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 and Luzum, 1991a). Contributed data are corrected for possible systematic differences. Biases and rates are determined with respect to the 97 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 residuals between the series and the combined EOP solution for 2006.

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

Table 1: Estimated accuracies of the techniques in 2006. Units are milliseconds of arc for x, y, $\delta\psi$, $\delta\varepsilon$, dX, and dY and milliseconds of time for UT1-UTC.

Contributor Information	Estimated Accuracy				
Name, Type	x	y	UT1	$\delta\psi$ (dX)	$\delta\varepsilon$ (dY)
CSR SLR	0.32	0.49	0.059*		
DUT SLR	0.35	0.37			
IAA SLR	0.18	0.18			
MCC SLR	0.18	0.21			
GSFC VLBI Intensives			0.018		
SPBU VLBI Intensives			0.018		
USNO VLBI Intensives			0.017		
GSFC VLBI	0.06	0.07	0.003	0.4	0.1
IAA[1] VLBI	0.07	0.11	0.003	(0.1)	(0.1)
IVS VLBI	0.10	0.08	0.004	0.4	0.1
USNO VLBI	0.07	0.09	0.003	0.4	0.1
IGS Final	0.04	0.04			
IGS Rapid	0.03	0.03			
USNO GPS UT*			0.015*		
EMR GPS UT*			0.028*		
USNO AAM UT			0.010		

*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] IAA VLBI nutation values are in terms of dX/dY using IAU 2000A Nutation Theory.

parameter time series so that x, y, UT1–UTC, dψ, and dε values are computed at the epoch of zero hours UTC for each day. Since the celestial pole offset software is written in terms of dψ and dε, the IAA VLBI dX and dY values are converted to dψ and dε for the combination process. The LOD are derived from the UT1–UTC data. The analytical expression for the first derivative of the cubic spline passing through the UT1–UTC data is used to estimate the LOD at the epoch of the UT1–UTC data.

The only data points that are excluded from the combination 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, the input data are not corrected for these effects (see IERS Gazette No. 13, 30 January 1997).

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 97 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 show the agreement between the Bulletin A running combination solution and the Bulletin B/97 C04 series for the entire year. The comparison of the

Table 2: Mean and standard deviation of the differences between the Rapid Service/Prediction Centre solutions and IERS Bulletin B and C04 EOP solutions for 2006. 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 - 97 C04	
	Mean	Std. Deviation	Mean	Std. Deviation
Bulletin A Rapid Solution (finals.data)				
X	-0.06	0.05	-0.06	0.05
Y	0.00	0.06	0.00	0.06
UT1-UTC	-0.003	0.015	-0.002	0.014
Bulletin A Weekly Solution (finals.data)[1]				
X	0.00	0.06	0.00	0.06
Y	-0.05	0.05	-0.06	0.05
UT1-UTC[2]	0.013	0.025	-0.014	0.035
Bulletin A Daily Solution (finals.daily)				
X	0.00	0.11	0.00	0.11
Y	-0.06	0.10	-0.06	0.10
UT1-UTC[2]	0.009	0.065	-0.010	0.064

[1] Statistics computed over the 7 day combination solution period prior to solution epoch.
[2] Standard deviations including periods of known VLBI intensive and GPS rapid data issues.

52 weekly solutions to the Bulletin B/97 C04 series gives the statistics of the residuals computed over the new combination results for the 7 days prior to the solution epoch. 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.

Figure 1 shows the residuals between the daily Bulletin A rapid solution and two other series (i.e., Bulletin B and 97 C04) and presents the data used in Table 2 for the determination of the Bulletin A daily solution statistics. This year Bulletin A had only small reductions in the mean difference while he standard deviations were mostly comparable. 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, $(UT1{-}TAI)_n$, the smoothed time value from n days in the past, $\langle(UT1R{-}TAI)_{-n}\rangle$ is subtracted from the most recent value, $(UT1R{-}TAI)_0$

$$(UT1{-}TAI)_n = 2(UT1R{-}TAI)_0 - \langle(UT1R{-}TAI)_{-n}\rangle.$$

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.

