The initial IERS Terrestrial Reference Frame

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Table of contents

- The initial IERS Terrestrial Reference Frame

Appendix 1 - A combined terrestrial reference frame based on space geodesy
Appendix 2 - List of potential IERS sites
Appendix 3 - Input systems
Appendix 4 - Results of ITRF-0
IERS Technical Notes

This series of publications gives technical information related to the IERS activities, e.g. reference frames, excitation of the Earth rotation, computational or analysis aspects, models, etc. It also contains the description and results of the analyses performed by the IERS Analysis Centres for the Annual Report global analysis.

Issues available

No 1: C. Boucher and Z. Altamimi. The initial IERS Terrestrial Reference Frame.


Future issues

IERS Standards.
The IERS Standards has adopted a description of the Conventional Terrestrial Reference System (CTRS) to be used for all IERS activities, either by individual techniques or combinations.

Its main characteristics are described by:

"a) it should be geocentric. The geocenter is defined for the whole Earth, including oceans and atmosphere

b) its scale should be the one of a local Earth frame , in the meaning of a relativistic theory of gravitation

c) its orientation should be given by the BIH orientation at 1984.0

d) its time evolution should follow a no global net rotation or translation condition.

When one wants to realize such a CTRS through a reference frame (CTRF), i.e. a network of stations reference points or ground marks with coordinates - or set of station coordinates (SSC) -, it is furthermore recommended:

e) to include the permanent solid earth tidal deformation, so that the adopted coordinates will differ from the instantaneous coordinates by only periodic terms (see chapter 6)

f) to adopt cartesian equatorial coordinates X, Y, Z, by preference. If geographical coordinates are needed, the GRS 80 ellipsoid is recommended ( a = 6378137 m 1/f = 298.257222 see IERS recommended values).

In order to facilitate the actual implementation of the IERS Terrestrial Reference System (ITRS) by the various analysis centers which participate to IERS, but also by potential users, in particular the GPS community, this study presents several informations which could be useful for these purposes:

1) a critical description of the latest TRF established by BIH, namely BTS 87.

2) a currently improved combination of BTS 87 input data,
following strictly the IERS standards, and to be used as Initial IERS Terrestrial Reference Frame (ITRF-0).

3) some suggestions for implementation of the ITRS, especially by the IERS Central Bureau in its future combined solution (ITRF 88...).

1) The BTS 87 terrestrial reference frame

The detailed description of the BTS 87 frame is given in a paper attached in appendix [4].

We want only to identify here the main characteristics of this frame, mainly in order to show the various little improvements which has been adopted for ITRF-0.

It is important to note that BIH has established each year from 1985 such frames, which were realizations of the BIH terrestrial system: BTS 84, BTS 85, BTS 86 and finally BTS 87. Details about the slight changes both in models and data can be found in the successive BIH Annual Reports, from 1984 to 1987.

The main characteristics of the BTS 87 are:

a) model

a.1) physical model

The physical model used for BTS 87 was described in [4]. It basically models equations which connect BTS frame to various sets of station coordinates (SSC) and Earth rotation parameter (ERP) series, belonging to various individual terrestrial reference systems.

As described below, input coordinate data were given at various epochs. The position in BTS 87 system at epoch \( t \) was modelled as:

\[
X(t) = \mathbf{X}_0 + \mathbf{x}(t-t_0)
\]

were \( \mathbf{x} \) was computed from AM0-2 model and \( t_0 \) was Jan. 1 1984.

As all considered input data were derived with a full solid earth tide correction, \( \mathbf{X}_0 \) is also corrected from the permanent
correction. The coordinates $X^*_o$ which would differ from the instantaneous position by only periodic term would be:

$$X^*_o = X_o + \Delta X_{\text{perm}}$$

with

$$\Delta X_{\text{perm}} = \frac{X_o}{|X_o|} \Delta h_{\text{perm}}$$

and

$$\Delta h_{\text{perm}} = -0.121 \left( \frac{3}{2} \sin^2 \varphi - \frac{1}{2} \right) \text{m}$$

See [1].

Table 2 gives $\Delta X_{\text{perm}}$ for primary sites, also plotted in Figure 1.

Finally as scale is derived from SLR, the relativistic model is the local earth frame.

a.2) adjusted parameters

In the BTS 87 adjustment, the following parameters were solved for:

- three coordinates per site $X_o$, $Y_o$, $Z_o$, representing the values at $t_o$ of the position of a particular mark selected as reference mark for the whole site. Local excentricities between this mark and the various points (VLBI or SLR intersection of axis...) to which coordinates of SSCs are referred, were held fixed in the BTS adjustment.

