An Assessment of the Accuracy of Broadcast Ephemerides for Multi-GNSS Positioning

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IGS Workshop | Oct 29th - Nov 2nd, 2018

SUMMARY

High accuracy GNSS positioning is dependent on the quality of satellite orbit information used to obtain a solution. In many applications, low-latency orbit products (rapid, ultra-rapid) or broadcast ephemerides are required at the cost of lower accuracy satellite positions. With the emergence of new global and regional GNSS constellations, in addition to updates to the legacy systems, it is crucial to determine the accuracy of broadcast orbits to develop the most effective processing strategies. The U.S. National Geodetic Survey is developing multi-GNSS capable software to replace the legacy PAGES software. Here we perform several tests using preliminary code for this new software in order to compare broadcast to precise orbits provided by the IGS MGEX group to (1) evaluate the accuracy of broadcast ephemerides for each global constellation, (2) explore the time sensitivity of broadcast orbit parameters, and (3) investigate the time system offsets between the global GNSS constellations.

Test 1: Accuracy and Time Sensitivity of Ephemeris Blocks

Comparing the RINEX 3.03 broadcast navigation file BRDC00IGS_R_20182710000_01D_MN.rnx and MGEX sp3 files from the GFZ analysis center corresponding to 28 September 2018, we perform the following steps for each navigation block in the global broadcast navigation file, yielding the results to the right:

1) Compute the satellite coordinates using the broadcast ephemeris at discrete intervals relative to the time of ephemeris.

2) Interpolate the sp3 coordinates from the MGEX sp3 file at each time interval.

3) Apply phase center offset (PCO) corrections from an IGS Antex file to the center of mass coordinates from the sp3 file.

4) Compare positions and compute the 3-D error between them.
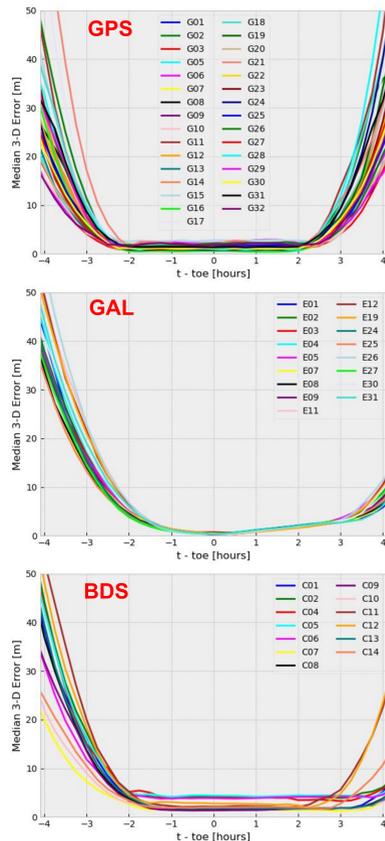
For each GNSS constellation, we find that in general, the broadcast ephemerides for all satellites show very similar patterns of agreement with the precise orbits. The GPS and GLONASS satellites exhibit symmetric patterns of errors before and after the time of ephemeris, while BeiDou and Galileo display better performance over longer periods of time after the ephemeris time than before. Beidou and GLONASS satellites exhibit the most variability in accuracy close to the time of ephemeris, in contrast with consistent meter to sub-meter accuracy for GPS and Galileo.
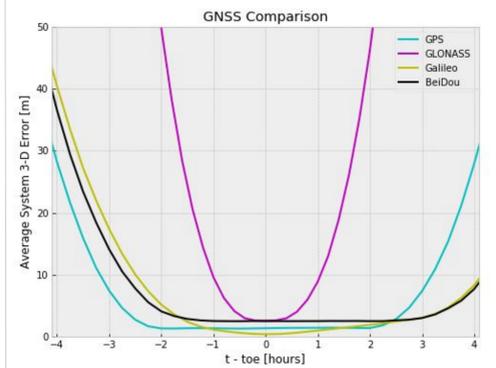
Comparing constellations, the average 3-D error is minimized for the longest amount of time ($\pm$ 2 hours) for GPS, with Galileo and BeiDou also agreeing at the meter level for over an hour before and after the time of ephemeris. Close to the ephemeris time, Galileo broadcast orbits agree the best (sub-meter) with the precise orbits while GLONASS and BeiDou differ by several meters.

Test 2: 24 Hour Comparison of Broadcast and Precise Orbits

Looking at a 24-hour timespan on 18 March 2018 over 5-minute intervals:

1) Compute broadcast satellite positions and clock offsets using the closest ephemeris block in RINEX Navigation file BRDC00IGS_R_20180980000_01D_MN.rnx.

2) Interpolate sp3 coordinates and clock offsets from the MGEX sp3 file from the GFZ analysis center.

3) Apply PCO corrections to sp3 coordinates based on the antex file.

4) Estimate and remove system mean clock biases for GLONASS, Galileo and BeiDou relative to GPS time (i.e., inter-system biases).

