Determination of multi-GNSS pseudo-absolute code biases and verification of receivers tracking technology

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Outline

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What are code biases?

Code biases are time delays within satellites and receiver caused by their hardware.

$$P_{1k}^i = \rho_k^i + I_k^i + T_k^i + c(\Delta \delta_k + B_{1k}) - c(\Delta \delta^i + B_{1k}^k)$$
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Code biases are dependent on (but not only):
- Frequency
- Signal type
- Receiver tracking technologies
- GNSS system
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**Observable-specific Signal Biases (OSB)**

Code biases are dependent on (but not only):

- Frequency
- Signal type
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- GNSS system
How to estimate code biases?

Methods

- Direct estimation (using ionosphere model)
- Clock analysis (ionosphere-free linear combination)
- Ionosphere analysis (geometry-free linear combination)
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→ pseudo-absolute Observable-specific Signal Biases (OSB)
GPS/GLO/GAL/BDS OSB’s

Input data

- Estimation based on over 250 IGS and MGEX stations
- RINEX3 favored over RINEX2
- Analyzed data period: November 2016
GPS/GLO/GAL/BDS OSB’s

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Observables

<table>
<thead>
<tr>
<th>System</th>
<th>C1C</th>
<th>C1W</th>
<th>C2C</th>
<th>C2W</th>
<th>C2L</th>
<th>C2S</th>
<th>C5Q</th>
<th>C5X</th>
<th>C7Q</th>
<th>C8Q</th>
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<tbody>
<tr>
<td>GPS</td>
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<td>C1C</td>
<td>C1P</td>
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<tr>
<td>GALILEO</td>
<td>C1C</td>
<td>C1X</td>
<td></td>
<td>C5Q</td>
<td>C5X</td>
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<tr>
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<td>C2I</td>
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<td>C7I</td>
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</tr>
</tbody>
</table>

Astronomical Institute, University of Bern
GPS Code Biases (OSB)

![Graph showing GPS Code Biases (OSB)](image-url)
GLONASS Code Biases (OSB)

![Graph showing GLONASS Code Biases](image)
GLONASS Code Biases (OSB)

GLONASS OSB: Sorted according to their frequency number
GLONASS OSB: Sorted according to their launch date
GALILEO Code Biases (OSB)

![Graph showing GALILEO Code Biases](image URL)
Comparison of differential code biases

- DLR bias solution (MGEX) for Jan-Mar 2016 [Montenbruck et. al, 2014]
- CODE solution for November 2016
- CODE DCB aligned to DLR solution
BeiDou Code Biases (OSB)

- Code Bias [ns]
  - C405
  - C407
  - C408
  - C409
  - C410
  - C412
  - C413
  - C415
  - C417
  - C2I
  - C6I
  - C7I

- Formal Error [ps]
  - C405
  - C407
  - C408
  - C409
  - C410
  - C412
  - C413
  - C415
  - C417
Code pseudo-range equations:

\[ P_{1k}^i = \rho_k^i + I_k^i + T_k^i + c(\Delta \delta_k + B_{1k}) - c(\Delta \delta^i + B_{1k}^i) \]

\[ P_{2k}^i = \rho_k^i + \frac{f_1^2}{f_2^2} I_k^i + T_k^i + c(\Delta \delta_k + B_{2k}) - c(\Delta \delta^i + B_{2k}^i) \]
Receiver Tracking Technology Verification

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Geometry free linear combination (L1-L2):
Receiver Tracking Technology Verification

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Geometry free linear combination (L1-L2): known unknown

\[
P_{LCk}^i = \left(1 - \frac{f_1^2}{f_2^2}\right) I_k^i + 1 \cdot B_{C1W_k} - 1 \cdot B_{C2W_k} - 1 \cdot B_{C1W} + 1 \cdot B_{C2W}
\]
**Receiver Tracking Technology Verification**

**Code pseudo-range equations:**

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Multiplier (one multiplier per observation type and system → \( m_{C1W}^S \))
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Multiplier (one multiplier per observation type and system → \( m_{C1W}^S \))

\[ P_{LCk}^i = \cdots - m_{C1W}^S \cdot B_{C1W}^i - m_{C1C}^S \cdot B_{C1C}^i + m_{C2W}^S \cdot B_{C2W}^i + m_{C2C}^S \cdot B_{C2C}^i \]
GPS Multipliers

\[ \kappa_1 \]

\[ \kappa_2 \]
BDS Multipliers

![Graph showing BDS Multipliers](image)
Conclusion

Multi-GNSS Code Biases

- Combination on NEQ level, clock and ionosphere analyzes and long time combination
- One set of biases for all purposes
- Fully compatible with differential mode
- Very flexible
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Receiver Tracking Technology Verification

- Based on OSB multiplier estimation (multi-GNSS capable)
- Multiplier estimation operationally done by CODE
- Multiplier depend on the satellite patterns
- GALILEO C5X patterns need further investigations, results show that they are not pure C5Q signal (RINEX3: $C_{5X} = C_{5Q} + C_{5I}$)