3.5.2 Rapid Service/Prediction Centre

This section provides a summary of the Earth orientation parameter (EOP) results produced by the IERS Rapid Service / Prediction Center (RS/PC) for the calendar year 2014. Additionally, this section contains an overview of the combination processing techniques, the prediction processing techniques, the activities under development to improve EOP results, and the web and FTP locations available to users for obtaining results.

Combination Processing Techniques and Results

In combining the contributed observational data to generate the quick-look EOP results, the IERS RS/PC employs a smoothing cubic spline that weights each of the input data based on their reported observational errors, which is referred to as a "weighted smoothing cubic spline" (McCarthy and Luzum, 1991a). Observational data contributions are corrected for possible systematic differences in the form of offsets and rates computed with respect to the 08 C04 system of the IERS Earth Orientation Centre (EOC) at the Paris Observatory; to this end, a robust linear estimator (using the MATLAB function 'regstats') is employed which ameliorates the effect of outliers on the computed offsets and rates. The statistical weights used in the spline are proportional to the inverse square of

Table 1: Estimated accuracies of the contributors in 2014. 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	0.20	0.18			
IAA SLR	0.33	0.20			
MCC SLR	0.15	0.24			
GSFC VLBI Intensives			0.020		
USNO VLBI Intensives			0.019		
GSI Intensives			0.016		
GSFC VLBI	0.11	0.11	0.007	0.53	0.13
IAA[1] VLBI	0.36	0.18	0.010	(0.22)	(0.27)
IVS[1] VLBI	0.10	0.17	0.002	(0.07)	(0.13)
USNO VLBI	0.15	0.12	0.006	0.26	0.11
IGS Final	0.01	0.02			
IGS Rapid	0.03	0.03			
IGS Ultra* (observations)	0.03	0.03	0.027*		
USNO GPS UT*			0.016*		

*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).

the estimated accuracy of the individual techniques computed over the past several years. Minimal smoothing is applied, consistent with the estimated accuracy of the observational data.

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. The estimated accuracies for each of the IERS RS/PC contributors to the EOP combination solutions for 2014 are provided in Table 1. These estimates are based on the residuals between the series and 08 C04 system of the IERS EOC from 2014.

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, some contributors provide direct measurements and others provide estimates based on quantities related to UT1. All of the Very Long Baseline Interferometry (VLBI) contributors provide direct measurements of UT1; the International GNSS Service (IGS) ultra-rapid observations (IGS ultras) provide a length-of-day-type input, which is a derivative of UT1; and the USNO GPS UT provides a UT1-like estimate based on GPS orbit modeling. 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 in both the IGS ultras and USNO GPS UT. The corresponding statistics shown for the IGS ultras and USNO GPS UT are computed after the bias corrections are applied. The Atmospheric Angular Momentum (AAM) inputs do not contribute to the EOP combination solution, but provide inputs to the EOP UT1–UTC predictions out to 7 days into the future; therefore, there is no mention of AAM results in Table 1. The combination corresponds to solutions of past EOP results; whereas, predictions refer to the current and future EOP look-ahead solutions which are discussed later in the chapter.

Operationally, the spline uses the following as inputs: the epoch of observation, the observed EOP value, and the corresponding weight. 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 for 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, it uses dψ and dε for historical reasons. 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

Table 2: Mean and standard deviation of the differences between the Rapid Service/Prediction Center combination solutions and the 08 C04 EOP solutions for 2014. 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	–0.01	0.03
y	–0.02	0.03
UT1–UTC	0.003	0.013
Bulletin A Weekly Solution (finals.data)[1]		
x	0.01	0.04
y	0.00	0.04
UT1–UTC	–0.004	0.024
Bulletin A Daily Solution (finals.daily)		
x	0.00	0.04
y	0.01	0.04
UT1–UTC	–0.017	0.036

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

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 EOP inputs whose errors, as reported by the contributors, are greater than three times their average reported precision. The other data excluded are those inputs that have a residual that is more than four times the associated *a priori* error estimate. (The value of 4 was chosen to eliminate 4-sigma outliers and was determined via an empirical approach; email communication with Dr. Dennis McCarthy, 2015.) Also, note that since all of the observations are reported to the IERS RS/PC 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 for 2014. The running solution statistics, shown under the label "Bulletin A Rapid Solution," are the residuals of the combination solution versus the 08 C04 over the 365-day period covering 2014. 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 obtained from the Bulletin A combination values for 2014 versus the 08 C04 series. These combination values for 2014 are the concatenation of all 52 Bulletin A, 7-day EOP combination results. For each Bulletin A, there is a set of 7-day EOP combination results listed prior to the solution epoch. (For example, the Bulletin A solution computed on January 9, 2014 has EOP combination results from January 3 through January 9, 2014.)

