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POSSIBLE SOLAR INFLUENCES OBSERVED IN GOES AND MODIS TOTAL PRECIPITABLE WATER PRODUCT DATA

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1. INTRODUCTION

During the International H2O Project (IHOP) (Parsons 2002), that was conducted in the summer of 2002, the authors began to compare the geostational operational environmental satellite (GOES) total precipitable water (TPW) product with ground-based global positioning system (GPS) integrated precipitable water (IPW) data. This led to two key findings. First, there was a noted moist bias in the GOES data, especially at asynoptic times, (Birkenheuer and Gutman 2005). Second, an algorithm to utilize GOES data without bias correction was devised. It focuses on a variational analysis solution minimizing differences between the solution and the GOES gradient field, relying on other data for absolute measurement in the resulting solution (Birkenheuer 2006). This solution led to a more effective use of GOES data in the current Local Analysis and Prediction System (LAPS, McGinley et al. 1991). At the same time, it appeared that we could better serve the operational community by devising an hourly bias correction algorithm for product data that could be supplied to the National Environmental Satellite Data and Information Service (NESDIS) for operational use. This correction uses hourly-independent, empirically derived coefficients from archived GOES TPW and GPS IPW data. The coefficient technique is described best in Birkenheuer et al. (2008).

Serious thought is being given to using GOES retrieval data as part of a climatology record (Birkenheuer, personal communication). Indeed, there is already a cloud climatology using GOES data (Desormeaux et al. 1993). The tracking of moisture on a high-resolution scale (15-30 km) could be made available through GOES sounder data and possibly even higher resolution if one could utilize imager data such as will be available for GOES R. The tracking of moisture still could not be done in cloudy areas that continue to obscure the low levels in the IR. Augmenting the GOES data with ancillary surface, aircraft, and other data, through an analysis system such as the LAPS, helps to solve this problem to a degree. Also, improvements in accuracy are needed, or at least an understanding of bias, to apply such a record effectively. This paper explores the observed accuracy of GOES TPW data with respect to GPS IPW, and reviews the recent treatments for the GOES error, along with recommendations for GOES R that were an outgrowth of this work.

2. DERIVED COEFFICIENT TRENDS

When the coefficient data were devised for GOES 12 and then later for GOES 10, they were tabulated for use and publication, but had never really been studied together. The essence of this paper is the comparison of the coefficient data and what this scrutiny of the data reveals. The equation devised for correcting the GOES product data is a simple scaling and power correction,

$$G_c = aG^b \qquad (1)$$

where G_c is the corrected GOES TPW value (cm), G is the initial GOES TPW value (cm), a is a scaling term, and b is a power term. A plot of GOES 12 and 10 correction coefficients, both a and b terms, published in Birkenheuer et al. (2008), is shown in Fig. 1. The prominent feature is that during night hours (0-12 UTC), we see no apparent correlation between the

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respective satellite correction coefficients; however, we do see a shape similarity during daylight hours. The power term (*b*) in both satellites rises and the scaling term (*a*) drops in value in apparent response to solar radiation over the field of view (FOV). Furthermore, the time at which both terms seem to respond to daylight appears offset by a similar phase difference that coincides with the longitudinal difference (and corresponding time zone difference) in the satellite subpoints. The resulting time difference corresponds roughly to the initial period of solar illumination in the satellite measured scenes. The initial observation that there might be a solar influence in the asynoptic times of GOES data was first revealed by the plot of the coefficients (Fig. 1). Parallel to this work, the Cooperative Institute for Meteorological Satellite Studies (CIMSS) devised a new algorithm that now takes into account an emissivity adjustment in the forward model (Li et al. 2008). In collaboration with the CIMSS, we compared the new GOES TPW algorithm product values with GPS data for roughly a quarter of a year (March – June 2008). This period represents more than half of the moist part of the year, which typically runs from March to October. The unmodified GOES 12 data are plotted vs. GPS IPW data in Fig. 2. Figure 3 shows the improvement in agreement after applying the GOES bias correction. We feel that the new CIMSS algorithm is accounting for the solar effects possibly through its first guess algorithm that now includes a refined emissivity term (Jin et al. 2008). We believe that this will offer better moisture representation and more than likely eliminate the need for bias correction of GOES when it begins operating at NOAA in FY09.

