

## 3.5.2 Rapid Service/Prediction Centre

This section provides a discussion and summary of the Earth orientation parameter (EOP) results produced by the IERS Rapid Service / Prediction Center (RS/PC) for the calendar year 2015. The accuracies of both the inputs (used in the generation of the IERS RS/PC results) and the IERS RS/PC combination and prediction results (as published in several formats that comprise the Bulletin A results) are provided. In addition, a plot of the polar motion path for the year, a summary of the expected times during each day at which inputs are provided to the IERS RS/PC solution, a low precision table of predictions of TT–UT1, and a comprehensive list of the inputs to the IERS RS/PC combination and prediction process are provided. Lastly, this section also contains an overview of the combination processing techniques and 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/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 series of the IERS Earth Orientation Centre (EOC) at the Paris Observatory; to this end, a robust linear estimator 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 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 2015 are provided in Table 1. The estimates are based on the residuals between the contributor series and the IERS RS/PC (USNO) EOP solution (contained in the file `finals.data`) for all the epochs in 2015.

The EOPs consist of polar motion, UT1–UTC, and celestial pole offsets. Some of the EOPs are measured directly while others are

a hybrid of direct measurements and related quantities. For polar motion ( $x$  and  $y$ ) and the celestial pole offsets ( $\delta\psi$ ,  $\delta\epsilon$ ,  $dX$ , and  $dY$ ), all the contributors (which have associated statistics in Table 1) provide direct measurements of these quantities. For UT1–UTC, some contributors provide direct measurements and others provide estimates based on the derivative of 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 (“UTGPS”). The corresponding statistics shown for the IGS ultras and UTGPS 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 seven 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.

The 2015 UT1–UTC GSFC, USNO, and GSI VLBI Intensives Estimated Accuracy values, listed in Table 1, all improved as compared to the corresponding 2014 values<sup>1</sup>. The largest decrease in the RMS of the residuals was for the USNO intensives – 0.019 milliseconds in 2014 and 0.010 milliseconds in 2015; the second largest improvement was for the GSI intensives – 0.016 in 2014 and 0.010 in 2015; and the 3<sup>rd</sup> largest improvement was for the GSFC intensives – 0.020 in 2014 and 0.015 in 2015. There were also decreases in accuracy of UTGPS and the integrated IGS Ultra LODs; for UTGPS the residuals went from 0.016 in 2014 to 0.027 milliseconds in 2015 and for the integrated IGS Ultra LODs, the residuals went from 0.027 to 0.046.

Part of the reason for the improvement in VLBI intensives estimated accuracies (and the corresponding decrease in UTGPS and integrated IGS Ultra LODs) might be explained by the decrease in formal error that was reported by all the VLBI Intensives. The formal error is an internal estimate of the errors that occur during the observations, processing, and estimated solutions – a kind of precision estimate reported by each input contributor. As discussed earlier, the weightings – used in the smoothing, weighted

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<sup>1</sup> The 2014 statistics are located in Table 1 of Section 3.5.2 of the IERS Annual Report 2014; located by clicking on the “Rapid Service/Prediction Centre” tab at <<https://www.iers.org/AR2014>>.

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*Table 1: Estimated accuracies of the contributions to the IERS RS/PC combination results in 2015 with respect to the IERS RS/PC EOP series. Units are milliseconds of arc for  $x$ ,  $y$ ,  $\delta\psi$ ,  $\delta\varepsilon$ ,  $dX$ , and  $dY$  and milliseconds of time for  $UT1-UTC$ . (All acronyms used in this table are defined in the Acronyms section of the Appendix of this report.)*

Contributor Information Name, Type	Estimated Accuracy				
	$x$	$y$	UT1	$\delta\psi$ (dX)	$\delta\varepsilon$ (dY)
ILRS SLR	0.20	0.23			
IAA SLR	0.19	0.23			
MCC SLR	0.24	0.26			
GSFC VLBI Intensives			0.015		
USNO VLBI Intensives			0.010		
GSI Intensives			0.010		
GSFC VLBI	0.16	0.11	0.006	0.32	0.18
IAA <sup>+</sup> VLBI	0.27	0.19	0.009	(0.11)	(0.16)
IVS <sup>+</sup> VLBI	0.10	0.21	0.003	(0.05)	(0.04)
USNO VLBI	0.14	0.20	0.006	0.41	0.16
IGS Final	0.01	0.01			
IGS Rapid	0.04	0.03			
IGS Ultra* (observations)	0.04	0.04	0.046*		
USNO GPS UT*			0.027*		

\*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.

<sup>+</sup> IAA and IVS VLBI nutation values are in terms of  $dX/dY$  using IAU 2000A Nutation Theory (see Petit and Luzum, 2010).

cubic spline of the EOP combination – are partly a function of the formal error. There was a 17% decrease in formal error for USNO intensives, a 24% decrease for GSI intensives, and a 10% decrease for Goddard intensives. The reason for the improvement in formal error is currently being reviewed; and since it is possible that the decrease in formal error is only partly responsible for the improvement in estimated accuracy of the VLBI intensives, other reasons for the decreased residuals of the VLBI intensives are also being considered.

Although there was not much improvement in the VLBI 24-hour estimated accuracies from 2014 to 2015, there were small, but noticeable decreases in the formal error of the VLBI 24-hour results. The effect is to also increase the weighting these inputs have on the smoothing, cubic spline, while decreasing the relative weighting of other inputs.