The statistics for the daily solution, shown under the “Bulletin A Daily solution” heading in Table 2, are the differences between the EOP solution, updated daily and at each corresponding daily epoch for 2014, versus the respective 08 C04 series solution for that epoch when it becomes available. The following will illustrate the process used in generating this section of Table 2. On May 6, 2014 (MJD = 56783), an EOP solution is produced a few minutes after 17:00 UTC on that day, and the solution is contained on the EOP server at <ftp://maia.usno.navy.mil/ser7/finals.daily> (and is archived appropriately). Within that file are generally 90 past EOP combination solutions, the solution on the current day, and 90 future EOP predictions starting from MJD 56694 to MJD 56874. (Note, the number of epochs before and after the current solution day may occasionally vary depending on the most recent observational data provided.) The EOP solution on the row of the file corresponding to MJD 56783 is compared to the 08 C04 combination solution corresponding to the same date and a residual is produced. This process is repeated for each MJD of 2014, and statistics on the set of residuals are computed.

Figure 1 contains plots of the residuals between the daily rapid and the 08 C04 solutions, and the corresponding statistical results are listed in Table 2 under “Bulletin A Daily Solution (finals.daily).” These daily rapid solutions are considered the last combination or 0-day prediction results. For 2014, the RMS of the residual results for polar motion between the daily rapid solution and the 08 C04 were similar to what resulted in 2013 (see IERS Annual Report 2013, <http://www.iers.org/AR2013>, Chapter 3.5.2). The standard deviation of polar motion X improved in 2014 from 2013 by approximately 20%; the polar motion Y and UT1–UTC values from 2014 were within 10% of the 2013 values. The RMS of the residual results for UT1–UTC appear to be similar when comparing the 2013 to 2014 results; however, when examining the UT1–UTC plot shown in Figure 1 of this 2014 report, one can see a degradation in the residuals occurring in roughly the 2nd half of the year.

On June 12, 2014, the electronic transfer of VLBI data (e-VLBI) from the Kokee Park (Kk) radio telescope ceased, and this lack of e-VLBI transfer caused an increased latency in the time from VLBI intensive INT1 (Stamatakos *et al.,* 2008) observation to

