Improved Modeling of GPS Block IIF Satellites for the GSPM13 Solar Radiation Pressure Model

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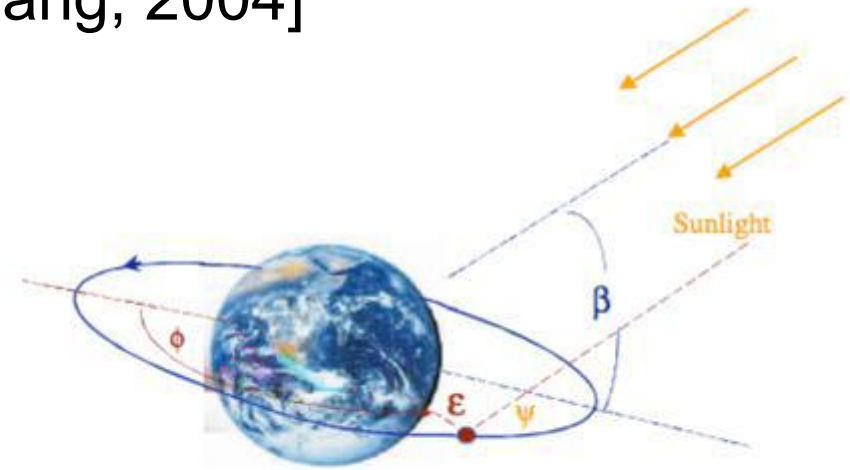
SRP Modeling at JPL

- GSPM04 [Bar-Sever and Kuang, 2004]

$$F_x = \lambda k \sum_{n=1,2,3,5,7} SX_n sin(n\epsilon)$$

$$F_y = mCY_0 + \lambda \sum_{n=1,2} CY_n cos(n\epsilon)$$

$$F_z = \lambda k \sum_{n=1,3,5} CZ_n cos(n\epsilon)$$



- SX_2 and CY_1 terms exhibit a dependence on the β-angle, determined in GSPM10 [Sibthorpe et. al., 2010] to be better modeled as:

$$SX_2 = \begin{cases} a_1^+ + a_2^+\beta + a_3^+\beta^2 & \beta > 0 \\ a_1^- + a_2^-\beta + a_3^-\beta^2 & \beta < 0 \end{cases}$$

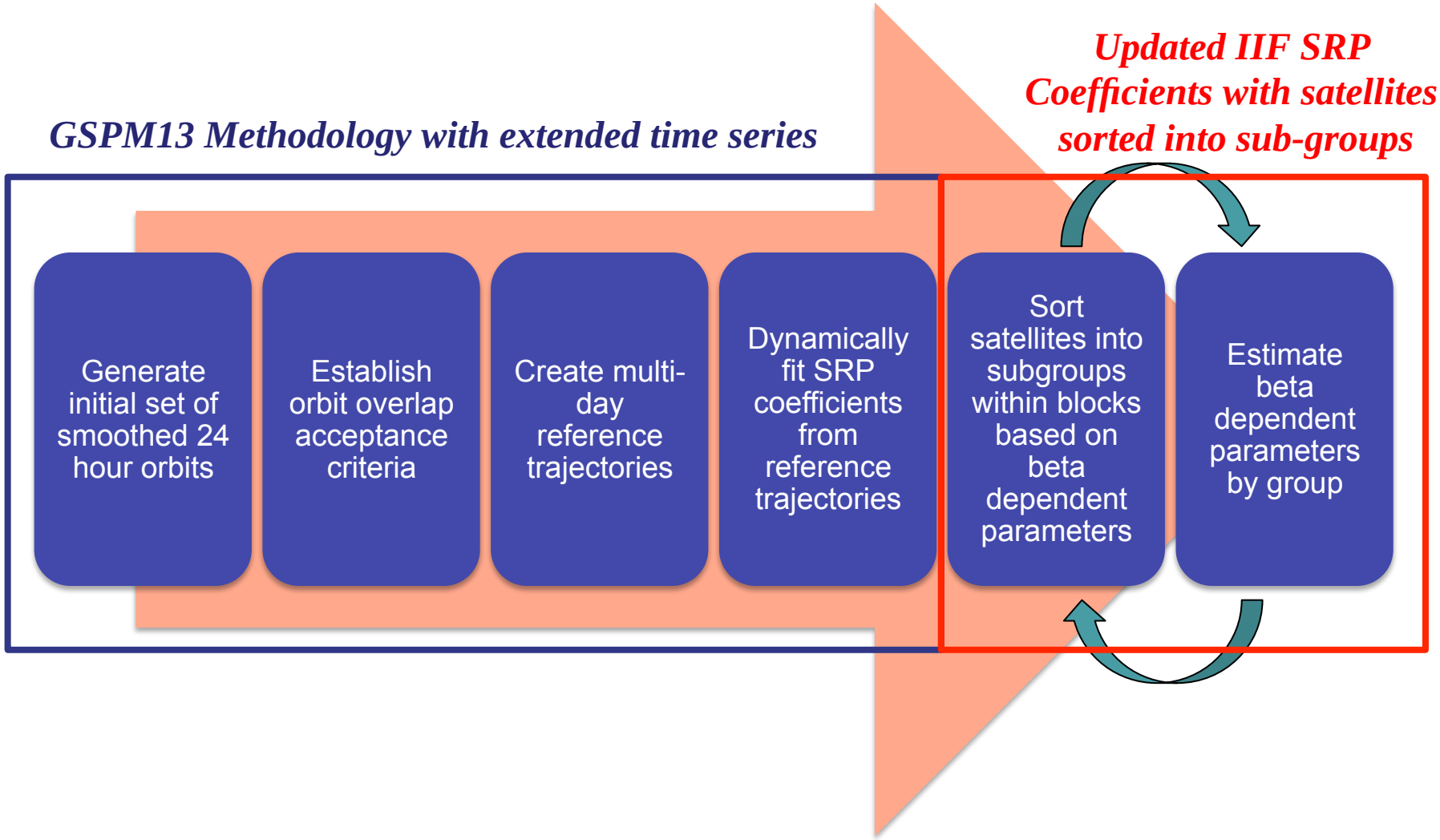
Motivation

- GSPM13 [Sibois et. al., 2013]
  - Updated SRP model based on 21 years (1992-2013) of daily JPL final orbit solutions for all GPS satellites
  - Satellites divided into sub-groups within GPS satellite blocks
  - Fourier coefficients are estimated from dynamical fits to carefully selected long (5-10 day) smooth reference trajectories

