The Magic of Moisture in NWP

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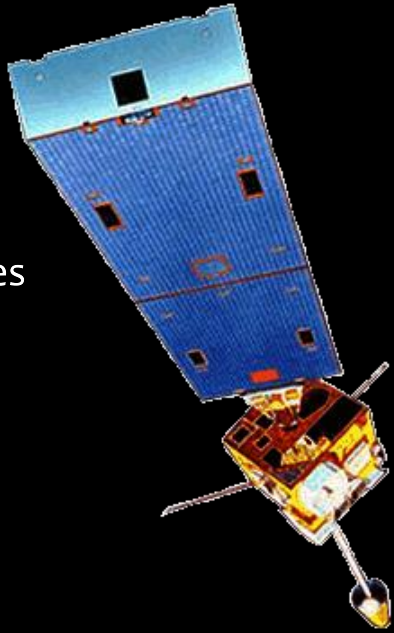


Session V – Tuesday, October 18, 2011
National Weather Association Annual Meeting, Birmingham, Alabama

Basic Premise of NWP

An Initial Value Problem

* The following constrain the accuracy of numerical weather prediction (NWP) solutions:
  * Parameterizations and approximations within the model
  * Atmospheric features occurring on scales smaller than resolved by the model
  * *Limited observations to populate the initial analysis (especially in the "upper air" and over oceans)*
  * Quality, precision, and accuracy of the observations
  * Boundary conditions and domain size

Information Extracted from Satellites for Numerical Weather Prediction

Radiances

- Direct assimilation (3Dvar)
- Requires model errors, observation errors
- Scale dependence
- Surface type restrictions

Retrieved parameters

- Dependent variable assimilation (1,3Dvar)
- Requires model errors, *retrieval errors*
- Physical accuracy, non-linearity
- Bypass surface type restrictions

The CIMSS Regional Assimilation System (CRAS) is used to assess the impact of space-based observations on numerical forecast accuracy.

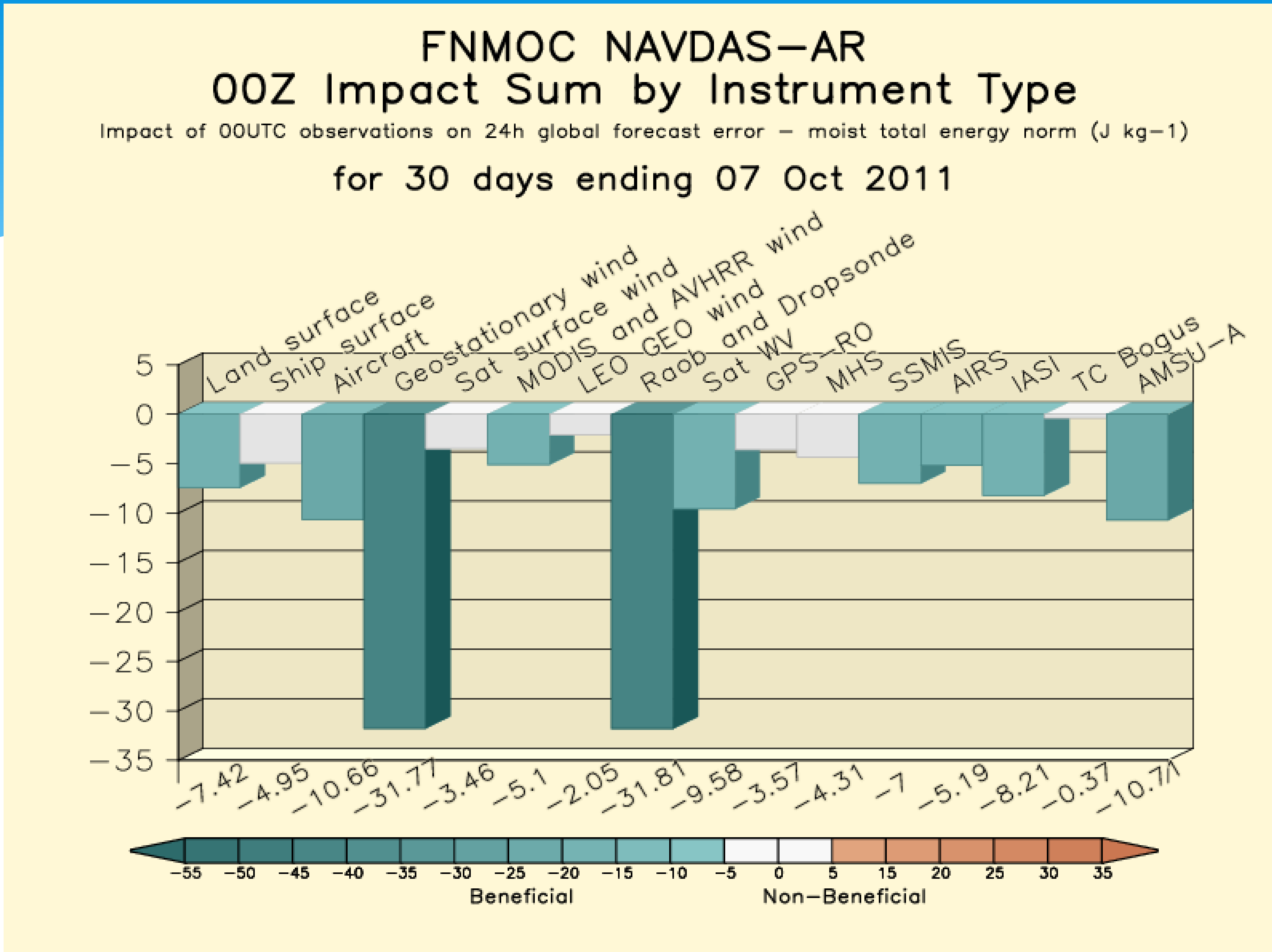
CRAS is unique in that, since 1996, it's development was guided by validating forecasts using information from GOES.

Motion

- Cloud track, water vapor track
- Height assignment errors
- Radiance tracking (4Dvar)

Output online:
http://cimss.ssec.wisc.edu/cras/

Slide credit: Robert Aune, NOAA/NESDIS



For Fleet Numerical Meteorology and Oceanography Center NOGAPS model

http://www.nrlmry.navy.mil/obsens/

US Operational Forecast Models

Limited use of GOES Sounder observations

* The North American Model (NAM) and Global Forecast System (GFS) **do** use brightness temperatures from the GOES Sounders (GOES-W/11 and GOES-E/13) <u>over ocean</u> as part of their radiance assimilation system.
* However, they **do not** use retrievals, and they **do not** use GOES Sounder observations <u>over land</u>.
* The Rapid Update Cycle (RUC) **does** use precipitable water (PW) *retrievals* <u>over ocean</u> from GOES-11 <u>only</u>.

Assimilating GOES Sounder in CRAS

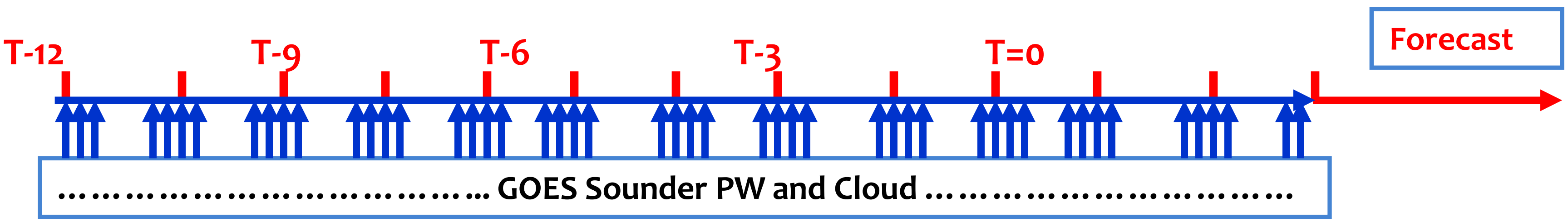
Cloud-top pressure and effective cloud amount are used adjust cloud water mixing ratio in the model. Cloud checks are performed for low, high, and multi-layer clouds.

Background	GOES	Operation
Clear	Clear	Do nothing (check RH)
Cloudy	Cloudy	Adjust cloud, RH, match top (up to two layers)
Cloudy	Clear	Clear cloud, adjust RH
Clear	Cloudy	Build new cloud, adjust RH

Water Vapor Adjustments using GOES 3-Layer Precipitable Water Retrievals.

1) Mean background mixing ratio profile is computed.
2) Perturbations are removed.
3) Mean profile is adjusted to match GOES 3-layer PW using 1D var (strong constraint).
4) Perturbations are added to adjusted profile.
5) RH profile checked for "clearness".

A 12-hour spin-up forecast is used to initialize water vapor and clouds.

