



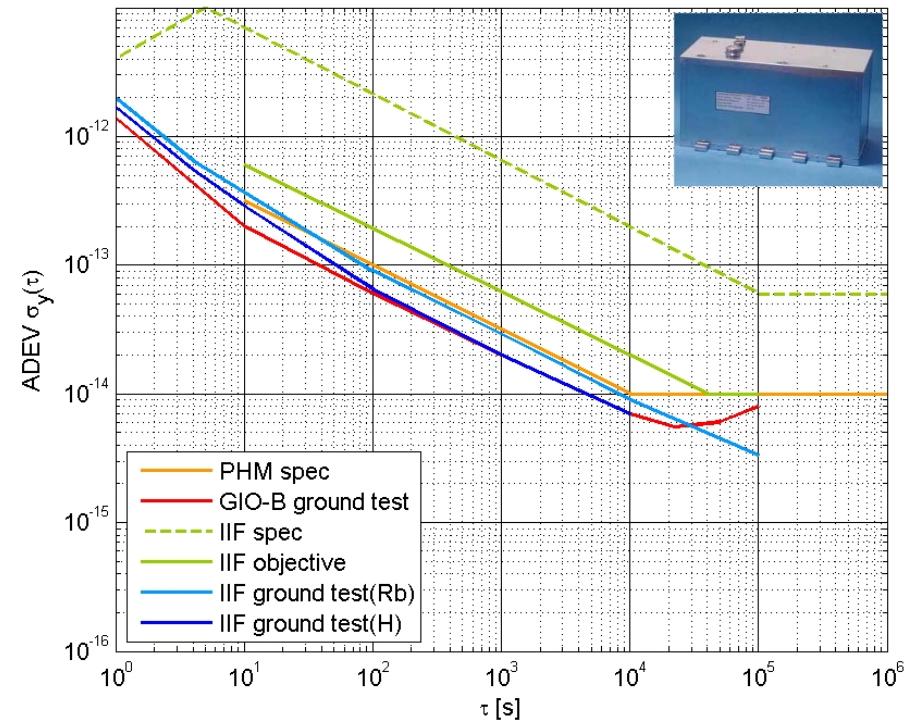
Line bias variations in GPS L1/L2/L5 signals

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GPS Block IIF



- First Block IIF satellite launched May 2010
- Presently two IIF satellites in orbit (SVN62/PRN25, SVN63/PRN01)
- L1/L2 and operational L5
- Advanced Rb clock (comparable to GIOVE hydrogen maser)



Triple-Frequency Carrier Phase Combination

➤ Geometry- and ionosphere-free linear combination

- Nominally (almost) constant
- Phase wind-up essentially negligible
- Phase noise and multipath

$$C = \alpha \cdot L_1 + \beta \cdot L_2 + \gamma \cdot L_5$$

$$\alpha + \beta + \gamma = 0$$

$$\alpha \cdot \lambda_1^2 + \beta \cdot \lambda_2^2 + \gamma \cdot \lambda_5^2 = 0$$

➤ First (?) proposed by A. Simsky [1]

➤ Scaling options

- Normalized noise/multipath [2]
- Difference of iono-free L1/L2 and L1/L5 combinations [3]

$$\alpha^2 + \beta^2 + \gamma^2 = 1$$

$$M = +0.142 \cdot L_1 - 0.767 \cdot L_2 + 0.626 \cdot L_5$$

$$\alpha = \left(\frac{f_1^2}{f_1^2 - f_2^2} - \frac{f_1^2}{f_1^2 - f_5^2} \right) \quad \beta = - \left(\frac{f_2^2}{f_1^2 - f_2^2} \right) \quad \gamma = \left(\frac{f_5^2}{f_1^2 - f_5^2} \right)$$