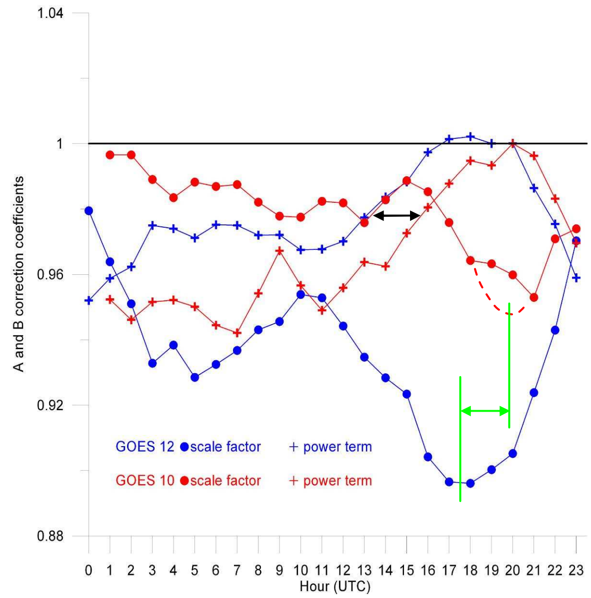

Fig. 1. Plot showing the *a* and *b* (scaling and power term) correction coefficients for both GOES 10 and GOES 12 as a function of hour (UTC). During dark hours (0-12 UTC) little correspondence is noted between the coefficients, however, during sunlit hours (12-23 UTC) similar response is seen. The approximate phase difference between the two curves during daylight is indicated by arrowed lines (black – power term, green – scaling term with vertical lines designating the separation in the minima). The dashed red line approximates a possible minimum in the scaling term for GOES 10. Fewer data for GOES 10 might have resulted in the absence of a clear minimum; however the scale factors retain a phase difference.

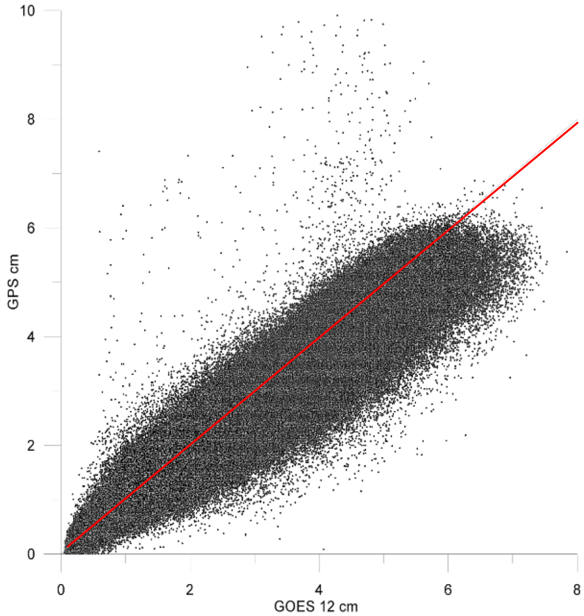

Fig 2. Scatter plot showing GOES 12 data (roughly 1.8 million points) plotted with GPS IPW data (cm). A clear moist bias is evident when comparing the points to the red 1:1 diagonal line.

