Empirical Modeling of Solar Radiation Pressure Forces Affecting GPS Satellites

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Outline

- Motivation
- Empirical Solar Radiation Pressure Modeling
- Internal Metrics
  - Ambiguity Resolution, Orbit Overlaps
- External Metrics
  - Satellite Laser Ranging

June 2009 to June 2010

- Orbit Prediction

June - Nov 2010

- Conclusion

Terminology

Precise Orbit Determination (POD)

Solar Radiation Pressure (SRP)

- **SRP Model (today's focus!):**

  A priori representation of SRP forces acting on a spacecraft

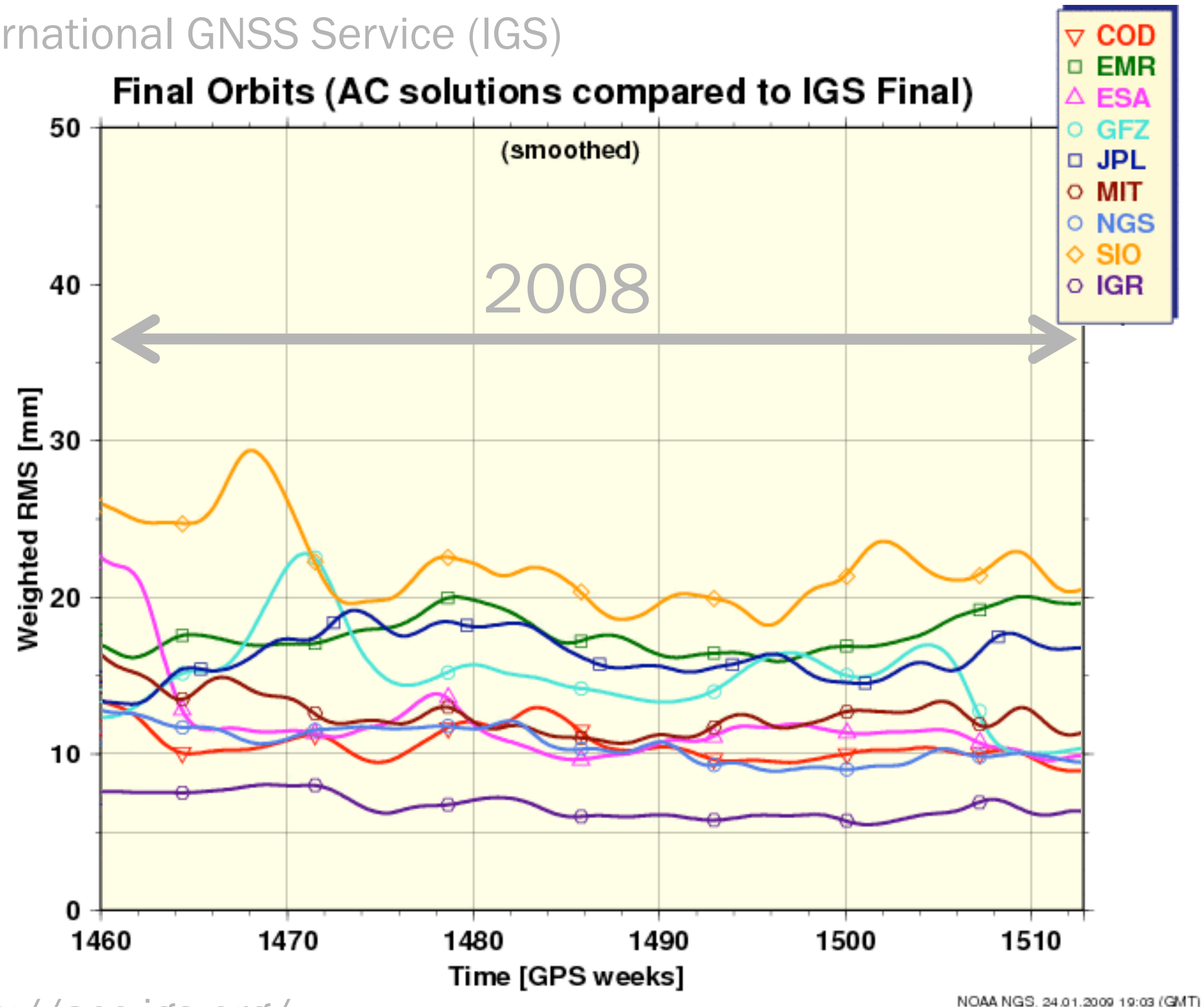
- SRP Strategy:

