Empirical Modeling of Solar Radiation Pressure Forces Affecting GPS Satellites

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• Motivation

• Empirical Solar Radiation Pressure Modeling

• Internal Metrics
  Ambiguity Resolution, Orbit Overlaps

• External Metrics
  Satellite Laser Ranging

• Orbit Prediction

• Conclusion

June 2009 to June 2010
June - Nov 2010
Terminology

Precise Orbit Determination (POD)

Solar Radiation Pressure (SRP)

• **SRP Model (today’s focus!):**
  
  A priori representation of SRP forces acting on a spacecraft

• **SRP Strategy:**
  
  Approach to estimating SRP forces during POD
  
  Does not explicitly require an a priori SRP model
Motivation

International GNSS Service (IGS)

Final Orbits (AC solutions compared to IGS Final)

Weighted RMS [mm]

Time [GPS weeks]

http://acc.igs.org/

• Based on 4.5 years of precise orbits (Jan 1998 – June 2002)
• Truncated Fourier series - coefficients combined from 10-day fits
• β-angle dependent SX₂ and CY₁ terms
• Block specific models (IIA/IIR)

\[
F_x = \frac{k10^{-5}(AU/r)^2}{m \sum_{i=1,2,3,5,7} SX_i \sin(iEPS)} \\
F_y = \frac{CY_0 + 10^{-5}(AU/r)^2}{m \sum_{i=1,2} CY_i \cos(iEPS)} \\
F_z = \frac{k10^{-5}(AU/r)^2}{m \sum_{i=1,3,5} CZ_i \cos(iEPS)}
\]

k  dimensionless scale factor
m  spacecraft mass (kg)
EPS  Earth-Probe-Sun angle
• GNSS Solar Pressure Model (GPS & GLONASS)
• More rigorous combination of coefficients from 10-day fits
• Improved modeling of $\beta$-angle dependent terms $S_{X_2}$ and $C_{Y_1}$
• For GPS - 13.5 years of precise orbits (Jan 1997 – May 2010)
• Separate GPS models for:
  IIA (non-eclipsing only)
  IIR-A & IIR-B (excluding GPS43 & 46)
  IIR-A & IIR-B (GPS43 & GPS46 only)
  IIR-M
Daily orbit & clock solutions computed from:

- GSPM04
- GSPM10

across the period June 2009 to June 2010.

Identical input data, software (GIPSY-OASIS) and strategies
Ambiguity Resolution

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<tr>
<th></th>
<th>Mean</th>
<th>1-σ</th>
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<tbody>
<tr>
<td>GSPM04</td>
<td>73.0</td>
<td>1.4</td>
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<tr>
<td>GSPM10</td>
<td>78.6</td>
<td>1.4</td>
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Values in %
Ambiguity Resolution

% NL DD

Centcycles from an Integer

# to fix

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<tr>
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<th>GSPM04</th>
<th>GSPM10</th>
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<td>to fix</td>
<td>55836681</td>
<td>55828557</td>
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</table>
Orbit Overlaps

**Maximum** (across available satellites) 1D RMS values of day-to-day overlap differences.

**Median** (across available satellites) 1D RMS values of day-to-day overlap differences.

Non-eclipsing satellites only

<table>
<thead>
<tr>
<th></th>
<th>GSPM04</th>
<th>GSPM10</th>
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<tbody>
<tr>
<td><strong>Maximum</strong></td>
<td>2.33</td>
<td>2.28</td>
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<tr>
<td><strong>Median</strong></td>
<td>1.31</td>
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Values in cm

Satellite Laser Ranging

 SVN36

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<th>IGS</th>
<th>GSPM04</th>
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<tr>
<td>Mean</td>
<td>16.0</td>
<td>16.4</td>
<td>16.1</td>
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<tr>
<td>Standard Deviation</td>
<td>39.4</td>
<td>24.7</td>
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Orbit Prediction

Values in cm

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<tr>
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<th>GSPM04</th>
<th>GSPM10</th>
<th>% Improved</th>
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<tbody>
<tr>
<td>IIA Non-Eclipsing</td>
<td>73.6</td>
<td>57.8</td>
<td>21.5</td>
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<tr>
<td>IIR Non-Eclipsing</td>
<td>52.5</td>
<td>40.3</td>
<td>23.2</td>
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<tr>
<td>IIR Eclipsing</td>
<td>250.7</td>
<td>233.0</td>
<td>7.1</td>
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4th day prediction-error 3D RMS
Non-eclipsing GPS IIR 4\textsuperscript{th} day prediction error difference by beta angle (GSPM04 – GSPM10). Positive values indicate improvement from GSPM10.
Conclusions

- GSPM10 - 14 years of data, models for IIA, IIR-A/B, IIR-M
- Assessing orbit accuracy is becoming increasingly demanding
- Orbit overlaps and satellite laser ranging are capable of differentiating the GSPM solutions
- GSPM10 model performance strongly supported in GIPSY by:
  - Ambiguity resolution statistics
  - Orbit prediction (better sampling and β-angle dependency)
Future Work

- IIA eclipsing model
- Iterate as more data becomes available
- IIF
- GSPM10 update for GLONASS due to new attitude model (Weiss et al., AGU 2010, poster)