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

Implications for the Next Generation of GNSS Systems

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UNAVCO – Boulder, CO USA

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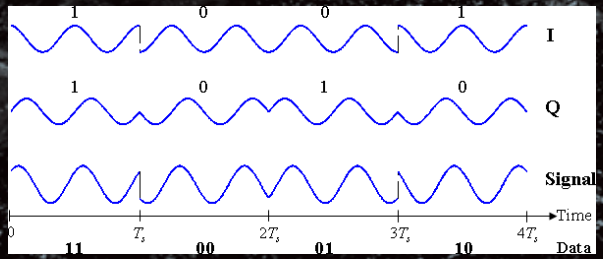
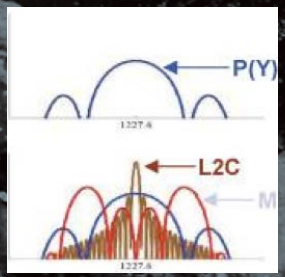
G52B-07

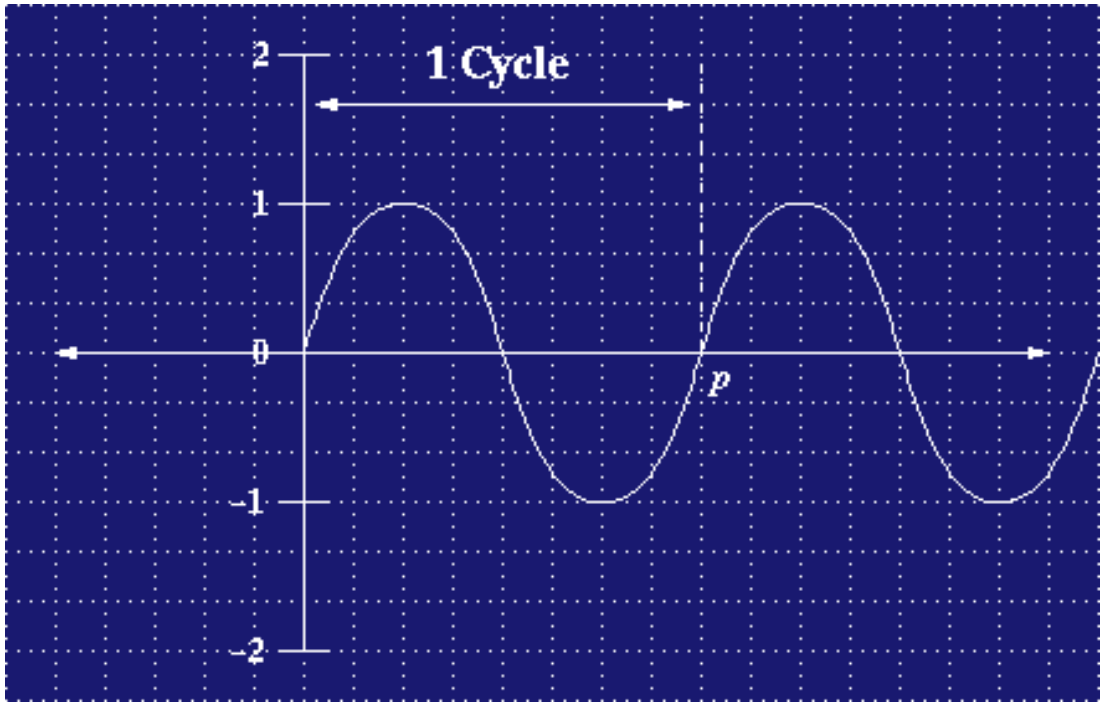




UNAVCO

L2C Basics

- L2C: Civilian code on L2 carrier broadcast by 7 Block IIR-M SV's since 2005, and 3 Block IIF since 2010.
  - Unencrypted code – tracked by civilian receivers without correlation.
  - Provides 6-12 dB-Hz SNR improvement over P2, stronger than L1 C/A.
  - Broadcast in quadrature (90° out of phase) with P2:



P2 Carrier (In Phase)

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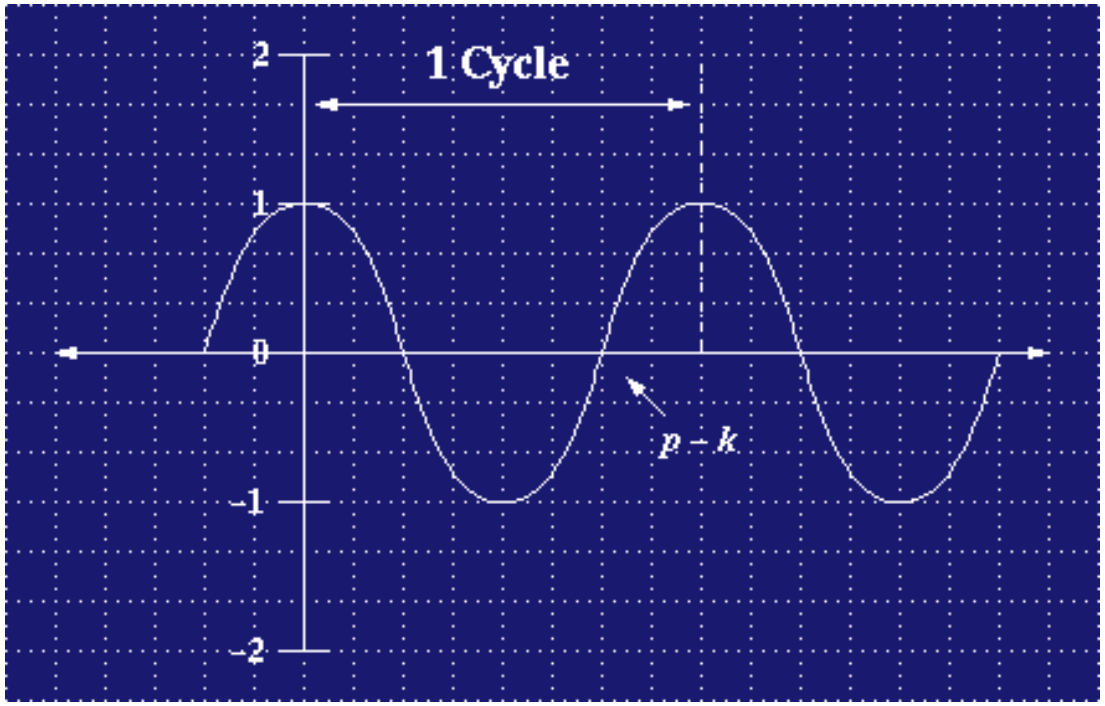
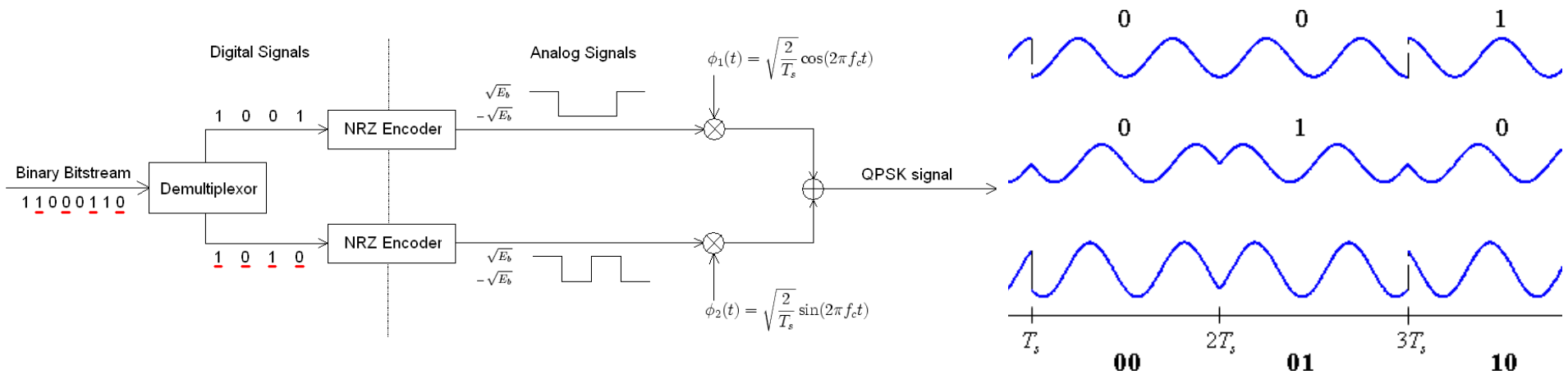