The exact meaning of $X_o$ was given in (a.1).

- ERP values, each 0.05 year

- 7 transformation parameters for each SSC, some of them being fixed (see Table 1 of [4]).
a.3) datum fixation

**Origin**: mean position of 5 SSCs (3 LLR and 2 SLR) - see Table 1 of paper [4]; obtained by constraining to zero the corresponding translation parameters (see Table 3 of [4]).

**Scale**: mean value of 2 SSC (SLR), obtained by constraining to zero the corresponding scale parameters (see Table 1 and 3 of [4]).

**Orientation**: aligned on BIH orientation by putting an alignment constraint on ERP parameters, using BIH values for 1986.

**Evolution with time**: Follows a no global net rotation, by adopting as fixed AM0-2 displacements.

b) input data

The list of SSC and ERP used in the BTS 87 solution is given in Table 1 of [4]. These data were used with diagonal variances.

Moreover as local excentricities were used as fixed data, it was legitimate to consider the contribution of their uncertainties into the a priori standard deviations put for SSCs.

Finally, in order to take that into account, and to avoid optimistic values which would not reflect the actual accuracy but rather the inner precision of the computed solutions for SSCs, it was decided to use 3 cm and 1 cm as lower bounds for standard deviations of SLR and VLBI coordinates respectively.

c) output data

In the official publication of BTS 87, namely the BIH Annual Report for 1987, the following data are provided:

- list of \(X_0, Y_0, Z_0\) for reference marks and tracking instrument of all sites participating to SSCs, distinguishing between colocation sites (i.e. the site occurs at least in two SSCs) and no-colocation sites (one occurrence) (Table 2A of [4])

- list of \(\hat{x}, \hat{y}, \hat{z}\) for each site, from AM0-2 (Table 2B of [4])

- list of transformation parameters (Table 3 of [4])

No standard deviation are published.
2) The Initial IERS Terrestrial Reference Frame

Considering what can be done on a short term basis, the following improvements has been adopted to compute a new frame (ITRF-0), to be accepted as initial frame:

1) the permanent solid earth tide correction should be applied, so that $X^*_o$ will be published, in place of $X_o$.

2) the reference epoch will be 1988 Jan 1 (MJD = 47161).

3) all 7 parameters will be adjusted, except for an additional SSC which will be the BTS87 values for 1984 Jan 1, with a priori standard deviations of 0.1 m for each point (only one per site - see table 3), and for which all 7 parameters are held fixed to zero. By this way:

- the new frame is in the BTS87 system
- no overconstraint is coming from a priori fixation of some scale or translation
- the initial BTS87 coordinates will influence weakly (10 cm!) the inner consistency of used data.

4) The finally accepted input data are:

   SSC(NGS) 88 R 01
   SSC(GSFC) 88 R 01
   SSC(CSR) 88 L 01
   SSC(GSFC) 87 L 14
   SSC(BIH) 88 C 01 (extract of BTS87)

   The used standard deviation are given in Appendix 3.

5) No ERP are now used.

6) The local survey data used in ITRF-0, together with the same data used for BTS87 are given in Table 3.

7) The sites are now classified, following the criteria described below.

   We call primary site any site where a threedimensional position can be estimated within a few centimeters in the IERS system, and for any epoch, within the present years.

   The criterion to select such a site are:

   a) to have a permanent instrument (SLR or VLBI) preferably. For a mobile unit, the relocation should be guaranteed by an accurate survey within a few mm.
b) to use the best technology: 3rd generation lasers, or S/X Mark III VLBI with H-masers

c) to get regular measurements in order to be able to estimate positions at regular epochs (typically monthly) at cm level, and for which the interpolation will keep this cm level for any epoch within the specific time span, which should include present days.

In order to have a better look to the characteristic of the stations, an inventory (given in appendix 2) has been done, giving for each potential IERS site the list of tracking points with:

- their description
- their CDP number (if available)
- their DOMES number
- a code T (temporary) or P (permanent) giving the status of the instrument
- a monthly code, from Jan 1976, giving the status of the measurements:

  blanc : no measurement
  - : potential measurement (i.e. the tracking instrument is installed but we do not know if it has produced significant data)
  * : actual measurement
  number : monthly position can be derived. Their accuracy, at one sigma level, labelled AMP (accuracy of monthly position) is classified (see appendix 2).

We must specify the strict definition of a tracking point, in this analysis: it is a physical mark to which one tracking technique has been attached. Specifically it can be:

- a permanent VLBI instrument (IAR)
- a permanent SLR instrument (IAR or ground mark)
- a ground mark with successive mobile VLBI occupancies
- a ground mark with successive mobile SLR occupancies

So, if a same mark has been used by two types of systems (SLR or VLBI), two tracking points are defined.

