ITRF2000(1997.0) AND REALIZING A GEODETIC SYSTEM

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ABSTRACT

The International Terrestrial Reference Frame (ITRF) is a realization of the International Terrestrial Reference System (ITRS). Since its first realization in 1988, there have been many variations and additions in data types and changes in computations of ITRF. Between ITRF88 and ITRF97, the reference epochs have also changed three times. Many technical notes from the International Earth Rotation Service (IERS) are available. These notes explain and provide in great details all the technical complexities of different realizations, which have been updated every year between 1988 and 1994. After 1994, the ITRF 96 and 97 are the two latest solutions.

This paper intends to present and clarify the technical interpretation of the ITRF realization and its definition for the practical geodesists who want to update the geodetic infrastructure of a nation, region, continent, or for the world. The attempt here is to include significant details and explanations to provide a clear and consistent interpretation.

INTRODUCTION

International Earth Rotation Service (IERS), since it's founding in 1988, has been updating ITRS with its realizations as ITRF. First solution was ITRF88, which then was followed yearly by ITRF89, 90, 91, 92, 93, and 94. After this, we got two more solutions, viz., ITRF96 and ITRF97.

ITRF realization consists in a set of station Cartesian coordinates, a velocity field, and a full variance-covariance matrix (Silard *et al*, 1998). The direction of the IERS Reference Pole (IRP) and Reference Meridian (IRM) corresponds to the Bureau International de L'Heure (BIH) Conventional Terrestrial System (CTS) Pole and Zero Meridian (McCarthy, 1996).

Between 1988 and 1993, ITRFyy (where "yy" corresponds to the year in which it was realized) solution was obtained by a combination of all data submitted to the beginning of yy+1 (Boucher *et al*, 1997). Here, the reference epoch was 1988.0. The ITRF94 was then defined to the reference epoch 1993.0.

Then, the reference frame definition (origin, scale, orientation, and time evolution) was achieved in such a way that ITRF96 is in the same system as ITRF94 (Boucher et al, 1997). This was followed by a combined solution for ITRF96 and ITRF97 with 1997.0 as reference epoch.

This paper provides and clarifies the technical details concerning the different ITRFs and their reference epochs with the each periodic IERS solution. A suggested approach is also included for geodetic use when updating national, regional, continental, and/or global geodetic system(s) or datum(s).

INTERNATIONAL TERRESTRIAL REFERENCE FRAME (ITRF)

ITRF is a realization of the International Terrestrial Reference System (ITRS). The orientation of its axes is consistent with the Bureau de L'Heure (BIH) Conventional Terrestrial System (CTS) at the epoch 1984.0, in accordance with the resolution of the International Union of Geodesy and Geophysics (IUGG) and International Astronomical Union (IAU).

The orientation of the system is such that it has no residual rotational horizontal velocity relative to the Earth's crust. The construction of the ITRF is based on the combination of sets of station coordinates and velocities derived from observations from Very Long Baseline Interferometry (VLBI), Satellite Laser Ranging (SLR), and Lunar Laser Ranging (LLR). Data from Global Positioning System (GPS) was introduced in 1991 and from Doppler Orbitography and Radio-positioning Integrated by Satellite (DORIS) in 1994.

ITRFyy represents a solution, which is based on the data sets that are available till the end of year "yy" and is performed in the year "yy+1". From the first ITRF88 the solutions are available for 89, 90, 91, 92, 93, 94, 96, 97, and a combined solution for 96 and 97.

ITRF COMPUTATIONS

The procedure is in sequential steps.

(1) First step involves a reduction of coordinates for the participating stations to a common reference epoch using their respective velocity models. These velocity models are either based on fixed tectonic plate motion or estimated velocity fields.

The computations (XS, XS')t0 are done separately for each system "S", e.g., VLBI.

(2) Second step involves a least-squares estimation at the reference epoch "t0" the coordinates and velocities for the ITRFyy of all the stations from all the systems, e.g., VLBI, SLR, LLR, GPS, and DORIS. The model used in the "combination" solution is based on Euclidian similarity of seven parameters:

$$\begin{pmatrix} X^S \\ Y^S \\ Z^S \end{pmatrix} = \begin{pmatrix} X \\ Y \\ Z \end{pmatrix}_{to} + \begin{pmatrix} T1^S \\ T2^S \\ T3^S \end{pmatrix} +$$

$$\begin{bmatrix} D^S & R3^S \\ R3^S & D^S \\ R2^S & R1^S \end{bmatrix} \begin{pmatrix} R2^S \\ R1^S \\ D^S \end{pmatrix} \begin{matrix} X \\ Y \\ Z \end{matrix}_{t0} \qquad (1)$$

where X,Y,Z are the coordinates of a station at reference epoch t0 in the ITRFyy, $T1^s$, $T2^s$, $T3^s$, D^s, $R1^s$, $R2^s$, $R3^s$ are respectively the three translations, scale factor, and three rotations between the ITRFyy and individual "S" solutions.

(3) The local geodetic survey ties, with their standard deviations, are used to tie the stations of the different systems.