C2 Carrier (Quadrature)

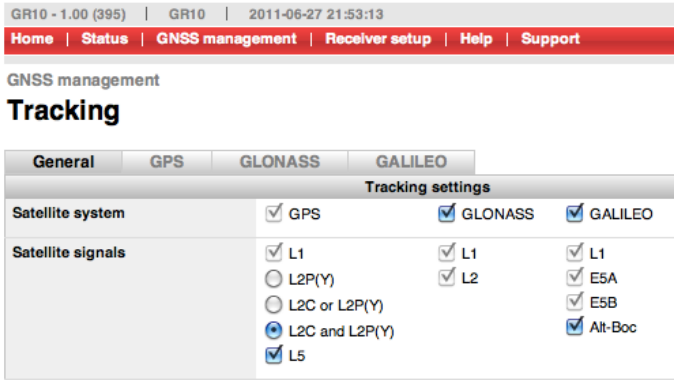
Quadrature Phase-Shift Key Modulation



- Do Phase Shifts Affect Carrier Phase Positioning?
  - Depends on who made your receiver
  - Depends on how you have configured your receiver
  - Depends on how you translate and pre-process your data
  - Depends on how you process the positions

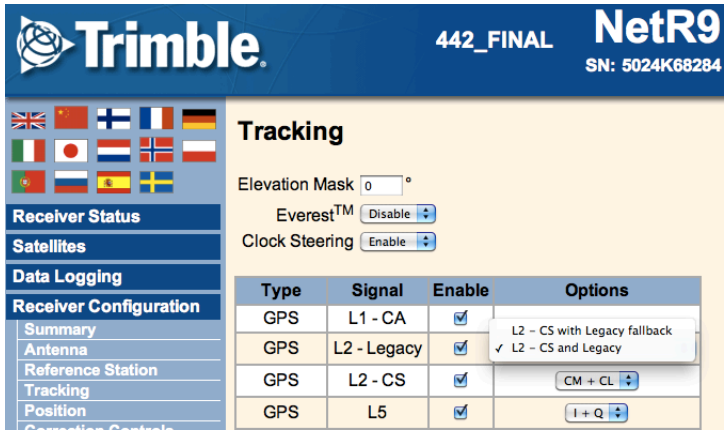
GPS Receiver Tracking Configuration

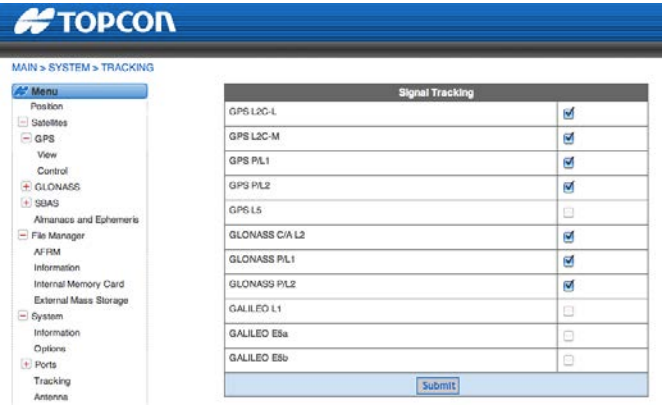
- Most receivers simultaneously track L2C and L2P(Y)
  - Can also be configured to track ONLY L2C if present (this is often the default)
  - Some can only do one or the other (e.g. Ashtech ProFlex CORS, Trimble NetRS with older firmware (1.1-5)



< Leica GR10

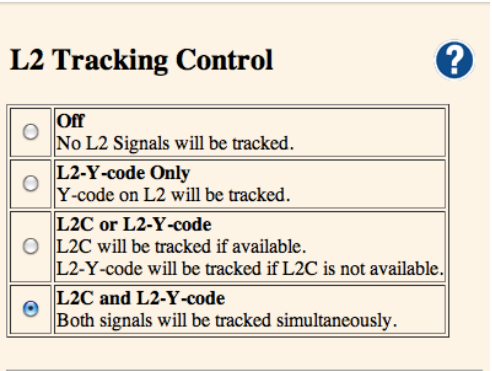
Trimble NetR9 >





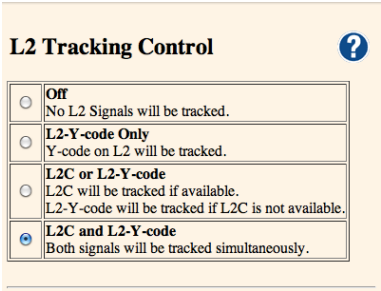
< Topcon Net-G3A

Trimble NetRS >

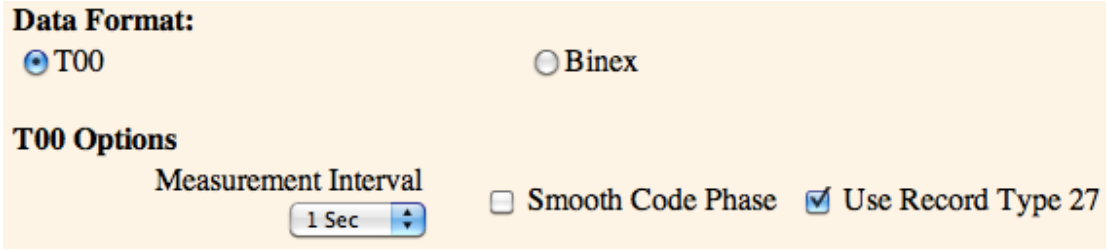


GPS Receiver Logging Configuration

- Some Data Formats Don't Allow for both L2C and L2P
  - Trimble Record Type 17 (RT17)
  - Default Topcon TPS Messages
  - BINEX Record 7f-03 (Leica and some Trimble Receivers)
- Just because you're *TRACKING* both L2 phases doesn't mean you're *LOGGING* both!



Trimble NetRS



	L2 OFF	L2-Y-code only	L2C or L2-y-code	L2C and L2-Y-code
BINEX	No L2 at all	P2 only	C2 for block IIR-M/II-F satellites and P2 for the rest	P2 only for all satellites
T00/RT17	No L2 at all	P2 only	C2 for block IIR-M/II-F satellites and P2 for the rest	P2 only for all satellites
T00/RT27	No L2 at all	P2 only	C2 for block IIR-M/II-F satellites and P2 for the rest	C2 AND P2 for block IIR-M/II-F satellites and P2 for the rest

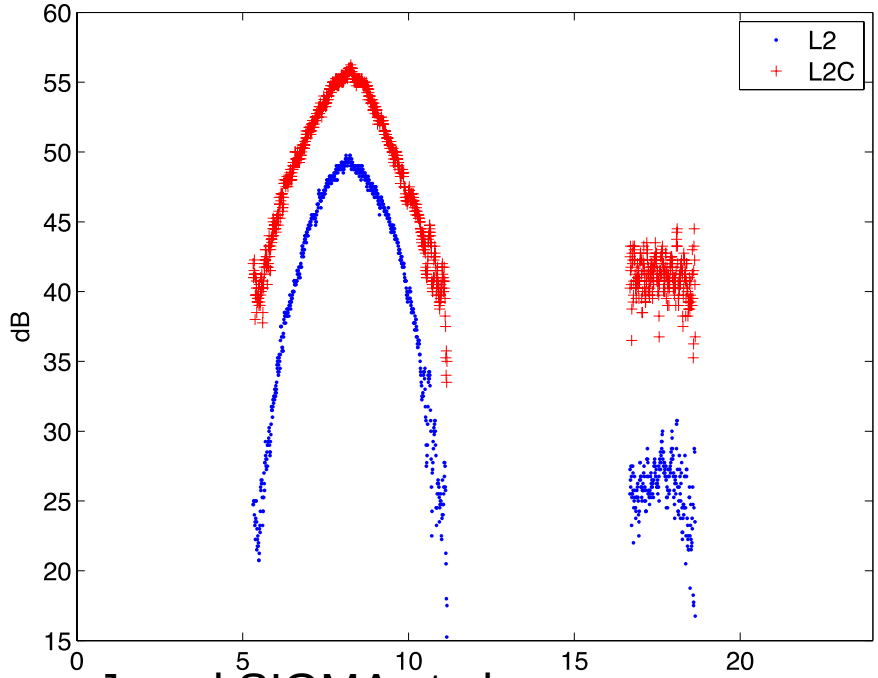
RINEX Translation Software

- Your RAW data contains BOTH L2C and L2P(Y)
- But RINEX 2.XX currently allows for a single L2 Phase and SNR (it does allow multiple pseudoranges)
  - RINEX 2.30 under development (UNAVCO/National Geodetic Survey) would allow both L2 phases and SNR's in the same file.
- For now, UNAVCO's teqc pre-processing software selects L2C phase and SNR when C2 observation is included in the RINEX file (+C2 flag in command line) since Sept 2009.

