Evaluation of the LEO based slant TEC quality

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Many low Earth orbit (LEO) satellites were/will be launched with GPS receiver for precise orbit determination (POD) purpose [CHAMP/GRACE/COSMIC/SAC-C/TerraSAR-X/Metop-A/Jason1,2,...], some have occultation observation.

LEO slant TEC observations especially occultation observations have shown great potential in ionospheric data assimilation (see jobs based on JPL GAIM model by Pi et al., Komjathy et al., etc) for better nowcast, forecast, and ionospheric drivers estimation because of:

- Global coverage
- Higher vertical resolution

TEC data quality (error&error covariance) is a key point for the data assimilation.
GPS radio link trajectories over 300 km altitude of COAMIC (blue), CHAMP (red), and GRACE-A (green) satellites during ~100 minutes.
So many POD slant TEC observations make the 3-D imaging of topside ionosphere/plasmasphere possible for the first time [see Mitchell and Spencer, 2011, Radio Sci.].


Big TEC error will make the data useless because of the relatively smaller amplitude of TEC in topside ionosphere and plasmasphere.
CDAAC slant TEC calculation

- Cycle Slip Correction
- Multipath Calibration

L1, L2

Relative TEC

P1, P2

Absolute TEC

Leveled TEC

Update TEC

GPS DCB calibrated by CODE

Receiver DCB Estimation
✓ Multipath Estimation: Statistical analysis on original observations using a multipath combination.
✓ Multipath is very stable versus time.
Multipath can be complicated, depend on the satellite surface design, e.g., COSMIC, Solar array Drive angle dependency.
Leveling Error:

\[ \sqrt{\sum_{i=1}^{n} (T_{EC_L} - T_{EC_p})^2} \]

COSMIC FM2 Leveling Error

COSMIC FM2

a: antenna 0

b: antenna 1

Leveling Example
Differential Code Bias (DCB) estimation:

- Spherical Symmetry assumption
- Constant assumption during one day
- Least Square Fit

\[(TEC_1 + DCB) \times m(\varepsilon_1) = (TEC_2 + DCB) \times m(\varepsilon_2)\]

DCB RMSE estimation:

\[RMSE = \sqrt{\frac{\sum_{i=1}^{n} (DCB_i - \bar{DCB})^2}{n}}\]
Comparison of COSMIC and CHAMP POD bias and RMSE:

COSMIC FM2

CHAMP

-10
-15
-20
-25
-30
-35
-40

Antenna 0  Antenna 1

DCC (tecu)


Year

DCC RMSE

3
2
1
0

0.5
1
2
3

CHAMP POD DCC

Year

CHAMP DCC RMSE
Possible reason: receiver temperature variations influence the daily constant DCB assumption.
Test the temperature effect on DCB by COSMIC data.
CHAMP POD DCB long term drift: influence from the environment temperature and solar radiation?
TEC Quality evaluation 1: Compare the processed TEC with original pseudo range TEC

- Assume the multipath and pseudo range error are unbiased

10 days COSMIC statistical results:
Mean difference: ~0.05 tecu, unbiased
TEC Quality evaluation 2: Compare the colocated TEC during the first stage of COSMIC

Statistical of difference between colocated TEC:

- Mean difference: 0.12 tecu
- RMSE: 1.36 tecu
TEC Quality evaluation 3: Compare with empirical model

- Ionosphere: IRI2007; Plasmasphere: Gallagher H+ model.
Comparison of POD TEC quality for multi-missions:

<table>
<thead>
<tr>
<th>Mission</th>
<th>Inclination (°)/Altitude (km)/Mass (kg)</th>
<th>GPS Receiver type</th>
<th>Operation years</th>
<th>POD antenna normal</th>
<th>Multipath RMSE (C/A, m)</th>
<th>Leveling error mean (tecu)</th>
<th>DCB RMSE mean (tecu)</th>
</tr>
</thead>
<tbody>
<tr>
<td>COSMIC FM4</td>
<td>72/700-800/70</td>
<td>Blackjack</td>
<td>2006-</td>
<td>75° off the zenith</td>
<td>0.30</td>
<td>0.12</td>
<td>0.69</td>
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<tr>
<td>CHAMP</td>
<td>87.3/460-30/522</td>
<td>Blackjack</td>
<td>2000-2009</td>
<td>zenith</td>
<td>0.20</td>
<td>0.19</td>
<td>0.11</td>
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<td>GRACE-A</td>
<td>89/495/432</td>
<td>Blackjack</td>
<td>2002-</td>
<td>zenith</td>
<td>0.42</td>
<td>0.31</td>
<td>0.14</td>
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<tr>
<td>SAC-C</td>
<td>98.2/710/467</td>
<td>Blackjack</td>
<td>2000-</td>
<td>zenith</td>
<td>0.42</td>
<td>0.60</td>
<td>0.87</td>
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<tr>
<td>TerraSAR-X</td>
<td>97.44/514/1230</td>
<td>IGOR</td>
<td>2007-</td>
<td>zenith</td>
<td>0.29</td>
<td>0.15</td>
<td>0.09</td>
</tr>
<tr>
<td>Metop-A</td>
<td>98.7/820/4093</td>
<td>GRAS</td>
<td>2006-</td>
<td>zenith</td>
<td>0.15</td>
<td>0.09</td>
<td>0.16</td>
</tr>
</tbody>
</table>
Conclusion:

✓ **Multipath:**
  - Depends on the satellite design (size, receiver, antenna, surface)
  - Stable with respect to the time

✓ **Leveling error and DCB error:**
  - Depends on the satellite
  - **Satellite thermal status** [receiver cpu temperature, environment temperature, solar radiation] can influence the DCB and DCB estimation error
  - The accuracy of the LEO slant TEC can be thought lying 1-3 tecu, depends on the satellite mission

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