The Effects of L2C Signal Tracking on High-Precision Carrier Phase GPS Positioning

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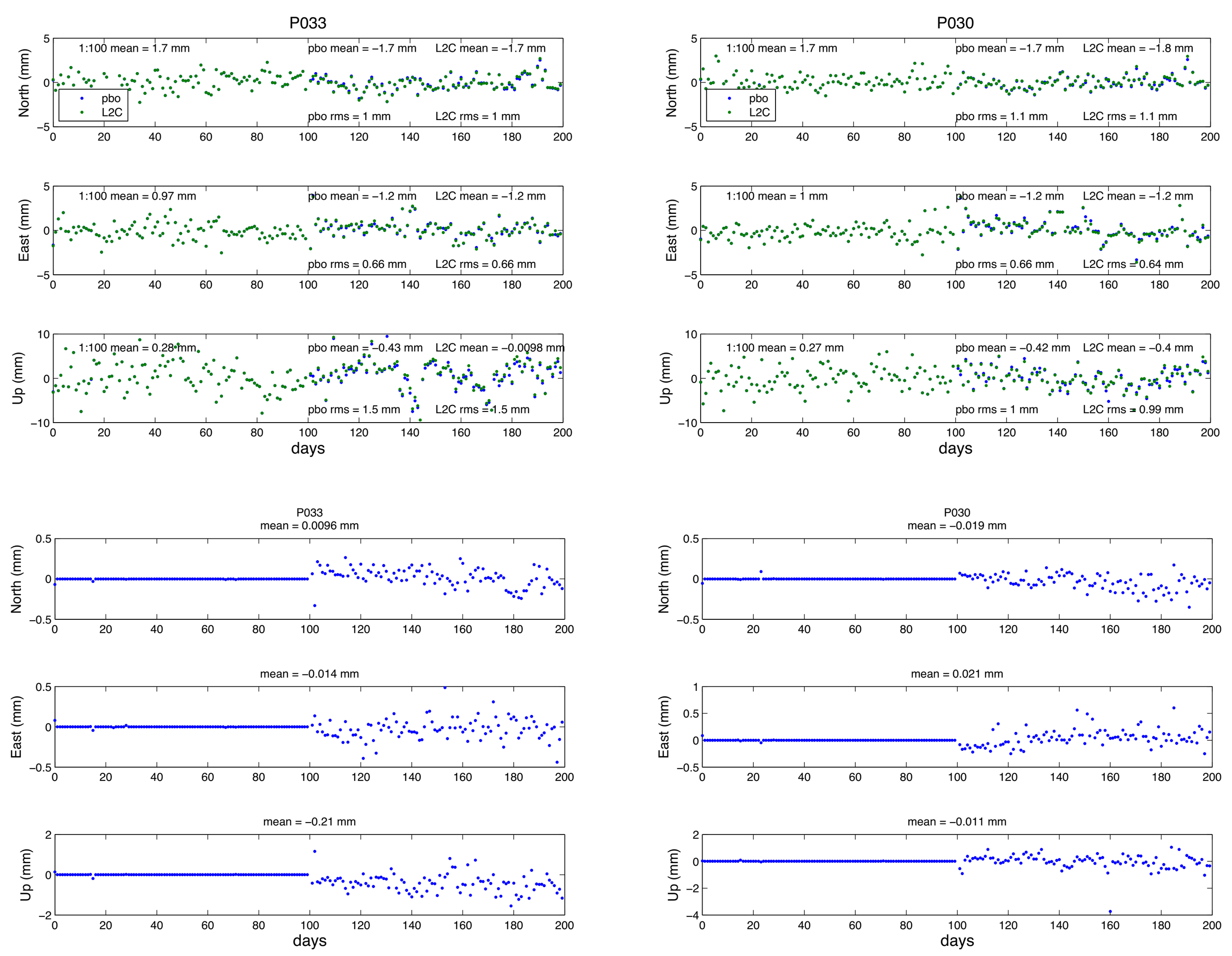
ABSTRACT BODY:

In 2005, the L2C signal was introduced to improve the accuracy, tracking and redundancy of the GPS system for civilian users. The L2C signal also provides improved SNR data when compared with the L2P(Y) legacy signal, comparable to that of the L1 C/A-code, which allows for better tracking at lower elevations. With the recent launch of the first block II-F satellite (SVN62/PRN25), there are 8 healthy satellites broadcasting L2C signals, or 25% of the constellation.

