ASSESSING THE PRELIMINARY PERFORMANCE IMPACT OF INCLUDING GALILEO OBSERVABLES INTO A PRECISE POINT POSITIONING PROCESSING SCHEME

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ABSTRACT

With the successful completion of the European Space Agency's Galileo In-Orbit Validation (IOV) campaign and the anticipated launch of several full-operational-capability (FOC) satellites in the coming months, point positioning users will, for the first time, be offered a potential enhancement of performance capabilities through the inclusion of Galileo observables into their existing processing schemes. Performance gains such as increased positional accuracy and decreased solution convergence times should be evident following the inclusion of appropriately weighted Galileo observables into a precise point positioning (PPP) processing engine, particularly in situations where signal loss is likely to occur due to limitations in the number of observable low-elevation-angle satellites. To validate such potential performance gains, the University of New Brunswick (UNB) GPS Analysis and Positioning Software (GAPS) has been modified to utilize available Galileo carrier-phase and pseudorange observables broadcast on the E1 and E5a Open Service (OS) frequencies. Integration of Galileo into the existing GPS-only processing scheme of GAPS was made possible, in part, by the use of the International GNSS Service (IGS) Multi-GNSS Experiment (MGEX) campaign's precise Galileo orbit and clock determinations as well as its L1X-L5X differential-code-bias (DCB) estimates. The use of the MGEX campaign's clock and orbit products additionally allows for the mitigation of certain inter-system biases, including the GPS-to-Galileo Time Offset (GGTO) and the use of the Galileo Terrestrial Reference Frame (GTRF).

Preliminary results from including Galileo observables into GAPS demonstrate insight into the currently achievable accuracy of the positional solution. While a slight degradation in the accuracy of the combined GPS + Galileo solution presently exists, the magnitude of this bias remains within 0.005 m, on average, of the IGS GPS-only combined weekly solutions for the UNB3 MGEX station. Additionally, with less than three hours of simultaneous observations from the four available Galileo IOV satellites, Galileo-only positional solutions of within 0.13 m, on average, of the IGS combined weekly solutions for the UNB3 MGEX station are observed for several days spanning between January and October of 2013. Further experimentation will be performed in order to determine the impact of Galileo observations on positional accuracy and solution convergence times in a simulated signal-loss environment. Future plans include making the Galileo processing option available in the publicly available online version of GAPS and conducting kinematic tests in the Fredericton area to confirm performance enhancement of GPS + Galileo solutions in obstructed environments.

1. INTRODUCTION

In the coming months and years, positioning, navigation, and timing (PNT) users will have increased access to new, modernized GNSS observables including those of the European Union's emerging GNSS, Galileo. In order to take advantage of the potential performance gains associated with the inclusion of the new Galileo observables into existing GPS-only processing schemes, steps must first be taken to ensure system interoperability, including the mitigation of certain system differences such as Galileo's selection of a unique time system and geodetic reference datum as well as use of different carrier frequencies and modulation techniques.

Figure [1] Galileo FOC satellites orbiting in one of three orbital planes

2. UNB's GAPS

Created in 2008, the University of New Brunswick's GAPS free online PPP service continues to provide users with a reliable positioning and GPS data analysis tool [Leandro, 2009]. GAPS' GPS-only data processing is currently made possible through acquisition and use of the IGS so-called "precise" products. These products provide GAPS with the satellite DCBs, orbit determinations, clock errors, and antenna calibration information necessary to then obtain the most accurate positional estimates achievable [Dow et al., 2009]. GAPS processing scheme also includes the mitigation of common PPP error sources including GPS receiver clock errors and hardware delays, ionospheric and neutral atmospheric delays, Earth body tides, and ocean tidal loading. Through use of the "precise" products and detailed implementation of the observation model, GAPS not only provides users with a positioning tool, but also a powerful GPS data analysis tool. In addition to final position estimates, GAPS is capable of providing users with precise estimates of ionospheric signal delay, code multipath, and receiver DCBs.

