3.5.2 Rapid Service/Prediction Centre

Processing Techniques

The algorithm used by the IERS Rapid Service/Prediction Center 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 (before 14 June 2007) and 05 C04 (on and after 14 June 2007) systems of the IERS Earth Orientation Center (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 Center are given in Table 1. These estimates are based on the residuals of between the series and the combined RS/PC EOP solution for 2007.

Table 1: Estimated accuracies of the techniques in 2007. 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)
ILRS SLR	0.21	0.21			
IAA SLR	0.17	0.21			
MCC SLR	0.12	0.15			
GSFC VLBI Intensives			0.013		
SPbU VLBI Intensives			0.014		
USNO VLBI Intensives			0.013		
GSFC VLBI	0.07	0.08	0.003	0.4	0.1
IAA[1] VLBI	0.10	0.11	0.004	(0.1)	(0.1)
IVS[1] VLBI	0.10	0.15	0.003	(0.1)	(0.1)
USNO VLBI	0.08	0.12	0.005	0.4	0.1
IGS Final	0.02	0.02			
IGS Rapid	0.02	0.03			
IGS Ultra	0.05	0.06			
USNO GPS UT*			0.017*		
EMR GPS UT*			0.024*		
USNO AAM UT			0.011		

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

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 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 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).

Table 2: Mean and standard deviation of the differences between the Rapid Service/Prediction Center solutions and 97/05 C04 EOP solutions for 2007. Polar motion x and y values are in milliseconds of arc and UT1–UTC values are in units of milliseconds of time.

	Bulletin A – C04	
	Mean	Std. Deviation
Bulletin A Rapid Solution (finals.data)		
x	–0.04	0.04
y	–0.01	0.04
UT1–UTC	0.000	0.014
Bulletin A Weekly Solution (finals.data)[1]		
x	–0.02	0.06
y	–0.03	0.04
UT1–UTC	–0.014	0.029
Bulletin A Daily Solution (finals.daily)		
x	0.00	0.11
(before MJD 54265/after MJD 54300)[2]		(0.14/0.07)
y	–0.03	0.12
(before MJD 54265/after MJD 54300)[2]		(0.16/0.08)
UT1–UTC	0.012	0.060

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

[2] before MJD 54265 indicates the data compared against the 97 C04 and after MJD 54300 indicates the data after the implementation of the IGS Ultra in the combination procedures.

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 Center's combination solution for the running, the weekly, and the daily products compared to the 97/05 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 97/05 C04 series for the entire year. The comparison of the 52 weekly solutions to the 97/05 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 the 97/05 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 and standard deviations. The small bias difference in the polar motion x component appears to be due to different corrections for the change in the International GNSS Service (IGS) series due to the switch from relative phase center to absolute phase center corrections. The two large residuals in the daily polar motion in the early part of the year are the result of an unexpected change in input data format from a contributor. The larger difference in UT1–UTC is caused by differences in the way non-VLBI UT data sources are handled between the two centers. These UT1 differences are an area of ongoing investigation.

Prediction Techniques

In 2007, the algorithm for polar motion predictions was changed to incorporate the least-squares, autoregressive (LS+AR) method created by W. Kosek and improved by T. Johnson (personal communication, 2006). This method solves for a linear, annual, semiannual, 1/3 annual, 1/4 annual, and Chandler periods fit to the previous 400 days of observed values for x and y. This deterministic model is subtracted from the polar motion values to create residuals, which are more stochastic in nature. The AR algorithm is then used to predict the stochastic process while a deterministic model consisting of the linear, annual, semiannual, and Chandler terms is used to predict the deterministic process. The polar motion prediction is the addition of the deterministic and stochastic predictions. The additional unused terms in the deterministic solution help to absorb errors in the deterministic model caused by the variable amplitude and phase of the deterministic components (T. Johnson, personal

