3.5.2 Rapid Service/Prediction Centre

Processing Techniques

The algorithm used by the IERS Rapid Service/Prediction Center (RS/PC) 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 with respect to the 05 C04 system of the IERS Earth Orientation Centre (EOC) at the Paris Observatory are determined using a robust linear estimator. 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

Table 1: Estimated accuracies of the techniques in 2010. Units are milliseconds of arc for x, y, $\delta\psi$, $\delta\varepsilon$, dX, and dY and milliseconds of time for UT1–UTC. Note that AAM results are no longer provided since the AAM data are now only used for predictions and the previous statistics were misleading.

Contributor Information	Estimated Accuracy				
Name, Type	x	y	UT1	$\delta\psi$ (dX)	$\delta\varepsilon$ (dY)
ILRS SLR	0.34	0.31			
IAA SLR	0.20	0.24			
MCC SLR	0.21	0.22			
GSFC VLBI Intensives			0.019		
USNO VLBI Intensives			0.018		
GSI Intensives			0.015		
GSFC VLBI	0.12	0.11	0.004	0.31	0.12
IAA[1] VLBI	0.19	0.17	0.007	(0.18)	(0.17)
IVS[1] VLBI	0.13	0.16	0.004	(0.15)	(0.07)
USNO VLBI	0.11	0.12	0.003	0.64	0.10
IGS Final	0.01	0.02			
IGS Rapid	0.08	0.10			
IGS Ultra	0.09	0.11			
USNO GPS UT*			0.016*		
EMR GPS UT*			0.069*		

*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.

Table 2: Mean and standard deviation of the differences between the Rapid Service/Prediction Centre solutions and the 05 C04 EOP solutions for 2010. Polar motion values 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	-0.02	0.03
y	-0.08	0.04
UT1–UTC	0.005	0.011
Bulletin A Weekly Solution (finals.data)[1]		
x	0.02	0.04
y	-0.10	0.04
UT1–UTC	0.000	0.017
Bulletin A Daily Solution (finals.daily)		
x	-0.01	0.04
y	-0.06	0.04
UT1–UTC	-0.006	0.031

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

based on the residuals between the series and the combined RS/PC EOP solution for 2010.

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. While the celestial pole offset combination software can combine either $\delta\psi$ and $\delta\varepsilon$ or dX and dY, for historical reasons, it uses $\delta\psi$ and $\delta\varepsilon$. Therefore, IAA and IVS VLBI dX and dY values are converted to $\delta\psi$ and $\delta\varepsilon$ in the combination process. The length of day (LOD) data are derived directly from the UT1–UTC data. The analytical expression for the first derivative of a 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 Center's combination solution for the running, weekly, and daily products compared to the 05 C04 series maintained by the IERS EOC. 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 05 C04 series for the entire year ("Bulletin A Rapid Solution" statistics). The comparison of the 52 weekly solutions to the 05 C04 series gives the statistics of the residuals computed over the new combination results for the 7-days prior to the solution epoch ("Bulletin A Weekly Solution" statistics). The statistics for the daily solution are determined from a series of differences spanning one year where each element of the series is the difference for the day of the solution epoch ("Bulletin A Daily Solution" statistics). 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 rapid solution and the 05 C04 and presents the data used in Table 2 for the determination of the daily solution statistics. The most notable feature in these plots is the significant bias in the polar motion y (PM-y) component. Analysis indicates that a significant portion of this bias is due mainly to a similar bias in the IGS Ultra PM-y data, which are a significant contributor to the Rapid Service/Prediction Center's polar motion solution. The periodic differences in the UT1–UTC residuals that had been seen in past Annual Report submissions appear to be greatly reduced with the change in the use of Atmospheric Angular Momentum (AAM) analysis data in the combination solution and the increasingly common use of electronically transferred VLBI (e-VLBI) data. These changes have produced a significant improvement in the UT1–UTC results (Stamatakos *et al.*, 2011).]

