Satellite Bias Corrections in Geodetic GPS Receivers

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BIOGRAPHY

Demetrios Matsakis received a B.S. in Physics from MIT, and a PhD in Physics for the University of California at Berkeley. He has been Head of the USNO's Time Service Department since 1997.

Stephen Mitchell received a B.S. in Mathematics from Virginia Tech in 2008. He has worked in the GPS Division of the Time Service Department at USNO since 2008.

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ABSTRACT

As described in Hegarty et al. (2005), GPS reception can have nanosecond-level biases as a function of satellite and receiver setting, and these could also vary between individual units even when observing the same signals. The bias problem is made even more complicated by the fact that all manufacturers don't infer their ionosphere corrections with the same signal set. Although bias correction tables exist, and are often implemented, individual receiver differences remain an issue. This paper presents the observed satellite biases of three different geodetic receiver models utilized at two facilities of the US Naval Observatory.

INTRODUCTION

Hegarty et al. (2005) considered the effect of frequency-dependent delays upon GPS timing measurements. They noted that user receiver systems frequently can have a delay variation of up to 150 nanosecond (ns) across the signal passband, as shown in Figure 1. Figure 1, which is their figure 2, shows the spectral decomposition of the C/A code signal superimposed upon a typical receiver filter. To study the effect of such delay variations, the authors simulated a typical spread-spectrum GPS signal. This can be understood as decomposing the signal into its Fourier components, applying the filter-related delay pattern shown in Figure 1, Fourier-transforming the signal back into its time-domain representation, and simulating the inferred time delay in an early-late correlator. They observed unequal changes in the group and phase delay which lead to ns-level receiver-dependent biases. The observed effect may result from GPS satellite signals having different frequency-dependent delays or amplitudes in their passbands, which will convolve with the receiver system electronics in a non-linear fashion. Different ensembles of receivers will then observe the satellite change differently.

Based upon Hegarty et al. (2005), Matsakis (2007) studied the Timing Group Delay (TGD) biases, which represent the bias between the P-code transmissions at the L1 and L2 frequencies. These biases exist at the several ns level, and indications were found in actual data to support the thesis that they were a function of satellite signal, receiver type, antenna, filtering, and receiver correlator spacing. This work extends those conclusions to the case of individual receivers of the same make.

DATA REDUCTION AND METHODOLOGY

The data reported herein were gathered from common antenna/common clock geodetic receivers located at the USNO's facilities in Washington DC and at the Alternate Master Clock (AMC), in Colorado Springs, Co. (Table 1), Mitchell et al. (2013). The receivers were maintained in a temperature-stabilized environment, and referenced to either the USNO Master Clock or the Alternate Master Clock. Signals from the common antenna were attenuated by about 10 db of cabling from the antenna before reaching a distribution amplifier whose port to port isolation was better than 100 db, L1 and L2 input port reflections were -16 db and -12 db respectively, and output port reflections were in the range of -20 db to -30 db. Overall receiver calibration and system delays are ignored because these are easily adjusted scalars that must always be determined or at least confirmed by the user, via either relative or absolute calibration.

Table 1. Receivers used in this work.

Formal Name	Informal Name	Make	Model	Location
USN3	USN3	Ashtech	Z12T	DC
USN4	SPX3	Septentrio	PolaRx3TR Pro	DC
USN5	NOV2	NovAtel	FlexPak6	DC
USN6	NOV1	NovAtel	ProPak-V3	DC
------	SPX2	Septentrio	PolaRx3TR Pro	DC
AMC2	AMC2	Ashtech	Z12T	AMC
AMC3	AMC3	NovAtel	ProPak-V3	AMC

Data were reduced from the RINEX files produced by the GNSS receivers. Each RINEX file was processed in two different ways. The use of two different techniques was not necessary, but useful as a consistency test. The first way was by direct extraction of the timing signals C1, P1, and P2 from the RINEX files. The other was the RINEX to CGGTTS (Common GPS GLONASS Time Transfer Standards) conversion package known as RINEX_CGGTTS (ftp://www.bipm.org), which computes corrected ionosphere-free P3 data (2.54563*P1-1.54573*P2), to produce a single timing value per satellite observation. C1 is substituted for P1 in NovAtels, and bias-corrected using standard tables. Since common receiver data are insensitive to orbital and atmospheric errors, these were ignored in the direct RINEX extraction, while IGS Rapid solutions were used for the RINEX_CGGTTS. We have verified by direct inspection that the applied orbital and troposphere corrections cancel for common-antenna receiver pairs.

