Absolute Code Biases Without Ionosphere Information – DCBs Without TEC Maps

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Summary:

Differential code biases (DCBs) are typically determined by co-estimating the first order ionosphere effect using the geometry-free linear combination of code measurements from two different GNSS frequencies. We developed ambiguity-free linear combinations based on the dual- or triple-frequency GPS carrier-phase and code measurements on only one GPS frequency. In this way, we can estimate code biases on a single GPS frequency. Since the datum of the GPS satellite clock corrections is defined by the ionosphere-free linear combination of the P-code measurements on L1 and L2 we can estimate these single-frequency code biases as "absolute biases" using the geometry-free approach. Our ambiguity-free linear combination removes single-frequency ambiguities, but it requires the estimation of one wide-lane ambiguity with a very large wavelength, a wavelength that is significantly larger than the size of the code biases. In addition, by forming single-differences between two GNSS satellites using measurements from one station, one can separate satellite-based from the station-based code biases. We show relations between the code biases and the narrow-lane biases in the Melbourne-Wübbena linear combination and DCBs. The same approach is extended to other multi-GNSS code observables.

Absolute Code Biases

Differential Code Bias:

$$DCB_{P_1,P_2} := AB_1 - AB_2$$

Absolute Code Bias on P_1 | Absolute Code Bias on P_2

Two-Frequency GNSS

Graphic Linear Combination:

$$LP_1 = \frac{1}{2}(P_1 + L_1) = \rho + \frac{1}{2}\lambda_1 N_1 + c\delta t - c\delta t^s + \frac{1}{2}AB_1 + \varepsilon(LP_1)$$

Iono-Free Linear Combination:

$$L_{iono\text{-}free} = \frac{f_1^2}{f_1^2 - f_2^2}L_1 - \frac{f_2^2}{f_1^2 - f_2^2}L_2 = \rho + \lambda_N N_1 + \frac{1}{2}(\lambda_W - \lambda_N)N_W + c\delta t - c\delta t^s$$

Ambiguity-free condition:

$$\kappa_1^{af}\lambda_N + \kappa_2^{af}\frac{\lambda_1}{2} := 0$$

Ambiguity-Free Linear Combination:

$$AF_1 = \rho + \frac{f_1}{f_1 - f_2}AB_1 - \underbrace{\frac{c \cdot f_2}{(f_1 - f_2)^2}}_{\lambda = 0.67\ \mathrm{m}} N_W + c\delta t - c\delta t^s$$

Geometry-Free:

$$AF_1 - P_{iono\text{-}free} = \kappa_1^{af} L_{iono\text{-}free} + \kappa_2^{af} LP_1 - P_{iono\text{-}free} = \frac{\kappa_2^{af}}{2}AB_1$$

IGS Clock Convention ("Iono-Free Clocks" based on P_1 and P_2)

Triple-Frequency GNSS

Iono-Free Linear Combinations:

$$L^{1,2}_{iono\text{-}free} = \frac{f_1^2}{f_1^2 - f_2^2}L_1 - \frac{f_2^2}{f_1^2 - f_2^2}L_2 = \rho + \lambda_N N_1 + \frac{1}{2}(\lambda_W - \lambda_N)N_W$$

$$L^{2,5}_{iono\text{-}free} = \frac{f_2^2}{f_2^2 - f_5^2}L_2 - \frac{f_5^2}{f_2^2 - f_5^2}L_5 = \rho + \lambda_{N(2,5)}N_1 - \lambda_{N(2,5)}N_W + \frac{1}{2}(\lambda_{W(2,5)} - \lambda_{N(2,5)})N_{W(2,5)}$$

Ambiguity-free condition:

$$\kappa_1^{af*}\lambda_N + \kappa_2^{af*}\lambda_{N(2,5)} := 0$$

$$L^{af*}_{iono\text{-}free} := \kappa_1^{af*}L^{1,2}_{iono\text{-}free} + \kappa_2^{af*}L^{2,5}_{iono\text{-}free}$$

$$:= \rho + \left[\frac{\kappa_1^{af*}}{2}(\lambda_W - \lambda_N) - \kappa_2^{af*}\lambda_{N(2,5)}\right]N_W + \frac{\kappa_2^{af*}}{2}(\lambda_{W(2,5)} - \lambda_{N(2,5)})N_{W(2,5)}$$

$$AF_1 = \rho - \frac{c \cdot f_2}{(f_1 - f_2)^2}N_W + \frac{f_1}{f_1 - f_2}AB_1 + c\delta t - c\delta t^s$$