- Only two Block IIF satellites were available for GPSM13

  ➔ An updated model is necessary to capture the full range of variability in the Block IIF satellites

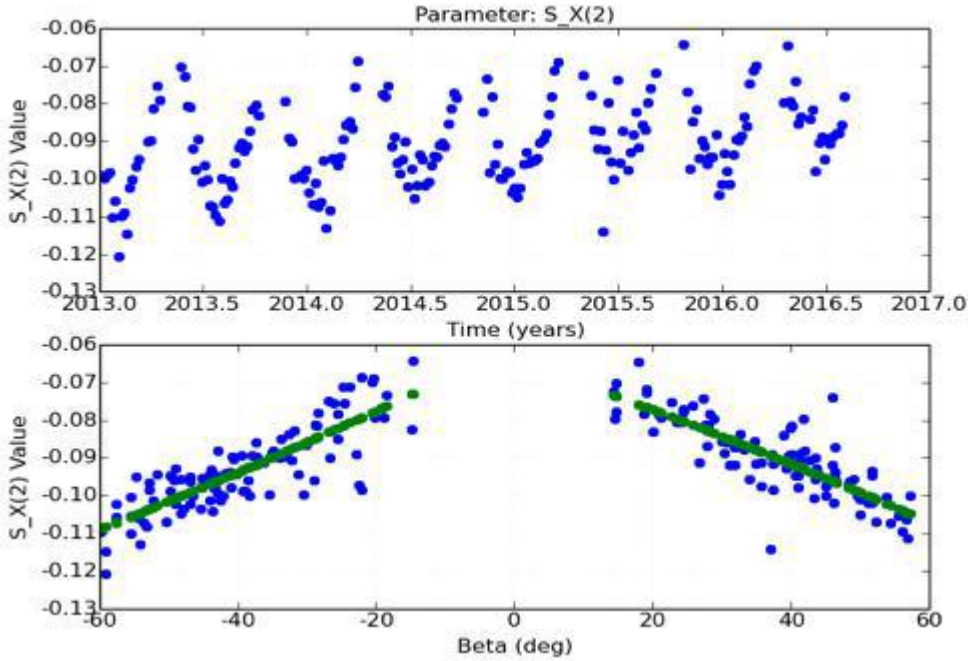
Methodology



Data Editing Considerations

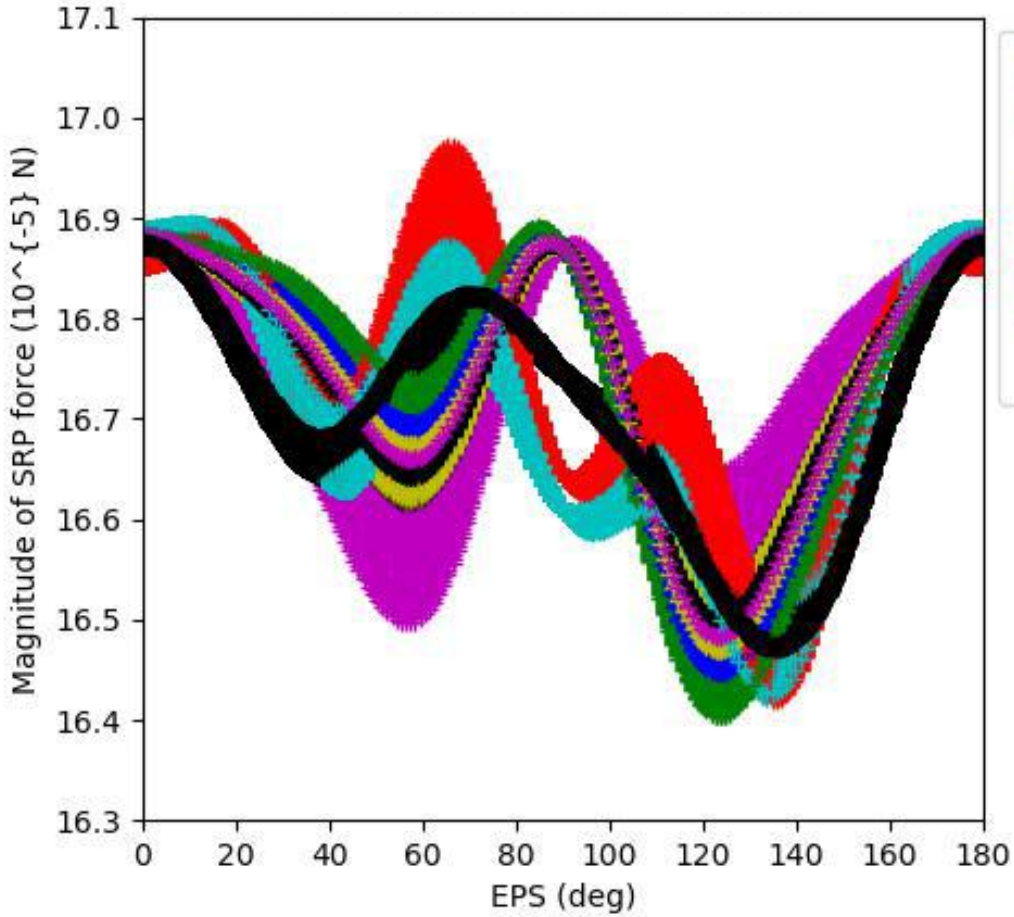
- Satellite outgassing periods eliminated
- Careful selection of reference trajectory arcs
  - 5-day orbit arcs
  - 1σ editing

GPS66



- Sorted into sub-groups based upon fit to SX_2 and CY_1 Fourier coefficients
  - Satellite groupings result from a tradeoff between specialization and data strength
- Can improve performance by estimating non β-dependent parameters by sub-group