➤ Second option matches difference of estimated clock offsets ($\text{cdt}_{L1/L5} - \text{cdt}_{L1/L2}$)

$$\text{DIF} = +0.285 \cdot L_1 - 1.546 \cdot L_2 + 1.261 \cdot L_5$$

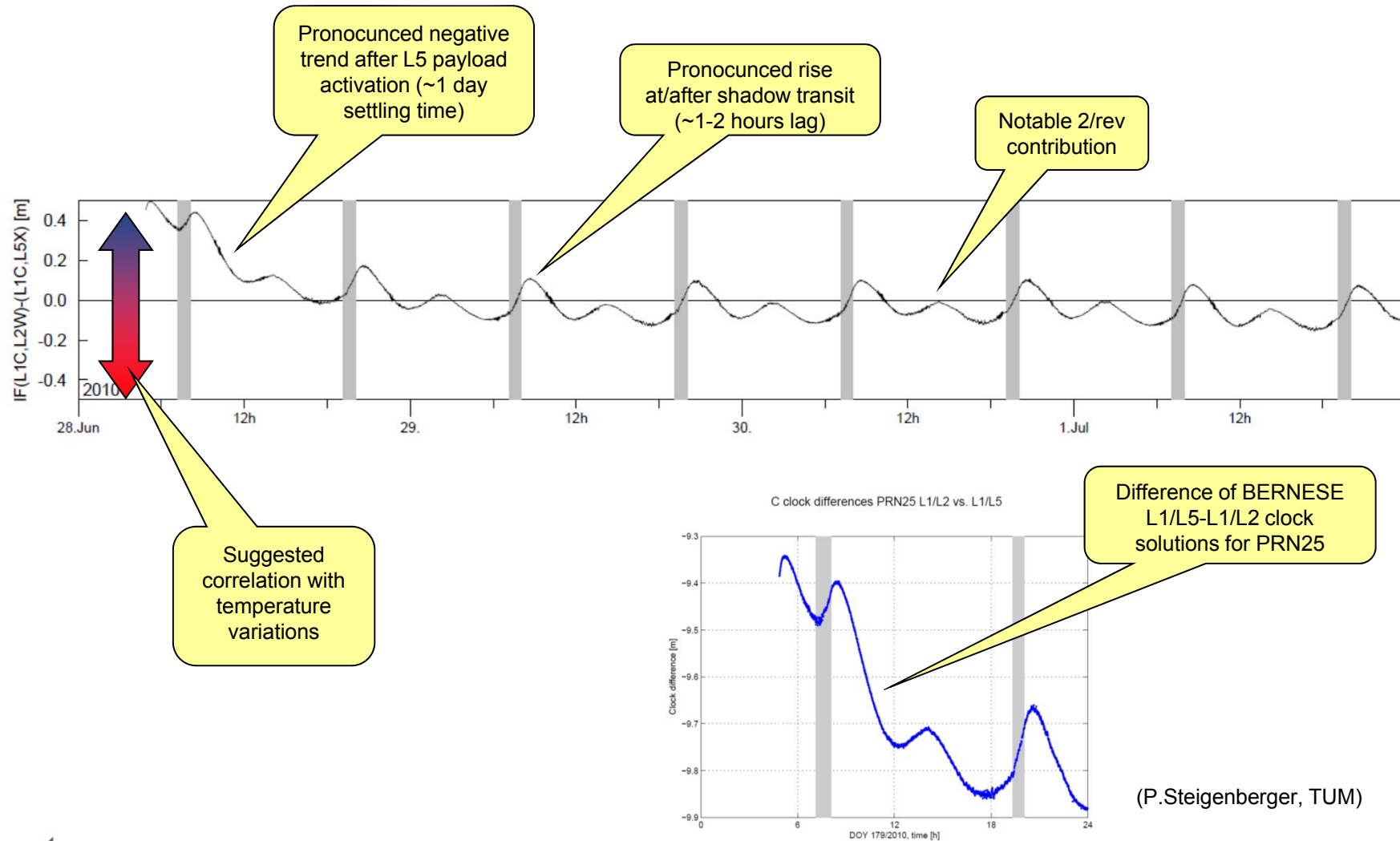
[1] A. Simsky, "Three's the Charm – Triple Frequency Combinations in Future GNSS", Inside GNSS, Vol. 1, No. 5, July/August 2006, pp. 38–41.