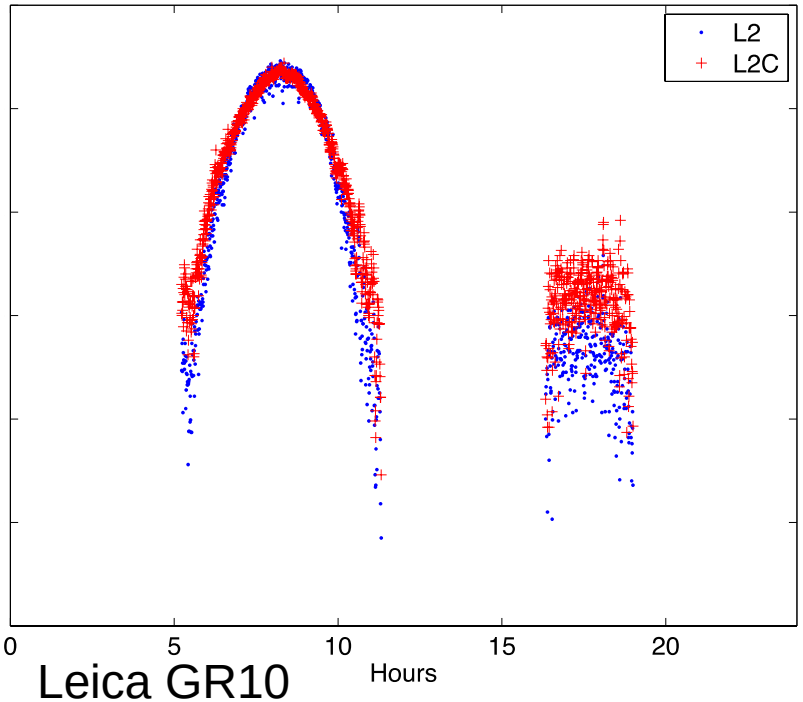
```
2.11           OBSERVATION DATA    G (GPS)         RINEX VERSION / TYPE
teqc  2012Jun06                    20110202 20:55:52UTCPGM / RUN BY / DATE
8    L1    L2    C1    P1    C2    P2    S1    S2     # / TYPES OF OBSERV

12  6 11 20 25 47.9600000  0 10G24G16G18G21G10G22G29G01G05G15

125698938.93146  97947222.94443  23919710.560    23919709.860
 23919708.380         40.700         22.100

108905294.44247  84861259.57448  20723987.560    20723987.020    20723985.400
 20723984.720         45.500         48.000
```

RINEX Translation Software

- If you do not control the receiver or pre-processing, how do you know which L2 information you have?
  - Some translators prefer P2 phase when C2 is present.
    - May find SV's with NO L2 observations in some cases
  - L2C 6-12 dB-Hz SNR improvement over P2.
  - SNR for L2C is higher than L1-C/A



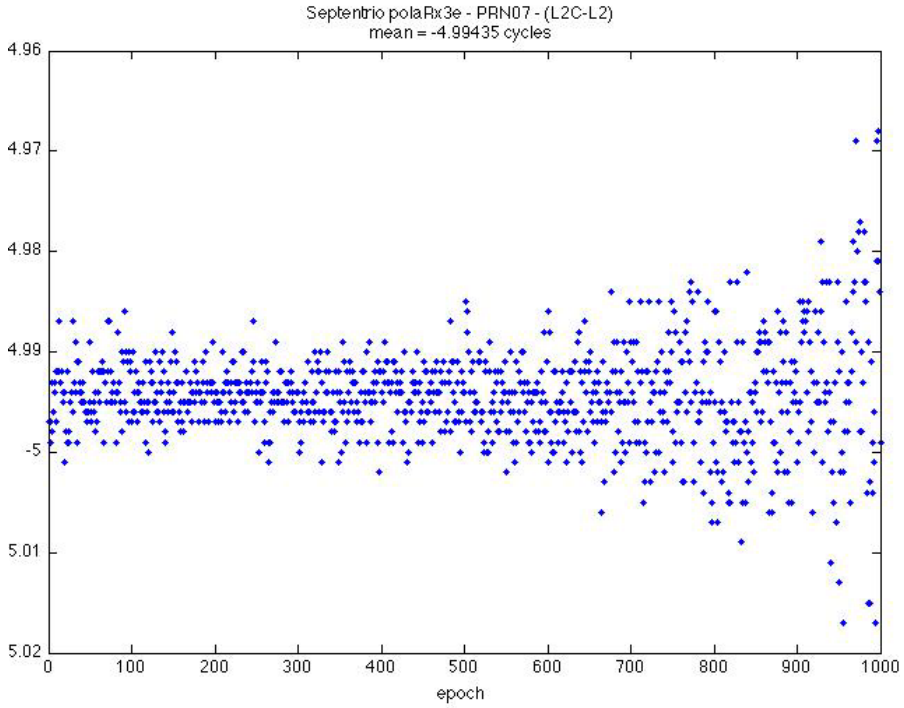
Javad SIGMA et al.

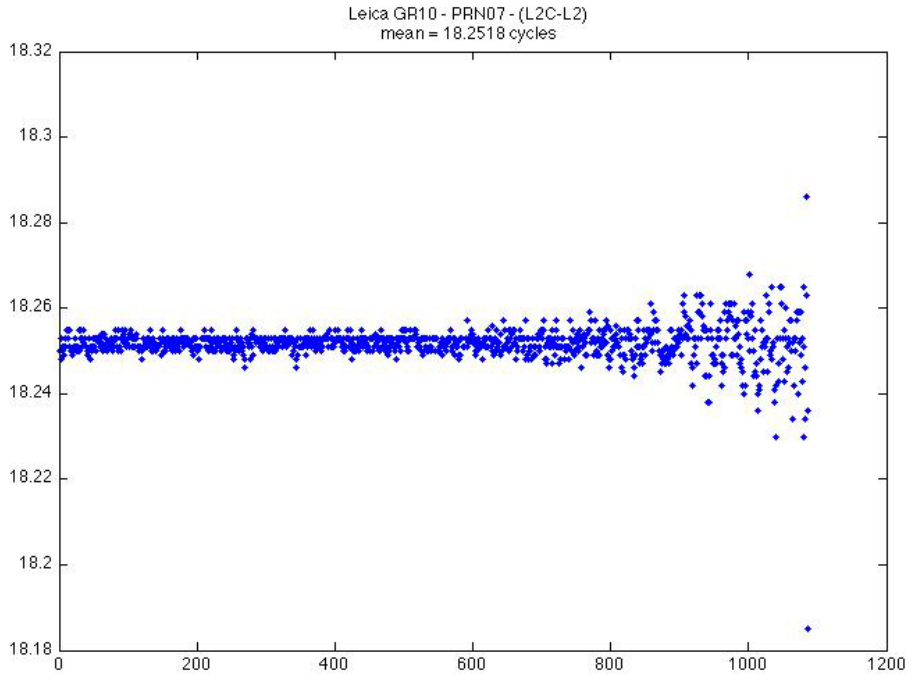


Leica GR10

Receiver Quadrature Phase Correction

- L2C Phase is ¼-wavelength out of phase with L2P(Y)
- Some manufacturers ***correct*** for this in the raw logged data by subtracting 0.25 from observed phase.
  - Ashtech, Septentrio, Trimble
- Others ***don't correct:*** Javad, Leica, Topcon



