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Improving Cloud and Moisture Representation by Assimilating GOES Sounder Products into Analyses for NWP

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Experiment Design

Objective: Quantify NWP response to GOES-13 Sounder-adjusted 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

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

Kain-Fritsch Convective Scheme

- The WRF simulations in this experiment utilize the Kain-Fritsch (KF) convective parameterization, which
  - is a mass flux scheme
  - requires an adjusted response based on the grid scaling
- The closure for the KF scheme is convective available potential energy (CAPE). This is an important source for latent heat release and accumulated convective precipitation.
- It has been shown in Kain and Fritsch (1990) that the normalized vertical mass flux varies significantly by a factor of two in the upper troposphere for changes of relative humidity between 50% and 90%.
- This sensitivity is critical because, for cold temperatures, the amount of water vapor mixing ratio required to adjust the relative humidity is not particularly substantial.

Assimilating Three-Layer Precipitable Water from GOES

r_M = GOES total precipitable water
r_B = Background total precipitable water
$w(\sigma)_B$ = background mixing ratio
$w'(\sigma)_B$ = background mixing ratio perturbation
w_0 = surface mixing ratio
$w_S(T)$ = saturation mixing ratio
$w(\sigma)_F$ = final mixing ratio

Let,

$$\bar{r}_M = \frac{1}{n}\sum_n r_M, \quad n = \text{number of GOES obs in grid cell}$$

Precipitable water is defined as: $r = \frac{p_0}{g}\int_\sigma w(\sigma)\,d\sigma$

Define a mean mixing ratio profile: $\hat{w}(\sigma) = w_0\sigma^\lambda - w'_B(\sigma)$ such that

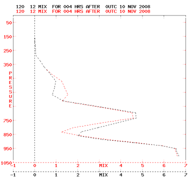
$$\frac{p_0}{g}\int_\sigma w'_B(\sigma)\,d\sigma \text{ is a minimum and } 1.0 < \lambda < 3.5 \text{ following Smith, 1966.}$$

Solve for $\lambda = \lambda'$ such that:

$$\bar{r}_M = \frac{p_0}{g}\int_\sigma \hat{w}_0\sigma^{\lambda'} + w'_B(\sigma)\,d\sigma \text{ with: } [\hat{w}_0\sigma^{\lambda'} + w'_B(\sigma)] < w_S(T)$$

The final adjusted mixing ratio is:

$$w_F(\sigma) = \hat{w}_0\sigma^{\lambda'} + w'_B(\sigma)$$



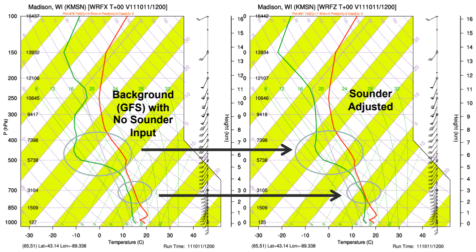
Mixing ratio profile before (red) and after (black) assimilating TPW from the sounder

* Smith, W.L., 1966: Note on the relationship between total precipitable water and surface dew point. J. Appl. Meteor., 5, 726-727.

GOES-13 Sounder Moisture Correction

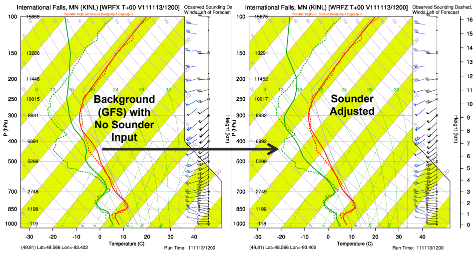
Madison, WI; 11 October 2011, 12 UTC

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

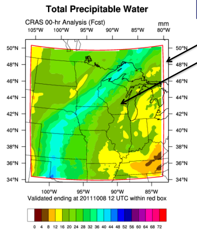


International Falls, MN; 13 November 2011, 12 UTC

This example shows the improvement to the background (left) by the GOES Sounder retrieval (right), compared to a radiosonde (dashed).



Experiment Domain



Based on NWS Milwaukee regional domain

Model
Verification (non-precipitation)

Model Evaluation Tools (MET) v3 used for statistics.

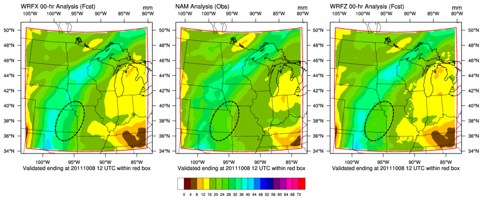
The verification subset was chosen to discount any boundary condition influences from the results. In addition, the GOES Sounder does not scan above 50° N (approximately).

