STATUS OF THE REALIZATION OF THE BIH TERRESTRIAL SYSTEM

C. BOUCHER and Z. ALTAMIMI
Institut Géographique National
2, Avenue Pasteur
94160 Saint-Mandé
France

ABSTRACT. A new realization of the BIH Terrestrial System, using space information (VLBI, LLR, SLR, Doppler), was published in the BIH Annual Report for 1984, under the name BTS 84. Details about the analysis, as well as comparisons between BTS 84 and BTS 85, and between BTS 85 and other individual systems, are presented. A study of origin, scale and orientation characteristics of BTS with regard to other systems is given. Further improvements of the model, taking time-like variations into account, are also outlined.

1. INTRODUCTION

It is of general agreement now that the frame of the Conventional Terrestrial System is to be defined on the basis of an adopted set of tridimensional coordinates of a global network of tracking stations.

In this way and from 1984 onwards, the BIH Terrestrial System has been redefined. A model, using least squares adjustment, was elaborated incorporating both Earth Rotation Parameters (ERP) and Sets of Station Coordinates (SSC), (Boucher and Altamimi, 1985). The SSC involved in the BTS realization are derived from observation programs using space techniques, from which series of ERP are also derived.

2. DETAILS ABOUT THE ANALYSIS

All details about the BTS 84 realization are given in the BIH Annual Report for 1984 and in (Boucher and Altamimi, 1985).

We give here some details about the BTS 85 realization, the results of which are published in the BIH Annual Report for 1985.

2.1. Sets of Station Coordinates

7 sets of station coordinates have been involved in the adjustment, incorporating 35 colocated sites.

A. K. Babcock and G. A. Wilkins (eds.), The Earth's Rotation and Reference Frames for Geodesy and Geodynamics, 107–114.

https://doi.org/10.1017/S0074180900119369 Published online by Cambridge University Press

2.1.1. Doppler. The coordinate data are from the classical DMA solution SSC (DMA) 77D01, used previously in the BTS 84 realization. It contains station coordinates in the 35 sites, determined in the NSWC 9Z2 system. The 7 transformation parameters of this system were held free in the adjustment.

2.1.2. Satellite Laser Ranging. The two CSR solutions : SSC(CSR) 84L01 and SSC(CSR) 85L07 have been incorporated, assuming that they are in the same reference system (CSR 84.02 system), (Tapley et al, 1985). There were 28 sites in common with other networks. The scale and the origin were held fixed in the adjustment.

2.1.3. Lunar Laser Ranging. The incorporated data are from the recent JPL solution : SSC(JPL) 86M02, containing 4 station coordinates : McDonald 2.7 and LRS, Haleakala, and Grasse. The origin of the corresponding system was held fixed.

2.1.4. VLBI. Three groups of data were used in the adjustment.

The first one is from the NGS solution, SSC(NGS) 85R02 involving 11 colocated sites.

The second one is from the GSFC solution, SSC(GSFC) 84R01, involving 10 colocated sites.

The third one is from the JPL solution, SSC(JPL) 83R05, involving 4 colocated sites.

For these three groups, the 7 transformation parameters were held free.

So, the adopted origin of the BTS is derived from the dynamical solutions SSC(JPL) 86M02 and SSC(CSR) 84L01, and the scale from SSC(CSR) 84L01.

2.2. Earth Rotation Parameters

The corresponding series of ERP used in the adjustment are (see Table 1 of the BIH Annual Report) :

- 3 VLBI : NGS 85, GSFC 85 and JPL 83
- 1 LLR : JPL 85
- 2 SLR : CSR 84 and 85

The continuity in the orientation of the axes is obtained by rotating the individual systems by the angles derived from the comparisons of the corresponding series of ERP with the BIH series over 1981-1984.

2.3. Results of the BTS realization

Tables 2 and 3 of the BIH Annual Report for 1985 list respectively the cartesian coordinates of the 35 sites and the transformation parameters between the individual systems and the BTS. Table 3 of the BIH Annual Report is reproduced here, Table III.

