Evaluation of GPS Orbit Prediction Strategies for the IGS Ultra-rapid Products

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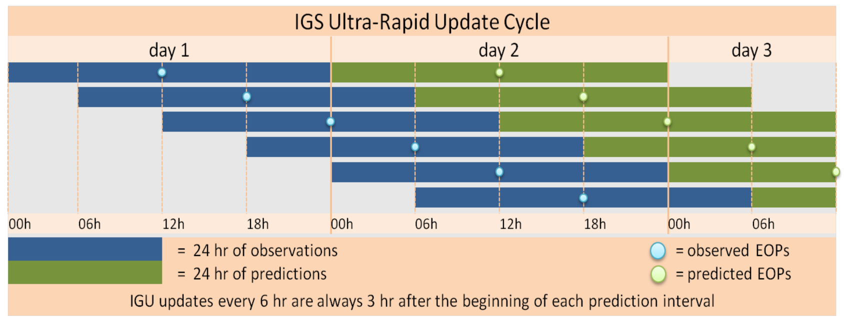
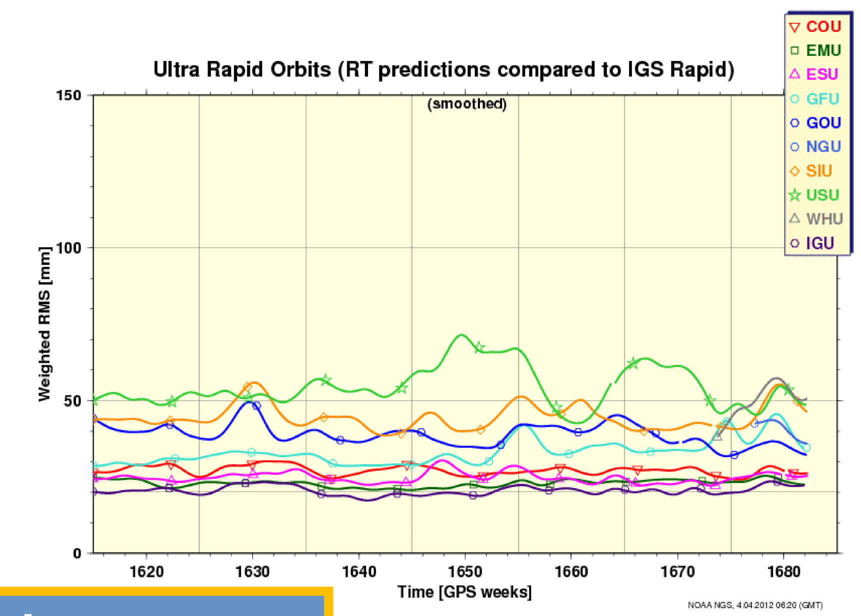
Introduction

To serve real-time and near real-time users, the International GNSS Service (IGS) produces Ultra-rapid GPS & GLONASS orbit product updates every 6 hr. Each is composed of 24 hr of observed orbits, with an initial latency of 3 hr, together with propagated orbits for the next 24 hr. We have studied how the orbit prediction performance varies as a function of the arc length of the fitted observed orbits and the parameterization strategy used to estimate empirical solar radiation pressure (SRP) effects.

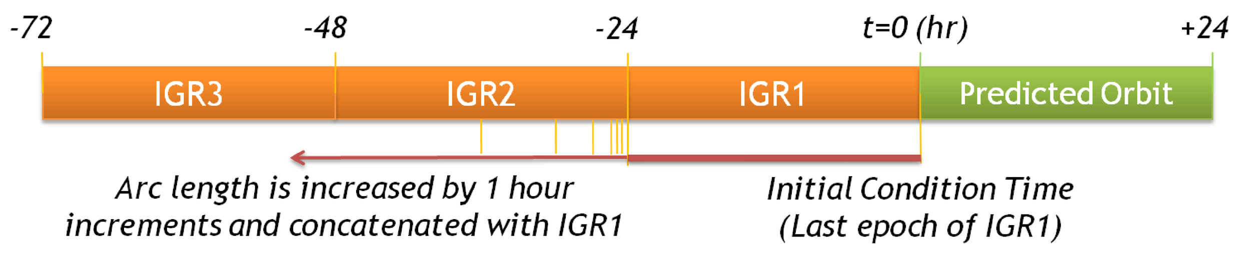


Recent IGU combination performance is shown below. This plot shows the comparison of the first 6 hours of prediction (for each IGS Analysis Center) with the IGR orbit products.