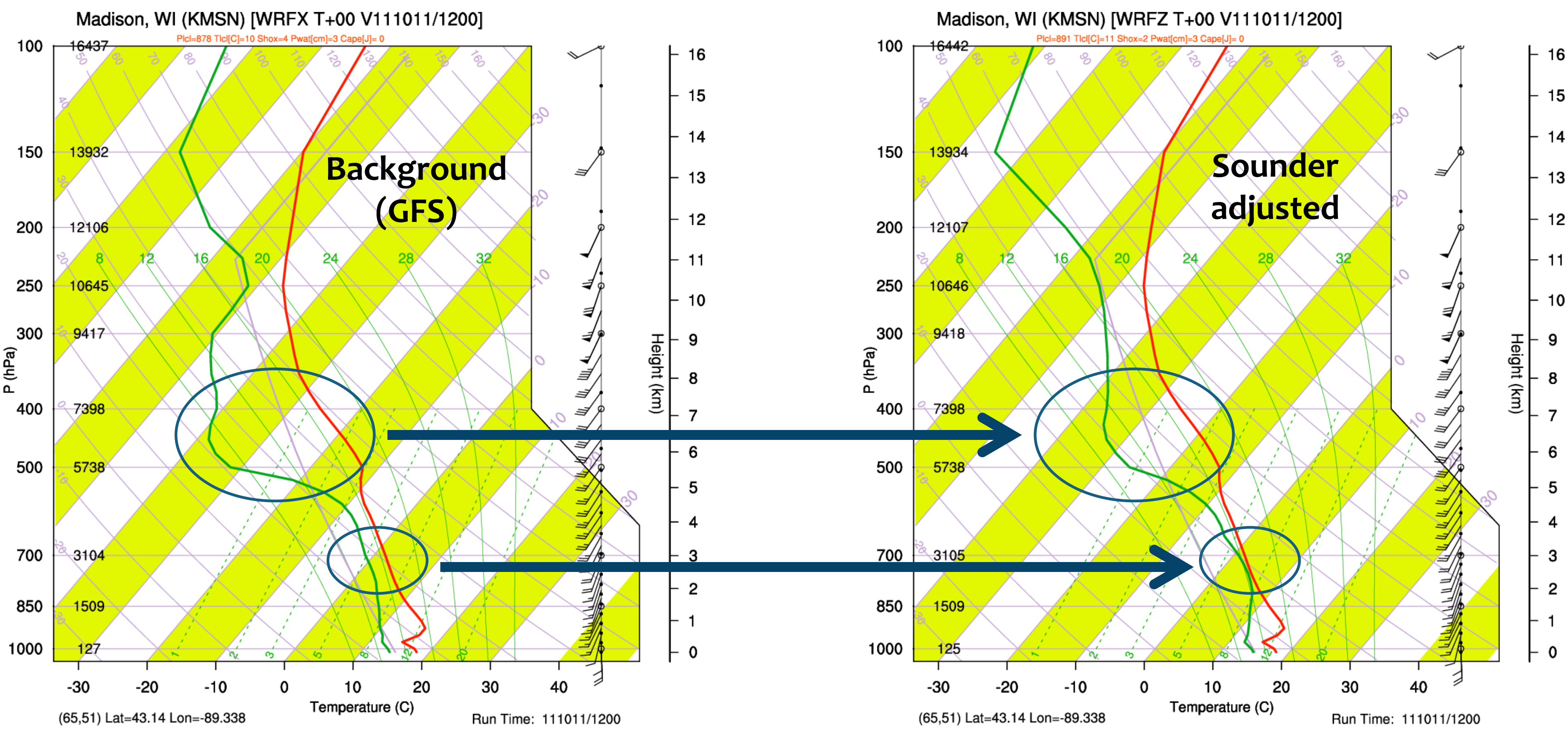


Slide credit: Robert Aune, NOAA/NESDIS

GOES-13 Moisture Correction

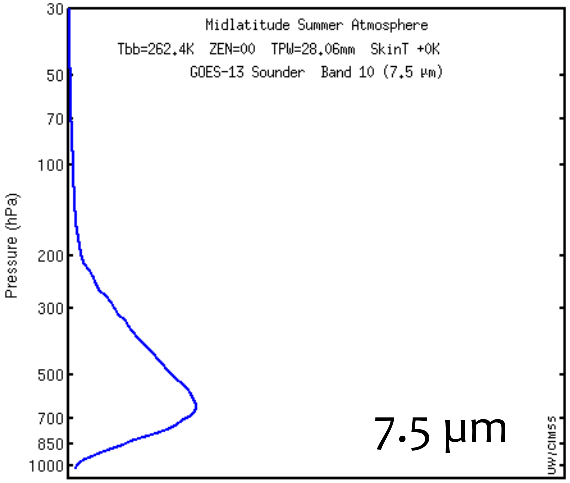
Madison, WI; 11 October 2011, 12 UTC

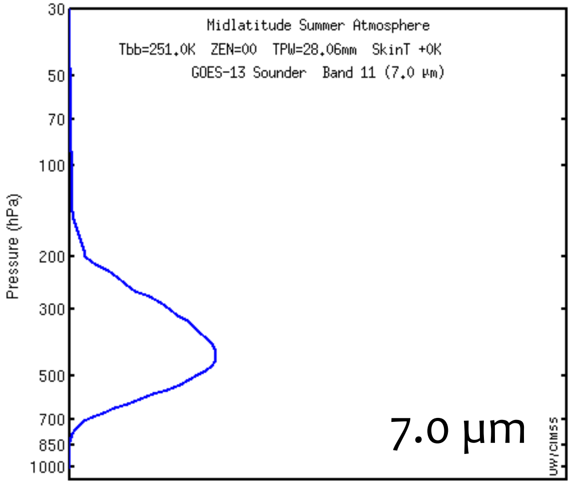
This example shows how moisture is added to the background analysis ahead of approaching precipitation while the distribution is maintained.

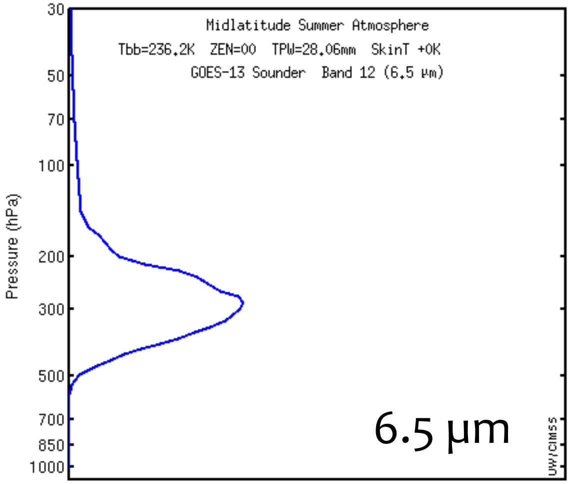


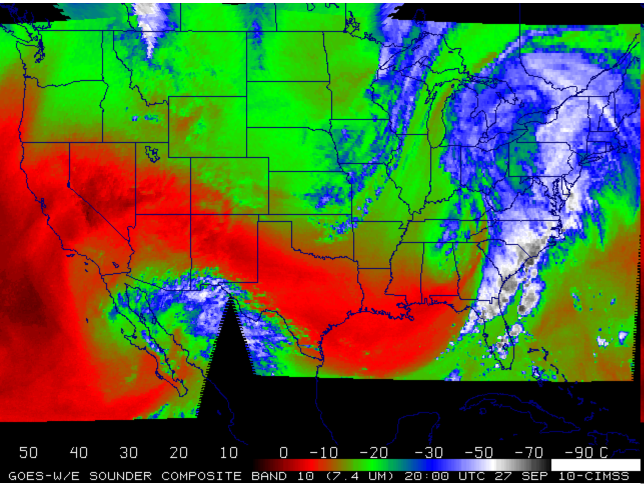
Current GOES-13 Sounder Weighting Functions

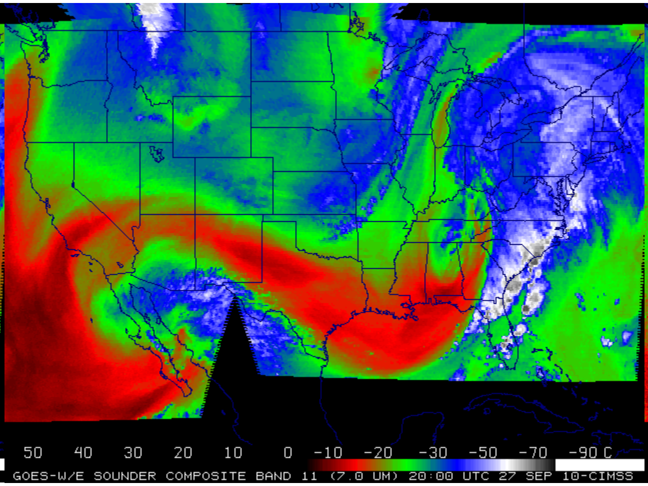
Geostationary satellites can provide information of mid-level water vapor.

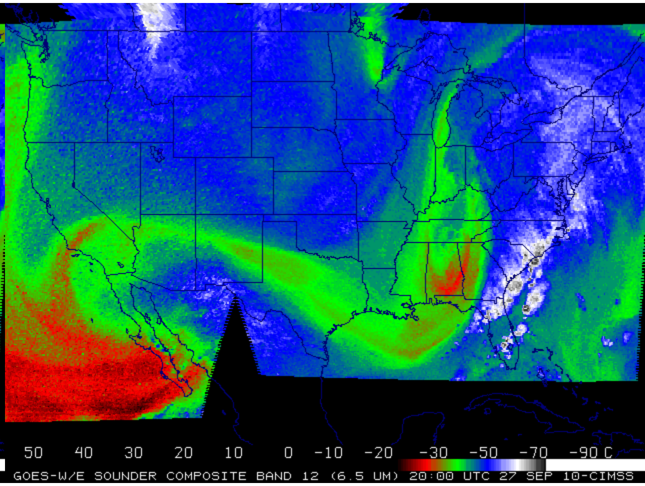








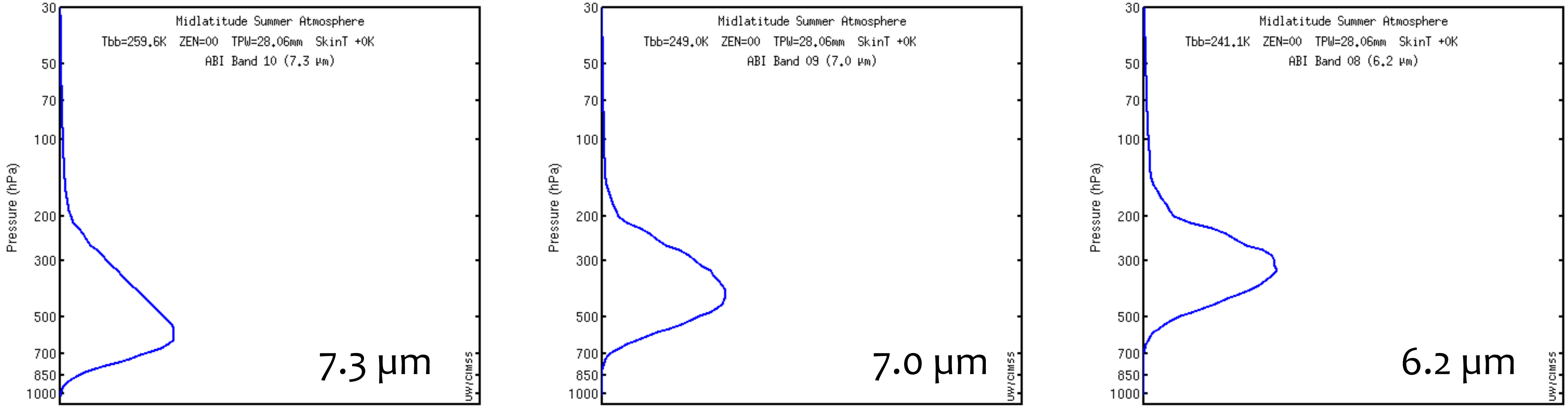


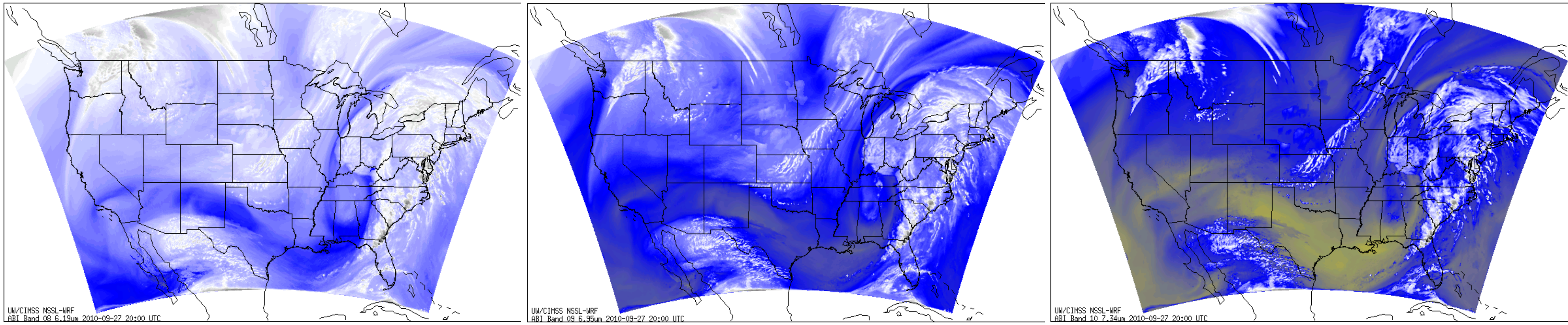


Plots courtesy of Mat Gunshor, CIMSS

GOES-R ABI Weighting Functions

This capability will continue in the GOES-R era, but still no surface moisture resolution.





