A Study on the Prediction of GPS Satellite Clock Bias with IGS Ultra-rapid Products – Preliminary Results

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SUMMARY

GPS real time precise point positioning (RT-PPP) requires real-time, accurate and reliable prediction of satellite clock biases (SCBs). This is one of the most challenging tasks in the development of a RT-PPP technique. Several approaches have been developed, like the grey model (GM), linear model (LM) and quadratic polynomial model (QPM). The above-mentioned approaches are discussed and compared using real data in this paper. We predicted the 24-hour SCBs using the IGS ultra-rapid products in the previous day. This paper compared the IGS predictions with those obtained with the GM, LM and QPM methods.

From the testing and analyzing the data of two adjacent days, some preliminary observations are made as follows.

— The predicted SCBs from the previous-day observations with the LM have similar accuracy as the IGS products;
— The QPM can not generate better results than the IGS products;
— We can get more accurate predictions with the GM as long as the EC is properly selected. This is the area worth exploring.

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1. INTRODUCE

The Analysis Centers of the IGS offer precise GPS ephemeris for post-processing. It is well known that the accuracy of orbit products is better than 5cm, and that of satellite clock bias (SCB) approaches 0.1ns (igscb.jpl.nasa.gov), which can meet the requirements of cm-level precise point positioning (PPP). However, IGS final products have a latency of 13 days (see in Table 1), and therefore can not meet the need of RT- PPP. For RT mode, only are the broadcast and the ultra-rapid (predicted) applicable, but the accuracy of the former is low. Therefore development of an approach to predict SCBs is of particular importance in the RT-PPP.
There are two commonly used schemes to predict SCBs. One is to predict the SCBs using the SCBs of the previous day obtained from IGS ultra-rapid products (observed), the other is to predict SCBs with other prediction means (e.g., Senior, et al 2001; Dounis, et al 2005). We prefer to first scheme because the ultra-rapid observations are ready available. In this paper we first analyze the SCBs in IGS ultra-rapid products, including the differences and correlations between the SCBs in two adjacent days. Three prediction models, i.e., grey model (GM), linear model (LM) and quadratic polynomial model (QPM), are then discussed and compared using real data. The results also were compared with the IGS predicted values. Some observations are finally given.

Table 1. IGS Products (GPS Satellite Ephemeris and Clock Bias)

		accuracy	latency	update	Sample interval
Broadcast	Orbit	160cm	RT		daily
	Sat. Clock	7ns			
Ultra-Rapid (predicted half)	Orbit	10cm	RT	4 times daily	15min
	Sat. Clock	5ns			
Ultra-Rapid (observed half)	Orbit	<5cm	3 hours	4 times daily	15min
	Sat. Clock	0.2ns			
Rapid	Orbit	<5cm	17hours	daily	15min
	Sat. Clock	0.1ns			5min
Final	Orbit	<5cm	13 days	weekly	15min

	Sat. Clock	0.1ns			5min

2. ANALYSIS OF SCBS IN IGS ULTRA-RAPID PRODUCTS

The official IGS products showed in Table 1 are the weighted averages of the results obtained from the Analysis Centers (Jay Oaks, Ken Senior, et al 2003; V. Broderbauer, R. Weber, 2003). To understand better the relationship between two adjacent-day SCB observations, predictions and final values, we used the SCB data of 7th and 8th Dec. 2004 and analyzed their differences and correlations.

2.1 The Differences between the Predicted and Final SCBs

Taking SCBs of satellite PRN-1 and PRN-8 as example: one has its SCBs increasing with time, and the other decreasing with time. We plotted the differences among the observed, predicted and final SCBs for those two days in Figure 1, where, the O-F means the differences in nanosecond between the observed and final results; the P-F is the differences between predicted and final; the P-O is the differences between the predicted and observed. It is showed that the differences between the observed and final SCBs are less than 2ns, using the final products with precision of 0.1-0.2ns as reference. It indicated the observed SCBs are quite accurate. The differences of the P-F or the P-O are about 20ns, indicating the precision of predictions is low. Figure 2 shows the results for PRN-8. The similar conclusions can be drawn. Hence, the predicted IGS ultra-rapid products are poor and can not be used for precise RT-PPP.

