Assessing Galileo Precise Point Positioning Capability for Integrated Water Vapor Estimation

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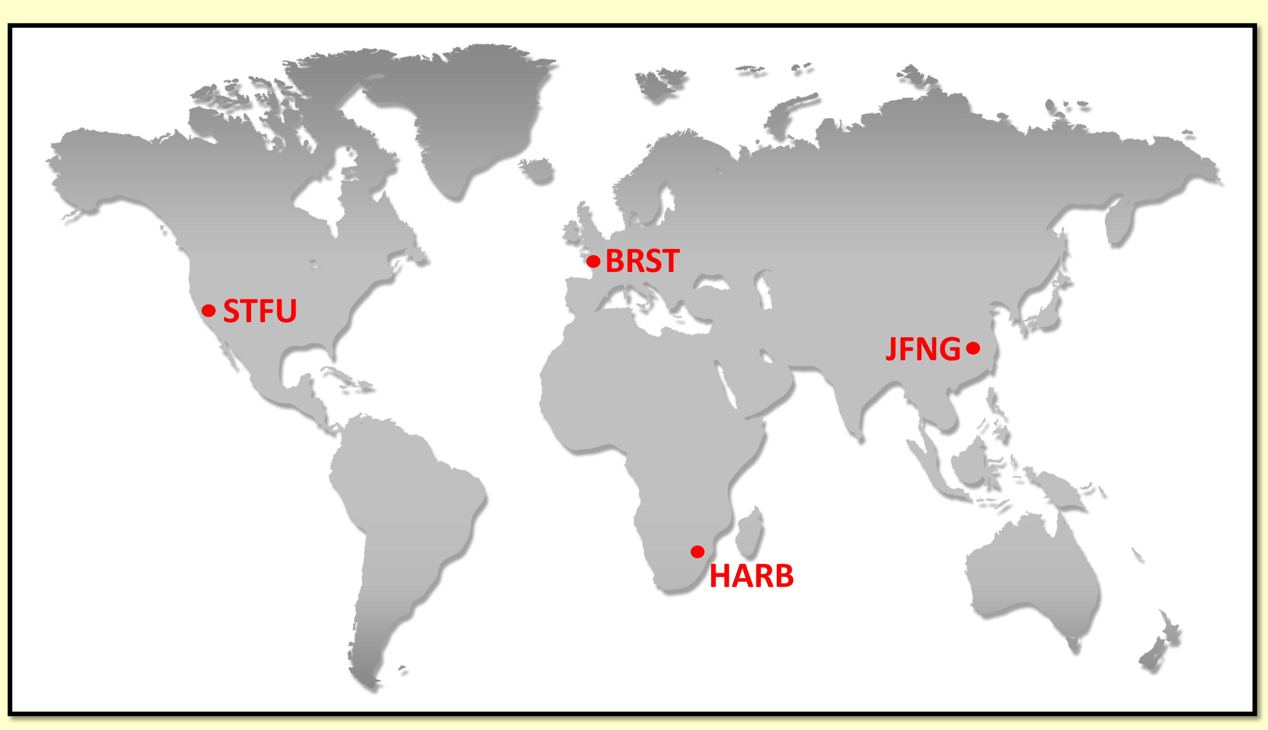
Introduction

Although most often used for positioning, navigation, and timing, GNSS observations constitute a useful tool for atmospheric remote sensing. By quantifying and analyzing the influence of the atmosphere on the propagation of electromagnetic signals, we can infer a significant amount of information for further understanding Earth's atmosphere as well its relationship with satellite positioning activities.