Ambiguity-free condition:

$$-\frac{c \cdot f_2}{(f_1 - f_2)^2}\kappa_1^{af**} + \kappa_2^{af**}\lambda_W^{af*} := 0$$

Two-frequency Ambiguity-Free LC (previous slide)

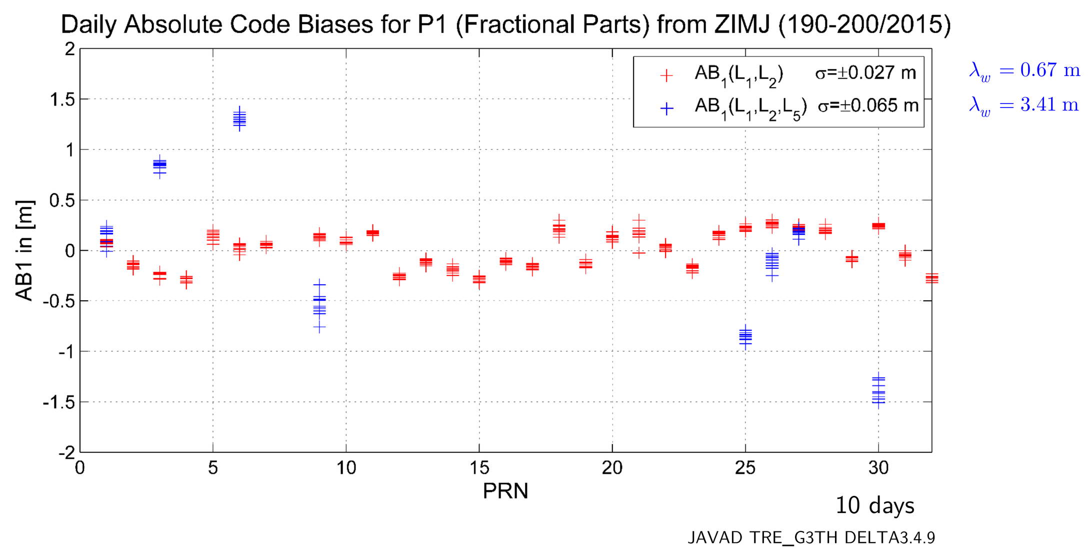
Ambiguity-Free Linear Combination:

Geometry-Free:

$$AB_1 = \frac{f_1 - f_2}{\kappa_1^{af**} f_1}\left[\left(\kappa_1^{af**}AF_1 + \kappa_2^{af**}L_3^{af*} - P_{iono\text{-}free}\right) - \underbrace{\kappa_2^{af**}\lambda^{af*}_{W(2,5)}}_{\lambda = 3.41\ \mathrm{m}}N_{W(2,5)}\right]$$