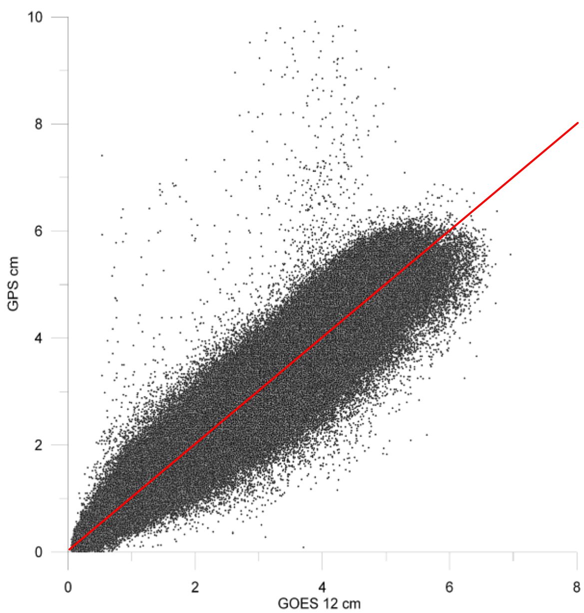

Fig 3. Scatter plot showing the improved agreement between GOES moisture and GPS IPW data after applying bias corrections.

In addition to GOES data, we have been looking ahead to GOES R. The best proxy we can find for GOES R real-time moisture products are those devised from the Moderate Resolution Imaging Spectroradiometer (MODIS). Figures 4 and 5 show MODIS scatter plots with GPS IPW broken into day and nighttime observations. Here night data show that MODIS has a dry bias while daytime measurements are more in line with GPS IPW. Better results during daylight hours may not be an indication of a better algorithm. It may well be that MODIS real-time soundings suffer from an emissivity problem in the forward model similar to that discovered in GOES, shifting the result to a moist bias during daylight. Also, it may be that MODIS has an initial dry bias.

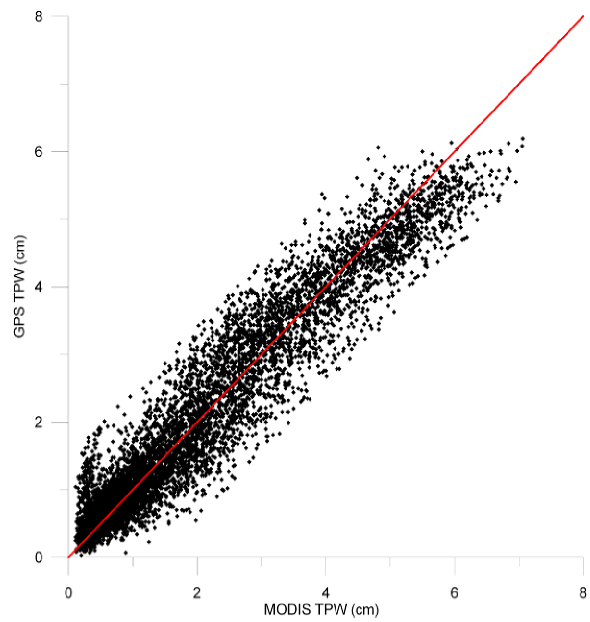

Fig. 4. Daytime scatter plot of MODIS TPW product data similar to GOES TPW data in Figs. 1 and 2. Again the red diagonal line indicates an optimal 1:1 correspondence.

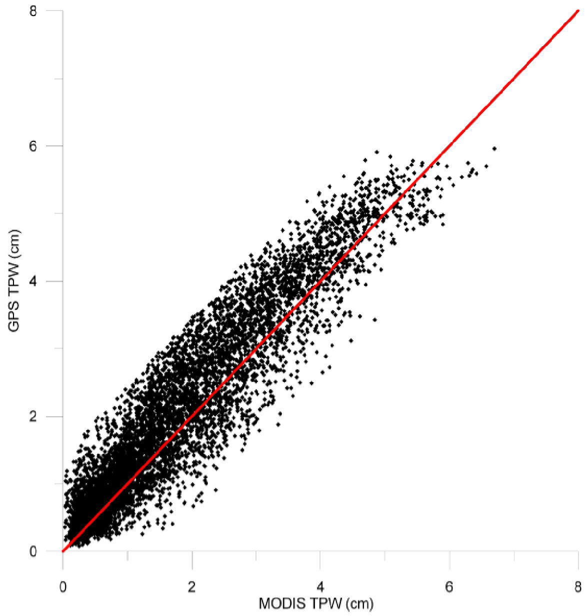

Fig 5. Nighttime scatter plot of MODIS data similar to Fig. 4.