Full description about the 35 colocated sites as well as the involved SSC is given in (Altamimi et al, 1986). Moreover, Table 5 of the BIH Annual Report lists series of ERP at 0.05 year interval, referred to the BTS, from 1985.00 to 1985.95.

3. COMPARISONS OF VARIOUS SYSTEMS WITH BTS 85

3.1. Comparison between BTS 84 and BTS 85

We firstly note that there are some significant coordinate differences between the two BTS in the following sites :

Site	DOMES nb.
Dionysos	12602M001
Madrid	13407S003
Orroral	50103M103
Washington	40451M110

These differences are due to some ground ties or coordinates which were updated. So, the coordinates of these sites were not involved in the comparison which gave the transformation parameters listed in Table I.

TABLE I : Transformation parameters from BTS 84 to BTS 85 (the uncertainties are given in the second line)

T1 m	T2 m	T3 m	D 10^{-6}	R1 "	R2 "	R3 "
0.023	0.044	0.037	-0.0021	-0.0002	-0.0014	-0.0042
0.020	0.020	0.020	0.0029	0.0008	0.0007	0.0007

Table I shows the good level of consistency of the two BTS realizations : a few cm in the origin, 0.002 ppm in the scale and up to 4 mas in the orientation.

3.2. Comparisons between various systems and BTS 85

During the MERIT campaign, several analysis centers had processed sets of station coordinates. Many of these SSC have been collected by BIH and IGN as part of the MERIT coordinating center.

Each SSC is defined in a specific reference system, and so, differences could arise between different SSC, even for the same technique, if different analysis centers used different methods and models in the reduction of the observations.

Fortunately, the availability of colocated stations in different sets of coordinates enables to determine the systematic differences between them.

Thus, comparisons between several SSC and BTS 85 have been

https://doi.org/10.1017/S0074180900119369 Published online by Cambridge University Press

elaborated. Table II lists the transformation parameters between different SSC and BTS 85.

TABLE II : Transformation parameters from MERIT SSC to BTS 85
(the uncertainties are given in the second line)

SSC	T1 m	T2 m	T3 m	D 10^{-6}	R1 "	R2 "	R3 "
CFA 85R01	-2.784 0.048	4.882 0.025	0.282 0.036	0.443 0.003	0.001 0.001	-0.011 0.002	-0.006 0.001
CERGA 85M07	0.336 0.158	0.024 0.158	-0.125 0.176	0.004 0.031			0.012 0.006
DGFII 85L04	-0.069 0.036	-0.002 0.034	-0.150 0.034	0.013 0.005	-0.002 0.001	0.006 0.001	0.002 0.001
GAOUA 85L02	-0.034 0.030	0.028 0.029	0.056 0.029	0.007 0.043	0.004 0.001	-0.007 0.001	-0.090 0.001
GSFC 85L00	-0.044 0.036	0.112 0.037	0.049 0.037	0.017 0.005	-0.011 0.001	-0.005 0.001	0.010 0.001
NAL 85L01	0.007 0.025	0.012 0.025	-0.097 0.024	0.016 0.004	-0.002 0.001	0.007 0.001	0.006 0.001
UPAD 85L01	-0.046 0.053	0.036 0.053	0.145 0.051	0.031 0.008	-0.010 0.002	-0.005 0.002	0.153 0.002
ZIPE 85L02	0.015 0.039	-0.020 0.038	-0.026 0.037	0.003 0.006	-0.003 0.006	-0.003 0.002	-0.107 0.001

TABLE III : Transformation parameters between the Individual Terrestrial Systems and BTS 85 (Table 3 of the BIH Annual Report)
(the uncertainties are given in the second line)

SSC	T1 m	T2 m	T3 m	D 10^{-6}	R1 "	R2 "	R3 "
NGS 85R02	1.631 0.075	-0.989 0.098	0.387 0.101	-0.039 0.019	-0.006 0.001	0.010 0.001	-0.004 0.001
GSFC 84R01	1.422 0.212	-1.013 0.247	0.367 0.280	-0.036 0.048	-0.005 0.001	0.008 0.001	0.014 0.001
JPL 83R05	0.160 0.123	-0.473 0.139	-0.040 0.134	-0.050 0.022	-0.006 0.002	-0.008 0.005	-0.005 0.004

https://doi.org/10.1017/S0074180900119369 Published online by Cambridge University Press