In Figures 2-9 we report the results from direct extraction, with an elevation mask of 20 degrees. Double differences using low-elevation data adds some new satellite pairs (such as SV1-SV2), some of which show double differences as high as 1 to 2 ns.

Figure 10 shows output via the RINEX_CGGTTS package, and it is seen that individual satellites generate time differences that range over a nanosecond but are reasonably constant. This is consistent with the magnitude of the discrepancies noted in the earlier figures. The double differences between the other common antenna receiver pairs in this study span about 2 ns.

So long as the same mix of satellites is used, the different satellite-based biases of Figures 1-10 would be absorbed into the relative receiver calibration. The effect on real-time pseudorange-based positioning would depend on the subset of satellites that happen to be visible. Such an effect would be less than the errors in broadcast orbit and phase corrections, but observable in common-antenna observations. Observations that utilize carrier phase for positioning would be insensitive to these biases as they are also insensitive to the code.

CONCLUSION

Biases that have been previously reported to be functions of satellite, receiver, and configuration have been observed at the 1 ns level. If not properly compensated for, these could affect both time and position determinations.

DISCLAIMER

USNO as a matter of policy does not endorse any commercial product. Manufacturers are identified for scientific clarity only. We further caution the reader that performances reported herein may not be characteristic of any receiver currently marketed.

ACKNOWLEDGMENTS

We thank Jeff Prillaman and Blair Fonville for their work in maintaining and developing the USNO GNSS receiver ensemble.

REFERENCES

[1] C. Hegarty, E. Powers, and B. Fonville, 2005, *"Accounting for the Timing Bias Between GPS, Modernized GPS, and Galileo Signals"*, Proceedings of the 36th Annual Precise Time and Time Interval (PTTI) Systems and Applications Meeting, August 2005, Washington, DC (U.S. Naval Observatory, Washington, D.C.) , pp. 307-317

[2] Matsakis, 2007, *"The Timing Group Delay Correction (TGD) and GPS Timing Biases,"* in Proceedings of the 63rd Annual ION National Technical Meeting, 23-25 April, 2007, Cambridge, Massachusetts, USA (Institute of Navigation, Alexandria, Virginia).

[3] S. Mitchell, E. Powers, J. Prillaman, V. Makarov, V, and D. Matsakis, 2013, *"GNSS Activities and Performance at the USNO"*, Proceedings of the 44th Annual Precise Time and Time Interval (PTTI) Systems and Applications Meeting, December 2012, Reston, Va., in press