Associating what was seen in the MODIS data to the GOES data, led us to another line of reasoning. Another major difference between these MODIS real-time products and GOES products is the absence of a first guess in MODIS. We now know that GOES R will be using the advanced baseline imager (ABI) data for sounding computation and will lack a hyperspectral advantage. In the sense that the current GOES retrievals are an undetermined mathematical problem, GOES R will fall into this same category, since the ABI does not provide enough channel data to offer enough independence in their weighting functions to render a unique solution. Therefore, improvements to the current GOES may be readily applied to GOES R.

3. INDICATIONS – BETTER FIRST GUESS AVAILABLE

The finding that both MODIS and GOES water vapor products appear to have a consistent characteristic moistening during daylight hours (before the new CIMSS algorithm), means that it is quite possible that the MODIS forward radiance model contains an emissivity response similar to GOES. Furthermore, the fact that GOES does start with a first guess may be the reason that nighttime GOES is more in agreement with GPS IPW than MODIS TPW. We know (Li et al. 2008), that the first guess has a direct relationship to product quality; it is therefore logical to focus on the quality of the first guess used in the retrieval.

An investigation of the various model first guesses has begun. The first look was at Global Forecast System (GFS) and North American Meso (NAM) models for analysis time only (hour zero). We examined both models for a good part of a year to understand the nature of the moisture error from potential first-guess models (integrated model/analyzed water profiles) compared to paired (both in space and time) GPS IPW measurements. Figure 6 shows the statistics from both GFS and the NAM. Shown first is the GFS, which provides the routine, real-time first guess to today's retrieval system for our operational GOES satellites. It is also probably a safe statement, assuming nothing changes, to say that the GFS will be the model used for ABI retrieval production when GOES R comes online. Second, the NAM, an operational model covering the conterminous United States (CONUS) domain, has a more frequent update frequency, making it a possible candidate to provide a better first guess to the retrieval system with minimal change to current model production schedules. We do not know whether the NAM offers the needed areal coverage to satisfy GOES retrievals operationally. When comparing the two sets of comparison statistics in Fig. 6, we see that the NAM model is superior in both stability over time, near-term rms (near-term here is the focus on the rms over a short-time interval (hrs), not the error seen varying by several days), and lower bias error.