Simulated imagery

Images courtesy of Justin Sieglaff, CIMSS

Experiment Design

Objective: Understand NWP response to variable moisture concentrations.

Three Advanced Research Weather Research and Forecast (WRF-ARW) simulations are run twice daily (00/12Z):

- **WRFX** – Initial conditions and boundary conditions from previous (06/18Z) GFS run
- **WRFY** – Initial conditions and boundary conditions from initial hour CRAS20MKX run
- **WRFZ** – Initial conditions of previous (06/18Z) GFS run modified with GOES-13 Sounder retrievals and GFS boundary conditions

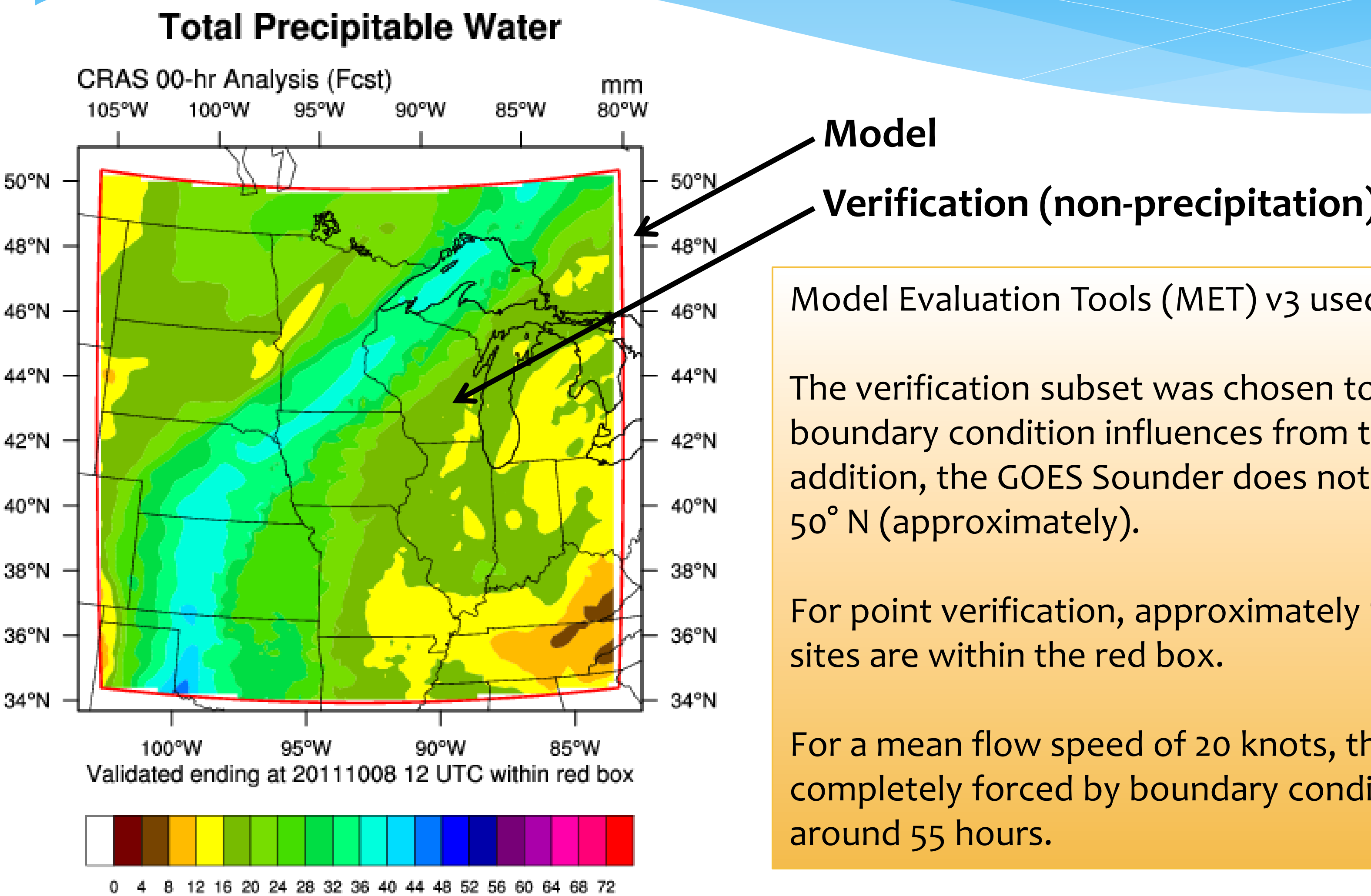
Each 36-hour simulation used:

* an adaptive time step,
* 20 km horizontal spacing on 100 x 100 square grid consisting of 45 vertical levels, with
* 50 hPa at the top of the model.

Dynamics	Non-Hydrostatic with Gravity Wave Drag
Cumulus Scheme	Kain-Fritsch
Microphysics Scheme	WSM Single-Moment 5-Class
PBL Scheme	Yonsei University
Land Surface Scheme	Noah 4-Layer LSM
Surface Layer Physics	Monin-Obukhov with heat and moisture surface fluxes
Long Wave Radiation	RRTM
Short Wave Radiation	Dudhia Scheme
Time-Integration Scheme	Runge-Kutta 3rd Order
Damping	Rayleigh

Experiment Domain

Model and Verification



Model Evaluation Tools (MET) v3 used for statistics.

The verification subset was chosen to discount any boundary condition influences from the results. In addition, the GOES Sounder does not scan above 50° N (approximately).

For point verification, approximately 70 GPS-TPW sites are within the red box.

For a mean flow speed of 20 knots, the domain is completely forced by boundary conditions after around 55 hours.

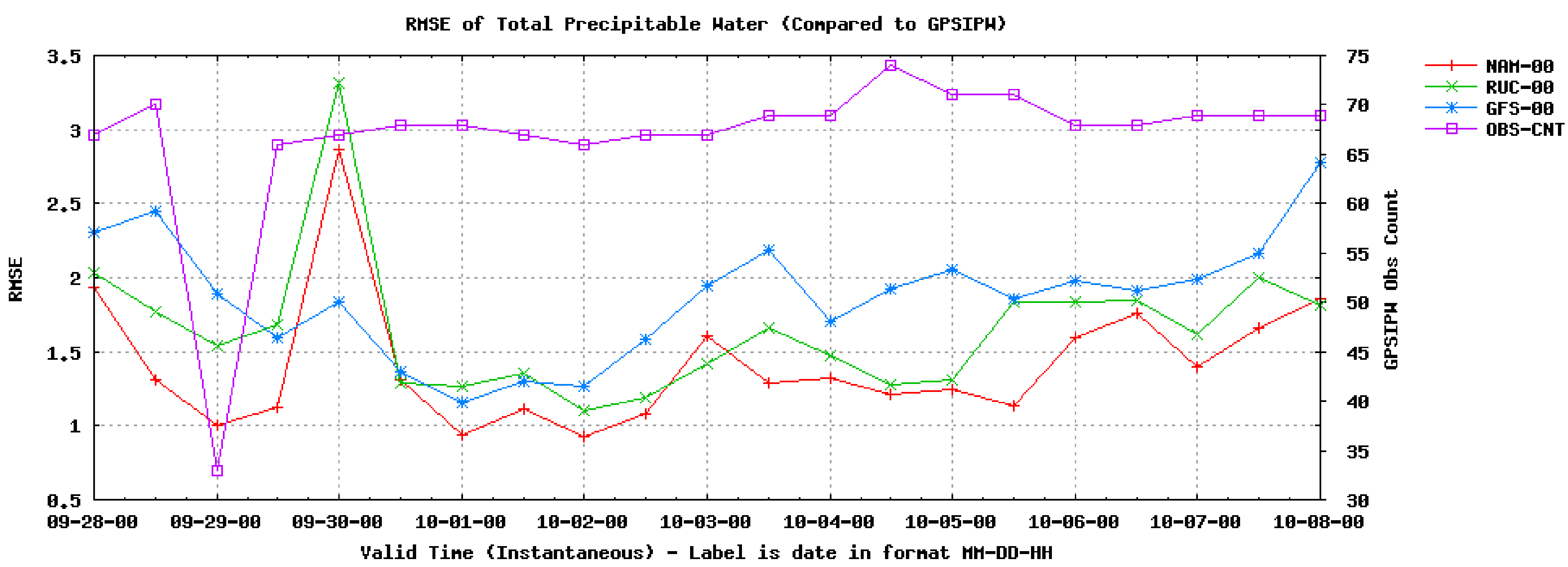
Total PW Mean Absolute Error

Analyses verified against GPS-TPW

Model	Mean MAE
NAM	1.04
RUC	1.24
GFS	1.43

The NAM and RUC assimilate GPS-TPW measurements, while the GFS does not.

