## 3.5.2 Rapid Service/Prediction Centre

### Processing Techniques

The algorithm used by the IERS Rapid Service/Prediction Centre for the determination of the quick-look Earth Orientation Parameters (EOP) is based on a weighted cubic spline with adjustable smoothing fit to contributed observational data (McCarthy and Luzum, 1991a). Contributed data are corrected for possible systematic differences. Biases and rates are determined with respect to the C04 system of the IERS Earth Orientation Centre (EOC). Statistical weighting used in the spline is proportional to the inverse square of the estimated accuracy of the individual techniques. Minimal smoothing is applied, consistent with the estimated accuracy of the observational data.

Weights in the algorithm may be either a priori values estimated by the standard deviation of the residual of the techniques or values based on the internal precision reported by contributors. Estimated accuracies of data contributed to the IERS Rapid Service/Prediction Centre are given in Table 1. These estimates are based on the statistical reports that were generated weekly as a part of the Bulletin A Rapid Service EOP solution for 2005.

Operationally, the weighted spline uses as input the epoch of observation, the observed value, and the weight of each individual

*Table 1: Estimated accuracies of the techniques in 2005. Units are milliseconds of arc for x, y, dψ, dε, dX, and dY and milliseconds of time for UT1–UTC and LOD.*

| Contributor Information | Estimated Accuracy | | | | | |
|---|---|---|---|---|---|---|
| Name, Sample Rate[1], Type | x | y | UT1 | LOD | dψ (dX) | dε (dY) |
| CSR 3-day SLR | 0.27 | 0.29 | 0.061* | | | |
| DUT daily SLR | 0.35 | 0.36 | | | | |
| IAA daily SLR | 0.17 | 0.17 | | | | |
| MCC daily SLR | 0.15 | 0.18 | | | | |
| GSFC daily VLBI Intensives | | | 0.019 | | | |
| SPbU daily VLBI Intensives | | | 0.018 | | | |
| USNO daily VLBI Intensives[2] | | | 0.020 | | | |
| GSFC twice-weekly VLBI | 0.06 | 0.07 | 0.003 | | 0.4 | 0.1 |
| IAA twice-weekly VLBI[3] | 0.11 | 0.12 | 0.005 | | (0.1) | (0.1) |
| IVS twice-weekly VLBI | 0.07 | 0.07 | 0.004 | | 0.4 | 0.1 |
| USNO twice-weekly VLBI | 0.07 | 0.08 | 0.003 | | 0.4 | 0.1 |
| IGS daily Final | 0.04 | 0.04 | | | | |
| IGS daily Rapid | 0.02 | 0.04 | | 0.01* | | |
| USNO daily GPS UT* | | | 0.016* | | | |
| EMR daily GPS UT* | | | 0.03* | | | |
| USNO daily AAM UT | | | 0.012 | | | |

*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] The sample rate of provided data sets and not the series update rate.

[2] USNO VLBI Intensive series began in May 2005.

[3] IAA VLBI nutation values are in terms of dX/dY using IAU 2000A Nutation Theory.

data point. The software computes the spline coefficients for every data point which are then used to interpolate the Earth orientation parameter time series so that x, y, UT1–UTC, dψ, and dε values are computed at the epoch of zero hours UTC for each day. Since the celestial pole offset software is written in terms of dψ and dε, the IAA VLBI dX and dY values are converted to dψ and dε for the combination process. The only data points that are excluded from this process are the points whose errors, as reported by the contributors, are greater than three times their average reported precision or those points that have a residual that is more than four times the associated a priori error estimate. Since all of the observations are reported with the effects of sub-daily variations removed, no processing is done to account for these effects (see IERS Gazette No. 13, 30 January 1997).