However, GNSS network operators such as the UNAVCO Plate Boundary Observatory (PBO) have been hesitant to use the new signal as it is not well determined how tracking and logging L2C could affect the positions derived from L2 carrier phase measurements for a given receiver. The L2C carrier phase is in quadrature (90° out of phase) with the L2P(Y) phase that has been used by high-precision positioning software since the beginning of GPS. To complicate matters further, some receiver manufacturers (e.g. Trimble) correct for this when logging L2C phase while others (e.g. Topcon) do not. The L2C capability of receivers currently in widespread use in permanent networks can depend on firmware as well as hardware; in some cases receivers can simultaneously track L2C and L2P(Y) phases and some can track only one or the other, and the resulting observation files can depend on how individual operators configure the devices. In cases where both L2C and L2P(Y) are logged simultaneously, translation software (such as UNAVCO's teqc) must be used carefully in order to select which L2 observation is written to RINEX (2.11) and used in positioning. Modifications were recently made to teqc to eliminate potential confusion in that part of the process; if L2C code observations appear in a RINEX (2.11) file produced by teqc, the L2 phase and S2 SNR observations were from the L2C carrier for those satellites. To date L2C analyses have been restricted to special applications such as snow depth and soil moisture using SNR data (Larson et al, 2010).

We use several different methods to determine the effect that tracking and logging L2C has on carrier phase measurements and positioning for various receiver models and configurations. Our analyses use GAMIT and TRACK to calculate positions and baseline lengths including zero-length baselines, position time series from a subset of 10 PBO stations that have been L2C enabled, phase residual comparisons and direct comparisons of the L2 phase observable. Twenty-four hour zero-length baseline solutions using L2 show sub-millimeter differences in the mean positions for both the horizontal and vertical components. Direct comparisons of the L2 phase observable from RINEX (2.11) files with and without the L2C observable show sub-millicycle differences over a 24 hour mean with variations up to ~±0.06 cycles for satellites that broadcast L2C. Our results show that the magnitude of the variations increased at low elevations. Separate correlation of the L2 and L2C signals may explain this difference. The number of L2 observations increased when the L2C observable was recorded, while the number of cycle slips above 10 degrees in elevation decreased when L2C was recorded. The behavior of the L2P(Y) phase observations or positions from a given receiver was not affected by the enabling of L2C tracking.

