# Improvements in GOES/GOES-R Water Vapor Calibration and Validation

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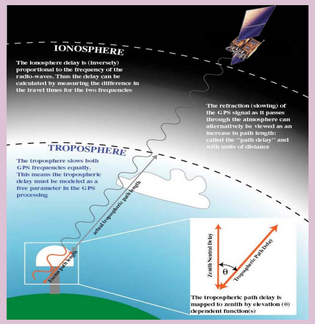
***Introduction:*** **Calibration and validation (Cal/Val) of GOES-R moisture products will be a challenge because temperature and humidity retrievals using the Advanced Baseline Imager (ABI) will be underdetermined and a numerical weather prediction model will be needed to provide the first guess for profiles. Over the last year, NOAA's Earth System Research Laboratory has been investigating several of the aspects of this problem including the characterization of systematic errors in operational NWP model analyses and forecasts of TPW and the characteristics of GOES and GOES-R proxy TPW products. The purpose of this poster paper is to summarize some of our major findings in FY2009 and make recommendations to improve current and future GOES water vapor products.**

***Recommendations:***

1. ***Change over to the CIMSS algorithm for retrieving TPW from GOES data. The forward model changes implemented by SSEC and CIMSS are having a sustained positive impact on GOES-E and GOES-W TPW retrievals.***
2. ***Investigate the impact of using the NAM rather than the GFS for GOES-R ABI and other satellite background estimation. Out to at least 3-hours, the NAM appears to be in better agreement with GPS TPW estimates over CONUS than other models including the RUC. Another factor is that since the GFS provides the background for the NAM, and systematic differences between GFS and GPS TPW estimates have been detected that appear to control the accuracy of > 3-h NAM predictions, consideration should be given to investigating and correcting the source of these errors in the GFS.***

## Why Use GPS for Cal/Val?

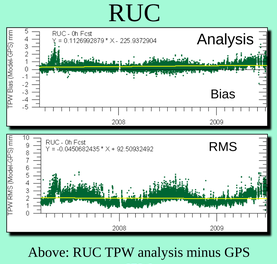



GPS Meteorology is based on our ability to use Global Navigation Satellite System (GNSS) receivers to measure the time of flight of L-Band radio signals as they travel from space to receivers at or near the surface of the Earth. The difference between the observed arrival time of the radio signal and its expected arrival time is called the signal delay. When all other factors are taken into account, the total signal delay is caused by changes in the refractivity of the upper and lower atmosphere. Refractivity in the upper atmosphere is caused primarily by changes in total electron content along the paths of the radio signals. Since the velocity of radio signals in a conductive medium is frequency dependent, and GNSS satellites broadcast in two or more frequencies, it is possible to remove ionospheric signal delays as a source of error in the estimation of tropospheric refractivity. The refractivity of the lower atmosphere depends to first (and second) order on changes in temperature, pressure and water vapor along the paths of the radio signals. Ultimately, the accuracy with which we are able to estimate tropospheric refractivity using GNSS signal delays depends on the accuracy and precision of the atomic clocks used to define the International System of Units (SI) timing standard. As a consequence, GNSS estimates of refractivity and quantities derived there from (e.g. TPW or integrated water vapor mixing ratio) require no external calibration, and measurement accuracy (*visa a vie* precision) are considered to be temporally invariant. This means that we can use GPS-Met techniques to independently check the accuracy of many of our observing systems, including radiosondes, satellite infrared and microwave radiometers, and possibly even satellite altimeters.

## NWP Model Analyses and Forecast Comparisons

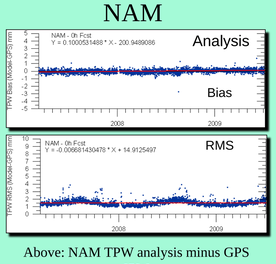
The purpose of this activity is to assess how well three operational NWP models (RUC, NAM and GFS) analyze and predict total column moisture at approximately 300 sites over CONUS. This assessment started on 11 MAR 2007, and the length of time covered in this report is 850 days (2.3 years). The goal of this study is to identify an operational NWP model that can reliably provide TPW analyses and predictions closest to GPS observations for GOES-R moisture retrievals. **NOTE:** the operational RUC and NAM models currently assimilate GPS observations each cycle while the operational GFS does not. No information about EMC plans to assimilate GPS into the GFS is available.