  Approach to estimating SRP forces during POD

  Does not explicitly require an a priori SRP model

Motivation

International GNSS Service (IGS)



http://acc.igs.org/

GSPM04

- GPS Solar Pressure Model - Bar-Sever & Kuang (2004, 2005)
- Based on 4.5 years of precise orbits (Jan 1998 – June 2002)
- Truncated Fourier series - coefficients combined from 10-day fits
- β-angle dependent SX_2 and CY_1 terms
- Block specific models (IIA/IIR)

$$F_x = \frac{k 10^{-5} (AU/r)^2}{m \sum_{i=1,2,3,5,7} SX_i \sin(iEPS)}$$

$$F_y = \frac{CY_0 + 10^{-5} (AU/r)^2}{m \sum_{i=1,2} CY_i \cos(iEPS)}$$

$$F_z = \frac{k 10^{-5} (AU/r)^2}{m \sum_{i=1,3,5} CZ_i \cos(iEPS)}$$

k dimensionless scale factor
m spacecraft mass (kg)
EPS Earth-Probe-Sun angle

GSPM10

- GNSS Solar Pressure Model (GPS & GLONASS)
- More rigorous combination of coefficients from 10-day fits
- Improved modeling of β-angle dependent terms SX_2 and CY_1
- For GPS - 13.5 years of precise orbits (Jan 1997 – May 2010)
- Separate GPS models for:

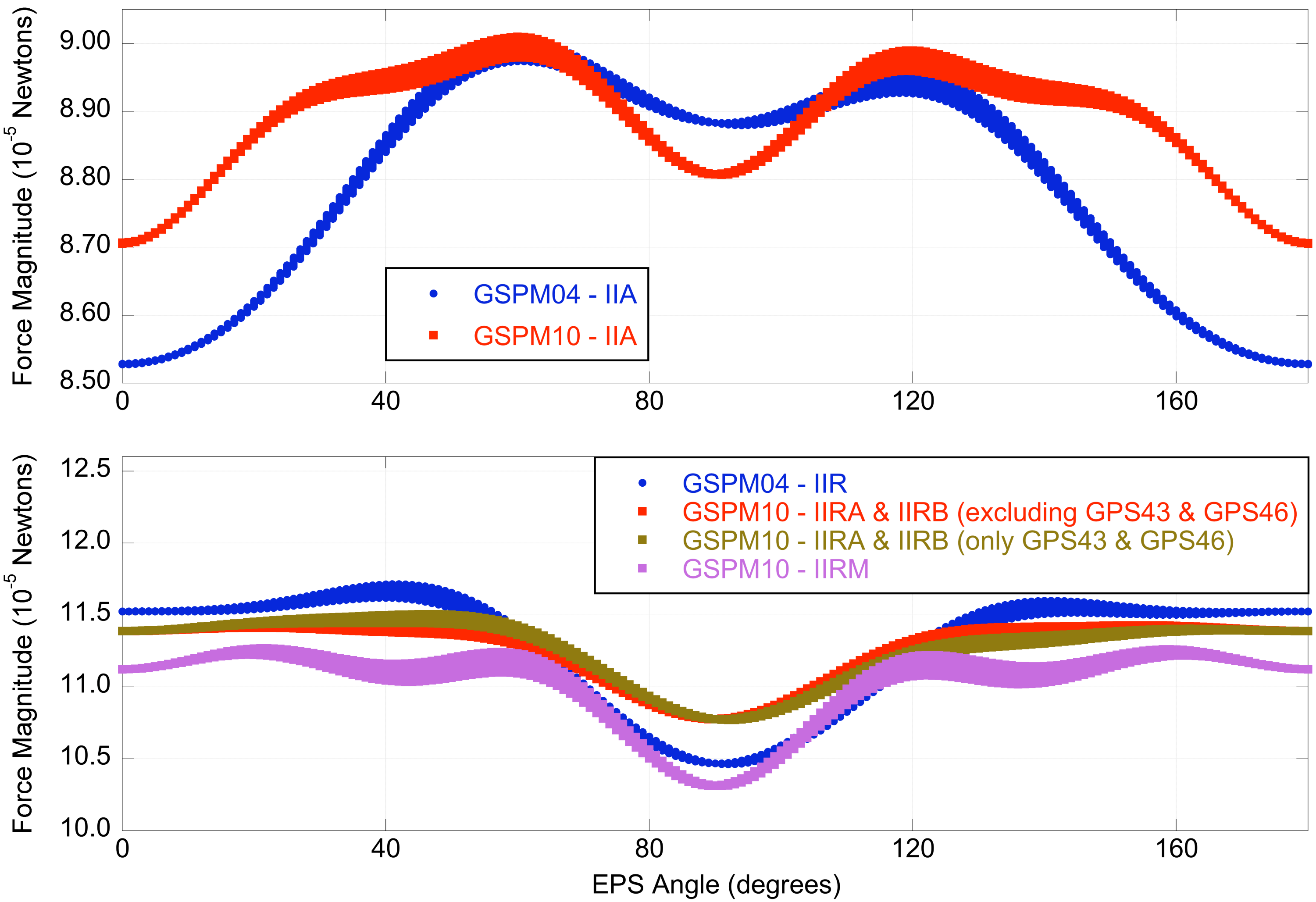
  IIA (non-eclipsing only)

