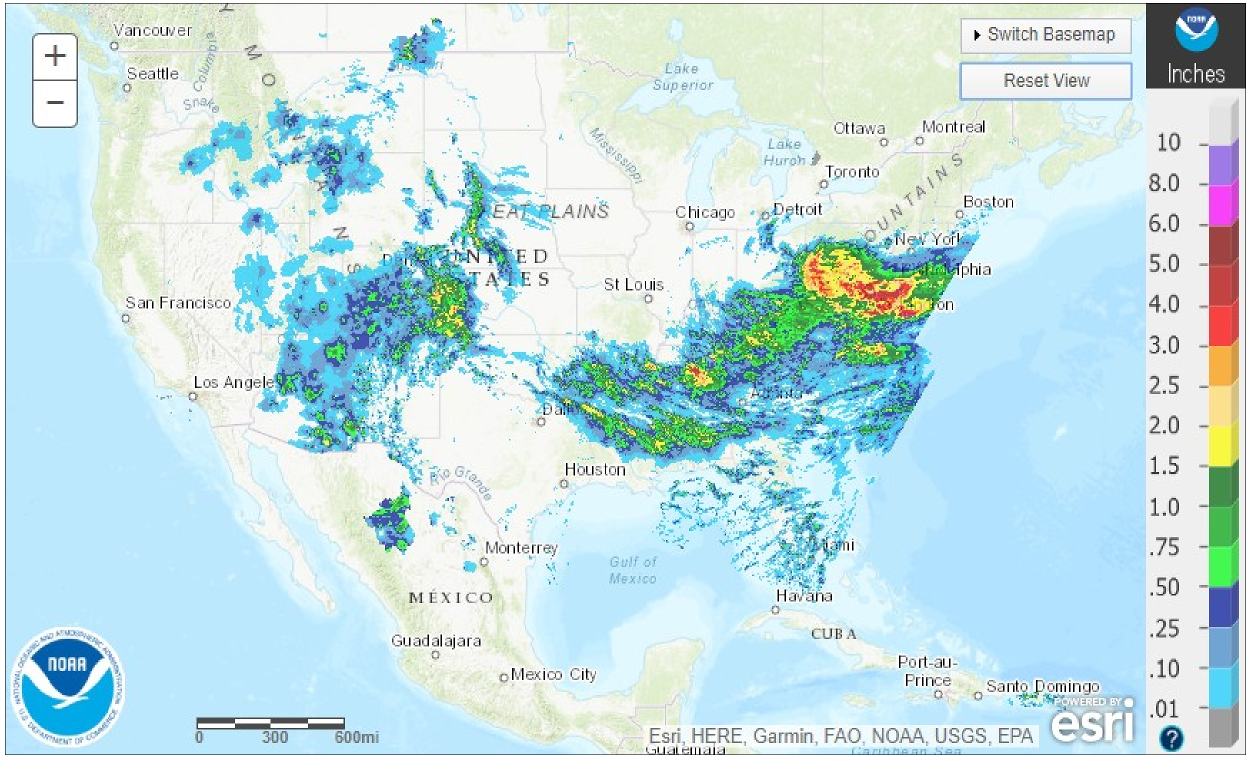
- **Output satellite sensor type**
  - … Impact on parameters depending on sensor
- **Output data age relative to analysis time**
  - … How old was the last observation used over specific regions?
- **Output the convergence of assimilated observations**
  - … How well does the final analysis field fit the assimilated observation?