Block IIF Satellite Groups



- ***GSPM13 was estimated with data from GPS62 and GPS63 only***

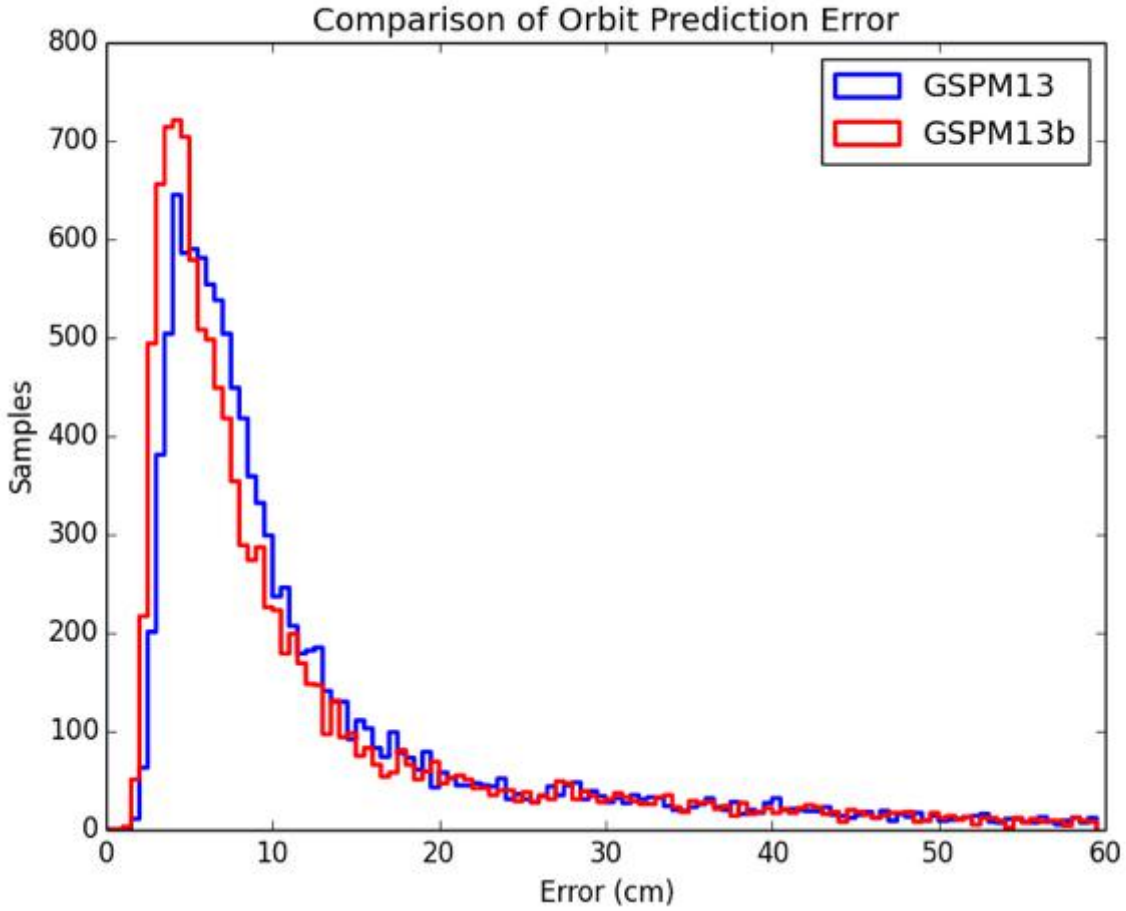
Group	Satellites
G1	GPS62
G2	GPS63
G3	GPS64, 65
G4	GPS66
G5	GPS67, 68
G6	GPS69, 70, 73
G7	GPS71, 72

Performance Metrics

- Orbit Prediction Error
  - One Day Predicts
    - Fit to IGS final orbits over a 30 hour arc, propagate forward for one day
  - Fourth Day Predicts
    - Fit to IGS final orbits over three days, propagate for four additional days
  - Error defined as position RMS difference over final day of predict period and corresponding IGS orbits

- Impact on Network POD
  - Orbit and clock overlap statistics
  - Resolution of phase ambiguities