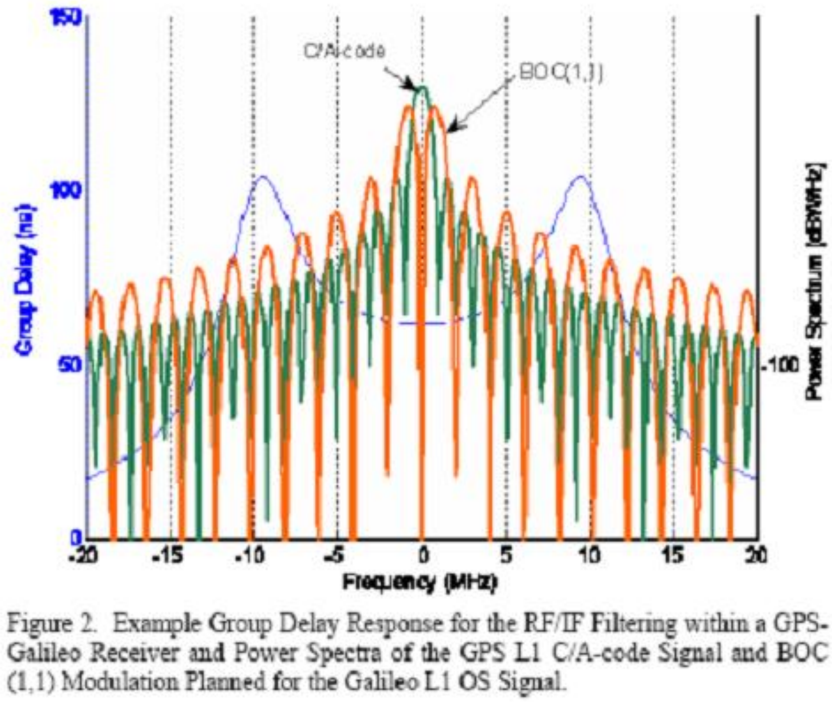

Figure 1 Delay as a function of passband, from Hegarty et al. (2005)

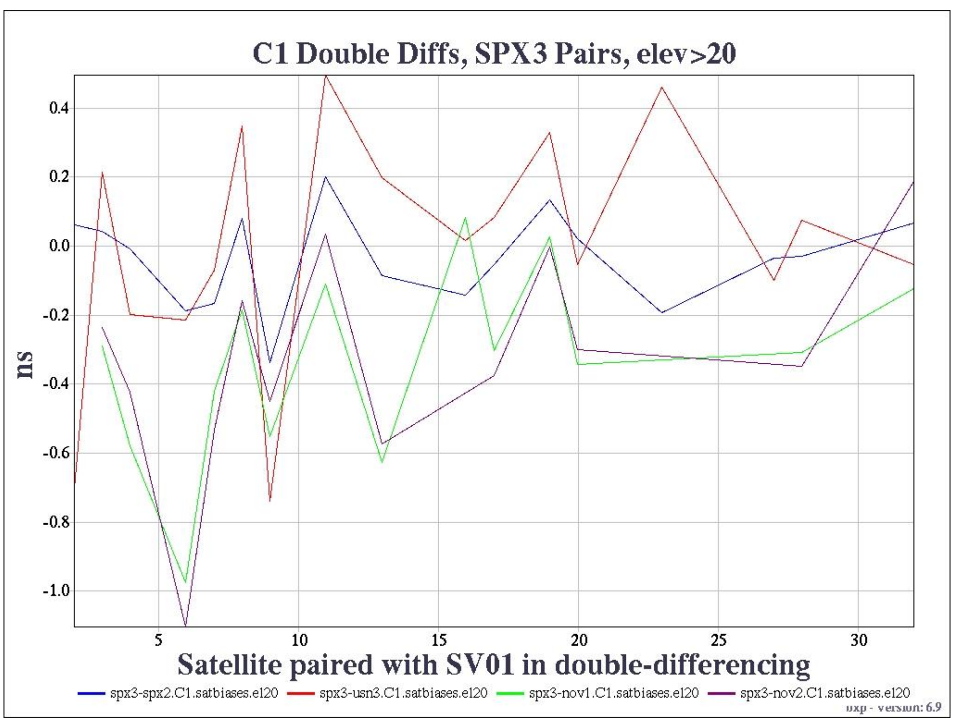

Figure 2 Double Differences of satellite time signal C1, as observed for four pairs of common antenna, common clock receivers. The satellite SV1 paired with all other satellites, and the Sepentrio SPX2 unit is paired with all receivers. Although the Septentrio pair (blue) is closest to 0, the two NovAtel receivers agree with each other better.