For some industrial sectors that require high accuracy and reliability, such as oil exploration, dredging, and aviation, the understanding of how GNSS satellite signals propagate across the atmosphere is crucial information. Among several improvements related to GNSS, the increasing number of in-orbit Galileo satellites opens a new window of opportunities for atmospheric research. Users can achieve improved satellite geometry and take advantage of Galileo signal characteristics, such as improved multipath mitigation. In this study, the use of Galileo signals for neutral atmospheric delay (NAD) estimation is assessed along with its integration with signals from the already established GPS constellation. Using the University of New Brunswick's GNSS Analysis and Positioning Software (GAPS) precise point positioning suite, the NAD values are estimated and integrated with in situ measurements of pressure, temperature, and humidity, allowing for the estimation of the integrated water vapor (IWV) of the atmosphere above a GNSS station. As a reference for the estimation assessment, available IWV values from radiosondes are used.

Data

For use in this investigation, four globally-distributed International GNSS Service Multi-GNSS Experiment (MGEX) tracking stations were selected at locations within 1 km of radiosondes launched daily at 0000Z and 1200Z.



These selected stations provide receivers with Galileo tracking capability as well as radiosonde data availability for the time interval of each station's GNSS observation period. While dual-frequency observables are available from the 7 current Galileo satellites, observation periods are rather inconsistent due to their limited number. Additionally, simultaneous observability of a minimum of four Galileo satellites is currently limited to four hours (at best) with very poor associated satellite geometry in most situations. These conditions hinder any accurate estimation of IWV using Galileo-only processing at this time.

For the processing of GPS observables, standard IGS final clock (5-minute) and orbit products have been utilized. For Galileo observable processing, clock (5-minute) and orbit products from the Center for Orbit Determination in Europe (CODE) made available through the IGS MGEX campaign have been utilized. While observables were logged at a 30-second sampling interval at each of the selected stations, processing was performed at a 5-minute interval as to avoid interpolation of satellite clock corrections. All products are available from the IGS FTP servers with a latency of approximately 2 weeks. The residual wet component of the tropospheric delay (D_{ZW}) is estimated within GAPS sequential least-squares filter and constrained with a random-walk processing noise of 5 $mm/\sqrt{hr}$.

Experiments

In order to assess the impact of using Galileo observables in a PPP solution, the chosen dataset was processed with GAPS using GPS-only and GPS + Galileo strategies. Estimates resulting from the GPS-only and GPS + Galileo processing are subsequently analyzed and compared to each other to see if the multi-GNSS solution is able to provide satisfactory results in terms of inferring total NAD.

As a second step, the D_{ZW}, along with the mean temperature of the troposphere (T_m), water vapor-specific constant (R_w), and atmospheric refractivity constants (k'_2, k_3) are used to estimate the amount of precipitable water in the atmosphere (IWV):

$$IWV = D_{ZW} \frac{10^6}{R_w \left[k'_2 + \frac{k_3}{T_m}\right]}$$

Once the IWV is determined, a comparison is performed against *in situ* radiosonde precipitable water sounding. The difference is then summarized and analyzed to assess the interoperability between GPS and Galileo for such an application as well as the appropriateness of the least-squares algorithm used in GAPS to estimate the wet delay.

Results

Although the Galileo constellation is still in its infancy, integration of Galileo observables with those of GPS is currently achievable and shows satisfactory results in terms of position and atmospheric parameter estimation. By analyzing the differences between GPS-only and GPS + Galileo D_{ZW} estimates, it can be seen that the differences between each are, on average, within 1 mm of the estimated D_{ZW} (station STFU) with a minimum difference of 0.08 mm (station JFNG). This represents approximately 0.16 and 0.13 kg/m^2 of precipitable water in the atmosphere, respectively. A maximum difference of about 1 cm occurred at station JFNG at 1200Z on day-of-year (DOY) 134, representing a discrepancy in the precipitable water estimate of approximately 1.7 kg/m^2. Figure 1 shows analysis of the entire dataset.