  IIR-A & IIR-B (excluding GPS43 & 46)

  IIR-A & IIR-B (GPS43 & GPS46 only)

  IIR-M

Model Comparison



POD Results

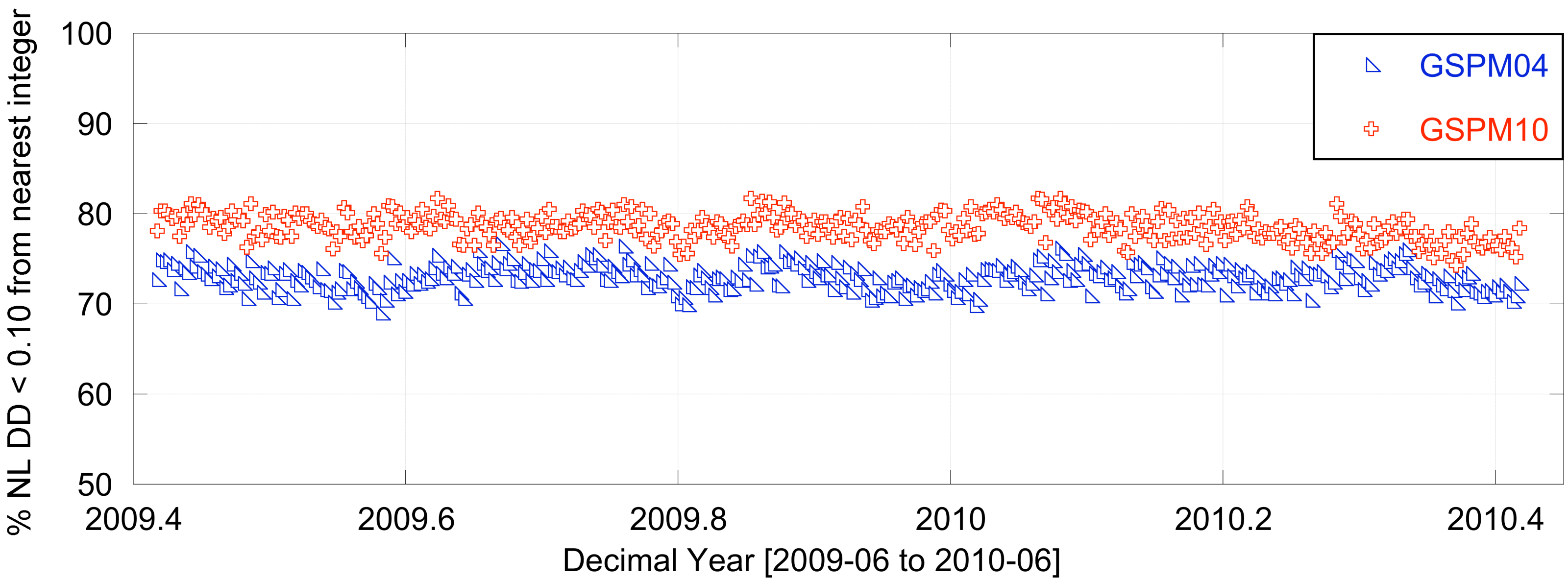
Daily orbit & clock solutions computed from:

- GSPM04
- GSPM10

across the period June 2009 to June 2010.

