# EARTH ROTATION PARAMETERS FROM DSN VLBI: 1997

JPL 97 R 01

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A description of the DSN VLBI data set and of most aspects of the data analysis can be found in IERS Technical Note 17, pp. R-19 to R-32 (see also IERS Technical Note 19, pp. R-21 to R-27).

This year we have adopted the new standard for Greenwich True Sidereal Time, which involves 18 yr and 9 yr terms (see IERS Technical Note 21, page 21) (see also IERS Gazette No 16; 1997 April 4).

Our approach to modeling the tropospheric effects on the VLBI observable was as follows. A priori dry zenith tropospheric delays were determined from barometric pressure measurements at the DSN sites, corrected for height differences between the pressure sensor and the antennas. A priori wet zenith tropospheric delays are based on historical radiosonde data and VLBI estimates from preliminary analyses. The Niell function was used for mapping zenith tropospheric delays to observed elevations. Adjustments to the wet troposphere zenith delays were estimated every two to three hours.

This year we have updated our data weighting scheme. For the delay observable, and separately for the delay rates, the raw uncertainties have been modified by adding quadratically several additional uncertainty components:

1: A source-specific constant determined from source-specific residual scatter, which tends to be associated with sources having known structure. Its value is zero for most sources.
2: For each of the two stations, a component proportional to the a priori wet tropospheric delay at that station, which grows as elevation angle decreases. For the delay rates, these components are also proportional to the -0.3 power of the scan duration. For the CAT M&E data the proportionality constants were adjusted separately for each observing session.
3: For the delay rates, a component for each station proportional to the a priori wet tropospheric delay rate at that station.
4: An "additive noise" constant that is adjusted for each of several blocks of observing sessions.

During calendar year 1996, the TEMPO project produced earth rotation measurements from 100 dual frequency observing sessions, with a median standard error along the minor axis of the error ellipse of 0.3 milliarcseconds (mas), and along the major axis of 1.6 mas. During 1996 the median turnaround time for TEMPO measurements, from observation to availability of earth orientation parameters, was 50 hours.

In the Tidal ERP table below, the argument conventions are those of Sovers et al. (1993). The formal errors range from 9 to 38 microarcseconds but realistic uncertainties are probably much larger.

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## Short Period Tidal ERP Variations

| Term | Period (hours) | UT1 (microseconds) Cosine | UT1 Sine | Polar Motion Amplitude (microarcseconds) prograde | Amplitude retrograde | Phase (degrees) prograde | Phase retrograde |
|---|---|---|---|---|---|---|---|
| K2 | 11.96724 | 2.2 | 4.2 | 52 | 100 | 23 | 233 |
| S2 | 12.00000 | 0.8 | 10.0 | 6 | 129 | 157 | 310 |
| M2 | 12.42060 | -10.1 | 16.1 | 79 | 257 | 122 | 274 |
| N2 | 12.65835 | - 2.4 | 0.9 | 10 | 23 | 104 | 227 |
| K1 | 23.93447 | 11.8 | 18.5 | 137 | 0 | 128 | * |
| P1 | 24.06589 | - 2.5 | - 3.4 | 49 | 0 | 323 | * |
| 01 | 25.81934 | -14.8 | -12.6 | 134 | 0 | 311 | * |
| Q1 | 26.86836 | 0.5 | 0.6 | 45 | 0 | 322 | * |