Verified output every 12 hours between September 28, 2011, 00 UTC, and October 8, 2011, 00 UTC, for a total sample of 21 times



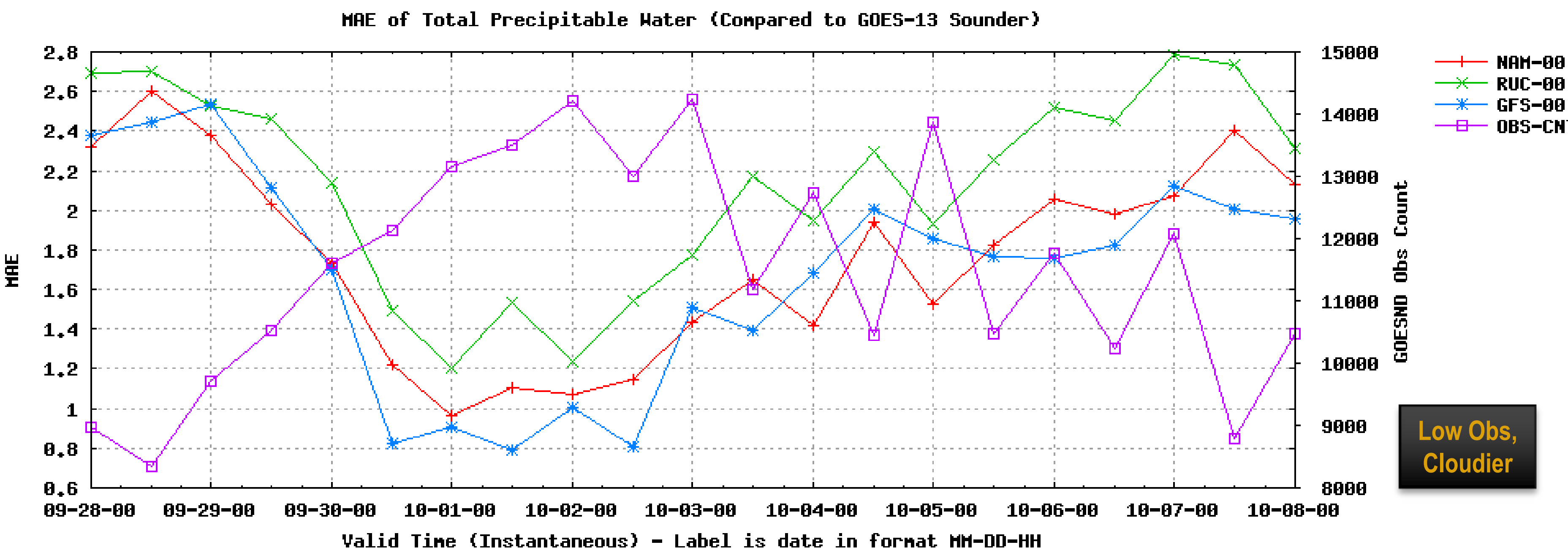
Total PW Mean Absolute Error

Analyses verified against GOES-13 Sounder

Model	Mean MAE
GFS	1.69
NAM	1.76
RUC	2.13

The GFS is used as the first guess for the GOES-13 Sounder retrievals, but not the GFS run it is verified against.

Verified output every 12 hours between September 28, 2011, 00 UTC, and October 8, 2011, 00 UTC, for a total sample of 21 times



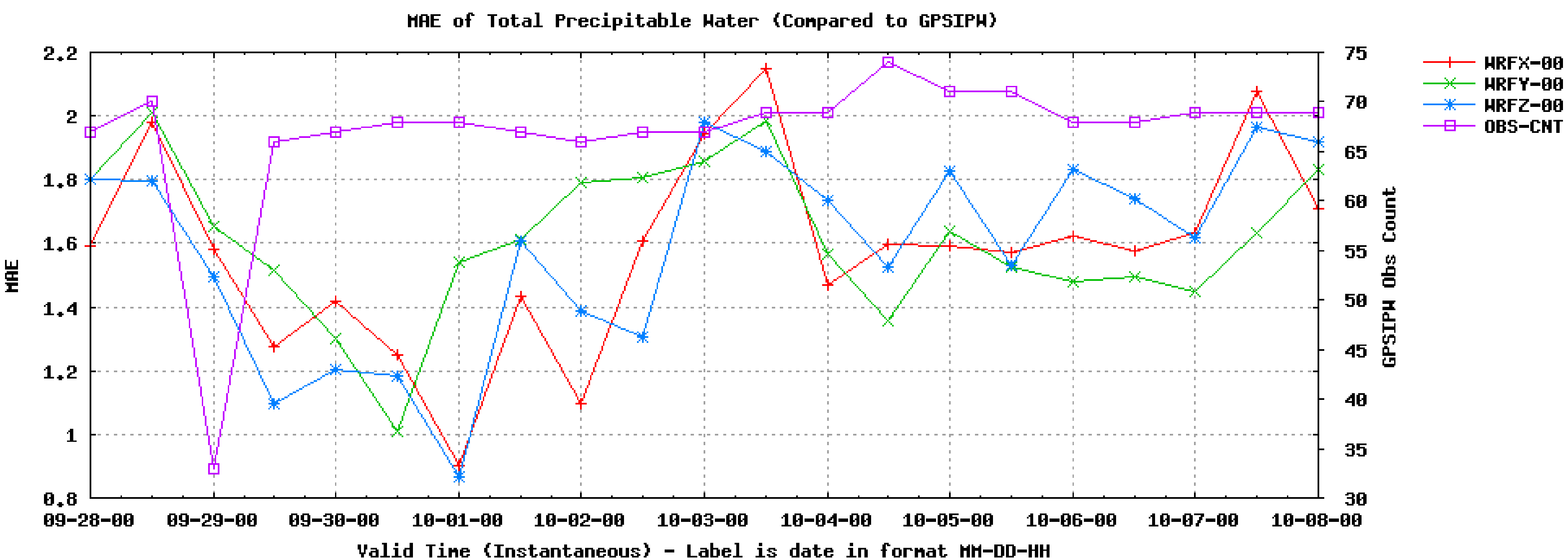
Total PW Mean Absolute Error

Analyses verified against GPS-TPW

Model	Mean MAE
WRFX	1.58
WRFZ	1.59
WRFY	1.61

Inconclusive results are due to the poor spatial heterogeneity of GPS sites across the domain compared to the magnitude of correction.

Verified output every 12 hours between September 28, 2011, 00 UTC, and October 8, 2011, 00 UTC, for a total sample of 21 times



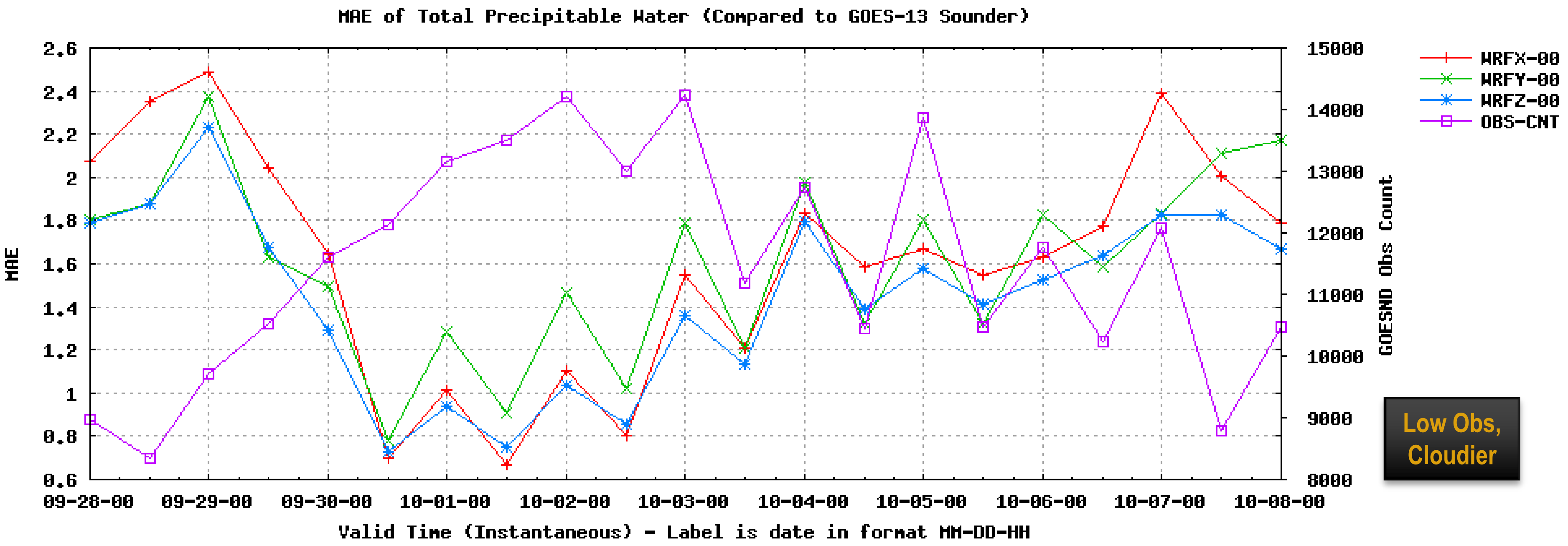
Total PW Mean Absolute Error

Analyses verified against GOES-13 Sounder

Model	Mean MAE
WRFZ	1.44
WRFY	1.59
WRFX	1.61

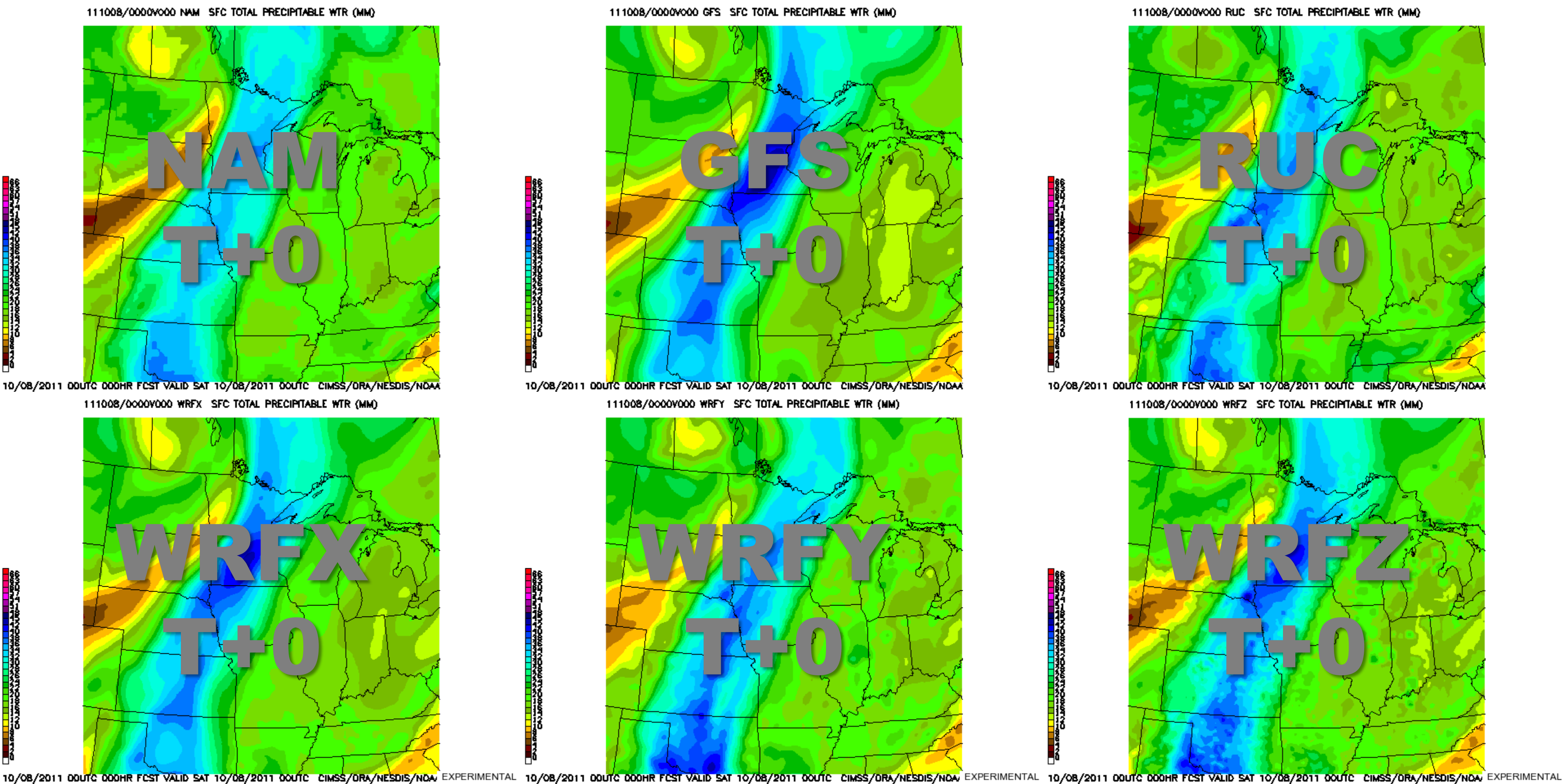
The WRFY and WRFZ contain Sounder retrievals which improve the MAE in clear fields of view.