*Table 2: Mean and standard deviation of the differences between the Rapid Service/Prediction Centre solutions and IERS Bulletin B and C04 EOP solutions for 2005. Polar motion X and Y values are in milliseconds of arc and UT1–UTC values are in units of milliseconds of time.*

| | Bulletin A – Bulletin B | | Bulletin A – C04 | |
|---|---|---|---|---|
| | Mean | Std.Deviation | Mean | Std. Deviation |
| ***Bulletin A Rapid Running Solution (finals.data)*** | | | | |
| X | –0.08 | 0.08 | –0.08 | 0.06 |
| Y | 0.12 | 0.08 | 0.12 | 0.05 |
| UT1–UTC | –0.010 | 0.020 | –0.010 | 0.021 |
| ***Bulletin A Weekly Solution (finals.data)***[1] | | | | |
| X | –0.05 | 0.08 | –0.05 | 0.05 |
| Y | –0.01 | 0.09 | –0.01 | 0.06 |
| UT1–UTC[2] | –0.012 | 0.036<br>0.028[3] | –0.011 | 0.037<br>0.027[3] |
| ***Bulletin A Daily Solution (finals.daily)*** | | | | |
| X | –0.04 | 0.12 | –0.04 | 0.10 |
| Y | –0.01 | 0.12 | –0.01 | 0.10 |
| UT1–UTC[2] | –0.023 | 0.060<br>0.048[3] | –0.023 | 0.059<br>0.048[3] |

[1] Statistics computed over the 7-day combination solution period prior to solution epoch.
[2] Standard deviations including periods with known VLBI intensive and GPS rapid data issues.
[3] Standard deviations, after implementation of e-VLBI intensives, using only the last 5 months of the year.

The uncertainties in the daily values listed in Bulletin A are derived from the quality of the spline fit in the neighborhood of the day in question. Table 2 shows the accuracies of Rapid Service/Prediction Centre's combination solution for the running, the weekly, and the daily products compared to the Bulletin B and C04 series maintained by the IERS EOC at the Paris Observatory. The running solution is the combination solution over the past 365-day period. The statistics for the running solution at year's end show the agreement between the Bulletin A running combination solution and the Bulletin B/C04 series for the entire year. The comparison of the 52 weekly solutions to the Bulletin B/C04 series gives the statistics of the residuals computed over the new combination results for the 7-days prior to the solution epoch. The statistics for the daily solution are the differences for the day of the solution epoch. EOP accuracies for the Bulletin A rapid weekly solution for the new combination for the day of the solution run and daily solution at the time of solution epoch are similar and therefore, not included in the table.

Figure 1 presents the data used in Table 2 for the determination of the Bulletin A daily solution statistics. This year Bulletin A had only small reductions in the standard deviations, while in August, UT1–UTC had larger reductions in standard deviations after the implementation of electronic VLBI (e-VLBI) data transfer. An examination of Figure 1 and Table 2 shows that the Centre's UT1–UTC solution accuracies were degraded from mid-May to late-June. Several difficulties had to be overcome in that time frame: problems with one of the UT GPS series, problems with software pre-processing of one of the VLBI Intensive series, and limited availability of valid AAM data sets for about a week while the operational weather model was being updated. These degradations were compounded by extended periods without VLBI data which further highlight the critical dependence of Earth orientation parameters on VLBI data.

The implementation and use of e-VLBI intensives has resulted in a 1 to 3 day reduction in delivery time of Intensive data. This coupled with the use of the "K"-intensives (KkSv-baseline) has resulted in an almost daily sample rate for VLBI intensives that are available in near real-time. This has improved the accuracy of the solution as reflected by improved standard deviations for both the weekly and daily UT1–UTC solutions. Compared to last year's standard deviations, the values for last 5 months of this year (after the introduction of e-VLBI data) indicate a 47% reduction computed over the last 7 days of the weekly UT1–UTC combination solution and a 20% reduction for the last day of the daily UT1–UTC combination solution.

Figure 1 shows the residuals between the daily Bulletin A rapid solution at the epoch time of the solution and two other series (i.e., Bulletin B and C04). These plots also show that during the months of February and April, the Bulletin B and the C04 EOP series had significantly larger differences. Bulletin A had better agreement with C04 during these periods. Overall, the agreement between the Bulletin A solutions and the IERS EOC solutions is quite good with a smaller variance than last year.