RUC



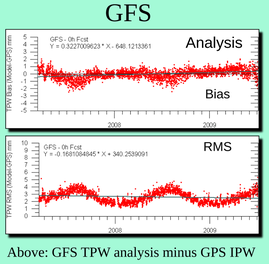

Above: RUC TPW analysis minus GPS IPW

NAM

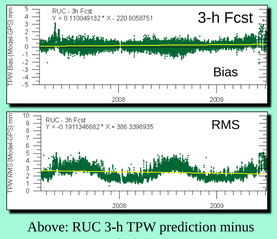



Above: NAM TPW analysis minus GPS IPW

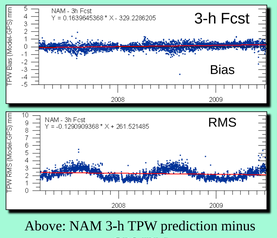
GFS



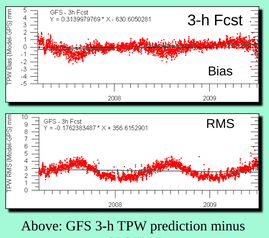

Above: GFS TPW analysis minus GPS IPW




Above: RUC 3-h TPW prediction minus GPS IPW




Above: NAM 3-h TPW prediction minus GPS IPW

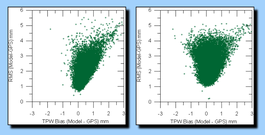



Above: GFS 3-h TPW prediction minus GPS IPW

## NWP Model Discussion

1.RUC

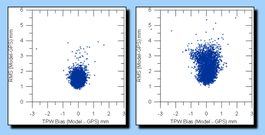
The operational RUC and its research derivatives assimilate GPS TPW at about 300 locations over CONUS every hour. Averaged over more than 2.3 years, the RUC analysis has a wet bias w.r.t. GPS of about 0.4 mm and a standard deviation of the differences of about 2 mm. At 3-h, the mean difference decreases to about 0.2 mm but the RMS differences increase to about 2.5 mm. Since January 2009, the mean differences between the RUC and GPS TPW have started to increase. This appears to coincide with the start of routine Radar reflectivity assimilation into the RUC and we suspect that these events may be linked.



Above left: RUC 0-h: bias vs rms
Above right: RUC 3-h bias vs rms

2. NAM

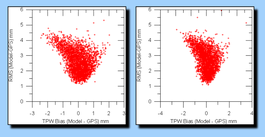
The operational NAM assimilates about 300 GPS TPW observations over CONUS every cycle. Averaged over the same period described above, the NAM analysis has a dry bias w.r.t. GPS of about 0.007 mm and the standard deviation of the differences is about 1.5 mm. It is interesting to note that these are almost the same differences observed between GPS and radiosondes when RAOB outliers are removed. At 3-h, the NAM is wet biased w.r.t. GPS by 0.07 mm and the standard deviation is 2.3 mm. As one observes changes in the characteristics of the NAM with time, we see that the NAM becomes more "GFS-like" as forecast duration increases. In fact, TPW differences between the NAM and the GFS after 12-h are virtually indistinguishable.



Above left: NAM 0-h bias vs rms
Above right: NAM 3-h bias vs rms

3.GFS

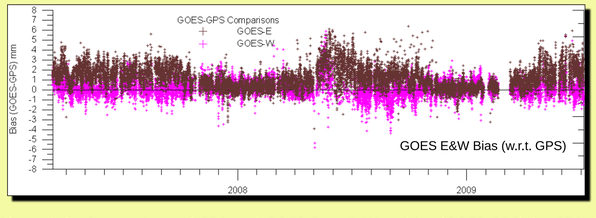
4.The GFS does not currently assimilate ground-based GPS-Met observations, but it does assimilate space-based refractivity derived from COSMIC RO data. Averaged over the same period described above, the GFS analysis has a dry bias w.r.t. GPS of about 0.022 mm and the standard deviation of 2.6 mm. The dry bias observed during the warm season is highly correlated with increased RMS differences. We have observed that the slope of the GFS-GPS TPW differences is increasing more-or-less systematically over time, suggesting that the GFS over CONUS is getting wetter with respect to GPS TPW estimates. Within 3-h, the GFS-GPS differences have a wet bias of 0.017 mm and a standard deviation of 2.7 mm. By 12-h (not shown) the bias and standard deviation are 0.087 mm and 2.86 mm, respectively. It is extremely interesting is that despite the copious number of moisture observations assimilated into the GFS each cycle, the TPW bias and RMS characteristics of the GFS don't seem to change significantly with time. One possible interpretation of this is that the GFS down-weights upper-air moisture observations and this may have a negative impact on all model parameters/fields dependent upon latent heating.

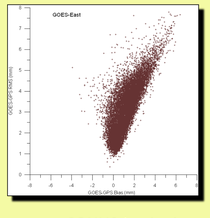


Above left: GFS 0-h: bias vs rms
Above right: RUC 3-h bias vs rms

## Evaluation of GOES-GPS TPW Differences

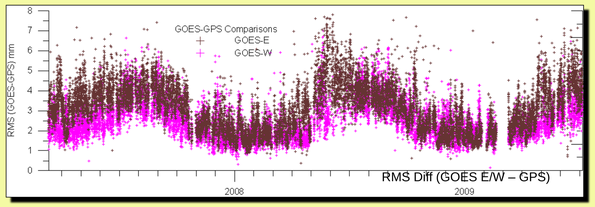
In work conducted over the last two years, ESRL/GSD identified systematic errors in the operational GOES TPW product, developed an algorithm to correct these errors, and demonstrated improvements in GOES TPW products over CONUS. We continue to monitor GOES TPW performance by comparing NESDIS operational GOES-E and GOES-W TPW products with GPS observations.

