3.5.2 Rapid Service/Prediction Centre

Processing Techniques

The algorithm used by the IERS Rapid Service/Prediction Centre for the determination of the quick-look Earth Orientation Parameters (EOP) is based on a weighted cubic spline with adjustable smoothing fit to contributed observational data (McCarthy & Luzum, 1991a). Contributed data are corrected for possible systematic differences. Biases and rates are determined with respect to the C04 system of the IERS Earth Orientation Centre (EOC). Statistical weighting used in the spline is proportional to the inverse square of the estimated accuracy of the individual techniques. Minimal smoothing is applied, consistent with the estimated accuracy of the observational data.

Weights in the algorithm may be either a priori values estimated by the standard deviation of the residual of the techniques or values based on the internal precision reported by contributors. Estimated accuracies of data contributed to the IERS Rapid Service/Prediction Centre are given in Table 1. These estimates are based on the statistical reports that were generated weekly as a part of the Bulletin A Rapid Service EOP solution for 2004.

Operationally, the weighted spline uses as input the epoch of observation, the observed value, and the weight of each individual data point. The software computes the spline coefficients for every data point which are then used to interpolate the Earth orientation parameter time series so that x, y, UT1–UTC, $\delta\psi$, and $\delta\varepsilon$ values are

Table 1. Estimated accuracies of the techniques in 2004. Units are milliseconds of arc for x, y, $\delta\psi$, $\delta\varepsilon$, dX, and dY and milliseconds of time for UT1–UTC and LOD.

Contributor Information	Estimated Accuracy					
Name, Sample Rate[1], Type	x	y	UT1	LOD	$\delta\psi$ (dX)	$\delta\varepsilon$ (dY)
CSR 3-day SLR	0.43	0.36	0.103*			
DUT daily SLR	0.32	0.33				
IAA daily SLR	0.18	0.18				
MCC daily SLR	0.17	0.15				
GSFC daily VLBI Int			0.025			
SPBU daily VLBI Int			0.022			
GSFC twice-weekly VLBI	0.11	0.09	0.003		0.4	0.1
IAA[2] twice-weekly VLBI	0.10	0.09	0.004		(0.1)	(0.1)
IVS twice-weekly VLBI	0.06	0.07	0.003		0.4	0.1
USNO twice-weekly VLBI	0.10	0.08	0.004		0.4	0.1
IGS daily Final	0.07	0.05				
IGS daily Rapid	0.01	0.02		0.02*		
USNO daily GPS UT*			0.020*			
EMR daily GPS UT*			0.02*			
USNO daily AAM UT			0.013			

*All satellite techniques provide information on the rate of change of Universal Time contaminated by effects due to unmodeled orbit node motion. VLBI-based results have been used to correct for LOD biases and to minimize drifts in UT estimates.

[1] The sample rate of provided data sets and not the series update rate.

[2] IAA VLBI celestial pole offsets are in terms of dX/dY using IAU 2000A Nutation Theory.

computed at the epoch of zero hours UTC for each day. Since the celestial pole offset software is written in terms of $\delta\psi$ and $\delta\varepsilon$, the IAA VLBI dX and dY values are converted to $\delta\psi$ and $\delta\varepsilon$ for the combination process. The only data points that are excluded from this process are the points whose errors, as reported by the contributors, are greater than three times their average reported precision or those points that have a residual that is more than four times the associated a priori error estimate. Since all of the observations are reported with the effects of sub-daily variations removed, no processing is done to account for these effects (see IERS Gazette No. 13, 30 January 1997).

Table 2. Mean and standard deviation of the differences between the Rapid Service/Prediction Center solutions and IERS Bulletin B and C04 EOP solutions for 2004. Polar motion X and Y values are in milliseconds of arc and UT1–UTC values are in units of milliseconds of time.

	Bulletin A – Bulletin B		Bulletin A – C04	
	Mean	Std. Deviation	Mean	Std. Deviation
Bulletin A Rapid Running Solution (finals.data)				
X	–0.09	0.11	–0.12	0.12
Y	0.07	0.08	0.07	0.11
UT1–UTC	0.000	0.032	0.001	0.052
Bulletin A Weekly Solution (finals.data)[1]				
X	–0.08	0.10	–0.12	0.11
Y	–0.01	0.08	–0.02	0.11
UT1–UTC	0.008	0.053	0.009	0.067
Bulletin A Daily Solution (finals.daily)				
X	–0.07	0.13	–0.11	0.13
Y	–0.02	0.12	–0.02	0.14
UT1–UTC[2]	–0.011	0.067	–0.010	0.079

[1] Statistics computed over the 7-day combination solution period prior to solution epoch.

