JET PROPULSION LABORATORY

INTEROFFICE MEMORANDUM

JPL IOM 335.1-11-93

May 21, 1993

To: Distribution wmf. jas SHO

From: W. M. Folkner, J. A. Steppe, and S. H. Oliveau

Subject: Earth Orientation Parameter (EOP) file description and usage

Introduction

The Earth Orientation Parameter (EOP) file is designed to deliver calibrations for the rotation of station locations from the Earth-fixed frame to the inertial (radio) frame. The EOP file is intended to replace the older STOIC file. The STOIC file includes calibrations for UT1-UTC and polar motion. The EOP file includes these calibrations and, in addition, nutation correction parameters necessary to determine inertial station locations at the few-cm level. The format of the EOP file is described below. The EOP file describes a rotation from a specific Earth-fixed reference frame to a specific inertial reference frame. In order to achieve cm-level accuracy for inertial station locations, the EOP file calibrations must be used according to a given set of models for Earth rotation and used with Earth-fixed and inertial frames consistent with those to which the EOP parameters refer. The models are described below. The Earth-fixed and inertial frames for a given EOP file are labeled by parameters in the EOP file. Currently the Earth-fixed frame is consistent with the International Earth Rotation Service (IERS) terrestrial reference frame labeled ITRF91 while the inertial frame is consistent with the IERS Celestial Reference Frame labeled ICRF91. These frames are described in the IERS Annual Report for 1991.

EOP files are currently produced twice each week in conjunction with STOIC file deliveries. The latest EOP files are located on the VAX PIGGY::TWS$DISK1:[SHO.JPLEOP]. Two files are available: the file JPL-EOP.LATEST and JPL-EOP.LATEST_LONG. The former file contains Earth orientation values spanning approximately one year, from 11 months prior to the creation of the file plus predictions to about 1 month past the date of file creation. The latter (LONG) file is identical to the former file except that Earth orientation values are extended back to 1962. With the creation of a new pair of files, the previous files are archived.

File Format

The format of the EOP file is a NAVIO NAMELIST file. The parameters of the EOP file are listed below. A sample file is given in Table 1. All characters in a line following a dollar sign ($) are comments included for convenience but ignored by all programs.

EOP double precision array (7,n)

This is the array containing the Earth orientation calibrations in 7-element records.

EOP(1,i)	Modified Julian Date (MJD) for the calibrations (times are UTC). (MJD = Julian Date - 2400000.5)
EOP(2,i)	Polar motion x calibration (milliarcsecond)
EOP(3,i)	Polar motion y calibration (milliarcsecond)
EOP(4,i)	TAI-UT1 or TAI-UT1R (seconds)
EOP(5,i)	TAI-UTC (seconds)
EOP(6,i)	Nutation correction $d\psi$ (milliarcsecond)
EOP(7,i)	Nutation correction $d\varepsilon$ (milliarcsecond)

The EOP records are in strictly increasing time order with any record spacing (not necessarily uniform). The file must contain a record at the Modified Julian Date where each leap second occurs within the span of the file. The number of records required depends upon the data span and the desired accuracy. Random variations of UT1 are of the order 1 milliarcsecond in one day, corresponding to about 3 cm on the surface of the Earth. Sub-daily tidal variations of both UT1 and polar motion exist with amplitude ~1 milliarcsecond. Currently files are produced with daily values to allow modeling inertial station locations with ~3 cm accuracy. The file format allows records to be more closely spaced if greater accuracy is desired.

EOPUT1 character*6

This flag indicates EOP(4,i) contains TAI-UT1 or TAI-UT1R. The two possible values of this variable are 'UT1' or 'UT1R'.

EOPTYP character*6

This flag is used by the ODP to determine whether to use the EOP array or the STOIC (TP) array for the computation of Earth orientation. The allowed values of this variable are 'EOP' and 'STOIC'.

EOPLBL character*80

This text label is used in identifying the EOP file.