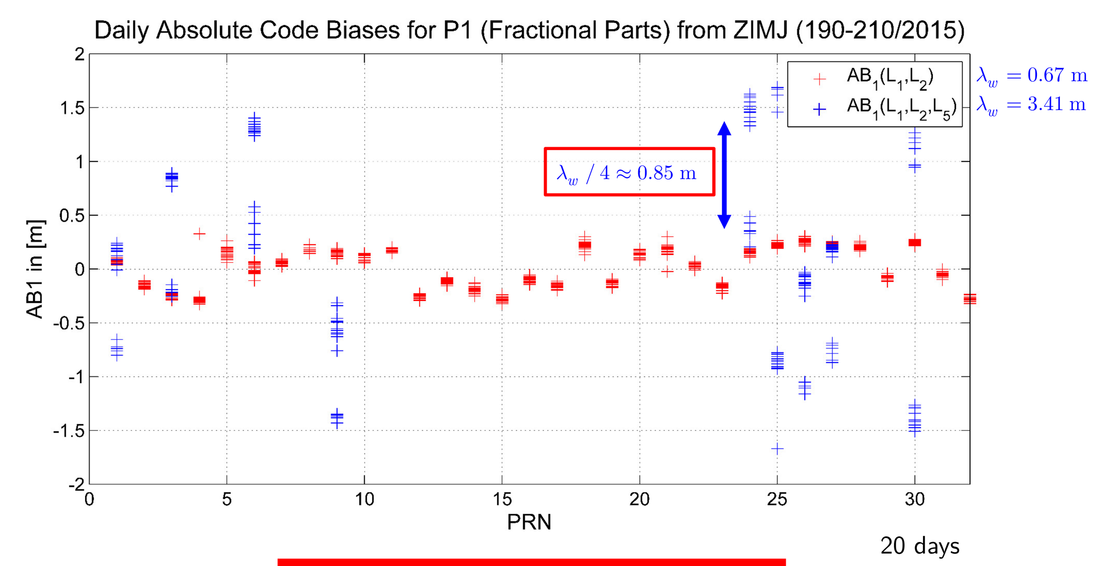
IGS Clock Convention ("Iono-Free Clocks")

Step1: Absolute Code Biases Fractional Parts



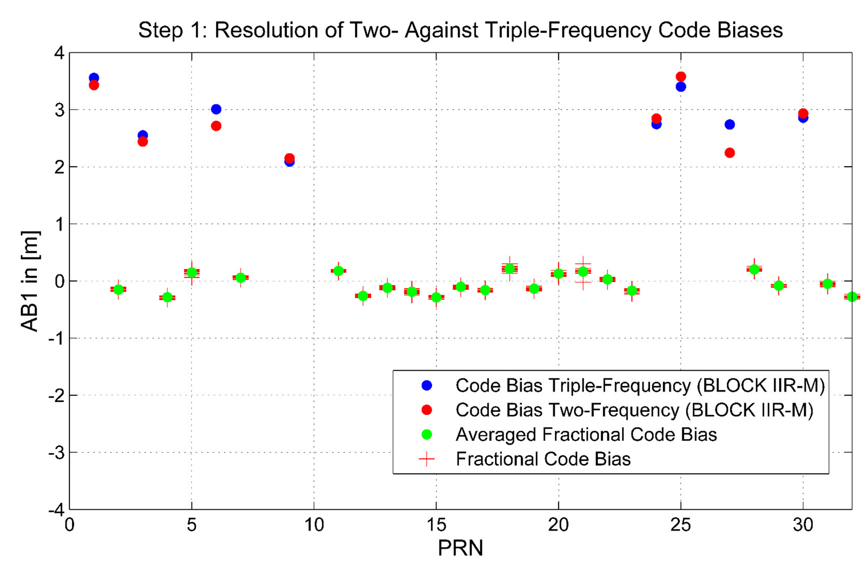
Daily estimates of absolute code biases show very low noise for two- and triple-frequencies with wavelengths of 0.67 m and 3.41 m respectively.

Absolute Code Biases ¼–Ambiguities



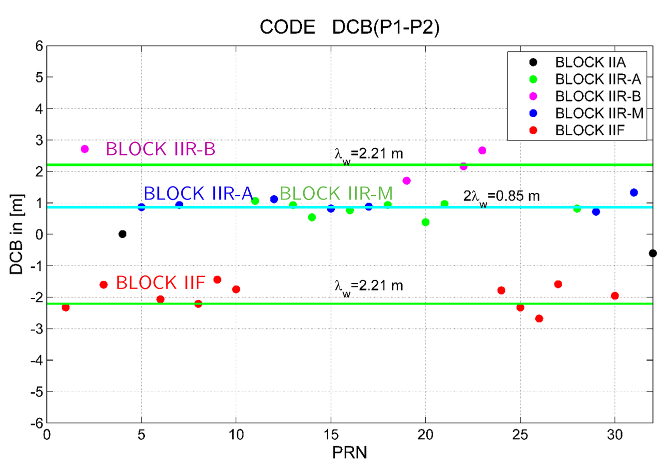
Very Low Noise Level!
Fractional parts with L5 can also be used to fix 1/4–ambiguities

