

3.5.2 Rapid Service/Prediction Centre



Processing Techniques

The algorithm used by the IERS Rapid Service/Prediction Centre (RS/PC) for the determination of the quick-look Earth orientation parameters (EOP) is based on a weighted cubic spline with adjustable smoothing fit to contributed observational data (McCarthy and Luzum, 1991a). Contributed data are corrected for possible systematic differences. Biases and rates are determined with respect to the 05 C04 system of the IERS Earth Orientation Centre (EOC) at the Paris Observatory by way of a robust linear estimator. Statistical weighting used in the spline is proportional to the inverse square of the estimated accuracy of the individual techniques. Minimal smoothing is applied, consistent with the estimated accuracy of the observational data.

Weights in the algorithm may be either *a priori* values estimated by the standard deviation of the residual of the techniques or values based on the internal precision reported by contributors. Estimated accuracies of data contributed to the IERS Rapid Service/Prediction Centre are given in Table 1. These estimates are based on the residuals between the series and the combined RS/PC EOP solution for 2008.

Table 1: Estimated accuracies of the techniques in 2008. Units are milliseconds of arc for x , y , $\delta\psi$, $\delta\epsilon$, dX , and dY and milliseconds of time for UT1–UTC.

Operationally, the weighted spline uses as input the epoch of observation, the observed value, and the weight of each individual data point. The software computes the spline coefficients for every data point, which are then used to interpolate the Earth orientation parameter time series so that x , y , UT1–UTC, $\delta\psi$, and $\delta\epsilon$ values are computed at the epoch of zero hours UTC for each day. While the celestial pole offset combination software can combine either $\delta\psi$ and $\delta\epsilon$ or dX and dY , for historical reasons, it uses $\delta\psi$ and $\delta\epsilon$. Therefore, IAA and IVS VLBI dX and dY values are converted to $\delta\psi$ and $\delta\epsilon$ in the combination process. The LOD are derived directly from the UT1–UTC data. The analytical expression for the first derivative of the cubic spline passing through the UT1–UTC data is used to estimate the LOD at the epoch of the UT1–UTC data.

The only data points that are excluded from the combination process are the points whose errors, as reported by the contributors, are greater than three times their average reported precision, or those points that have a residual that is more than four times the associated *a priori* error estimate. Since all of the observations are reported with the effects of sub-daily variations removed, the input data are not corrected for these effects (see IERS Gazette No. 13, 30 January 1997).

Table 2: Mean and standard deviation of the differences between the Rapid Service/Prediction Centre solutions and 05 C04 EOP solutions for 2008. Polar motion x and y values are in milliseconds of arc and UT1–UTC values are in units of milliseconds of time.

The uncertainties in the daily values listed in Bulletin A are derived from the quality of the spline fit in the neighborhood of the day in question. Table 2 shows the accuracies of Rapid Service/Prediction Center's combination solution for the running, weekly, and daily products compared to the 05 C04 series maintained by the IERS EOC. The running solution is the combination solution over the past 365-day period. The statistics for the running solution at year's end show the agreement between the Bulletin A running combination solution and the 05 C04 series for the entire year. The comparison of the 52 weekly solutions to the 05 C04 series gives the statistics of the residuals computed over the new combination results for the 7-days prior to the solution epoch. The statistics for the daily solution are determined from a series of differences spanning one year where each element of the series is the difference for the day of the solution epoch. EOP accuracies for the Bulletin A rapid weekly solution for the new

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combination for the day of the solution run and daily solution at the time of solution epoch are similar and, therefore, not included in the table.

Figure 1 shows the residuals between the daily rapid solution and the 05 C04 and presents the data used in Table 2 for the determination of the daily solution statistics. This year, the mean residuals between the daily solution and the 05 C04 were essentially the same. The small bias difference in the polar motion x component appears to be due to different corrections for the change in the International GNSS Service (IGS) series due to the switch from relative phase center to absolute phase center corrections. The most significant change for the standard deviation came in the daily solution residuals. This is due to the incorporation of the IGS Ultra data into the daily solution in 2007. It is anticipated that the inclusion of the new USNO UTGPS data set into the combination in March 2009 will have a positive impact on the UT1-UTC results (Stamatakos *et al.*, 2009). This will be a topic for further investigation.