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

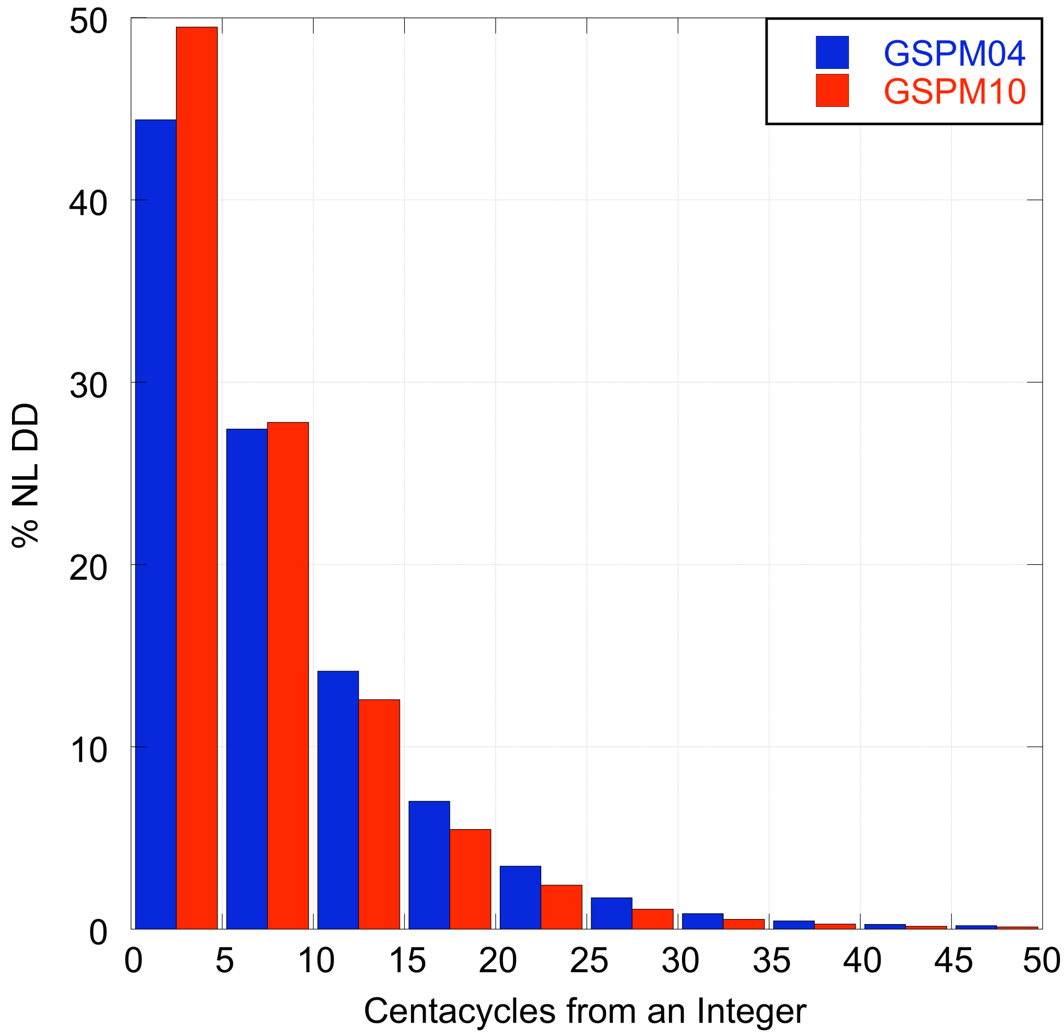
Ambiguity Resolution



	Mean	1-σ
GSPM04	73.0	1.4
GSPM10	78.6	1.4

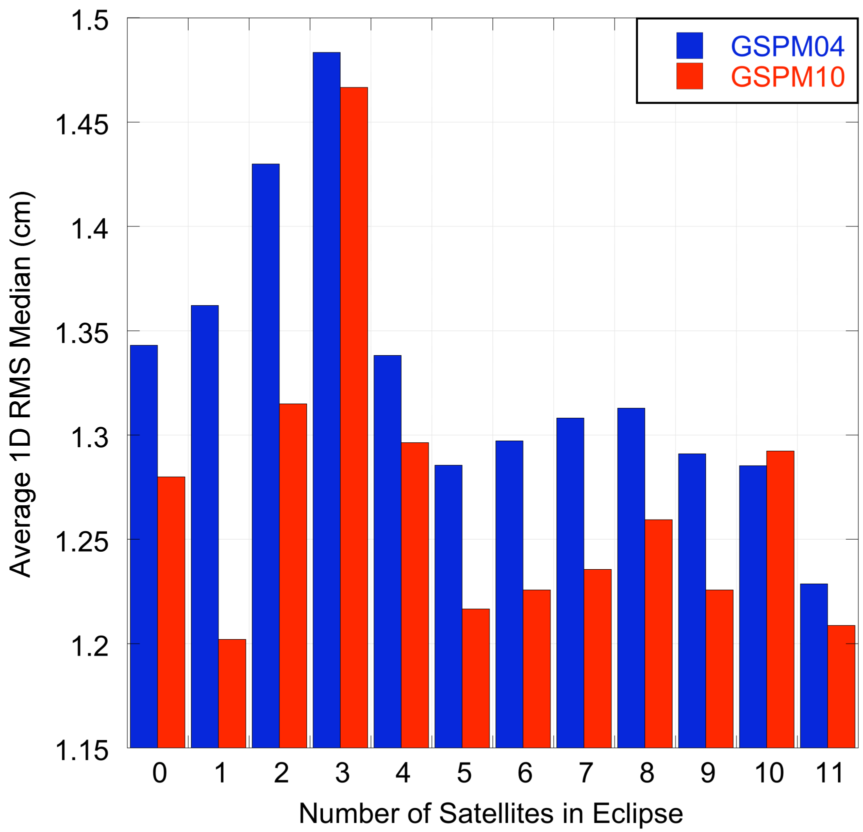
Values in %