[2] Standard deviation computed over entire year, excluding periods with known VLBI intensive data problems and GPS rapid data issues.

The uncertainties in the daily values listed in Bulletin A are derived from the quality of the spline fit in the neighborhood of the day in question. Table 2 shows the accuracies of Rapid Service/Prediction Centre's combination solution for the running, the weekly, and the daily products compared to the Bulletin B and C04 series maintained by the IERS EOC at the Paris Observatory. The running solution is the combination solution over the past 365-day period. The statistics for the running solution at year's end shows the agreement between the Bulletin A running combination solution and the Bulletin B/C04 series for the entire year. The statistics for the weekly solution are computed from the combination results for the 7-days prior to the solution epoch for each of the 53 weeks. The statistics for the daily solution are the differences for the day of the solution epoch. EOP accuracies for the Bulletin A rapid weekly solution for the new combination for the day of the solution run and daily solution at the time of solution epoch are similar and therefore, not included in the table.

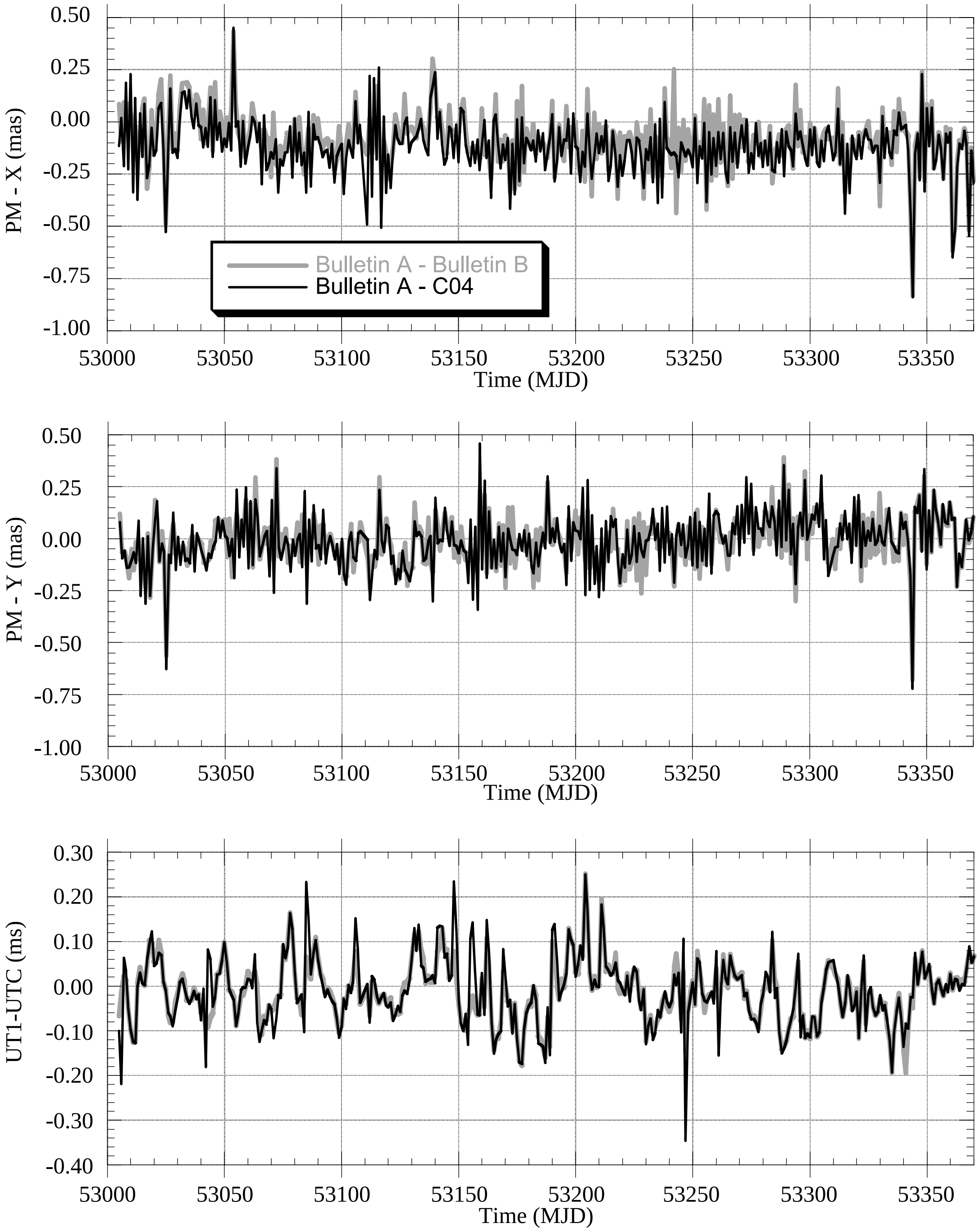

Fig. 1: Differences between Daily Bulletin A Rapid Solutions at each daily solution epoch for 2004 and the Earth Orientation Parameters available in Bulletin B and C04 series produced in March of 2005.

Figure 1 displays the data used in Table 2 for the determination of the Bulletin A daily solution statistics. Our analysis determined that the periods with larger residuals appear to be the result of one or more of the following: large latency of VLBI data, VLBI 24-hour sessions for which a station or two dropped out or had a large number of dropped scans, VLBI intensives with low observation numbers (UT1–UTC only), network problems with respect to obtaining the daily IGS EOP rapid files, or IGS rapid data that caused the UT1–UTC combination to fail. The Centre activities section provides more details. Overall, the agreement between the Bulletin A solutions and the IERS EOC solutions is quite good.

Prediction Techniques