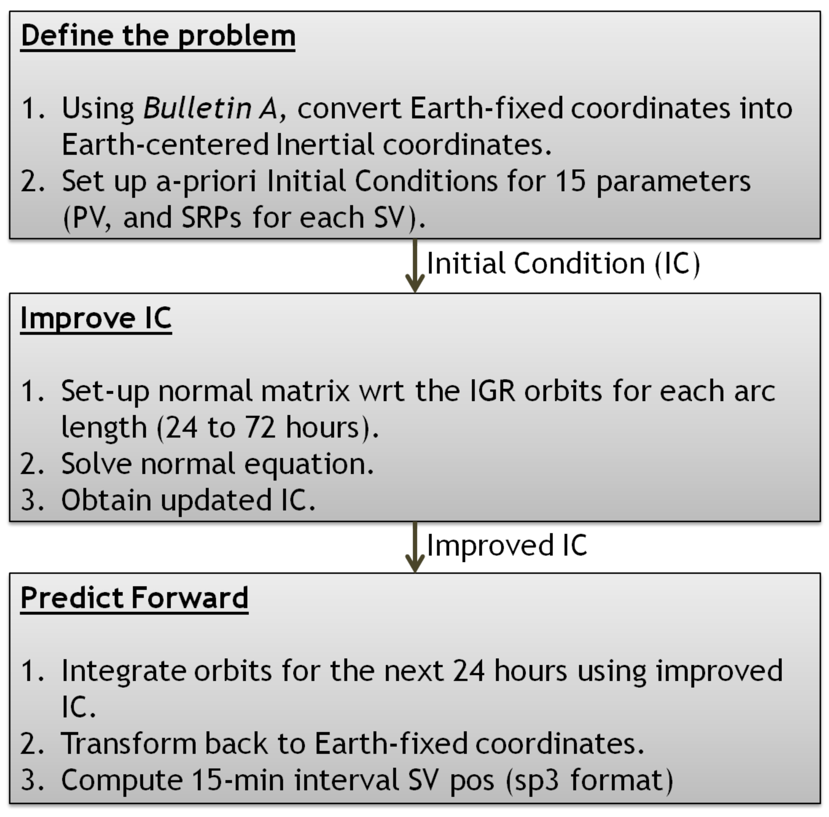


Experiment Setting

To focus on the dynamical aspects of the problem, nearly ideal conditions have been adopted by using IGS Rapid orbits (IGR) as observations and known Earth orientation parameters (EOPs).



Flow chart for orbit integration test →



Performance was gauged by comparison of the predicted orbits with IGR as truth by examining weighted RMS (WRMS – weight by satellite accuracy code in the Rapid Orbit products) and median orbit differences over the first 6 hr and the full 24 hr prediction intervals, as well as the stability of the Helmert alignment parameters. Note that the actual IGS Ultra-rapid accuracy is limited mostly by rotational instabilities, especially about the Z axis due to errors in near real-time and predicted UT1 values.

Helmert alignment Equation

$$\begin{bmatrix} x_2 \\ y_2 \\ z_2 \end{bmatrix} = \begin{bmatrix} x_1 \\ y_1 \\ z_1 \end{bmatrix} + \begin{bmatrix} T_x \\ T_y \\ T_z \end{bmatrix} + S \cdot \begin{bmatrix} x_1 \\ y_1 \\ z_1 \end{bmatrix} + \begin{bmatrix} 0 & R_z & -R_y \\ -R_z & 0 & R_x \\ R_y & -R_x & 0 \end{bmatrix} \begin{bmatrix} x_1 \\ y_1 \\ z_1 \end{bmatrix}$$