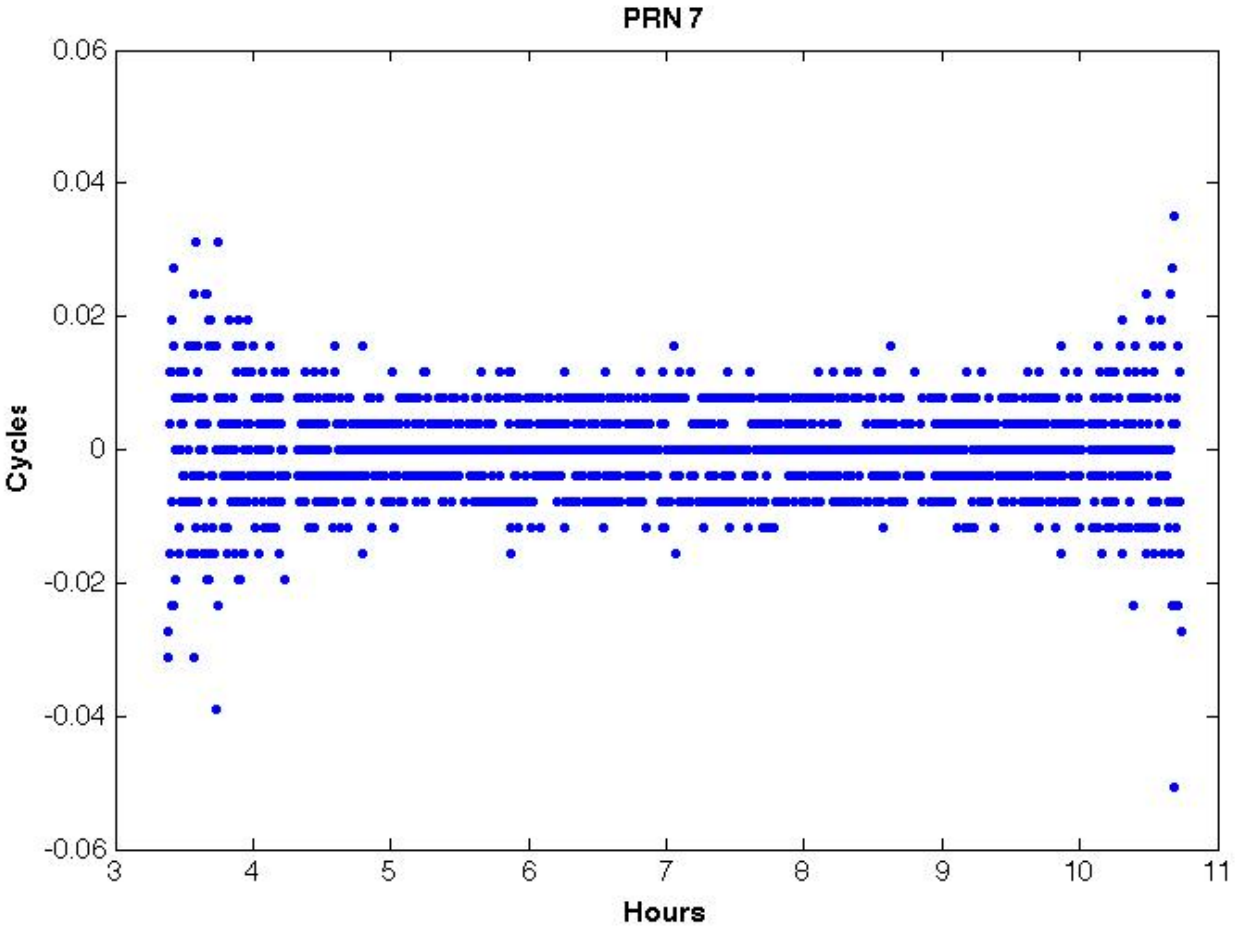


How do Receivers Track L2C and L2P?

- Receivers use separate correlators for each L2 carrier phase.
  - Instrument noise is independent, reveals Rx digitizing resolution

$Phase_{L2C} - Phase_{L2P(Y)}$

Same raw data file containing
Both L2C and L2P(Y)
Different teqc translation method



Trimble NetRS: Banding at 1/256 cycle ≈ 1 mm (8-bit A-D)

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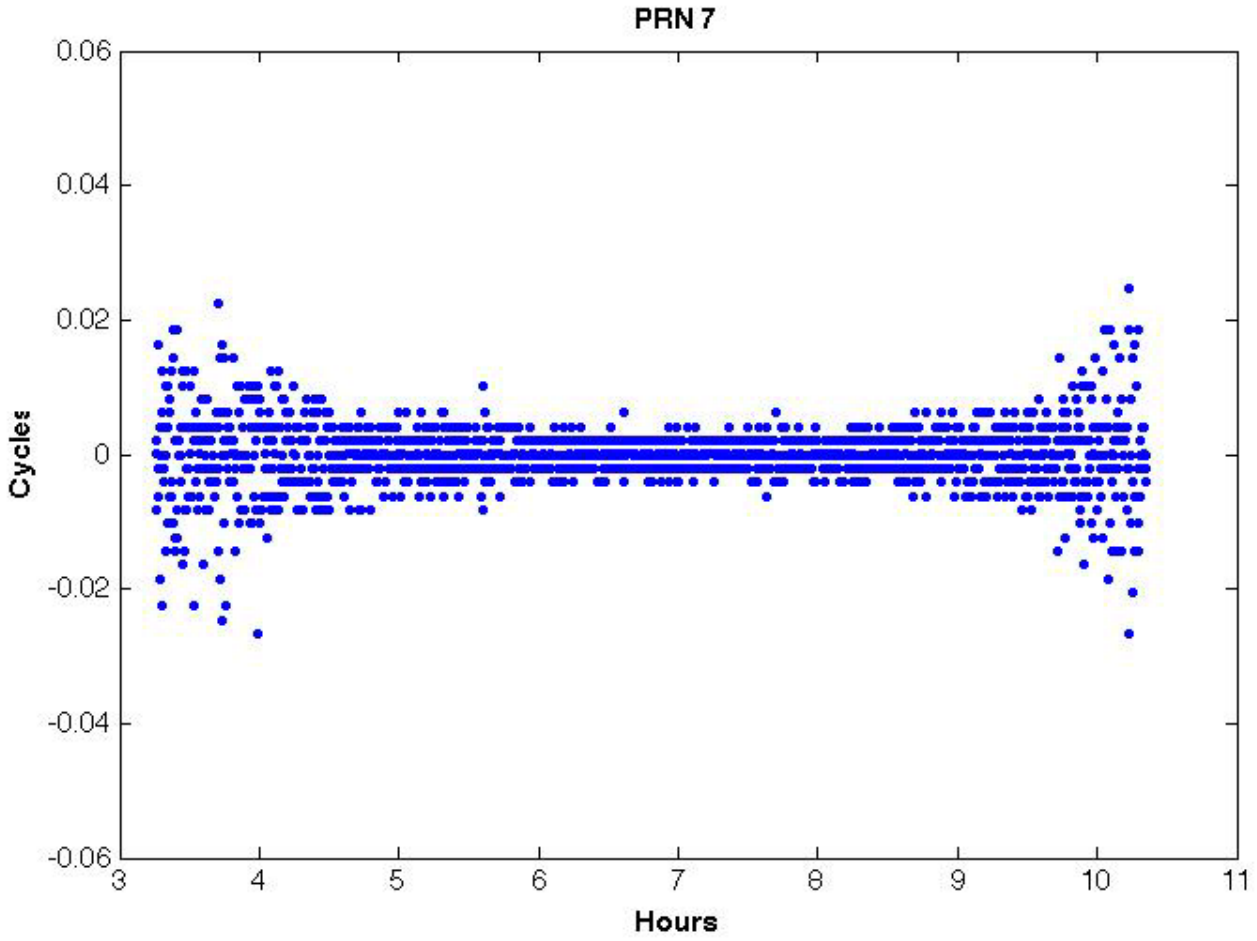

Leica GR10, Topcon Net-G3A: Banding at 1/512 cycle ≈ 0.5 mm (9-bit A-D)