Polar motion predictions are based on the extrapolation of an annual and semiannual ellipse and a Chandler circle fit to the previous 400 days of observed values of x and y (McCarthy and Luzum, 1991b; Johnson, 2002). The differences between the last observed pole position and rate and those of the curve are computed. These differences are then used to adjust the extrapolated curve by an amount that decreases with the length of the forecast. In February 1998, the near-term polar motion predictions (less than about 30 days) were improved significantly by modifying the transition process from the last observed polar motion result to the long-term predictions. Continuity in the first derivatives was enforced placing great weight on the observed polar motion rate reported by the IGS in their Rapid series. The improvement was most pronounced for the shortest prediction intervals. The procedure for UT1–UTC involves a simple technique of differencing (McCarthy and Luzum, 1991b). All known effects such as leap seconds, solid Earth zonal tides, and seasonal effects are first removed from the observed values of UT1–UTC. Then, to determine a prediction of UT1–UTC n days into the future, $(\mathrm{UT1{-}TAI})_n$, the smoothed time value from n days in the past, $<(\mathrm{UT1R{-}TAI})_{-n}>$ is subtracted from the most recent value, $(\mathrm{UT1R{-}TAI})_o$

$$(\mathrm{UT1{-}TAI})_n = 2(\mathrm{UT1R{-}TAI})_o - <(\mathrm{UT1R{-}TAI})_{-n}>.$$

The amount of smoothing used in this procedure depends on the length of the forecast. Short-term predictions with small values of n make use of less smoothing than long-term predictions. Once this value is obtained, it is possible to account for known effects in order to obtain the prediction of UT1–UTC. This process is repeated for each day's prediction.

The very near-term UT1–UTC prediction is strongly influenced by the observed daily Universal Time estimates derived at USNO from the motions of the GPS orbit planes reported by the IGS Rapid service. The IGS estimates for LOD are combined with the GPS-based UT estimates to constrain the UT1 rate of change for the most recent observation.

The near-term to sub-monthly UT1–UTC prediction also makes use of a UT1-like data product derived from the operational NCEP AAM analysis and forecast data (UTAAM). For the 5 days after the latest observation, AAM-based predictions of LOD excitation are combined smoothly with the longer-term UT1 predictions described above.