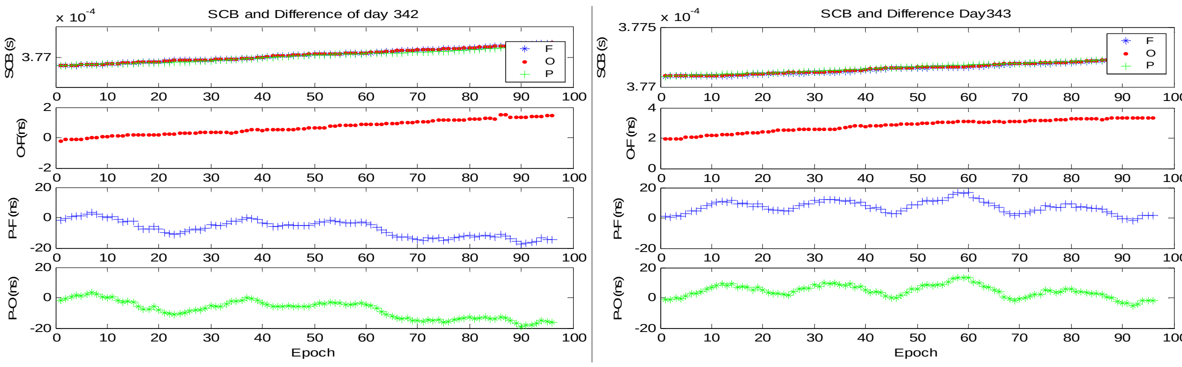

Fig.1 the differences among the predicted, observed and final SCBs for PRN-1

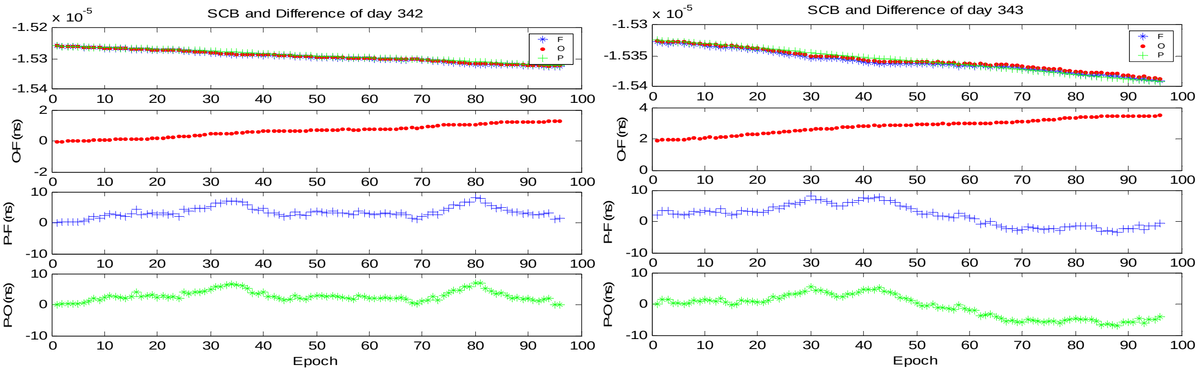

Fig.2 the differences among the predicted, observed and final SCBs for PRN-8

2.2 Correlations between two Adjacent-day SCBs

To predict SCBs with the previous-day observed SCBs it is useful to analyze the correlations between the observed, predicted and final SCBs. Taking the SCBs of PRN-8 as example, Figure 3 plots the differences of the O-F for two days (left side) and that of the P-O (right side). One can see from the figures that there is a similar trend suggesting a strong correlation in the O-F between two adjacent days, but less in the P-O. The strong correlation implies that we can predict the SCBs using the previous-day observed values.