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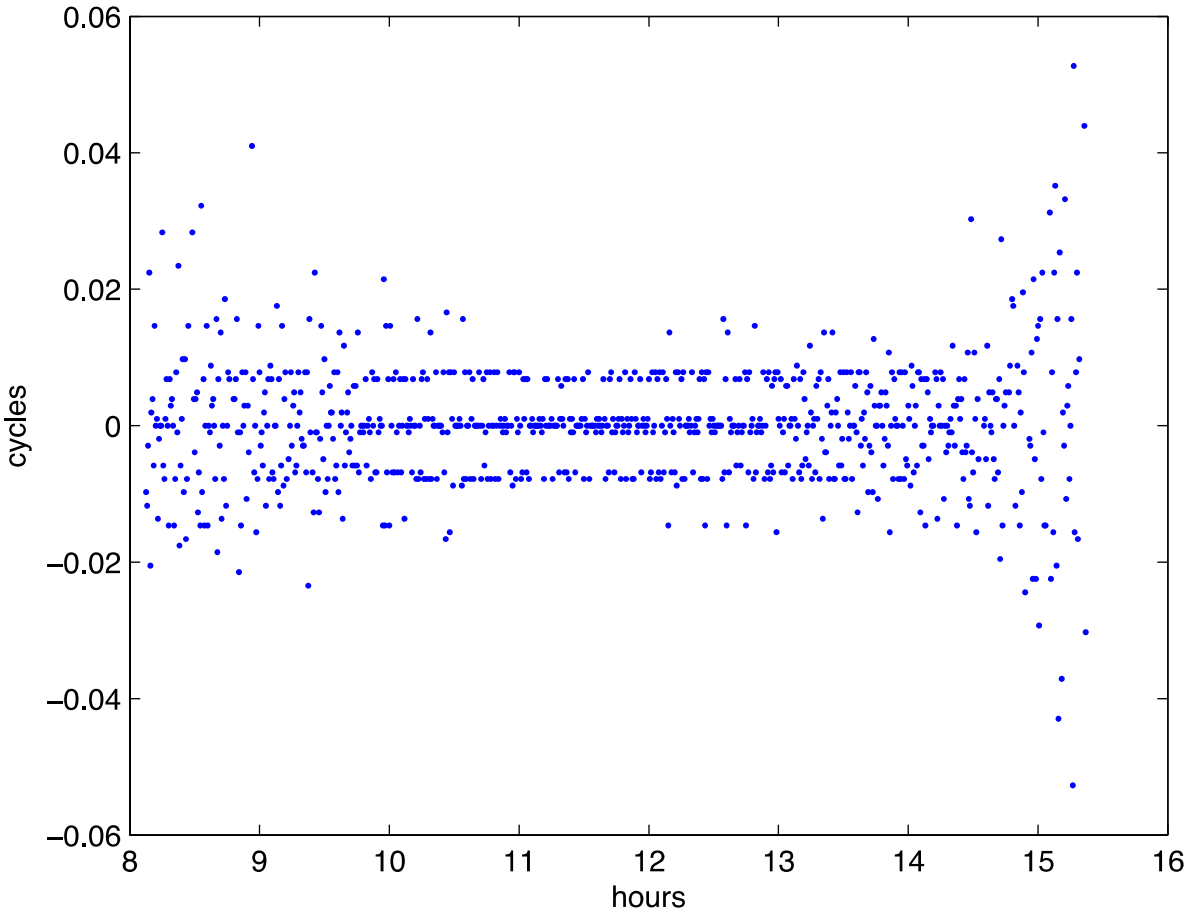
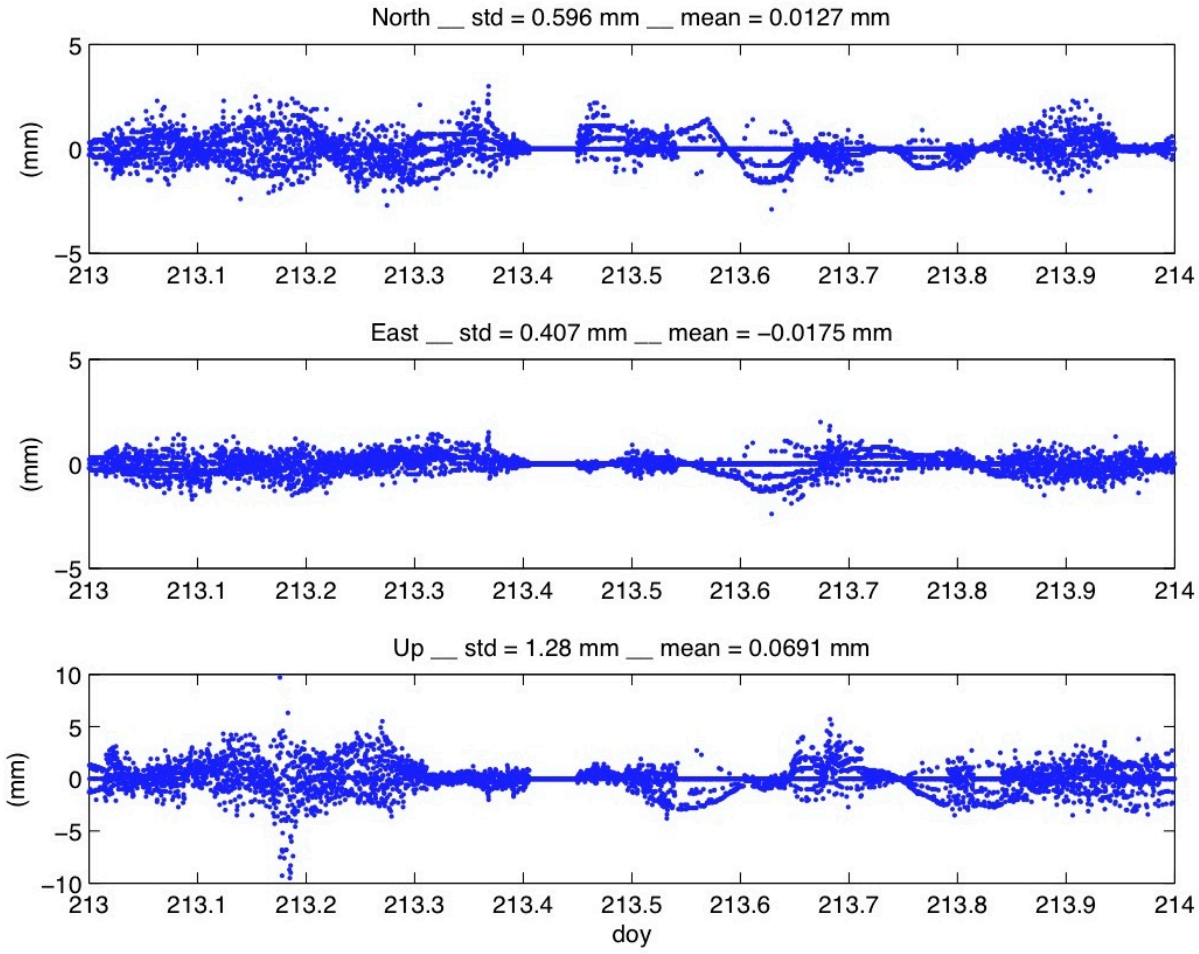


Trimble NetR9, Javad SIGMA: Banding at 1/1024 cycle ≈ 0.25 mm (10-bit A-D)

How Does This Affect Position?