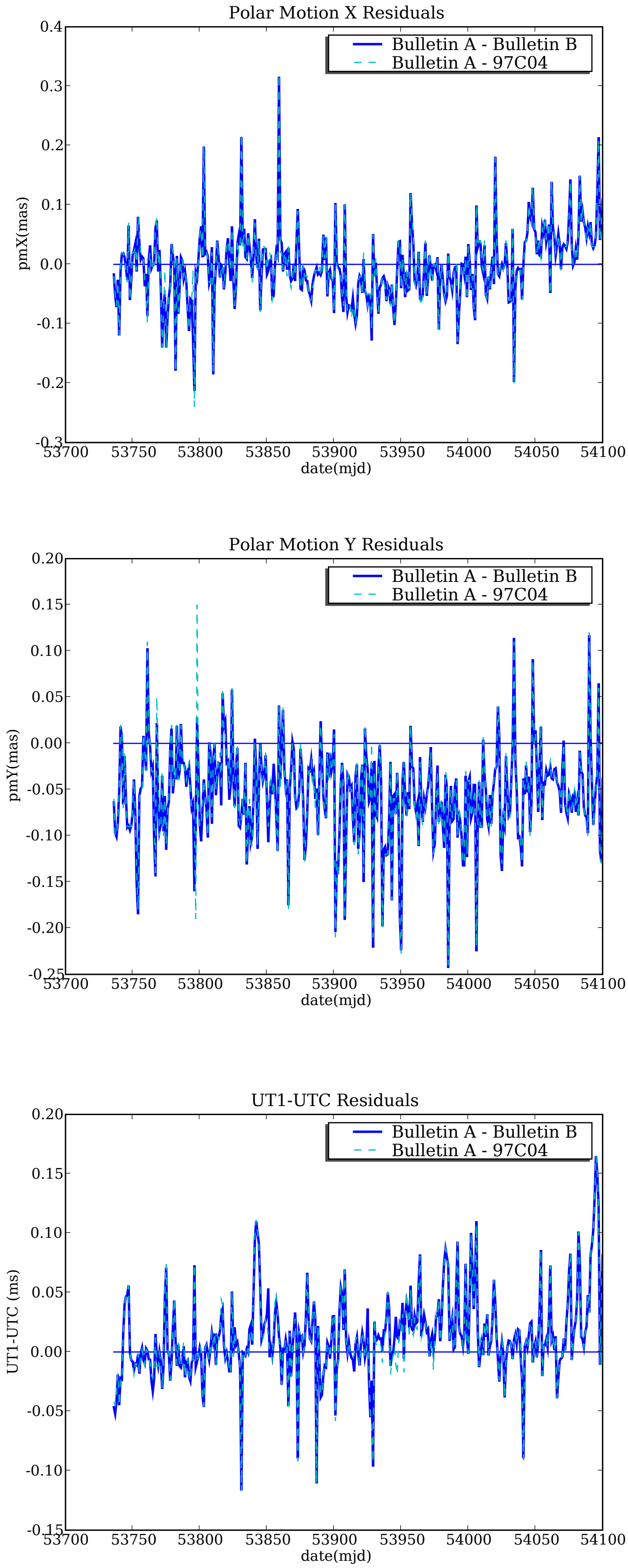

Fig. 1: Differences between daily Bulletin A rapid solutions at each daily solution epoch for 2006 and the Earth orientation parameters available in Bulletin B and 97 C04 series produced in July 2007.

The UT1–UTC prediction out to a few days 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 UT1–UTC prediction also makes use of a UT1-like data product derived from the operational NOAA AAM analysis and forecast data (UTAAM). In September 2006, the U.S. Navy NOGAPS AAM data were combined with the NOAA AAM data. AAM-based predictions are used to determine the UT1 predictions out to a prediction length of 5 days. For longer predictions, the LOD excitations 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 can be 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 97 C04 solution for 2006. Initial estimates indicated that the UT1-UTC prediction performance would be improved by 42% at 10 days into the future by the addition of UTAAM to the combination and prediction process (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.

For 2006, the prediction errors were fairly comparable to those of 2005. Note that the statistics reported in Table 3 have been changed from standard deviation to root mean square to give a better indication of the overall accuracy of the predictions. The only unusual increase in error is for the 90-day UT1-UTC predictions that suffered from some unusually large prediction errors in the beginning of 2006. Excluding these predictions, the errors were more consistent with past prediction errors. The longer-term polar motion predictions also continued to have larger than historically computed errors. This is due to the presence of small sub-monthly retrograde loops in the polar motion. The operational prediction method does not solve for these loops although the least-squares plus autoregressive (LS+AR) polar motion prediction implemented in early 2007 may help in the future.

The predictions of celestial pole offsets (both dX/dY and $\delta\psi/\delta\varepsilon$ representations) are produced through the use of the KSV1996 model. In addition, a bias between the model and the last 20 days worth of celestial pole offset observations is computed. This bias is

Table 3: Root mean square of the differences between the Earth orientation parameter prediction series produced by the daily Bulletin A rapid solutions and the C04 combination solutions for 2006.

Days in Future	PM-x mas	PM-y mas	UT1-UTC ms
1	.42	.36	.147
5	2.33	1.51	.518
10	4.44	2.55	1.06
20	8.25	4.72	3.11
40	16.3	9.14	6.88
90	33.5	18.7	22.1

tapered so that as the prediction length is extended, the bias becomes increasingly small. Since celestial pole offsets 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 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 the 97 C04 for 2006 are given in Table 4.

Table 4: Root mean square of the differences between the nutation prediction series produced by the daily Bulletin A rapid solutions and the 97 C04 solution for 2006.

Days in Future	dX mas	dY mas	$\delta\psi$ mas	$\delta\varepsilon$ mas
1	.13	.16	.35	.16
5	.13	.16	.35	.16
10	.12	.16	.35	.17
20	.12	.16	.38	.18
40	.15	.17	.41	.20

Predictions of TT–UT1 up to 2016 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 TT–UT1 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 5: Predicted values of TT-UT1, 2007-2016. Note that UT1-TAI can be obtained from this table using the expression UT1-TAI = 32.184s - (TT-UT1).