EOPTIM character*25

This gives the date and time (UTC) of creation of the EOP file
(dd-mmm-yyyy hh:mm:ss.ffff)

EOPTRF character*6

A label denoting the Terrestrial Reference Frame for station locations and site velocities to which the EOP parameters refer; currently the value assigned is 'ITRF91'

EOPCRF character*6

A label denoting the Celestial Reference Frame to which the EOP parameters refer; currently the value assigned is 'ICRF91'

Earth Rotation Models

At a given UTC time t at an Earth station, the Earth-fixed station location $\vec{r}_E$ is given by

$$\vec{r}_E = \vec{r}_0 + \vec{v}_0(t - t_0) + \Delta\vec{r}_{SET} + \Delta\vec{r}_{OL} + \Delta\vec{r}_{PT} \quad (1)$$

where t_0 is the reference UTC epoch for tectonic motion (site velocity) used in the definition of the terrestrial reference frame, $\vec{r}_0$ is the (tabulated) station location at the reference epoch, $\vec{v}_0$ is the site velocity, and $\Delta\vec{r}_{SET}$, $\Delta\vec{r}_{OL}$, and $\Delta\vec{r}_{PT}$ are corrections for solid earth tides, ocean loading, and pole tides. The Earth orientation calibrations in the EOP file are based on a specific terrestrial reference frame. To maintain the highest possible accuracy, the station locations and site velocities used in conjunction with the EOP file must be consistent with the assumed terrestrial reference frame.

The Earth-fixed station location $\vec{r}_E$ is mapped to an inertial location $\vec{r}_I$ by the rotation given below:

$$\vec{r}_I = (\mathbf{YXBNA})^T \ \vec{r}_E \tag{2}$$

where **A** is the precession matrix, **N** is the nutation matrix, **B** is the sidereal rotation (including the equation of the equinoxes), and **X** and **Y** are polar motion rotations. These rotations are described by rotations about intermediate *x, y,* and *z* axes according to the following convention, where the rotations are positive, right-handed rotations of the coordinate axes (passive rotations):

$$R_x(\vartheta) = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\vartheta & \sin\vartheta \\ 0 & -\sin\vartheta & \cos\vartheta \end{pmatrix} \tag{3a}$$

$$R_y(\vartheta) = \begin{pmatrix} \cos\vartheta & 0 & -\sin\vartheta \\ 0 & 1 & 0 \\ \sin\vartheta & 0 & \cos\vartheta \end{pmatrix} \tag{3b}$$

$$R_z(\vartheta) = \begin{pmatrix} \cos\vartheta & \sin\vartheta & 0 \\ -\sin\vartheta & \cos\vartheta & 0 \\ 0 & 0 & 1 \end{pmatrix} \tag{3c}$$

Some rotations are parameterized by angles with polynomial expressions in terms of T, the barycentric coordinate time (TDB) in Julian centuries past the epoch J2000 (Julian date 2451545.0). The relation between TDB time at the station and the UTC time at the station is given by Moyer [1981].

The precession matrix **A**, which rotates from mean of epoch coordinates to mean of date coordinates, is given by Lieske et al.[1977] in terms of angles z_A, θ_A, and ς_A by

$$\mathbf{A} = \mathbf{R}_z(-z_A)\mathbf{R}_y(\theta_A)\mathbf{R}_z(-\varsigma_A) \tag{4}$$

Polynomial expressions for the precession angles in terms of the TDB coordinate time T (in centuries) at the station are given by Lieske [1979];

$$\begin{aligned} \varsigma_A &= 2306.''218100 \ T + 0.''301880 \ T^2 + 0.''017998 \ T^3 \\ z_A &= 2306.''218100 \ T + 1.''094680 \ T^2 + 0.''018203 \ T^3 \\ \theta_A &= 2004.''310900 \ T - 0.''426650 \ T^2 - 0.''041833 \ T^3 \end{aligned} \tag{5}$$

The nutation matrix is given by

$$\mathbf{N} = \mathbf{R}_x(-\bar{\varepsilon}_A - \Delta\varepsilon - d\varepsilon)\mathbf{R}_z(-\Delta\psi - d\psi)\mathbf{R}_x(\bar{\varepsilon}_A) \tag{6}$$

where $\bar{\varepsilon}_A$ is the mean obliquity of date of the ecliptic, $\Delta\varepsilon$ and $\Delta\psi$ are the nutations in obliquity and longitude from the 1980 IAU nutation model [Seidelmann, 1982], and $d\varepsilon$ and $d\psi$ are corrections to the nutations in obliquity and longitude as tabulated on the EOP file. A polynomial expression for $\bar{\varepsilon}_A$ in terms of TDB time T (in centuries) is given in Lieske et al. [1977].

$$\bar{\varepsilon}_A = 84381.''448 - 46.''8150\ T - 0.''00059\ T^2 + 0.''001813\ T^3 \tag{7}$$