Ambiguity Resolution



	# to fix
GSPM04	55836681
GSPM10	55828557

Orbit Overlaps



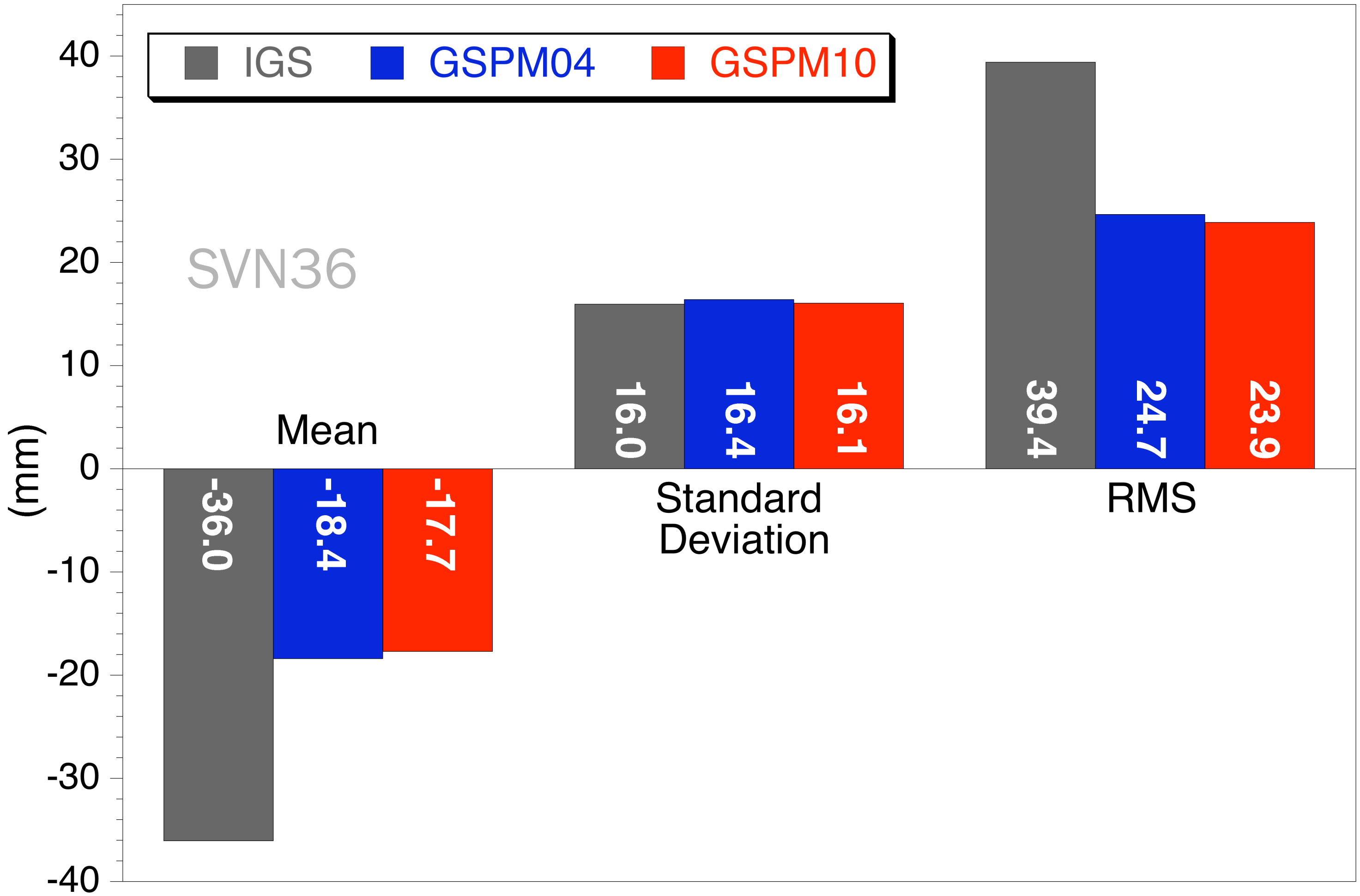
Maximum (across available satellites) 1D RMS values of day-to-day overlap differences.