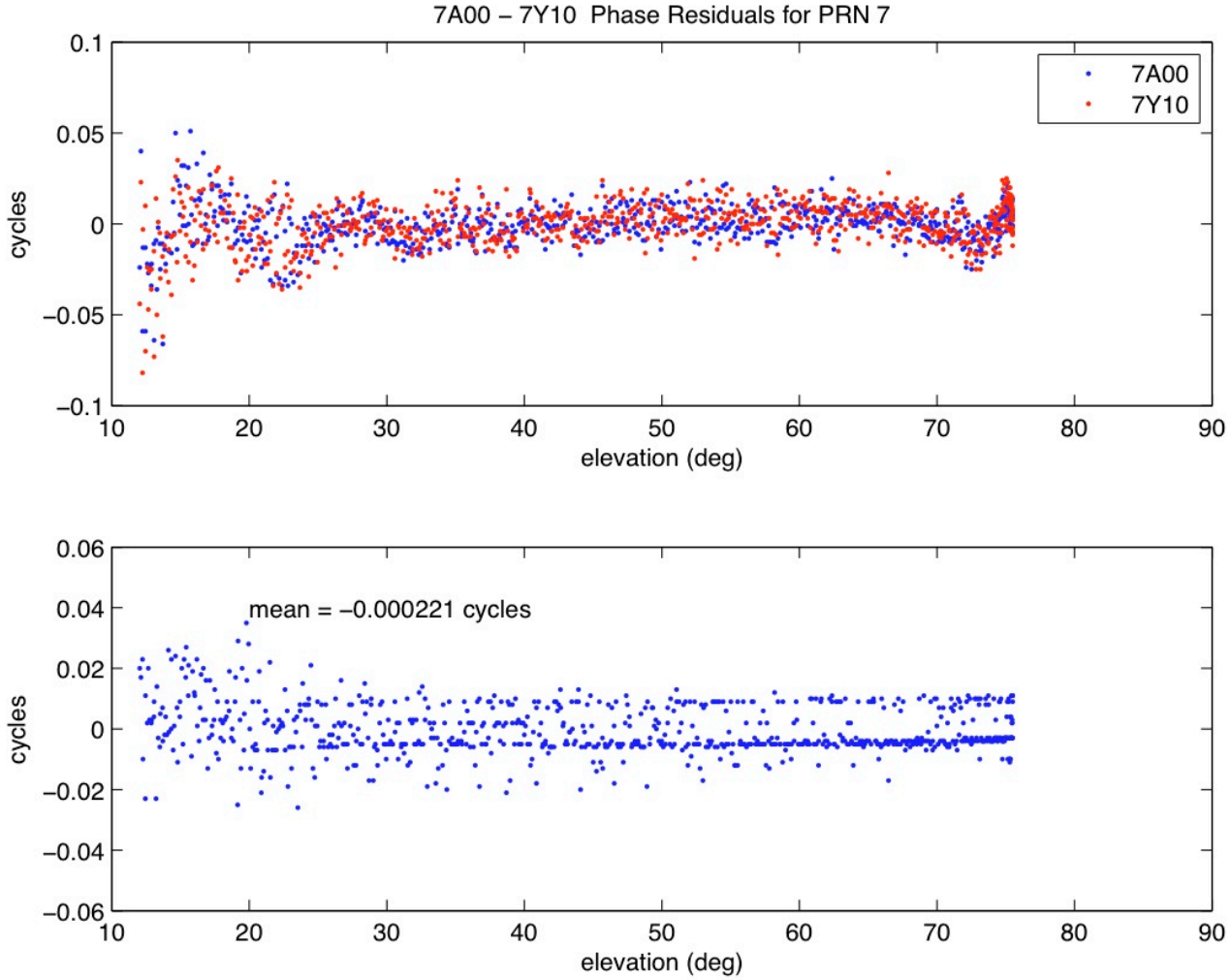
- Zero-Baseline (same receiver, different L2 phase used)



24-hour TRACK Solution: No net bias, noise depends on L2C visibility

How Does This Affect Position?

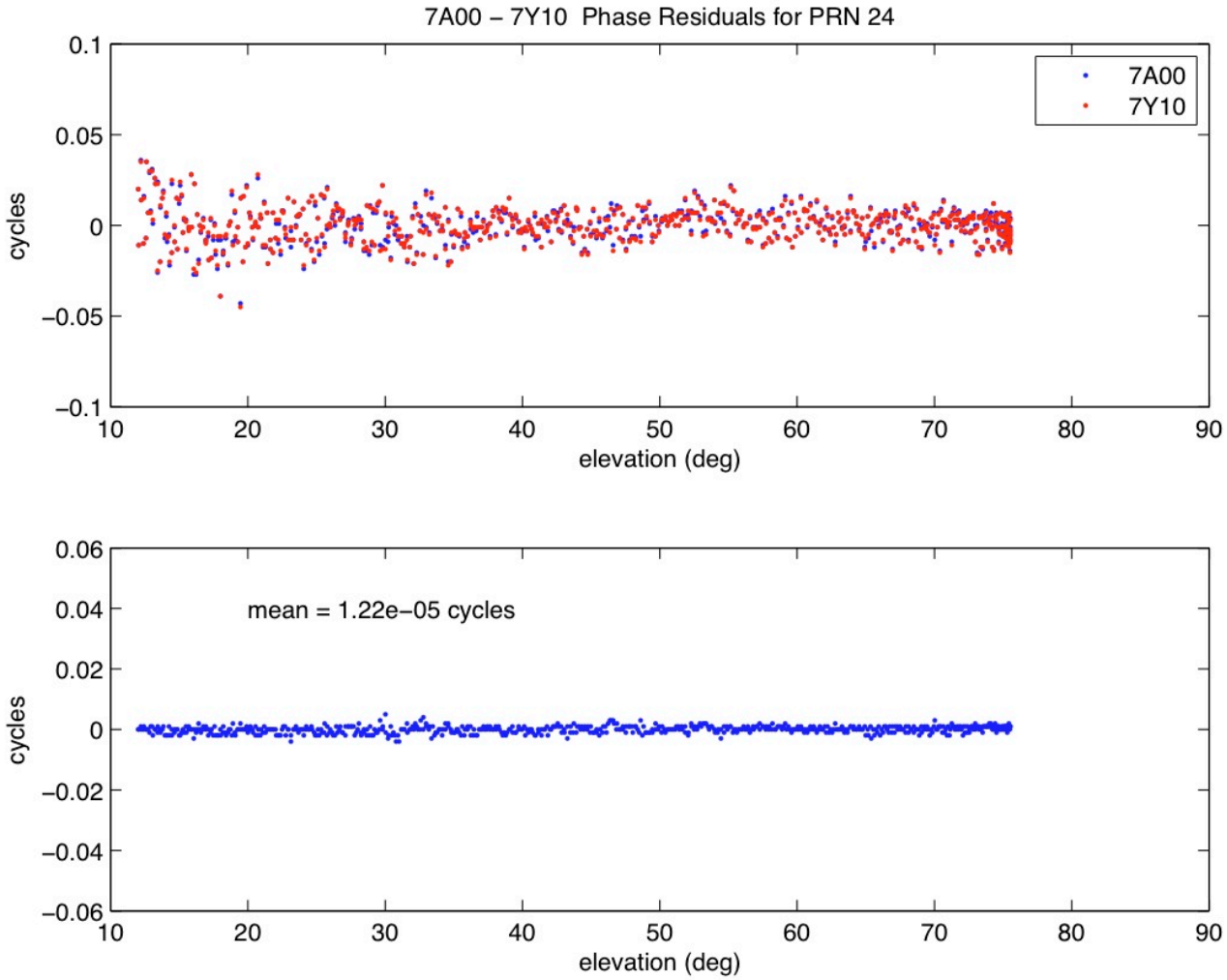
- TRACK phase residuals for L2C Satellite



Lower figure shows difference between L2C (red) and L2P (blue)

How Does This Affect Position?

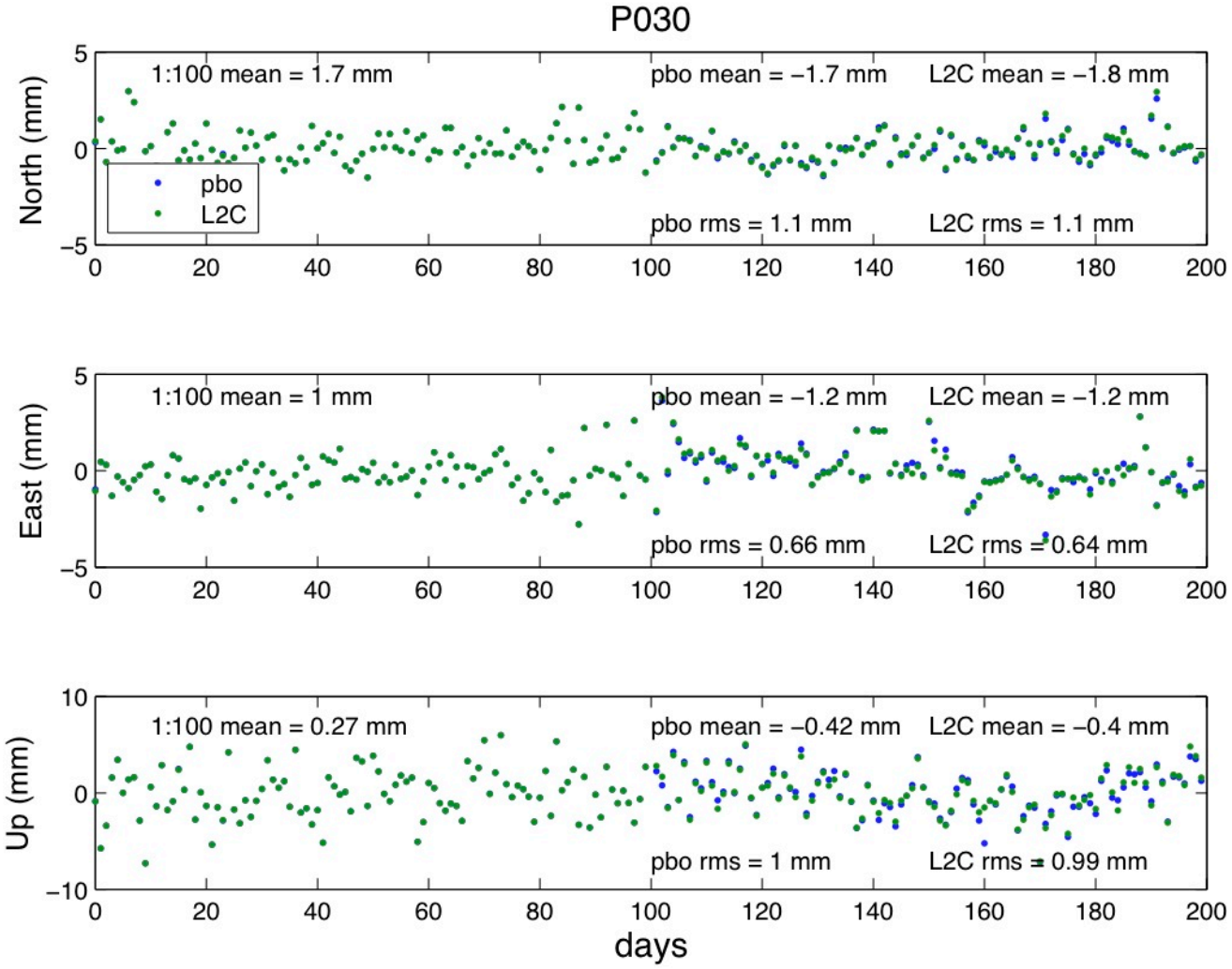
- TRACK phase residuals for non-L2C Satellite