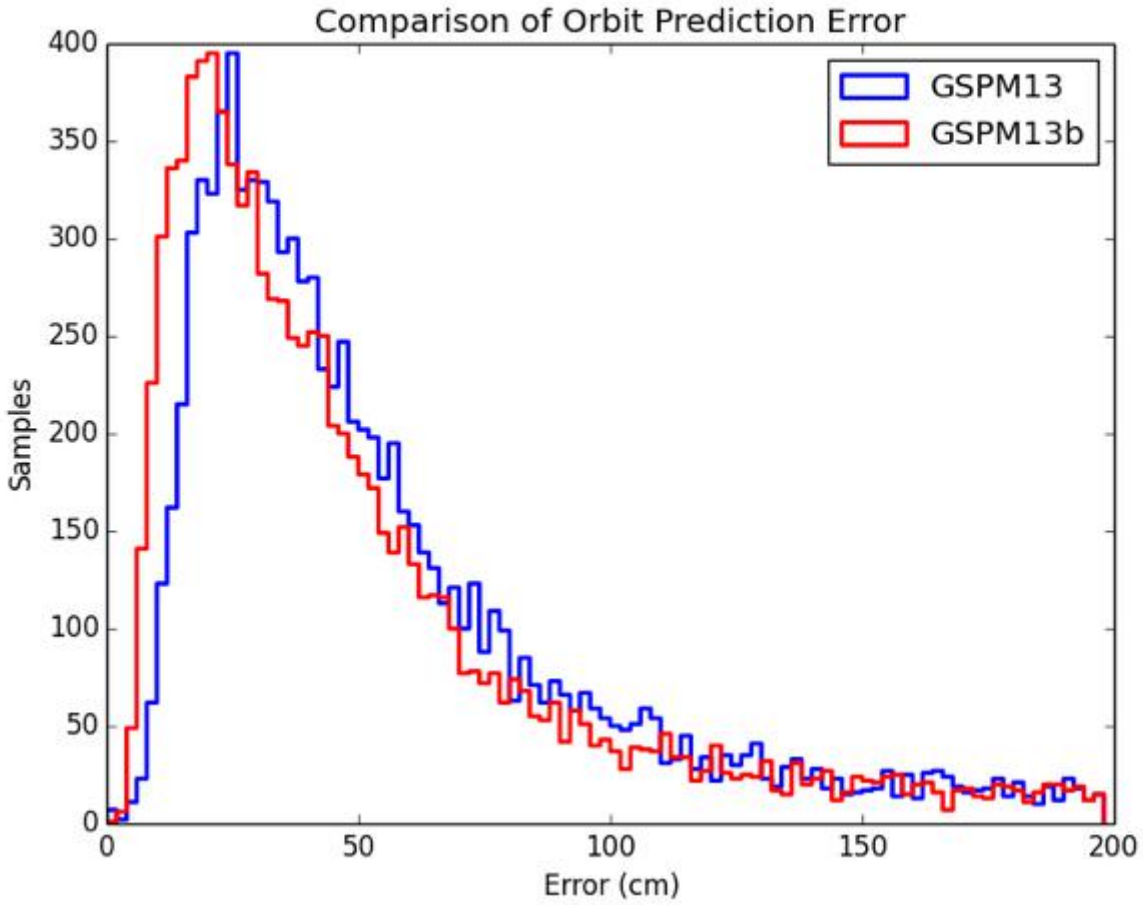
One Day Orbit Prediction Error



	GSPM13	GSPM13b	Mean Relative % Change
Mean Non-Eclipsing Error	8.3 cm	6.8 cm	18.1%
Mean Eclipsing Error	38.6 cm	36.2 cm	6.2%

- ***GSPM13b shows a clear improvement in orbit prediction error***

Error in Fourth Day Orbit Prediction



	GSPM13	GSPM13b	Mean % Change
Mean Non-Eclipsing Error	43.6 cm	36.5 cm	16.3%
Mean Eclipsing Error	361.8 cm	358.1 cm	1.0%

- ***GSPM13b shows a clear improvement in orbit prediction error***

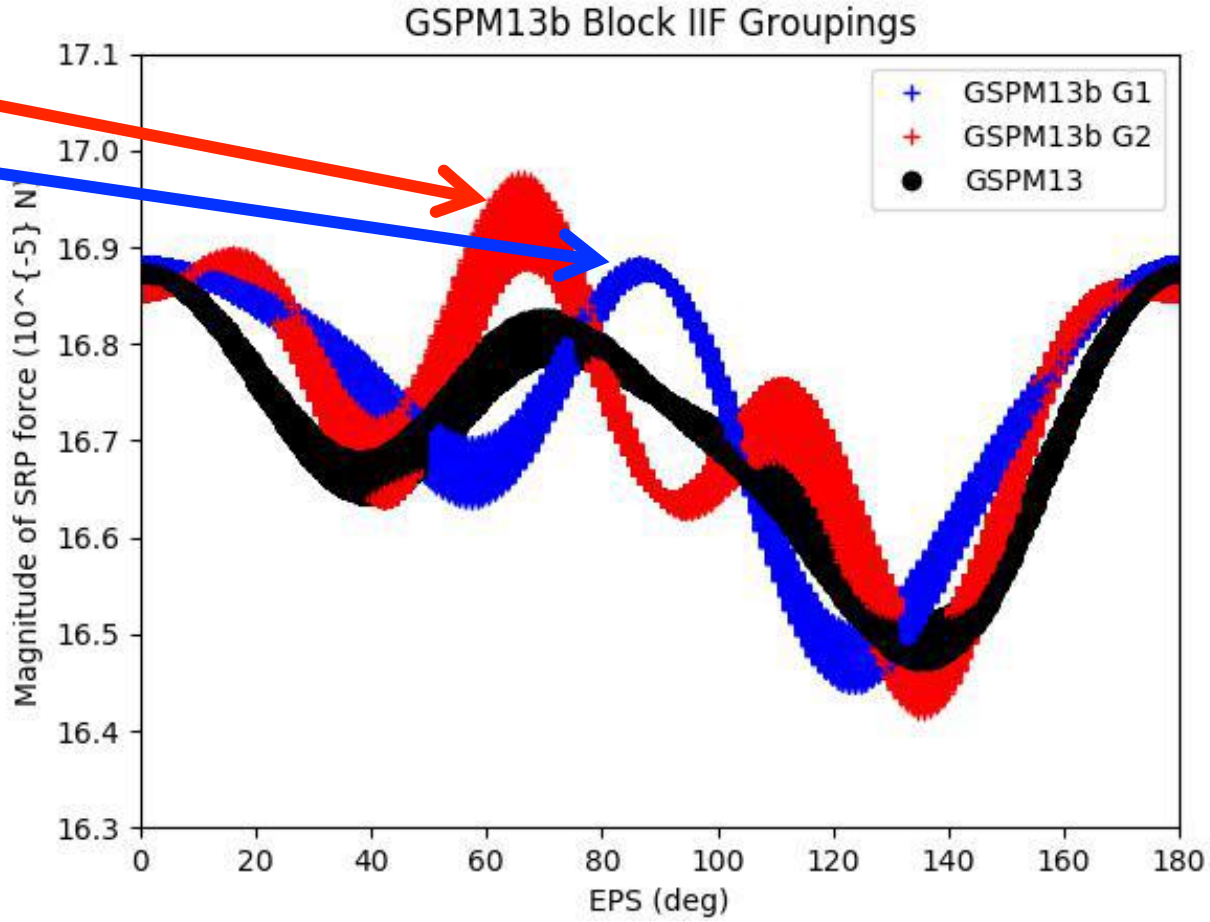
Fourth Day Orbit Prediction Error

Group	GSPM13: Median Error (cm)	GSPM13b: Median Error (cm)	% Change in Median Error
GPS62	51.6	45.4	12.2 %
GPS63	46.7	41.2	12.0 %
GPS64	53.4	45.8	14.2 %
GPS65	51.2	49.7	2.8 %
GPS66	67.3	49.8	26.0 %
GPS67	46.5	44.4	4.7 %
GPS68	62.9	48.9	22.2%
GPS69	51.0	48.5	4.9%
GPS70	63.7	46.5	26.9%
GPS71	52.1	51.6	1.1%
GPS72	59.8	52.3	12.6 %
GPS73	48.6	43.3	10.8 %
All Satellites	54.6	47.3	13.3 %

Block IIF Satellite Groups

GPS63

GPS62



- *GPS62 and GPS63 show very different responses to solar radiation pressure force*
- *GSPM13 was a compromise between the two patterns*