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,

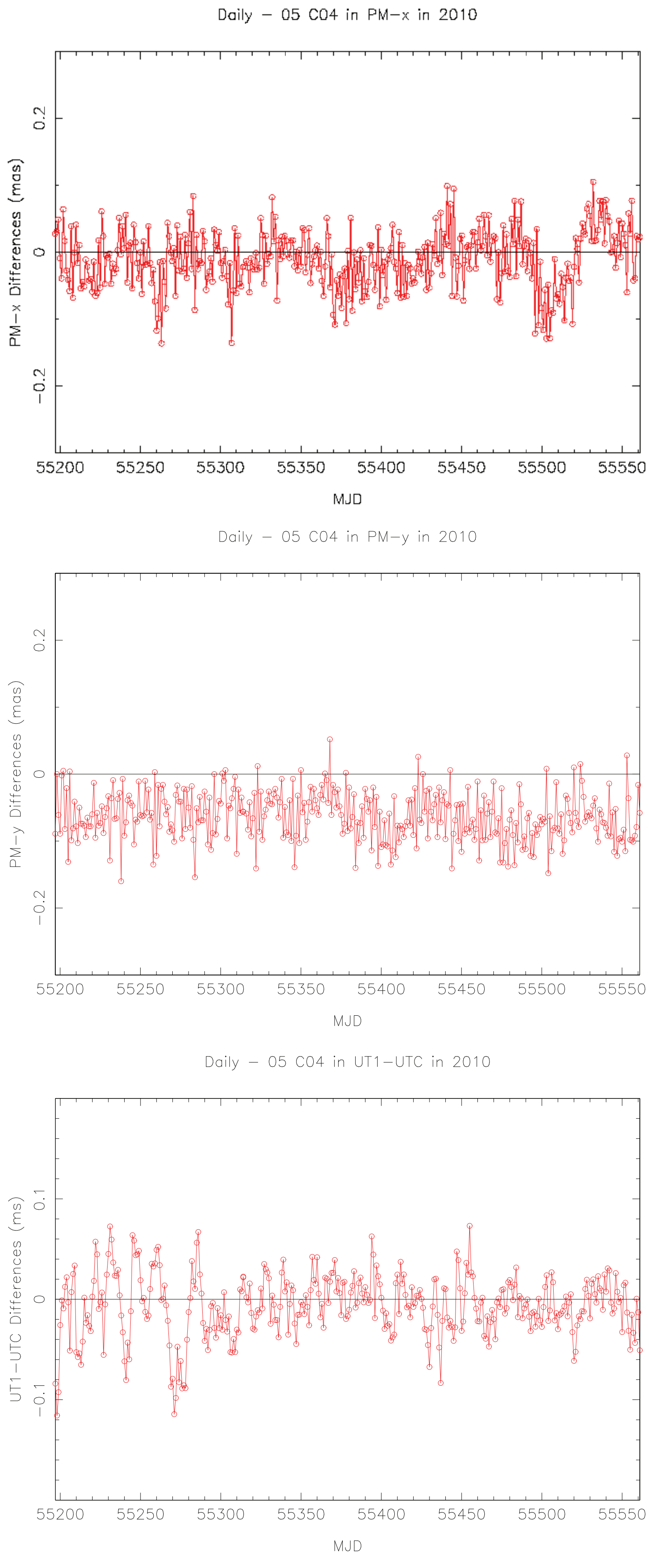

Fig. 1: Residuals between daily rapid solutions at each daily solution epoch for 2010 and the Earth orientation parameters available in 05 C04 series produced in April 2011.

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 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, $\langle(UT2R-TAI)_{-n}\rangle$ is subtracted from twice the most recent value, $(UT2R-TAI)_0$

$$(UT2R-TAI)_n = 2(UT2R-TAI)_0 - \langle(UT2R-TAI)_{-n}\rangle.$$

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.