[2] Montenbruck, O.; Hauschild A.; Steigenberger P.; Langley R. B.; "Three's the challenge: A close look at GPS SVN62 triple-frequency signal combinations finds carrier-phase variations on the new L5"; GPS World 21(8), 8-19 (2010).

[3] Montenbruck O., Hugentobler U., Dach R., Steigenberger P., Hauschild A.; „Apparent Clock Variations of the Block IIF-1 (SVN62) GPS Satellite," GPS Solutions (2011). DOI 10.1007/s10291-011-0232-x

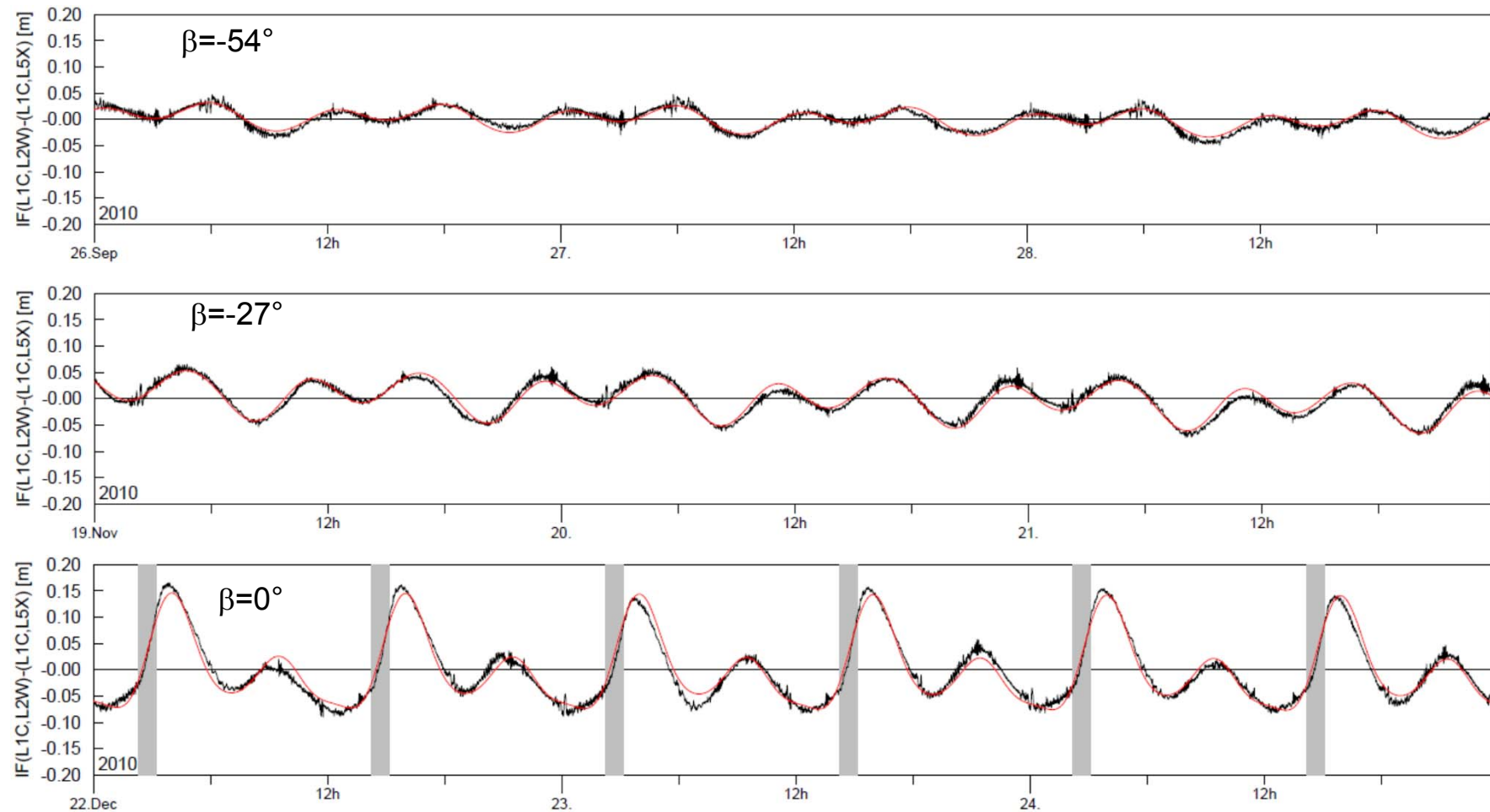


Initial Results (L5 Signal Activation)