## Celestial Ephemeris Pole Motion Model
(nutations relative to ZMOA-1990-2)

| IAU-Index | Period days | Phase | Component | Adjustment mas | Formal Error mas | Generalized Error mas |
|---|---|---|---|---|---|---|
| precession | | | Longitude | -2.98/yr | 0.04/yr | 0.05/yr |
| obliquity rate | | | Obliquity | -0.28/yr | 0.02/yr | 0.02/yr |
| Y-offset | | | L sin eps | -17.13 | 0.20 | 0.23 |
| X-offset | | | Obliquity | + 5.44 | 0.23 | 0.23 |
| 1 | -6798.38 | In | Longitude | - 0.02 | 0.24 | 0.28 |
| | | | Obliquity | - 0.04 | 0.07 | 0.07 |
| | | out | Longitude | + 0.19 | 0.15 | 0.19 |
| | | | Obliquity | - 0.12 | 0.10 | 0.10 |
| 2 | -3399.19 | In | Obliquity | - 0.21 | 0.04 | 0.04 |
| | | out | Longitude | - 0.14 | 0.10 | 0.11 |
| | | | Obliquity | + 0.14 | 0.05 | 0.05 |
| 10 | 365.26 | In | Longitude | - 0.20 | 0.04 | 0.05 |
| | | | Obliquity | + 0.08 | 0.02 | 0.02 |
| | | out | Longitude | + 0.37 | 0.04 | 0.05 |
| | | | Obliquity | - 0.05 | 0.02 | 0.02 |
| 9 | 182.62 | In | Longitude | + 0.06 | 0.04 | 0.04 |
| | | | Obliquity | - 0.00 | 0.02 | 0.02 |
| | | out | Longitude | + 0.30 | 0.05 | 0.05 |
| | | | Obliquity | + 0.07 | 0.02 | 0.02 |
| 31 | 13.66 | In | Longitude | - 0.27 | 0.04 | 0.08 |
| | | | Obliquity | + 0.11 | 0.02 | 0.03 |
| | | out | Longitude | + 0.35 | 0.04 | 0.08 |
| | | | Obliquity | + 0.11 | 0.02 | 0.03 |
| | -429.8 | In | Longitude | - 0.19 | 0.05 | 0.05 |
| | | | Obliquity | + 0.00 | 0.02 | 0.02 |
| | | out | Longitude | - 0.30 | 0.04 | 0.04 |
| | | | Obliquity | - 0.15 | 0.02 | 0.02 |

# Technical description of solution JPL 97 R 01

1 - Technique: VLBI

2 - Analysis Center: JPL

3 - Software used: MODEST

4 - Data span: Ott 78 - Mar 97

5 - Celestial Reference Frame: **RSC(JPL)** 97 R 01

a - Nature: **extragalactic**

b - Definition of the orientation:
The Right Ascension and Declination of OJ 287 (0851+202) and the Declination of CTD 20 (0234+285) were held fixed at the values specified in **RSC(IERS)94** C 01.

6 - Terrestrial Reference Frame: **SSC(JPL)** 97 R 01

a - Relativity scale: LET (TDT=geocentric with IAT) The relativity model used is essentially equivalent to the "consensus model" described by Eubanks.

b - Velocity of light: 299 792 458 m/s

c - Geogravitational constant: 3.9860 0448 *1O**14 m**3*s**-2

d - Permanent tidal correction: Yes

e - Definition of the origin, and

f - Definition of the orientation:
Six constraints were applied to the nine coordinates (at epoch 1993.0) of DSS 15, DSS 45, and DSS 65, such that if a seven parameter transformation (3 translations, 3 rotations, 1 scale) between the JPL 1997-1 and **ITRF-93** systems were estimated by unweighed least squares applied to the coordinates of DSS 15, 45, and 65, then the resulting 3 translation and 3 rotation parts of the transformation would be zero while the scale could be nonzero and unknown in advance of computing the catalog. (When expressed as the dot product of a nine dimensional unit vector with the nine station coordinates, each constraint is assigned an a priori standard deviation of 5 mm; this does not affect the resulting coordinates but does affect the calculated formal errors, giving them a more spherical distribution than would result if either very large **or** very small a priori standard deviations were used.)

g - Reference epoch: 1993.0

h - Tectonic plate model: **ITRF-93** plus adjustments

i - Constraint for time evolution:
Three-dimensional site velocities were estimated for each of the three DSN complexes. All stations in each DSN complex were assumed to have the same site velocity. The velocities were constrained so as to produce no net translation rate and no net rotation rate, for the network composed of the three DSN complexes, relative to the net motion of this network of three sites as expressed in the ITRF-93 velocity field. (When expressed as the dot product of a nine dimensional unit vector with the nine site velocity components, each constraint is assigned an a priori standard deviation of 1.0 mm/yr; this does not affect the resulting velocity components but does affect the calculated formal errors, giving them a more spherical distribution than would result if either very large or very small a priori standard deviations were used.)