The nutation adjustments $\Delta\varepsilon$ and $\Delta\psi$ are evaluated from the series

$$\begin{aligned} \Delta\psi &= \sum_{j=1}^{106} (a_j + b_j\ T)\sin\left[\sum_{i=1}^{5} k_{ji}\alpha_i\right] \\ \Delta\varepsilon &= \sum_{j=1}^{106} (c_j + d_j\ T)\cos\left[\sum_{i=1}^{5} k_{ji}\alpha_i\right] \end{aligned} \tag{8}$$

where the coefficients a_j, b_j, c_j, d_j, and k_{ji} are taken from Table 1 of the 1980 IAU theory of nutation [Seidelmann, 1982]. Here α_1 is the mean anomaly of the moon (l), α_2 is the mean anomaly of the sun (l'), α_3 is the mean argument of latitude of the moon (F), α_4 is the mean elongation of the moon from the sun (D), and α_5 is the mean longitude of the lunar ascending node (Ω). Expressions for α_i are found in Seidelmann [1982]. The nutation corrections $d\varepsilon$ and $d\psi$ for a given UTC time at the station are interpolated from the values tabulated in the EOP file [Newhall, 1993].

The rotation **B** is a rotation about the z axis by the angle H:

$$\mathbf{B} = \mathbf{R}_z(H)$$

The angle H is the sum of the hour angle of the mean equinox of date, h_γ, and the equation of the equinoxes, α_E. The (conventional) hour angle of the mean equinox of date is given by the expression (Aoki et al, 1982)

$$h_\gamma = \frac{2\pi}{86400^s}(UT1 + 24110.^s54841 + 8640184.^s812866\ T_u + 0.^s093104\ T_u^2 - 6.^s2 \times 10^{-6}\ T_u^3) \tag{9}$$

where $UT1$ ranges from 0^s to 86400^s and the quantity T_u is computed from $UT1$ by

$$T_u = \frac{(JD_u - 2451545.0)}{36525} \tag{10}$$

with JD_u being the (continuous) Julian date corresponding to the UT1 date and time. (At 12:00 UT1 on January 1, 2000, $T_u = 0$). $UT1$ is computed from the UTC time at the station and the tabulated values of TAI-UTC and TAI-UT1 (or TAI-UT1R) on the EOP file. The equation of the equinoxes is given by

$$\alpha_E = (\Delta\psi + d\psi)\ \cos(\bar{\varepsilon}_A + \Delta\varepsilon + d\varepsilon) \tag{11}$$

It may be noted that there is as yet no universally accepted definition of the equation of the equinoxes. The form given above is adopted here as being a simple extension of the formulation within the ODP and consistent (within <1 prad) of the formulation within the VLBI software data reduction package MODEST [Sovers, 1991]. The IERS has proposed a different equation of the equinoxes, to take effect in 1997, that is different from that adopted here and has the disadvantage of requiring significant adjustments to existing UT1-UTC series. For consistency with the EOP file, h_γ and α_E must be computed according to the relations given above.

The polar motion rotations are given by

$$\begin{aligned} \mathbf{X} &= \mathbf{R}_y(-X) \\ \mathbf{Y} &= \mathbf{R}_x(-Y) \end{aligned} \tag{12}$$

where X and Y are the polar motion calibrations from the EOP file interpolated to the UTC time at the station. Note that the ODP does not use the expression above but instead uses the approximation (Moyer, 1991)

$$\mathbf{YX} = \begin{pmatrix} 1 & 0 & X \\ 0 & 1 & -Y \\ -X & Y & 1 \end{pmatrix} \tag{13}$$

where X and Y are expressed in radians. With typical polar motion amplitudes of 0."2, this approximation is accurate to about 0."2 × 10^{-6}.

EOP file accuracy and stability

Currently the EOP file, when used in conjunction with the models above and consistent terrestrial and celestial reference frames, will give inertial station locations with accuracy ~2 mas from 1984 up to two weeks before the creation of the file. The accuracy is limited in part by our uncertainty in the specification of the terrestrial reference frame. It is anticipated that station locations and site velocities within the IERS system will improve significantly in the near future. For times more recent than two weeks prior to the EOP file creation, less data is available and hence the accuracy of UT1 and polar motion is degraded (Freedman, 1991). Before 1984 the knowledge of UT1 and polar motion is less accurate due to the limited data accuracy available prior to regular VLBI observations. The nutation corrections, unlike polar motion and UT1, are not random in nature, so that nutation corrections for times prior to 1984 will improve as more data are acquired; this improvement will be reflected in the time history of EOP files.

References

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O. J. Sovers, "Observation Model and Parameter Partials for the JPL VLBI Parameter Estimation Software MODEST - 1991", JPL Publication 83-39 Rev. 4, August 1, 1991.