Fig. 1: Residuals between daily rapid solutions at each daily solution epoch for 2008 and the Earth orientation parameters available in 05 C04 series produced in March 2009.

Prediction Techniques

In 2007, the algorithm for polar motion predictions was changed to incorporate the least-squares, autoregressive (LS+AR) method created by W. Kosek and improved by T. Johnson (personal communication, 2006). This method solves for a linear, annual, semiannual, 1/3 annual, 1/4 annual, and Chandler periods fit to the previous 400 days of observed values for x and y. This deterministic model is subtracted from the polar motion values to create residuals, which are more stochastic in nature. The AR algorithm is then used to predict the stochastic process while a deterministic model consisting of the linear, annual, semiannual, and Chandler terms is used to predict the deterministic process. The polar motion prediction is the addition of the deterministic and stochastic predictions. The additional unused terms in the deterministic solution help to absorb errors in the deterministic model caused by the variable amplitude and phase of the deterministic components (T. Johnson, personal communication, 2006). For more information on the implementation of the LS+AR model, see Stamatakos *et al.* (2008).

The procedure for UT1-UTC involves a simple technique of differencing (McCarthy and Luzum, 1991b). All known effects such as leap seconds, solid Earth zonal tides, and seasonal effects are first removed from the observed values of UT1-UTC. Then, to determine a prediction of UT1-UTC n days into the future, $(UT2R-TAI)_n$, the smoothed time value from n days in the past, $\langle(UT2R-TAI)_{-n}\rangle$ is subtracted from the most recent value, $(UT2R-TAI)_0$

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

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

The UT1-UTC prediction out to a few days is strongly influenced by the observed daily Universal Time estimates derived at USNO from the 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.

The UT1-UTC prediction also makes use of a UT1-like data product derived from a combination of the operational National Centers for Environmental Prediction (NCEP) and U.S. Navy's Operational Global Atmospheric Prediction System (NOGAPS) model's AAM analysis and forecast data (UTAAM). AAM-based predictions are used to determine the UT1 predictions out to

a prediction length of 7 days. For longer predictions, the LOD excitations are combined smoothly with the longer-term UT1 predictions described above. For more information on the use of the UT AAM data, see Stamatakos *et al.* (2008).

Errors of the estimates are derived from analyses of the past differences between observations and the published predictions. Formulas published in Bulletin A can be used to extend the tabular data. The predictions of $\delta\psi$ and $\delta\epsilon$ are based on the IERS Conventions (McCarthy, 1996; McCarthy and Petit, 2004). Table 3 shows the standard deviation of the differences between the daily solution predictions and the 05 C04 solution for 2008. Initial estimates indicated that the UT1–UTC prediction performance would be improved by 42% at 10 days into the future by the addition of UTAAM to the combination and prediction process (Johnson *et al.*, 2005). However, comparisons of the UT1–UTC prediction performance from 2003 to those estimated in 2001 (before UTAAM was introduced) indicated a better than 50% improvement in prediction error at both 10 day and 20 days into the future.

For 2008, the prediction errors were, in general, better than those of 2007. The polar motion prediction errors improved slightly over 2007 due to the incorporation of the IGS Ultra data into the daily combination. The UT1–UTC prediction shows a slight improvement due to the switch from AAM forecast lengths being extended from 5 to 7.5 days as well as the occasional availability of rapid turnaround e-VLBI intensives. The use of the new USNO UTGPS series should also positively impact the near-term UT1-UTC predictions.

Table 3: Root mean square of the differences between the EOP time series predictions produced by the daily Bulletin A rapid solutions and the 05 C04 combination solutions for 2008. Note that the prediction length starts counting from the day after the last available observation is made for polar motion or UT1-UTC/LOD.