## Prediction Techniques

Polar motion predictions are based on the extrapolation of an annual and semiannual ellipse and a Chandler circle fit to the previous 400 days of observed values of x and y (McCarthy and Luzum,

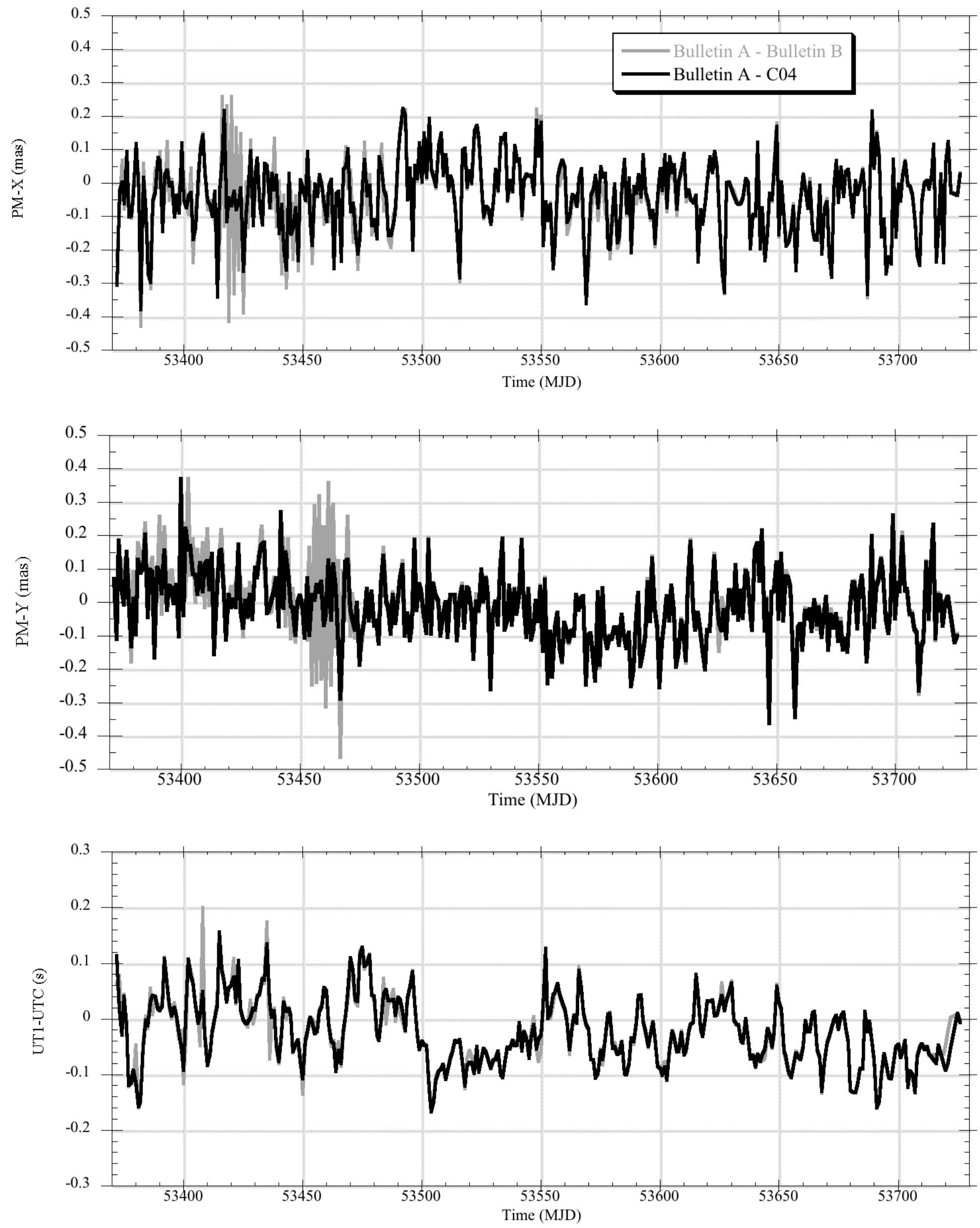


*Fig. 1: Differences between daily Bulletin A rapid solutions at each daily solution epoch for 2005 and the Earth Orientation Parameters available in Bulletin B and C04 series produced in April 2006.*