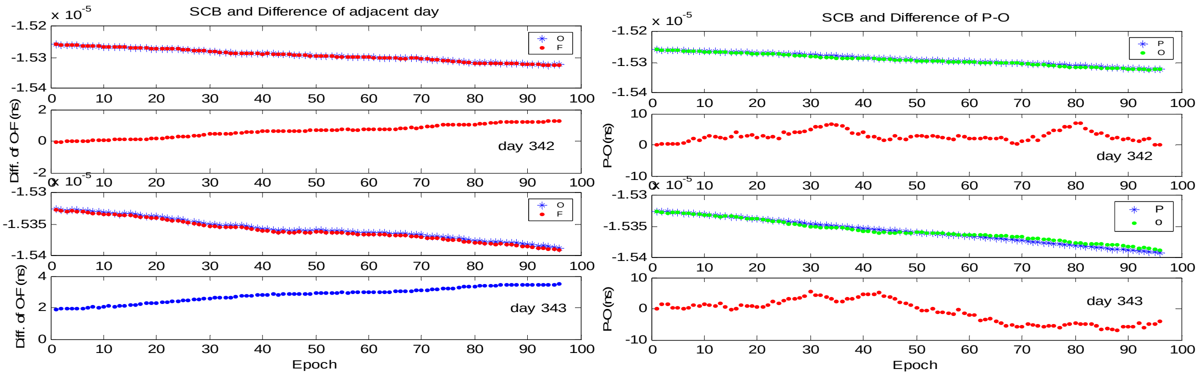

Fig.3 the differences between observed and final SCBs (left) and predicted and observed SCBs (right) for PRN-8 for two days

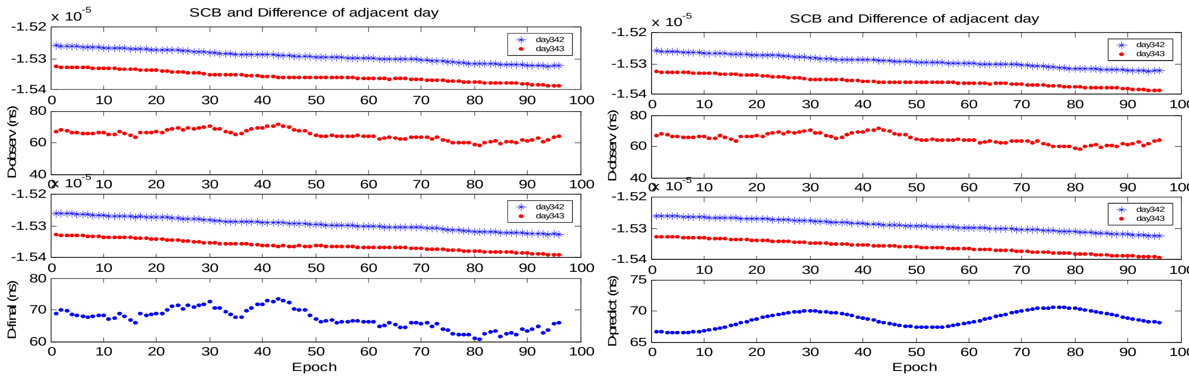

Fig.4 the differences of SCBs between two adjacent days for PRN-8

Figure 4 is another group of plots using SCBs data for PRN-8. The first and second plots in both left and right sides shows the observed SCBs for different days, and the differences between them, respectively. The third plot in the left side shows the final SCBs, and the third plot in the right side shows the predicted SCBs. The differences in the final SCBs between two adjacent days and in the predicted SCBs are shown in the fourth plot of left side and right side, respectively. Comparing the second and fourth plots in the left side and the right side, one can see that the differences of the observed SCBs between two days have a similar trend to the differences of the final SCBs, but not the case for the differences of the predicted SCBs. Table 2 gives the correlation coefficients between the two day's SCBs, where (O-F)[x] and (P-O)[x] stand the differences between the observed and final SCBs for day x, respectively, and O[7-8], F[7-8], and P[7-8] represent the differences between days 7 and 8 observed, final, and predicted SCBs, respectively. From the table it is clear that the two adjacent day differences between the observed and final SCBs exhibits a strong correlation, but not so for the differences between the predicted and observed SCBs. Also a strong correlation exists for the differences of two adjacent day's observed SCBs versus the differences of two adjacent day's final SCBs, while no clear indication for the predicted versus the observed.