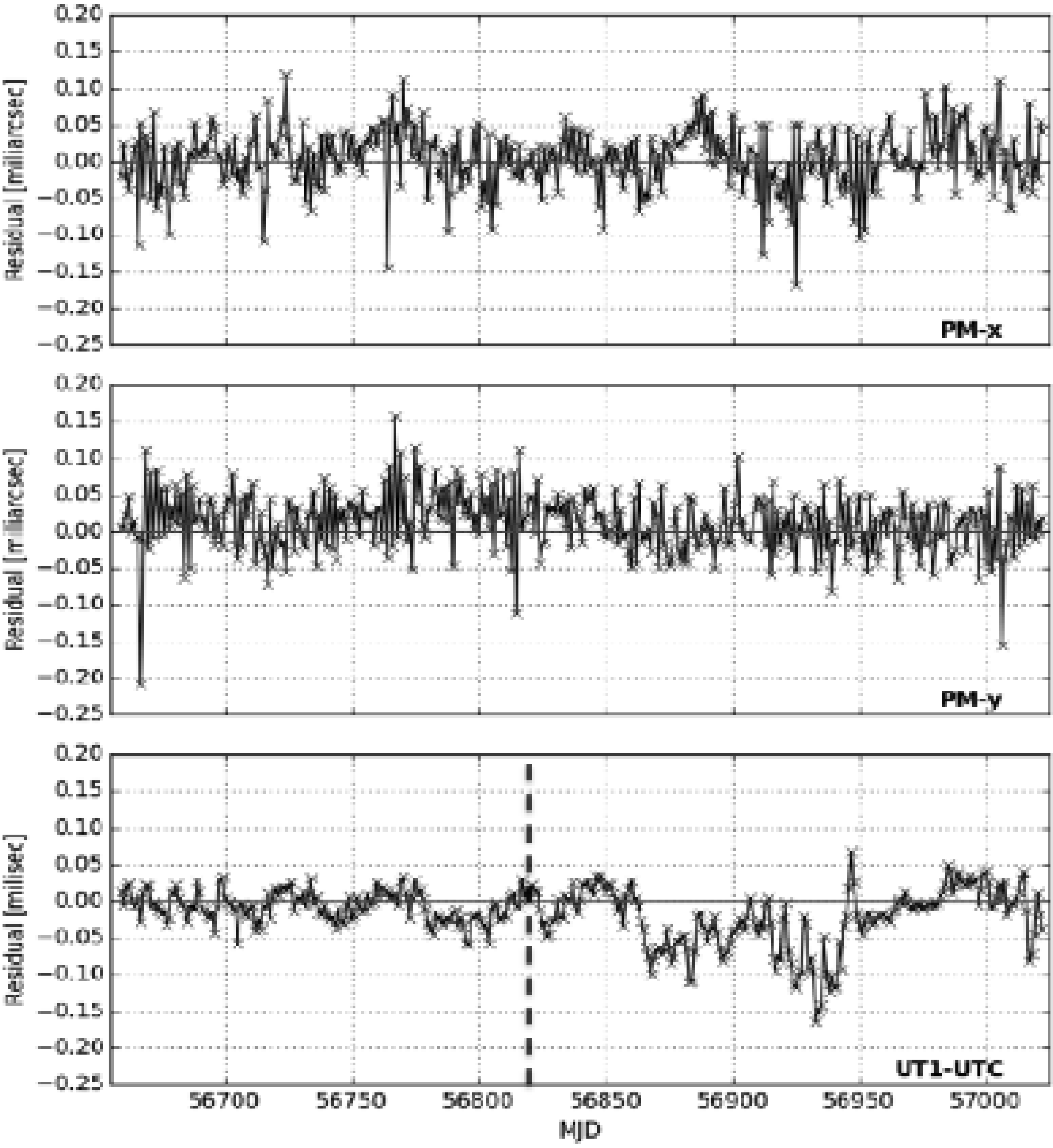

Fig. 1: Differences between the EOP solution updated daily (called the 'daily rapid solution') for 2014 and the respective 08 C04 series combination solution (produced in February 2015). The Earth Orientation Parameters shown are: a) Polar Motion X; b) Polar Motion Y; c) UT1–UTC. The vertical dotted line denotes the loss of electronic transfer capabilities from Kokee Park Observatory on MJD 56820.

correlation, fringing, analysis, and finally inclusion in the IERS RS/PC EOP solution. The INT1 observational data from Kk had to be recorded on media and shipped via FedEx to USNO instead of being electronically transferred via e-VLBI. The latency increased from about 1 day before June 12, 2014 to 2 or 3 days (and occasi-