1991b; Johnson, 2002). The differences between the last observed pole position and rate and those of the curve are computed. These differences are then used to adjust the extrapolated curve by an amount that decreases with the length of the forecast. In February 1998, the near-term polar motion predictions (less than about 30 days) were improved significantly by modifying the transition process from the last observed polar motion result to the long-term predictions. Continuity in the first derivatives was enforced placing great weight on the observed polar motion rate reported by the IGS in their Rapid series. The improvement was most pronounced for the shortest prediction intervals. The procedure for UT1–UTC involves a simple technique of differencing (McCarthy and Luzum, 1991b). All known effects such as leap seconds, solid Earth zonal tides, and seasonal effects are first removed from the observed values of UT1–UTC. Then, to determine a prediction of UT1–UTC n days into the future, $(UT1-TAI)_n$, the smoothed time value from n days in the past, $<(UT1R-TAI)_{-n}>$ is subtracted from the most recent value, $(UT1R-TAI)_o$

$$(UT1-TAI)_n = 2(UT1R-TAI)_o - <(UT1R-TAI)_{-n}>.$$

The amount of smoothing used in this procedure depends on the length of the forecast. Short-term predictions with small values of n make use of less smoothing than long-term predictions. Once this value is obtained, it is possible to account for known effects in order to obtain the prediction of UT1–UTC. This process is repeated for each day's prediction.

The very near-term UT1–UTC prediction is strongly influenced by the observed daily Universal Time estimates derived at USNO from the motions of the GPS orbit planes reported by the IGS Rapid service. The IGS estimates for LOD are combined with the GPS-based UT estimates to constrain the UT1 rate of change for the most recent observation.

The near-term to sub-monthly UT1–UTC prediction also makes use of a UT1-like data product derived from the operational NCEP AAM analysis and forecast data (UTAAM). For the 5 days after the latest observation, AAM-based predictions of LOD excitation are combined smoothly with the longer-term UT1 predictions described above. Additional improvements to the combination and prediction process for UT1 have been implemented (Wooden et al., 2005).

Errors of the estimates are derived from analyses of the past differences between observations and the published predictions. Formulas published in Bulletin A are used to extend the tabular data. The predictions of $d\psi$ and $d\varepsilon$ are based on the IERS Conventions (McCarthy, 1996; McCarthy and Petit, 2004). Table 3 shows the standard deviation of the differences between the Bulletin A daily solution predictions and the C04 solution for 2003. Initial Centre estimates indicated that the UT1–UTC prediction performance would be improved by 42% at 10 days into the future (Johnson et al., 2005). However, comparisons of the UT1–UTC prediction performance from 2003 to those estimated in 2001 (before UTAAM was introduced) indicated a better than 50% improvement in prediction error at both 10 day and 20 days into the future by the addition of UTAAM to the combination and prediction routine.

For 2005, there was only a small improvement in the short-term UT1–UTC predictions. This was most likely the result of the addition of the e-VLBI Intensives. A comparison of a 4-month period at the beginning of 2005 to the last 4 months of 2005 did show a slight reduction in the standard deviations. However, the statistical significance of this improvement cannot be truly determined without a longer series of solutions. The longer-term polar motion predictions had large increases in their standard deviations. This was due to the presence of small sub-monthly retrograde loops in the polar motion. The operational prediction method could not solve for these loops.

*Table 3: Standard deviation of the differences between the EOP time series predictions produced by the daily Bulletin A rapid solutions and the C04 combination solutions for 2005.*

| Days in Future | PM–X | PM–Y | UT1–UTC |
|---|---|---|---|
| | mas | mas | ms |
| 1 | .44 | .37 | .127 |
| 5 | 2.44 | 1.70 | .380 |
| 10 | 4.13 | 2.77 | .935 |
| 20 | 6.82 | 4.56 | 3.30 |
| 40 | 11.9 | 8.32 | 5.98 |
| 90 | 25.2 | 18.9 | 7.61 |

The predictions of celestial pole offsets (both dX/dY and dψ/dε representations) are based solely on VLBI data. If no new VLBI 24-hour session observations are available, a new rapid combination/prediction of these angles is not determined. Therefore, the predictions of celestial pole offset start before the solution epoch time and the length of the prediction into the future can and does vary in the daily solution files. The differences between the daily Bulletin A predictions and those of the C04 for 2005 are given in Table 4.