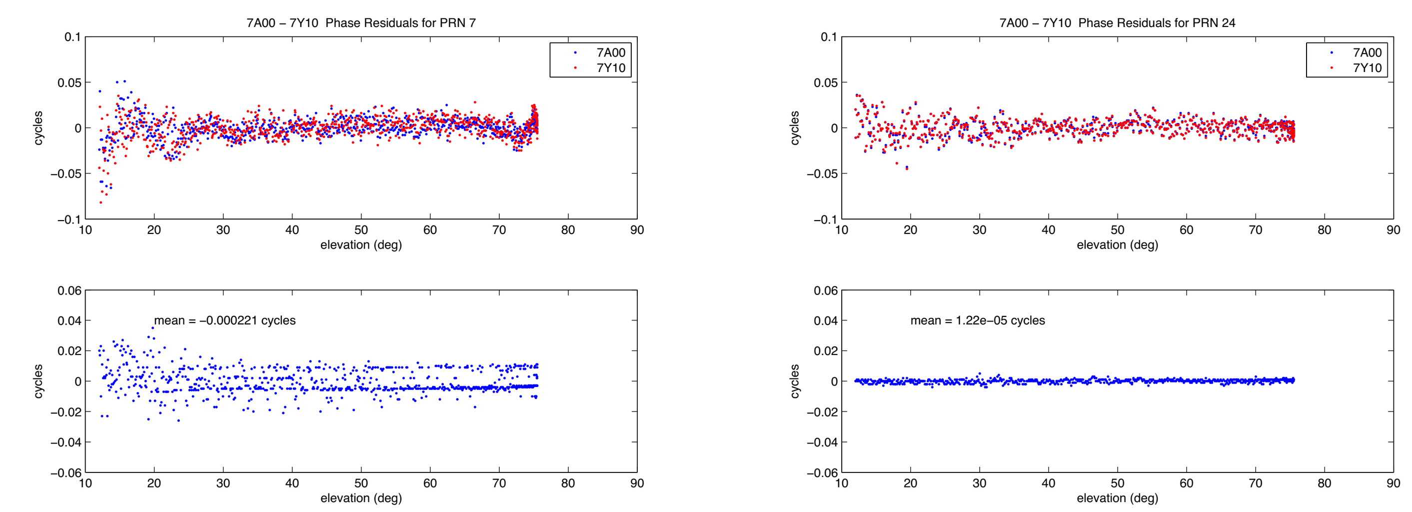
200 day position time series (GAMIT)



(Top) 200 day position time series for the PBO stations P033 (left) and P030 (right) with a linear trend removed from each component (East, North , Up). Tracking of the L2C phase observable was enabled at day 100. Position time series were estimated using the L2C observables when available (green) and with the standard L2 observables only (blue).

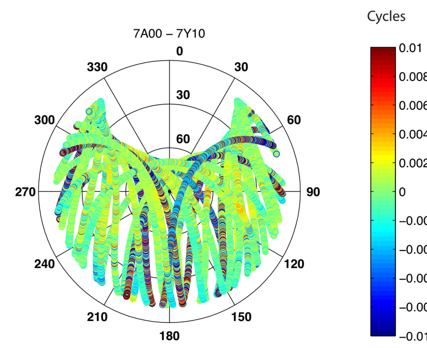
(Bottom) 200 day position time series with and without L2C enabled for PBO stations P033 and P030 show sub-millimeter differences in the estimated horizontal positions and differences < ~3 mm in the estimated vertical positions. Mean differences between the position time series are < ~ 0.1 mm in the horizontal and < ~0.2 mm in the vertical components.

Phase residuals (GAMIT)



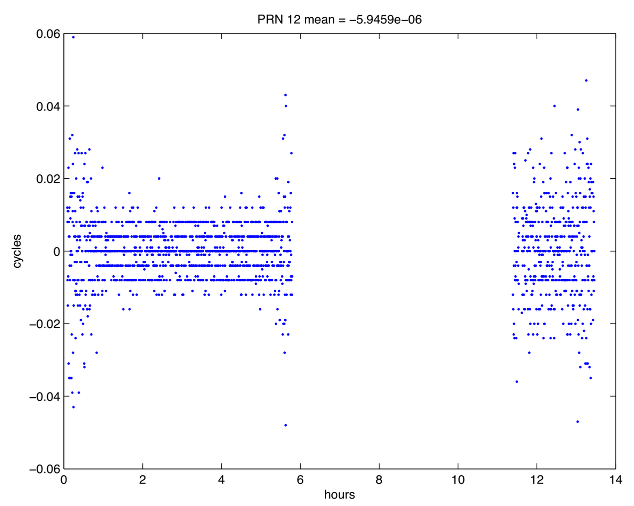
(Top) Phase residuals (in cycles) for PRN 7 (left) and PRN 24 (right) plotted with respect to elevation angle of the satellite. L2C is broadcast by the Block IIR-M satellite PRN 7, but is not broadcast by the older Block IIA satellite PRN 24. Red circles show the phase residuals from GAMIT processing using the L2C carrier phase observables when available from L2C broadcasting satellites. Blue circles show the phase residuals from GAMIT processing using only the L2 carrier phase observables from all satellites. Both the L2C and L2 carrier phase observables were logged simultaneously using the same receiver/antenna combination.

