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 smoothing (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 08 C04 system of the IERS Earth Orientation Centre (EOC) at the Paris Observatory are determined using a robust linear estimator (Matlab function 'regstats'). The statistical weights used in the spline are proportional to the inverse square of the estimated accuracy of the individual techniques computed over the past several years. Weights for each contributor in the algorithm may be either a priori values estimated by determining the standard deviation of a long history of residuals or values based on the internal precision reported by contributors. Minimal smoothing is applied, consistent with the estimated accuracy of the observational data.

Estimated accuracies of data contributed to the IERS Rapid Service/Prediction Center for 2013 are given in Table 1. These

Table 1: Estimated accuracies of the contributors in 2013. Units are milliseconds of arc for x, y, dψ, dε, dX, and dY and milliseconds of time for UT1–UTC.

Contributor Information	Estimated Accuracy				
Name, Type	x	y	UT1	δψ (dX)	δε (dY)
ILRS SLR	0.30	0.35			
IAA SLR	0.23	0.20			
MCC SLR	0.19	0.20			
GSFC VLBI Intensives			0.020		
USNO VLBI Intensives			0.021		
GSI Intensives			0.012		
GSFC VLBI	0.13	0.15	0.005	0.65	0.29
IAA[1] VLBI	0.21	0.21	0.009	(0.14)	(0.22)
IVS[1] VLBI	0.11	0.16	0.004	(0.20)	(0.21)
USNO VLBI	0.29	0.37	0.008	0.37	0.11
IGS Final	0.01	0.00			
IGS Rapid	0.04	0.03			
IGS Ultra*	0.04	0.04	0.056*		
USNO GPS UT*			0.019*		

*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 (see Petit and Luzum, 2010).

estimates are based on the residuals between the series and the combined RS/PC EOP solution for 2013. For polar motion (x and y) and the celestial pole offsets (dψ, dε, dX, and dY), all the contributors (which have associated statistics in Table 1) provide direct measurements of these quantities, respectively. For UT1, all the Very Long Baseline Interferometry (VLBI) contributors provide direct measurements of UT1; however, the International GNSS Service (IGS) ultra-rapid observations (IGS ultras) provide a length-of-day-type input, which is a derivative of UT1. The VLBI-based results have been used to correct for the length-of-day (LOD) bias in the IGS ultras and to minimize drifts in UT estimates, and the corresponding statistics shown for the IGS ultras are computed after the bias correction is applied.

Operationally, the smoothing (weighted) spline uses the following as inputs: the epoch of observation, the observed EOP 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, dψ, and dε values are computed at the midnight (00:00) UTC epoch for each day. While the celestial pole offset combination software can combine either dψ and dε or dX and dY, for historical reasons, it uses dψ and dε. Therefore, the Institute of Applied Astronomy (IAA) and the International VLBI Service (IVS) VLBI dX and dY values are converted to dψ and dε in the combination process. The LOD for the combination 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 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.

Two groups of data points are excluded from the combination process. One group consists of the points whose errors, as reported by the contributors, are greater than three times their average reported precision. The other data excluded are 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 shows the accuracies of Rapid Service/Prediction Center's combination solution for the running, weekly, and daily products compared to the 08 C04 series maintained by the IERS EOC. The running solution statistics, shown under the label

Table 2: Mean and standard deviation of the differences between the Rapid Service/Prediction Center combination solutions and the 08 C04 EOP solutions for 2013. 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	0.00	0.03
y	0.00	0.03
UT1-UTC	0.003	0.011
Bulletin A Weekly Solution (finals.data)[1]		
x	0.03	0.05
y	0.01	0.04
UT1-UTC	0.005	0.020
Bulletin A Daily Solution (finals.daily)		
x	0.02	0.05
y	0.01	0.04
UT1-UTC	0.002	0.037

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

"Bulletin A Rapid Solution", are the residuals of the combination solution versus the 08 C04 over the past 365-day period. The statistics for the running solution at year's end show the level of agreement between the Bulletin A running combination solution and the 08 C04 series.

The "Bulletin A Weekly Solution" results shown in Table 2 are the statistics of the residuals of the 7-day period, prior to the Bulletin solution epoch, of the 52 weekly Bulletin A solutions to the 08 C04 series. Each weekly Bulletin A solution is normally produced on Thursdays and contains EOP solutions for a prior 7-day period ending on the Thursday solution epoch. In generating the statistics, these periods are concatenated for the entire year, and then residuals and statistics versus the 08 C04 are computed.