The decrease in accuracy of UTGPS, from 2014 to 2015 (and as mentioned above), is also being reviewed. One partial explanation for this decrease is that since the UTGPS estimated accuracy is assigned a constant in the combination software, its relative weighting versus the VLBI intensives effectively decreased

because the intensive weightings increased, as discussed in the previous paragraphs. Other factors are being considered as well.

The decrease in accuracy of the integrated IGS Ultra LODs is also being reviewed, and its relative weighting is also possibly affected by the decrease in the VLBI formal errors mentioned above when discussing the UTGPS estimated accuracies.

Operationally, the spline, which combines the contributors, 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,  $\delta\psi$ , and  $\delta\epsilon$  values are computed for the midnight (00:00) UTC epoch for each day.

While the celestial pole offset combination software can combine either  $\delta\psi$  and  $\delta\epsilon$  or  $dX$  and  $dY$ , it uses  $d\psi$  and  $d\epsilon$  for historical reasons. Therefore, the Institute of Applied Astronomy (IAA) and the International VLBI Service (IVS) VLBI  $dX$  and  $dY$  values are converted to  $\delta\psi$  and  $\delta\epsilon$  in the combination process.

Additionally, LOD and estimated error results are published along with the EOP combination results. The LOD results 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 (after leap second discontinuities are removed) 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 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<sup>2</sup> the associated *a priori* error estimate. 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 2015; the latter series uses somewhat different data inputs and a different combination algorithm, which makes it suitable for comparison. Nominally, each Thursday, the IERS RS/PC produces a weekly EOP solution in two general file formats – the

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<sup>2</sup> 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).

*Table 2: Mean and standard deviation of the differences between the Rapid Service/Prediction Center combination solutions and the 08 C04 EOP solutions for 2015. Polar motion x and y values are in milliseconds of arc and UT1–UTC values are in units of milliseconds of time. For the polar motion residuals, the values to the left of the “|” symbol have all outliers included; those to the right have outliers greater than 5-σ removed.*

	Bulletin A – C04	
	Mean	Std. Deviation
<b>Bulletin A Rapid Solution (finals.data)</b>		
x	-0.02   -0.01	0.20   0.05
y	-0.02   -0.02	0.14   0.04
UT1–UTC	0.003	0.021
<b>Bulletin A Weekly Solution (finals.data)<sup>1</sup></b>		
x	0.01   0.02	0.20   0.08
y	-0.02   -0.01	0.15   0.06
UT1–UTC	-0.007	0.037
<b>Bulletin A Daily Solution (finals.daily)</b>		
x	-0.02   0.00	0.20   0.06
y	-0.00   0.00	0.15   0.05
UT1–UTC	-0.017	0.056

<sup>1</sup> Statistics computed over the 7-day combination solution period prior to solution epoch.

“finals.data” and the “ser7.dat” files. The finals.data solution contains EOP data in a tabular, machine-readable form, for each day from 1992 to one year into the future from the Thursday updated solution date. At the same time, the results are published in the ser7.dat file, which is more in a human readable format. Formats for each can be found at: <http://maia.usno.navy.mil/ser7/readme>. finals and ser7/readme.bulla. In addition, each day, the IERS RS/PC computes and publishes an EOP solution in the file “finals.daily”. This file is also in the same format as the finals.data file; however, it only contains the current day, three prior months, and three future months of EOP results.

As shown in Table 2, for the polar motion residuals, there were several large outliers, which were mainly due to unexpected and potentially suspect (for reasons explained below) 08 C04 results, and therefore, the polar motion statistics each have two reported results – one in a left and another in a right column, separated by the “|” symbol. The left column contains the statistics with all outliers included, and the right column has outliers greater than approximately 5-σ removed.

The 08 C04 is an IERS EOP reference series. It is customary in the international scientific community that (a) significant changes

in algorithms used to compute such series and (b) changes to already-published series values are announced to the community prior to being made. However, the polar motion values for 2015 in the 08 C04 series have been changed several times per month since the start of 2016. This unusual circumstance has caused several challenges in determining the accuracies of the IERS RS/PC polar motion EOP solution. The reference series to which the RS/PC solution is compared, 08 C04, has not had stable 2015 values and also appears to have accuracy problems for polar motion, as will be shown below. For UT1–UTC, the 08 C04 solution does appear to be stable and reasonably accurate.

The running solution statistics, shown under the label “Bulletin A Rapid Solution (finals.data),” are the residuals of the combination solution, contained in finals.data, versus the 08 C04 series over the 365-day period covering 2015. The finals.data file used in computing these statistics was computed on January 14, 2016 (and also archived). Nominally, the last observational input data for the year (in this case, 2015) is processed and provided to the IERS RS/PC by January 14 of the following year (in this case, 2016); the last observational data is usually the 24-hour VLBI input series. Thus, the running solution includes the effects of any late-submitted, but highly accurate data.

The “Bulletin A Weekly Solution” results shown in Table 2 are the statistics of the residuals obtained from the Bulletin A combination values for 2015 versus the 08 C04 series. These combination values for 2015 are the concatenation of all 53 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 8, 2015 has EOP combination results from January 2 through January 8, 2015.)

The statistics for the daily solution, shown under the “Bulletin A Daily solution (finals.daily)” heading in Table 2, are the differences between the EOP solution, updated daily and at each corresponding daily epoch for 2015, 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, 2015 (MJD = 57148), 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 57059 to MJD 57239. (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 values on the row of the file corresponding to MJD 57148 is compared to the 08 C04 combination values corresponding to the same date and

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a residual is produced. This process is repeated for each MJD of 2015, and statistics on the set of residuals are computed.