The UT1–UTC prediction out to a few days is strongly influenced by the observed daily Universal Time estimates derived at USNO from the Earth motion relative to the GPS orbit planes reported by the IGS Rapid service (Kammeyer, 2000). 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 National Centers for Environmental Prediction (NCEP) and U.S. Navy’s Operational Global Atmospheric Prediction System (NOGAPS) model’s AAM analysis and forecast data (UTAAM). AAM-based predictions are used to determine the UT1 predictions out to a prediction length of 7 days. For longer predictions, the LOD excitations are combined smoothly with the longer-term UT1 predictions described above. The AAM data used are the combined northern and southern hemisphere data (winds+pressure, inverted barometer). 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

Table 3: Root mean square of the differences between the EOP time series predictions produced by the daily rapid solutions and the 05 C04 combination solutions for 2010. Note that the prediction length starts counting from the day after the last available observation is made for polar motion or UT1–UTC/LOD. (Note that for all of 2010, the last observation for polar motion and UT1–UTC was made on the last combination day and so the first prediction day always occurred the following day.)

Days in Future	PM-x mas	PM-y mas	UT1–UTC ms
1	.46	.29	.075
5	2.20	1.35	.308
10	4.49	2.33	.718
20	8.33	4.26	2.17
40	14.7	9.11	5.09
90	21.0	23.3	7.90

shows the standard deviation of the differences between the daily solution predictions and the 05 C04 solution for 2010. 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% reduction in prediction error with the updated method at both 10 days and 20 days into the future.

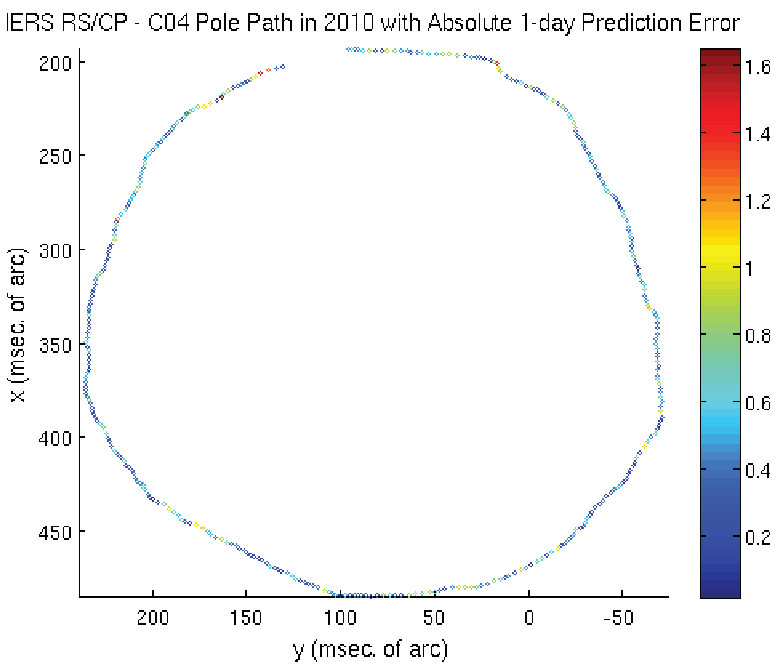

Fig. 2: Errors in polar motion prediction, denoted by the color of the plotting symbol, as a function of polar motion. The units of the polar motion error are mas.

Table 4: Root mean square of the differences between the nutation prediction series produced by the daily solutions and the 05 C04 combination solutions for 2010.

Days in Future	dX mas	dY mas	$\delta\psi$ mas	$\delta\varepsilon$ mas
1	.15	.17	.40	.16
5	.15	.16	.41	.16
10	.16	.17	.42	.17
20	.18	.18	.47	.18
40	.20	.20	.52	.20

For 2010, the polar motion prediction errors were slightly worse in x, better in the shorter y predictions, but worse in the long-term y predictions as compared to 2009. A plot of the polar motion error (shown as color codes of the plotting symbol) as a function of pole path is provided in Figure 2. The UT1–UTC prediction showed a significant improvement (~30%) to the prediction errors from 2009. As mentioned above, the improvement in UT1–UTC is likely due to changes in the use of AAM analysis data and the more frequent availability of rapid turnaround e-VLBI intensives.

The predictions of celestial pole offsets (both dX/dY and $\delta\psi/\delta\varepsilon$ representations) are produced through the use of the KSV1996 model (IERS Conventions (1996)). In addition, a bias between the model and the last 20 days worth of celestial pole offset observations is computed. This bias, used to correct the predictions, is tapered so that as the prediction length is extended, the bias becomes progressively smaller. 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 offsets 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 predictions and the 05 C04 for 2010 are given in Table 4.