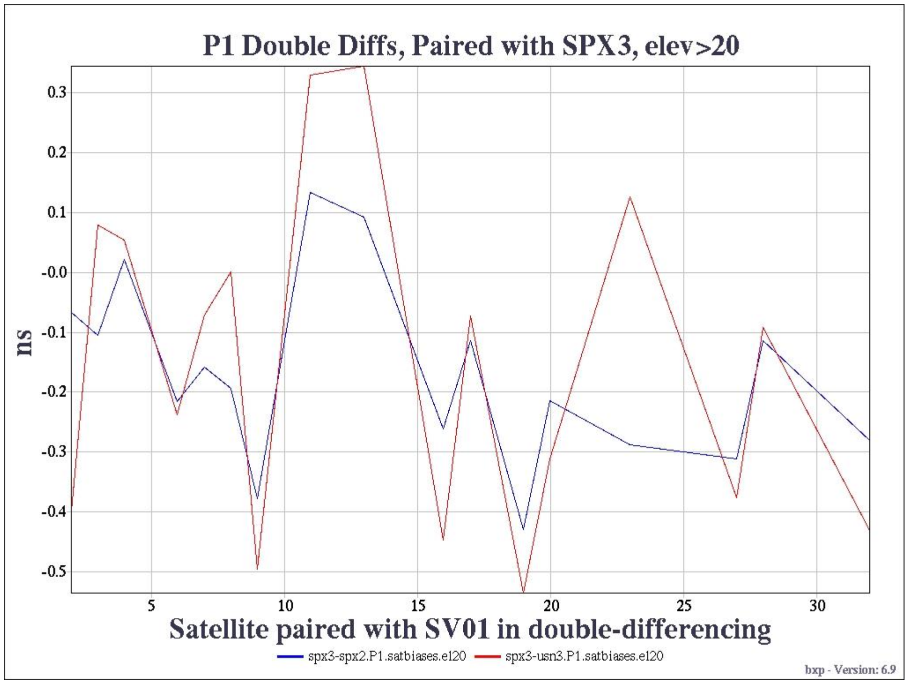

Figure 3 Double Differences of satellite time signal P1, as observed for two pairs of common antenna, common clock receivers and satellite SV1 paired with all other satellites. The pair of Septentrios (blue) is slightly closer to zero than the Sepentrio/Ashtech pair. NovAtels do not observe a P1 signal.

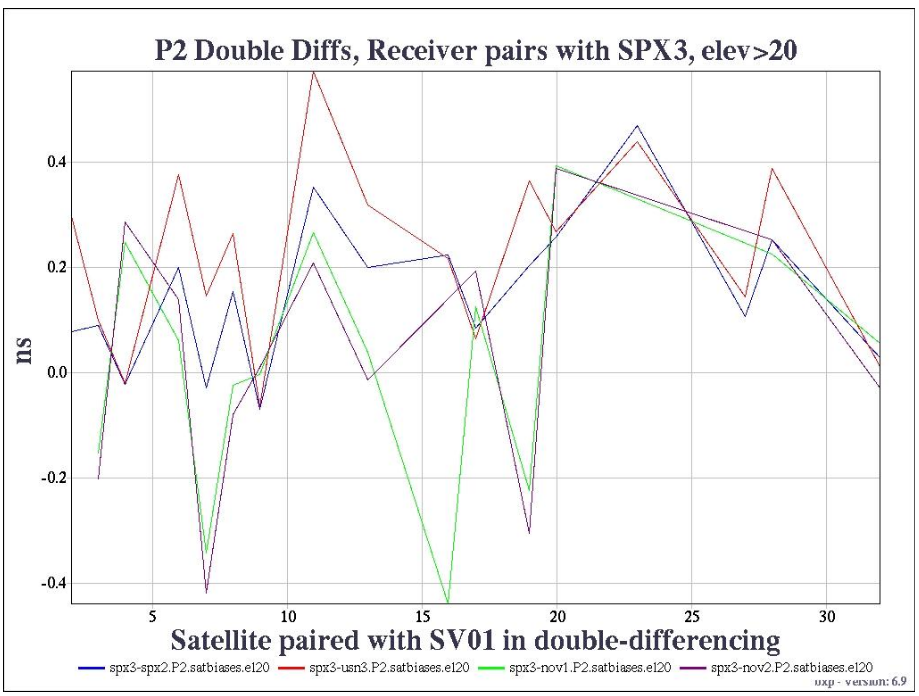

Figure 4 Double Differences of satellite time signal P2, as observed for four pairs of common antenna, common clock receivers and satellite SV1 is paired with all other P2 satellites. The Septentrio pair (blue) is closer to zero than the Septentrio/Ashtech pair. But the two Ashtechs (Nov1 and Nov2) are closest to each other.

