Effect of PCOs on phase biases

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Satellite PCO model

- Classical model is to estimate frequency-independent satellite PCO by IGS ACs
  - Earlier GPS, GLONASS satellites
- Spacecraft manufacturers tend to provide trustworthy frequency-specific PCO calibrations
  - GPS Block III, Galileo, BDS satellites

<table>
<thead>
<tr>
<th>Satellite</th>
<th>X</th>
<th>Y</th>
<th>Z</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1</td>
<td>394.00</td>
<td>0.00</td>
<td>1247.10</td>
</tr>
<tr>
<td>L2</td>
<td>394.00</td>
<td>0.00</td>
<td>1247.10</td>
</tr>
</tbody>
</table>

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<thead>
<tr>
<th>Satellite</th>
<th>X</th>
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<tbody>
<tr>
<td>L1</td>
<td>3.80</td>
<td>-18.10</td>
<td>1082.20</td>
</tr>
<tr>
<td>L2</td>
<td>3.10</td>
<td>-16.20</td>
<td>590.30</td>
</tr>
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Effect of satellite PCOs on phase bias

- Frequency-specific PCO effect cannot cancel in the Melbourne-Wübbena combination

\[ L_{MW} = \frac{f_1 L_1 - f_2 L_2}{f_1 - f_2} - \frac{f_1 P_1 + f_2 P_2}{f_1 + f_2} \]  \(\leftarrow\) Melbourne-Wübbena combination

\[ S_{MW} = \frac{f_1 s_1 - f_2 s_2}{f_1 - f_2} - \frac{f_1 s_1 + f_2 s_2}{f_1 + f_2} = \frac{2 f_1 f_2}{f_1^2 - f_2^2} (s_1 - s_2) \]  \(\leftarrow\) Effect of satellite PCO

- \( S_{MW} \) become zero only when PCO (i.e., \( S_1 \) and \( S_2 \)) are equal on the two frequencies
Effect of satellite PCOs on phase bias

- The PCO effect on the Melbourne-Wübbena ranges from 0.1 to 2.3 cycles
Effect of satellite PCOs on phase bias

- The satellite PCO effects are mostly absorbed into wide-lane phase biases

![Graph showing residuals of MW bias (cycle) over Day of year 2020 for different satellite PCO corrections: PCO corrected (TUG and EMR), PCO uncorrected (COD and GRG).]
Effect of satellite PCOs on phase bias

- Such phase bias products cannot be applied to uncombined PPP-AR
  - Wide-lane ambiguities in uncombined PPP are computed by raw ambiguity estimates
- **Case study**: uncombined PPP-AR at 15 stations for day 4, 2020 using Wuhan phase bias products with/out PCO corrections

<table>
<thead>
<tr>
<th></th>
<th>Biases without PCO corrections</th>
<th>Biases with PCO corrections</th>
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</thead>
<tbody>
<tr>
<td>GPS fixing rate (%)</td>
<td>98.48/93.62</td>
<td>98.46/93.56</td>
</tr>
<tr>
<td>Galileo fixing rate (%)</td>
<td>71.53/97.15</td>
<td>98.96/97.84</td>
</tr>
</tbody>
</table>
Effect of receiver PCOs on phase bias

- The receiver PCO effects are generally much less significant than the satellite PCO
  - Some exceed 0.2 cycles
- The receiver PCO effect is highly elevation and azimuth dependent

Data source: igsR3_2135.atx
Approximate mitigation of PCO effects

- Approximate the true satellite PCO effect by the difference of frequency-specific $z$-PCO:

$$s_{MW} = \frac{2 f_1 f_2}{f_1^2 - f_2^2} \left( s_1 - s_2 \right) \approx \frac{2 f_1 f_2}{f_1^2 - f_2^2} \left( z_1 - z_2 \right)$$

Data source: igsR3_2135.atx

- The residuals of PCO effects after approximate corrections
Approximate mitigation of PCO effects

- The interoperability between wide-lane biases from different ACs can be recovered
- The consistency among the corrected wide-lane biases are less than 0.03 cycles
Summary

• The frequency-specific PCO effect cannot cancel in the Melbourne-Wübbena combination
  • Phase biases without correcting for PCO cannot be applied to uncombined PPP-AR
  • The interoperability between phase biases from different ACs might be corrupted
• The PCO effect on wide-lane biases can be mitigated by a z-PCO approximation strategy
• ACs are recommended to correct for PCO effects fully in their every observation modeling with no exception
  • For a rigorous processing, receiver PCO effects should also be corrected though