Verified output every 12 hours between September 28, 2011, 00 UTC, and October 8, 2011, 00 UTC, for a total sample of 21 times



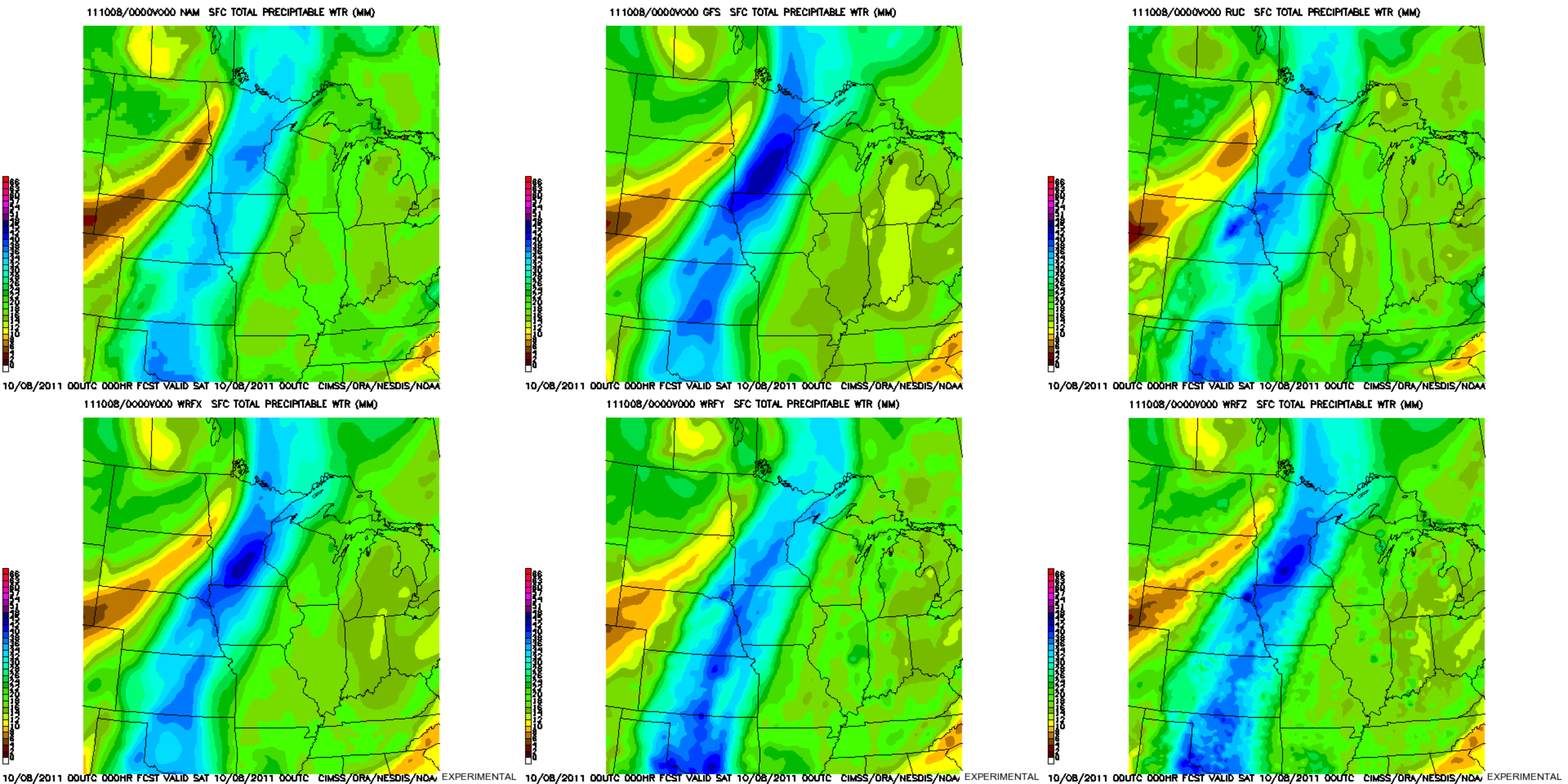
Total Precipitable Water

Analyses for 8 October 2011, 00 UTC



Total Precipitable Water

Analyses for 8 October 2011, 00 UTC



Total PW Mean Absolute Error

Forecasts verified against GPS-TPW

12-hour

Model	Mean MAE
WRFZ	1.72 ☑
WRFX	1.77
WRFY	1.81

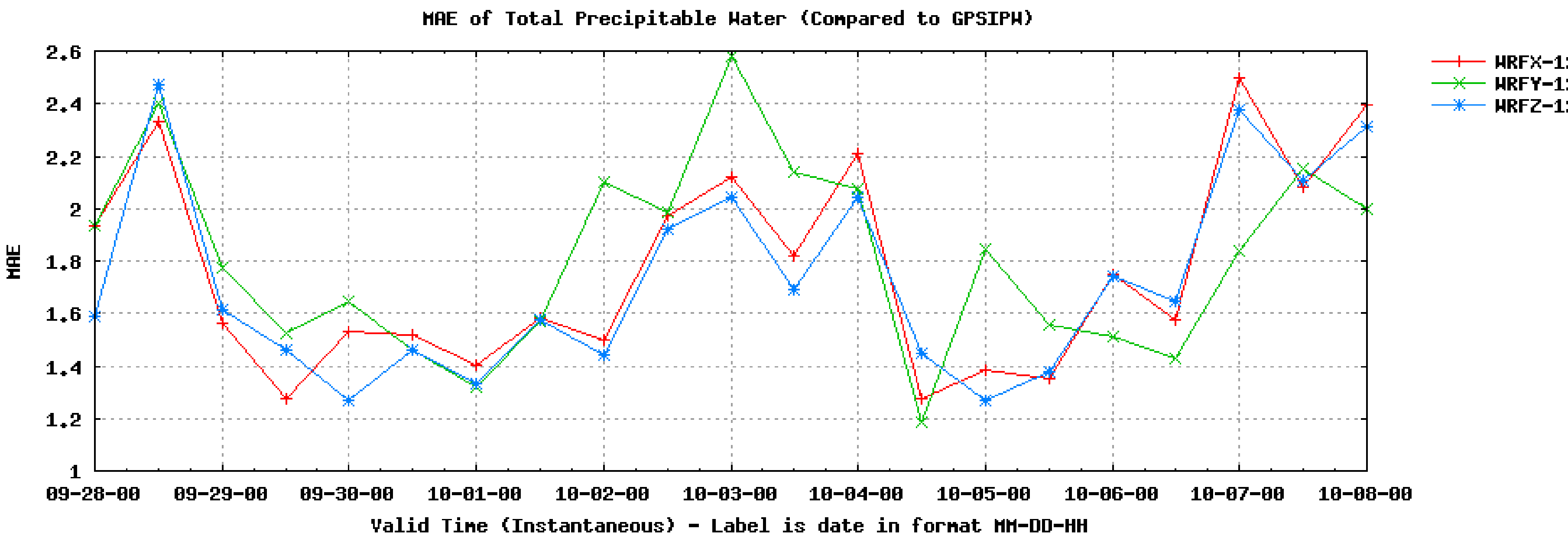
Verified output every 12 hours between September 28, 2011, 00 UTC, and October 8, 2011, 00 UTC, for a total sample of 21 times

24-hour

Model	Mean MAE
WRFZ	2.01 ☑
WRFX	2.01
WRFY	2.23

36-hour

Model	Mean MAE
WRFX	2.30 ☑
WRFZ	2.31
WRFY	2.79



Total PW Mean Absolute Error

Forecasts verified against NAM analysis

12-hour

Model	Mean MAE
WRFZ	1.93 ☑
WRFX	1.97
WRFY	2.09

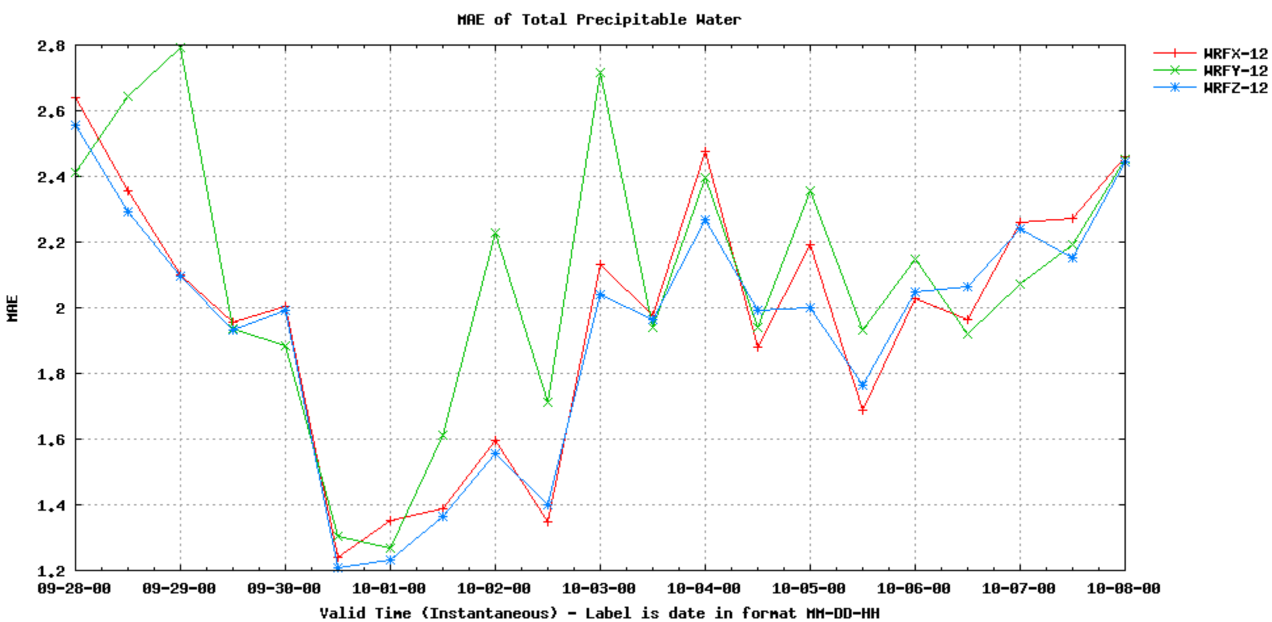
Verified output every 12 hours between September 28, 2011, 00 UTC, and October 8, 2011, 00 UTC, for a total sample of 21 times