Data window
Current cycle

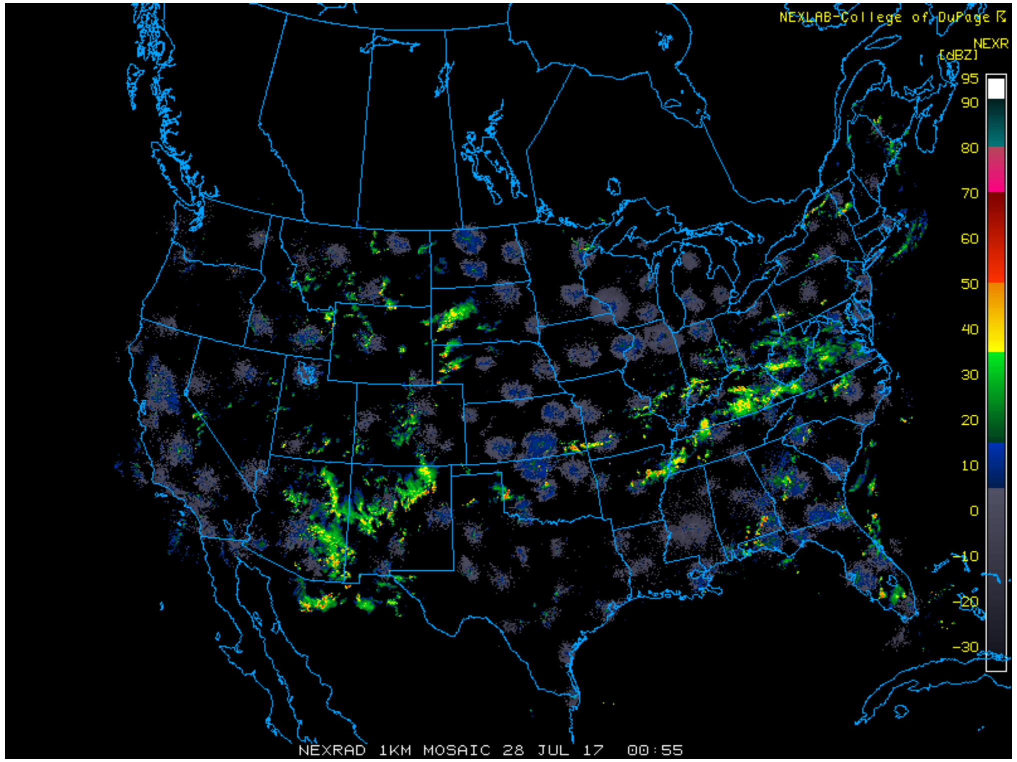
illustration of case study

Extreme Mid-Atlantic Precipitation Event July 28, 2017

24-hr Accumulated Precipitation Ending 07/29/2017 12Z



NEXRAD Hourly Reflectivity



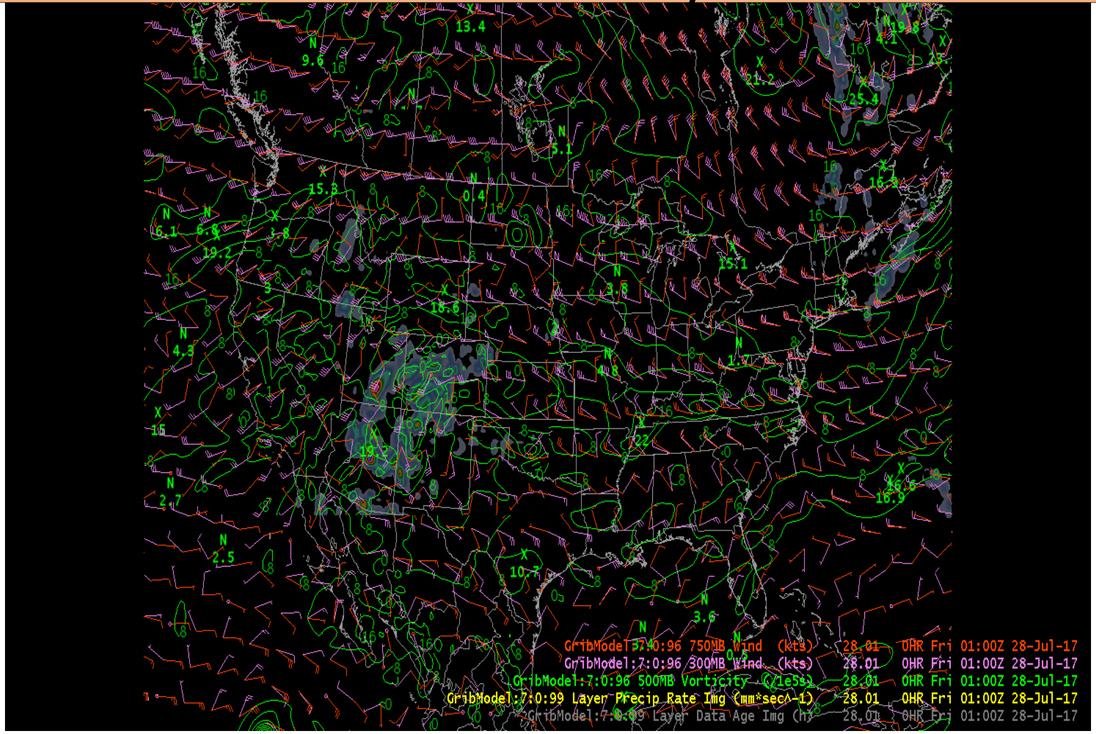
Extreme mid-atlantic precipitation July, 28 2017

