NEAR REAL-TIME IERS PRODUCTS

W.H. WOODEN, T.J. JOHNSON, M.S. CARTER, A.E. MYERS
U.S. Naval Observatory
Washington, DC 20392, U.S.A.
e-mail: whw@usno.navy.mil

ABSTRACT. Earth orientation parameters (EOP), which relate the terrestrial reference system to the celestial reference system, are critical to modern navigation and space applications. The Rapid Service/Prediction Center (RS/PC) of the International Earth Rotation and Reference Systems Service (IERS) produces EOP for those users who reduce data collected in the very recent past (require rapid service) or who operate in real time (require predictions). The IERS Bulletin A and its associated data files constitute the near real-time IERS products which meet these users' needs. This paper discusses the RS/PC's current combination and prediction process, recent improvements to the process, accuracy of the current solutions, and planned improvements.

1. INTRODUCTION

Accurate knowledge of Earth orientation parameters (EOP) is needed for a variety of high-precision applications including modern navigation, astronomy, geodesy, communications, and timekeeping. The EOP provide the time-varying alignment of the Earth's terrestrial reference frame with respect to the celestial reference frame. The U.S. Naval Observatory (USNO) operates the Rapid Service/Prediction Center (RS/PC) for the International Earth Rotation and Reference Systems Service (IERS). The RS/PC produces the IERS Bulletin A on a rapid turnaround basis, primarily for real-time users and others needing the highest quality EOP information before the IERS final (Bulletin B) values are available. Bulletin A and its associated standard and the daily rapid EOP data files constitute the near real-time IERS products. Bulletin A includes polar motion (x,y), universal time (UT1-UTC), and the celestial pole offsets ($\delta\psi, \delta\varepsilon$ and dx, dy) and predictions of these parameters. Two versions of Bulletin A are prepared, a daily and a weekly. Long-term stability and consistency with the other IERS products is achieved by aligning Bulletin A with the IERS final (Bulletin B) series, which is produced by the IERS Earth Orientation Center at the Paris Observatory in France.

The observational estimates of EOP from the IERS Technique Centers, especially their rapid and preliminary series, are key contributions to the Bulletin A. USNO's ability to function as the RS/PC is enhanced by its active involvement in the Technique Centers. As an Associate Analysis Center of the International GPS Service, USNO has the opportunity to examine ways to improve the contribution of GPS observations to EOP. As an Operations Center, Correlator, and supporter of observing stations within the International VLBI Service, USNO is intimately involved in all aspects of the collection of VLBI observations and understanding their impact on EOP.

In an effort to improve the accuracy of near real-time EOP, the RS/PC has continued to modify its combination and prediction procedures. This paper highlights recent changes since the summary of the process given by Luzum et al. (2001).

2. COMBINATION AND PREDICTION PROCESS

The combination and prediction process contains five major steps: data preparation, combination, prediction, product generation, and dissemination. To a great extent this process has been automated. The contributed observations used in the preparation of the Bulletin A are available at ftp://maia.usno.navy.mil/bulla-data.html. The contributed analysis results are based on data from Very Long Baseline Interferometry (VLBI), Satellite Laser Ranging (SLR), the Global Positioning System (GPS) satellites, Lunar Laser Ranging (LLR), and meteorological predictions of variations in Atmospheric Angular Momentum (AAM).

The data preparation consists of retrieving each of the data types (either automatically or manually), preprocessing the data (e.g., doing unit conversions, reformatting, etc.), and applying the biases and rates for each data type. Each of the data types are processed in turn: VLBI data (24-hr and Intensive sessions), GPS data (EOP and UTGPS), SLR data, and AAM data.

The combination program calculates polar motion (x, y), UT1-UTC, length of day (LOD), and nutation offsets ($\delta\psi$, $\delta\varepsilon$). For polar motion, UT1-UTC, and LOD, known signals are removed (e.g., zonal solid Earth tides), the data are sorted by time and a cubic-spline fit to the data is determined, the fit is used to determine the daily solution, data for the fit and residual plots are written to files, the known signals are added back into the daily solution, and the final data file is updated. For the nutation offsets, VLBI 24-hour session data are read in, weights applied, the 1980 nutation theory is subtracted from the observations, the data are sorted by date and a cubic fit is determined, the fit is used to determine daily solution, data for fit and residual plots are written to files, and $\delta\psi$ and $\delta\varepsilon$ offsets are written to the final data file.