The statistics for the daily solution, shown under the "Bulletin A Daily solution" heading in Table 2, 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. EOP accuracies for the Bulletin A rapid weekly combination solution for the day of the solution run and the daily solution at the time of solution epoch are similar and, therefore, not included in Table 2.

Figure 1 contains plots of the residuals between the daily rapid solution and the 08 C04, and the corresponding statistical results are listed in Table 2 under "Bulletin A Daily Solution (finals.daily)".

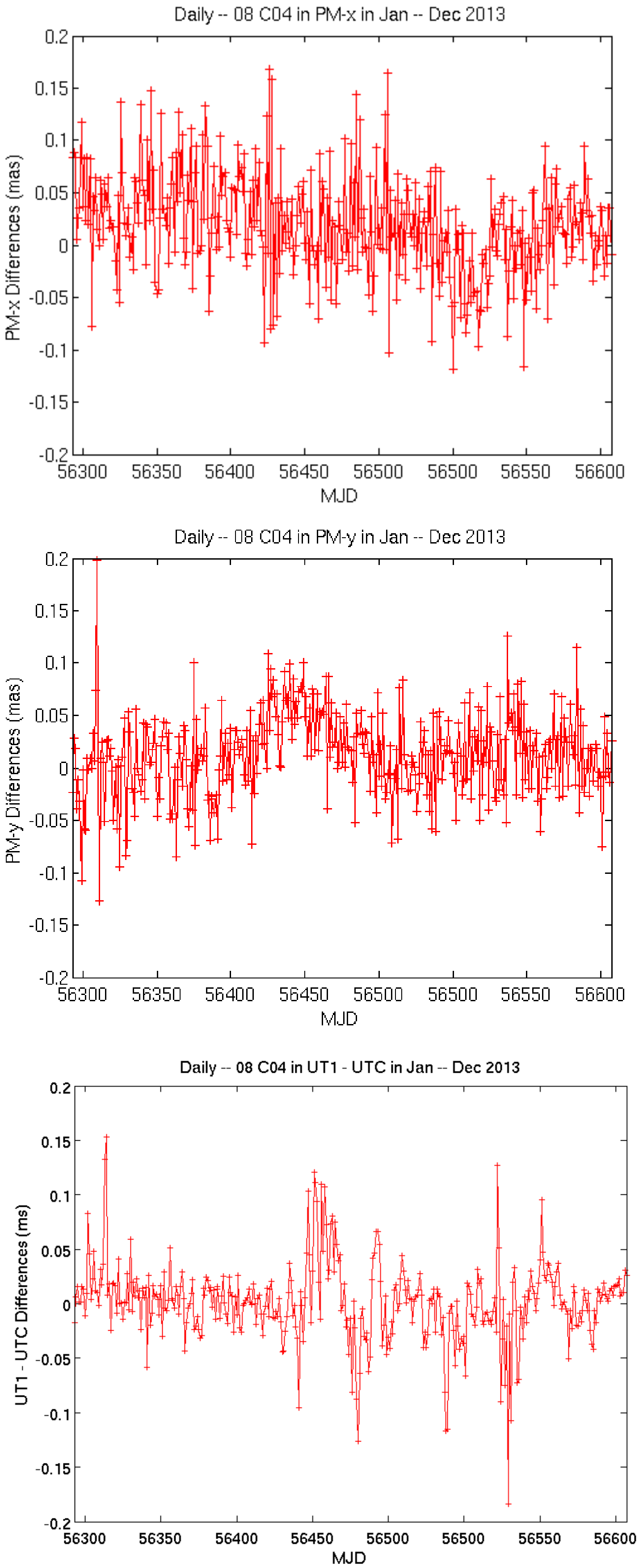

Fig. 1: Differences between the daily rapid solutions at each daily solution epoch for 2013 and the Earth orientation parameters available in the 08 C04 series produced in April 2014.

In 2013, the statistical results between the daily solution and the 08 C04 were similar to what resulted in 2012.

The mean and standard deviation for the UT1–UTC daily rapid residuals for 2013 were similar to the 2012 values (as reported in the IERS Annual Report for 2012). Until about mid-May 2013 (@ MJD 56425), the rms of the residuals was significantly lower than for the rest of the year, with an rms of 27 microseconds. Then, from around mid-May to the beginning of November, the level of the residuals increased significantly, with an rms of 46 microseconds. From November until the end of December 2013, the rms level decreased back to 24 microseconds.