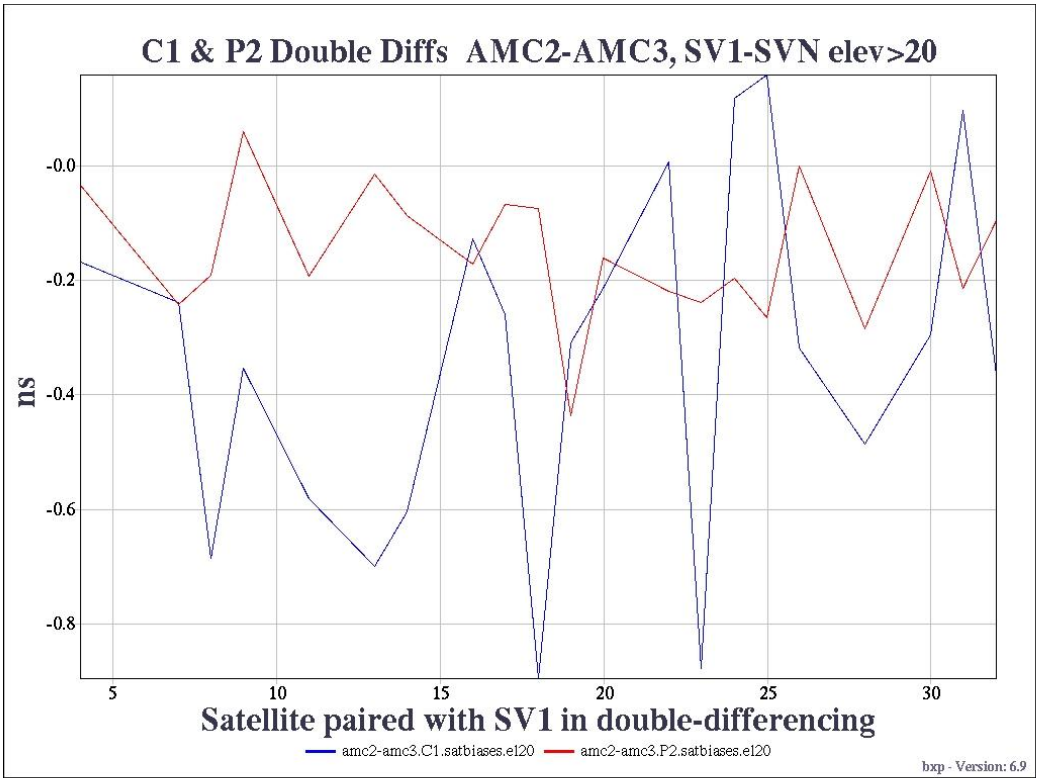

Figure 5 Double Differences of satellite signals C1 and P2, for Ashtech/NovAtel receiver pair at the AMC, and Satellite SV1 paired with the other satellites.