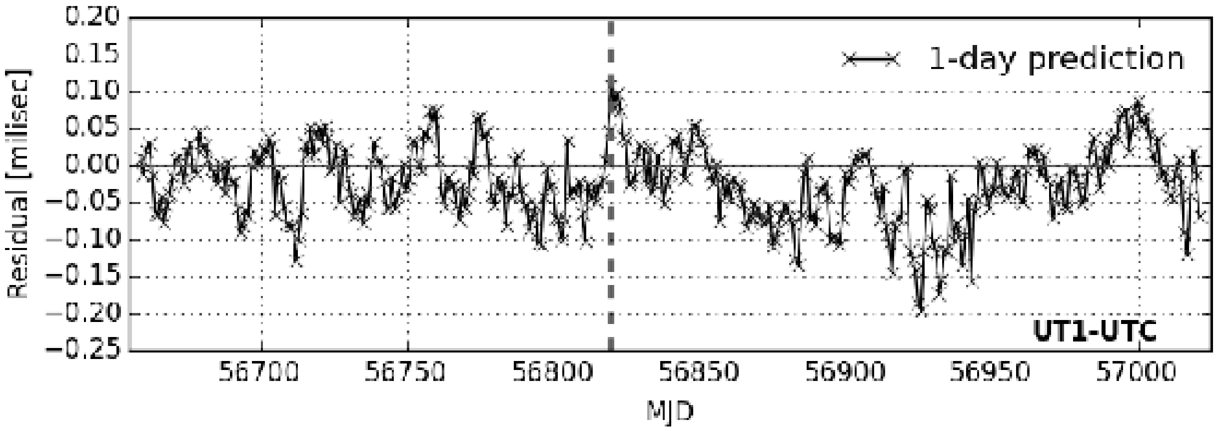

Fig. 2: Difference between the daily 1-day UT1–UTC prediction for 2014 from the 'daily rapid solution' and the respective 08 C04 series solution produced in February 2015. The vertical dotted line denotes the loss of electronic transfer capabilities from Kokee Park Observatory on MJD 56820. The effects from the loss of the electronic data transfer at Kokee Park on the daily solution (0-day prediction) can also be seen in Figure 1c.

onally longer) after that date. Also, Figure 2, which contains a plot of the UT1–UTC 1-day prediction residuals versus the 08 C04, has a similar signature to that shown in Figure 1 for UT1–UTC. (In that plot, there is a vertical line indicating when June 12, 2014 occurred.) There is a potential correlation between an increase in residuals, which is shown in Figures 1 (UT1–UTC plot) and 2, and the loss of e-VLBI when the change in UT1–UTC (with known tidal and seasonal effects removed) versus time was large. To determine the strength of this potential correlation among these effects, a larger study (beyond the scope of the analyses done for this report) is needed.

Prediction Techniques and Results

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 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 (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 combined smoothly with the longer-term UT1 predictions described below. For more information on the use of the UT AAM 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 – resulting in a quantity called UT2R–TAI. (UT2R is a smoothed version of UT1, filtering out periodic seasonal and long period variations due to tides.) 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 2-times the most recent value, $2(UT2R–TAI)_0$

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

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 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 Bulletin A 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).

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. The error values correspond to the color-coded vertical bar at the right – ranging from less than 0.1 (dark blue) to greater than 0.9 (dark red) milliarcseconds.

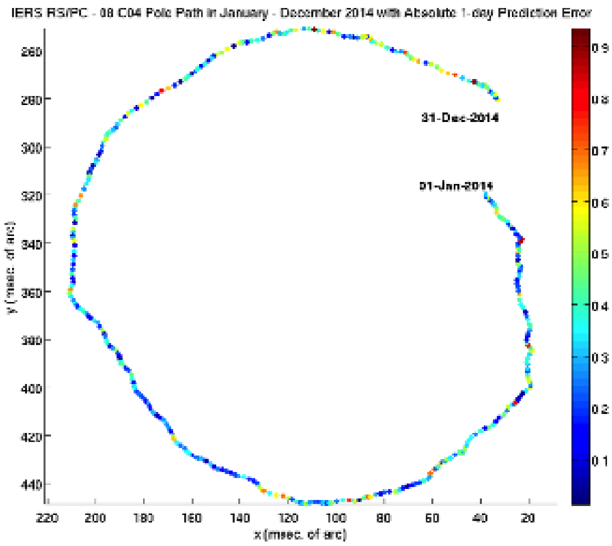

Table 3a: Root mean square of the differences between the EOP time series predictions produced by the 17:00 UTC daily EOP solutions and the 08 C04 combination solutions for 2014. Note that the prediction length starts counting from the day after the date of the solution epoch.

Days in Future	PM-x Mas	PM-y mas	UT1–UTC ms
0	.042	.043	.039
1	.305	.234	.056
5	1.68	1.16	.204
10	3.14	2.00	.481
20	5.50	3.34	1.61
40	10.1	5.32	4.51
90	21.7	12.1	14.3

Table 3b: Root mean square of the differences between the EOP time series predictions produced by the 21:10 UTC daily EOP solutions and the 08 C04 combination solutions for 2014.

Days in Future	PM-x mas	PM-y mas	UT1–UTC ms
0	.034	.034	.038
1	.272	.206	.054
5	1.63	1.13	.203
10	3.08	1.96	.483
20	5.47	3.30	1.62
40	10.2	5.27	4.50
90	21.7	12.1	14.3

Table 3c: Root mean square of the differences between the EOP time series predictions produced by the 03:10 UTC daily EOP solutions and the 08 C04 combination solutions for 2014.

Days in Future	PM-x mas	PM-y mas	UT1–UTC ms
0	.035	.035	.037
1	.265	.124	.051
5	1.77	1.20	.202
10	3.18	2.05	.482
20	5.53	3.32	1.61
40	10.1	5.24	4.49
90	21.1	12.2	14.3

Table 3d: Root mean square of the differences between the EOP time series predictions produced by the 09:10 UTC daily EOP solutions and the 08 C04 combination solutions for 2014.