DATE	TT–UT1 (s)	Uncertainty (s)
2007 Jan 1	65.146	0.000
2007 Apr 1	65.249	0.000
2007 Jul 1	65.341	0.000
2007 Oct 1	65.371	0.000
2008 Jan 1	65.466	0.008
2008 Apr 1	65.56	0.01
2008 Jul 1	65.64	0.02
2008 Oct 1	65.66	0.02
2009 Jan 1	65.8	0.2
2009 Apr 1	66.0	0.3
2009 Jul 1	66.2	0.4
2009 Oct 1	66.4	0.4
2010 Jan 1	66.5	0.5
2010 Apr 1	66.6	0.7
2010 Jul 1	66.8	0.8
2010 Oct 1	66.9	0.9
2011 Jan 1	67.	1.
2011 Apr 1	67.	1.
2011 Jul 1	67.	1.
2011 Oct 1	67.	1.
2012 Jan 1	68.	2.
2012 Apr 1	68.	2.
2012 Jul 1	68.	2.
2012 Oct 1	68.	2.
2013 Jan 1	68.	2.
2013 Apr 1	68.	2.
2013 Jul 1	68.	2.
2013 Oct 1	68.	3.
2014 Jan 1	69.	3.
2014 Apr 1	69.	3.
2014 Jul 1	69.	3.
2014 Oct 1	69.	3.
2015 Jan 1	69.	3.
2015 Apr 1	69.	3.
2015 Jul 1	69.	4.
2015 Oct 1	70.	4.
2016 Jan 1	70.	4.

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

Centre Activities in 2006

During 2006 a number of changes occurred that affected the performance of IERS Bulletin A. Electronic-VLBI (e-VLBI) became operational for certain aspects of the VLBI Intensive observations. Additional efforts included improving operational software, automating the process for updating data sets used in the combination, updating and monitoring currently used datasets, investigating potential new data sets, and investigating the improvement of polar motion prediction technique. Additional work on better establishing an alternate site to mirror data storage for the combination processing was carried out.

New global solutions were received from GSFC and USNO VLBI analysis centres. These new solutions were examined and new rates and biases were computed.

Collaborative efforts with colleagues at Poland's Center for Space Research showed the potential for improving our polar motion predictions by 20%–30% at 2 to 3 months into the future. Using updated software algorithms, efforts to utilize this new method into the operational software came to fruition with the incorporation of the algorithm in January 2007.

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 GNSS Service; UT from USNO GPS; UT from NRCanada (EMR) GPS; UT from NCEP AAM; UT from NAVY NOGAPS 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 through

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

Internet users can also direct an anonymous FTP to

<ftp://maia.usno.navy.mil/ser7>

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

Centre Staff

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

William Wooden	director
Thomas Johnson	program manager, research, and software maintenance
Brian Luzum	program manager, research, and software maintenance
Merri Sue Carter	daily operations and support assistance

At the end of October 2006, Thomas Johnson left USNO. Brian Luzum is now the program manager for the EOP Combination and Prediction Program. In the first half of 2007, Nicholas Stamatakos and Gillian Brockett joined the IERS Rapid Service and Prediction Centre.

References

Johnson, T.J, 2002, Rapid Service/Prediction Centre, *IERS Annual Report 2001*, 47–55.

Johnson, T.J, Luzum, B.J., and Ray, J.R., 2005, Improved near-term UT1R predictions using forecasts of atmospheric angular momentum, *J. Geodynamics*, **39**(3), 209.

Luzum, B.J., Ray, J.R., Carter, M.S., and Josties, F.J., 2001, Recent Improvements to IERS Bulletin A Combination and Prediction, *GPS Solutions,* **4**(3), 34.

McCarthy, D.D. and Luzum, B.J., 1991a, Combination of Precise Observations of the Orientation of the Earth, *Bulletin Geodesique,* **65**, 22.

McCarthy, D.D. and Luzum, B.J., 1991b, Prediction of Earth Orientation, *Bulletin Geodesique,* **65**, 18.

McCarthy, D.D. (ed.), 1996, IERS Conventions (1996), *IERS Technical Note* No. 21, Paris Observatory, France.

McCarthy, D.D. and G. Petit (eds.), 2004, IERS Conventions (2003), *IERS Technical Note* No. 32, Verlag des Bundesamts für Kartographie und Geodäsie, Frankfurt am Main, Germany.

Wooden, W.H., Johnson, T.J., Carter, M.S., and Myers, A.E., 2004, Near Real-time IERS Products, *Proc. Journées Systèmes de Référence Spatio-Temporels*, St. Petersburg, 22–25 Sept 2003, 160–163.

Wooden, W.H., Johnson, T.J., Kammeyer, P.C., Carter, M.S., and Myers, A.E., 2005, Determination and Prediction of UT1 at the

IERS Rapid Service/Prediction Center, *Proc. Journées Systèmes de Référence Spatio-Temporels*, Paris, 20–22 Sept 2004, 260–264.

Brian Luzum, Thomas Johnson, Merri Sue Carter,
Nicholas Stamatakos, Gillian Brockett, William Wooden