Figures 1a and 1b contain 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 2015, there were several outliers for polar motion, as illustrated in Figure 1a. All the outliers for polar motion x, except for two, were determined to be due to issues with the 08 C04 series; all the polar motion y outliers were probably due to 08 C04 issues. As mentioned previously, an outlier was considered to be any residual with a value greater than  $5\text{-}\sigma$ ; there were 22 outliers for polar motion x and 10 for polar motion y.

The IERS RS/PC polar motion series had no significant outliers when compared to the ITRF 2014 series, which ended on February 14, 2015. When compared to the JPL Space<sup>3</sup> series, USNO had only two outliers for polar motion x and none for polar motion y. The potential, two identified IERS RS/PC polar motion outliers occurred on MJDs 57089 (March 8, 2015) and 57092 (March 11, 2015).

One cause of the large IERS RS/PC polar motion x outliers on those epochs was probably the removal of IGS ultra observation results. There was a problem with the UT1 solution that occurred on those two epochs, and in order to obtain a reasonable solution in LOD/UT1, some of the IGS ultra observations were removed from the combination; as a result, it was assumed that several of the IGS ultra EOP observations might have been poor for that day, and the polar motion contribution was removed as well.

Note that the statistics provided in Table 2 for polar motion (to the right of the “|” symbol) under “Bulletin A Daily Solution (finals. daily)” were provided with those two outliers and all other outliers removed. The IERS RS/PC can supply statistics with the associated outliers included upon request.

Starting on June 12, 2014 and continuing throughout 2015, 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 correlation, fringing, analysis, and finally inclusion in the IERS RS/PC EOP UT1–UTC 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 occasionally longer) after that date. (During early 2016, e-VLBI was restored.)

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<sup>3</sup> The JPL SPACE series is the “JPL Operational Kalman Earth Orientation Series” found at [ftp://euler.jpl.nasa.gov/keof/predictions/latest\\_midnight.eop](ftp://euler.jpl.nasa.gov/keof/predictions/latest_midnight.eop).