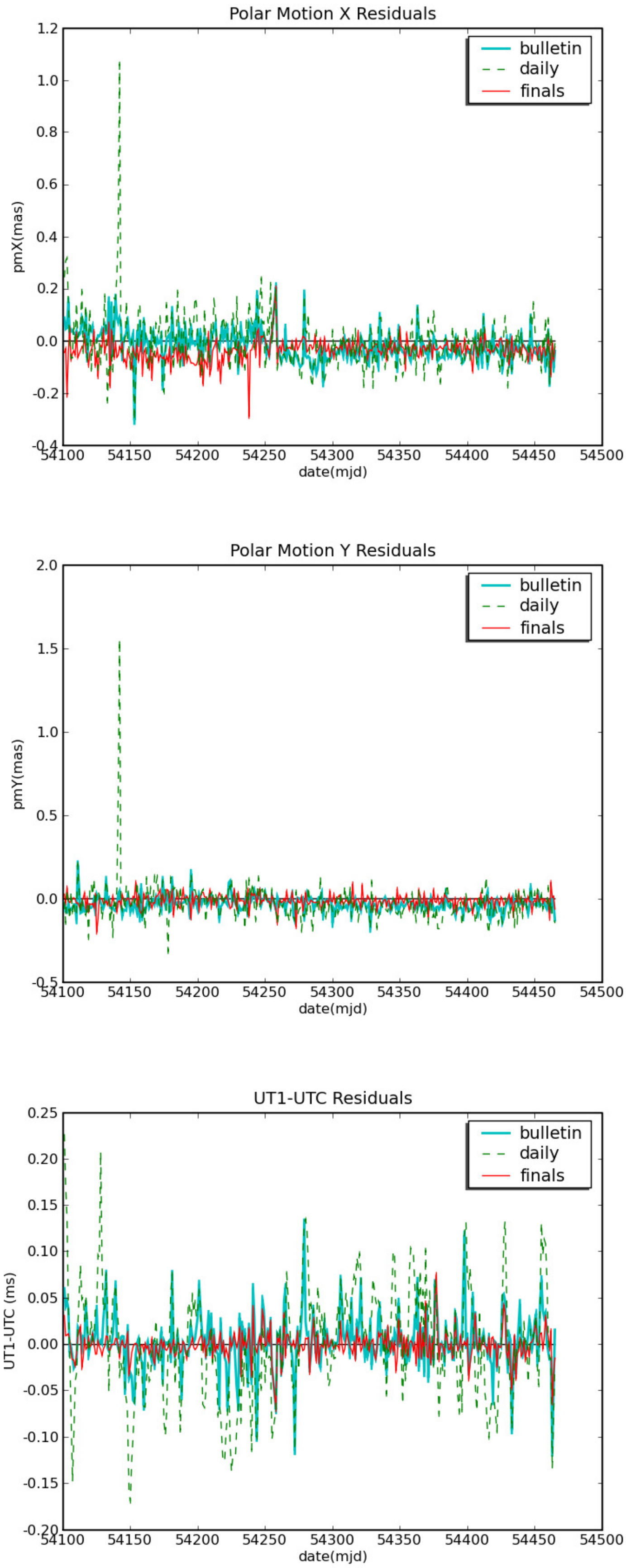

Fig. 1: Residuals between daily Bulletin A rapid solutions at each daily solution epoch for 2007 and the Earth orientation parameters available in 97/05 C04 series produced in April 2008.

communication, 2006). For more information on the implementation of the LS+AR model, see Stamatakos *et al.* (2008).

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, $(UT2R–TAI)_n$, the smoothed time value from n days in the past, $<(UT2R–TAI)_{-n}>$ is subtracted from the most recent value, $(UT2R–TAI)_0$

$$(UT2R–TAI)_n = 2(UT2R–TAI)_0 – <(UT2R–TAI)_{-n}>.$$

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 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 a combination of the operational NCEP and U.S. Navy NOGAPS AAM analysis and forecast data (UTAAM). 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. In October 2007, the length of AAM forecasts increased from 5 to 7.5 days. This change means that AAM forecasts are the basis of UT1 predictions out to 7 days. For more information on the use of the UT AAM data, see Stamatakos *et al.* (2008).

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 97/05 C04 solution for 2007. 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

Table 3: Root mean square of the differences between the EOP time series predictions produced by the daily Bulletin A rapid solutions and the 97/05 C04 combination solutions for 2007.

Days in Future	PM-x	PM-y	UT1–UTC
	mas	mas	ms
1	.42	.33	.141
1[1]	(.46/.37)	(.39/.28)	
5	2.06	1.33	.452
10	3.75	2.27	.921
20	6.92	4.26	3.29
40	12.1	8.47	7.77
90	15.3	17.7	13.4

[1] the first number indicates the data compared against the 97 C04 and the second number indicates the data after the implementation of the IGS Ultra in the combination procedures.

was introduced) indicated a better than 50% improvement in prediction error at both 10 day and 20 days into the future.

For 2007, the prediction errors were, in general, better than those of 2006. The polar motion predictions errors returned to historical levels as the amplitude of the polar motion loops is much smaller than the amplitude of the polar motion in 2007. The prediction of polar motion has been improved by the switch to the LS+AR prediction method. The UT1–UTC prediction shows a slight indication of improvement due to the switch from AAM forecast lengths being extended from 5 to 7.5 days. Further investigation to confirm this trend is needed.