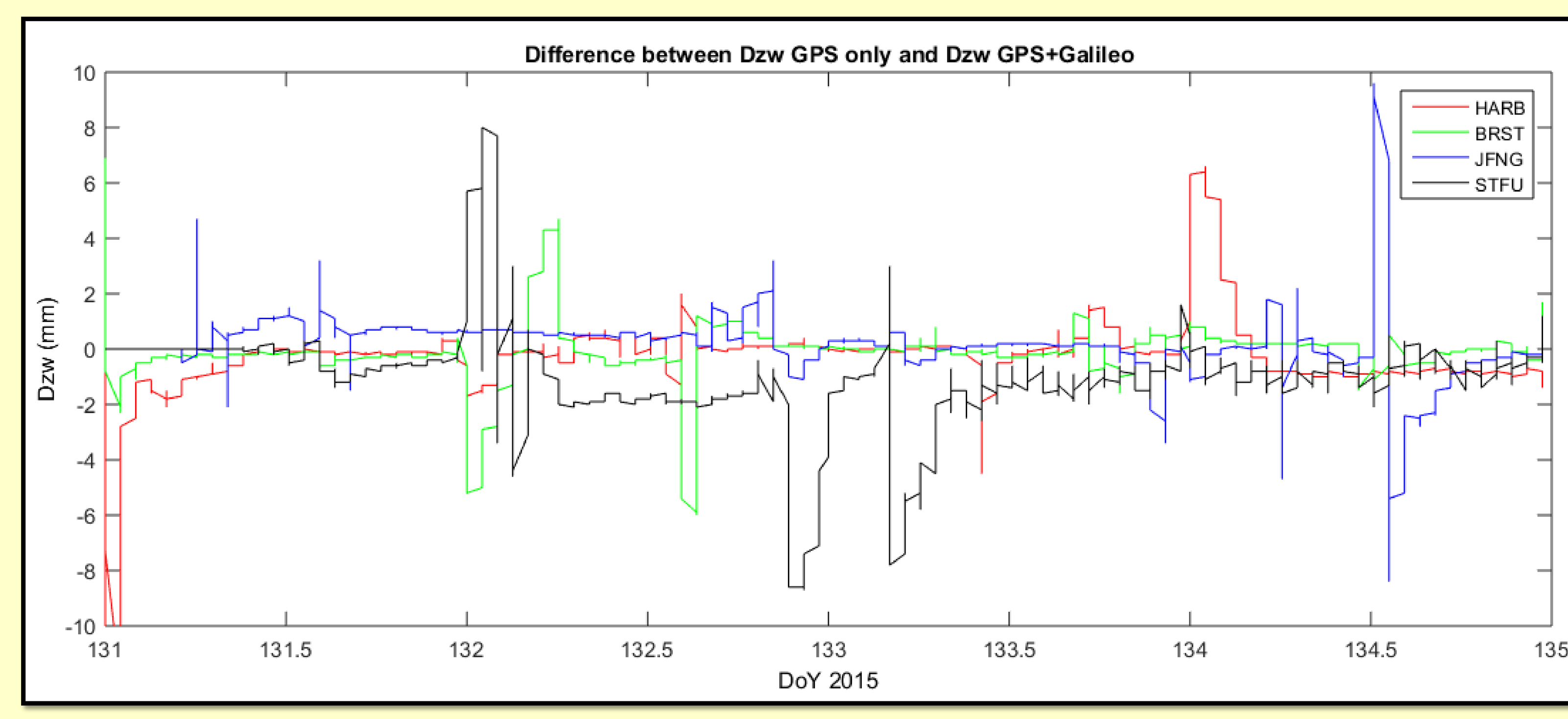


Figure 1 – Time series of the difference between GPS-only and GPS + Galileo D_{zw} estimates between DOY 131 and 135, 2015.

Although occasional outliers exist, the average difference remains within the expected noise of Galileo observable integration when considering the sporadic availability of Galileo satellites and the use of experimental Galileo orbit and clock products . To investigate if these outliers are due to the integration algorithm or, perhaps, with the tropospheric delay estimation, radiosonde sounding data are used as a benchmark tool for further comparison of estimated precipitable water. Figure 2 shows the discrepancy between GPS-only minus radiosonde IWV and GPS + Galileo minus radiosonde IWV. Figure 3 shows error bars for each station related to the difference between the average PPP-based estimation of IWV and the radiosonde-measured IWV.