Table 2 the correlation coefficients in adjacent day's SCBs

Satellite	(O-F)[7] versus (O-F)[8]	(P-O)[7] versus (P-O)[8]	O[7-8] versus F[7-8]	P[7-8] versus O[7-8]
PRN-1	0.9622	0.5237	0.9996	0.6484
PRN-3	0.9912	-0.5867	0.9995	-0.5282
PRN-8	0.9944	0.1785	0.9997	-0.2961
PRN-16	0.9945	-0.6054	0.9260	-0.0184
PRN-30	0.9920	0.9206	0.9995	0.9594

3. SCB PREDICTION

Three prediction models, i.e., the GM, LM, and QPM, will be used to predict the 24 hour-SCBs using the previous day's observed SCBs. The prediction accuracy will be evaluated.

3.1 Grey Model (GM)

The grey model is discussed in detail in (Deng, 1987; Yan and Dai, 1989; Zhao, 1997; Jiao, 2003; and Cui, 2005). The modified GM by Zheng and Chen (2007) reads

$$\hat{x}^{(0)}(k+p) = \left[x^{(0)}(1) - \frac{b}{a} \right] e^{-a \cdot \lambda \cdot (k+p-1)} \cdot (1 - e^{a}) .$$

Where, k is the number of original data used for prediction; p is the prediction point and $p \in Z$; a, b are constants; λ is an exponent coefficient (EC). Taking the SCB data of PRN-1 on 7 Dec. 2004 as an example, we applied the GM to predict the SCBs of the adjacent-day (i.e., 8 Dec. 2004). Here the observed SCBs were used as references because they have small differences with the final products. We took k=10 as the number of initial epochs and 15 minutes as sampling interval. Figure 5 shows the predicted SCBs and the computed EC values using the reverse analysis method. The second plot in the left side of the figure tells the prediction error is about 5~10ns. Table 3 gives the statistics, where the P-O (Ultra) means the differences between observations and predictions from IGS Ultra-rapid products, and the P-O (GM) means the differences between observations and predictions with the GM. One can see that the prediction precision with the GM is better than that of Ultra-rapid product, and the accuracy of the GM-predicted SCBs is about 2-3ns, but about 10ns from the Ultra-rapid product.

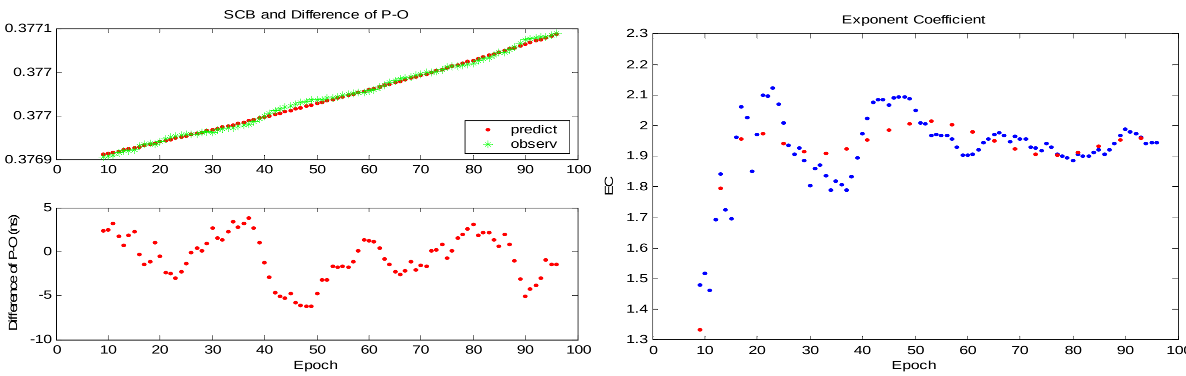

Fig.5 the SCB predictions and model EC of PRN-1 on 7th Dec. 2004

Table 3 the statistics of SCB prediction precision and model EC for PRN-1

	Max (ns)	Min (ns)	Mean (ns)	Std (ns)
P-O (Ultra)	3.3240	-18.8910	-7.8584	5.5121
P-O (GM)	3.8422	-6.1804	-0.6438	2.5733
EC	2.12	1.46	1.93	0.25