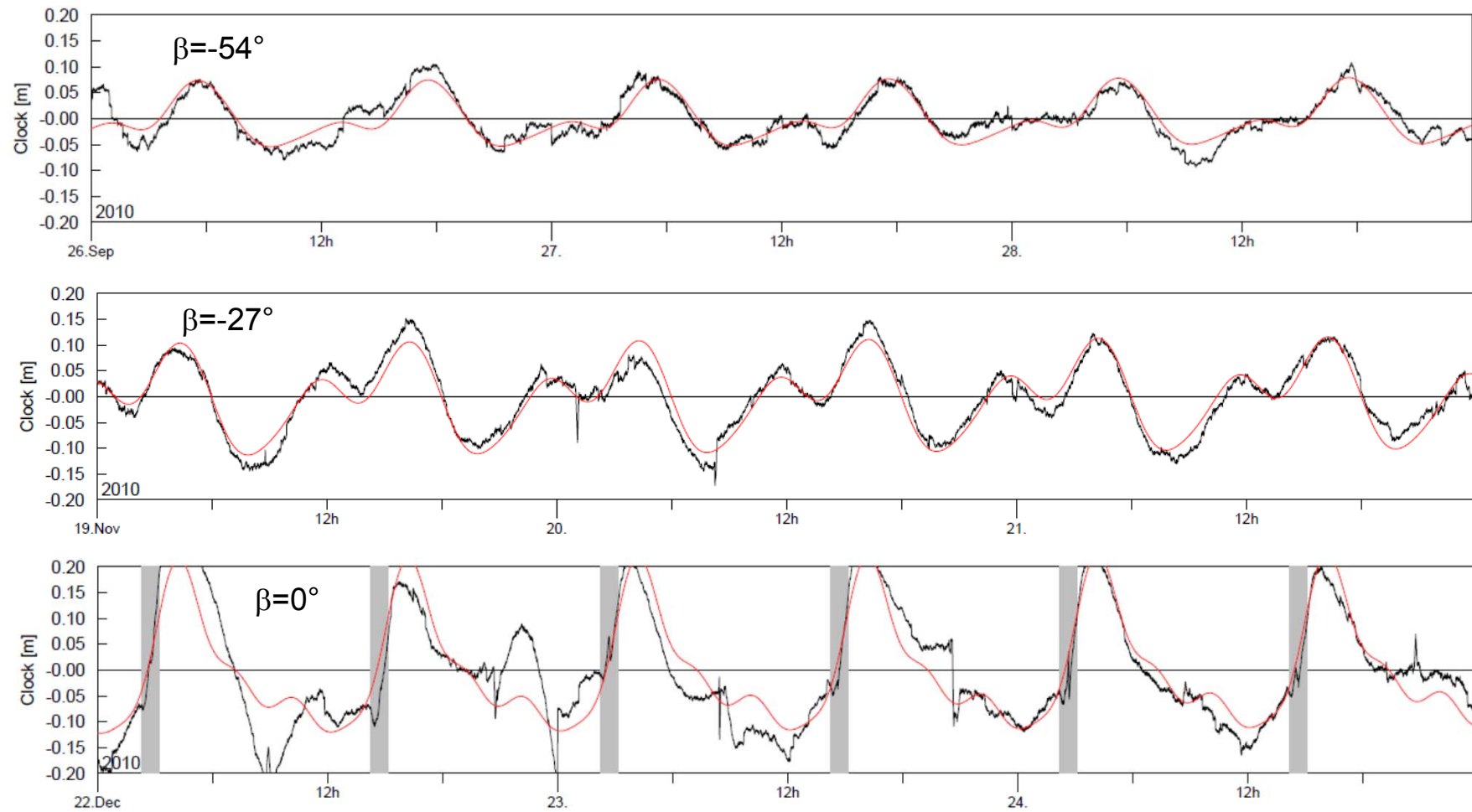


Seasonal Variation of L1/L5-L1/L2 Clock Difference





Seasonal Variation of Periodic L1/L2 Clock Errors

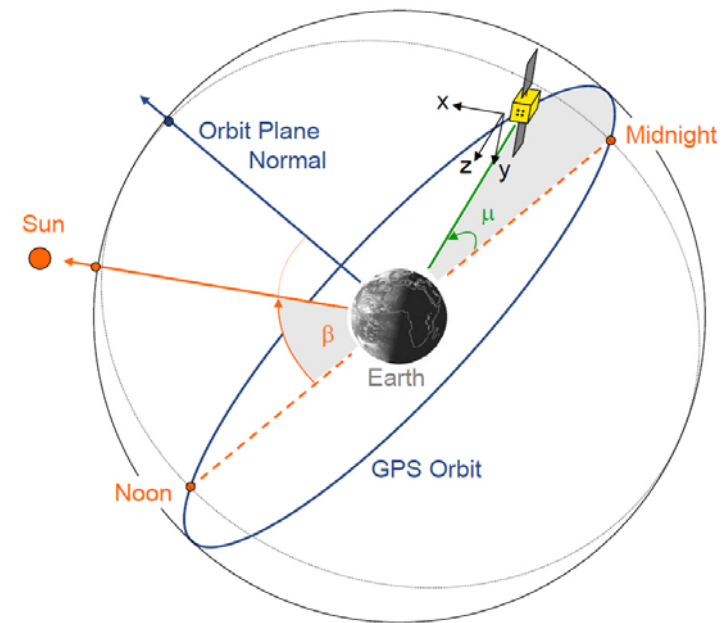




Harmonic Analysis

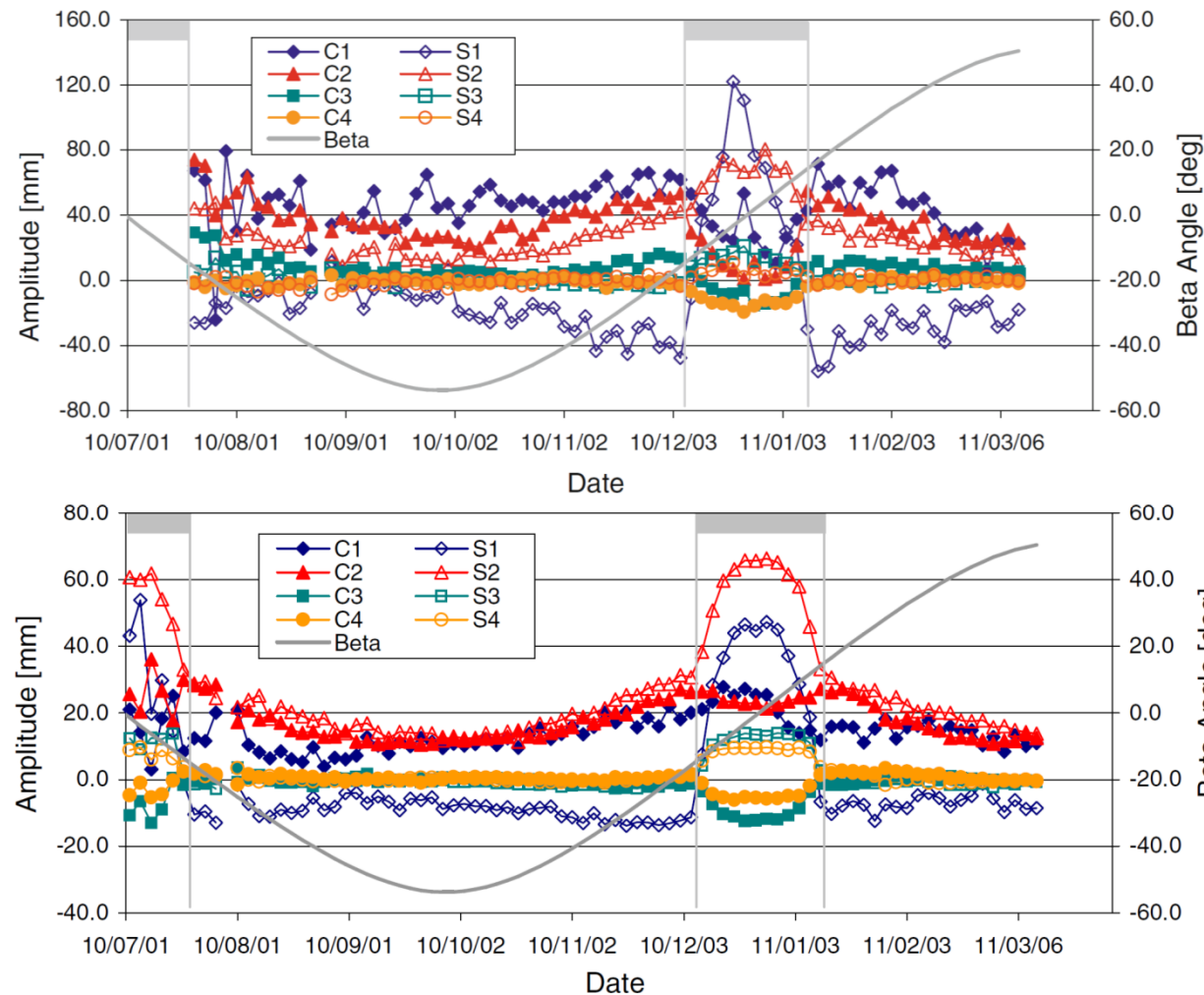
- $\Delta c\delta t_{L125}$ varies with thermal conditions
- Sun illumination depends on
 - β = Sun elevation above orbit plane
 - μ = orbit angle relative to midnight-line

$$\begin{aligned} \Delta c\delta t_{L125} = & (a + b \cdot t) \\ & + c_1 \cdot \cos(\mu) + s_1 \cdot \sin(\mu) \\ & + c_2 \cdot \cos(2\mu) + s_2 \cdot \sin(2\mu) \\ & + c_3 \cdot \cos(3\mu) + s_3 \cdot \sin(3\mu) \\ & + c_4 \cdot \cos(4\mu) + s_4 \cdot \sin(3\mu) \end{aligned}$$