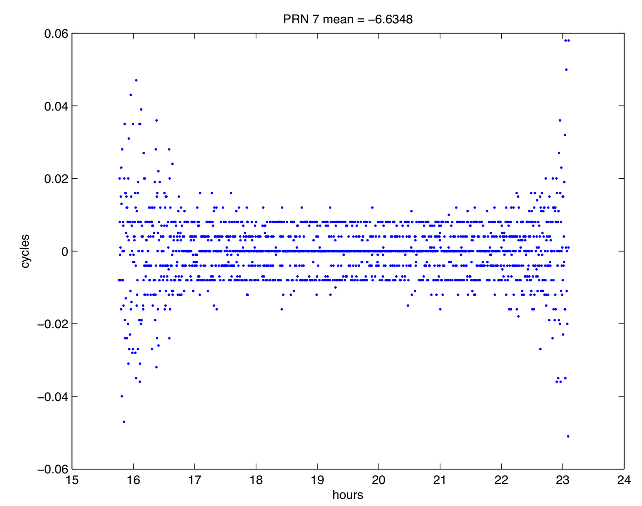
(Bottom) Shows the difference between the phase residuals with and with out using the L2C carrier phase observable for PRN 7 and PRN 24. The variance of the difference is greater for the phase residuals from PRN 7, which broadcasts the L2C carrier phase. The variance of the difference for PRN 7 increases as elevation angle decreases. This is likely due to increased noise in both the L2C and L2 carrier phase measurements at low elevations. The mean of the phase residual differences for PRN 7 and PRN 24 are -2.2 x 10^{-4} cycles and 0.12 x 10^{-4} cycles, respectively.



The elevation-azimuth plot above shows the differences between the phase residuals from GAMIT processing with and without using the L2C carrier phase observables. The figure shows 31 tracked PRN's over a 24 hour period. As expected the largest differences between phase residuals occur with satellite PRN numbers that broadcast L2C.

Direct comparisons of the L2 phase observables

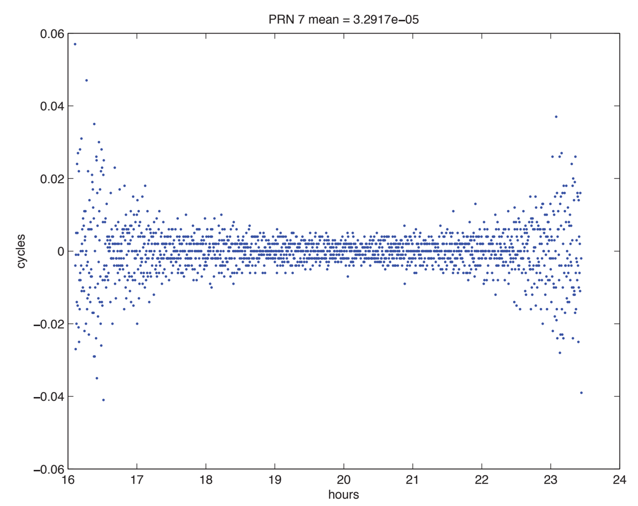




The two figures above show direct comparisons of the L2 phase observable from two RINEX (2.11) files separately translated from the same receiver over the same time period. The change in cycles between each epoch for the L2 and L2C observables is differenced and plotted with respect to time (hours) above. One of the RINEX files was translated by teqc using the +C2 flag to include the L2C observations. The second RINEX file was translated to exclude the L2C observations. The figure on the left shows the difference between L2 and L2C observations for PRN 12. The figure on the right shows the difference between the L2 and L2C observations PRN 7.