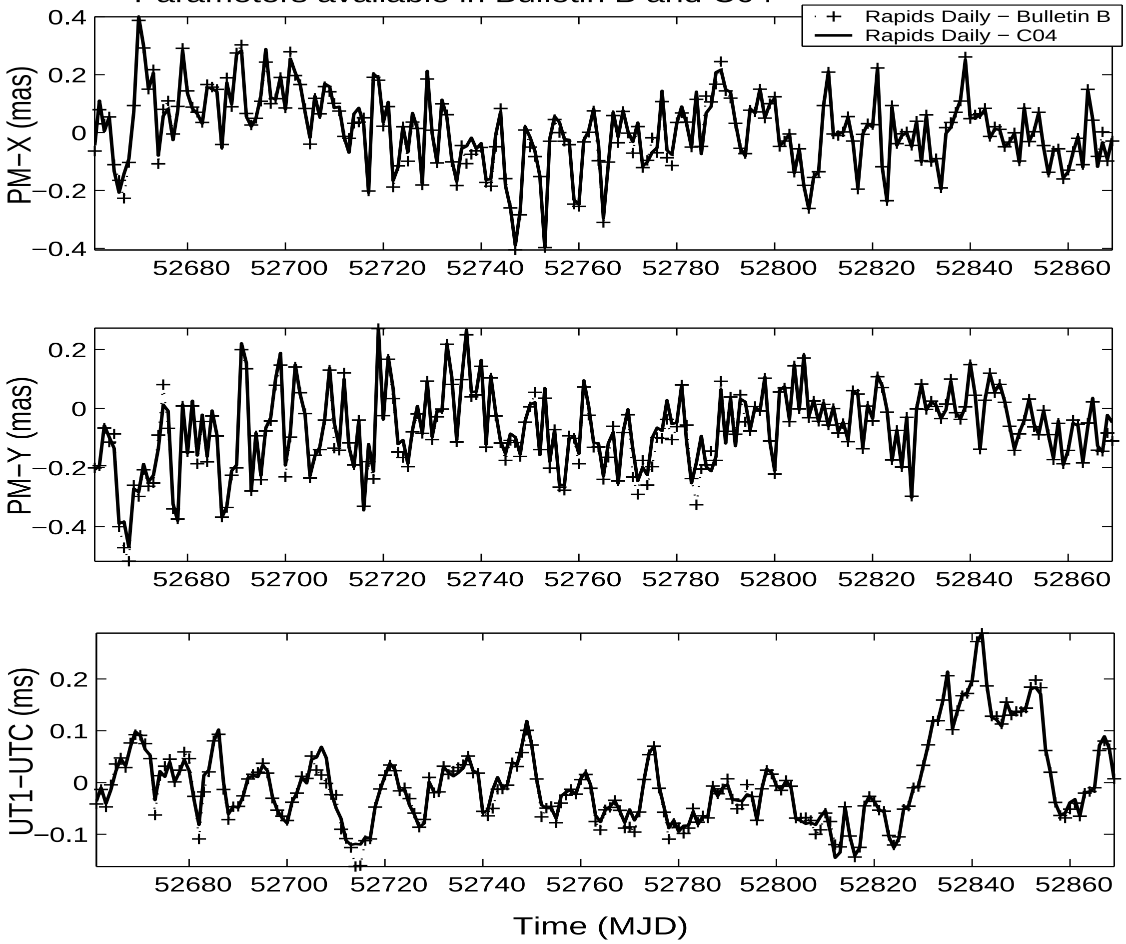
For polar motion ~400 days′ worth of data are used in the prediction routine. The prediction is based on an extrapolation of an annual and semiannual ellipse and a Chandler circle fit to the last 400 days of x and y data and the rate of the last observed polar motion observation. For UT1-UTC ~365 days′ worth of data are used. The auto-regressive integrated moving average (ARIMA) is used. For the nutation offsets, the predictions of $\delta\psi$ and $\delta\varepsilon$ are based solely on VLBI data. If no new data are available, a new prediction of these nutation angles cannot be determined. Therefore, the length of the prediction into the future for $\delta\psi$ and $\delta\varepsilon$ can and does vary in the daily solution files.

Additional details on the processing and prediction techniques are given by Wooden and Johnson (2003).