The UT1–UTC residuals are largely influenced by the accuracy and timeliness of VLBI intensive inputs. Consequently, the large increase in rms from the mid-May to early-November period could be partly attributed to several factors: a) from the end of April through the end of 2013, the Tsukuba–Wettzell (TsWz) radio telescope baseline was not available due to problems with the Tsukuba antenna; and so Saturday and Sunday weekend, short 1-hr long VLBI observations, called intensives, were replaced with a single Saturday or Sunday Kokee–Wettzell (KkWz) baseline-based intensive – thus, effectively reducing the normal observations per week from 7 to 6; b) from the end of May through at least October, the Kokee antenna receiver X-band and S-Band system temperatures were higher than normal; and c) from mid-July to September 30, the Wettzell antenna was off-line for scheduled repairs, with Ny-Ålesund and then Svetloe substituting for Wettzell in the normal KkWz baseline (resulting in KkNy and KkSv baselines). The KkWz baseline is a well-established operational baseline; whereas the KkNy and KkSv baselines, while extremely useful as alternatives to KkWz, may not have been characterized for geodetic purposes to the same level as the KkWz baseline.

Figure 2 is a plot of the residuals from the daily rapid solution (labeled finals.daily in the legend) and the individual NASA Goddard produced KkWz, TsWz, KkNy, and KkSv baseline UT1–UTC residuals from Jan 1, 2013 through May 15, 2013. A correlation between the increased noise level of these NASA Goddard intensives, beginning around MJD 56427 (May 15, 2013), and the increased level of residuals in the daily rapid solution is apparent from the plot.

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

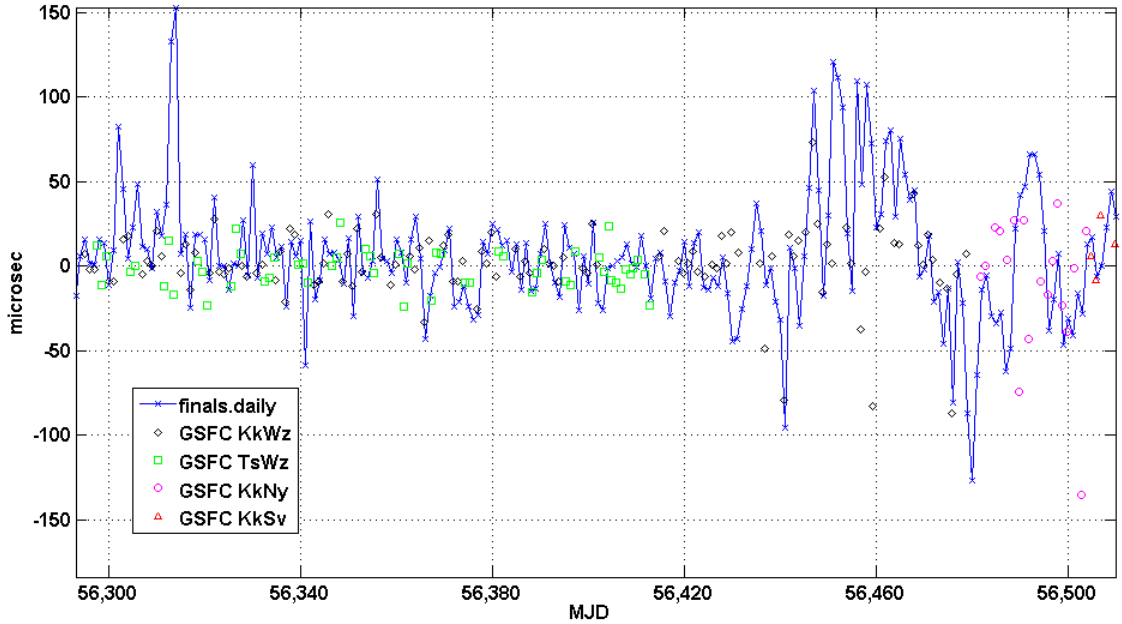

Fig. 2: The residuals of the daily rapid solution (labeled finals.daily in the legend) and the individual NASA Goddard produced KkWz, TsWz, KkNy, and KkSv baseline UT1–UTC residuals from Jan 1, 2013 through May 15, 2013.

residuals that 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 communication, 2006). For more information on the implementation of the LS+AR model, see Stamatakos *et al.* (2008). A deficiency with the current implementation of this algorithm occasionally causes poor quality short-term polar motion predictions. Mitigation strategies are being investigated.