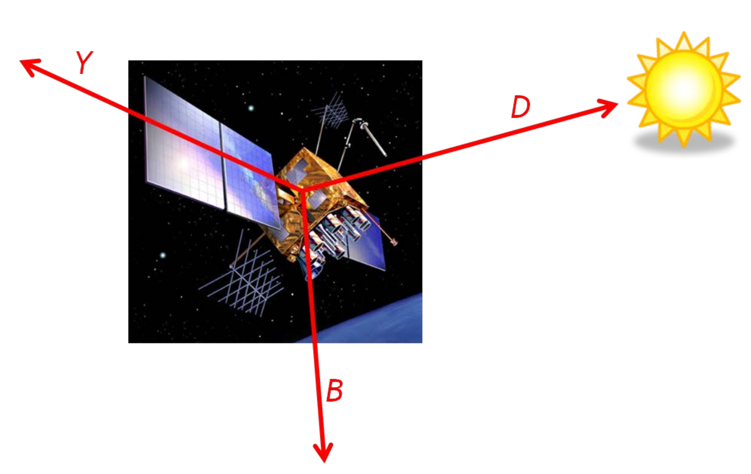
where, S is orbital scale, ***T*** is translational vector, and ***R*** is rotational vector.

Models and Data

Orientation of Solar Radiation Pressure model [1]

❑9 Parameter model ("6+9" Model)

$$\begin{bmatrix} D(u) \\ Y(u) \\ B(u) \end{bmatrix} = \begin{bmatrix} D_0 \\ Y_0 \\ B_0 \end{bmatrix} + \begin{bmatrix} D_C \\ Y_C \\ B_C \end{bmatrix} \cdot \cos(u) + \begin{bmatrix} D_S \\ Y_S \\ B_S \end{bmatrix} \cdot \sin(u)$$



❑5 Parameter model ("6+5" Model)

$$\begin{bmatrix} D(u) \\ Y(u) \\ B(u) \end{bmatrix} = \begin{bmatrix} D_0 \\ Y_0 \\ B_0 \end{bmatrix} + \begin{bmatrix} D_C \\ Y_C \\ B_C \end{bmatrix} \cdot \cos(u) + \begin{bmatrix} D_S \\ Y_S \\ B_S \end{bmatrix} \cdot \sin(u)$$

↗ = Tightly held fixed to 0

Orbit Models and Constants [2]

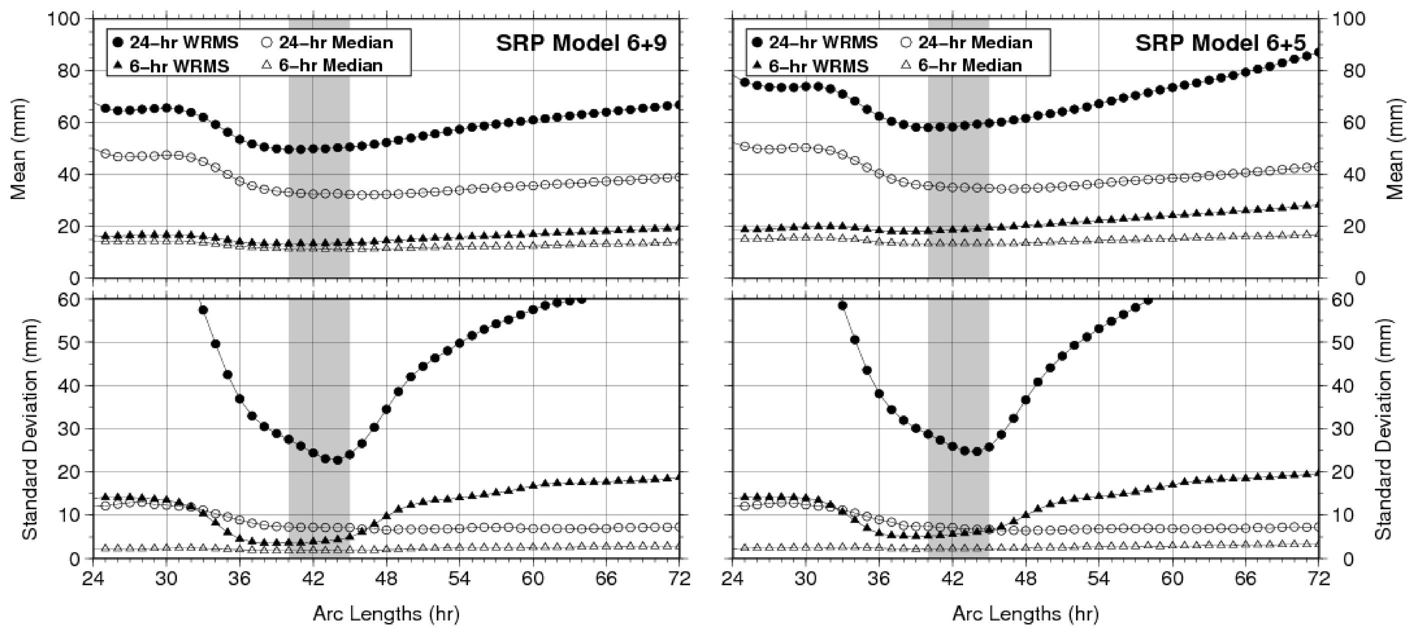
Models	Reference/Source	Max deg/order
Geopotential model	EGM08 (tide-free)	12/12
Radius of Earth	6378136.3 [m]	
Gravitational Constant (GM)	398600.4415E+09 [km^3s^{-2}]	
Tidal variations	IERS 2010	
Solid Earth Tides	IERS 2010	
Ocean tides	IERS 2010 using FES2004	8/8
Third-body forces (point mass)	DE405 from JPL Sun, Moon, Venus, Jupiter, Mars	
Solar Radiation Pressure	CODE 9-parameter SRP model	
Earth Radiation Model (Albedo)	Not applied	
Integration Step Size	900 s	