Fourth Day Orbit Prediction Error

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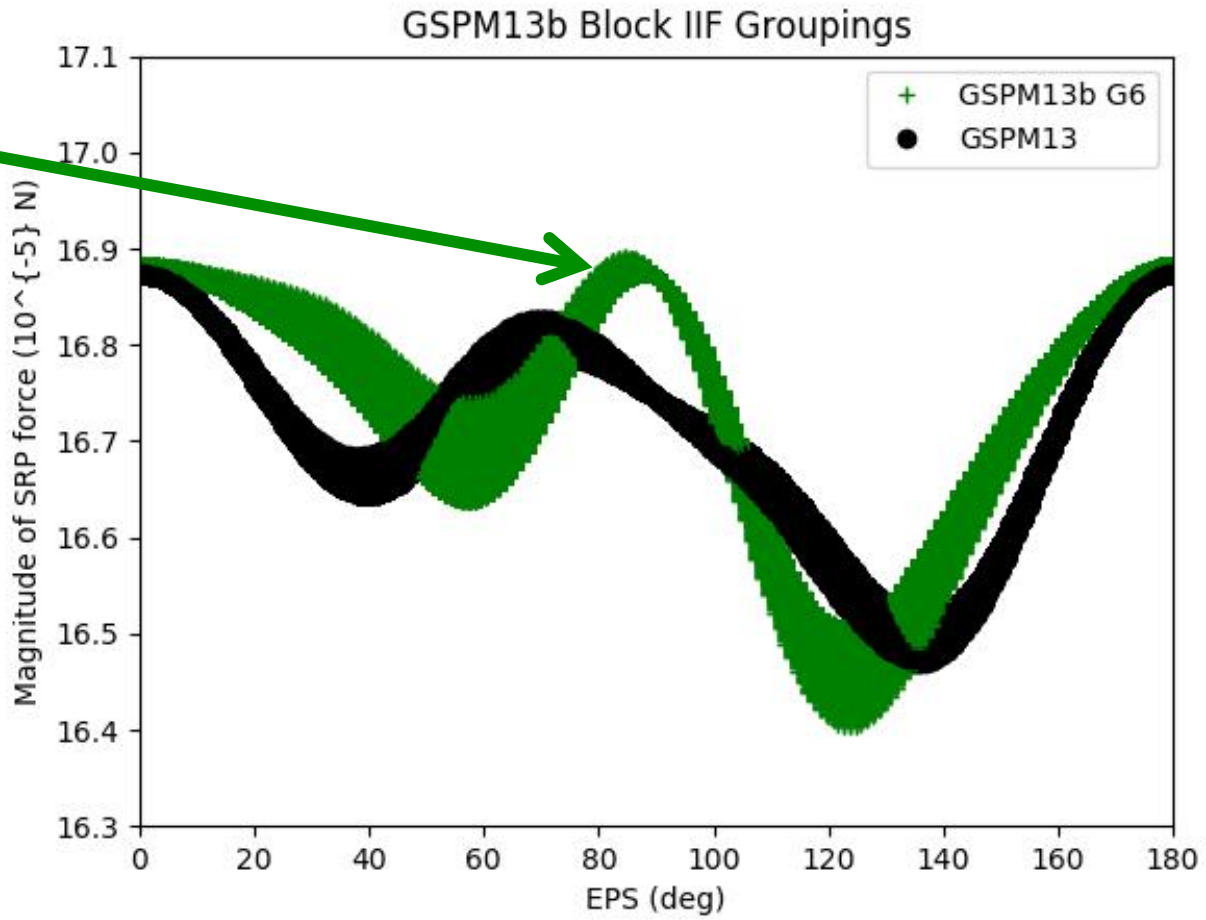
GPS63	46.7	41.2	12.0 %
GPS64	53.4	45.8	14.2 %
GPS65	51.2	49.7	2.8 %
GPS66	67.3	49.8	26.0 %
GPS67	46.5	44.4	4.7 %
GPS68	62.9	48.9	22.2%
GPS69	51.0	48.5	4.9%
GPS70	63.7	46.5	26.9%
GPS71	52.1	51.6	1.1%
GPS72	59.8	52.3	12.6 %
GPS73	48.6	43.3	10.8 %
All Satellites	54.6	47.3	12.5 %