The UT1–UTC prediction 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 Global Environmental Model[1] (NAVGEM) Atmospheric Angular Momentum (AAM) analysis and forecast data (UTAAM). AAM-based predictions are used to determine the UT1 predictions out to a prediction length of 7.5 days. For longer predictions, the LOD excitations are com-

[1] On July 25, 2013, the contribution of the US Navy Fleet Numerical Meteorology and Oceanography Center (FNMOC) to the AAM inputs was upgraded from the Navy Operational Global Atmospheric Prediction System (NOGAPS) to the Navy Global Environmental Model (NAVGEM).

bined smoothly with the longer-term UT1 predictions described below. For more information on the use of the UTAAM data, see Stamatakos *et al.* (2008).

The procedure for generating UT1–UTC predictions after 7.5 days 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 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 restore the 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 also 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 (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.

Errors of the prediction 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, but predictions derived from these formulas are significantly less accurate than the tabular predictions and are not recommended for operational use. The predictions of $d\psi$ and $d\varepsilon$ are based on the IERS Conventions (McCarthy, 1996; McCarthy and Petit, 2004).

Table 3a shows the root mean square of the differences between the 17:00 UTC solution predictions and the 08 C04 solution for 2013. Prediction errors were improved by roughly 7 to 9% when comparing 2013 to 2012 results. Figure 3 provides a plot of the 1-day prediction error as a function of polar motion value. There was also a roughly 8% improvement in the 1-day UT1–UTC predictions – despite the issues with the Kokee antenna, discussed several paragraphs above. The longer-term polar motion and UT1–UTC predictions also showed general improvement when comparing 2013 to 2012 results. The reasons for improvements in polar motion are being examined; however, preliminary indications point to improved IGS ultras. The improvement over the last few years in UT1–UTC short-term prediction is due to increased availability of rapid turnaround electronically transferred VLBI (e-VLBI) intensives.

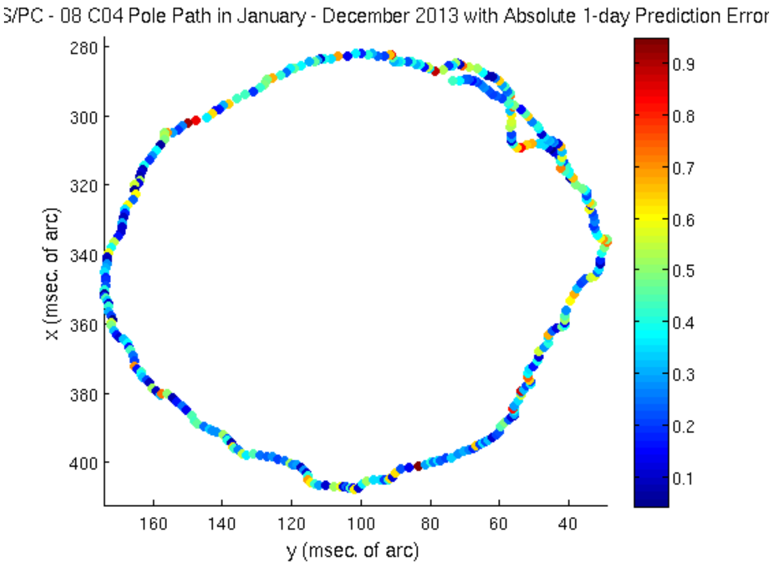

Fig. 3: Plot of the 1-day prediction error as a function of polar motion. The prediction error is in units of milliseconds of arc.

Table 3a: Root mean square of the differences between the EOP time series predictions produced by the daily solutions and the 08 C04 combination solutions for 2013. Note that the prediction length starts counting from the day after the date of the solution epoch.

Days in Future	PM-x Mas	PM-y mas	UT1-UTC ms
1	.327	.228	.058
5	1.81	1.22	.214
10	3.46	1.94	.525
20	6.75	2.66	1.88
40	12.9	4.12	2.82
90	23.8	16.5	8.49

In previous annual reports, the prediction length was determined from epoch of the last known VLBI or IGS observation, and not based on the date of the solution epoch. It has been determined that many EOP users base their inputs on the prediction based on the date of the solution epoch, and also using this new paradigm simplifies the comparison of results among the 17:00 UTC EOP solution and the 21:10, 03:10 and 09:10 UTC solutions (which are discussed below). In general, the results are very similar since on most days an observation is made either on the solution day or the day before. The statistics based upon the older paradigm are available upon request from ser7@maia.usno.navy.mil .

In addition to the 17:00 UTC EOP solution, three additional EOP solutions are computed each day – new solutions at 21:10, 03:10, and 09:10 UTC. These solutions are collectively referred to as the Nxdaily solutions. The original solution at 17:00 UTC has been

Tables 3b, 3c, and 3d: Root mean square of the differences between the EOP time series predictions produced by the 4x daily solutions and the 08 C04 combination solutions for 2013. Note that the prediction length for the 1-day predictions is as shown in Figure 4.