From the analysis of this inventory, we have selected, at this stage, 34 primary sites (Figure 2 and Table 1).

The SSC(BIH) 88 C 01 is the set of BTS 87 coordinates (epoch 1984.0) with 0.1 m as standard deviation of each cartesian
component, for reference point of each primary site.

8) The output of the adjustment is given in Appendix 4:

- transformation parameters with a posteriori standard deviations
- input standard deviations and residuals.

The final coordinates are given for primary sites in Table 1, with a posteriori standard deviations. In each site, both reference point and tracking points are given.

3) Proposal for ITRF

For analysis within IERS, we think that further improvements are necessary:

a) positions should be introduced in the model as time series $X_k$, for each point of the site. The basic epoch could be the month. The time series $X_k$ should be expressed as

$$X_k = X_o + V_o(t_k - t_o) + L_k$$

where $X_o$ will be the mean position at a reference epoch $t_o$ (1988.0).

$V_o$ would be the trend over several years (horizontal and vertical).

$L_k$ would be the offset from the trend, including several variations (ground waters...), and eventually local discrepancies from the trend, if it is computed from a global model.

b) input data should be enlarged:

- analysis centers should provide preferably monthly values, or by default, yearly values, or position and velocity at a reference epoch

- local surveys (terrestrial or GPS) should be included with their epoch and covariance matrix

- geophysical information for $V_o$ should also be included as a priori information, with a proper stochastic model
c) transformation parameters between ITRS and individual systems will be determined for $t_0$, together with a rate of change (in particular for orientation)

d) the time evolution will be ensured by Tisserand conditions.

References


Acronyms

AMP : Accuracy of Monthly Position
BTS : BIH Terrestrial System
CTRF : Conventional Terrestrial Reference Frame
CTRS : Conventional Terrestrial Reference System
GRS : Geodetic Reference System
IERS : International Earth Rotation Service
ITRF : IERS Terrestrial Reference Frame
ITRS : IERS Terrestrial Reference System
Table 1

The Initial IERS Terrestrial Reference Frame (ITRF-0)

Reference epoch 1988.0 AMO-2 model (see note below)

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<th>Y^o [m]</th>
<th>Z^o [m]</th>
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Note: The permanent solid earth tide correction is not applied. To obtain X^o, add the values as given in Table 2.
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**Legend:**
- X1, Y1: Coordinates
- X2, Y2: Coordinates
- Longitude, Latitude: Geographic Coordinates
- Delta X, Delta Y: Distance
- Tolerance: Measurement Tolerance
- Pitch, Yaw: Orientation Angles
Permanent correction of the solid Earth tide.

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FIG. 1. PERMANENT CORRECTION OF THE SOLID EARTH TIDE

LATITUDE (DEGREES)
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M004  7596 SLR TLRS-1,2 mark
M005  7597 SLR TLRS-1 mark
M007  7599 SLR TLRS-1 mark
S004  7224 VLBI Ref. Point
S002  7834 SLR IAR

20702 Bar Giyyora
M001  7530 SLR mark 7530
S001  7530 MOBLAS-2 (ML0214)

21605 Shanghai
M001  Mark connect with bedrock
S001  7837 SLR IAR
S008  7226 VLBI 6m radiotelescope
S009  7227 VLBI 25m antenna

21701 Kashima
M001  Metal station mark (Denken 1)
S001  1856 VLBI 26m antenna

21726 Simosato
M001  Stone marker
M002  7838 SLR mark (center of the ring of the base pier)
S001  7838 SLR IAR fixed

40405 Goldstone
M001  7085 MOBLAS 7085 Goldstone val
M002  7115 MOBLAS 7115-1979 standard NASA disk
M006  7265 Mojave NCMN 1983 NGS station disk
M010  7287 Mojave TLRS 1984 standard NASA disk
S009  7222 Mojave fixed 12m VLBI ref. point
S001  1514 Mars 64m fixed VLBI ref. point (DSS14)
S014  1513 Venus 26m fixed VLBI ref. point (DSS13)
S019  Mars 34m fixed VLBI ref. point (DSS15)

40408 Fairbanks
S001  26m antenna
S002  7225 26m VLBI ref. point (GILMORE CREEK)

40420 Vandenberg
M001  7111 DMA disk MOBLAS 7111 (1981)
M002  7223 DMA disk VLBI 7223 (1983)
M004  7887 DMA disk TLRS 7887 (1983)