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$  JPL Earth Orientation Parameter File
$  Last Data Point 24-JUL-1992
$  Predicts to     27-AUG-1992
$
EOPLBL='JPL Earth Orientation Parameters to 7/24/92, predict to 8/24/92'
EOPUT1='UT1'
EOPTYP='EOP'
EOPTRF='ITRF91'
EOPCRF='ICRF91'
EOPTIM='25-JUL-1992 12:05:04.2321'
$
$  MJD         PM x       PM y       TAI-UT1    TAI-UTC   dPsi       dEps
$             (mas)      (mas)       (sec)      (sec)    (mas)      (mas)
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48130.00,  305.1,    375.0,    25.11707,     25.,  -15.2,      -3.5,    $ 27-AUG-1990
48135.00,  307.3,    356.9,    25.12334,     25.,  -14.3,      -3.3,    $  1-SEP-1990
48140.00,  312.1,    337.9,    25.13271,     25.,  -13.8,      -3.2,    $  6-SEP-1990
48145.00,  313.4,    317.4,    25.14281,     25.,  -15.2,      -3.4,    $ 11-SEP-1990
48150.00,  311.5,    297.9,    25.15066,     25.,  -13.5,      -3.1,    $ 16-SEP-1990
48155.00,  307.8,    279.8,    25.16209,     25.,  -13.9,      -3.1,    $ 21-SEP-1990
48160.000,  301.16,  262.10,  25.171044,    25.,  -14.46,     -3.19, $ 26-SEP-1990
48162.000,  298.88,  254.08,  25.174299,    25.,  -13.60,     -3.03, $ 28-SEP-1990
48164.000,  297.31,  246.50,  25.178144,    25.,  -12.76,     -2.88, $ 30-SEP-1990
48166.000,  295.83,  239.80,  25.182970,    25.,  -12.50,     -2.83, $  2-OCT-1990
48168.000,  293.81,  233.45,  25.188472,    25.,  -12.94,     -2.88, $  4-OCT-1990
48170.000,  290.64,  226.81,  25.193745,    25.,  -13.63,     -2.95, $  6-OCT-1990
48171.000,  288.73,  223.28,  25.196041,    25.,  -13.86,     -2.96, $  7-OCT-1990
48172.000,  286.72,  219.62,  25.198070,    25.,  -13.93,     -2.95, $  8-OCT-1990
48173.000,  284.68,  215.86,  25.199899,    25.,  -13.81,     -2.90, $  9-OCT-1990
48174.000,  282.66,  212.07,  25.201643,    25.,  -13.50,     -2.83, $ 10-OCT-1990
48175.000,  280.68,  208.29,  25.203421,    25.,  -13.07,     -2.74, $ 11-OCT-1990
48176.000,  278.62,  204.57,  25.205315,    25.,  -12.58,     -2.65, $ 12-OCT-1990
    .          .         .          .          .        .          .        .
    .          .         .          .          .        .          .        .
    .          .         .          .          .        .          .        .
48848.000,  -50.50,  469.20,  26.619660,    27.,  -18.11,     -4.16, $ 14-AUG-1992
48849.000,  -47.50,  470.70,  26.621380,    27.,  -18.19,     -4.17, $ 15-AUG-1992
48850.000,  -44.60,  472.10,  26.623150,    27.,  -18.45,     -4.21, $ 16-AUG-1992
48851.000,  -41.60,  473.40,  26.624920,    27.,  -18.85,     -4.26, $ 17-AUG-1992
48852.000,  -38.60,  474.70,  26.626650,    27.,  -19.32,     -4.33, $ 18-AUG-1992
48853.000,  -35.50,  475.90,  26.628310,    27.,  -19.77,     -4.39, $ 19-AUG-1992
48854.000,  -32.50,  477.20,  26.629870,    27.,  -20.12,     -4.43, $ 20-AUG-1992
48855.000,  -29.40,  478.30,  26.631320,    27.,  -20.31,     -4.44, $ 21-AUG-1992
48856.000,  -26.40,  479.40,  26.632680,    27.,  -20.30,     -4.43, $ 22-AUG-1992
48857.000,  -23.30,  480.50,  26.634020,    27.,  -20.10,     -4.39, $ 23-AUG-1992
48858.000,  -20.20,  481.60,  26.635410,    27.,  -19.77,     -4.33, $ 24-AUG-1992
48859.000,  -17.00,  482.50,  26.636950,    27.,  -19.38,     -4.27, $ 25-AUG-1992
48860.000,  -13.90,  483.50,  26.638730,    27.,  -19.02,     -4.22, $ 26-AUG-1992
48861.000,  -10.80,  484.40,  26.640790,    27.,  -18.77,     -4.18, $ 27-AUG-1992
```

Table 1. Sample EOP file

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