DETERMINATION AND PREDICTION OF UT1 AT THE IERS RAPID SERVICE/PREDICTION CENTER

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ABSTRACT. According to the terms of reference of the International Earth Rotation and Reference Systems Service (IERS), the Rapid Service/Prediction Center (RS/PC) is responsible for producing Earth orientation parameters (EOP) on a rapid turnaround basis, primarily for real-time users and others needing the highest quality EOP information sooner than that available in the final series published by the IERS Earth Orientation Center. The IERS Bulletin A and its associated data files contain preliminary and predicted EOP information including Universal Time (UT1). This paper focuses on the RS/PC′s current combination and prediction process for UT1, 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 time-keeping. 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 emphasis of the RS/PC is on near-term prediction (weeks) rather than long-term prediction (years) of EOP.

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 (IGS), 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. Both GPS and VLBI are key data sets contributing to the determination and prediction of universal time (UT1-UTC), the focus of this paper.

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, and meteorological predictions of variations in Atmospheric Angular Momentum (AAM).

The data preparation consists of retrieving each of the data types, preprocessing the data, and applying the biases and rates for each data type. Each of the following data types are processed: 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 appropriate 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 the 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 the prediction of UTI-UTC approximately 365 days$'$ worth of data are used in an auto-regressive integrated moving average (ARIMA) model. Additional details on the processing and prediction techniques are given by Luzum et al. (2001), Wooden and Johnson (2003), Johnson et al. (2004a), and Wooden et al. (2004). The variability of UT1-UTC as shown in the examples of Figure 1 highlights the difficulty of near-term prediction. The difficulty is predicting the occurrence of an inflection point and the resulting change of direction.

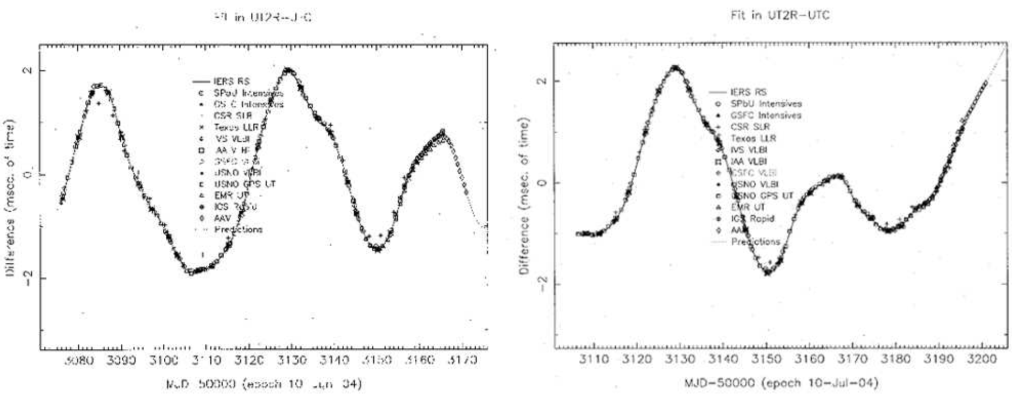

Figure 1: Residuals of the fit of UT1R-UTC for June and July 2004

3. IMPROVEMENT TO THE PROCESS

The recent improvements to the process include the enhanced GPS UT1-like quantity that improves UT1-UTC combination results at the solution epoch, the introduction of AAM UT1-like quantity that improves near-term UT1-UTC prediction, changing the processing criteria for some of the data sets to eliminate systematic effects, and the modernization of six programs within the combination and prediction process. The GPS UT1-like quantity, UTGPS, and the AAM UT1-like quantity, UTAAM, are discussed in the following sections. A careful evaluation of the VLBI data sets was done to better understand potential sources of error affecting the results and to determine improved editing criteria. Some VLBI data, which are from experiments not designed to measure EOP, were degrading the results. New editing criteria were established to mitigate this problem. The introduction of a new VLBI data set caused a problem with one of the processing routines. As a consequence of this incident, an effort to modernize the current operational code was initiated. Currently, six programs have been updated.

4. GPS UT1-LIKE QUANTITY

Kammeyer developed a UT1-like quantity, UTGPS, which improves the UT1-UTC combination results at solution epoch and strongly influences the very-near-term UT1-UTC prediction. UTGPS is determined from the Rapid GPS orbit files produced by the IGS. These Earth-referenced positions are, for each day and for each GPS satellite considered, compared to a propagated orbit plane, and this comparison gives an estimate of UT1 from that satellite alone. In propagating each orbit plane, that part of the motion of the normal caused by radiation pressure cannot be expressed by standard models and is therefore expressed empirically by a component along the projection of the Sun direction on this plane and one in the perpendicular direction in this plane. These two components are functions of the angular distance of the Sun direction from this plane. These functions have, until now, been updated occasionally, most recently in 2000. The median of the single-satellite estimates of UT1 is UTGPS. For additional details see Kammeyer (2000).

5. AAM UT1-LIKE QUANTITY

The AAM UT1-like quantity is generated from AAM analysis and forecast files of the U.S. National Center for Environmental Prediction (NCEP). Each day the operational NCEP AAM daily analysis and forecast files are retrieved from the U.S. National Oceanic and Atmospheric Administration. The daily analysis and forecast files are combined with the previous 19 day′s worth of AAM analysis data. All five days of forecast data are used in the combination. The bias between the forecast and analysis data is determined and applied to the forecast data. The analysis time series is smoothed and sub-sampled. AAM forecast data are then appended to the analysis time series. Finally, results are integrated to produce the UT1-like quantity, UTAAM. Additional details are given by Johnson et al. (2004b).