7 - Earth Orientation: EOP(JPL) 97 R 01

a - A priori precession model: IAU(1976) plus adjustments

b - A priori nutation model: ZMOA-1990-2 plus adjustments

c - Short-period tidal variations in X, Y, UT1:
As part of the JPL 1997-1 catalog solution we estimated coefficients of a model of ERP variations at four nearly-diurnal and four nearly-semidiurnal tidal frequencies. (Nearly-diurnal polar motion variations were constrained to have no retrograde part, thus allowing simultaneous estimation of notations.) The reported earth rotation parameters have had these tidal frequency variations removed according to the parametric model estimated in the catalog solution. (In other words, these effects have NOT been added back in producing EOP(JPL)97 R 01.)

8 - Estimated Parameters:

a - Celestial Frame: right ascension, declination (all sources, but see 5b)

b - Terrestrial Frame: Xo, Yo, 20, (by station) $\dot{X}$, $\dot{Y}$, $\dot{Z}$ (by site)

c - Earth Orientation:
UT0-UTC and Variation of Latitude of the baseline vector
precession constant, obliquity rate, celestial pole offsets at J2000
coefficients of 23 nutation terms
coefficients of 40 diurnal and semidiurnal tidal terms in ERP

d - Others:
wet zenith tropospheric delays
station clock offsets, rates, and frequency offsets

Appendix 1: Summary of TEMPO Report to IERS:

JPL. NASA's Deep Space Network operates radio telescopes in three complexes: in Australia, Spain, and the USA (California). VLBI data collected from these sites by JPL between 1978 and 1997 were analyzed for celestial and terrestrial frames and earth rotation parameters, and reported as JPL 97 R 01. The celestial frame gives coordinates for 287 radio sources and is tied to RSC(IERS)94 C 01 through three coordinates of two sources. The terrestrial frame gives station coordinates and velocities for 10 stations in 3 sites, and is tied to ITRF-93 in both location and velocity using one station in each site. The analysis gives a time series EOP(JPL)97 R 01 containing the UT0-UTC and Variation of Latitude of a baseline vector at a frequency of two measurements per week. Additional earth rotation information is provided in estimated corrections to precession, obliquity rate, celestial pole offsets at epoch, 23 coefficients of nutation terms, and 40 coefficients of a parametric model for the nearly-diurnal and nearly-semidiurnal tidal frequency variations of UT1 and polar motion.

Appendix 2: Operational Characteristics of TEMPO VLBI Data:

NASA's Deep Space Network (DSN) operates radio telescopes for the primary purpose of communicating with interplanetary spacecraft. The DSN has three complexes: in California, in Spain, and in Australia. The Time and Earth Motion Precision Observations (TEMPO) project uses the DSN telescopes to make rapid turnaround VLBI measurements of station clock synchronization and earth orientation in support of spacecraft navigation, which needs extremely timely, moderate accuracy earth rotation information. In TEMPO observations <the raw bit streams recorded at the telescopes are telemetered to JPL for correlation, so that no physical transportation of magnetic tapes is involved. TEMPO uses the JPL-developed Block I VLBI system, which has a 500,000 bits/second sampling rate, with time-division multiplexing of channels. This sampling rate permits the telemetry, and thus makes rapid turnaround possible. The reduced sensitivity caused by the relatively low sampling rate in comparison to other present-day VLBI systems is largely compensated by the very large antennas and very low system noise levels of the DSN telescopes. At present the DSN nominally schedules two TEMPO observing sessions per week, one on the Spain-California (SC) baseline, and the other on the Australia-California (AC) baseline. Each session is generally 3 hours in duration (occasionally less), and records a maximum of 20 sources.

The Earth rotation results from each TEMPO measurement session are reported by specifying the UTO and Variation-of-Latitude (DPHI) of the baseline VECTOR for that session. Each such UT0-DPHI pair has an associated error ellipse in the UT0-DPHI plane. Each such error ellipse is completely specified by the reported standard errors and correlation coefficient between UTO and DPHI. For single baseline VLBI measurements of ERP, such as the TEMPO measurements, this error ellipse is typically quite elongated, with a ratio of major axis to minor axis of about 4:1. Therefore, for a proper interpretation of these data, it is CRUCIAL to make full use of the reported correlation coefficient. For a single-baseline VLBI estimate of earth rotation, the orientation of the error ellipse in the UT0-DPHI plane is mostly determined by the global station geometry. The direction of the minor axis of the error ellipse in the *UT0-DPHI* plane as predicted by the station geometry is called the transverse rotation direction, and corresponds to the motion of the baseline in the local horizontal at each station or equivalently to a rotation about an axis through the center of the earth and the midpoint of the baseline. In addition to being relatively insensitive to random measurement errors, the transverse rotation component is also relatively free of errors introduced by tropospheric modeling errors, antenna deformations, and other sources of systematic local-vertical errors.