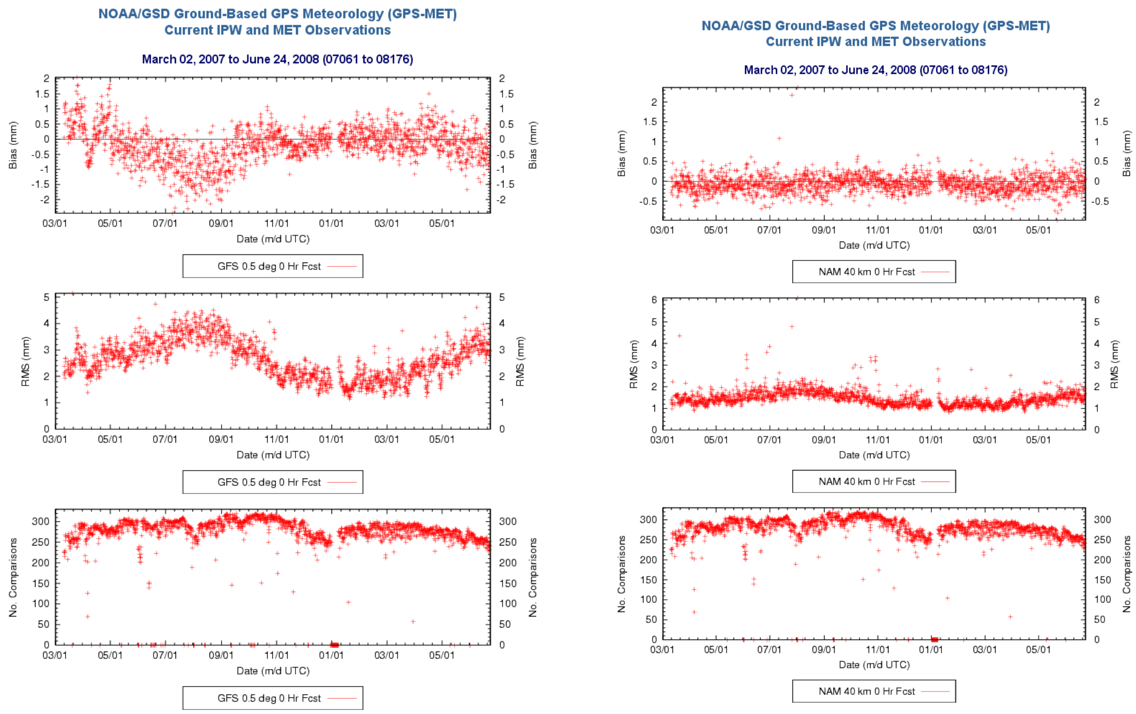

Fig 6. The GFS (left column) and NAM (right column) 0 hr forecast statistics as derived using GPS IPW data as reference. Each column contains at its top, a bias plot, in the center, an rms plot, and at the bottom, the observation count that comprises the data set. The most easily visualized discrepancy is seen in comparing the rms plots; the NAM is far more stable over time with a consistent low value. Note that the zero bias horizontal lines in the upper plots differ, but the scale spacing is the same.

To be fair, one needs to look at forecasts of the NAM; since the forecasts are what would be routinely used for retrieval first-guess generation. We need not look past six hours since the model runs every 6 hours. Also we need only look at the NAM, since the GFS model, which is not assimilating GPS IPW, has a greater bias at the initial time and it is not likely that it will improve over time. Figures 7 (a-d) show a set of 3-hr forecasts from the NAM compared with GPS IPW for one year at each model initialization time. These scatter plots reveal no perceptible GPS IPW differences in the model forecasts, which is important for operational considerations. Furthermore, the scatter in the plots is similar to the error one would nominally see in RAOB comparisons (Gutman et al. 2005). Accepting RAOB data as a standard, one would then say that the model forecasts are as good as RAOB data, and would not be expected to improve substantially. We are not making the argument that the model forecasts cannot improve, but rather that they are deemed reasonable to use as a first guess and given RAOB data as a measure of quality, they are comparable.