40424 Kauai
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40433 Quincy
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M006  7260  Quincy ARIES 1979
M005  7886  TLRS 7886 (1982) standard NASA disk
M004  7221  TLRS and VLBI standard NASA disk

40439 Owens Valley
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M003  7084  MOBLAS, TLRS 7084 standard NASA disk
M004  7853  Mobile VLBI Jul 87 standard NASA disk
S002  7207  40m VLBI ref. point

40440 Haystack
M001  7091  MOBLAS HAYSTACK INTER COMP 1977
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S003  7209  18m VLBI ref. point of radio telescope

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M005  7885  MLRS, MOBLAS, TLRS-1 standard NASA disk
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S007  7206  LLR MLRS
S003  7216  85-foot VLBI ref. point (HRAS 085)

40445 Maui
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S005  7210  LLR HALEAKALA transmitter

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M108  7101  MOBLAS 7101-1977 standard NASA disk
M101  7102  MOBLAS 7102-1978 standard NASA disk
M102  7103  Mobile SLR 7103-1978 standard NASA disk
M103  7104  Mobile SLR 7104-1978 standard NASA disk
M104  7105  MOBLAS -7 7105-1981 standard NASA disk
M105  7100  Mobile SLR 7100-1977 standard NASA disk
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M112  7063  STALAS fixed Laser standard NASA disk
M114  7125  MTLRS 7125-1985 standard NASA disk
M116  7130  TLRS-2 7130-1985 standard NASA disk
M117  7920  TLRS-1 7125-B standard NASA disk
M118  7889  TLRS 7889-1981 standard NASA disk
M119  7917  Steel plate SAO-3 (previously 7807)
M120  7918  TLRS-3 standard NASA disk
M121  7919  TLRS-4 standard NASA disk

40489 Hat Creek
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Appendix

1 - A combined terrestrial reference frame based on space geodesy
2 - List of potential IERS sites
3 - Input systems (from BIH Annual Report for 1987)
4 - Results of ITRF-0 (transformation parameters and residuals)
Appendix 1

A COMBINED TERRESTRIAL REFERENCE FRAME BASED ON SPACE GEODESY

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International Earth Rotation Service
Institut Géographique National

H. Feissel
International Earth Rotation Service
Observatoire de Paris

INTRODUCTION

A terrestrial reference frame of 64 sites has been compiled on the basis of several space geodesy analyses, leading to the last realization of the Terrestrial System of the Bureau International de l'Heure (BIH), BTS 1987 (BIH 1988), before the BIH activities on Earth rotation be transferred to the new International Earth Rotation Service (IERS). This realization provides the initial definition of the IERS Terrestrial System.

The method described hereafter is based on a proposal of Guinot (1981). Its implementation has been studied by Boucher and Feissel (1984), following models described by Zhu and Mueller (1983).

The definition is as follows. A direct geocentric system of tri-rectangular axes is selected. The axis Cx is in the direction of the BIH pole origin in its previous realization; the axis Cy is in the direction of the origin of longitudes, as previously realized by the BIH; the length unit is the metre (SI).

DATA ANALYSIS

The analysis takes into account homogeneous Sets of Stations Coordinates (SSC) derived from programs of observations using space techniques in several networks, from which series of Earth Rotation Parameters (ERP: coordinates of the pole and universal time) are derived. The networks and series of ERP participating to the adjustment are listed in Table 1.

The fiducial points selected for the realization of the terrestrial system are one point per colocation site, i.e., sites for which station coordinates are available in at least two of the networks of Table 1. A site is defined as an area of dimension up to 50 km for which precise geodetic ties between space geodesy stations and geodetic marks are available. The selected sites are listed in Table 2. Some of the ground stations on these sites do not belong to the permanent tracking networks used in the determination of the Earth's rotation. Nevertheless their coordinates are assumed to be consistent with those of the permanent stations of the same network. This is the case for the VLBI networks, and the Doppler network for which a number of points obtained with portable receivers are included. Some other sites could not be included due to lack of information either on the local geodetic ties or on the station coordinates in one of the networks.
The epoch of the BTS (1987) is 1984.0. The plate motion model AM0-2 (no net rotation) of J.B. Minster and T.H. Jordan (1978) is adopted. This model is the one recommended in the MERIT Standards (Melbourne et al., 1985).

The terrestrial system is realized through the cartesian coordinates adopted for the selected sites. For linking the system to the geocentre, the adopted origin is derived from the determinations of the dynamical solutions SSC(JPL) 88 M 01, SSC(CERGA) 88 M 01, SSC(SHA) 86 N 01, SSC(CSR) 88 L 01, and SSC(GSFC) 87 L 14. The adopted scale is based on SSC(CSR) 88 L 01 and SSC(GSFC) 87 L 14. The orientation is obtained by insuring the continuity of the derived series of ERP with the preceding BIH series.