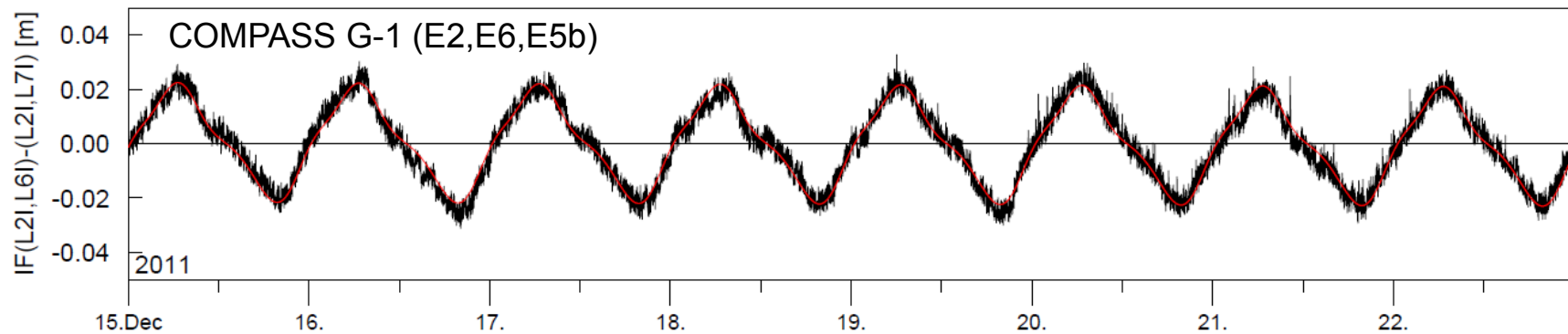
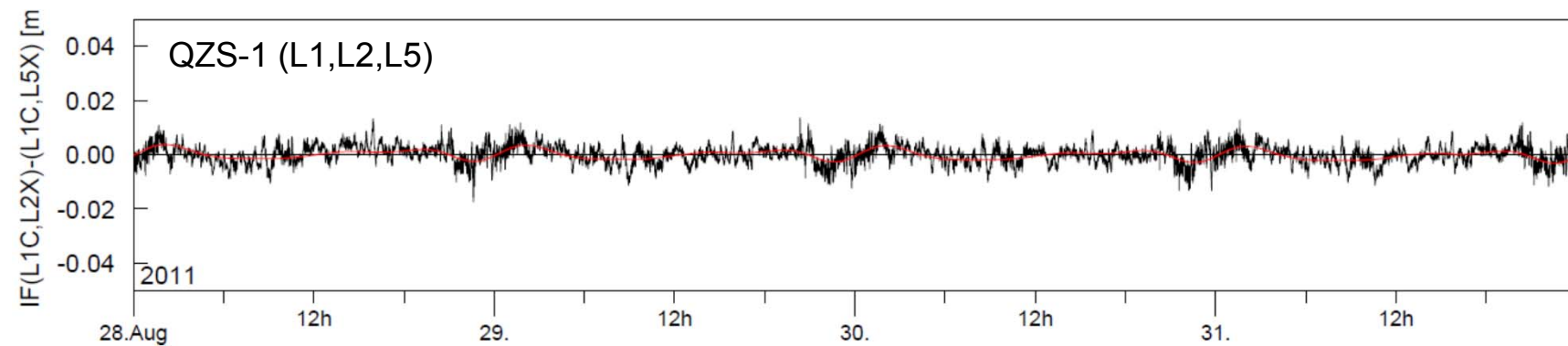
Harmonic Analysis



- Dominant 1/rev and 2/rev variations
- Similar variations of L1/L2 clock (top) and L1/L5-L1/L2 clock difference (bottom)
- Reasonable modeling accuracy (3 cm / 1 cm)
- Different models required for PRN1 & 25



Other GNSS Satellites





Summary and Conclusion

- Triple frequency carrier phase combination provides evidence for thermally dependent line bias variations in GPS IIF satellites
- Apparent L1/L2 clock is affected by similar variations despite highly stable Rubidium Frequency Standard (→ all frequencies are affected)
- Need
 - independent L1/L5 clock product or
 - L1/L5-L1/L2 bias product (with e.g. 15-min sampling) or
 - Empirical L1/L5-L1/L2 model
- Problem most evident in GPS; other GNSSs are less affected (or not at all)