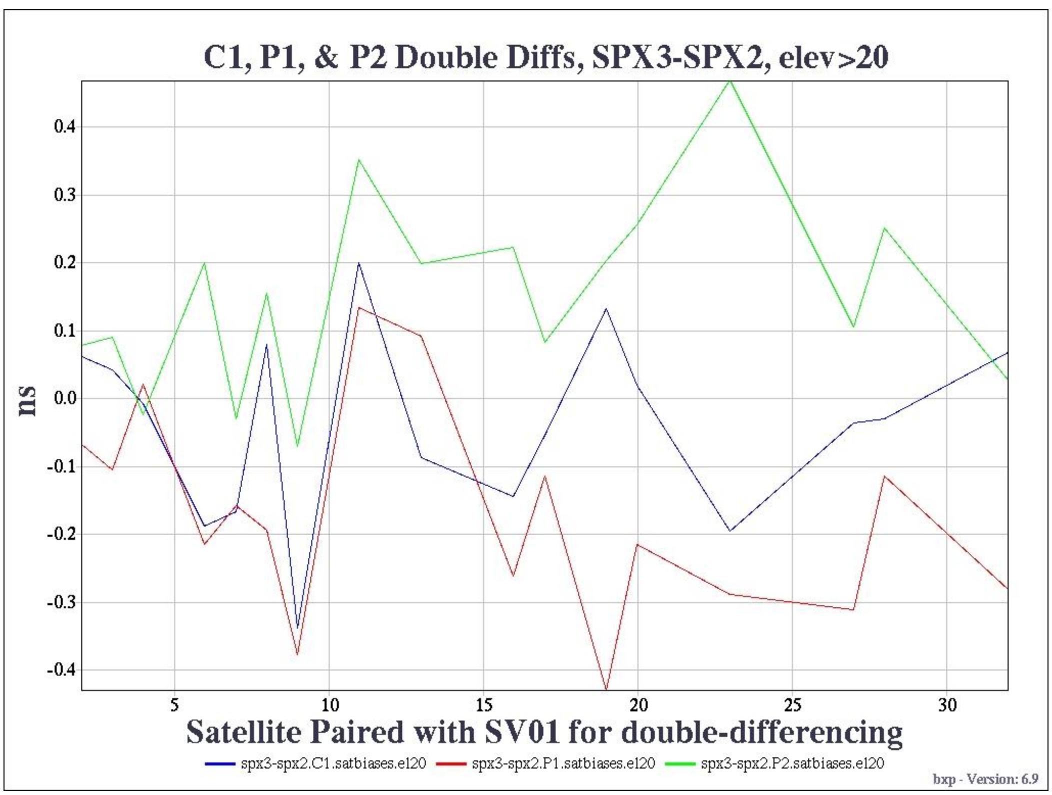

Figure 6 Double Differences of three satellite signals between two Septentrios, and satellite SV 1 minus the other satellites.

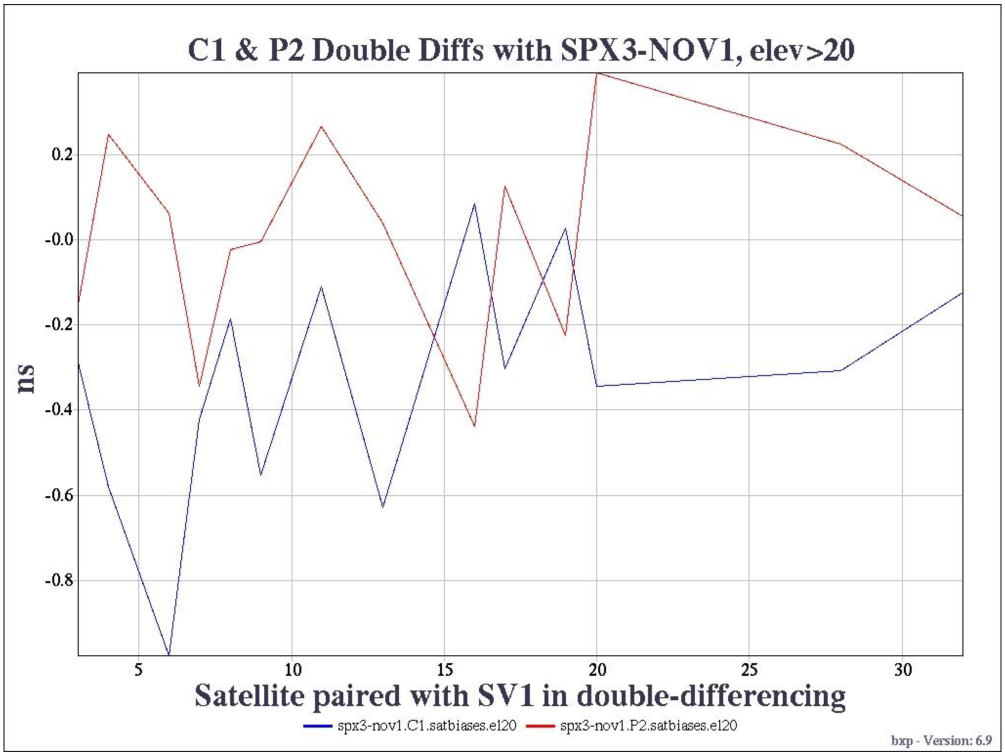

Figure 7 Double Differences for C1 and P1 signals between a Septentrio/NovAtel receiver pair, and satellite SV 1 minus the other satellites.