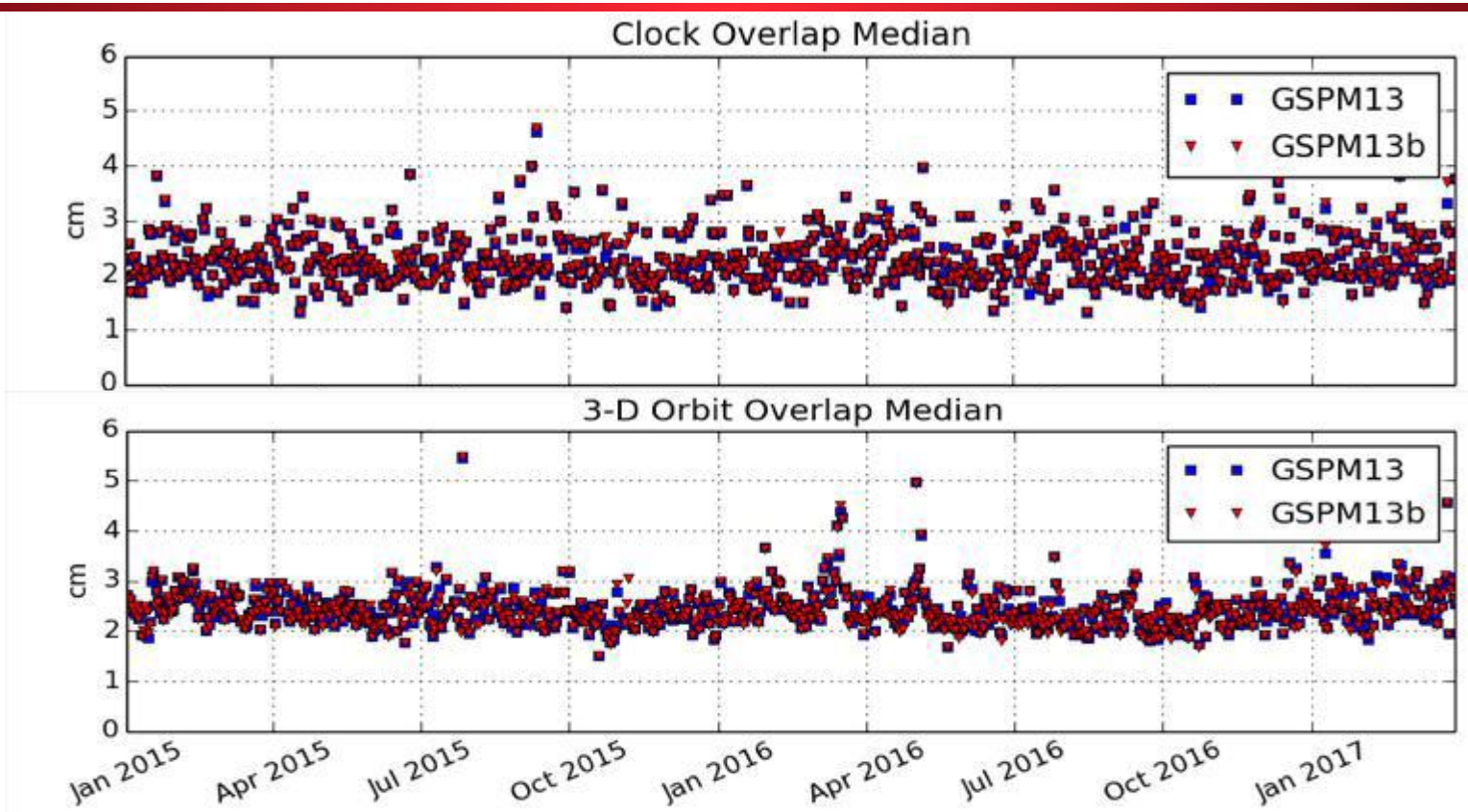
Block IIF Satellite Groups

GPS69
GPS70
GPS73



- ***GPS70 improves by 27% compared to GSPM13, with small changes in the SRP model***
- ***In contrast, GPS73 improves by 11% and GPS69 improves by only 5%***

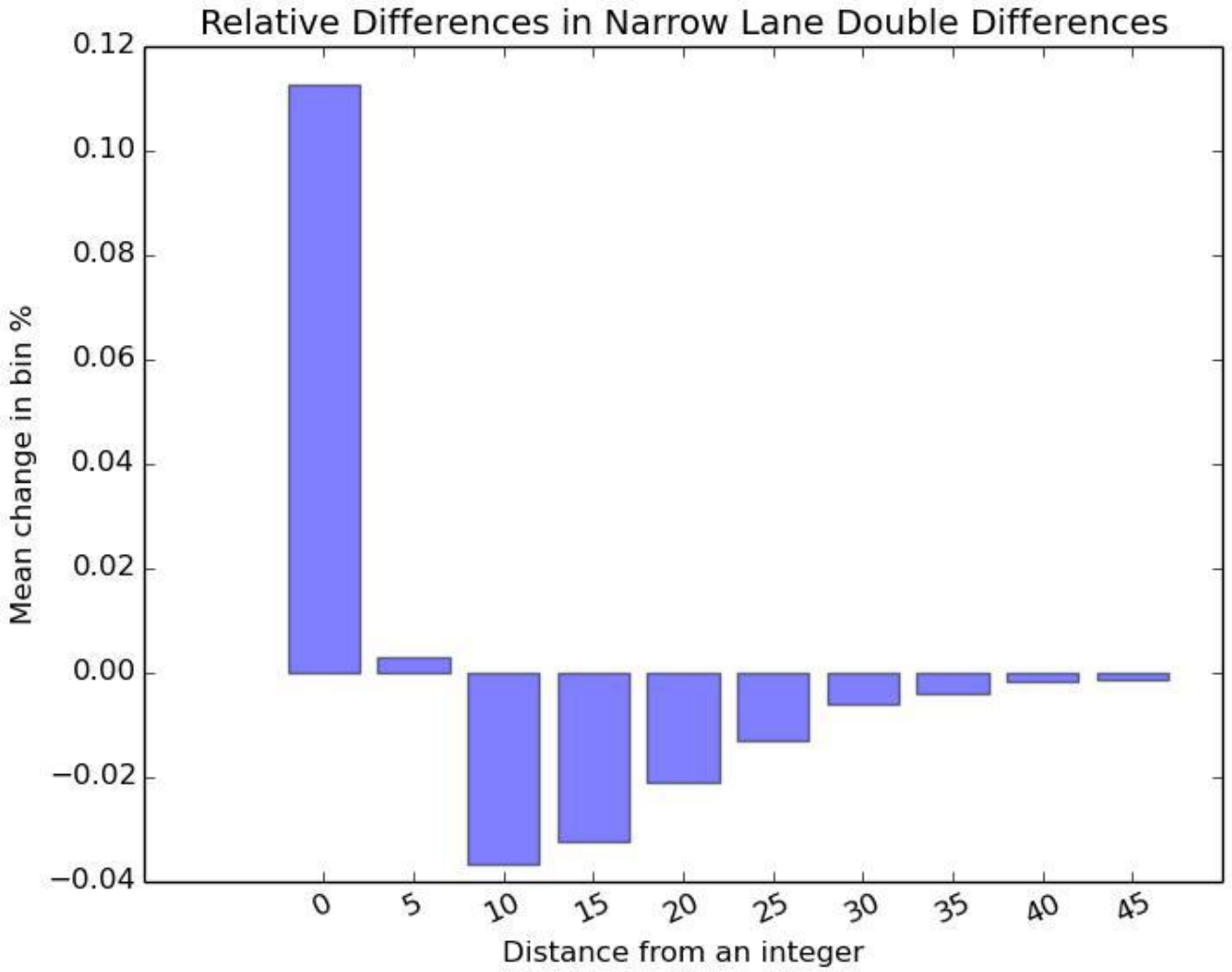
Impact on Network POD Precision



	Orbit Overlaps		Clock Overlaps	
	Median (cm)	Maximum (cm)	Median (cm)	Maximum (cm)
GSPM13	2.42	5.12	2.24	4.72
GSPM13b	2.39	5.09	2.24	4.71

Impact on Ambiguity Resolution

- ***Small improvement in resolution of phase ambiguities with GSPM13b compared to GSPM13***



Conclusions and References

- GSPM13b updated and specialized the GSPM13 Block IIF SRP model to account for increased information and inter-satellite variability
  - The twelve IIF satellites were sorted into seven sub-groups based upon the beta angle dependent Fourier coefficients SX_2 and CY_1
- In comparison to GPSM13 fourth day orbit prediction error was reduced by 13% overall and one day prediction error was reduced by 18%
- Resolution of phase ambiguities is slightly improved with the new model
- Negligible impact on orbit and clock overlaps