Figure 6 shows the predicted values for PRN-1 on 8 Dec. 2004. In the left plots EC is fixed as 2.2. The EC values computed from the observed SCBs of 8 Dec. 2004, using the reverse analysis method, are plotted in the right side. One can see the EC values are significantly different from those on 7 Dec. It is therefore expected that the prediction accuracy using the EC of 7 Dec. is low.

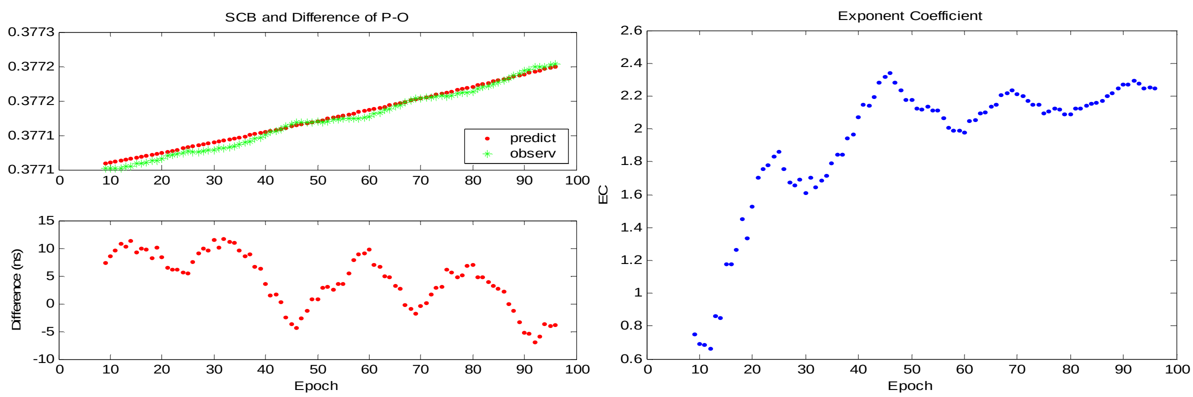

Fig.6 the predicted SCBs and model EC for PRN-1 on 8 Dec. 2004

Figure 7 shows the differences in the prediction errors using different EC values. In the prediction the initial values were took the first 10 epochs of 8th. The left plots are the results with an average EC from the data on 7 Dec., while the right plots the results with corresponding EC values on 7 Dec. One can see that the different prediction results are obtained with different EC values, and the predictions precision is too low with the EC computed by the previous-day's SCB observations.