5) Compare satellite coordinates and clock offsets.
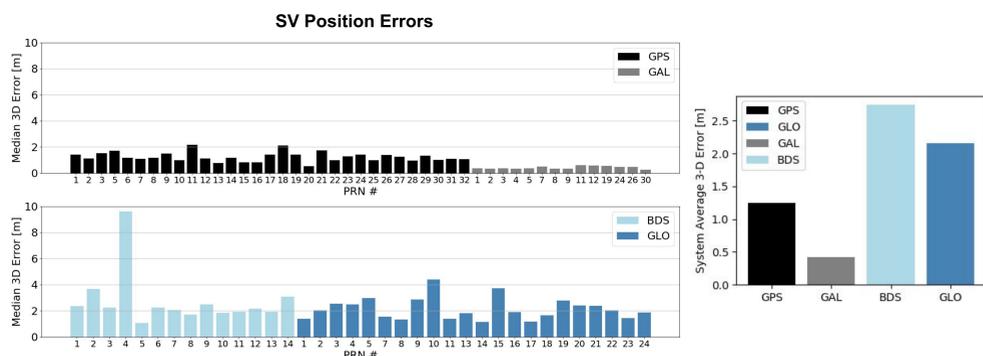
The satellite and constellation-specific average errors for broadcast-derived coordinates (above) and satellite clock offsets (below) show that Galileo performs the best, while BeiDou is susceptible to the largest errors. The presence of inter-system biases (ISBs) makes it difficult to directly compare the broadcast (system time) and sp3 (GPS time) satellite clock offsets. Averaged offsets of 32.2, 20.9, and 102.2 nanoseconds were estimated and removed for GLONASS, Galileo, and BeiDou for the clock analysis.
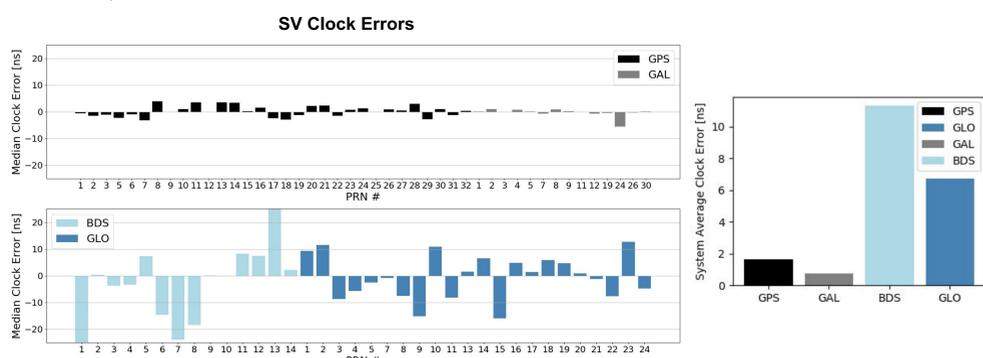
Test 3: Time System Offsets

Due to imperfect alignment of the GNSS time systems, satellite clock offsets obtained from a broadcast ephemeris exhibit time system biases (relative to GPS time) when compared to sp3 or precise clock files.

To estimate the magnitude of the time system offsets in our example files, we perform epoch-by-epoch pseudorange point positioning and estimate the inter-system biases using observation data collected at IGS station PTVL on 18 March 2018.
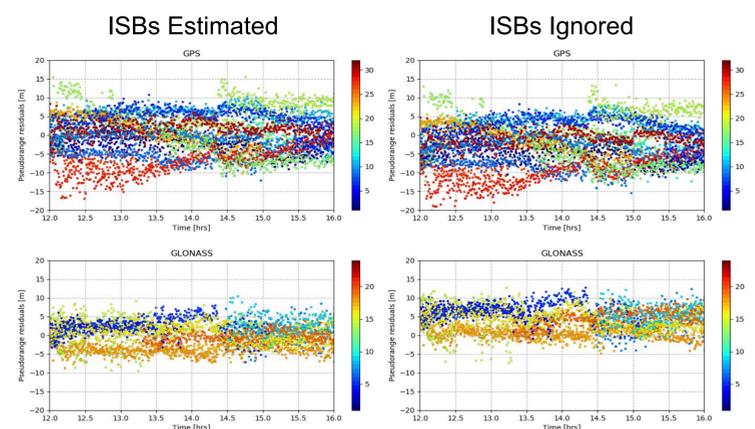
Pseudorange residuals for GPS and GLONASS with (left) and without (right) estimating the inter-system biases for IGS station PTVL. The color scales indicate SV PRN number. There is a clear bias in the GLONASS residuals in particular when ISBs are ignored.

Epoch by epoch point positioning results for station PTVL using GPS, GLONASS, Galileo, and BeiDou. The averaged ISB values relative to GPS are 23.4, 8.79, and 114.6 ns for GLONASS, Galileo, and BeiDou, respectively. These correspond to ranging errors of approximately 7.0, 2.6, and 34.4 meters.