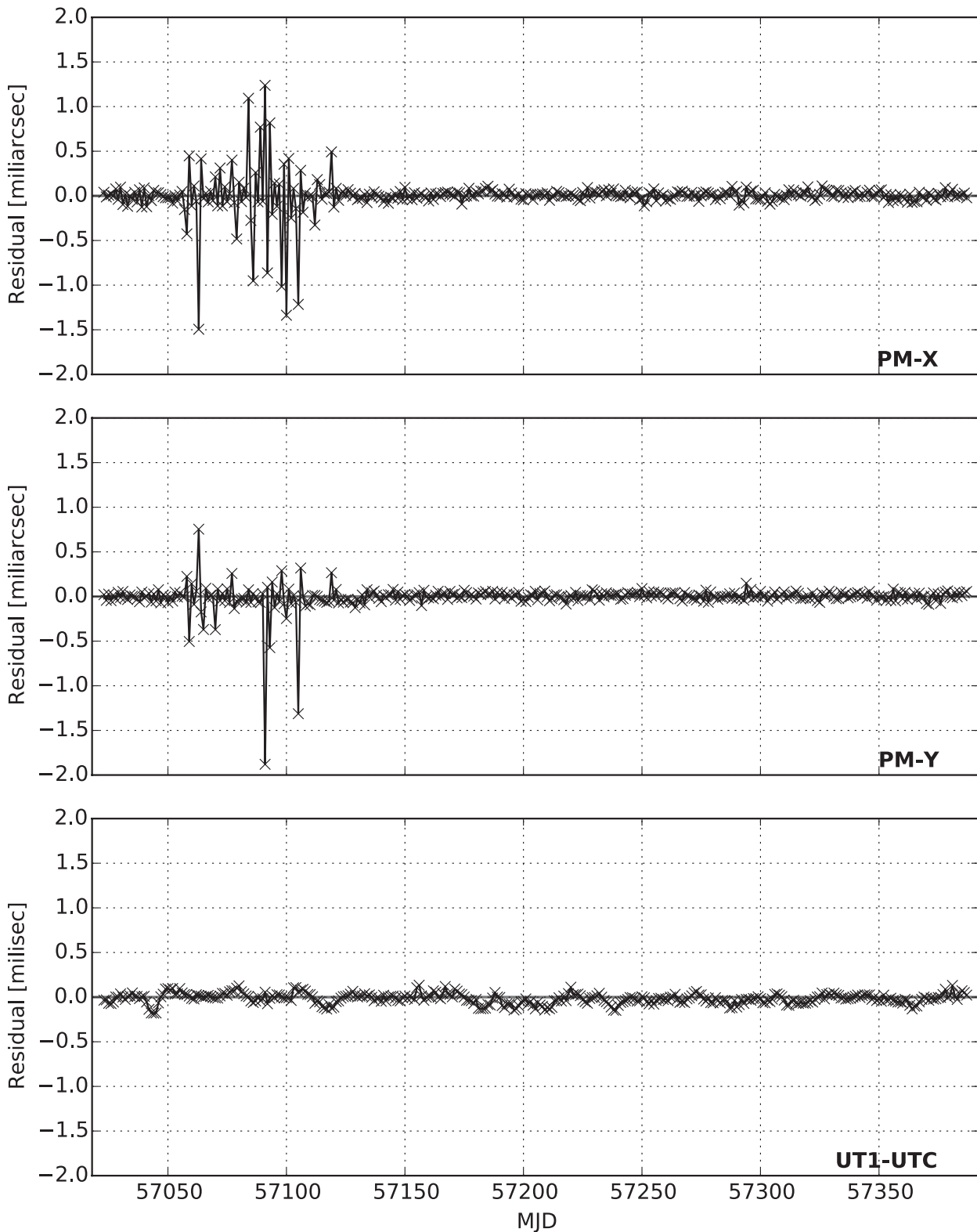


Fig. 1a: Differences between the EOP solution updated daily (called the ‘daily solution’) for 2015 and the respective 08 C04 series combination solution (produced on 01 April 2016). For the polar motion residual plots, the y-axis limits were chosen to show all outliers; there were no such large outliers as shown on the UT1–UTC residual plot. The Earth Orientation Parameters shown are: a) Polar Motion X; b) Polar Motion Y; c) UT1–UTC.

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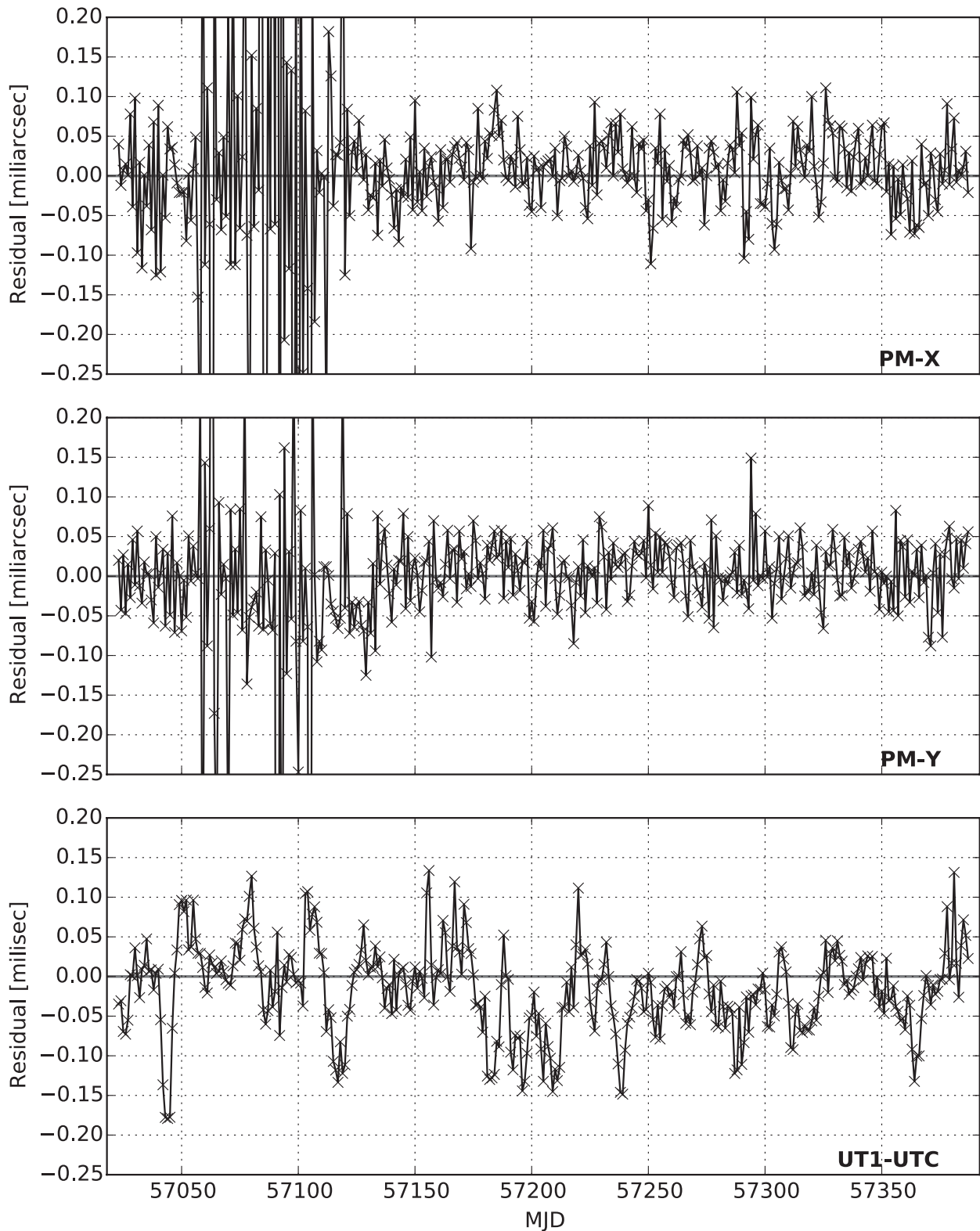


Fig. 1b: Differences between the EOP solution updated daily (called the ‘daily solution’) for 2015 and the respective 08 C04 series combination solution (produced on 01 April 2016). For the polar motion residual plots, the y-axis limits were chosen to better show the signal of the non-outlier residuals; there were no such large outliers for the UT1–UTC residual plot. The Earth Orientation Parameters shown are: a) Polar Motion X; b) Polar Motion Y; c) UT1–UTC.