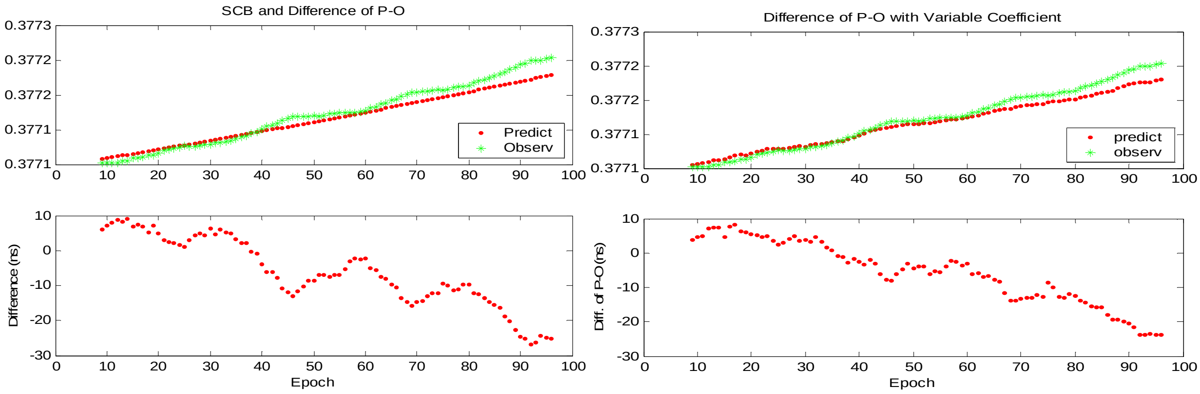

Fig.7 the SCB predictions of PRN-1 on 8th (left: with an average EC of 7th; right: with corresponding EC of 7th)

Figure 8 gives the SCB predictions for two adjacent days (7th and 8th) with the EC computed by SCB observations on 7th. The initial values are at the first 10 epochs of 7th. From the left plots, we can see the prediction errors increase rapidly when predictions are made for 8th. The right plot shows the ECs computed from the IGS ultra-rapid observations on 7th and 8th. It is obvious that EC values for both days are not correlated. The statistics of SCB predictions and model EC of PRN-1 on 8th are given in table 4.

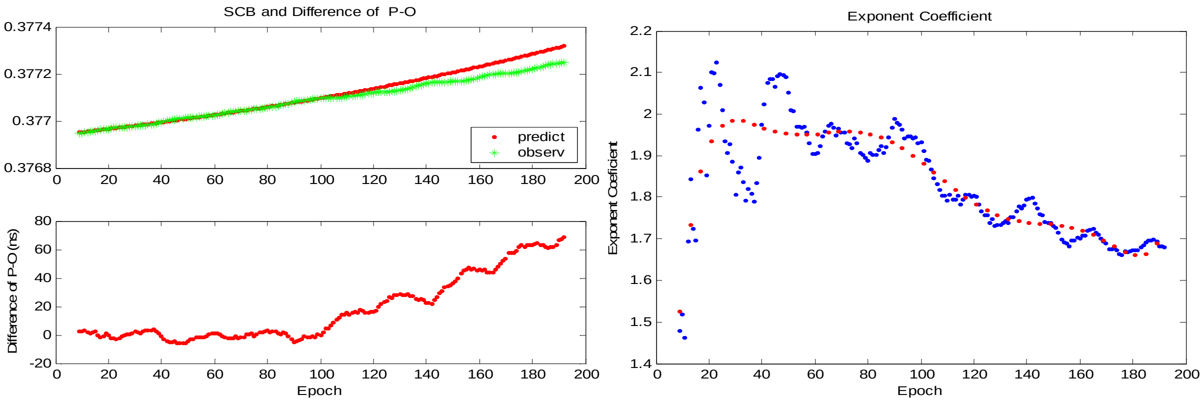

Fig.8 the SCB prediction and model EC of PRN-1 at 7th and 8th

Table 4 the statistics of SCB prediction and model EC of PRN-1 at 8th

	Max	Min	Mean	Std
P-O (Ultra)	13.5219	-5.0710	4.4704	4.1799
P-O(GM)2.2	11.6770	-6.9395	4.2645	4.8789
P-O(GM) average	8.9629	-26.9629	-6.2155	9.7608
P-O(GM) Corresponding	8.2244	-23.8212	-5.6662	9.0345
EC	2.34	0.66	1.92	0.41

3.2 Linear model (LM)

We used the LM based on the SCB observations of 7^{th} to predict the SCB of 8^{th}. Figure 9 shows the residuals of SCBs after fitting a linear function into the data (left plot) and the discrepancies between the predict SCBs of the 8^{th} and the observations (right plot). Table 5 lists the statistics. The results tell us that the precision of prediction (Std) using the LM is about 5.7ns, lower than IGS prediction. However, there is a significant bias of 4.5ns in the IGS predictions. The accuracy of the prediction with the LM is therefore higher.