Days in Future	PM-x mas	PM-y mas	UT1–UTC ms
0	.034	.035	.036
1	.154	.124	.049
5	1.47	1.20	.201
10	2.93	2.06	.481
20	5.45	3.39	1.61
40	10.1	5.27	4.50
90	21.3	12.1	14.3

** The number of days from the midnight epoch associated with the EOP solution generated at 17:00 UTC. E.g., the 1-day prediction epoch for all Nxdaily EOP solutions is shown in Figure 4.*

Table 3a shows the RMS of the differences between the 17:00 UTC Polar Motion and UT1–UTC solution predictions and the 08 C04 solutions for 2014. When comparing the 2014 results to 2013, there was a small improvement in the polar motion predictions out to 10 days – the level of improvement was approximately 5 to 10%. Unfortunately, there was almost no improvement in the short-term UT1–UTC predictions. As was previously mentioned in the discussion of Figure 1, this lack of improvement was possibly, in part, due to the loss of the e-VLBI results from Kokee Park, which is one of the two radio telescopes used in the 2-baseline INT1 intensives. As to be expected with longer-term predictions (20 days or more into the future), the comparison of 2013 to 2014 results do not follow a discernable pattern.

In previous annual reports, the prediction length (as shown in Table 3a) was determined from the 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 from 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 could be made 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 four solutions are collectively referred to as the Nxdaily solutions. At these solution times, the EOP results are recomputed and made available to users. The original solution at 17:00 UTC has been 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 results 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 e-VLBI 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, whose latencies between observations to availability to the EOP solution are under a few days, 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. While the IGS contributions have a consistent update time, the VLBI intensives updates are not as regular as the IGS updates. For example, new IGS ultra rapid observations are regularly updated every 6 hours with only a handful of missed or late solutions each year; whereas, a few VLBI intensives could be late or missing each month. So, the contributors shown for each solution are only an ideal case that occurs less than 100% of the time. (Since the e-VLBI outage occurred in June 2014 for the INT1 solutions, the corresponding rows referring to INT1 VLBI Intensives in Table 4b were not applicable from June 13 to Dec 31, 2014.) 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 Update 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 Update 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. Also, this row was not applicable after June 12, 2014 due to e-VLBI outage at Kokee Park.

[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 2014. 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 solutions will have more recent observations. The 2014 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 — 50% for PMx and 47% 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 14%.

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.

The predictions of celestial pole offsets (both dX/dY and $d\psi/d\varepsilon$ representations) are produced through the use of the KSV1996 model (McCarthy, 1996). In addition, a bias, based on several years of past observations compared to the 08 C04 solution, is computed and applied to ensure consistency with the 08 C04 solution. Since celestial pole offsets are based solely on VLBI data,

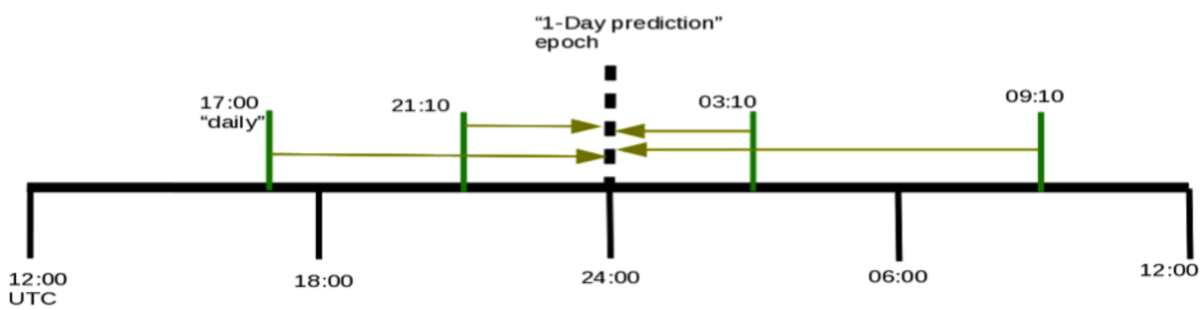

Fig. 4: Timeline of EOP 1-day prediction solutions in relation to the EOP "daily" solution produced at 17:00 UTC.

if no new VLBI 24-hour session observations are available, a new rapid combination/prediction of these angles is not determined. Therefore, the updates 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 RMS differences between the daily predictions and the 08 C04 for 2014 are provided in Table 5.