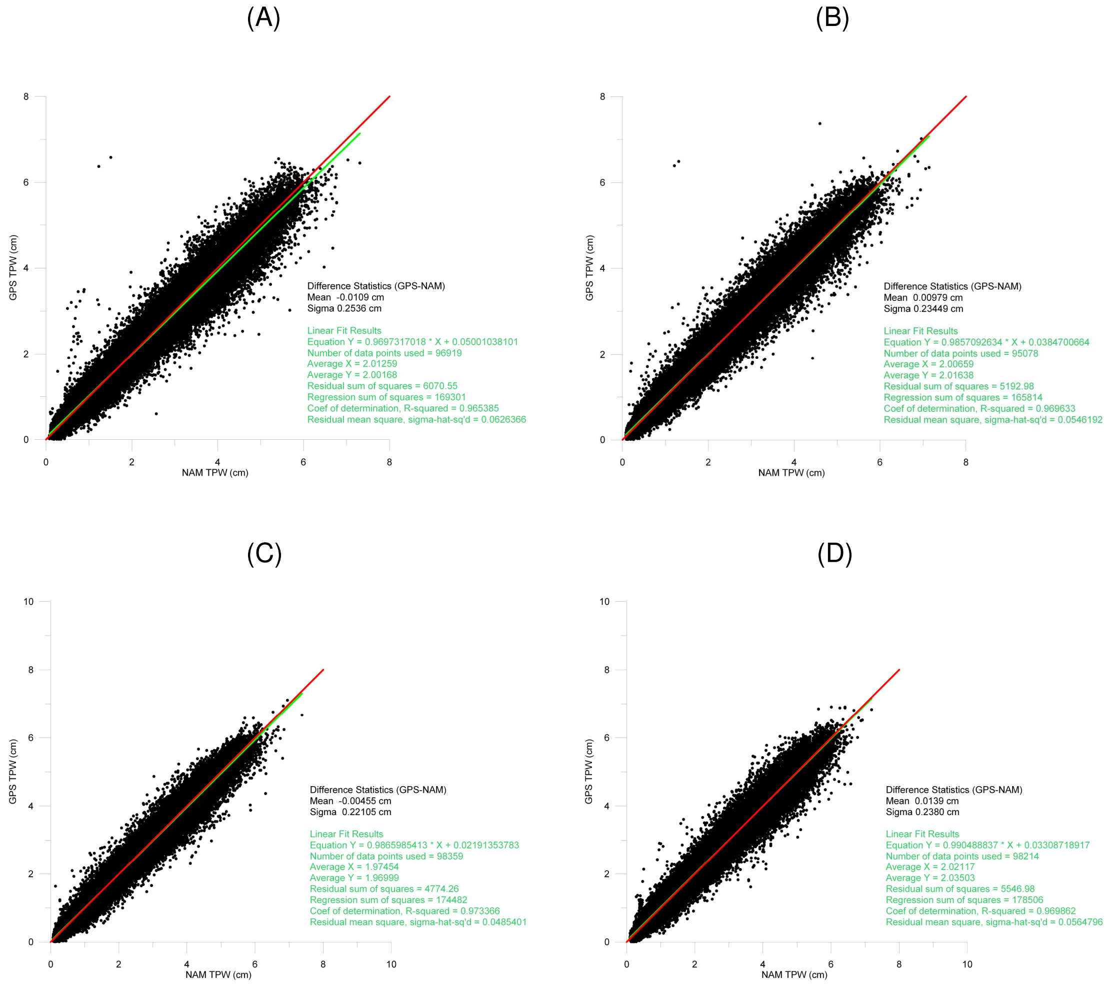

Fig. 7 Scatter plots a-d comparing NAM 3-hr forecast TPW with GPS IPW for approximately one year of data (~100,000 data points each). The plots a-d represent initialization times of 0, 6, 12, and 18 UTC respectively and are correspondingly valid at 3, 9, 15, and 21 UTC. Each plot also shows a linear fit result (green text and plotted green line) along with the difference statistics – mean (cm), and sigma (cm). The plotted diagonal red line is the optimal fit (1:1) line. The best observed fit is Fig. 7c (valid 15 UTC).

4. SUMMARY AND CONCLUSIONS—VALUE TO GOES R

GPS IPW has been of unprecedented value to us in the assessment of current GOES product representativeness. Additionally, it has aided formulation of techniques to work around the problems in assimilation. GPS IPW has helped identify the nature of the errors seen not only in current GOES product data, but also in MODIS moisture products. A new retrieval algorithm devised by CIMSS that compensates for emissivity in its first guess (Li et al. 2008), has been shown to resolve many of the bias problems now validated by GPS IPW. If the suspected source of the dry tendency in MODIS data is deemed true and the first guess helped current GOES avoid a potential dry bias, then, this indicates that improving the first guess quality would positively impact the resulting product (irrespective of satellite, or retrieval system).

Thus, the GPS IPW data has helped to validate the current GOES improvements implemented in test mode by CIMSS. It has also indicated with unambiguous clarity that the GFS, at least in its current configuration, is an inferior choice compared to the NAM, as a first guess for moisture retrievals. The authors believe that NAM should replace GFS forecasts as the model first guess for water vapor and possibly temperature, or if the NAM does not satisfy possible areal extent requirements, the GFS model should include GPS IPW in its assimilation and initialization. Note, that our assessment has not examined the thermal profile. If ancillary findings point to GFS or some other model as having a superior thermal profile, then perhaps the NAM moisture profile could be used in a hybrid model combination to improve the moisture profile quality. Hence, it is potentially worthwhile for retrieval research to consider testing both the thermal and moisture profiles from the NAM in retrieval testing.

The value of identifying a superior first guess for the current GOES is that it shortens the spin-up time required to use the "best" first guess forecast for application in the GOES R ABI system that will become available in a few years.

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