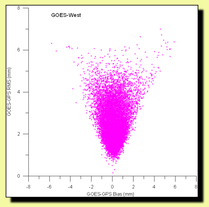


**Above left:** Comparison of GPS and GOES East & West bias (GOES-GPS) for 850 days over CONUS beginning 11 MAR 2007. Over the period of evaluation, GOES-E is wetter than GPS by 1.173 mm and GOES-W is wetter than GPS by 0.141 mm. **Above right:** Scatterplot of bias versus RMS for GOES-East. Consistent with previous results using shorter evaluation periods, GOES-E has a strong wet bias. RMS differences increase with increasing TPW, and the magnitude of the RMS differences are larger than those observed from GOES West (above right

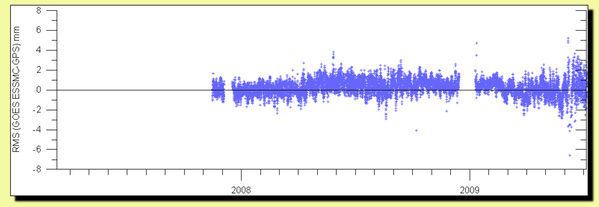
## Evaluation of GOES-GPS TPW Differences (Cont.)

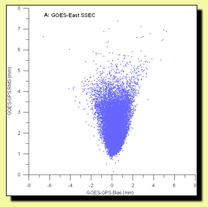


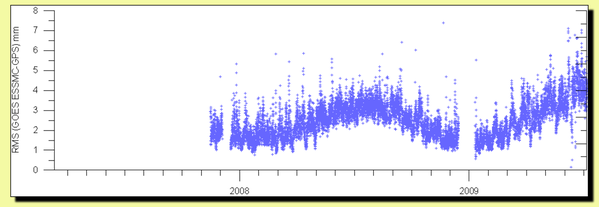



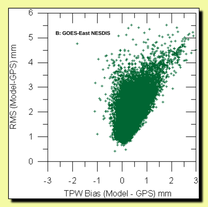
**Above left:** Comparison of RMS differences between GOES-E/W and GPS over CONUS for 850 days beginning 11 MAR 2007. Over the period of evaluation, the RMS difference between GOES-E & GPS is 3.111 mm, while the RMS difference between GOES-W and GPS is 2.490. **Above right:** Scatterplot of bias versus RMS for GOES-West. Consistent with previous results using shorter evaluation periods, GOES-W has negligible bias and the increase in RMS differences is less pronounced than we see in GOES-E below.

**Below left & right:** We are also evaluating the processing of GOES-E data at SSEC and comparing it with GPS TPW estimates just as we have done with the operational GOES discussed previously). By comparison, the bias and RMS differences in the SSEC processing (0.274 mm and 2.496 mm, respectively) have more in common with the operational processing of GOES-W (above-right) than they do with the operational GOES-E product. Obviously the forward model changes and adjustments made by SSEC and CIMSS are having a sustained positive impact on GOES-E accuracy. Accordingly, ***the SSEC version of the GOES TPW product should be considered as a replacement for the current operational GOES TPW product.***

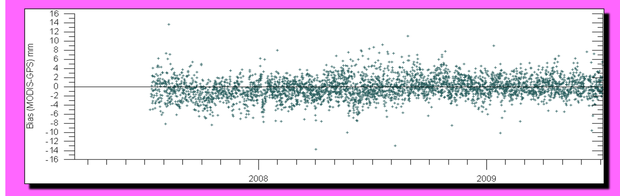


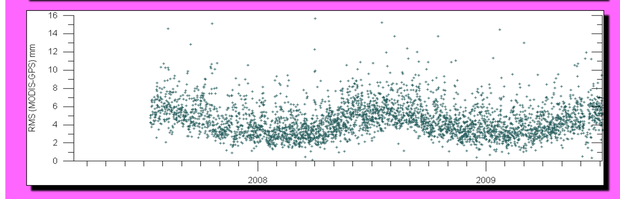


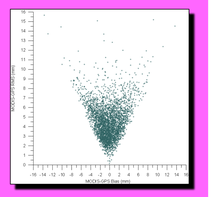




## ABI Simulation Using MODIS







**Note Change in scale from previous time series and scatterplots**

The bias of the ABI simulation is small (comparable to the SSEC GOES-E results) and a little dry compared to GPS (bias = 0.278 mm) but the RMS differences (4.5 mm) are considerably larger than we have thus far encountered with GOES. Using the NAM instead of GFS for the first guess may mitigate some of this behavior.