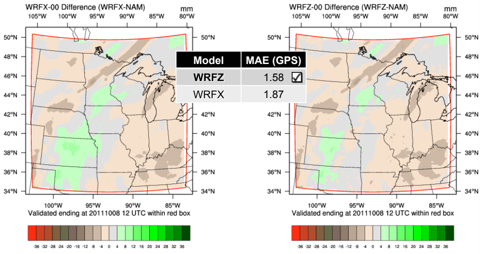
For point verification, approximately 70 GPS-TPW sites are within the red box.

PW Analysis: WRFX vs. WRFZ

Comparison for 8 October 2011, 12 UTC

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



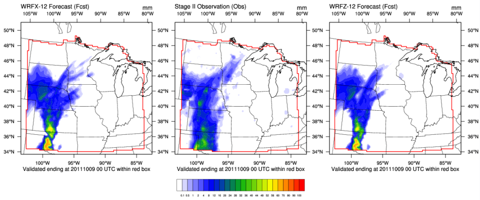


Model	MAE (GPS)
WRFZ	1.58 ☑
WRFX	1.87

WRFX and WRFZ Precipitation Comparison with Stage II

The WRFX and WRFZ produced more precipitation than observed over south central Kansas. However, the WRFZ was a drier solution compared to the WRFX. The WRFX and WRFZ predicted similar precipitation coverage patterns.

Model	MAE (ST2)
WRFZ	1.48 ☑
WRFX	1.65



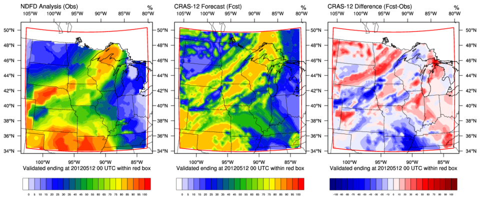
Using Linear Programming to Optimize Sky Cover Output

The process employed for staging and using background data was as follows:

- **Initialize the dynamical model at time t = -12 (hours).**
- **Obtain the 12-hour forecast from the model initialized at t = -12.**
- **Obtain the analysis from t = 0.**
- **Run linear program to minimize the objective function comparing the 12-hour forecast and analysis both valid at t = 0.**
- **Initialize the dynamical model at time t = 0.**
- **Apply fixed variable values from the linear program (a coefficient and scalar) to dynamical model output at t = 12, t = 24, and t = 36. Calculate skill.**

For this case, the absolute error (post-execution objective function value) from the linear program was 127075.8 (%) using the CRAS (mean absolute error of 13.0% per grid point) and 138651.3 (%) using the WRFX (mean absolute error of 14.1% per grid point).

Mean absolute error (MAE) was computed using the NDFD analysis as truth against the 12-hour sky cover forecasts from the CRAS and WRFX models, all valid on 12 May 2012 at 12 UTC (7 AM CDT). For the CRAS, the linear adjustment only had a minor improvement of 1.2%. The post-optimization forecast MAE was 17.1%, compared to 18.3% without the adjustment. For the WRFX, the improvement was substantial at 24.5%. The post-optimization forecast MAE was 18.4%, compared to 42.9% without the adjustment.



Experiment Results

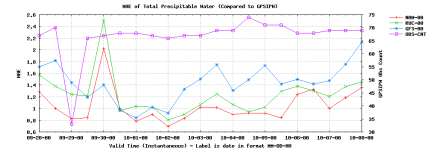
Total PW Mean Absolute Error

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



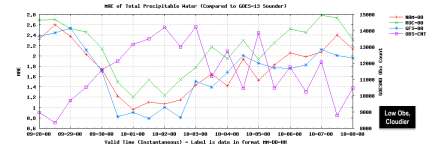
Total PW Mean Absolute Error

Analyses verified against GOES-13 Sounder (Ma retrievals)

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



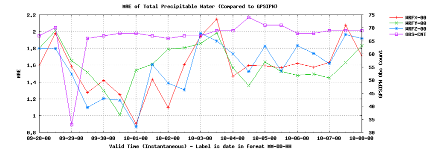
Total PW Mean Absolute Error

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



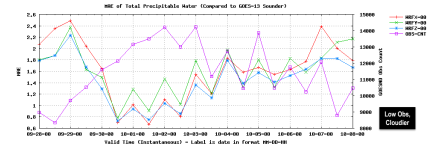
Total PW Mean Absolute Error

Analyses verified against GOES-13 Sounder (Ma retrievals)

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 PW Mean Absolute Error

Forecasts verified against GPS-TPW

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

12-hour

Model	Mean MAE
WRFZ	1.72 ☑
WRFX	1.77
WRFY	1.81

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