3. IMPROVEMENTS TO THE PROCESS

The most recent improvements to the process include the enhanced GPS UT1-like quantity that improves UT1-UTC combination results at solution epoch, the introduction of AAM UT1-like quantity that improves UT1-UTC prediction, the addition of USNO and IVS-combination data to VLBI data sets, the automated VLBI data retrieval and updating, the automated weekly SLR data retrieval and updating, and the compliance with IAU 2000 resolutions with respect to the production of new nutation series, dX and dY. The analysis of GPS orbit planes performed at USNO to produce a UT1-like quantity, UTGPS, is described by Kammeyer (2000). The introduction of the AAM UT1-like quantity that improves UT1-UTC prediction is given by Johnson et al. (2003). A careful evaluation of the USNO and IVS Combination 24-hour VLBI data sets clearly indicated that the robustness of the solution, especially for the nutation angles, would be significantly improved. As a consequence, these data sets were introduced into the combination solution in January 2003. The data processing software was modified in February

Figure 1. Differences Between Bulletin A Daily Solutions and the Earth Orientation Parameters available in Bulletin B and C04



2003 to enable the editing of all data types used in the polar motion and UT1 combination solutions, including the nutation software. In July 2003 the processing software was modified to do automated SLR data retrieval and updating. Near the end of 2002, USNO prepared for the implementation of the IAU 2000 resolutions by creating a dX and dY series with respect to the IAU 2000A Precession/Nutation theory. Additional files that contain the dX and dY series were created and implemented in Bulletin A as of 1 January 2003.

4. ACCURACY

The accuracy of the near real-time IERS products is assessed by comparing the daily Bulletin A to the IERS C04 and the Bulletin B series. Figure 1 shows these comparisons from the beginning of 2003. The agreement for the x and y components of polar motion is relatively good. The large difference in UT1-UTC is a result of the lack of VLBI data due to problems with the observing network in late-June and July. The figure highlights the criticality of VLBI observations for UT1-UTC determination. If current prediction accuracies are to be maintained, VLBI observations must be retained as part of the EOP determination and prediction process.

Table 1 gives the statistics of the differences between the Bulletin A solution and the Bulletin B and C04 solutions for 2002 and 2003. For 2003 the UT1-UTC numbers in parentheses are the differences when the extended period without VLBI data is excluded. Although the mean differences in the y-component are somewhat larger, the overall agreement for 2003 is better than that for 2002. The uncertainty of the x-component of polar motion is 20 percent smaller,

Table 1. Comparisons of Daily Bulletin A Solutions to Bulletin B and C04 for Years 2002 and 2003

Year	Daily Bulletin A - Bulletin B Mean (mas or ms)	Daily Bulletin A - Bulletin B Std. Dev. (mas or ms)	Daily Bulletin A - C04 Mean (mas or ms)	Daily Bulletin A - C04 Std. Dev. (mas or ms)
2002				
PM-X	0.01	0.15	0.02	0.15
PM-Y	-0.04	0.14	-0.03	0.13
UT1-UTC	-0.012	0.060	-0.015	0.057
2003				
PM-X	0.01	0.12	0.01	0.12
PM-Y	-0.06	0.12	-0.05	0.12
UT1-UTC	-0.002	0.072*(0.047)	-0.001	0.071*(0.043)

*Includes values during an extended period without VLBI (late June and July).

the y-component is 8-15 percent smaller, and the UT1-UTC uncertainty is 20-25 percent smaller.

5. FUTURE IMPROVEMENTS

There are several areas of research being pursued to improve the accuracy of our near real-time IERS products. As was mentioned earlier, a dX and dY series with respect to the IAU 2000A Precession/Nutation Theory was created and implemented in Bulletin A on 1 January 2003 in order to be in compliance with the IAU 2000 resolutions. However, the new theory is not fully implemented in our processing. Our near-term goal is to complete the replacement of the old IAU 1980 Nutation Theory with the new IAU 2000A Nutation Theory. Another effort is to improve and standardize the techniques used in estimating the rates and biases that are applied to the different analysis center data products. The goal is to improve the consistency of data handling and to decrease the time required to add updated data sets into our process. A third research area is to examine the weighting applied to the data from different analysis centers to improve the high frequency signal content of the combination. Finally, different prediction methods are being investigated to quantify the potential improvement in current prediction accuracies.

Acknowledgments. It is a pleasure to acknowledge the contribution of agencies and individuals that provide Earth orientation data to the IERS. In addition the helpful comments and assistance of James Rohde and Drs. Dennis McCarthy and Victor Slabinski are gratefully acknowledged.

6. REFERENCES

Johnson, T. J., Luzum, B. J., Ray, J. R., 2003, Improved Near-term UT1R Predictions Using Forecasts of Atmospheric Angular Momentum, *Journal of Geodynamics*, in press.

Kammeyer, P., 2000, A UT1-like Quantity from Analysis of GPS Orbit Planes, *Celest. Mech. Dyn. Astr.*, **77**, 241–272.

Luzum, B.J., Ray, J. R., Carter, M. S., Josties, F. J., 2001, Recent Improvements to IERS Bulletin A Combination and Prediction, *GPS Solutions*, **4**, No. 3, 34–40.

Wooden, W. H., Johnson, T. J., 2003, Rapid Service/Prediction Centre, *IERS Annual Report 2002*, 46–53.