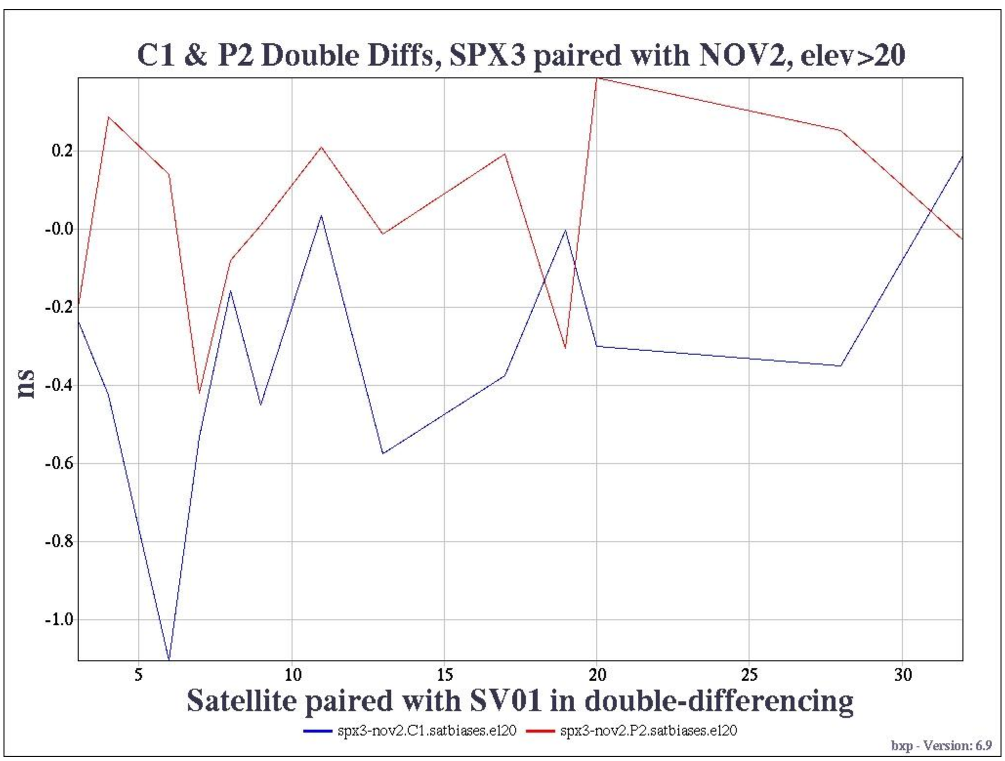

Figure 8 Double Differences for C1 and P1 signals between a Septentrio/NovAtel receiver pair, and satellite SV 1 minus the other satellites.