Recently, the actual reduction in UT1-UTC prediction errors resulting from the introduction of UTAAM into the EOP combination was more rigorously determined. This estimate was computed by comparing the C04 UT1-UTC time series to both the operational UT1-UTC that uses both geodetic and UTAAM and the formerly used operational geodetic-only daily UT1-UTC for the same 12-month period starting March 2003. Table 1 gives the results. The results indicate that the introduction of UTAAM reduces prediction error by approximately 60 percent at 10 days. This comparison clearly shows that for predictions of 5 to 60 days, the addition of

UTAAM into the combination process significantly reduces the UT1-UTC prediction error.

Days into future	Bulletin A without AAM (ms)	Bulletin A with AAM (ms)
1	0.091	0.130
5	0.992	0.421
10	2.11	0.840
20	3.68	2.53
30	5.22	4.28
60	9.62	8.88

Table 1: Standard deviation of the differences between the UT1-UTC time series predictions produced by the daily Bulletin A solutions (with and without AAM) and C04 from March 2003 to February 2004

6. ACCURACY

As a measure of the UT1-UTC prediction error of the weekly Bulletin A solutions, each solution (from August 2002 to August 2003) was propagated forward for 365 days and then compared to the C04 solution at each day. The resulting prediction errors were calculated and then averaged for each of the weekly solutions. The standard deviation of the differences between the Bulletin A and C04 at each prediction interval is shown in Figure 2.

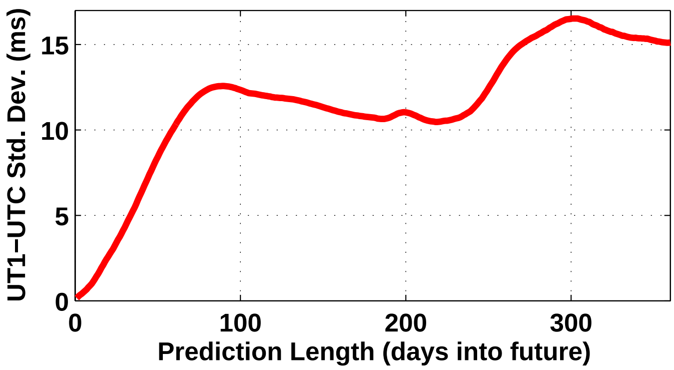

Figure 2: Prediction error of the weekly Bulletin A solutions with respect to the C04 series from August 2002 to August 2003

The accuracy of the UT1-UTC solutions is assessed by comparing the daily Bulletin A solutions to the IERS C04 and the Bulletin B series. Figure 3 shows these comparisons from the beginning of 2004. The agreement is relatively good. The occasional large difference in UT1-UTC is a result of the lack of VLBI data due to problems with the observing network.

7. FUTURE IMPROVEMENTS

Because of the critical role played by UTGPS in the very near-term prediction of UT1-UTC, the modeling of the rates of motion of GPS angular momentum vectors is continuing. The uncertainty in the rates caused by lack of knowledge of radiation pressure effects dominates that due to time variations in the Earth′s gravitational field. Past values of gravitational field

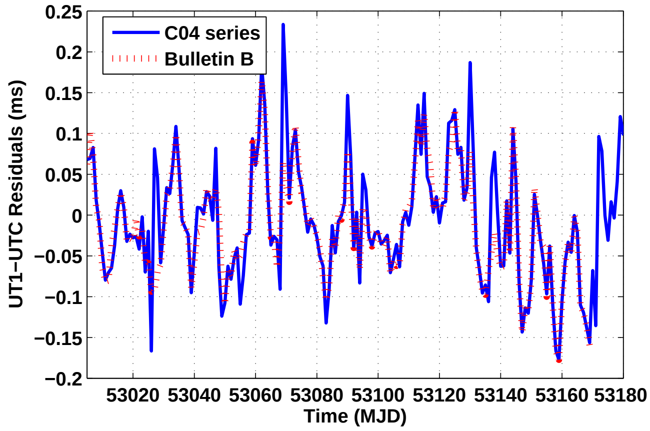

Figure 3: Difference between the daily Bulletin A UT1-UTC solutions and the Bulletin B and C04 series

variations can be determined from other satellite systems such as LAGEOS and GRACE. Thus, the emphasis for improvement is on radiation pressure effects.

The geophysical processes related to AAM are not well modeled. Although significant progress on near-term prediction of UT1-UTC using AAM has been made, the interaction between the oceans and the atmosphere needs further study if progress is to be made in understanding variations in Earth rotation.

Additional areas of research being pursued to improve the accuracy of Bulletin A products are the following: improvement and standardization of the techniques used in estimating the rates and biases that are applied to the different analysis center data products, an examination of the weighting applied to data from different analysis centers to improve the high frequency signal content of the combination, and an investigation of different prediction methods to quantify the potential improvement in current prediction accuracies.

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8. REFERENCES

Johnson, T.J., Carter, M.S., Myers, A.E., Wooden, W.H. (2004a) "Rapid Service/Prediction Centre," IERS Annual Report 2003, pp 48-57

Johnson, T.J., Luzum, B.J., and Ray, J.R. (2004b) "Improved Near-term UT1R Predictions Using Forecasts of Atmospheric Anugular Momentum," *Journal of Geodynamics*, In press

Kammeyer, P. (2000) "A UT1-like Quantity from Analysis of GPS Orbit Planes," *Celestial Mechanics and Dynamical Astronomy*, *77*, pp 241-272

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

Wooden, W.H. and Johnson, T.J. (2003) "Rapid Service/Prediction Centre," IERS Annual Report 2002, pp 46-53

Wooden, W.H., Johnson, T.J., Carter, M.S., and Myers, A.E. (2004) "Near Real-time IERS Products," *Journées Systèmes de Référence Spatio-Temporels 2003*, pp 160-163