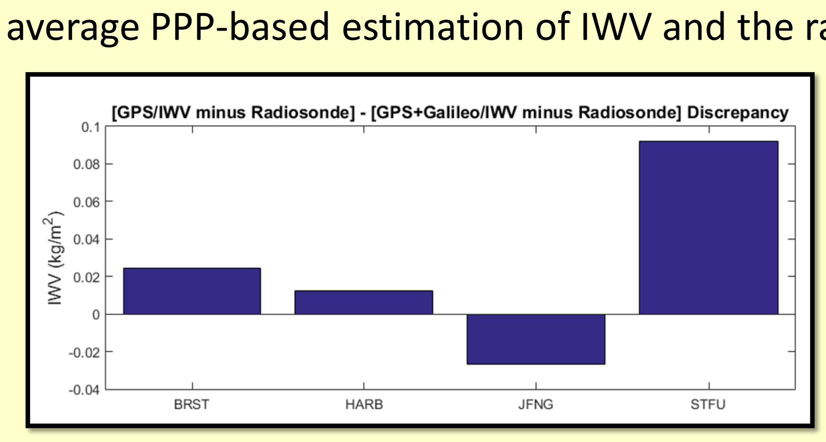


Figure 2 – Discrepancy between GPS-only minus radiosonde IWV and GPS + Galileo minus radiosonde IWV for each station

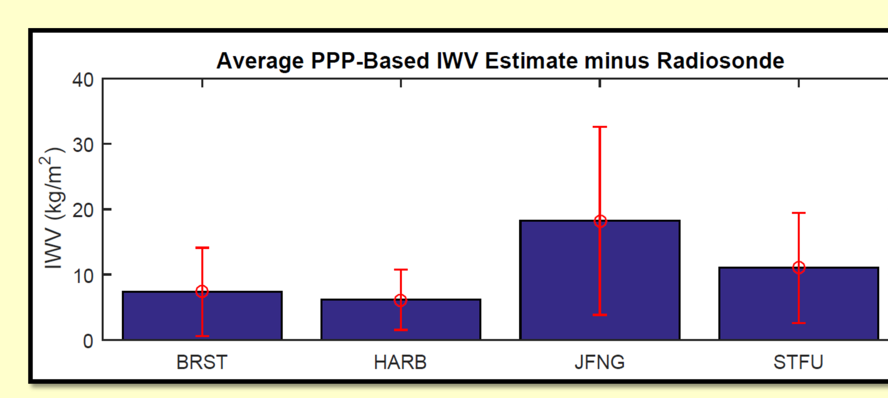


Figure 3 – Error bars for each station related to the difference between the average PPP-based estimation of IWV and the radiosonde-measured IWV

It is possible to see that the error in both estimations are close in terms of bias and dispersion from the radiosonde estimates. This, again, indicates a success in terms of the system integration being that GPS + Galileo estimations are, on average, closer to the radiosonde IWV measurements than GPS-only solutions, but points towards a necessary investigation of the D_{zw} estimation algorithm for either method.

Conclusion

Results show that the Galileo + GPS IWV estimations are close to those of GPS-only at a level of 0.13 kg/m^2 of precipitable water. This demonstrates that both systems can be successfully used together to improve data quality, specifically in challenging environments where satellite geometry can be an issue. Although the selected dataset is from sites with unobstructed surroundings to eliminate other possible error sources, it is safe to say that users can, by now, begin to take advantage of the Galileo GNSS.

For atmospheric research, Galileo-only processing is still not currently feasible as the constellation as-is provides very large DOP values. However, with the anticipated launch of several more full-operational-capability satellites in the coming year, Galileo will soon become a useful tool for atmospheric parameter estimation and IWV determination.

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