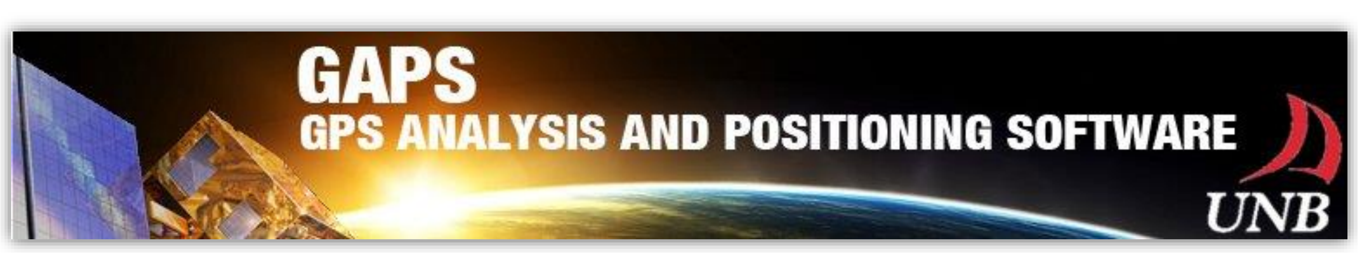

Figure [2] UNB's GAPS free online PPP service

3. GAPS GALILEO INCLUSION MODIFICATIONS

In order to take advantage of the Galileo system's recent progress towards FOC status as well as the potential performance impacts associated with a multi-GNSS solution, GAPS has been modified to include the Galileo E1 and E5a OS observables into its existing GPS-only processing scheme. Although Galileo's level of interoperability with GPS has been improved through utilization of the Code Division Multiple Access (CDMA) modulation technique as well as use of carrier frequencies identical to those of GPS, other system differences remain that require mitigation prior to true system interoperability. Fortunately, most of these differences can be eliminated following minor modifications to GAPS existing processing scheme.

Just as is the case with the GAPS GPS-only processing scheme, Galileo observable processing also requires the acquisition and use of the appropriate IGS "precise" orbit, clock, and DCB products. While the standard GPS-based products remain available for direct download from the IGS online ftp servers, the necessary Galileo orbit, clock, and DCB products are currently only available for download as experimental products through the IGS MGEX campaign database [Montenbruck et al., 2014a].

Galileo Orbit Determinations

- Currently estimated by Technische Universität München (TUM)
  - MGEX product availability: *GPS weeks 1711 – 1796*
  - Daily .sp3 file with satellite positions at 15-minute intervals
  - Orbit determination processing features:
    - Galileo E1 and E5a frequencies
    - 5-day arc lengths
    - A-priori orbits predicted from the previous day
    - Orbit parameters estimated from 6 Keplerian elements and 5 radiation pressure points
    - Generic MGEX satellite antenna phase center offsets
    - No satellite antenna phase center variation considered

TUM TECHNISCHE UNIVERSITÄT MÜNCHEN

**** The TUM orbit product aligns Galileo satellite positions to ITRF08, thus mitigating effects associated with the use of GTRF ****

Galileo Clock Corrections

- Currently estimated by the Center for Orbit Determination in Europe (CODE)
  - MGEX product availability: *GPS weeks 1689 – 1784*
  - Daily .clk file with satellite clock corrections at 5-minute intervals
- "Back-up" clock product, estimated by TUM (.sp3 file)
  - MGEX product availability: *GPS weeks 1711 – 1796*
  - Daily .sp3 file with satellite clock corrections at 5-minute intervals

AIUB

**** The CODE and TUM clock products both serve to align Galileo observables to GPS System Time, thus mitigating effects associated with the use of Galileo System Time ****

Galileo L1X - L5X Satellite DCBs

- Currently estimated by the German Aerospace Center (DLR) and TUM [Montenbruck et al., 2014b]
  - MGEX product availability: *GPS weeks 1721 – 1821*
  - Yearly file with daily estimates of Galileo L1X-L5X satellite DCBs

DLR

Galileo Receiver Clock Estimation

In addition to the difference between GPS and Galileo satellite-dependent DCBs, different receiver-dependent combined clock and hardware delay values will be observed when using Galileo observables. For GPS-only processing, GAPS utilizes the estimation of this combined GPS-only parameter within its existing least-squares filter. In order to properly account for the differing clock error and modulation delays experienced by the Galileo observables, the estimation of an additional Galileo-only combined clock and hardware delay parameter is necessary within the GAPS least-squares filter. Through the uncorrelated estimation of a GPS-only and Galileo-only combined receiver clock and DCB correction, it is possible to account for the different delays that each system will experience.

4. PRELIMINARY RESULTS: GPS + Galileo Processing

Following the successful modification of GAPS, combined GPS + Galileo observable processing was performed using GNSS data from the UNB3 MGEX station for several days spanning between January and October of 2013. Upon analysis, a slight degradation of the overall accuracy of the positional solution is observed following the inclusion of the four available Galileo IOV satellites. However, despite the presence of this bias, the combined GPS + Galileo solutions remain within less than 0.005 m, on average, of the IGS GPS-only combined weekly solutions for the UNB3 MGEX station (Figure 5).