Predictions of TT–UT1, up to 1 January 2019, 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.*, 2005; Stamatakos *et al.*, 2008; Stamatakos *et al.*, 2009).

Table 5: Predicted values of TT–UT1, 2011–2020. 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)
2011 Apr 1	66.396	0.000
2011 Jul 1	66.475	0.000
2011 Oct 1	66.506	0.000
2012 Jan 1	66.61	0.01
2012 Apr 1	66.70	0.02
2012 Jul 1	66.8	0.2
2012 Oct 1	66.9	0.3
2013 Jan 1	67.1	0.2
2013 Apr 1	67.2	0.3
2013 Jul 1	67.3	0.4
2013 Oct 1	67.5	0.4
2014 Jan 1	67.6	0.5
2014 Apr 1	67.7	0.7
2014 Jul 1	67.8	0.8
2014 Oct 1	68.0	0.9
2015 Jan 1	68.	1.
2015 Apr 1	68.	1.
2015 Jul 1	68.	1.
2015 Oct 1	68.	1.
2016 Jan 1	68.	2.
2016 Apr 1	69.	2.
2016 Jul 1	69.	2.
2016 Oct 1	69.	2.
2017 Jan 1	69.	2.
2017 Apr 1	69.	2.
2017 Jul 1	69.	2.
2017 Oct 1	69.	3.
2018 Jan 1	70.	3.
2018 Apr 1	70.	3.
2018 Jul 1	70.	3.
2018 Oct 1	70.	3.
2019 Jan 1	70.	3.
2019 Apr 1	70.	3.
2019 Jul 1	70.	4.
2019 Oct 1	70.	4.
2020 Jan 1	70.	4.

Center Activities in 2010

In early 2010, a revised method of processing AAM data was implemented, resulting in a significant improvement in the combination and short-term prediction of UT1–UTC. The AAM analysis data were removed from the UT1–UTC combination except for the one data point corresponding to the last combination point. It should be noted that the AAM forecasts are still a valuable part of the UT1–UTC prediction process.

In June 2010, a new web-based transformation calculator was added to the RS/PC web site. This calculator provides both the transformation matrices as well as quaternion representations of the rotations between terrestrial and celestial reference frames. This calculator was tested against the IERS Earth Orientation Center calculator and the rms difference between the two was less than 0.5 mas. This difference is expected to be an upper bound on the error of the rotation matrices. Additional work in 2011 is expected to make this calculator IERS Conventions (2010) compliant.

In August 2010, the automated VLBI intensive solution generated by GSI was added to the combination procedure. This solution has improved the RS/PC combination and prediction products particularly on the weekends where there had been a dearth of new VLBI results.

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

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, dX, and dY from IVS combination VLBI; UT1–UTC from GSFC 1-day Intensives; UT1–UTC from USNO 1-day Intensives; UT1–UTC from GSI 1-day Intensives; x and y from International Laser Ranging Service 1-day SLR; x and y from Institute of Applied Astronomy 1-day SLR; x and y from the Russian Mission Control Centre 1-day SLR; x, y, and 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, $\delta\psi$, $\delta\varepsilon$, dX, and dY from the IERS Rapid Service/Prediction Center; x, y, UT1–UTC, $\delta\psi$, and $\delta\varepsilon$ from the IERS Earth Orientation Centre; and predictions of x, y, UT1–UTC, $\delta\psi$, $\delta\varepsilon$, dX, and dY 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 Centre in a number of forms. You may request a weekly machine-readable version of the IERS Bulletin A containing the current 365 days' worth of predictions via electronic mail from

ser7@maia.usno.navy.mil or through

<http://www.usno.navy.mil/USNO/earth-orientation>.

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 RS/PC Center staff consisted of the following members:

Brian J. Luzum	Director
Nick Stamatakos	Chief, Earth Orientation Parameters Combination and Prediction Division
Merri Sue Carter	Assists in daily operations and support
Beth Stetzler	Assists in daily operations and support, research, and software maintenance
Nathan Shumate	Assists in daily operations and support, research, and software maintenance

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