Data

❑ IGS rapid orbit products are used for orbit fitting.
❑ 24-hour propagation for each 365 days using CODE 6+9 and 6+5 models.
❑ Tested for 1 calendar year (from Jan 1 to Dec. 31, 2010)
❑ Satellites with NANU messages are excluded from the processing.

Results

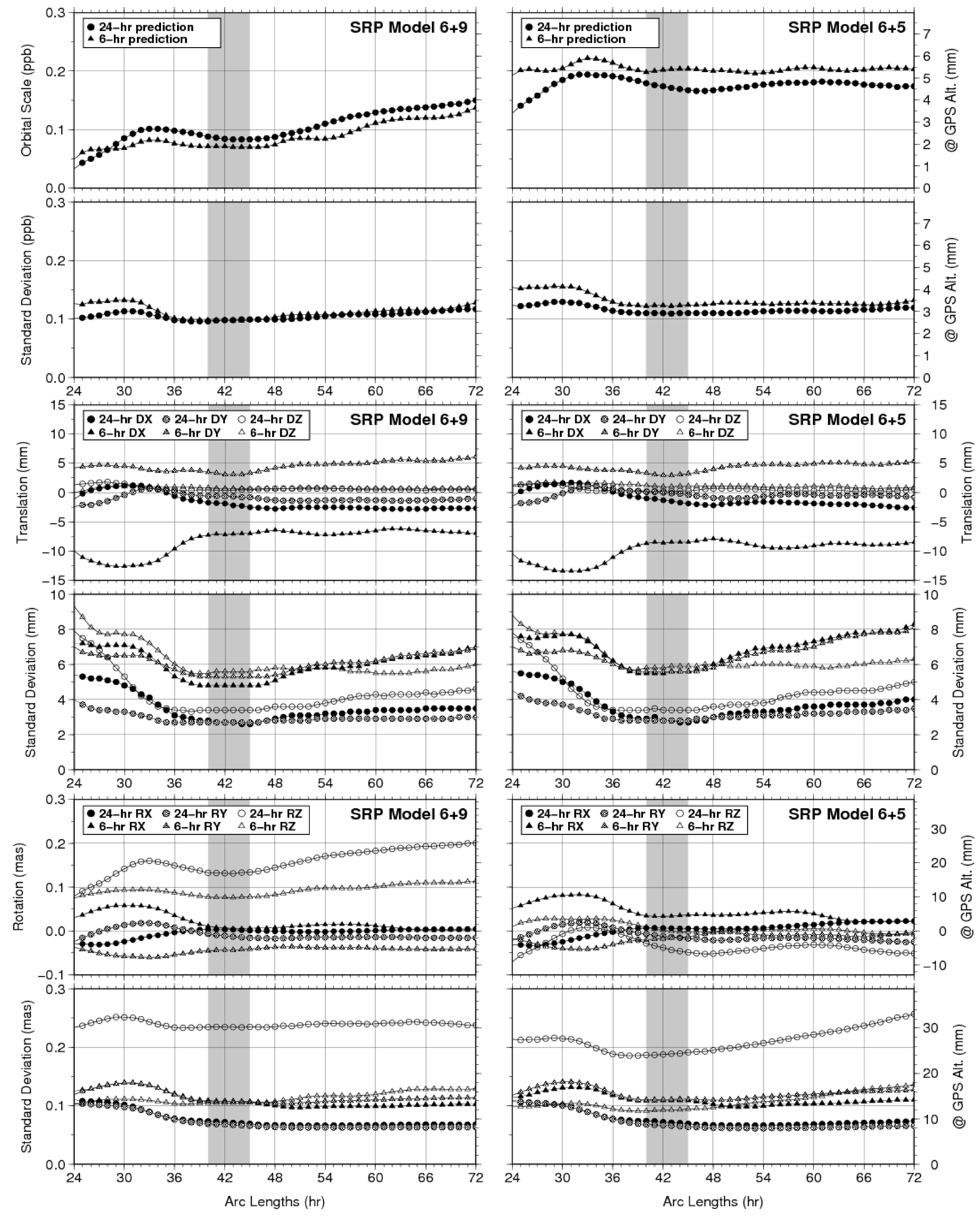
Finding an optimal arc length



- o The quality of propagated GPS orbit is sensitive to Initial condition (position, velocity, SRP) and Dynamic models (IERS convention)
- o The initial condition is affected by the fitted arc lengths (Tested 24 to 72 hours of arc lengths by 1 hour increment).
- o OBJECTIVE: Finding minimum arc length that shows minimum combined RMS and median, and small standard deviation over 1-year.
- o Arc lengths between 40 and 45 hours (grey bands in the plot) shows the best fit to the IGR for both 6+9 and 6+5 models.
- o 6+9 model fits well (smaller WRMS and Median) after 7-parameter transformation.
- o 6+5 model shows better alignment (smaller rotation) with less scatter to IGR.

7-Parameter Transformation Statistics over One Year

- o All 7 parameters show the best stable results for the arc lengths range 40-45 h.
- o Orbit predictions using 6+5 model show smaller rotations wrt the IGS Rapid orbits.
- o Note that 1 mas ~ 128.85 mm in GPS altitude in the rotation plots.



Conclusion

Implication on the ultra-rapid orbit prediction strategy