There were no significant outliers for the UT1–UTC residuals. However, the RMS of the 0-day prediction residuals for 2015 was larger than that obtained for 2014. For 2015, the RMS was 0.058 milliseconds; whereas, for 2014, the RMS was 0.039 milliseconds. We suspect that part of the increase is due to the extra latency from VLBI intensives observation to inclusion of the result into the EOP combination. The lack of e-VLBI occurred for all of 2015; whereas, e-VLBI was functional from January 1 to June 11, 2014. This period from January to June, 2014, which had e-VLBI functioning, possibly had the effect of lowering the RMS of the residuals computed over the entire year of 2014.

### 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 (Johnson *et al.*, 2005). 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 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 obser-

ved values of UT1–UTC, resulting in a quantity called UT2R–TAI. (UT2R is a smoothed version of UT1, removing 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,  $\langle(UT2R-TAI)_{-N}\rangle$  is subtracted from 2-times the most recent value,  $2(UT2R-TAI)_0$

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

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 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  $\delta\psi$  and  $\delta\varepsilon$  are based on the IERS Conventions (McCarthy, 1996; McCarthy and Petit, 2004).

Table 3a shows, for 2015, the RMS of the differences between the polar motion and UT1–UTC solution predictions produced daily at 17:00 UTC and those of the 08 C04 series. In computing the statistics for polar motion listed in Table 3a through 3d, several outliers greater than  $5\text{-}\sigma$  were identified; the statistics shown for polar motion in these tables were computed with outliers greater than  $5\text{-}\sigma$  removed. This issue is very similar to what was discussed earlier in the Combination Processing Techniques and Results section, which reviewed the polar motion residuals and associated outliers in Table 2; it has been determined that the outliers are mainly due to problems with the 08 C04 reference series. Statistics for the polar motion values listed in Tables 3a through 3d with all outliers included are available from the IERS RS/PC upon request.

Note that while choosing a  $5\text{-}\sigma$  threshold for removing outliers was quite conservative and reasonable, it also left large outliers in the residuals negatively affecting the polar motion residual statistics for 2015. It has been determined that the vast majority of these smaller, but significant outliers are likely due to issues with the 08 C04 series. Therefore, the polar motion residuals statistics show

*Table 3a\*\*: RMS 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 2015. 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	0.06	0.05	0.058
1	0.34	0.24	0.073
5	2.02	1.18	0.207
10	3.42	2.01	0.567
20	5.50	3.09	2.319
40	9.34	4.69	5.897
90	*	*	17.253

*Table 3b\*\*: RMS 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 2015.*

Days in Future	PM-x mas	PM-y mas	UT1–UTC ms
0	0.07	0.05	0.056
1	0.30	0.21	0.071
5	1.97	1.13	0.206
10	3.39	2.01	0.567
20	5.46	3.07	2.321
40	9.31	4.68	5.909
90	*	*	17.273

*Table 3c\*\*: RMS 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 2015.*

Days in Future	PM-x mas	PM-y mas	UT1–UTC ms
0	0.07	0.06	0.055
1	0.25	0.09	0.070
5	2.02	1.08	0.206
10	3.68	1.97	0.567
20	5.71	2.98	2.322
40	9.59	4.68	5.909
90	N/A	N/A	17.278

*Table 3d\*\*: RMS 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 2015.*

Days in Future	PM-x mas	PM-y mas	UT1–UTC ms
0	0.07	0.06	0.053
1	0.22	0.09	0.068
5	1.86	1.09	0.205
10	3.50	1.96	0.566
20	5.60	3.00	2.323
40	9.54	4.69	5.915
90	N/A	N/A	17.301

\* 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 3.

\*\* The 08 C04 combination solutions used for the residuals listed in Tables 3a through 3d were determined on April 4, 2015. Also, the statistics for polar motion do not include outliers greater than  $5\text{-}\sigma$ . Statistics with all outliers included are available from the IERS RS/PC upon request.

a distinct decrease in accuracy from 2014 to 2015; this decrease, however, is probably not an issue with the IERS RS/PC solution, but rather a problem with 08 C04.

A plot of the polar motion path, with the corresponding 1-day prediction residual values for 2015, is shown in Figure 2. Each colored circle on the plot corresponds to the pole location at a midnight epoch during 2015, and the colors indicate the corresponding residual. The residual values correspond to the color-coded vertical bar at the right of the plot. The residuals are the RMS of the combined polar motion x and y residual values at each epoch. For this plot, the outliers greater than  $5\text{-}\sigma$  were removed; and, therefore, gaps appear in the plot.

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Table 3e: RMS of the differences between the EOP time series predictions produced by the 2015 17:00 UTC daily EOP solutions and the corresponding 08 C04 combination solutions downloaded in May, 2016. The statistics for polar motion do not include outliers greater than  $5\sigma$ .

Days in Future	PM-x Mas	PM-y mas	UT1-UTC ms
90	15.97	12.87	17.253

Table 3g: RMS of the differences between the EOP time series predictions produced by the 2015 03:10 UTC daily EOP solutions and the corresponding 08 C04 combination solutions downloaded in May, 2016. The statistics for polar motion do not include outliers greater than  $5\sigma$ .

Days in Future	PM-x mas	PM-y mas	UT1-UTC ms
90	15.99	13.01	17.278

Table 3f: RMS of the differences between the EOP time series predictions produced by the 2015 21:10 UTC daily EOP solutions and the corresponding 08 C04 combination solutions downloaded in May, 2016. The statistics for polar motion do not include outliers greater than  $5\sigma$ .