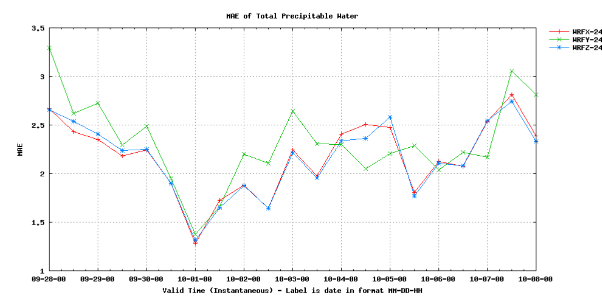
24-hour

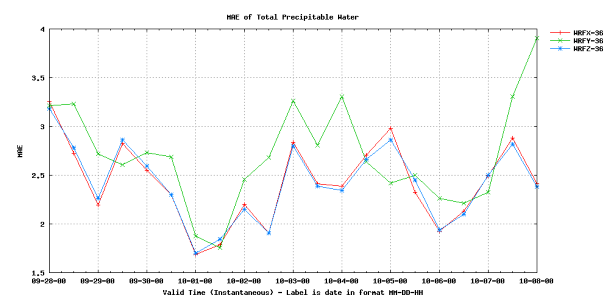
Model	Mean MAE
WRFZ	2.17 ☑
WRFX	2.17
WRFY	2.32

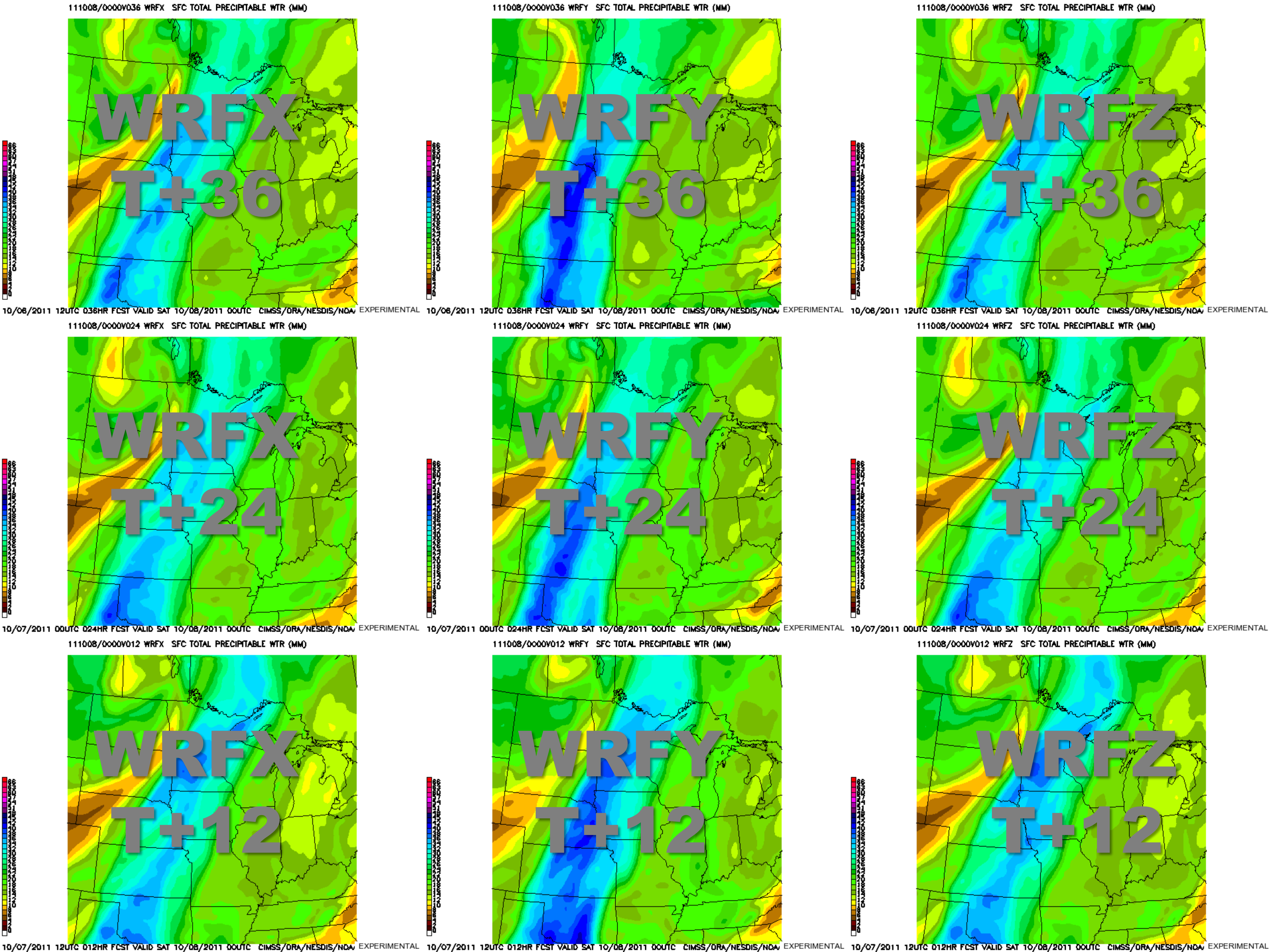
36-hour

Model	Mean MAE
WRFZ	2.42 ☑
WRFX	2.43
WRFY	2.71








111008/0000V036 WRFX SFC TOTAL PRECIPITABLE WTR (MM)
WRFX
T+36
10/06/2011 12UTC 036HR FCST VALID SAT 10/08/2011 00UTC CIMSS/ORA/NESDIS/NOA
EXPERIMENTAL
111008/0000V036 WRFY SFC TOTAL PRECIPITABLE WTR (MM)
WRFY
T+36
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WRFZ
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111008/0000V024 WRFX SFC TOTAL PRECIPITABLE WTR (MM)
WRFX
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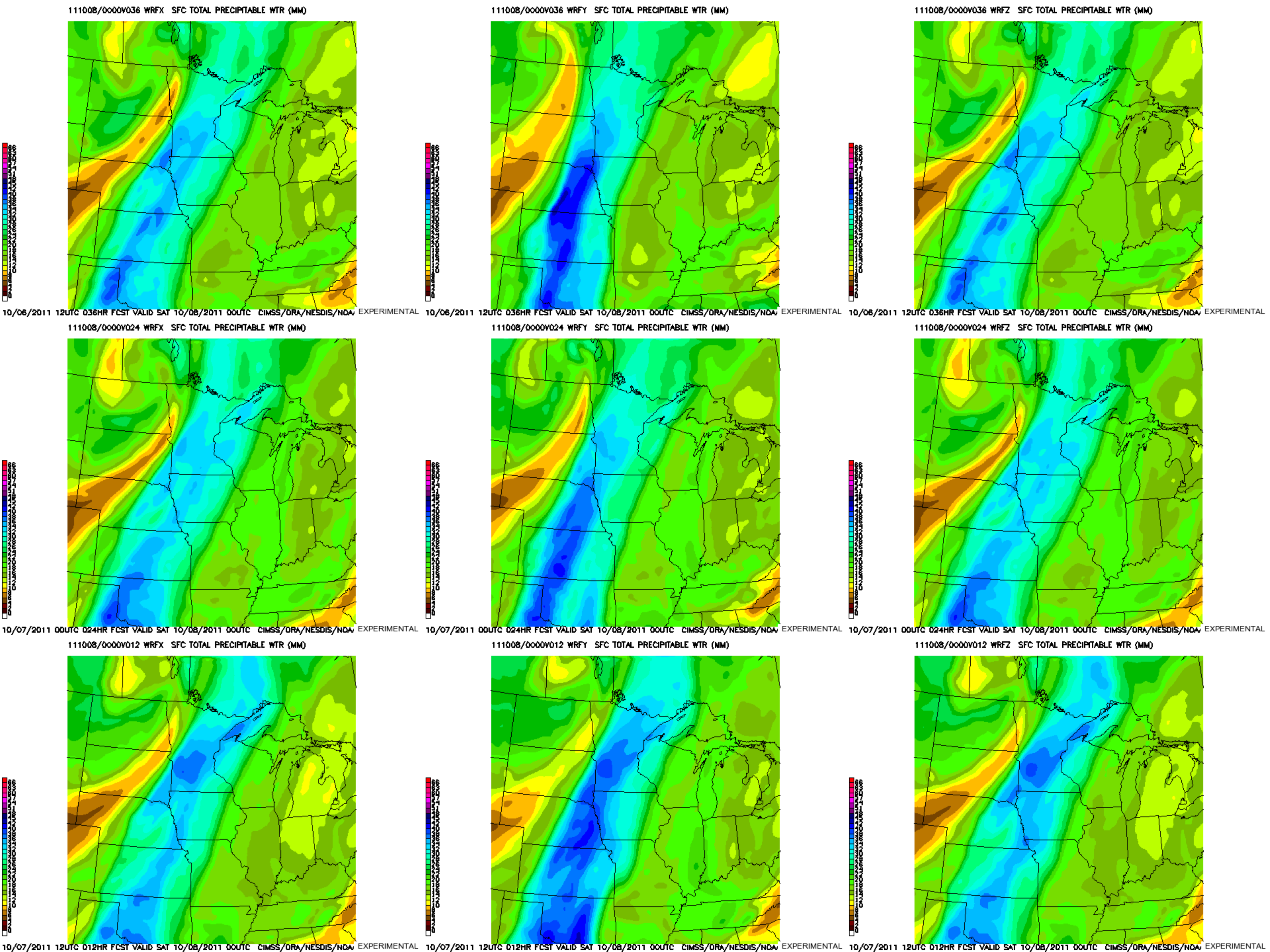
EXPERIMENTAL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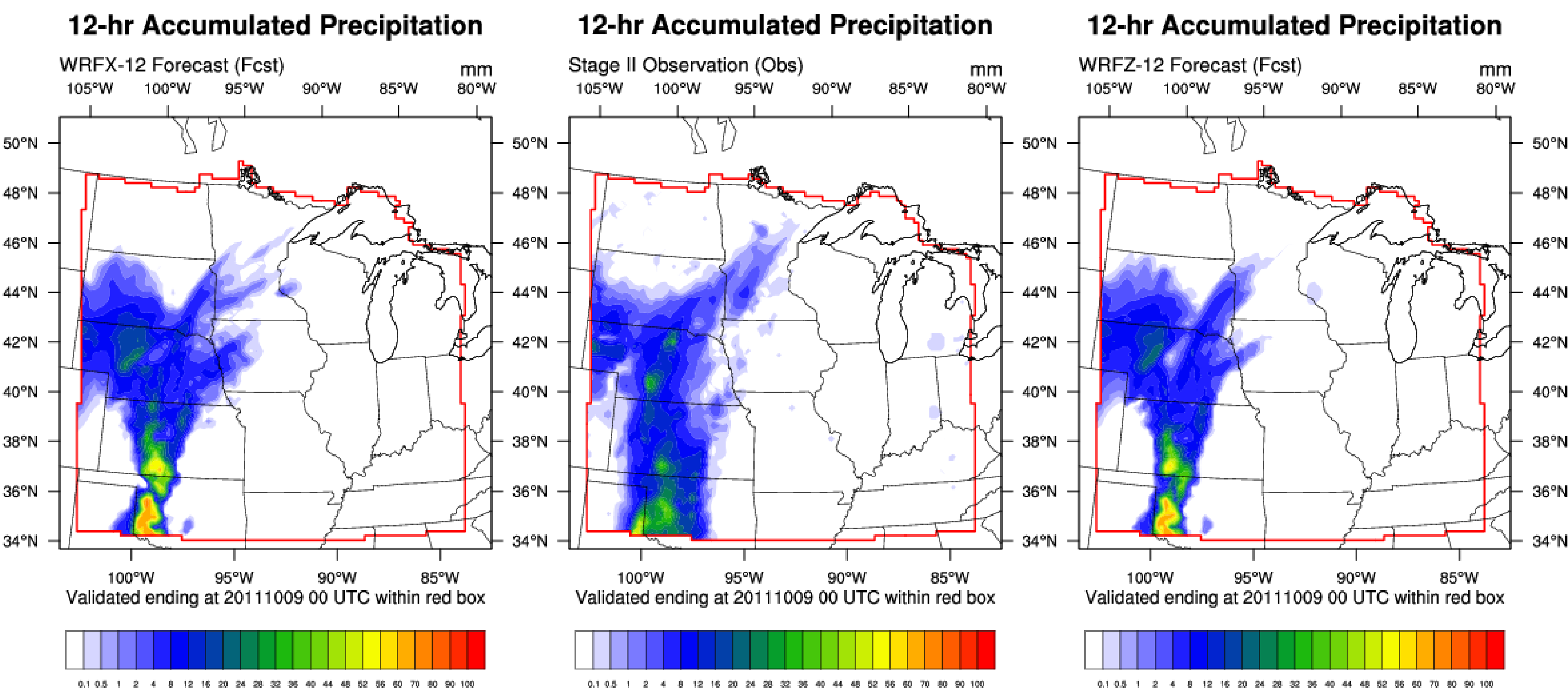
10/07/2011 12UTC 012HR FCST VALID SAT 10/08/2011 00UTC CIMSS/ORA/NESDIS/NOA
EXPERIMENTAL