Added-value to Situational Awareness/Nowcasting

A view of Data Fusion products through the AWIPS2 interface

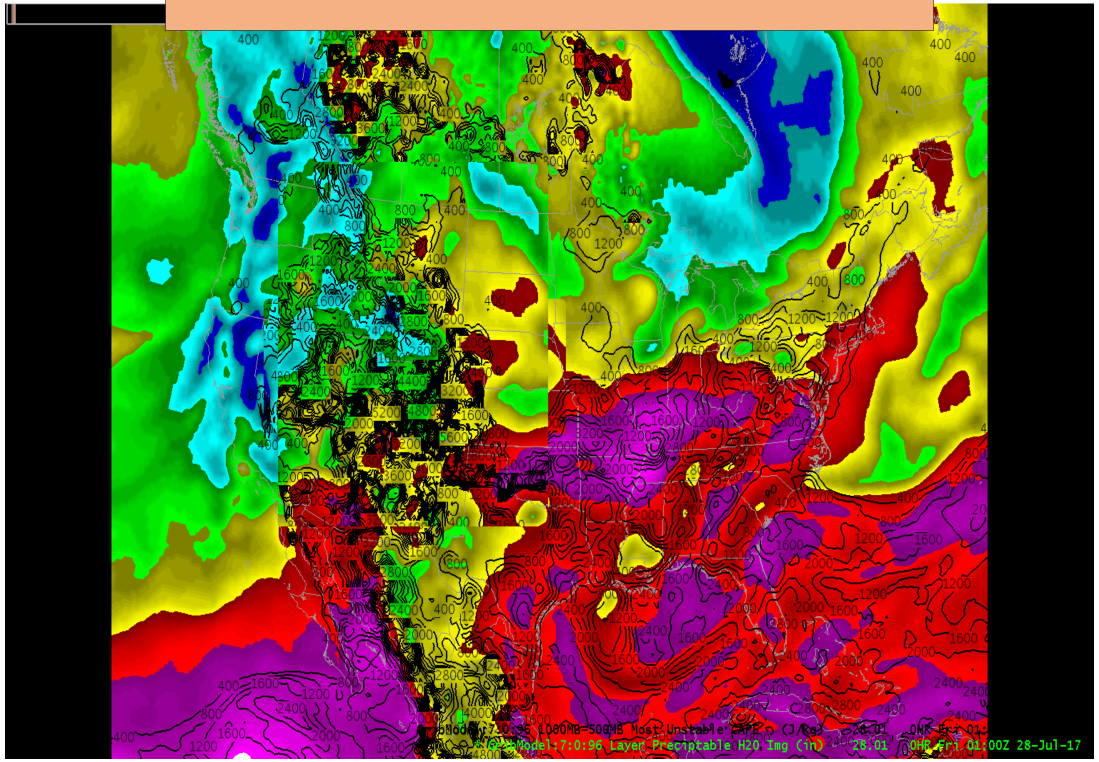
Consistent coverage and timely delivery of products - Simplifies user procedures.