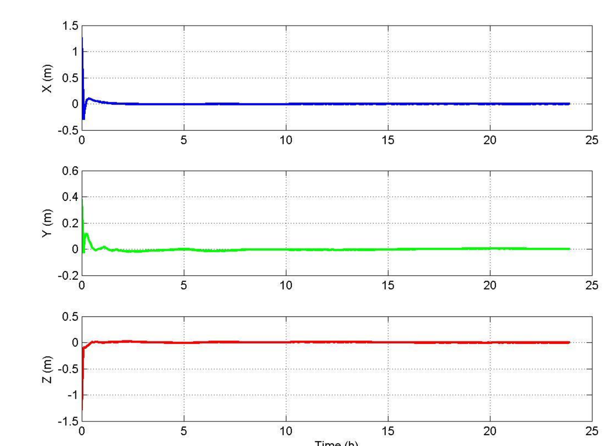

Figure [3] Station UNB3 (MGEX) combined GPS + Galileo X (top), Y (middle), and Z (bottom) coordinate convergence times for DOY 297, 2013.

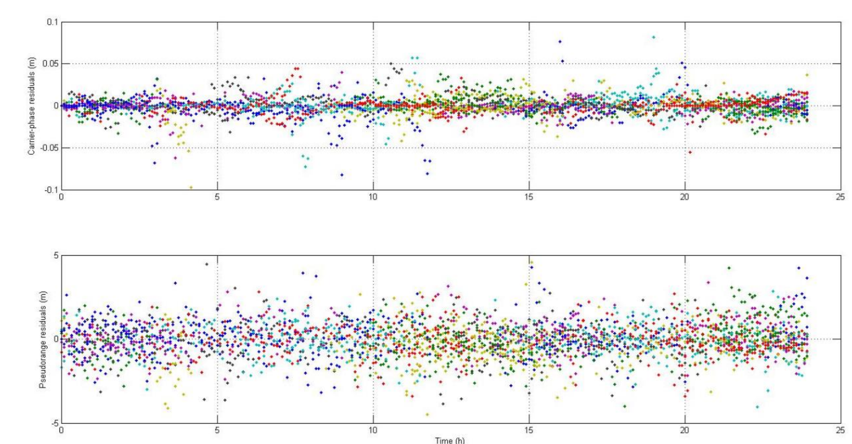

Figure [4] Station UNB3 (MGEX) combined GPS + Galileo carrier-phase and pseudorange residuals for DOY 244, 2013.

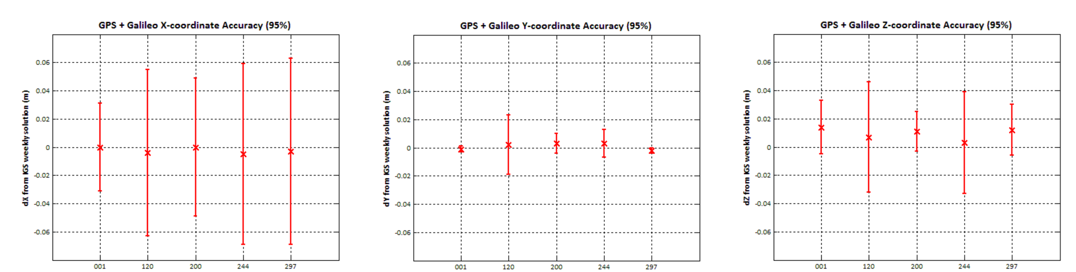

Figure [5] Station UNB3 (MGEX) differences in daily combined GPS + Galileo PPP solutions from published IGS GPS-only combined weekly solutions for the ITRF08 X (left), Y (middle), and Z (right) coordinates.

5. PRELIMINARY RESULTS: Galileo – Only Processing

Currently, the four active Galileo IOV satellites represent the minimum number of satellites required in order to determine a positional solution in PPP. While limited to a maximum of approximately three hours on certain days and only in certain locations, all four Galileo IOV satellites are capable of simultaneous observation, thus allowing for some of the first ever Galileo-only PPP positioning. Using Galileo data from the UNB3 MGEX station, Galileo-only processing was performed using the modified version of GAPS for several days spanning between January and October of 2013. Despite being limited to less than three hours of simultaneous observations from the minimum number of required satellites, the Galileo-only solutions remain within less than 0.13 m, on average, of the IGS GPS-only combined weekly solutions for the UNB3 MGEX station.

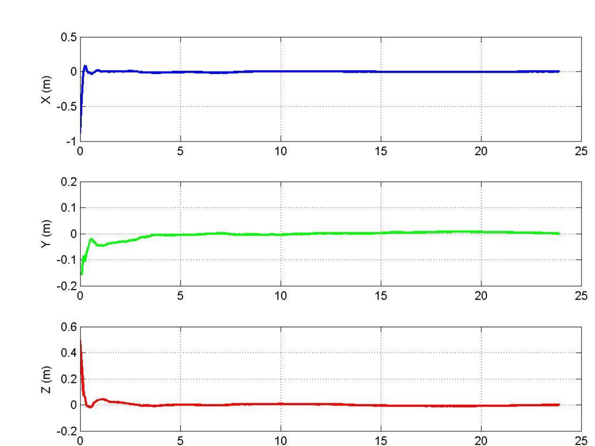

Figure [6] Station UNB3 (MGEX) Galileo-only X (top), Y (middle), and Z (bottom) coordinate convergence times for DOY 200, 2013.