A least square estimation is performed among the observed coordinates of the colocation sites in the different networks, and the determinations of the ERP of the different series. The station coordinates are brought to the fiducial point of their site by means of the known geodetic ties; the series of ERP are under the form of normal values at 0.05 year interval. In the case of VLBI, the rotation angles of the associated frames of Radio Source Coordinates around the polar axis (A3) are constrained to values obtained from the comparison of coordinates of common radio sources (Arias et al., 1988). The following unknowns are adjusted:

- a set of cartesian coordinates for each site in the BTS (Table 2),
- a set of 7 transformation parameters which relate the individual SSC to the BTS (Table 3), for 1984.0,
- a series of ERP at 0.05 year interval, referred to the BTS, from 1987.00 to 1987.95.

RESULTS

Table 1 lists the Sets of Stations Coordinates (SSC) and the corresponding series of Earth Rotation Parameters (ERP) contributing to the realization of the BTS, with the following information.

SSC : label of the SSC, plate motion model used, number of colocated sites, status of the transformation parameters in the global adjustment.

ERP : name and label of the series, time span and a priori standard deviations used in the constraints for the orientation of the axes of the BTS. The later are proportional to the formal uncertainties of normal values of the coordinates of the pole (x, y) and universal time (UT) at 0.05 year interval. The multiplying factors are derived from the analysis of the stability of each time series. The original series which were originally referred to the AMI-2 plate motion model are brought to the AMO-2 model by linear drifts derived from the relative rotation of the two models.

Table 2 lists the cartesian coordinates for 1984.0 (MJD=45700) of the reference points of the colocated sites. Each site is designated by its name, the DOMES number of the reference point, the mention of the networks to which it is related, and the plate to which it belongs. DOMES is the Directory of MERIT sites, a part of the space geodesy coordinates data base of the Institut Géographique National.
The complete description of the points of each site and the local ties used in the adjustment is given in Note interne du BIH nr 5, available on request. In addition to the site reference marks, the table contains for each site the coordinates of the VLBI, LLR and SLR reference points, using local excentricities published in the Note interne. Because doubts can exist on some local surveys, the coordinates of these reference points are in some cases more reliable that those of the reference marks. For colocation sites between two different observing techniques, this reliability is tested by the combined adjustment.

The site coordinates can be brought to date by use of the velocity vectors given in Table 2A (AMO-2 model).

Table 3 lists the numerical values of the parameters which transform the coordinates in the SSC's of Table 1 into the BTS at epoch 1984.0. In the case of VLBI, the associated values of A3 are listed. The transformation parameters for the terrestrial systems are in the sense combined towards individual system.

The transformation parameters for the World Geodetic System 1984 (WGS 84) of the U.S. Defense Mapping Agency are also listed. They are obtained as explained by Boucher et al. (1988).

ACCESS TO THE TERRESTRIAL SYSTEM, LINK TO CELESTIAL SYSTEM

The access to the terrestrial system can be obtained through comparison of an individual series of ERP with the series ERP(BIH) 87 C 02 (Feissel and Guinot, 1988). This series is identical to the BIH combined solution for the years 1984-1987. Starting with 1988, the IERS series can be used. Prior to this date, it is based on a calibration of the earlier BIH series of ERP. The part of the uncertainty which is due to the instability of this series in this type of access is given hereafter for averaging times of one day and one year, in units of 0.001".

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When using the transformation parameters of the terrestrial systems, the uncertainty due to the realization of the BTS is estimated to a few cm in the origin, 0.002 ppm in the scale and up to 0.004" in the orientation.

The tie of the BTS polar origin with the Conventional International Origin as realized by the International Latitude Service (ILS) is estimated from the differences between the ILS and BIH series of the coordinates of the pole over 1964-1966. The coordinates of the ILS CIO with respect to the BTS pole are:

\[
x = -0.034\," \pm 0.018", \quad y = \pm 0.010" \pm 0.014".
\]

This terrestrial frame, the combined celestial frame of Arias et al. (1988), the series ERP(BIH)87 C 02, and the corresponding time series of celestial pole offsets with respect to the IAU 1976 precession and IAU 1980 Nutation models (available on request) form a consistent ensemble, with uncertainties given in the present report and by Arias et al. (1988).
REFERENCES


MELBOURNE, W., (Ed.): 1983. Projet MERIT Standards, USNO Circular nr167


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(2) Motion of the sites adjusted.
(3) NSWC 92-2.