Data Fusion Rainfall Rate, 700/300 hPa Winds, 500 hPa Vorticity



Physical consistency between precipitation fields and dynamical forcing

Data Fusion TPW, MU-CAPE



Physical consistency between moisture and stability fields

Extreme mid-atlantic precipitation July, 28 2017

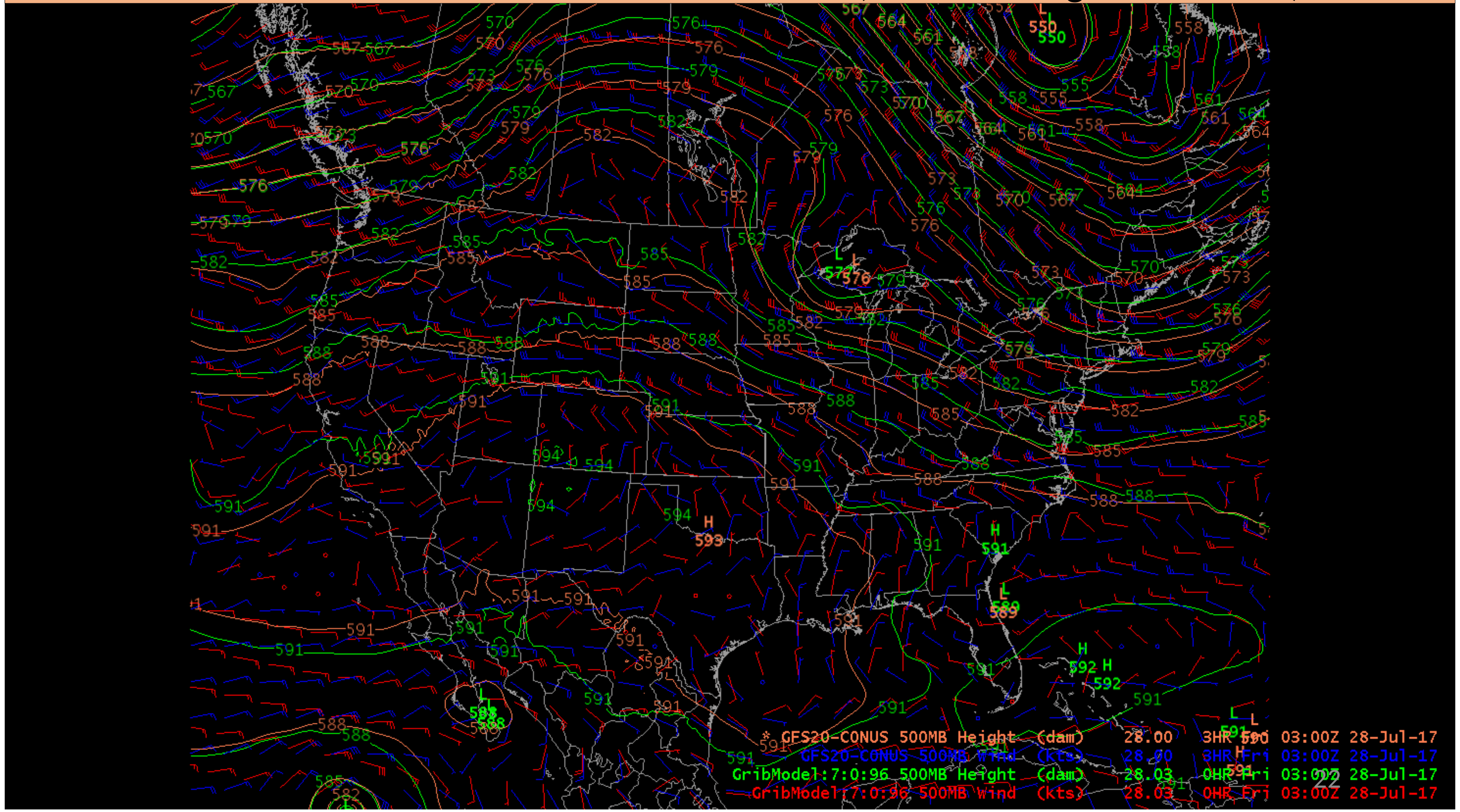
Added-value to Model Diagnostics/Verification

A view of Data Fusion products through the AWIPS2 interface

Intercomparison with regional/global forecast, other analyses, or products (e.g. GOES Imagery)

Data Fusion added value to perform verification of short-term forecasts, identify trends in model performance for specific features.

Data Fusion and GFS Forecast Parameters (500 hPa Height and Wind)



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- **next steps**

Next steps

High-level Challenges

- Maintaining physical balances cycle to cycle
- Aligning capabilities of remote sensing and data assimilation systems
- Maintenance of data assimilation systems within EDF framework
- Requirements for HPC to minimize latency (~45 minutes for 1 cycle)
- Establishing required input data flows to run EDF