Days in Future	PM-x mas	PM-y mas	UT1-UTC ms
90	15.93	12.85	17.275

Table 3h: RMS of the differences between the EOP time series predictions produced by the 2015 09:10 UTC daily EOP solutions and the corresponding 08 C04 combination solutions downloaded in May, 2016. The statistics for polar motion do not include outliers greater than  $5\sigma$ .

Days in Future	PM-x mas	PM-y mas	UT1-UTC ms
90	15.97	12.97	17.301

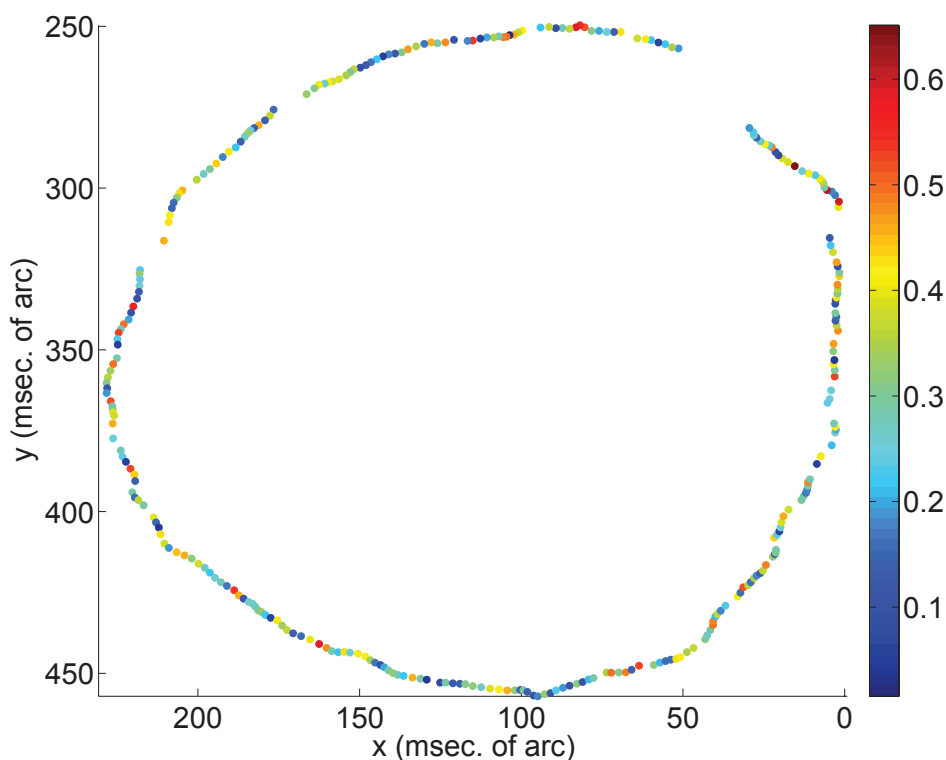


Fig. 2: Plot of the polar motion path for 2015 with corresponding 1-day prediction residual values. Residual outliers values greater than  $5\sigma$  were removed. The residual is the RMS of the combined polar motion x and y residual values and is in units of milliseconds of arc. The error values correspond to the color-coded vertical bar at the right – ranging from less than 0.1 (dark blue) to greater than 0.6 (dark red) milliarcs.

It has been noticed, as mentioned previously, that the polar motion section of the 08 C04 series has been changing its results for 2015 several times per month since the start of 2016. For previous annual reports, the Table 3 statistics were computed for rows, corresponding to 0 through 40-day predictions, using the 08 C04 series determined in April of the following year. The 08 C04 series is only updated up to 30 days prior to the current date. So, for example, on April 30, 2016, the latest possible EOP solution whose accuracy could be evaluated would be for March 31, 2016. Since it is desired to write this contribution to IERS Annual Report as early as possible, as much of the statistics as possible was computed in early April.

In order that the results in Table 3a through 3d remain self-consistent, the 90-day prediction results were omitted from those tables for polar motion. The 90-day prediction residual results for polar motion were made using the 08 C04 from early May 2016 and are listed in Tables 3e through 3f. In previous annual reports, in early May of the following year, the 90-day prediction statistics are normally computed (and simply added onto the rows in Tables 3a through 3d); that way all of the 365 90-day residuals versus the 08 C04 can be obtained. However, for 2016, the 08 C04 series results for polar motion changed significantly between April and May 2016. Therefore, for polar motion, the statistics for the 0 to 40-day predictions presented in Tables 3a through 3d that were computed using the early April 2016 08 C04 would have been different if using the 08 C04 results from May, 2016. Note, that the 08 C04 solution created in early May, 2016 also had significant outliers for polar motion, and the 08 C04 solution has been updated several times in June 2016.

Since the 08 C04 has not been changing for UT1–UTC, the prediction results for Table 3a through 3d are self-consistent. Therefore, the 90-day prediction is included in those tables.

The UT1–UTC RMS prediction statistics for 2015 were generally worse than for 2014. For example, for the 17:00 UTC solution 1-day prediction results, the RMS for 2015 was 0.073 milliseconds; for 2014 it was 0.058 milliseconds. A possible reason for part of the decrease in accuracy was that the e-VLBI was not functioning for all of 2015; whereas, it functioned for part of 2014. As discussed in the Combination Processing Techniques and Results, when the e-VLBI is not functioning there is extra latency from VLBI intensives observation to inclusion of the result into the EOP combination; the e-VLBI was not functioning for all of 2015 (but was resumed in early 2016). The e-VLBI was functioning from January 1 to June 11, 2014; however, it became non-functional starting on June 12, 2014.