The predictions of celestial pole offsets (both dX/dY and $\delta\psi/\delta\varepsilon$ representations) are produced through the use of the KSV1996 model (McCarthy, 1996). In addition, a bias between the model and the last 20 days worth of celestial pole offset observations is computed. This bias is tapered so that as the prediction length is ex-

Table 4: Root mean square of the differences between the nutation prediction series produced by the daily Bulletin A rapid solutions and the 97/05 C04 solution for 2007.

Days in Future	dX	dY	$\delta\psi$	$\delta\varepsilon$
	mas	mas	mas	mas
1	.11	.12	.33	.14
5	.11	.12	.33	.14
10	.11	.11	.34	.14
20	.11	.11	.33	.15
40	.11	.11	.34	.16

tended, 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 97/05 C04 for 2007 are given in Table 4.

Predictions of TT–UT1 up to 2017 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.

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; Stamatakos et al. 2008).

Center Activities in 2007

During 2007 a number of changes occurred that affected the performance of IERS Bulletin A. On 14 June, the system of the Bulletin A was changed to match the system of the new 05 C04 solution of the IERS EOC. This change made the EOPs more consistent with the ITRF. The LS+AR polar motion prediction algorithm was implemented on 25 January. Electronic-VLBI (e-VLBI) became operational for certain aspects of the VLBI Intensive observations improving the quick-turnaround UT1 combination and short-term UT1 predictions. IGS Ultra data were added to the polar motion combination on 19 July, improving the quick-turnaround polar motion combination. The improvement can be seen in the statistics presented in Tables 2 and 3. These statistics show that there was a significant reduction in the scatter of the residuals after the inclusion of the IGS Ultras. This reduction is seen in both the daily combination and 1-day daily prediction values, as expected. The ILRS Series A was added to the operational procedures on 25 January, improving the robustness of the combined polar motion solution. On 4 October, the forecast length of the AAM data increased from 5 days to 7.5 days, improving the information available for near-term UT1 forecasts. Additional efforts included improving operational software, updating and monitoring currently used datasets, and investigating potential new data sets. Additional work to increase the robustness of an alternate site to mirror data storage for the combination processing was carried out.

New global solutions were received from GSFC, USNO, IAA, and IVS VLBI analysis centers. These new solutions were examined and new rates and biases were computed.

Table 5: Predicted values of TT–UT1, 2008–2017. 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)
2008 Jan 1	65.457	0.000
2008 Apr 1	65.545	0.000
2008 Jul 1	65.60	0.007
2008 Oct 1	65.62	0.01
2009 Jan 1	65.70	0.02
2009 Apr 1	65.79	0.02
2009 Jul 1	66.2	0.2
2009 Oct 1	66.3	0.3
2010 Jan 1	66.5	0.4
2010 Apr 1	66.6	0.4
2010 Jul 1	66.8	0.5
2010 Oct 1	66.9	0.7
2011 Jan 1	67.1	0.8
2011 Apr 1	67.2	0.9
2011 Jul 1	67	1.
2011 Oct 1	67	1.
2012 Jan 1	68.	1.
2012 Apr 1	68.	1.
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	69.	2.
2014 Jan 1	69.	2.
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.	3.
2015 Oct 1	70.	3.
2016 Jan 1	70.	4.
2016 Apr 1	70.	4.
2016 Jul 1	70.	4.
2016 Oct 1	70.	4.
2017 Jan 1	70.	4.

Availability of Rapid Service

The data available from the IERS Rapid Service/Prediction Center 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, δX and δY 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 from Institute of Applied Astronomy 1-day SLR; x, y from the

Russian Mission Control Center 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 Center; x, y, UT1–UTC, $\delta\psi$ and $\delta\varepsilon$ from the IERS Earth Orientation Center; and predictions of x, y, UT1–UTC from the IERS Rapid Service/Prediction Center.

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; LOD from ILRS 1-day SLR; x, y, UT1–UTC from CSR LAGEOS 3-day SLR; x and y from CSR LAGEOS 5-day SLR; x and y from Delft 1-, 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 Center in a number of forms. You may request a weekly machine-readable version of the IERS Bulletin A containing the current ninety days' 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.

Center Staff

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

William Wooden	Director
Brian Luzum	Program manager, research, and software maintenance
Nick Stamatakos	Operational procedure manager, research, and software maintenance
Gillian Brockett	Assists in daily operations and support, research, and software maintenance
Merri Sue Carter	Assists in daily operations and support
Beth Stetzler	Assists in daily operations and support, research, and software maintenance

In the second half of 2007, Beth Stetzler joined the IERS Rapid Service and Prediction Center.

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