Precipitation: WRFX vs. WRFZ

12-hr Accumulation ending 9 October 2011, 00 UTC

WRFX produced more precipitation than observed over south central Kansas.

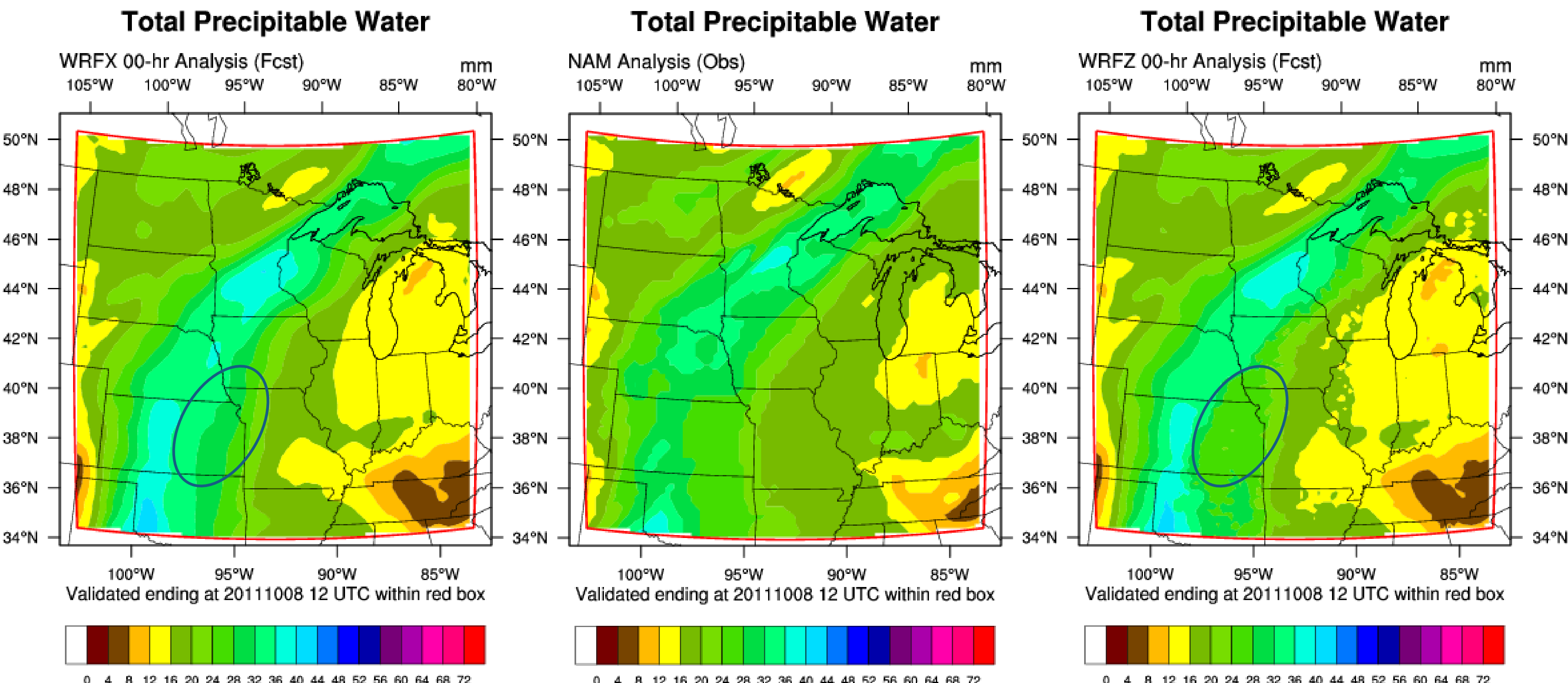
Model	MAE (ST2)
WRFZ	1.48 ☑
WRFX	1.65



PW Analysis: WRFX vs. WRFZ

Valid 8 October 2011, 12 UTC

WRFX started with PW up to 8 mm too moist over eastern Kansas, whereas the WRFZ exhibited less bias.

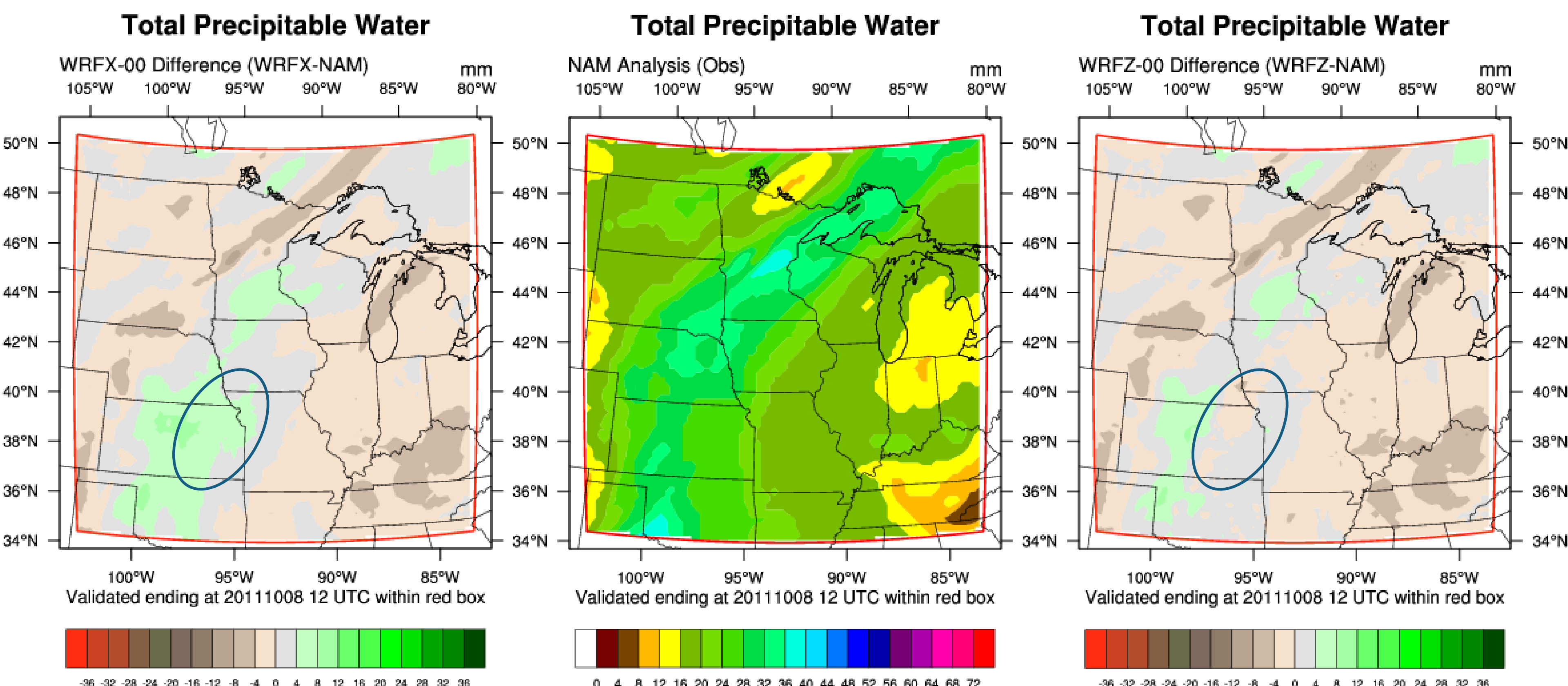


PW Analysis: WRFX vs. WRFZ

Valid 8 October 2011, 12 UTC

WRFX started with PW up to 8 mm too moist over eastern Kansas, whereas the WRFZ exhibited less bias.