Table 3b: RMS for the 21:10 UTC EOP solution for 2013.

Days in Future	PM-x mas	PM-y mas	UT1-UTC ms
1	.286	.195	.056
5	1.77	1.16	.215
10	3.45	1.89	.527
20	6.73	2.60	1.89
40	12.8	4.09	2.82
90	23.7	16.4	8.48

Table 3c: RMS for the 03:10 UTC EOP solution for 2013.

Days in Future	PM-x mas	PM-y mas	UT1-UTC ms
1	.230	.204	.052
5	1.73	1.27	.214
10	3.39	1.99	.528
20	6.75	2.69	1.89
40	12.8	3.76	2.82
90	23.7	15.9	8.48

Table 3d: RMS for the 09:10 UTC EOP solution for 2013.

Days in Future	PM-x mas	PM-y mas	UT1-UTC ms
1	.175	.151	.051
5	1.60	1.15	.211
10	3.30	1.92	.525
20	6.62	2.69	1.89
40	12.7	3.82	2.84
90	23.6	16.1	8.53

produced by the IERS RS/PC each day for over 15 years. The additional solutions are part of an ongoing effort to improve the accuracy of the EOP solutions by updating EOP solutions soon after new observational data are available, thereby reducing the latency between observations and EOP solution updates. Examples of these new observational input data are eVLBI intensives and the IGS ultras. Tables 4a and 4b illustrate the relationship between the EOP solution times and these input data.

At each Nxdaily UTC solution time listed in Tables 4a and 4b, major contributors, with a small amount of time between observation to EOP available solution, are listed with an associated “epoch at midpoint”. IGS and VLBI solutions are determined from a span of observations and the EOP estimate is provided at the midpoint of this span.Typically IGS orbits are determined over a 24-hour period and VLBI intensives sessions span a 1-hour period. The “Contributor” column contains the most recently available input at the time of each UTC solution. Although major contributors, the 24-hr VLBI solutions are not shown in the table since the time between observations and availability to the EOP solutions is generally greater than 7 days.

Table 4a lists the most recent major input contributors for each polar motion Nxdaily solution. For example, by the polar motion 17:00 UTC <MJD> solution time, the most recently computed IGS rapid observation solution (IGS rapid), which has an epoch at midpoint of 12:00 UTC noon from the previous day, <MJD-1>, is available. In addition, there are two IGS ultras available that contain an epoch at midpoint after the IGS rapid. By 21:10 UTC <MJD>, the IGS has produced an updated IGS ultra, the 18-hr solution, and the corresponding EOP solution will use this latest data. Similarly, the 03:10 UTC and 09:10 UTC solutions will have later IGS ultra data available as shown in the table. Finally, for the next day, <MJD+1>, the sequence of IGS Rapids and Ultras will repeat – the 17:00 UTC <MJD+1> solution will have the next IGS rapid solution whose midpoint was at 12:00 UTC <MJD> along with the next 6-hr and 12-hr Ultras.

In Table 4b, a similar pattern for UT1–UTC to what was described above for polar motion is shown. In addition to the IGS contributions, the VLBI intensives series are included. However, VLBI intensives are not available as regularly as the IGS observations, and so the contributors shown for each solution are only an ideal case that occurs less than 100% of the time. There are 3 sets of VLBI intensives that are used in the EOP RS/PC UT1–UTC solution – called INT1, INT2, and INT3 intensives. The INT1 intensives are typically only observed on weekdays, the INT2 intensives on weekends, and the INT3 intensives on Mondays. For more information about the relation of the INT1, INT2, and INT3 VLBI intensives observation times to the EOP solution see Stamatakos *et al., 2012, AGU poster G51A-1084*.

Within each Nxdaily EOP solution file – each called finals.daily and finals2000A.daily, but located in separate sub-directories – there are EOP solutions for polar motion, UT1–UTC and celestial pole offsets. Each has an identical format to the original 17:00 UTC solution. As shown in Figure 4, the 1-day EOP prediction from the 17:00 UTC <MJD> EOP solution will make a prediction of the EOP for 00:00 UTC <MJD+1>; the 1-day EOP prediction from the

Tables 4a and 4b: Tables describing the data available for each of the Nxdaily solutions. Note: the 24-hr VLBI solutions are not shown in the table since the time between observations and availability to the EOP solutions is generally greater than 7 days.