In annual reports up through 2013, the prediction length (as shown in Tables 3a) was determined from the epoch of the last known VLBI or IGS observation, and not based on the date of the

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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](mailto: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 provided 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. (After June 12, 2014 and throughout all of 2015, there was an e-VLBI outage at Kokee Park, and therefore, the INT1 VLBI intensive had an additional 2 to 3 days of latency. So, the Epoch at Midpoint value for this VLBI intensive was actually  $-24 \times X - 05:00$  hours, where “X” is the number of days of latency.) 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.

Within each Nxdaily EOP solution file, which are 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 3, 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 09:10 UTC <MJD+1> EOP solution will also make an estimate of the EOP value for the same 00:00 <MJD+1> epoch.

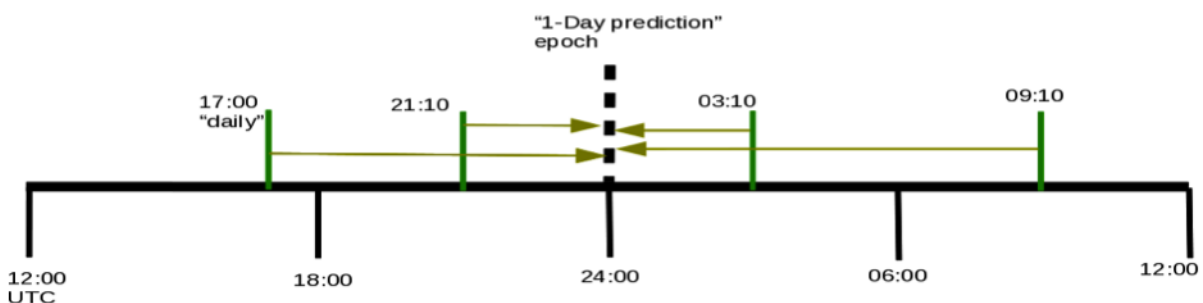


Fig. 3: Timeline of Nxdaily EOP 1-day prediction solutions in relation to the EOP “daily” solution produced at 17:00 UTC.

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 <sup>3</sup>		AAM LOD <sup>3</sup>		AAM LOD <sup>3</sup>		AAM LOD <sup>3</sup>	
INT2 / 3 VLBI intensive <sup>1</sup>	+08:00	INT2 / 3 VLBI intensive <sup>1</sup>	+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 <sup>1</sup>	+08:00	IGS 0 hr Ultra	+12:00
INT1 VLBI intensive <sup>2</sup>	-05:00	IGS 12 hr Ultra	00:00	IGS 18 hr Ultra	+06:00	INT2 / 3 VLBI intensive <sup>1</sup>	+08:00
IGS 6 hr Ultra	-06:00	INT1 VLBI intensive <sup>2</sup>	-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 <sup>2</sup>	-05:00	IGS 12 hr Ultra	00:00
		IGS Rapid	-12:00	IGS 6 hr Ultra	-06:00	INT1 VLBI intensive <sup>2</sup>	-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.  
<sup>1</sup> INT2 intensives are normally observed Saturday and Sunday and INT3s on Monday; both sets with an epoch at midpoint at approximately 08:00 UTC.  
<sup>2</sup> INT1 intensives are normally observed Monday through Friday with an epoch at midpoint at approximately 19:00 UTC. The Epoch at Midpoint value of -05:00 is an idealized situation. After June 12, 2014 and throughout 2015, there was an e-VLBI outage at Kokee Park; therefore the INT1 VLBI intensive had two or more days of latency. So, the Epoch at Midpoint was actually (-24\*X -05:00) hours, where "X" is the number of days of latency.  
<sup>3</sup> The AAM LOD inputs contain 7.5 days of forecast data from 00:00 to 180:00 hours.

In general, each of the Nxdaily solutions for UT1–UTC made after the 17:00 UTC solution on day MJD, i.e. at 21:10 on day MJD, and 03:10 and 09:10 on day MJD+1, will have reduced residuals. For example, by examining the 1-day UT1–UTC prediction residual statistics in Tables 3a through 3d, one sees an improvement from 0.073, 0.071, 0.070, and to 0.068 milliseconds in the RMS, respectively. However, because of the outlier issues that occurred for polar motion (which was discussed previously in this section and in the Combination Processing Techniques and Results section), there is no consistent pattern when comparing polar motion RMS statistics among Tables 3a through 3d.

The predictions of celestial pole offsets (both  $dX/dY$  and  $\delta\psi/\delta\epsilon$  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, 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 RMS differences between the daily predictions and the 08 C04 for 2015 are provided in Table 5.

Predictions of TT–UT1, up to 1 January 2026, 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., 2011).