(4) UT1 - UTC
(5) Series referred to AMO-2 by the following linear corrections.

x = - 0.00052"/y.
y = - 0.00024"/y.
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Complete reference to the data listed can be found in the BIH Annual Report for 1987, p. D-2 to D-6.
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**Notes:**
- **NOAM** indicates the network is part of the National Optical Astronomy Museum.
- **PC FC** indicates the network is part of the The Pacific Centennial Foundation.
- **SOAM** indicates the network is part of the Southern Observations Astronomy Mission.

**Additional Information:**
- Domes Network (1) and coordinates are provided for each site.
- The coordinates are given in meters for the X, Y, and Z axes.
- The plate indicates the location of each site.
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TABLE 3 - TRANSFORMATION BETWEEN THE INDIVIDUAL AND THE COMBINED TERRESTRIAL SYSTEMS

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Notes
1 - NSWC 92-2

Remark.

The table lists the values of the parameters which transform the coordinates in the SSC's into the combined system at epoch 1984.0, according to the relationship

\[
\begin{pmatrix}
X \\
Y \\
Z
\end{pmatrix} = \begin{pmatrix}
X_S \\
Y_S \\
Z_S
\end{pmatrix} - \begin{pmatrix}
T_1 \\
T_2 \\
T_3
\end{pmatrix} - \begin{pmatrix}
D & -R_3 & R_2 \\
R_3 & D & -R_1 \\
-R_2 & R_1 & D
\end{pmatrix} \begin{pmatrix}
X_S \\
Y_S \\
Z_S
\end{pmatrix}
\]

where X, Y, Z are the coordinates in the combined system, and X_S, Y_S, Z_S are the cartesian coordinates in the individual system. T1, T2, T3 are the components of the translation vector, R1, R2, R3 are the rotation angles and D is the excess to 1 of the scale factor.
APPENDIX 2
Appendix 2

LIST OF POTENTIAL IERS SITES

A - List by DOMES numbers

B - Catalogue by alphabetic order

Codes for monthly information:
--------------------------------
- potential measurements
* actual measurements

1 AMP = 1-3 cm (3rd generation SLR or LLR, VLBI SX Mark 3)
2 AMP = 3-6 cm (idem, mobile equipments or poor data)
3 AMP = 6-10 cm (2nd generation SLR or LLR; VLBI SX Mark 2; DORIS)
4 AMP = 10-50 cm (poor SLR or VLBI; best Transit Doppler with PE)
5 AMP = 50-100 cm (typical Transit Doppler with PE)
6 AMP = 100-300 cm (Transit Doppler with BE)

AMP : Accuracy of Monthly Position (at one sigma)
BE : Broadcast Ephemerides
PE : DMA Precise Ephemerides
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APPENDIX 3
INPUT SYSTEMS (from BIH Annual Report for 1987)

EARTH ORIENTATION RESULTS FROM THE NASA CRUSTAL DYNAMICS PROJECT

Mark III VLBI data acquired since 1979 by the NASA Crustal Dynamics Project and the NGS POLARIS/IRIS programs have been analyzed for Earth orientation parameters. The reference frame is defined by the position of the Haystack 37-m antenna moving with AMO-2 velocity and its position defined on 1980 Oct. 17. The orientation of the frame is defined by values from BIH Circular D and the standard J2000.0 precession and IAU 1980 nutation models for the same date. Short period tidal terms in UT1 have not been removed from the tabulated values of UT1-UTC. All uncertainties are 1-sigma formal statistical errors from the sequential least-squares estimation described below.

The basic models used in calculating the VLBI theoreticals are described in Ma (1978), and the data analysis procedures are described in Ryan et al. (1986) and Ma et al. (1986). These models are contained in the GSFC program CALC 6.0 and are consistent with the MERIT standards with the addition of the pole tide. In the analysis which generated these results, however, the ocean loading model was not used and adjustments in longitude and obliquity were estimated for each session except the reference day. All stations move with their AMO-2 velocities on the listed tectonic plates. It should be noted that Kashima has been placed on the North American plate.

222 183 Mark III observations from 566 sessions were used to estimate station positions, source positions, Earth orientation parameters, nutation parameters and local clock and troposphere behavior from a least-squares solution with 192 global parameters and 14 246 arc, i.e., session-dependent, parameters. A weak input covariance on the Earth orientation parameters (X, Y-15 mas, UT1-1 ms) was used so that all three components could be estimated for each session with a more reliable indication of uncertainty and correlation. This affected only single baselines and nearly degenerate triangles. The overall rms fit of the solution was 83.1 ps for delay and 73.0 fs/s for rate. The reduced chi-square of the solution was .98.