Table 4a: Major Contributors for the Polar Motion EOP solution at the Nxdaily Solution Times

1700 UTC solution		2110 UTC solution		0310 UTC solution		0910 UTC solution	
Contributor	**Epoch at Midpoint***	**Contributor**	**Epoch at Midpoint***	**Contributor**	**Epoch at Midpoint***	**Contributor**	**Epoch at Midpoint***
IGS 12 hr Ultra	00:00	IGS 18 hr Ultra	+06:00	IGS 0 hr Ultra	+12:00	IGS 6 hr Ultra	+18:00
IGS 6 hr Ultra	-06:00	IGS 12 hr Ultra	00:00	IGS 18 hr Ultra	+06:00	IGS 0 hr Ultra	+12:00
IGS Rapid	-12:00	IGS 6 hr Ultra	-06:00	IGS 12 hr Ultra	00:00	IGS 18 hr Ultra	+06:00
		IGS Rapid	-12:00	IGS 6 hr Ultra	-06:00	IGS 12 hr Ultra	00:00
				IGS Rapid	-12:00	IGS 6 hr Ultra	-06:00
						IGS Rapid	-12:00

Table 4b: Major Contributors for the UT1-UTC EOP solution at the Nxdaily Solution Times

1700 UTC solution		2110 UTC solution		0310 UTC solution		0910 UTC solution	
Contributor	**Epoch at Midpoint***	**Contributor**	**Epoch at Midpoint***	**Contributor**	**Epoch at Midpoint***	**Contributor**	**Epoch at Midpoint***
AAM LOD[3]		AAM LOD[3]		AAM LOD[3]		AAM LOD[3]	
INT2 / 3 VLBI intensive[1]	+08:00	INT2 / 3 VLBI intensive[1]	+08:00	IGS 0 hr Ultra	+12:00	IGS 6 hr Ultra	+18:00
IGS 12 hr Ultra	00:00	IGS 18 hr Ultra	+06:00	INT2 / 3 VLBI intensive[1]	+08:00	IGS 0 hr Ultra	+12:00
INT1 VLBI intensive[2]	-05:00	IGS 12 hr Ultra	00:00	IGS 18 hr Ultra	+06:00	INT2 / 3 VLBI intensive[1]	+08:00
IGS 6 hr Ultra	-06:00	INT1 VLBI intensive[2]	-05:00	IGS 12 hr Ultra	00:00	IGS 18 hr Ultra	+06:00
IGS Rapid	-12:00	IGS 6 hr Ultra	-06:00	INT1 VLBI intensive[2]	-05:00	IGS 12 hr Ultra	00:00
		IGS Rapid	-12:00	IGS 6 hr Ultra	-06:00	INT1 VLBI intensive[2]	-05:00
				IGS Rapid	-12:00	IGS 6 hr Ultra	-06:00
						IGS Rapid	-12:00

* IGS and VLBI solutions are determined by integrating a period of observation times. The EOP reported is the observation mid-point.

1 INT2 and INT3 intensives are normally observed Saturday through Monday with an epoch at midpoint at approximately 08:00 UTC.

2 INT1 intensives are normally observed Monday through Friday with an epoch at midpoint at approximately 19:00 UTC.

3 The AAM LOD inputs contain 7.5 days of forecast data from 00:00 to 180:00 hours.

09:10 UTC <MJD+1> EOP solution will also make a prediction of the EOP value for the same 00:00 <MJD+1> epoch.

Tables 3a through 3d contain the RMS for the 1- to 90-day prediction errors for the 17:00, 21:10, 03:10, and 09:10 UTC EOP solutions for 2013. The polar motion short-term prediction solutions should improve at each later EOP update (starting from the 17:00 UTC <MJD> to the 09:10 UTC <MJD+1> solution) since the later EOP solution will have more recent observations. The 2013 1-day and 5-day polar motion prediction results shown in Tables 3a 3b, 3c and 3d generally confirm this improvement, especially when comparing Table 3a and 3d results.

The percentage decrease in the 1-day polar motion error from the 17:00 to 09:10 UTC solutions (as shown in Table 3a and 3d) was significant – 46% for PMx and 34% for PMy. As expected, improvements of a consistently smaller magnitude are made between the 17:00 and 21:10 UTC and between the 17:00 and 03:10 UTC solutions, as can be seen by comparing results among Tables 3a, 3b, and 3c. The UT1–UTC 1-day predictions also show improvements from the 17:00 UTC <MJD> to the 09:10 UTC <MJD+1> solutions; however, the percentage decrease is much smaller than it was for polar motion – a decrease in error of 12%.