*Table 5: RMS of the differences between the nutation prediction (also known as celestial pole offset) series produced by the daily solutions and the 08 C04 combination solutions for 2015.*

Days in Future	dX mas	dY mas	$\delta\psi$ mas	$\delta\epsilon$ mas
0	.14	.14	.34	.17
1	.15	.14	.35	.17
5	.15	.15	.37	.17
10	.17	.16	.40	.18
20	.19	.17	.45	.20
40	.23	.21	.56	.24

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*Table 6: Predicted values of TT–UT1, 2016–2026. 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)
2016 Oct 1	68.47	0.01
2017 Jan 1	68.6	0.01
2017 Apr 1	68.8	0.02
2017 Jul 1	68.9	0.02
2017 Oct 1	69.1	0.2
2018 Jan 1	69.3	0.3
2018 Apr 1	69.4	0.4
2018 Jul 1	69.6	0.5
2018 Oct 1	69.7	0.6
2019 Jan 1	69.8	0.8
2019 Apr 1	69.9	0.9
2019 Jul 1	70.0	1.0
2019 Oct 1	70.	1.
2020 Jan 1	70.	1.
2020 Apr 1	70.	1.
2020 Jul 1	71.	1.
2020 Oct 1	71.	2.
2021 Jan 1	71.	2.
2021 Apr 1	71.	2.
2021 Jul 1	71.	2.
2021 Oct 1	71.	2.
2022 Jan 1	71.	2.
2022 Apr 1	71.	2.
2022 Jul 1	72.	3.
2022 Oct 1	72.	3.
2023 Jan 1	72.	3.
2023 Apr 1	72.	3.
2023 Jul 1	72.	3.
2023 Oct 1	72.	3.
2024 Jan 1	72.	4.
2024 Apr 1	72.	4.
2024 Jul 1	73.	4.
2024 Oct 1	73.	4.
2024 Oct 1	73.	4.
2025 Jan 1	73.	4.
2025 Apr 1	73.	4.
2025 Jul 1	73.	5.
2025 Oct 1	73.	5.
2026 Jan 1	73.	5.

### Center Activities in 2015

During 2015, 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 v1.2 to v1.3 in April, 2015;
- b) the USNO VLBI 24-hour and intensive data series was upgraded from the usno2014a to usno2015a series on April 30, 2015;
- c) the USNO VLBI 24-hour and intensive data series was upgraded from the usno2015a to usno2015b series on December 10, 2015.

Also, efforts continued in the following areas as well: a) using the Very Long Baseline Array (VLBA) estimates as additional UT1–UTC inputs to the EOP solution (Stamatakos *et al.*, 2012, *AGU poster G51A-1084*), b) using combined AAM and OAM inputs to improve polar motion predictions (Stamatakos *et al.*, 2016), and c) studying methods to better optimize the use of the IGS Ultra-rapid observations for LOD inputs to the EOP solution.

In addition, preparations were made to change the methodology used to compute IERS RS/PC celestial pole offsets. This new code uses computations based on the  $dX$  and  $dY$  as opposed to the  $\delta\psi$  and  $\delta\varepsilon$  paradigm, and thus it will accept VLBI  $dX$  and  $dY$  inputs. Only minor changes to the code are needed to make it operational; however, it was decided to delay operational implementation until the next OP series after the 08 C04, since OP has stated that they will also use computations based on the  $dX$  and  $dY$  paradigm. By waiting for the new C04 series, the IERS RS/PC and EOC series for celestial pole offsets can then be cross-validated.

The Earth Orientation transformation matrix calculator<sup>4</sup> 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

<sup>4</sup> <<http://maia.usno.navy.mil/t2c36e/t2c36e.html>>

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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. <sup>a</sup>			✓					
USNO Int.			✓					
GSI <sup>b</sup> Int.			✓					
ILRS <sup>c</sup>	✓	✓						
IAA <sup>d</sup> SLR <sup>e</sup>	✓	✓						
MCC <sup>f</sup> SLR	✓	✓						
IGS	✓	✓		✓				
USNO GPS			✓					
NCEP AAM			✓					
NAVGEM AAM			✓					
IERS EOC	✓	✓	✓		✓	✓	✓	✓
IERS RS/PC <sup>g</sup>	✓	✓	✓		✓	✓	✓	✓

<sup>a</sup> The word “Int” is an abbreviation for the word Intensive.

<sup>b, c, d, e, f</sup> Defined in the Acronyms section of the Appendix of this report.

<sup>g</sup> Both combination and prediction values are available.

géodynamique et astrométrie (CERGA) LLR; UT0–UTC from JPL VLBI; latitude and UT0–UTC from Washington, DC, Photographic Zenith Tubes (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,  $\delta\psi$  and  $\delta\varepsilon$  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 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 lists 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) <sup>1</sup>	Subdirectory Location	Approximate time solution is posted <sup>1</sup>
17:00	ser7	17:15 <sup>2</sup>
21:10	eop2100utc	21:15
03:10	eop0300utc	03:15
09:10	eop0900utc	09:15

<sup>1</sup> 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.

<sup>2</sup> At <http://maia.usno.navy.mil>, <ftp://maia.usno.navy.mil>, <http://toshi.nofs.navy.mil>, and <ftp://toshi.nofs.navy.mil>, this time represents the approximate time an updated EOP solution 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 (at the USNO EO Department) consisted of the following members:

Dr. Christine Hackman    Director; Head, Earth Orientation (EO) Department

Mr. Nick Stamatakos    Project Director and Lead Scientist; Chief, EOP Combination and Prediction (EOP C/P) Division

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Ms. Merri Sue Carter	Assists in daily operations and support; Research Astronomer, EOP C/P Division
Mr. Nathan Shumate	Assists in daily operations and support, research, and software maintenance; Astronomer, EOP C/P Division
Ms. Maria Davis	Assists in daily operations and support, research, and software maintenance; Astronomer, EOP C/P Division

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