❑Optimal arc length of observed orbits to fit is around 40-45 hours.
❑According to the results of this study, if we rotationally align the predicted orbit from 6+9 model to 6+5 model orbit, we will achieve statistically the best predicted GPS orbits (See the table). Translational and scale scatter is insignificant.
❑The actual prediction performance will also be affected by errors in the EOP predictions required to transform from the inertial reference frame to an Earth-fixed frame. In practice, the EOP prediction errors usually dominate.

	6+9 SRP				6+5 SRP			
	24-h		6-h		24-h		6-h	
	Mean	STD	Mean	STD	Mean	STD	Mean	STD
WRMS (mm)	49.95	24.60	13.38	4.03	58.73	26.23	18.65	5.75
Median (mm)	32.53	7.17	11.27	1.85	35.05	6.98	13.33	2.22
Scale (mm)	2.13	2.66	1.86	2.66	4.52	2.92	5.32	3.19
DX (mm)	-2.07	2.68	-7.12	4.80	-1.42	2.82	-8.55	5.55
DY (mm)	-0.68	2.70	3.23	5.30	-0.08	2.80	3.08	5.60
DZ (mm)	0.43	3.40	0.70	5.58	0.23	3.42	1.08	5.85
RX (mm)	0.33	9.18	0.93	13.87	0.82	9.23	4.42	14.05
RY (mm)	-1.50	8.67	-5.57	13.82	-1.62	8.51	-2.17	14.25
RZ (mm)	17.05	30.22	9.88	13.50	-5.12	24.26	0.22	11.95

References

[1] T. A. Springer, G. Beutler, M. Rothacher, (1998) A new Solar Radiation Pressure Model for the GPS Satellites, IGS Analysis Center Workshop, ESOC, Darmastadt, Germany.
[2] NOAA/NGS Analysis Strategy Summary (http://igscb.jpl.nasa.gov/igscb/center/analysis/noaa.acn)