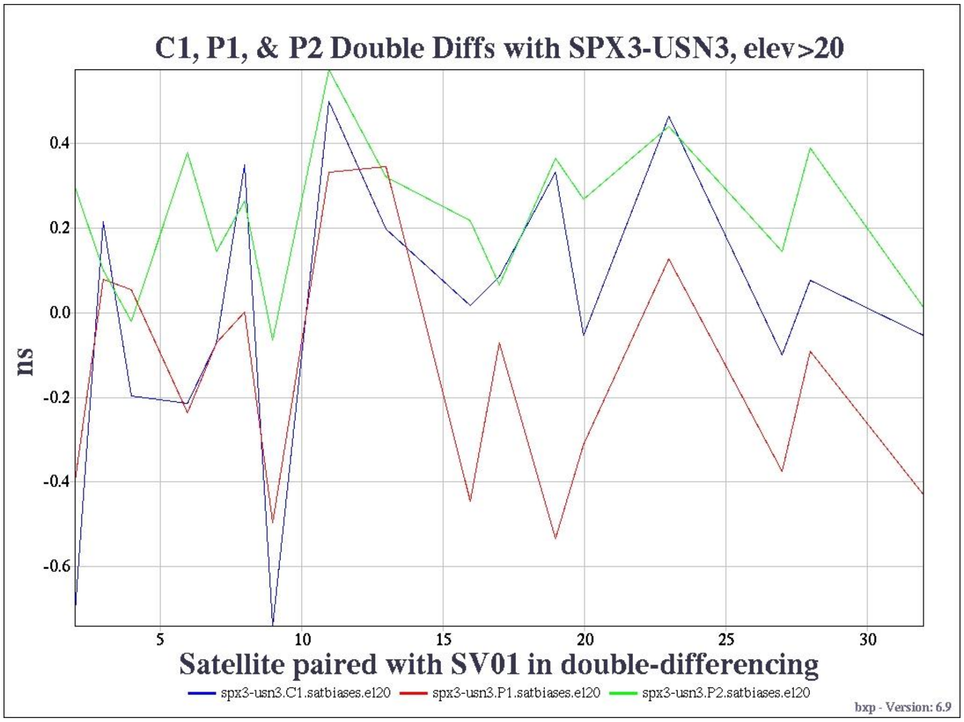

Figure 9 Double Differences for three signals between a Septentrio/Ashtech receiver pair, and satellite SV 1 minus the other satellites.

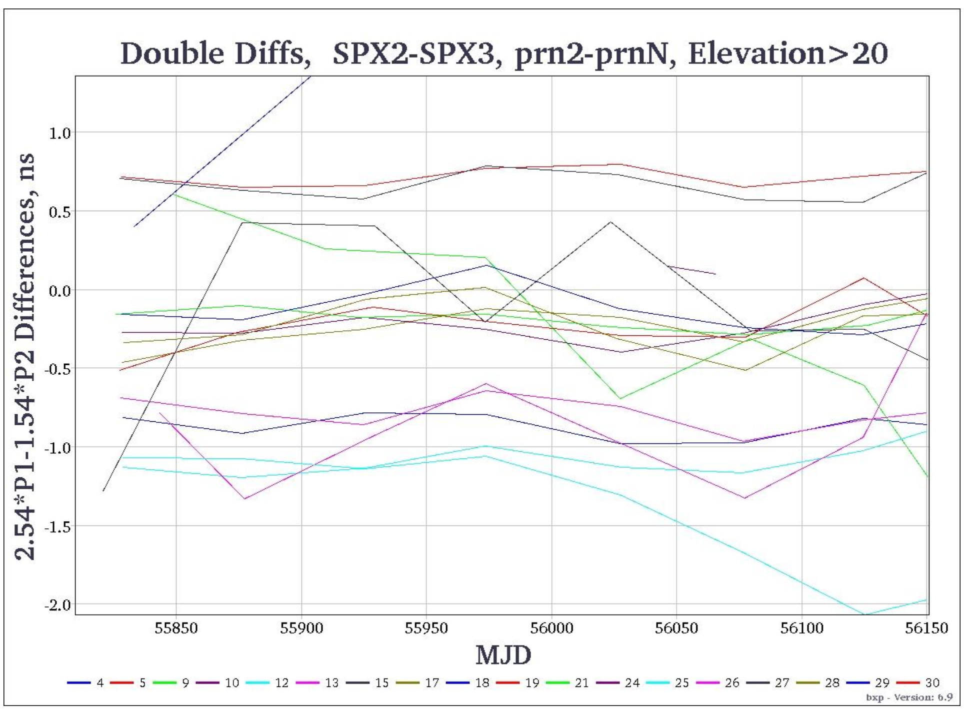

Figure 10 Ten-day smoothed double-differences over time between two Septentrio receivers and satellite pairs. Each curve represents a different satellite paired with SV2. This figure is the only one generated with the output of RINEX_CGGTTS.