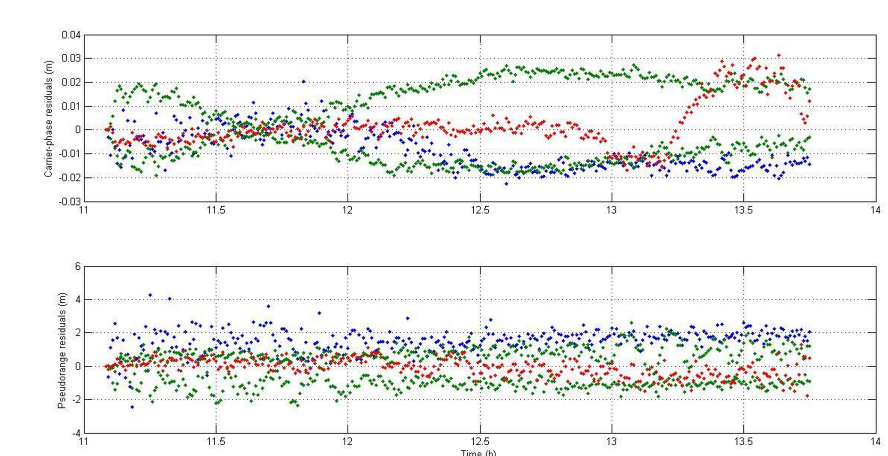

Figure [7] Station UNB3 (MGEX) Galileo-only carrier-phase and pseudorange residuals for DOY 001, 2013 from approximately 11:10 – 13:45 UT.

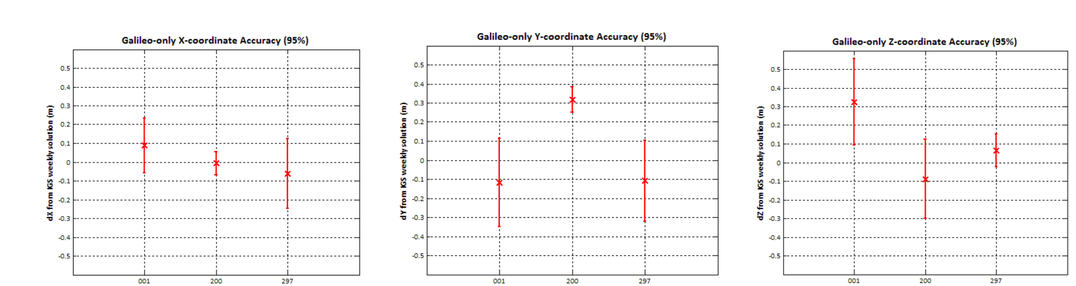

Figure [8] Station UNB3 (MGEX) differences in Galileo-only PPP solutions from published IGS GPS-only combined weekly solutions for the ITRF08 X (left), Y (middle), and Z (right) coordinates.

6. CONCLUSIONS

Preliminary inclusion of Galileo observables into the GAPS processing scheme result in:

- Combined GPS + Galileo positional solutions within good agreement (±0.005 m) of IGS GPS-only combined weekly solutions.
- Galileo-only positional solutions within reasonable agreement (±0.13 m) of IGS GPS-only combined weekly solutions.
- Validation of the preliminary quality of the IGS MGEX campaign's clock, orbit, and DCB products.

7. FUTURE WORK

In order to further assess the impact of the Galileo observable inclusion into the GAPS processing scheme, future research will focus on the analysis of both static and kinematic processing of GPS and Galileo data within the modified version of GAPS. For the static processing experimentation, several days of non-continuous static observations will be processed using GPS and Galileo data from the UNB3 MGEX station. Analysis of the processed GNSS data will help to determine the impact of the Galileo inclusion on positional solution accuracy and solution convergence times in a simulated signal-loss environment where more and more available GPS observations will be unavailable for the final solution.

For the kinematic processing experimentation, several days of short kinematic observation sessions (approximately 1-2 hours per day) will be processed using GPS and Galileo data collected using a multi-GNSS capable receiver and antenna affixed to the roof of a vehicle as it navigates through the greater-Fredericton area. Analysis of the processed kinematic data will help to confirm any performance enhancement in the positional solution generated through inclusion of Galileo observables in a real-life obstructed environment such as downtown Fredericton.

Future plans also include the continued enhancement of the Galileo observable inclusion into GAPS as well as eventually adding both the GPS + Galileo and Galileo-only processing options to the publicly available online version of GAPS.

8. ACKNOWLEDGEMENTS

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NSERC CRSNG

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