The predictions of celestial pole offsets (both dX/dY and $\delta\psi/\delta\epsilon$ representations) are produced through the use of the KSV1996 model (IERS Conventions (1996)). In addition, a bias between the model and the last 20 days worth of celestial pole offset observations is computed. This bias is tapered so that as the prediction length is extended, the bias becomes progressively smaller. Since celestial pole offsets are based solely on VLBI data, if no new VLBI 24-hour session observations are available, a new rapid combination/prediction of these angles is not determined. Therefore, the predictions of celestial pole offsets start before the solution epoch and the length of the prediction into the future can and does vary in the daily solution files. The differences between the daily predictions and the 05 C04 for 2008 are given in Table 4.

Table 4: Root mean square of the differences between the nutation prediction series produced by the daily rapid solutions and the 05 C04 solution for 2008.

Predictions of TT–UT1 up to 2018 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 TT–UT1 are used. Estimates of the expected one-sigma error for each of the predicted values are also given. These are based on analyses of the past performance of the model with respect to the observations.

Additional information on improvements to IERS Bulletin A and the significance for predictions of GPS orbits for real-time users is available (Luzum *et al.*, 2001; Wooden *et al.*, 2004; Stamatakos *et al.*, 2008; Stamatakos *et al.*, 2009).

Table 5: Predicted values of TT–UT1, 2009–2018. Note that UT1-TAI can be obtained from this table using the expression $UT1-TAI = 32.184s - (TT-UT1)$.

Centre Activities in 2008

During 2008, much of the RS/PC activities have concentrated on improving the operational software, updating and monitoring currently used datasets, and investigating potential new data sets. Specific accomplishments include modifying the nutation combination code to more readily use either $\delta\psi/\delta\epsilon$ or dX/dY representations and making modifications for the announced leap second. In addition, diagnostics for the AAM data are now available. A new web site was created as part of an organization-wide effort. This new web presence is located at <http://www.usno.navy.mil/USNO/earth-orientation>. Additional work to increase the robustness of an alternate site now allows us to run EOP solutions off site.

New global solutions were received from GSFC and USNO VLBI analysis centers. These new solutions were examined and new rates and biases were computed.

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, $\delta\psi$ and $\delta\epsilon$ from GSFC VLBI; x, y, UT1-UTC, $\delta\psi$ and $\delta\epsilon$ from USNO VLBI; x, y, UT1-UTC, δX and δY 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 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 NRCCanada (EMR) GPS; UT from NCEP AAM; UT from NAVY NOGAPS AAM; x, y, UT1-UTC, $\delta\psi$ and $\delta\epsilon$ from the IERS Rapid Service/Prediction Centre; x, y, UT1-UTC, $\delta\psi$ and $\delta\epsilon$ 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 at Austin LLR, UT0-UTC from JPL LLR; UT0-UTC from CERGA LLR; UT0-UTC from JPL VLBI; latitude and UT0-UTC from Washington PZTs 1,3,7; latitude and UT0-UTC from Richmond PZTs 2,6; LOD from ILRS 1-day SLR; x, y, UT1-UTC from CSR LAGEOS 3-day SLR; x and y from CSR LAGEOS 5-day SLR; x and y from Delft 1-, 3- and 5-day SLR; and x, y, UT1-UTC, $\delta\psi$ and $\delta\epsilon$ from IRIS VLBI.

The data described above are available from the Centre in a number of forms. You may request a weekly machine-readable version of the IERS Bulletin A containing the current 365 days' worth of predictions via electronic mail from

ser7@maia.usno.navy.mil or through <http://www.usno.navy.mil/USNO/earth-orientation>.

Internet users can also direct an anonymous FTP to

<ftp://maia.usno.navy.mil/ser7>

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

Centre Staff

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

William Wooden

Brian Luzum

Nick Stamatakos

Director

Program manager, research, and software maintenance

Operational procedure manager, research, and software maintenance

Gillian Brockett

Assists in daily operations and support,
research, and software maintenance

Merri Sue Carter

Assists in daily operations and support

Beth Stetzler

Assists in daily operations and support,
research, and software maintenance

In June 2008, Gillian Brockett resigned from the IERS Rapid Service and Prediction Center to attend graduate school.

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