There are no rapid turnaround estimates of celestial pole offsets; only 24-hour VLBI solutions provide celestial pole offsets. These 24-hr solutions can be latent by one to two weeks, and therefore, it is anticipated that there will be no statistically significant difference between celestial offset prediction solutions. No tables of statistics for celestial pole offsets are presented in this report.

Each of the Nxdaily EOP solutions are updated daily at approximately 17:00 UTC, 21:10 UTC, 03:10 UTC, and 09:10 UTC, respectively. They are located in subdirectories of the following URLs:

<http://maia.usno.navy.mil/> or <http://toshi.nofs.navy.mil/>

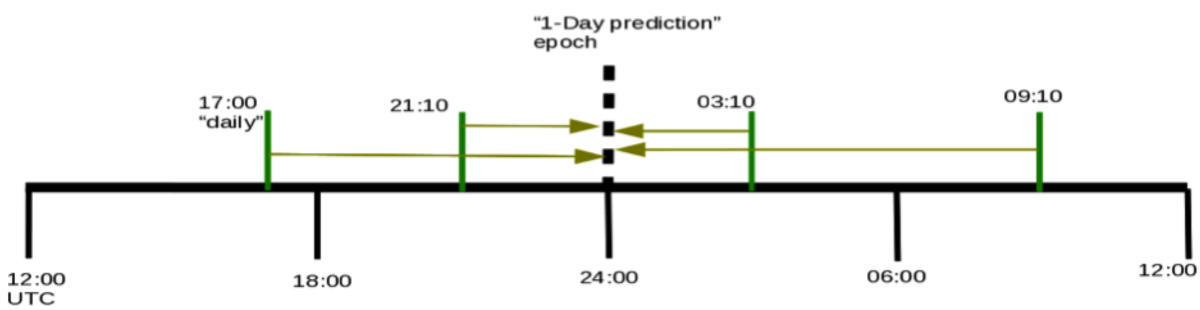

Fig. 4: Timeline of EOP 1-day prediction solutions in relation to the EOP "daily" solution produced at 17:00 UTC.

Time (UTC)	Sub-directory
17:00	ser7
21:10	eop2100utc
03:10	2xdaily
09:10	eop0900utc

For, example, the EOP USNO DC solution produced at 03:10 UTC is located at <http://maia.usno.navy.mil/2xdaily/finals.daily> or <.../finals2000A.daily>.

The predictions of celestial pole offsets (both dX/dY and dψ/dε representations) are produced through the use of the KSV1996 model (McCarthy, 1996). In addition, a bias between the model and the last 20 days of celestial pole offset observations is computed. Correcting for this bias allows for a seamless transition between the observed and predicted celestial pole offsets. This bias 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 08 C04 for 2013 are given in Table 5.

Predictions of TT–UT1, up to 1 January 2024, are given in Table 6. 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 errors 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; Stamatakos *et al.*, 2010).

Table 5: Root mean square of the differences between the nutation prediction series produced by the daily solutions and the 08 C04 combination solutions for 2013.

Days in Future	dX mas	dY mas	δψ mas	δε mas
1	.12	.16	.30	.15
5	.13	.17	.32	.16
10	.14	.18	.35	.17
20	.17	.20	.42	.19
40	.23	.25	.58	.24

Table 5: Predicted values of TT–UT1, 2013–2024. 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)
2014 Jan 1	67.249	-0.015
2014 Apr 1	67.386	-0.005
2014 Jul 1	67.52	0.02
2014 Oct 1	67.66	0.05
2015 Jan 1	67.79	0.09
2015 Apr 1	67.9	0.1
2015 Jul 1	68.0	0.2
2015 Oct 1	68.2	0.3
2016 Jan 1	68.3	0.3
2016 Apr 1	68.4	0.4
2016 Jul 1	68.5	0.5
2016 Oct 1	68.6	0.6
2017 Jan 1	68.7	0.8
2017 Apr 1	68.9	0.9
2017 Jul 1	69.	1.
2017 Oct 1	69.	1.
2018 Jan 1	69.	1.
2018 Apr 1	69.	1.
2018 Jul 1	70.	1.
2018 Oct 1	70.	2.
2019 Jan 1	70.	2.
2019 Apr 1	70.	2.
2019 Jul 1	70.	2.
2019 Oct 1	70.	2.
2020 Jan 1	70.	2.
2020 Apr 1	70.	2.
2020 Jul 1	70.	3.
2020 Oct 1	71.	3.
2021 Jan 1	71.	3.
2021 Apr 1	71.	3.
2021 Jul 1	71.	3.
2021 Oct 1	71.	3.
2022 Jan 1	71.	4.
2022 Apr 1	71.	4.
2022 Jul 1	71.	4.
2022 Oct 1	72.	4.
2023 Jan 1	72.	4.
2023 Apr 1	72.	5.
2023 Jul 1	72.	5.
2023 Oct 1	72.	5.
2024 Jan 1	72.	5.