This case demonstrates that L2C noise does not affect other satellites

Direct Comparison of L2C-L2P Position

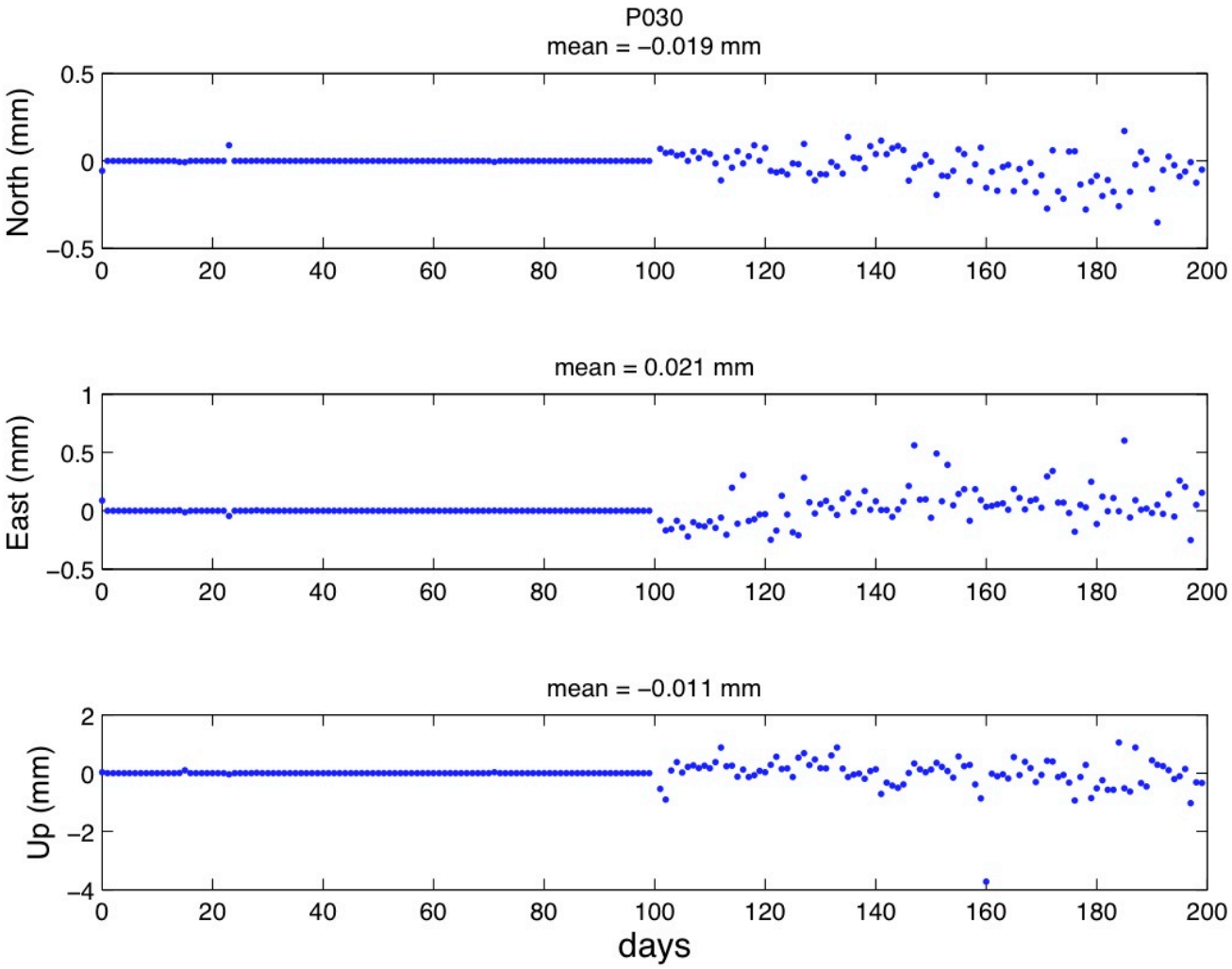
- GAMIT Solution Using L2-P(Y) Phase (GREEN) vs. L2C Phase (BLUE)



Same Receiver (Trimble NetRS) – L2C enabled on day 100

Direct Comparison of L2C-L2P Position

- Sub-millimeter differences in L2C and L2-P(Y) GAMIT Solutions



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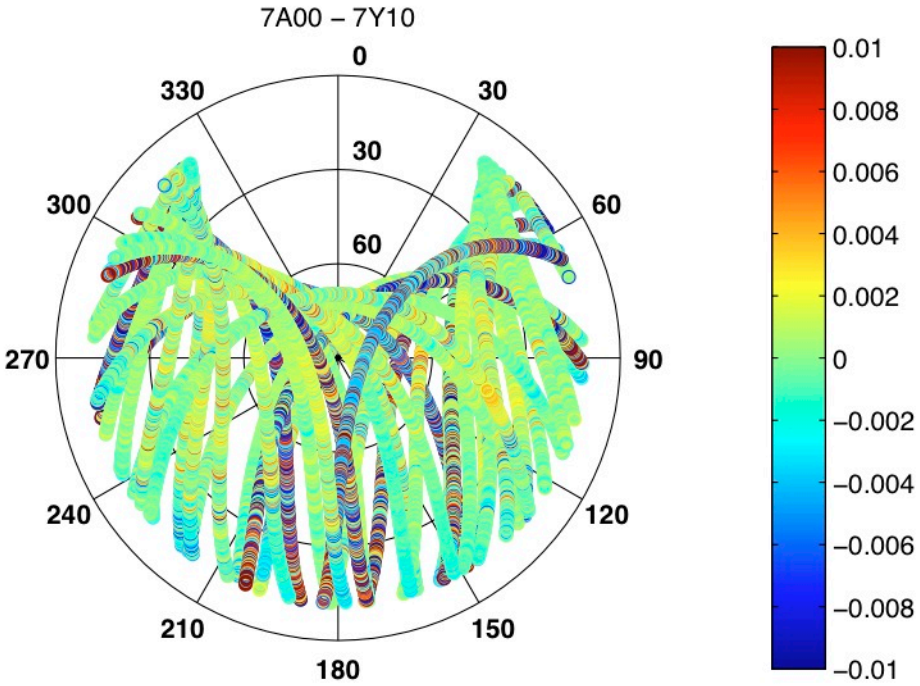
Direct Comparison of L2C-L2P Position