Errors of the estimates are derived from analyses of the past differences between observations and the published predictions. Formulas published in Bulletin A are used to extend the tabular data. The predictions of $\delta\psi$ and $\delta\varepsilon$ are based on the IERS Conventions (McCarthy, 1996; McCarthy and Petit, 2004). Table 3 shows the standard deviation of the differences between the Bulletin A daily solution predictions and the C04 solution for 2003. Initial Centre estimates indicated that the UT1–UTC prediction performance would be improved by 42% at 10 days into the future (Johnson et al., 2005). However, comparisons of the UT1–UTC prediction performance from 2003 to those estimated in 2001 (before UTAAM was introduced) indicated a better than 50% improvement in prediction error at both 10 day and 20 days into the future by the addition of UTAAM to the combination and prediction routine.

Table 3. Standard Deviation of the differences between the Earth Orientation Parameter time series predictions produced by the Bulletin A Daily solutions and the C04 solutions for 2004.

Days in Future	PM–X	PM–Y	UT1–UTC
	mas	mas	ms
1	.46	.39	.129
5	2.26	1.66	.407
10	3.67	2.96	.935
20	6.09	4.77	3.00
40	8.87	6.74	5.43
90	12.7	10.2	10.9

The predictions of celestial pole offsets (both dX/dY and $\delta\psi/\delta\varepsilon$ representations) are based solely on VLBI data. If no new VLBI 24-hour session observations are available, a new rapid combination/prediction of these angles is not determined. Therefore, the predictions of celestial pole offset start before the solution epoch time and the length of the prediction into the future can and does vary in the daily solution files. The differences between the daily Bulletin A predictions and those of the C04 for 2004 are given in Table 4.

Predictions of UT1–TAI up to 2014 January 1, are given in Table 5. They are derived using a prediction algorithm similar to that employed in the Bulletin A predictions of UT1–UTC. Up to twenty years of past observations of UT1–TAI are used. Estimates of the expected one-sigma error for each of the predicted values are also given. These are based on analyses of the past performance of the model with respect to the observations.

Table 4. Standard Deviation of the differences between the Celestial Pole Offset time series predictions produced by the Bulletin A Daily solutions and the C04 solutions for 2004.*

Days in Future	dX mas	dY mas	$\delta\psi$ mas	$\delta\varepsilon$ mas
1	.09	.14	.27	.18
5	.10	.17	.27	.18
10	.12	.17	.28	.19
20	.13	.18	.28	.19
40	.13	.21	.30	.22

*Bulletin B combination used for dX and dY.

Additional information on improvements to IERS Bulletin A and the significance for predictions of GPS orbits for real-time users is provided in the papers by Luzum et al. (2001) and Wooden et al. (2004).

Centre Activities in 2004

During 2004 a number of changes occurred that affected the performance of IERS Bulletin A. In January a few routines in the combination process required modification. Some of these changes reduced the number of initializations required at the beginning of a new year.

In February biases and rates of the IVS VLBI series were adjusted to reduce their residuals and a library of SOFA routines was added. Unfortunately, the x-component of polar motion was over corrected which introduced a small drift. Shortly after this, new VLBI solutions were released by GSFC and the following week by USNO. The addition of these new solutions obscured the problem which required a couple of weeks to detect and correct. However, by this time a small bias had been introduced into the x-component of polar motion. The bias in the y-component of polar motion between the C04 and the Bulletin A was reduced.

In the April-May timeframe a number of software-related issues became apparent and a major effort was undertaken to update a number of our routines to FORTRAN90. The major enhancement was to shift from explicitly-sized arrays to dynamically-allocated arrays.

In June a sign error was discovered and corrected in the tidal correction algorithm used for GPS data. A new VLBI intensive data set became available from USNO's VLBI analysis group. After a careful evaluation of this data set, it was added to our weekly solution on 4 November. Improved data checks and editing criteria for VLBI were also incorporated into our combination process.

Table 5. Predicted values of UT1–TAI, 2005–2014. Note that TT–UT1 can be obtained from this table using the expression TT–UT1=32.184s – (UT1–TAI).