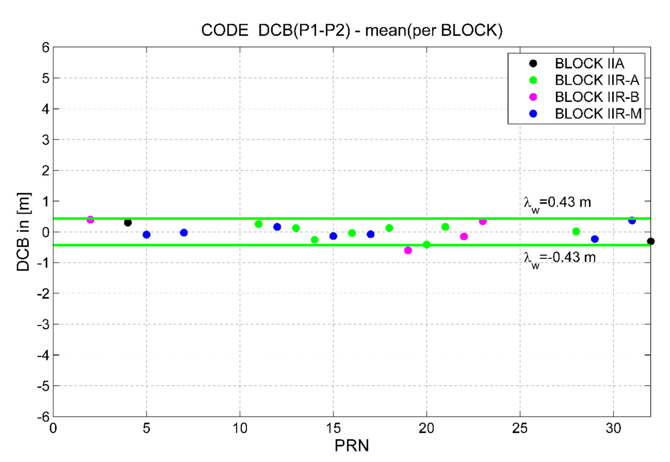
Step 2: Resolution of Code Biases with L5



Triple-code biases with large wavelength are used as a reference for the two-frequency data

CODE DCBs





Resolution of Code Biases (without L5)

- **DCBs between satellites within the same GPS BLOCK** are small in size: 32 SVs
- **DCBs between GPS BLOCKs** are small in size: IIR-A/IIR-M and IIR-B/IIF

Relationship Between Absolute Code Biases and DCBs

Differential Code Bias:

$$DCB_{P_1,P_2} := AB_1 - AB_2$$

Absolute Code Bias on P_1 | Absolute Code Bias on P_2

IGS Clock Convention:
("Iono-Free Clocks" based on P_1 and P_2)

$$P_{iono\text{-}free} = \frac{f_1^2}{f_1^2 - f_2^2}P_1 - \frac{f_2^2}{f_1^2 - f_2^2}P_2$$

Effect of DCB_{P_1,P_2} is Zero

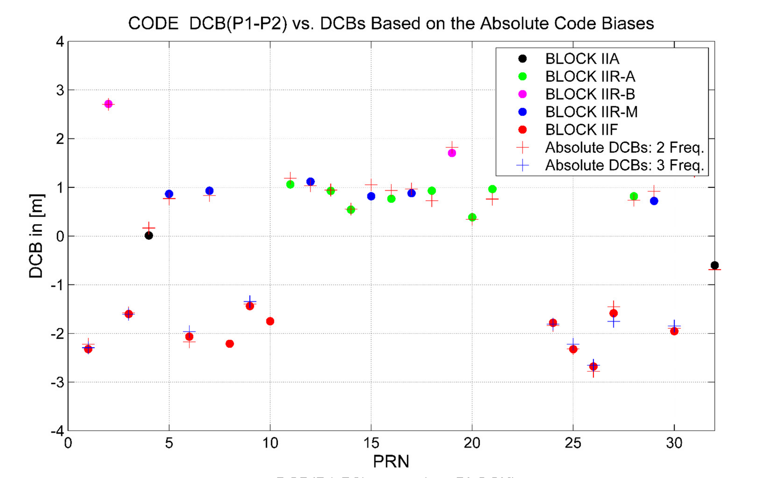
Ionosphere-free condition:

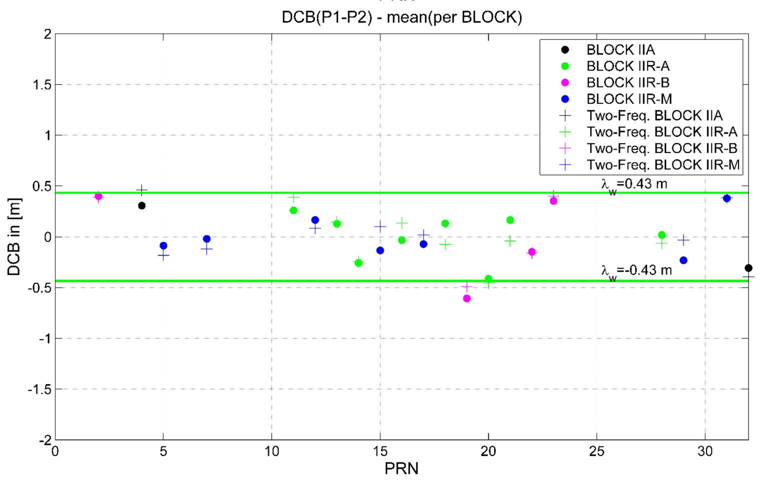
$$\frac{f_1^2}{f_1^2 - f_2^2}AB_1 - \frac{f_2^2}{f_1^2 - f_2^2}AB_2 = 0 \;\rightarrow\; AB_2 = \frac{f_1^2}{f_2^2}AB_1 \;\rightarrow\; DCB_{P_1,P_2} = -\frac{f_1^2 - f_2^2}{f_2^2}AB_1$$

$\lambda_w = 0.43\ \mathrm{m} / \sigma = \pm 0.017\ \mathrm{m}$
$\lambda_w = 2.21\ \mathrm{m} / \sigma = \pm 0.042\ \mathrm{m}$

$\lambda_w = 0.67\ \mathrm{m} / \sigma = \pm 0.027\ \mathrm{m}$
$\lambda_w = 3.41\ \mathrm{m} / \sigma = \pm 0.065\ \mathrm{m}$

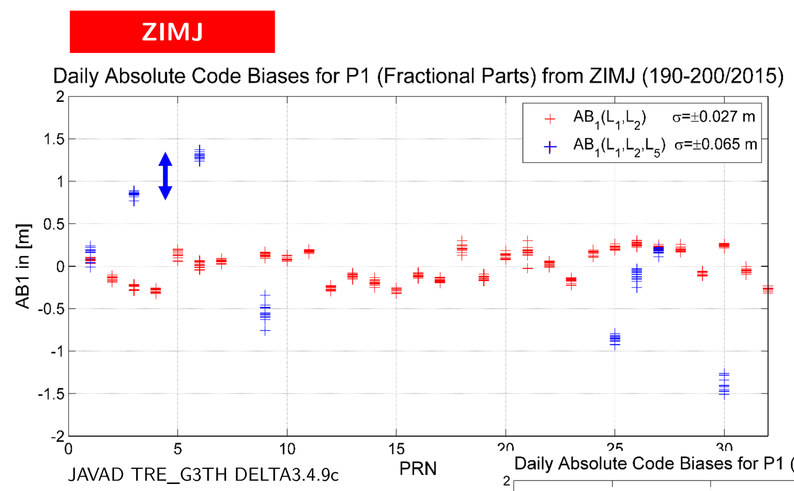
CODE DCBs vs. DCBs Based on the Absolute Code Biases