Model	MAE (GPS)
WRFZ	1.58 ☑
WRFX	1.87



Summary of Presented Results

Runs from 28 September to 8 October 2011

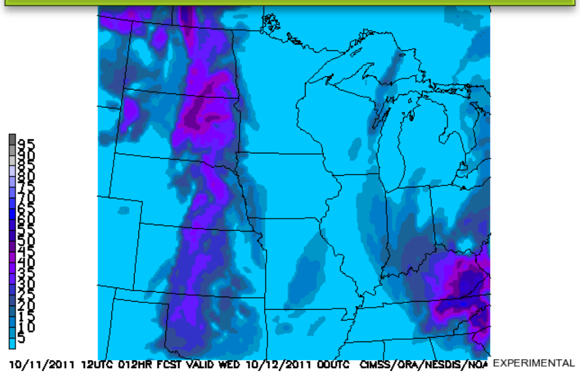
* Comparing WRFX and WRFZ, two sources of precipitable water verification confirm forecasts are better 12 hours after initialization ***if GOES-13 Sounder input is included***.
    * This may produce better precipitation verification, but not in regimes favoring light precipitation or limited areal extent.
* No substantial impact of added observations at 24 or 36 hours in the late September, early October flow regime.
* Lesser performance of WRFY suggests that CRAS dynamics and physics are influencing the solution negatively.

Advantages of CRAS

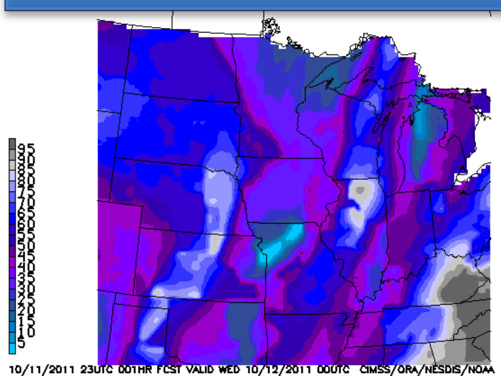
Cloud Fraction Still Supreme

- Default WRF cloud fraction takes the average of three primary layers (low, mid, and high). Maximum cloud fraction can be computed if those three layers are averaged (they can be output).
- 12-hr Cloud Cover Forecast MAE compared to the 1-hr NDFD is approximately 20% for CRAS, 25% for WRF with maximum cloud adjustment, and 30% for default WRF.
- NDFD may overestimate clouds when actually clear.
- These sample images, compared 12-hr forecasts to the NDFD, are valid at 12 October 2011, 00 UTC.

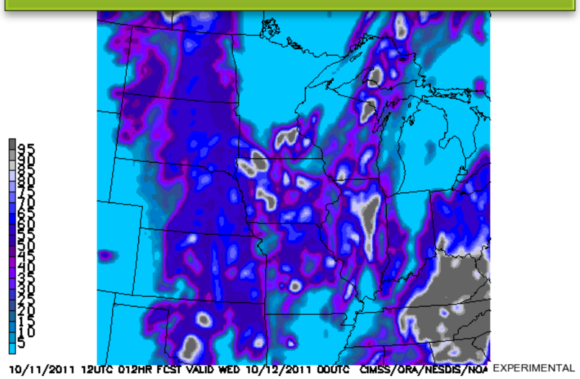
WRFX Default Cloud Fraction



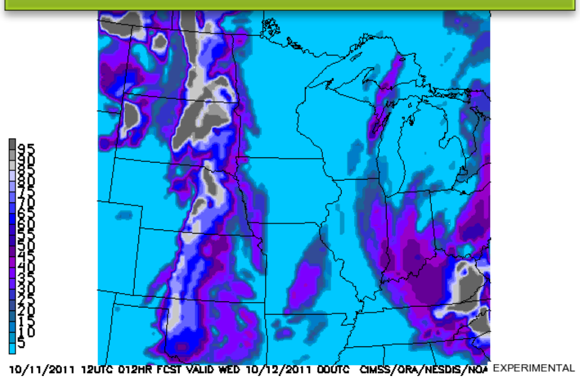
NDFD 1-hr Cloud Cover Forecast



CRAS Cloud Fraction Default



WRFX Maximum Cloud Fraction

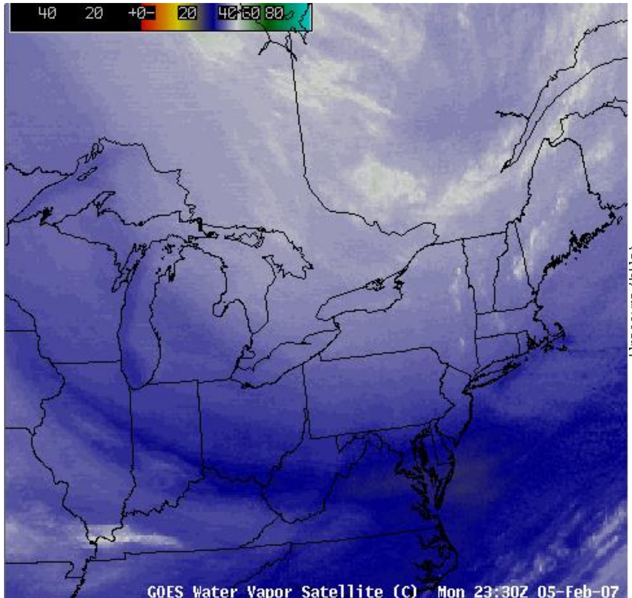


Predictions for Winter Performance

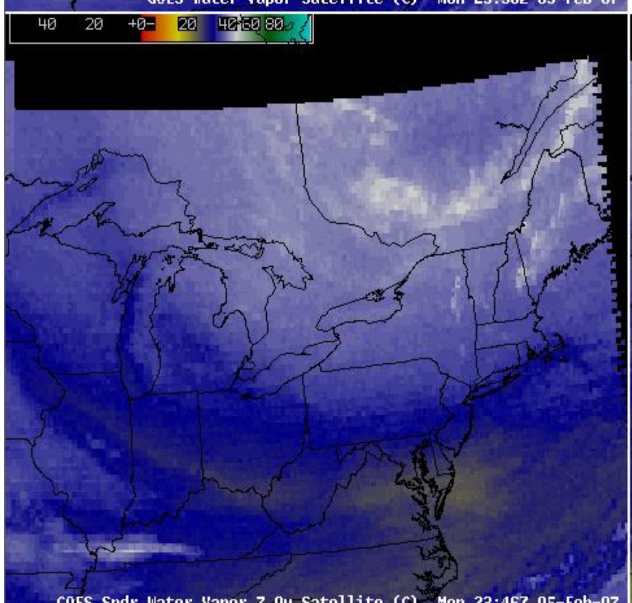
Statistics online at http://cimss.ssec.wisc.edu/cras/

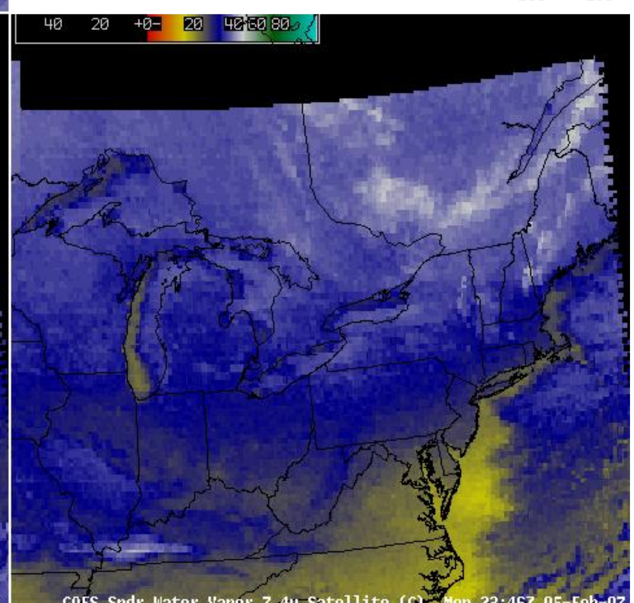
* More clouds means likely less Sounder observations.
* Faster flow conditions will advect observations off the domain fairly early in the simulations.
* In clear conditions, a drier upper troposphere will favor observed moisture contributions from lower in the atmosphere.
* Dynamic weather systems resulting in well-forced precipitation may show impact of precipitable water assimilation on precipitation amounts better than weakly-forced, high-moisture convective precipitation regimes.

Example from CIMSS Satellite Blog: Wintertime Water Vapor



Calculated weighting functions based on February 6, 2007, 00 UTC, radiosonde taken at Upton, NY.

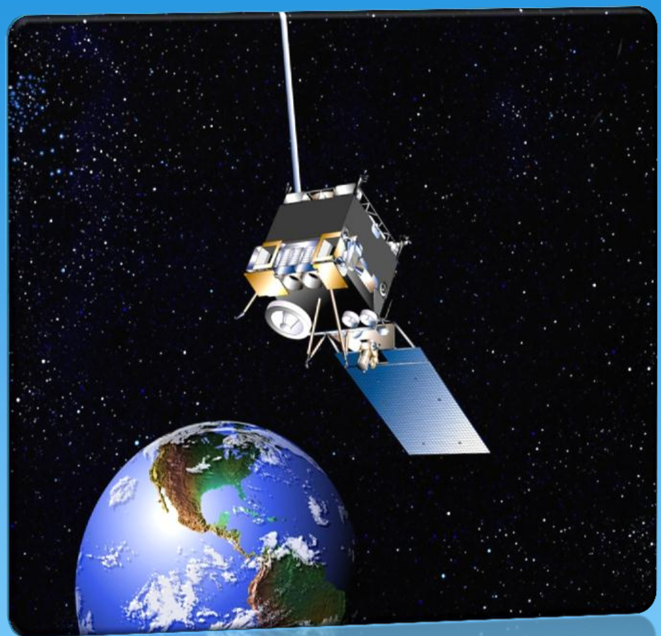




Water vapor near the surface is detected by the GOES-12 Imager and Sounder due to very limited emission (low water vapor) in the upper troposphere.

http://cimss.ssec.wisc.edu/goes/blog/

Final Thoughts



Satellite observations play a fundamental role in NWP solutions.

Leveraging the GOES Sounder is one way to improve the accuracy of the WRF-ARW forecast within the first 12 to 24 hours, especially away from oceans, where TPW retrieval assimilation does not occur in operational models.

Subtle changes to the moisture field can impact NWP performance.

Graphical output and real-time statistics from experiment are available online, as well as BUFKIT profiles for select cities.

We are always interested in partners looking to engage in joint projects involving satellite meteorology and NWP.

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