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 2014.

Days in Future	dX mas	dY mas	δψ mas	δε mas
0	.16	.16	.38	.14
1	.16	.16	.39	.15
5	.17	.17	.42	.15
10	.18	.17	.44	.16
20	.21	.19	.51	.18
40	.26	.23	.62	.23

Predictions of TT–UT1, up to 1 January 2025, 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).

Center Activities in 2014

During 2014, several input data series to the EOP operational solution were upgraded. A list of these upgrades is as follows:

a) the U.S. Navy Fleet Numerical Meteorology and Oceanography Center (FNMOC) AAM input was upgraded from NAVGEM v1.1 to v1.2 in February 2014;

b) the NASA Goddard VLBI 24-hour and intensive data series was upgraded from the gsf2012a to gsf2014a series in May 2014; and

c) the USNO VLBI 24-hour and intensive data series was upgraded from the usno2012b to usno2014a series in June 2014.

In addition, it was determined that the systematic corrections for the International Laser Ranging Service (ILRS) SLR needed to

Table 5: Predicted values of TT–UT1, 2015–2025. 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)
2015 Oct 1	68.02	0.009
2016 Jan 1	68.1	0.01
2016 Apr 1	68.3	0.02
2016 Jul 1	68.4	0.02
2016 Oct 1	68.5	0.3
2017 Jan 1	68.6	0.4
2017 Apr 1	68.7	0.5
2017 Jul 1	68.8	0.6
2017 Oct 1	69.0	0.8
2018 Jan 1	69.1	0.9
2018 Apr 1	69.2	1.0
2018 Jul 1	69.	1.
2018 Oct 1	69.	1.
2019 Jan 1	70.	1.
2019 Apr 1	70.	1.
2019 Jul 1	70.	2.
2019 Oct 1	70.	2.
2020 Jan 1	70.	2.
2020 Apr 1	70.	2.
2020 Jul 1	70.	2.
2020 Oct 1	70.	2.
2021 Jan 1	71.	2.
2021 Apr 1	71.	3.
2021 Jul 1	71.	3.
2021 Oct 1	71.	3.
2022 Jan 1	71.	3.
2022 Apr 1	71.	3.
2022 Jul 1	71.	3.
2022 Oct 1	71.	4.
2023 Jan 1	72.	4.
2023 Apr 1	72.	4.
2023 Jul 1	72.	4.
2023 Oct 1	72.	4.
2024 Jan 1	72.	4.
2024 Apr 1	72.	5.
2024 Jul 1	72.	5.
2024 Oct 1	72.	5.
2025 Jan 1	73.	5.

be updated, and as a result, new corrections were included in the operational EOP solution in June 2014.

Also, efforts were continued in the following areas as well: a) using the Very Long Baseline Array (VLBA) inputs as additional UT1–UTC inputs to the EOP solution (Stamatakos *et al., 2012, AGU poster G51A-1084*), b) studying the use of the IGS Ultra-rapid predictions for enhanced polar motion and LOD inputs to the EOP solution, and c) using combined AAM and OAM models to improve polar motion predictions (Salstein *et al.*, 2014).

The IERS RS/PC replicates the USNO (Washington D.C.) EOP solutions at the Naval Observatory, Flagstaff station (NOFS). The USNO and NOFS products are generated independently, and the 17:00 UTC EOP solutions at the USNO DC and NOFS are compared each day 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 products, such as due to an internet outage or power outage.

The Earth Orientation transformation matrix calculator (<http://maia.usno.navy.mil/t2c36e/t2c36e.html>) was maintained throughout the year. The calculator can 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.

Rapid Service Input Data Contributors and Products

A list of the inputs to the EOP combination and prediction solutions are provided in Table 7; in addition, this table indicates which EOPs are provided by each contributor.