The Earth orientation time series spanning nine years is given in ERP(GSFC)88 R 01. It should be noted that values from IRIS normally have X-UT correlations of 0.7 and that single baseline correlations approach unity. These correlations should be taken into account when applying the parameter uncertainties since the size of the error ellipsoid will otherwise be excessively large. Other results are source positions given in RSC(GSFC)88 R 01, station coordinates at epoch 1980 Oct. 17 given in SSC(GSFC)88 R 01, and nutation adjustments relative to 1980 Oct. 17 in NUT(GSFC)88 R 01.

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Epoch of station positions is 1980 October 17.
Estimates of X. Y. and UT1-UTC have been derived from a composite set of Mark III Very Long Baseline Interferometry (VLBI) observations collected under the aegis of projects MERIT (Wilkins, 1984), POLARIS and IRIS (Carter et al., 1985). More than 138,000 observations amassed during 460 observing sessions conducted between September 9, 1980, and January, 1988, were combined in a single least squares adjustment to obtain self consistent Earth orientation time series (Table NGS-1), source coordinates (Table NGS-2) (see Robertson et al., 1986) and the coordinates of the VLBI reference points of each of the radio telescopes (Table NGS-3).

Table NGS-4 contains corrections to the IAU 1980 nutation series from the IRIS 5-day observing sessions.

Table NGS-5 contains a daily series of UT1 values for the period April through June, 1984, and April 1985 through January, 1988. These UT1 values were produced from a series of special observing sessions using only the Westford-Wettzell baseline for 45 minutes each day. These restricted observing sessions are sufficient to determine only UT1. The daily values track smoothly between the regular 5-day IRIS values, and we estimate their accuracy to be 0.1 milli-sec (Robertson et al., 1985b).

The observations were processed at NGS using algorithms generally consistent with the MERIT standards (Melbourne et al., 1983), which include use of the IAU 1980 nutation model, an Earth tide model based on ephemeris positions for the Sun and Moon with the K1 term removed, and a model for ocean loading displacements. Hellings' model for the relativistic corrections for signal propagation was used (Hellings, 1986). Atmospheric refraction was modeled with the CFA-2.2 model (Davis et al., 1985), using meteorological data (pressure, temperature, humidity) taken at each VLBI station during each observing session. Wahr's model was used for the solid Earth deformations resulting from the motion of the pole (Wahr, 1985). Plate motions are modeled using the no-net-rotation model of Minster and Jordan (Minster and Jordan, 1978). The most significant deviation from the MERIT standards was that the IAU 1980 nutation model was corrected by estimating daily adjustments in longitude and obliquity. This deviation is necessary because the accuracy of the VLBI observations is sufficient to detect the errors in the annual, semi-annual, and fortnightly terms in the model (Herring, 1986). X and Y coordinates of the pole derived from satellite laser ranging (SLR) (Eanes et al., 1988), modified to remove a constant offset between the VLBI and SLR time series, were used in processing the single-baseline 24-hour observing sessions, to determine the Y component of the pole prior to January, 1984. After that time values interpolated from the IRIS series were used.

The standard errors quoted in tables 1–4 are strictly the formal values obtained from the adjustment, and should be understood as a limit on the accuracy of the determinations, the limit that would be attained in the absence of unmodeled systematic errors. Based on intercomparisons with satellite laser ranging series we estimate that since the Wettzell observatory became operational in January 1984 the IRIS X and Y components of polar motion have accuracies no worse than 2 milliseconds of arc (Robertson et al., 1985a), and intercomparisons between these values and the daily UT1 values (see below) indicates that the UT1 values are accurate to at least ± 0.1 milliseconds of time (Robertson et al., 1985b).

On behalf of the joint International Association of Geodesy (IAG), Committee on Space Research (COSPAR) Subcommission International Radio Interferometric Surveying (IRIS) the N3S distributes the monthly IRIS Bulletin A, Earth Orientation Information, and maintains a file containing the same data on the NGS computers which can be accessed via telephone by users who would like to have the data in machine-readable form. Additional information or assistance concerning the data presented here, or the data available through the MARK 3, IRIS Bulletin A, or NGS computer system may be obtained by contacting the authors.

References:


### TABLE NGS-3. Station Coordinates

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The station coordinate epoch is January 1, 1984.
A single continuous Lageos ephemeris was fit to Lageos laser range data for the interval from May 1976 to January 1988. The data base contained about 316,000 three-minute normal points formed from over 32,000 passes collected from more than 90 sites.