Future Investigation

- Separate model for satellites in eclipse
- Comparison with other SRP models

1. Bar-Sever, Y. and Kuang, D. (2004), "New Empirically Derived Solar Radiation Pressure Model for GPS Satellites", The Interplanetary Network Progress Report 42-159

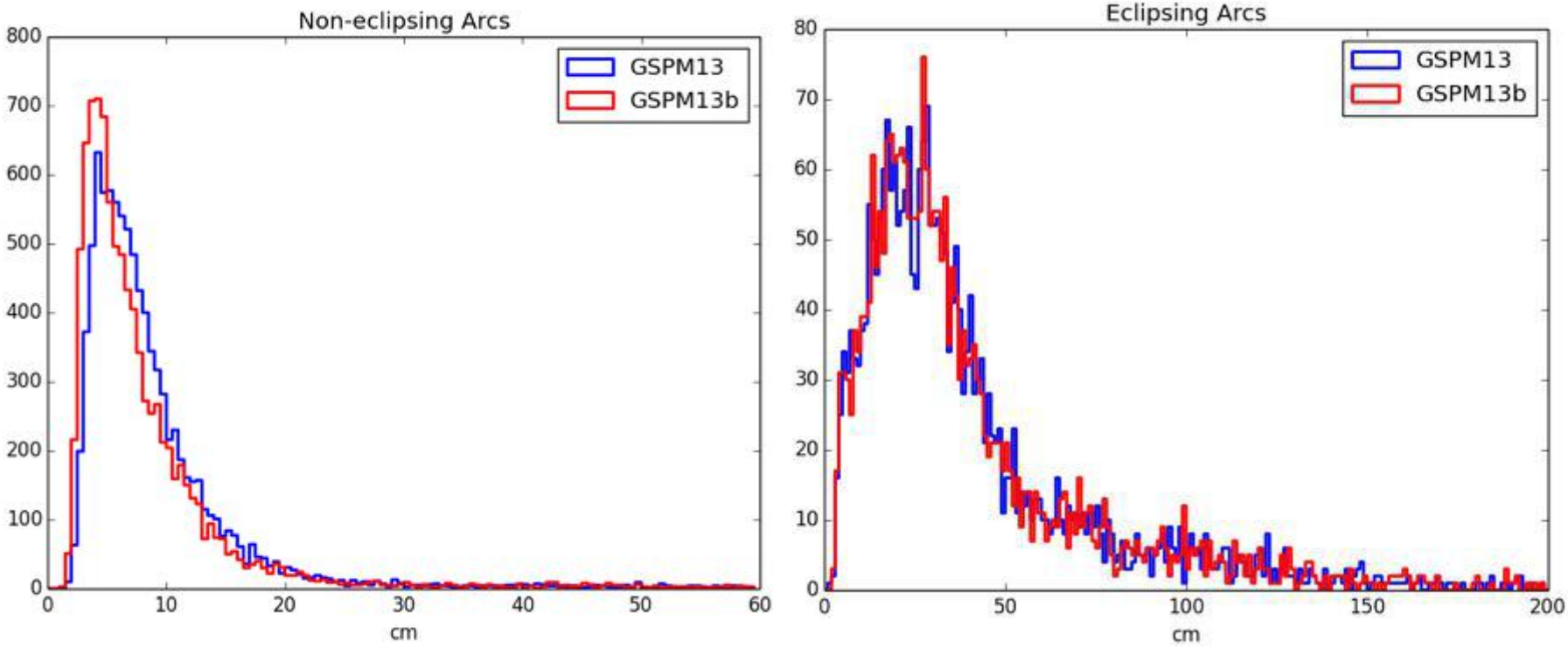
2. Sibois, A. et al. (2013), "GSPM13: An Updated Empirical Model for Solar Radiation Pressure Forces Acting on GPS Satellites", IGS Workshop 2014.

3. Sibthorpe, A. et al. (2010), "Empirical Modeling of Solar Radiation Pressure Forces Affecting GPS Satellites", AGU Fall Meeting 2010

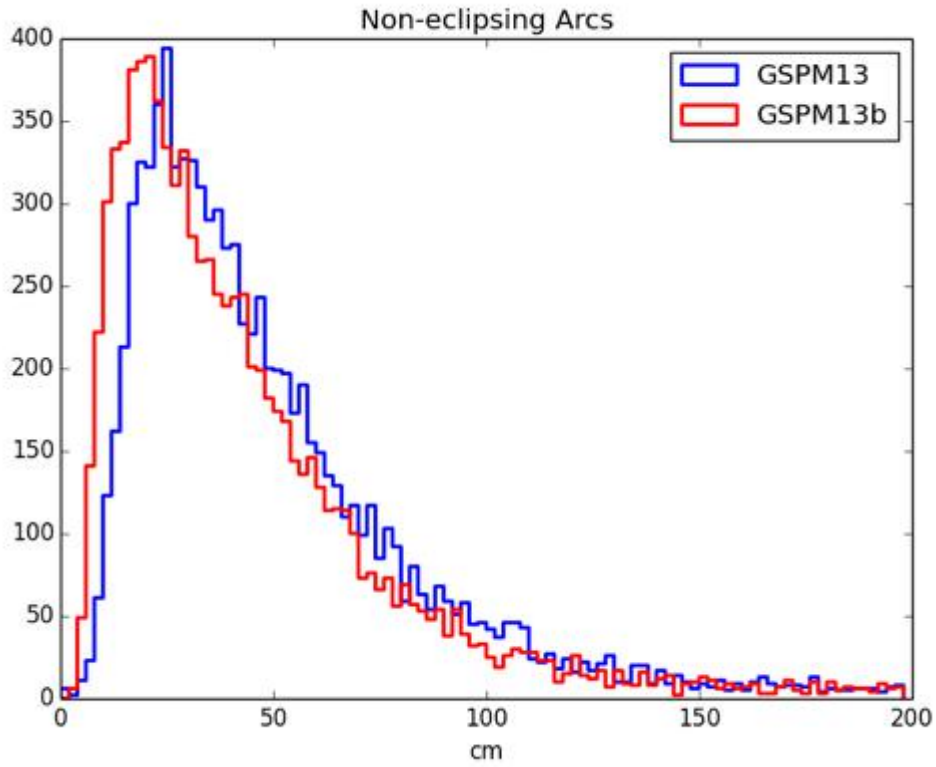
4. Desai, S. et al. (2012), "The JPL IGS Analysis Center: Status and Plans", IGS Workshop 2012