TEMPO VLBI measurements are intended to support near-real-time knowledge of earth orientation. As a VLBI data type, the TEMPO results provide UT1 information that is stable with respect to the celestial and terrestrial reference frames. As a result, the TEMPO data are particularly effective when combined with a high time-resolution, rapid turnaround, but not inertially stable source of UT1 information. At JPL, meteorologically measured global atmospheric angular momentum values (and forecasts) are combined with geodetic ERP data, including the TEMPO VLBI results, to provide near-real-time values and short term predictions of earth orientation (see: Freedman, A.P., Steppe, J.A., Dickey, J.O., Eubanks, T.M., and Sung, L-Y., The Short-Term Prediction of Universal Time and Length-of-Day Using Atmospheric Angular Momentum, J. Geophys. Res., 99, 6981-6996, April 10, 1994).

The quality of real time knowledge of earth orientation is critically dependent on the timeliness of the most recent measurement, even if it has relatively large uncertainty. Therefore TEMPO results are reported even when the observing session was degraded so that the measurement uncertainty is much larger than the typical TEMPO uncertainty. Thus it is important to account for the reported uncertainty accompanying each TEMPO result. Empirical RMS residuals from a set of TEMPO data will be dominated by the small number of large-uncertainty points. Therefore RMS residuals are not a good measure of the typical accuracy of TEMPO measurements . The uncertainty scaling factors for the TEMPO data developed by Richard Gross in producing the combination-of-techniques EOP series SPACE96 were in the range 1.1 to 1.4. During calendar year 1996, the TEMPO measurements had a median standard ***error along*** the ***minor*** axis of the error ellipse of 0.3 **milliarcseconds (mas),** and **along** the major axis of 1.6 mas.

TEMPO formal uncertainties have decreased dramatically from the beginning of the program in 1980 to the present. Thus “average” uncertainties over the full history of the program are not representative of the uncertainties of current measurements. Similarly, typical residuals ***over*** the full history are not representative of current residuals.

Typical TEMPO results from the Australia-California (AC) baseline have an error ellipse in the **AC-UT0**--AC-Variation-of-Latitude plane that has its major axis nearly aligned with the **AC-UT0** axis and its minor axis nearly aligned with AC-Variation-of-Latitude. Thus for AC points UTO is essentially the weak direction and residuals of order 1.6 mas are to be expected. Most of the information content of AC points is in the Variation-of-Latitude component, so failure to use the Variation-of-Latitude amounts to throwing away most of the value of the AC points. Properly used, the AC points contribute substantially to near-real-time knowledge of Polar Motion Y, and significantly to very-near-real-time knowledge of UT1.

Typical TEMPO results from the Spain-California (SC) baseline have an error ellipse in the SC-UTO--SC-Variation-of-Latitude plane that has its major axis rotated roughly 34 degrees away from SC-Variation-of-Latitude towards negative SC-UTO. Thus the SC points have a typical UTO uncertainty of about (1.6 mas) * sin(34 degrees) = 0.9 mas. If used without considering the correlation between UTO and Variation of Latitude, the UTO values will have errors of order 0.9 mas, which amounts to throwing away most of the value of the SC points. To get full value from the SC points when combining them with other EOP measurements, it is best to perform a fully multivariate combination; failing this, one should at least combine one's knowledge from non-TEMPO sources of the SC-Variation-of-Latitude with the TEMPO-reported UTO-Variation-of-Latitude pair and standard errors and correlation coefficient, to get an improved SC-UTO before transforming it to UT1. Geometrically this amounts to intersecting the angled SC error ellipse with a "small in polar motion but large in UTI° error ellipse from other sources; if the polar motion were perfectly known this would yield a typical UTO uncertainty of approximately (0.3 mas / cos(34 degrees) ) = 0.36 mas. Properly used, the SC points contribute substantially to near-real-time knowledge of UT1.