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

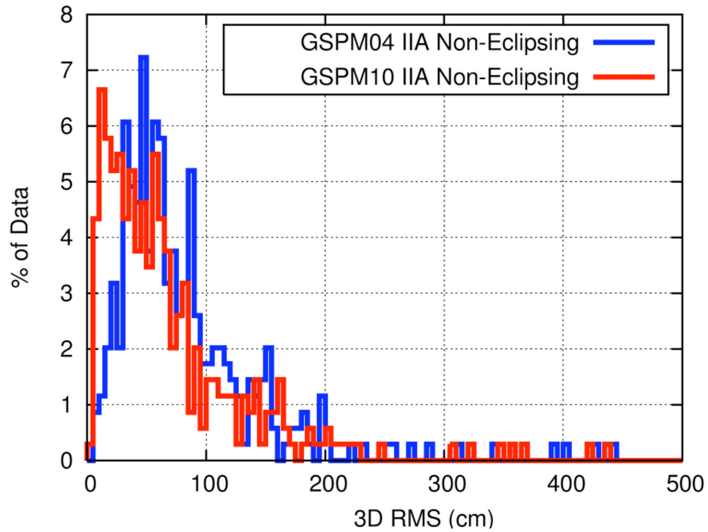
Non-eclipsing satellites only	GSPM04 Mean	GSPM10 Mean
Maximum	2.33	2.28
Median	1.31	1.25