ITRF EPOCHS

From the first ITRF88, the reference epochs used to define different ITRF solutions (Altamimi, 2000) are:

ITRF88 to ITRF93	-	1988.0
ITRF94	-	1993.0
ITRF96	-	1993.0
ITRF96 and ITRF97	-	1997.0
ITRF00	-	1997.0

Here, we can interpret that ITRF 89 to ITRF93 represent the realization of ITRF88 with additional data sets in each subsequent solution. Thus, in real sense, each of the solutions for the years 1988 to 1993 only realized the same ITRF.

It is important to note that the combined solution for the ITRF96 and ITRF97 was obtained by combining positions and velocities simultaneously. This procedure allowed the use of full variance-covariance matrices of the individual VLBI, SLR, GPS, and DORIS data solutions. This will allow users to propagate the 1997.0 positions to any desired epoch. Thus, this approach also replaced the old ITRF96 as a separate realization.

ITRF DEFINITION

Coordinates are defined in a conventional "tide-free" system (APPENDIX 1) where effects of all tidal have been removed. To achieve this, the Equation 6 (Pp. 57, IERS Tech Note 21, 1996) is used.

ITRF ORIENTATION AND SCALE

(1) The orientation is defined by adopting IERS Earth Orientation Parameters (ERP) at a "reference" epoch (See Section 3).

(2) The orientation of the IERS Reference Pole (IRP) and Reference Meridian (IRM) were initially given by the BIH Terrestrial System (BTS) 1984.0 (McCarthy, 1996). Subsequently, the IRP and IRM are consistent with the "corresponding" directions of the BTS within 0.005". Thus, the corresponding BTS for the ITRF solutions from 1988 to 1993 (Section 4) will then be:

ITRF88 to ITRF93 - BTS 1988.0

Since BIH was replaced by IERS from 1988, the orientations for ITRF94, ITRF96, and ITRF97 followed an independent definition.

According to Montag (1997), the IRP and IRM were defined by IERS on the basis of the Conventional International Origin (CIO). However, it is not clear which CIO would have been used.

(3) The scale is obtained by relativistic modeling and is consistent with the Geocentric Coordinate Time (TCG) for a geocentric local frame (Chapter 11, IERS Tech. Note 21, 1996).

(4) The unit is meter (SI).

The time evolution of the orientation is maintained by using a no-net- rotation condition with regards to the horizontal tectonic motions over the whole Earth.

MOVEMENT OF THE GEOCENTRE

Recent analysis of SLR and other satellite data has shown that the coordinates of stations connected to the solid Earth, as realized by the ITRF, show variations as compared with the ITRF, which is assumed to be fixed to the rigid Easrth's crust (Montag, 1997). Thus, the origin of the ITRF is defined such that the time-dependent translation vector T (from the ITRF origin to the instantaneous center of mass of the Earth) is minimum (Montag, 1997).

GEODETIC APPLICATION

A. Important Considerations (McCarthy, 1996) -

a. ITRF coordinates are realized in the tide-free system and it is important to note that this system is not realistic and the crust can not be observed.

b. Alternatively, in the zero-tide system, the crust corresponds to the realistic time average which varies because of the action of luni-solar tides.

c. The ITRF coordinates (Section 8.A.a. above) contradicts the IAG Resolution 16, adopted at The 1983 General Assembly (APPENDIX 2).

B. Recommendation -

The following steps relate to a 10-day GPS campaign scenario which is observed from 25 June to 5 July 2001, with mid-epoch of 2001.5.

a. Select the IGS stations, which are to be used as constraints to define the intended geodetic system.

b. Using the "latest" available ITRF coordinates and velocities, viz., ITRF00 with reference epoch 1997.0, propagate coordinates of the stations to the mid-epoch 2001.5.

c. To be consistent with the IAG Resolution 16, 1983 (APPENDIX 2), compute the IGS station coordinates to the zero-tide environment.

d. Adjust the network using the propagated and restored coordinates with the zero-tide effects as constraints with appropriate weights.

The reference frame of the geodetic system can be held fixed till the next accuracy enhancement. It need not change with each new realization of an ITRFyy. A reference epoch change would be optional but may not be necessary.

REFERENCES

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APPENDIX 1

To account for the effect of the permanent tide, terrestrial reference frames may be defined:

Zero-tide - Permanent or "zero frequency tide" is retained.

The crust corresponds to the realistic time average, which varies with the luni-solar tides.

Tide-free - All effects of permanent tide are removed.

This is not realistic since the crust can not be observed.

Mean-tide - This a "tide-free" system except the geoid is modeled with permanent tide effects.

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APPENDIX 2

IAG Resolution No. 16, 1983[1]

The International Association of Geodesy (IAG), *recognizing* the need for the uniform treatment of tidal corrections to various geodetic quantities such as gravity and station positions, and *considering* the reports of the Standard Earth Tide Committee and S.S.G. 2.55,

recommends that :

1. the rigid Earth model be the Cartwright - Taylor - Edden model with additional constants specified by the International Centre for Earth Tides,
2. the elastic Earth model be that described by Wahr using the 1066 A model Earth of Gilbert and Dziewonski,
3. the indirect effect due the permanent yielding of the Earth be not removed,

   and
4. ocean loading effects be calculated using the tidal charts and data produced by Schwiderski as working standards.

1 Text obtained from IAG.