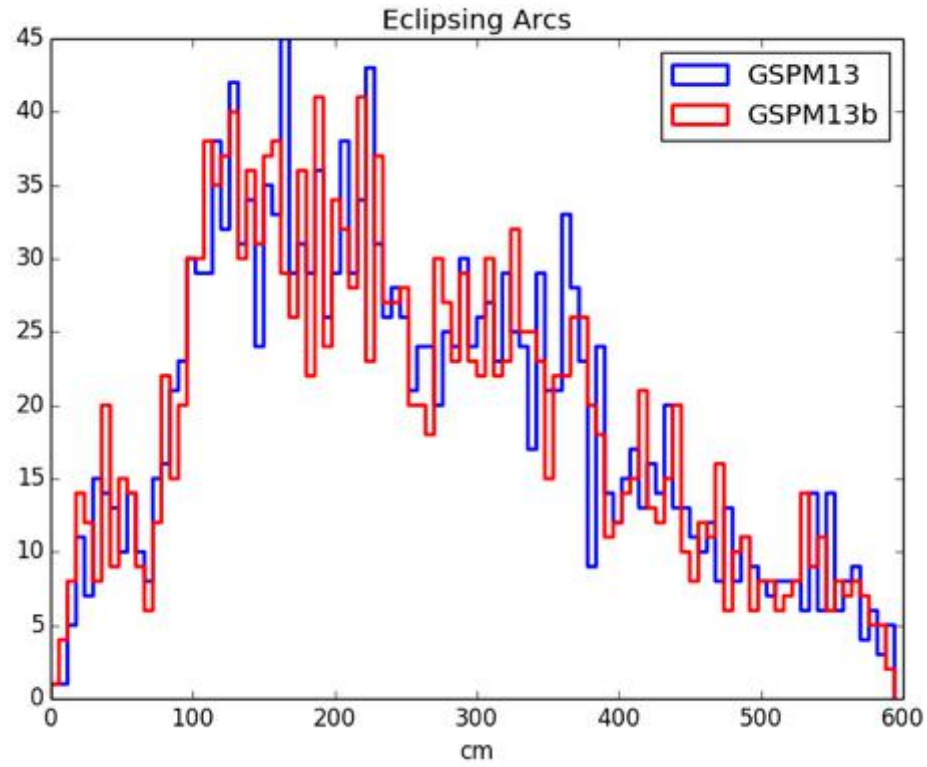
BACKUP

One Day Orbit Prediction Error

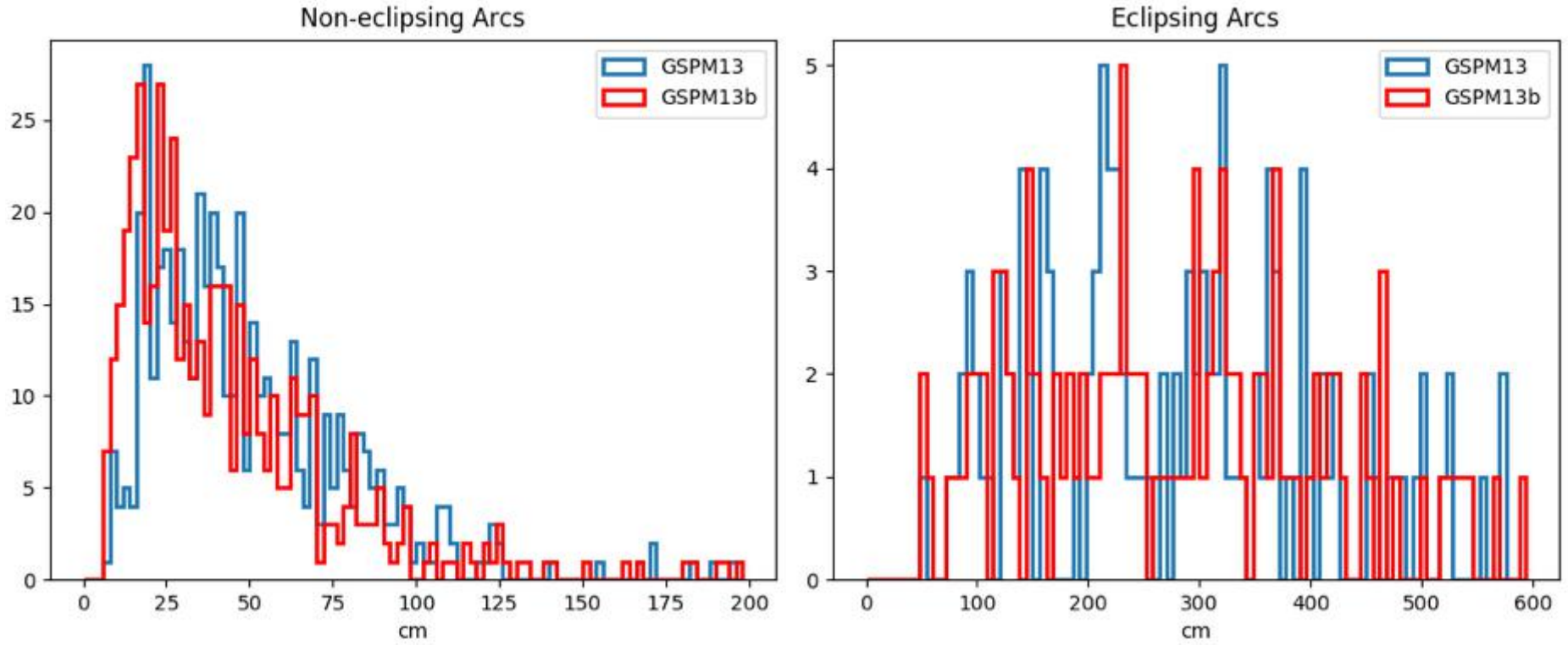


Fourth Day Orbit Prediction Error





Fourth Day Prediction Error: Untrained Data



Scatter in Solar Scale Parameter