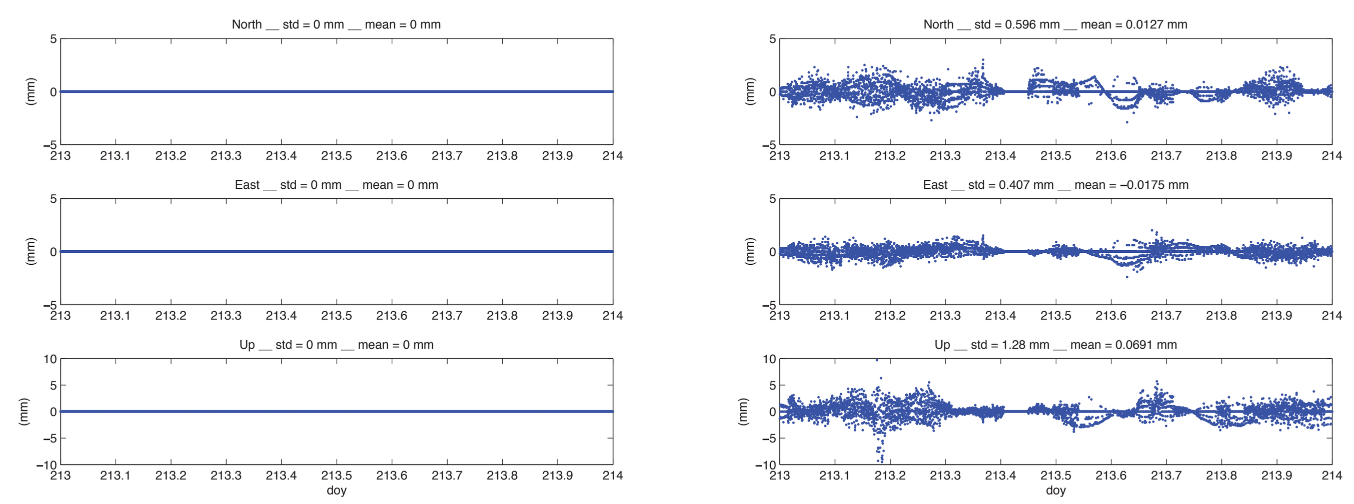
The variance of the difference between the L2 phase measurement and L2C phase measurement increases as elevation angle decreases. This is likely due to the increasing measurement noise from tracking satellites at low elevation angles. The L2 and L2C observables show sub-millicycle differences over a 24 hour mean with variations up to ~±0.06 cycles. The larger calculated mean for PRN 7 (-6.6 cycles) is the result of a cycle slip that occurred at low elevation in L2, but did not occur in L2C.

Preliminary analysis of cycle slips in L2 and L2C have shown that slips occur more frequently at elevations >10° in the L2 observable than in the L2C observable. Analysis using teqc has also shown that the number of observations increased when the L2C observable was recorded.