The force model referred to as the CSR 8801 system contains some departures from the MERIT Standards: $GM=398600.440$ km$^3$/s$^2$ and the order one GEM-L2 coefficients were adjusted for consistency with the MERIT $C(2,1)$ and $S(2,1)$. Furthermore, some ocean tide parameters depart from the Standards.

The station coordinates were obtained simultaneously with the ephemeris and selected force model parameters. The stations were assumed to be attached to the tectonic plates noted in the following table with rates defined by the AMI-2 model of Minster and Jordan (1978). The epoch of the derived station coordinates is 1983 January 1 00:00 UTC.

The earth rotation parameters estimated simultaneously with the other parameters were three day values of pole position $(x, y)$ and UT1. The estimated UT1 values contain Lageos node model errors which were filtered to remove periods greater than about 80 days. The reference UT1 series was the combined series of T.M. Eubanks (this volume p.D-85) from 1976 to 1986. After 1986, the reference was the monthly IRIS values reported on G.E. Mark 3. As a consequence, the long period (greater than 80 days) represents the reference UT1 series, but for periods below about 40 days, the Lageos UT1 estimates are independent of the reference series. During periods from 1976 to 1980, some three-day intervals did not have adequate tracking coverage, as reflected by larger standard errors when compared to the period from 1980 to 1988.


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This solution was done by fitting 30 day (and occasionally 35 day) day arcs of LAGEOS laser ranging normal point data from May 1976 through June 1987. There were 362,810 normal points used to form the solution, which were constructed from approximately 50 million full rate laser range observations. In each of the monthly arcs the initial state vector, two coefficients of solar radiation pressure and two coefficients of along track acceleration were estimated. The monthly arcs were combined to form a solution for earth orientation parameters and station positions. The following is a summary of the kinematic and dynamic models used for these solutions:

FORCE MODEL

- GEM-T1 Gravity model complete to degree and order 20.
- Third body perturbations: Sun, Moon, Venus, Mars, Jupiter, and Saturn (positioned with the JPL DE200 ephemeris)
- GM = 398600.4400 km³/sec²
- Tidal perturbations: Solid earth from Wahr, ocean tidal coefficients from GEM-T1
- Direct effect of solar radiation pressure adjusted twice in each monthly arc
- Along track acceleration adjusted twice in each monthly arc

MEASUREMENT MODEL

- Marini-Muray wavelength dependent refraction model with site meteorological measurements
- Velocity of light = 299792.458 km/sec
- Vertical and horizontal tide displacements: h2=0.6090, 12=0.0852
- 2 minute normal points following the Herstmonceux recommendations

REFERENCE FRAME

- Wahr nutation series
- J2000 precession (JPL DE200 ephemeris)
- $\Delta e = 6378137. m$
- Flattening = 1/298.257

- Apriori earth orientation (Xp, Yp, and A1-UT1) obtained from a weakly Vondrak smoothed earth orientation from SL7. These input values are adjusted at 5-day intervals (Xp, Yp, and A1-UT1); except that the first 5 day value of A1-UT1 in each monthly arc is fixed at the input value.

- The station positions were constrained to move according to the Minster/Jordan (1978) tectonic motion model AMO-2. The positions have an epoch of January 1983.

The Xp and Yp positions for the pole and the LOD values are in ERP(GSFC) 87 L 14

The sigmas given are scaled formal errors from the least squares adjustment.

The station positions are presented in cartesian coordinates in SSC(GSFC) 87 L 14.

The positions are for an epoch of January 1983, and, as for the EOP, the sigmas given are scaled formal errors from the least squares adjustment.

The positions for stations

7051, 7061, 7062, 7063, 7069, 7082, 7086, 7090, 7091, 7092, 7096, 7100, 7101, 7102, 7103, 7104, 7105, 7109, 7110, 7112, 7114, 7115, 7120, 7121, 7122, 7210, 7220, 7265, 7517, 7520, 7525, 7530, 7541, 7545, 7550, 7590, 7838, 7882, 7885, 7887, 7888, 7890, 7891, 7892, 7896, and 7899 are for the pad marker at the site.

The positions for stations

1181, 7400, 7401, 7805, 7810, 7833, 7834, 7835, 7837, 7839, 7840, 7843, 7886, 7894, 7907, 7921, 7929, 7939, and 7943 are for the optical axis of the laser ranging system.
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APPENDIX 4
## Appendix 4

### RESULTS OF ITRF-0

**TRANSFORMATION PARAMETERS BETWEEN THE INDIVIDUAL TERRESTRIAL SYSTEMS**

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