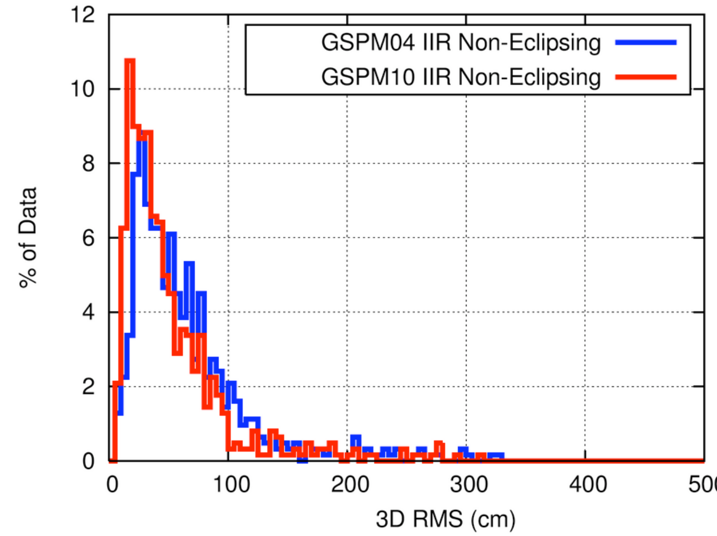
Values in cm

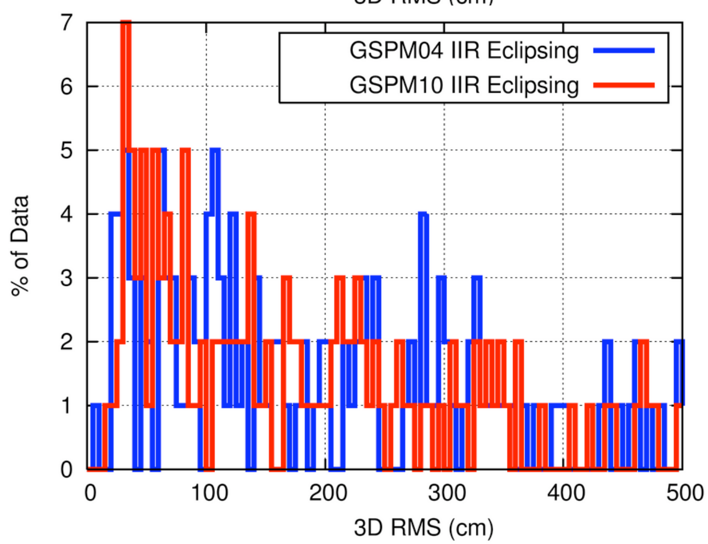
Satellite Laser Ranging



Orbit Prediction







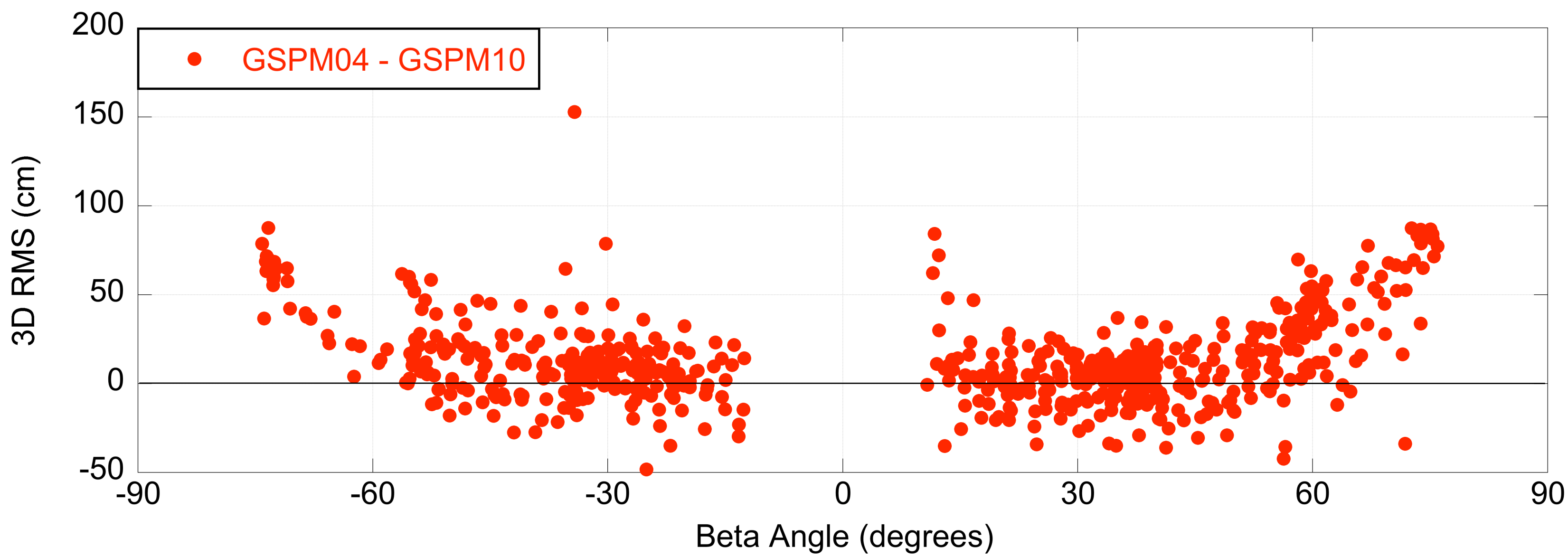
4th day prediction-error 3D RMS

	GSPM04 Mean	GSPM10 Mean	% Improved
IIA Non-Eclipsing	73.6	57.8	21.5
IIR Non-Eclipsing	52.5	40.3	23.2
IIR Eclipsing	250.7	233.0	7.1

Values in cm

Orbit Prediction

Non-eclipsing GPS IIR 4th 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)