DATE		UT1-TAI (s)	Uncertainty (s)
2005	Jan 1	–32.50	.02
	Apr 1	–32.57	.02
	Jul 1	–32.61	.03
	Oct 1	–32.58	.03
2006	Jan 1	–32.62	.04
	Apr 1	–32.67	.04
	Jul 1	–32.69	.06
	Oct 1	–32.72	.07
2007	Jan 1	–32.76	.08
	Apr 1	–32.8	.1
	Jul 1	–32.9	.2
	Oct 1	–32.9	.2
2008	Jan 1	–33.0	.3
	Apr 1	–33.0	.4
	Jul 1	–33.1	.5
	Oct 1	–33.2	.6
2009	Jan 1	–33.4	.8
	Apr 1	–33.8	.9
	Jul 1	–33.7	1.
	Oct 1	–34	1.
2010	Jan 1	–34.	1.
	Apr 1	–34.	1.
	Jul 1	–34.	1.
	Oct 1	–34.	2.
2011	Jan 1	–34.	2.
	Apr 1	–34.	2.
	Jul 1	–34.	2.
	Oct 1	–34.	2.
2012	Jan 1	–34.	2.
	Apr 1	–34.	2.
	Jul 1	–34.	3.
	Oct 1	–34.	3.
2013	Jan 1	–34.	3.
	Apr 1	–34.	3.
	Jul 1	–34.	3.
	Oct 1	–34.	3.
2014	Jan 1	–34.	4.

In November the software was modified to handle the VLBI K-series and the non-standard I-series intensives. The non-standard I-series involving the Svetloe station required special editing until the VLBI analysis centers were able to provide a new global solution for the station position.

On 20 and 27–28 November and 4–5 December, the inclusion of the IGS Rapid solution resulted in a bad combination solution for UT1–UTC. Therefore, the IGS Rapid solution was removed on those dates and the polar motion solution on those days had larger than normal errors.

Availability of Rapid Service

The data available from the IERS Rapid Service/ Prediction Centre consist mainly of the data used in the IERS Bulletin A. These data include: x, y, UT1–UTC, dX and dY from IAA VLBI; x, y, UT1–UTC, $\delta\psi$ and $\delta\varepsilon$ from GSFC VLBI; x, y, UT1–UTC, $\delta\psi$ and $\delta\varepsilon$ from USNO VLBI; x, y, UT1–UTC, $\delta\psi$ and $\delta\varepsilon$ from IVS combination VLBI; UT1–UTC from Saint Petersburg University 1-day Intensives; UT1–UTC from GSFC 1-day Intensives; UT1–UTC from USNO 1-day Intensives; x, y, UT1–UTC from CSR LAGEOS 3-day SLR; x, y from Delft University of Technology 1-day SLR; x, y from Institute of Applied Astronomy 1-day SLR; x, y from the Russian Mission Control Centre 1-day SLR; x, y, LOD from the International GPS Service; UT from USNO GPS; UT from NRCanada (EMR) GPS; UT from NCEP AAM; x, y, UT1–UTC, $\delta\psi$ and $\delta\varepsilon$ from the IERS Rapid Service/Prediction Centre; x, y, UT1–UTC, $\delta\psi$ and $\delta\varepsilon$ from the IERS Earth Orientation Centre; and predictions of x, y, UT1–UTC from the IERS Rapid Service/Prediction Centre.

In addition to this published information, other data sets are available. These include: UT0–UTC from University of Texas as Austin LLR, UT0–UTC from JPL LLR; UT0–UTC from CERGA LLR; UT0–UTC from JPL VLBI; latitude and UT0–UTC from Washington PZTs 1,3,7; latitude and UT0–UTC from Richmond PZTs 2,6; x and y from CSR LAGEOS 5-day SLR; x and y from Delft 3- and 5-day SLR; and x, y, UT1–UTC, $\delta\psi$ and $\delta\varepsilon$ from IRIS VLBI.

The data described above are available from the Centre in a number of forms. You may request a weekly machine-readable version of the IERS Bulletin A containing the current ninety day's worth of predictions via electronic mail from

<ser7@maia.usno.navy.mil> or <http://maia.usno.navy.mil/>.

Internet users can also direct an anonymous FTP to

<maia.usno.navy.mil>

and change to the ser7 directory where the IERS Bulletin A and more complete databases can be accessed including the daily Bulletin solutions.

World Wide Web access is available at

<http://maia.usno.navy.mil/>.

Centre Staff

The Rapid Service/Prediction Centre staff consisted of the following members:

William Wooden	director
Thomas Johnson	program manager, research, and software maintenance
Arvid Myers	assists in operations, software maintenance, and support
Merri Sue Carter	assists in daily operations and support
Sebastien Lambert	research and software development

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