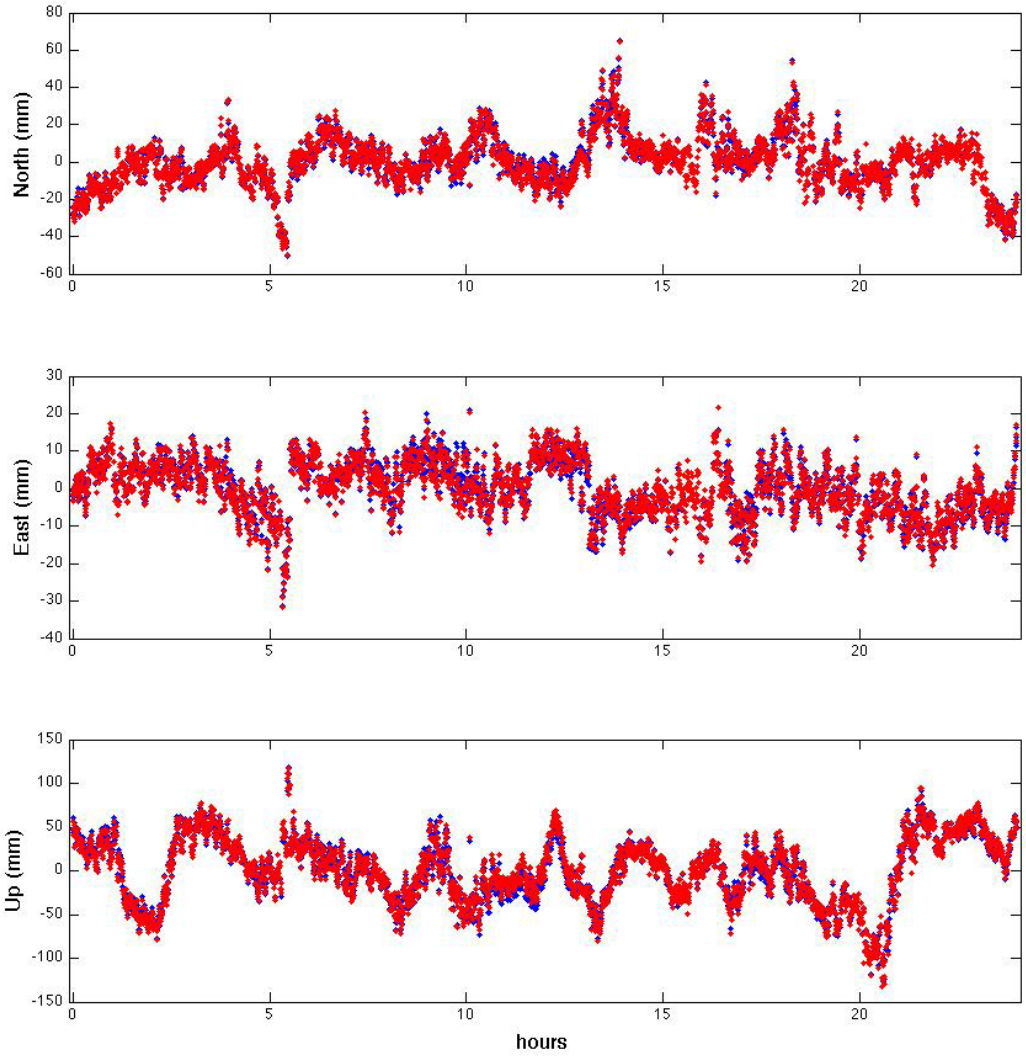
Elevation Dependent Phase Residuals between L2C and L2P GAMIT Solutions



L2C Noisier at Low Elevations – Increased Multipath due to SNR (remember this!)

10 km Baseline – Mixed Receivers

Carrier Phase Position Comparison for L2-P(Y) and L2C

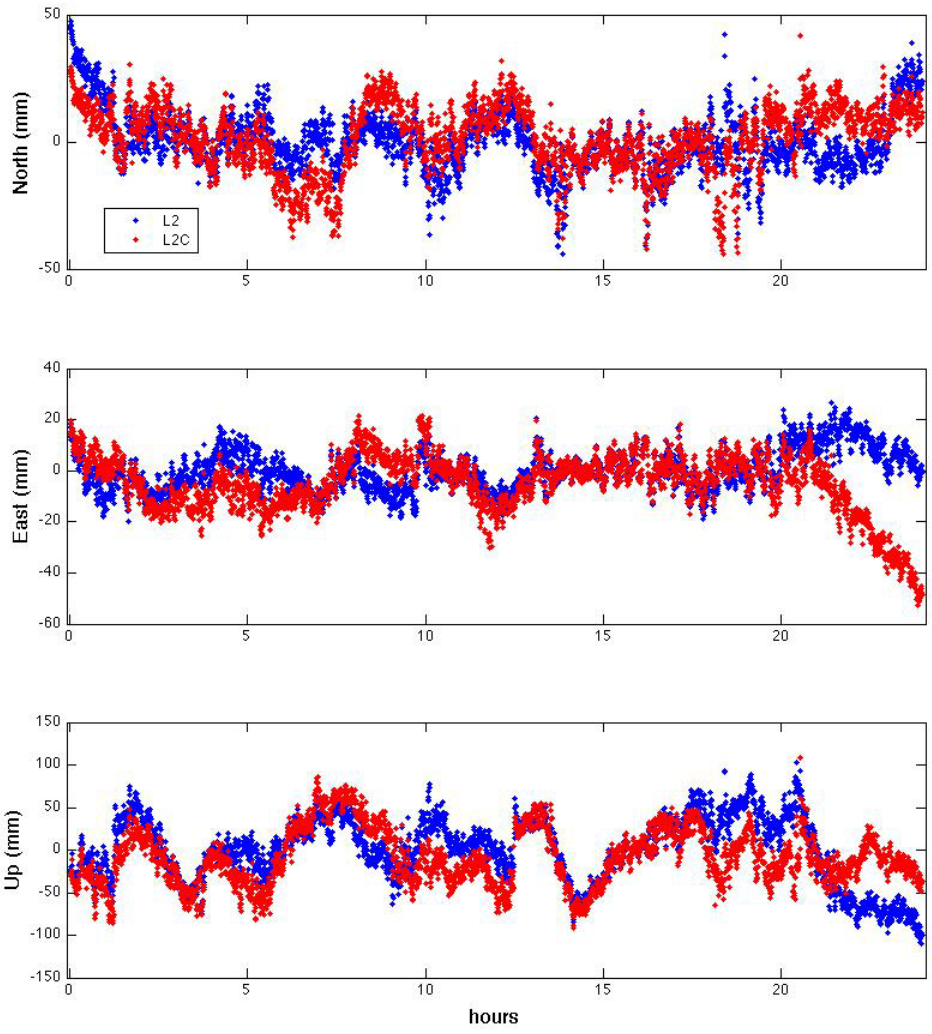


L2P – BLUE
L2C - RED

Trimble NetRS to Trimble NetR9 TRACK Processing: Both correct Quadrature in L2C

10 km Baseline – Mixed Receivers

Carrier Phase Position Comparison for L2-P(Y) and L2C



L2P – BLUE
L2C - RED

Trimble NetRS to Leica GR10 (no quadrature correction) TRACK Processing

Conclusions

- L2C Is Not Yet Suitable For Use in Carrier-Phase Positioning
  - Only Partial Constellation Available
  - Confusion over receiver configuration and pre-processing
    - Improper receiver configuration and/or translation can result in loss of L2-P Phase information and missing observations
  - Fundamental Incompatibility of receiver brands
    - IGS and RTCM should encourage universal quadrature correction as has been done with L1P and L1-C/A
  - Problems in kinematic processing with mixed receivers
    - Real-time issues (not discussed here) are worse!
- Recommendations:
  - L2C phase **not** be used in “production” RINEX files used for position time-series.
  - Log both L2-P(Y) and L2C iff raw data format allows, and use separate pre-processing flows for positioning and special uses.

Questions:

- If adopting something as “simple” as a new carrier on an existing frequency is so difficult, what about:
  - New GPS frequency: L5?
  - Existing GNSS Constellation: GLONASS?
  - Future constellations: Galileo, Compass?
    - Most GNSS signals have phase-shifted carriers
- Issues to address:
  - Upgrade timeline of existing infrastructure
    - Receivers & Antennas (disrupt time-series)?
  - Data Formats and metadata
    - RINEX 3 (not (yet) supported by teqc)
  - Data Analysis software
    - Carrier phase and multi-code analysis