Other data sets are available and are listed below; however, they are not used in the EOP combination and prediction solutions. They include: UT from Natural Resources Canada GPS; UT0–UTC from University of Texas at Austin Lunar Laser Ranging (LLR); UT0–UTC from JPL LLR; UT0–UTC from the Centre de recherches en géodynamique et astrométrie (CERGA) LLR; UT0–UTC from JPL VLBI; latitude and UT0–UTC from Washington [state] PZTs 1,3,7; latitude and UT0–UTC from Richmond, Florida PZTs 2,6; LOD from ILRS 1-day SLR; x, y, UT1–UTC from Center for Space Research (CSR) UT at Austin LAGEOS 3-day SLR; x and y from CSR LAGEOS 5-day SLR; x and y from Delft, Netherlands 1-, 3- and 5-day SLR; and x, y, UT1–UTC, $d\psi$ and $d\varepsilon$ from International Radio Interferometric Surveying (IRIS) VLBI.

The data described above are available from the IERS RS/PC in a number of forms. You may also request a weekly machine-readable version of the IERS Bulletin A containing the current

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

Contributor	PM-x	PM-y	UT1–UTC	LOD	$d\psi$	$d\varepsilon$	dX	dY
IAA VLBI								
GSFC VLBI								
USNO VLBI								
IVS VLBI								
GSFC Int.[a]								
USNO Int.								
GSI[b] Int.								
ILRS[c]								
IAA[d] SLR[e]								
MCC[f] SLR								
IGS								
USNO GPS								
NCEP AAM								
NAVGEM AAM								
IERS EOC								
IERS RS/PC[g]								

[a] The word “Int” is an abbreviation for the word Intensive.

[b, c, d, e, f] Defined in the Acronyms section of the Appendix of this report.

[g] Both combination and prediction values are available.

365 days’ worth of predictions via electronic mail from ser7@maia.usno.navy.mil or through <http://www.usno.navy.mil/USNO/earth-orientation>.

Daily and Bulletin A weekly EOP solutions can be obtained from the primary Earth Orientation (EO) server at <http://maia.usno.navy.mil> and <ftp://maia.usno.navy.mil>, and from the backup EO server at <http://toshi.nofs.navy.mil> and <ftp://toshi.nofs.navy.mil>. An additional backup mirror of the daily and Bulletin A EOP data is now hosted by NASA’s Archive of Space Geodesy Data server at <ftp://cddis.gsfc.nasa.gov/pub/products/iers>.

Table 8 contains a listing of the locations and update times of several of the EOP solutions discussed in this report. The first column lists the EOP solution time in UTC. These are the approximate times when an EOP result is computed; the actual solution time may occur as much as one hour later than what is listed. The second column contains the subdirectory under each FTP or web address listed in the above paragraph where an EOP solution resides. For example, at <http://maia.usno.navy.mil>

there exists a subdirectory called “ser7” (i.e., <http://maia.usno.navy.mil/ser7>) where the daily EOP solution computed at 17:00 UTC will be updated each day. Similarly, at <ftp://cddis.gsfc.nasa.gov>, there exists a subdirectory called “eop0300utc” (i.e., <ftp://cddis.gsfc.nasa.gov/pub/products/iers/eop0300utc>), where an EOP solution update computed at approximately 03:10 UTC will be uploaded each day.

Table 8: EOP server locations and update times.

EOP solution time (UTC)[1]	Subdirectory Location	Approximate time solution is posted[1]
17:00	ser7	17:15[2]
21:10	eop2100utc	21:15
03:10	eop0300utc	03:15
09:10	eop0900utc	09:15

[1] *Solution times are the approximate times when an EOP result is computed; actual solution time may occur as much as one hour later than what is listed.*

[2] *This time represents the approximate time updated EOP solutions, found at http://maia.usno.navy.mil, ftp://maia.usno.navy.mil, http://toshi.nofs.navy.mil, and ftp://toshi.nofs.navy.mil, will be available. For ftp://cddis.gsfc.nasa.gov/pub/products/iers, the solution is posted at 18:00 UTC, which is approximately 45 minutes after the “maia” and “toshi” servers have data posted. The additional time is needed to allow the EOP solution to finish at USNO and to be verified by EOP personnel before the mirroring is performed to post the solution to CDDIS.*

Center Staff

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

Dr. Christine Hackman	Director; Head, Earth Orientation Department
Nick Stamatakos	Operational program manager, research, and software maintenance; Chief, Earth Orientation Combination and Prediction Division
Merri Sue Carter	Assists in daily operations and support; Research Astronomer
Nathan Shumate	Assists in daily operations and support, research, and software maintenance; Astronomer
Maria Davis	Assists in daily operations and support, research, and software maintenance; Astronomer

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