*Table 4: Standard deviation of the differences between the nutation prediction series produced by the daily Bulletin A rapid solutions and the C04 solutions for 2005.*

| Days in Future | dX mas | dY mas | dψ mas | dε mas |
|---|---|---|---|---|
| 1 | .08 | .12 | .21 | .13 |
| 5 | .11 | .15 | .27 | .16 |
| 10 | .12 | .14 | .33 | .18 |
| 20 | .12 | .18 | .36 | .22 |
| 40 | .15 | .17 | .44 | .25 |

Predictions of UT1–TAI up to 2015 January 1, are given in Table 5. They are derived using a prediction algorithm similar to that employed in the Bulletin A predictions of UT1–UTC. Up to twenty years of past observations of UT1–TAI are used. Estimates of the expected one-sigma error for each of the predicted values are also

*Table 5: Predicted values of UT1–TAI, 2006–2015. Note that TT–UT1 can be obtained from this table using the expression TT–UT1=32.184s – (UT1–TAI).*

| DATE | | UT1-TAI (s) | Uncertainty (s) |
|---|---|---|---|
| 2006 | Jan 1 | –31.659 | .005 |
| | Apr 1 | –31.732 | .006 |
| | Jul 1 | –31.78 | .01 |
| | Oct 1 | –31.76 | .04 |
| 2007 | Jan 1 | –31.81 | .04 |
| | Apr 1 | –31.86 | .05 |
| | Jul 1 | –31.80 | .06 |
| | Oct 1 | –31.79 | .07 |
| 2008 | Jan 1 | –31.79 | .08 |
| | Apr 1 | –31.8 | .1 |
| | Jul 1 | –31.8 | .2 |
| | Oct 1 | –31.8 | .2 |
| 2009 | Jan 1 | –31.8 | .3 |
| | Apr 1 | –31.8 | .4 |
| | Jul 1 | –31.8 | .5 |
| | Oct 1 | –31.8 | .6 |
| 2010 | Jan 1 | –31.8 | .8 |
| | Apr 1 | –31.8 | .9 |
| | Jul 1 | –31.8 | 1. |
| | Oct 1 | –32. | 1. |
| 2011 | Jan 1 | –32. | 1. |
| | Apr 1 | –32. | 1. |
| | Jul 1 | –32. | 1. |
| | Oct 1 | –32. | 2. |
| 2012 | Jan 1 | –32. | 2. |
| | Apr 1 | –32. | 2. |
| | Jul 1 | –32. | 2. |
| | Oct 1 | –32. | 2. |
| 2013 | Jan 1 | –32. | 2. |
| | Apr 1 | –32. | 2. |
| | Jul 1 | –32. | 3. |
| | Oct 1 | –32. | 3. |
| 2014 | Jan 1 | –32. | 3. |
| | Apr 1 | –32. | 3. |
| | Jul 1 | –32. | 3. |
| | Oct 1 | –32. | 3. |
| 2015 | Jan 1 | –32. | 4. |

given. These are based on analyses of the past performance of the model with respect to the observations.

Additional information on improvements to IERS Bulletin A and the significance for predictions of GPS orbits for real-time users is available (Luzum et al., 2001; Wooden et al., 2004).

## Centre Activities in 2005

During 2005 a number of changes occurred that affected the performance of IERS Bulletin A. An electronic-VLBI (e-VLBI) proof-ofconcept experiment demonstrated the advantages of reducing the latency in VLBI data. Additional efforts included improving operational software, automating the process for updating data sets used in the combination, updating and monitoring currently used datasets, investigating potential new data sets, and investigating the improvement of polar motion prediction technique as well as preparing for the addition of a positive leap second in December 2005. To provide more robustness, an alternate site was established to mirror data storage for the combination processing.