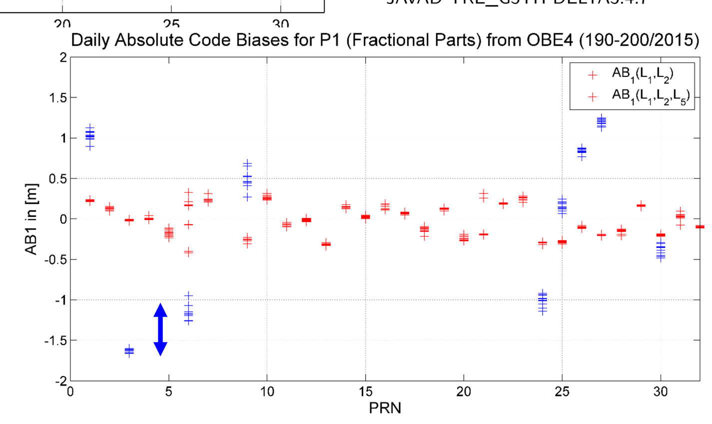
Fractional Parts

ZIMJ



OBE4

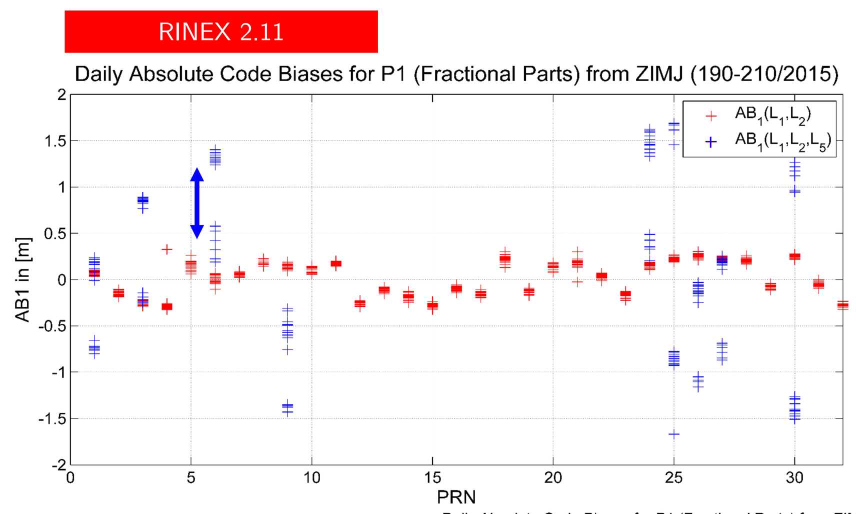
JAVAD TRE_G3TH DELTA3.4.7



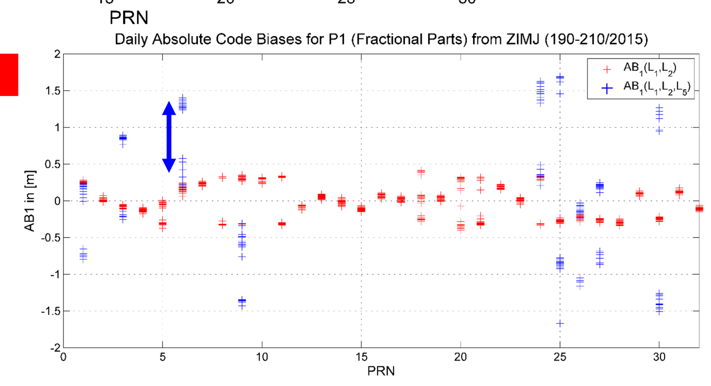
Triple-frequency ABs are shifted between stations (as expected), but relative differences between satellites are preserved!

Absolute Code Biases: ¼–Ambiguities

RINEX 2.11



RINEX 3.02



Conclusions

- **Absolute code biases and associated DCBs are called "absolute" because they do not require TEC information and are defined against the IGS clock Convention ("P3 clocks")**
- **Triple-Frequency Ambiguity-Free Linear** combinations offers a very large wavelength of $\lambda_w = 3.41\ \mathrm{m}$ and a very low noise level $\sigma = \pm 0.065\ \mathrm{m}$ (per ambiguity) to detect and estimate:
  - wide-lane ambiguities (two- and triple-frequency)
  - ¼-ambiguities
  - absolute code biases and DCBs
- 1/3 of GPS constellation (10 SVs) offers third GPS frequency (L5) and, thus, the straightforward estimation of absolute code biases and associated DCBs
- Absolute code biases estimated using two-frequency ambiguity-free LC for GPS BLOCK-IIF satellites, show similar results compared to the triple-frequency LC on the same satellite and can be used for the resolution of code biases on two-frequencies (0.67 m in 3.41 m). In this way, the noise level of the estimated code biases is reduced by 50% (from 6 cm to 3 cm STD per satellite pass).
- Resolution of Code Biases (without L5):
  - Max. Size of the Code Bias = 3.41 m (with L5)
  - Max. Size of the Code Bias = 0.67 m (without L5)
    – DCBs between satellites within the same GPS BLOCK are small in size: 32 SVs
    – DCBs between several GPS BLOCKs are small in size: IIR-A/IIR-M and IIR-B/IIF
- For those GPS satellites with only two-frequencies, fractional parts of the estimated code biases are consistent to satellites of different GPS BLOCKs and integer ambiguities can be estimated with a wavelength of $\lambda_w = 0.43\ \mathrm{m}$ and a very low noise level of $\sigma = \pm 0.017\ \mathrm{m}$

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