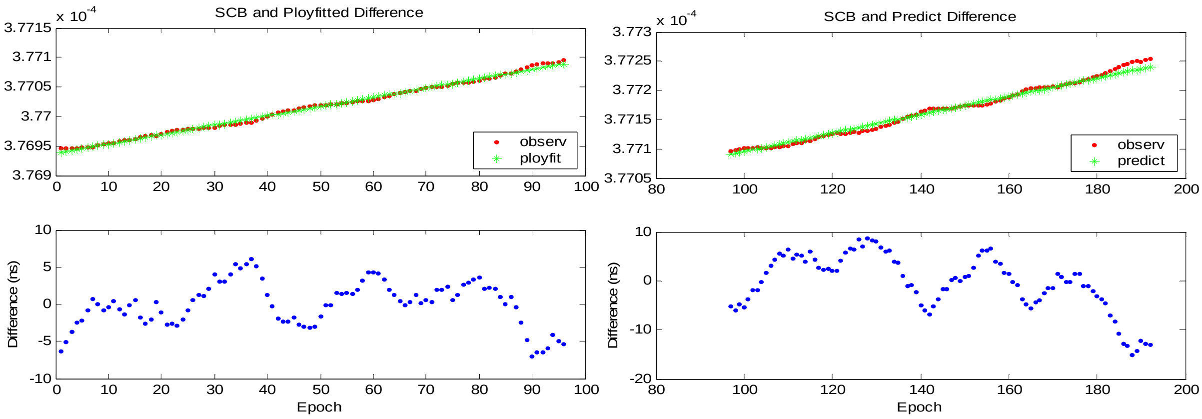

Fig.9 Prediction of 8^{th} SCBs based on a LM fitting to the data from 7^{th} Dec. 2004

Table5 the fitting and prediction statistics with the LM

	LM	Max	Min	Mean	Std
7	P-O (Ultra)	3.3240	-18.8910	-7.8584	5.5121
	P-O (Ployfit)	6.1160	-7.0168	0	2.9759
8	P-O (Ultra)	13.5219	-5.0710	4.4704	4.1799
	P-O (Predict)	8.7475	-15.0471	-0.2785	5.6836

3.3 Quadratic Polynomial Model (QPM)

Similar to the LM, we used the QPM to fit a quadratic polynomial function into the data of the 7^{th}. The estimated function was then used to predict the SCBs of the 8^{th}. The results are in Figure 10 and table 6. It is clear that the results are not as good as those with the LM.