The editing criteria in the combination program were modified to incorporate the number of useful scans as well as the formal error for the VLBI K-intensive data. In addition software was developed to estimate rates and biases between different observational data sets used in the EOP combination process. This new software applies similar editing criteria and a uniform statistical approach to that used within the combination software itself.

In July the IERS Earth Orientation Centre announced the addition of a positive leap second on December 31, 2005. As a consequence, the announcement was inserted into Bulletin A to alert users of the change, the leap second data file was updated, and the production software was modified to handle leap seconds automatically from the leap second file. The combination software was also modified to handle the problem of introducing a leap second into the UT1-like quantity derived from AAM.

New global solutions were received from GSFC, IAA, and USNO VLBI analysis centers. These new solutions were examined and new rates and biases were computed. Also, changes in rates and biases of currently combined SLR data were estimated. New data sets from the IDS, the ILRS, and IGS were examined. A careful analysis indicated that the addition of the ILRS-combined SLR solution series A and the IGS Ultra-rapid solutions may be useful in reducing errors in the polar motion combination. Some of this work was undertaken as a result of USNO's participation in the IERS Combined Pilot Project.

Collaborative efforts with colleagues at Poland's Center for Space Research showed the potential for improving our polar motion predictions by 20%–30% at 2 to 3 months into the future. Using updated software algorithms, an effort was begun to incorporate this new method into the operational software.

## Availability of Rapid Service

The data available from the IERS Rapid Service/Prediction Centre consist mainly of the data used in the IERS Bulletin A. These data include: x, y, UT1–UTC, dX and dY from IAA VLBI; x, y, UT1–UTC, $d\psi$ and $d\varepsilon$ from GSFC VLBI; x, y, UT1–UTC, $d\psi$ and $d\varepsilon$ from USNO VLBI; x, y, UT1–UTC, $d\psi$ and $d\varepsilon$ from IVS combination VLBI; UT1–UTC from Saint Petersburg University 1-day Intensives; UT1–UTC from GSFC 1-day Intensives; UT1–UTC from USNO 1-day Intensives;

x, y, UT1–UTC from CSR LAGEOS 3-day SLR; x, y from Delft University of Technology 1-day SLR; x, y from Institute of Applied Astronomy 1-day SLR; x, y from the Russian Mission Control Centre 1-day SLR; x, y, LOD from the International GNSS Service; UT from USNO GPS; UT from NRCanada (EMR) GPS; UT from NCEP AAM; x, y, UT1–UTC, dψ and dε from the IERS Rapid Service/Prediction Centre; x, y, UT1–UTC, dψ and dε from the IERS Earth Orientation Centre; and predictions of x, y, UT1–UTC from the IERS Rapid Service/Prediction Centre.

In addition to this published information, other data sets are available. These include: UT0–UTC from University of Texas as Austin LLR, UT0–UTC from JPL LLR; UT0–UTC from CERGA LLR; UT0–UTC from JPL VLBI; latitude and UT0–UTC from Washington PZTs 1,3,7; latitude and UT0–UTC from Richmond PZTs 2,6; x and y from CSR LAGEOS 5-day SLR; x and y from Delft 3- and 5-day SLR; and x, y, UT1–UTC, dψ and dε from IRIS VLBI.

The data described above are available from the Centre in a number of forms. You may request a weekly machine-readable version of the IERS Bulletin A containing the current ninety day's worth of predictions via electronic mail from

<ser7@maia.usno.navy.mil> or <http://maia.usno.navy.mil/>.

Internet users can also direct an anonymous FTP to

<maia.usno.navy.mil>

and change to the ser7 directory where the IERS Bulletin A and more complete databases can be accessed including the daily Bulletin solutions.

World Wide Web access is available at

<http://maia.usno.navy.mil/>.

## Centre Staff

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

| | |
|---|---|
| William Wooden | director |
| Thomas Johnson | program manager, research, and software maintenance |
| Arvid Myers | assists in operations, software maintenance, and support |
| Merri Sue Carter | assists in daily operations and support |
| Sebastien Lambert | research and software development |

In September 2005 Arvid Myers retired after more than two decades of service to USNO and Sebastien Lambert accepted a position at the Royal Observatory of Belgium.

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