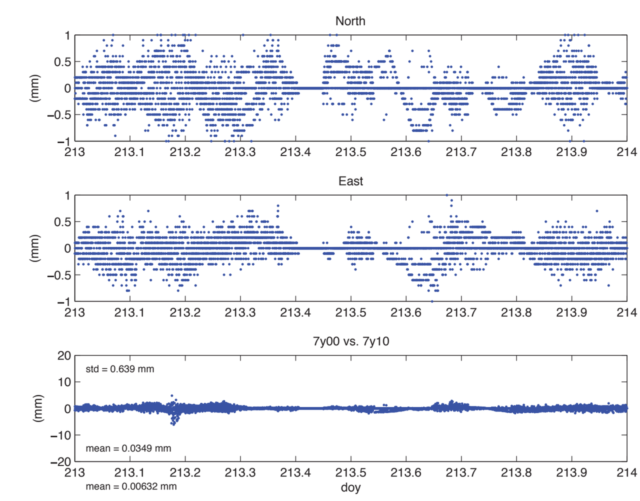


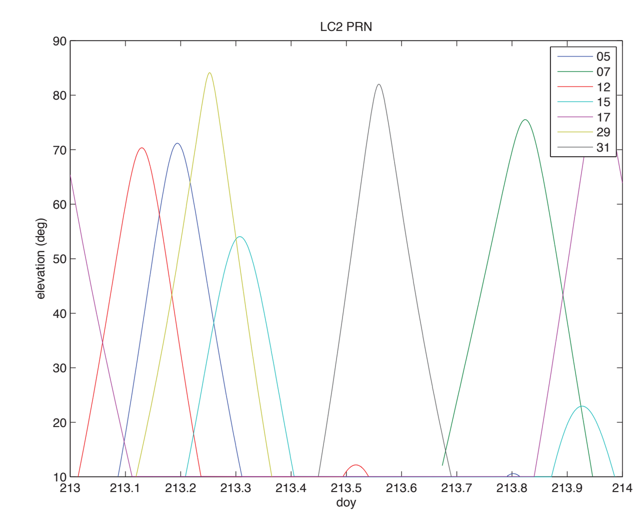
The figure above shows the direct comparison of the L2 and L2C phase observables for PRN 7 recorded by a different type of receiver. The noise characteristics of this receiver are clearly different.

24-hour zero-length baselines (TRACK)



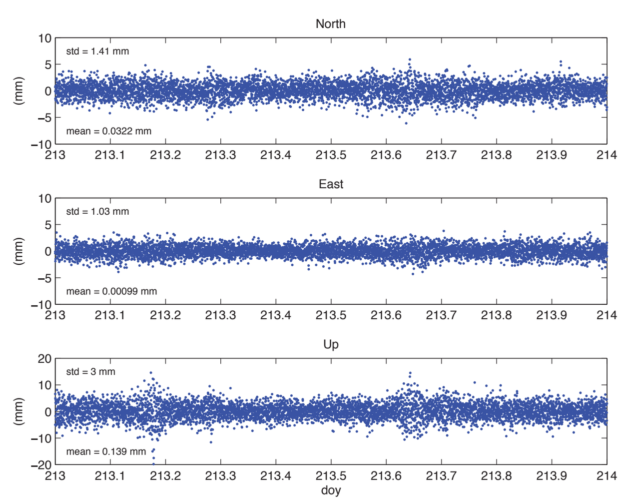
In addition to the direct comparisons of the L2 and L2C observables, we processed the GPS data with a kinematic GPS processing software package (TRACK). The figures above show the estimated baseline between two RINEX files from the same receiver. L2C was enabled for one of the RINEX files and excluded from the other file. As expected, the baseline estimates using only the L1 phase observable (left) are zero because the L1 observations in both files are identical. However, the baseline estimates from the L2 observations (right) do vary significantly. The variance in the baseline estimates varies depending on the number of visible satellites that broadcast L2C. The 24 hour zero-length baselines estimated using the L2 observable show sub-milimeter differences in the mean.





(Top) In this figure, the y-axis (mm) has been exaggerated to show the north and east components in greater detail.

(Bottom) Elevation angle (degrees) vs. time (day of year) for PRN's that broadcast L2C over the same 24 hour period as in the figure above.



The figure above shows the estimated baseline components (north,east,up) between two RINEX files from two receivers using the same antenna via a splitter. One receiver is set to track L2C, while on the other receiver, L2C has been disabled. When evaluating the difference between two recievers with separate clocks, the effects of L2C are dominated by receiver noise.

Summary:

- Twenty-four hour zero-length baseline solutions comparing L2 and L2C show sub-millimeter differences in the mean positions for both the horizontal and vertical components.

- Direct comparisons of the L2 phase observable from RINEX (2.11) files with and without the L2C observable show sub-millicycle differences over a 24 hour mean with variations up to ~±0.06 cycles for satellites that broadcast L2C.

- The number of L2 observations increased when the L2C observable was recorded, while the number of cycle slips above 10 degrees in elevation decreased when L2C was recorded.