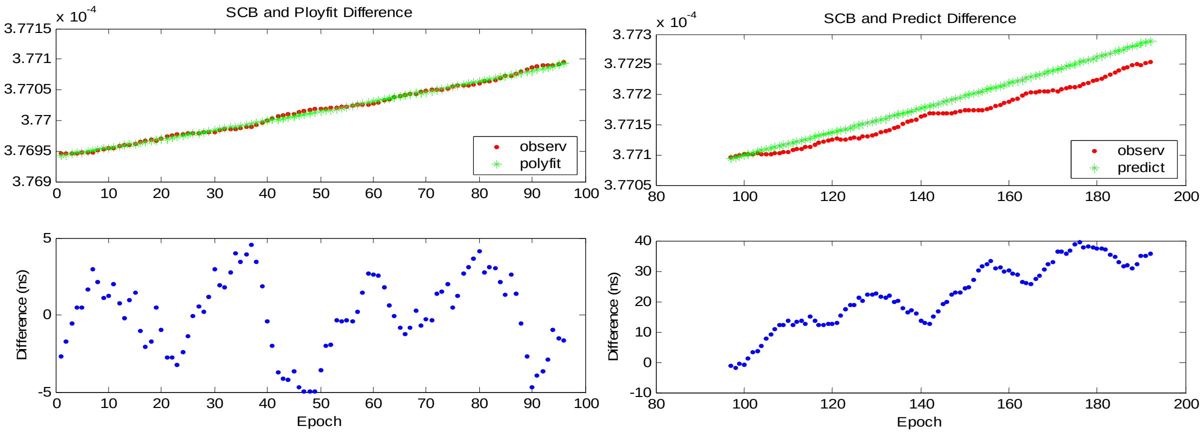

Fig.10 Predicting 8th SCB according to QPM fitted from 7th Dec. 2004

Table 6 the fitting and prediction residual statistics with QPM

	QPM	Max	Min	Mean	Std
7	P-O (Ultra)	3.3240	-18.8910	-7.8584	5.5121
	P-O (Ployfit)	4.5566	-4.9961	0	2.4470
8	P-O (Ultra)	13.5219	-5.0710	4.4704	4.1799
	P-O (Predict)	39.3848	-1.8073	22.3285	10.8388

Table 7 summarizes the results for other satellites. When measuring the accuracy of the predicted values two components of the Std and the bias must be taken into account. From the table one can conclude that in general, the QPM predicted SCBs have lower accuracy than the IGS predictions, and the LM produces the SCBs with similar accuracy to the IGS predictions.

Table7 the statistics of the SCB predictions with the LM and QPM

Sat.	Time	Method	LM				QPM			
			Max	Min	Mean	Std	Max	Min	Mean	Std
PRN-3	7	P-O (Ultra)	9.2140	0.9450	5.0954	2.4319	9.2140	0.9450	5.0954	2.4319
		P-O (Ployfit)	2.2647	-3.2010	0	1.2782	2.2836	-3.0807	0	1.2733
	8	P-O (Ultra)	5.5600	-9.7489	-3.7058	4.0162	5.5600	-9.7489	-3.7058	4.0162
		P-O (Predict)	7.4437	-10.2702	2.6100	4.1438	6.8339	-11.5840	4.0934	4.6994
PRN-8	7	P-O (Ultra)	6.9199	-0.05199	2.8181	1.6533	6.9199	-0.05199	2.8181	1.6533
		P-O (Ployfit)	3.3040	-3.9879	0	1.4799	3.3912	-4.0931	0	1.4651
	8	P-O (Ultra)	5.4509	-6.8889	-0.9107	3.6734	5.4509	-6.8889	-0.9107	3.6734
		P-O (Predict)	5.3204	-6.5887	1.3065	3.5088	7.5653	-2.7162	1.4807	2.6244
PRN-16	7	P-O (Ultra)	1.6639	0.0960	0.8352	0.4271	1.6639	0.0960	0.8352	0.4271
		P-O (Ployfit)	0.3728	-0.5476	0	0.1888	0.3899	-0.5379	0	0.1871
	8	P-O (Ultra)	-0.2989	-1.3190	-0.9246	0.2525	-0.2989	-1.3190	-0.9246	0.2525

		P-O (Predict)	-0.2874	-1.1982	0.8088	0.2040	-0.3459	-1.6130	1.1493	0.2816
PRN-30	7	P-O (Ultra)	7.1110	-0.0060	4.1524	1.8166	7.1110	-0.0060	4.1524	1.8166
		P-O (Ployfit)	0.9684	-1.4057	0	0.5633	0.8662	-1.0729	0	0.5202
	8	P-O (Ultra)	6.1799	-0.7549	2.1653	1.8332	6.1799	-0.7549	2.1653	1.8332
		P-O (Predict)	9.1972	-0.3974	3.8953	2.5176	15.4028	0.0985	6.7802	4.1914

4. CONCLUSIONS

The IGS produces SCB predictions, which are the weighted average of the results obtained by the IGS Analysis Centers. Each center may use different prediction methods. This paper compared the IGS predictions with those obtained with the GM, LM and QPM methods.

From the testing and analyzing the data of two adjacent days, some preliminary observations are made as follows.

— The predicted SCBs from the previous-day observations with the LM have similar accuracy as the IGS products;

— The QPM can not generate better results than the IGS products;

— We can get more accurate predictions with the GM as long as the EC is properly selected. This is the area worth exploring.

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BIOGRAPHICAL NOTES

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