Center Activities in 2013

During 2013, several changes occurred in the generation of the RS/PC products: In July, the US Navy Fleet Numerical Meteorology and Oceanography Center (FNMOC) upgraded their AAM inputs to the EOP RS/PC solution from the Navy Operational Global Atmospheric Prediction System (NOGAPS) to NAVGEM; in August, a new global solution was received from the Institute of Applied Astronomy (IAA) 24-hr VLBI series; and in October, the UT1-like quantity generated from GPS inputs (UTGPS) based on the IGS rapids (UTGPS rapids) was replaced with one based on the 12-hour IGS Ultra-rapid observational inputs (UTGPS 12hr-ultras). The UTGPS 12hr-ultra has advantages over the UTGPS rapids. The 12hr-ultra solution is available at 15:00 UTC; whereas, the rapids solution is available at 17:00 UTC. If a problem occurs with the12hr-ultra solution the operator will have 2 hours to correct the problem before the 17:00 UTC EOP daily solution; however, there is very little time for the operator to correct a problem with the rapids solution before its use in the EOP solution at 17:00 UTC. Also, there was a small decrease in UT1–UTC error in using the 12-hour ultra solution rather than using the rapids solution. Additional UTGPS solutions based on the other ultras, namely the 0, 6, and 18-hr ultras are available; however, there are several implementation issues that need to be addressed before using these in an operational solution.

Also, several potential improvements to the EOP solution were investigated including using a) the Very Long Baseline Array (VLBA) inputs as a backup or additional UT1–UTC inputs, b) the IGS Ultra-rapid predictions for enhanced polar motion and LOD inputs to the EOP solution, and c) an improved polar motion solution using U.S. based Oceanic and Hydrological Angular Momentum (OAM and HAM) models.

The IERS RS/PC now provide the same operational EOP products, generated at USNO DC, at an offsite location at the Naval Observatory Flagstaff Station (NOFS); both are generated independently. The solutions at the USNO DC and NOFS are checked on a daily basis to ensure that there are no discrepancies between the two. This redundancy provides an alternative location from which to obtain a solution should the primary facility at USNO DC be unable to deliver its EOP product due to internet outage, power outage, etc.

The Earth Orientation transformation matrix calculator was maintained throughout the year. The calculator can now produce rotation matrix elements calculated using the IERS Technical Note 36 equinox-based algorithm (Petit and Luzum, 2010). This web-based product will provide both the transformation matrices as well as quaternion representations of the rotations between terrestrial and celestial reference frames.

Availability of Rapid Service

The data available from the IERS Rapid Service / Prediction Center consist mainly of the data used to derive the IERS Bulletin A combination solution. Table 7 indicates which EOPs are provided by each contributor.

Table 7: Input data available for contributors to the IERS Bulletin A EOP solution.

Contributor	PM-x	PM-y	UT1-UTC	LOD	$\delta\psi$	$\delta\varepsilon$	dX	dY
IAA VLBI								
GSFC VLBI								
USNO VLBI								
IVS VLBI								
GSFC Int.[1]								
USNO Int.								
GSI[2] Int.								
ILRS[3]								
IAA[4] SLR[5]								
MCC[6] SLR								
IGS								
USNO GPS								
NCEP AAM								
NAVGEM AAM								
IERS EOC								
IERS RS/PC[7]								

1 The word “Int” an abbreviation for the word Intensive.
2 Geospatial Information Authority of Japan.
3 International Laser Ranging Service.
4 Institute of Applied Astronomy of the Russian Academy of Sciences.
5 Satellite Laser Ranging.
6 Russian Mission Control Centre.
7 Both combination and prediction values are available.

Other data sets are available that include: UT from NRCanada (EMR) GPS; 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, dψ and dε 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 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> or
<ftp://toshi.nofs.navy.mil/ser7>.

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

Center Staff

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

Brian Luzum	Director
Nick Stamatakos	Operational program manager, 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
Nathan Shumate	Assists in daily operations and support, research, and software maintenance

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Nicholas Stamatakos, Merri Sue Carter, Nathan Shumate