TABLE III (continued)

JPL	86M02	0.0 0.0	0.0 0.0	0.0 0.0	-0.035 0.048	0.005 0.013	0.001 0.013	-0.010 0.001
CSR	84L01	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	-0.004 0.001	-0.003 0.001	0.001 0.001
DMA	77D01	0.061 0.730	-0.363 0.732	-4.732 0.716	0.604 0.100	0.020 0.030	0.002 0.028	-0.806 0.023

4. SOME CHARACTERISTICS OF BTS IN COMPARISON WITH OTHER SYSTEMS

Taking the origin of BTS from SLR and LLR, and the scale from SLR, we note hereafter some remarks about the origin, scale and orientation, issued from Table II and Table III (Table 3 of the BIH Annual Report for 1985).

4.1. Origin

Apart from VLBI solutions for which the selection of an origin is arbitrary, other solutions, namely LLR and dynamical (SLR and Doppler), should be identical. This is well verified for SLR on Lageos, the shifts ranging up to 15cm, whereas it reaches 30cm for the CERGA LLR solution. The most noticeable result is the Z-axis shift of 4.73m for Doppler. This last result is well known although previous estimates were not so well accurately determined.

4.2. Scale

Usually, SLR solutions are in a good agreement with the BTS scale. But we note that all VLBI and LLR scales are in disagreement by about 4.10^{-8} from BTS, i.e. SLR scale. The reason is not fully explained although 2.5×10^{-8} are due to a relativistic bias in the definition of the terrestrial system in the various techniques (Hellings, 1986, Boucher, 1986).

4.3. Orientation

We note the most significant result in Z-axis rotation for Doppler which is about 0.81 second. This longitude bias confirms again previous findings.

We mention also some orientation differences for UPAD and ZIPE solutions, respectively 0.15 and 0.11 second in Z-axis rotation.

5. TEMPORAL MAINTENANCE OF THE BTS

We summarize below some guide-lines to be followed in future studies

https://doi.org/10.1017/S0074180900119369 Published online by Cambridge University Press

to improve and maintain the BTS. Most of these guide-lines are given in (Boucher and Feissel, 1983).

5.1. Local survey ties

The improvement of the model has to take inaccuracies and time variation in local ties between stations (terrestrial or GPS baselines) into account. So, they have to be introduced as observations with appropriate variances and not as fixed values. For example, for two stations ℓ and k in the same site or not, we have :

$$X_{\ell}(t) - X_{k}(t) = dX_{k,\ell}(t) + V_{k,\ell} \qquad (1)$$

5.2. Modelling

Monitoring of time variations of station positions implies the modelling of all crustal displacements of individual station.

So, to maintain the BTS temporally, it is therefore necessary to define and update it on the basis of various deformations of the Earth's crust. The types of these deformations are essentially : Earth tides, ocean tidal loading, local deformation and motion of tectonic plates.

A reasonable approach to do is that the axes of the BTS are to be fixed in the Tisserand sens. Thus, we have to maintain a discrete Tisserand's mean axes of the crust, related to the system (P_k , m_k), $1 \leqslant k \leqslant K$, where P_k is the location of the stations affected of a conventional mass m_k which acts as a weight function. Such a system is defined by a minimum kinematic energy, T :

$$T = \frac{1}{2} \int_c V^2 \, dm \quad \text{is minimum} \qquad (2)$$

where $\vec{V}$ is the velocity of a particle in the terrestrial frame.

In such a system, the linear and angular momentum of the crust (c) are therefore null :

$$\left| \begin{array}{l} \vec{P} = \int_c \vec{V} \, dm = \vec{0} \\ \vec{H} = \int_c \vec{X} \wedge \vec{V} \, dm = \vec{0} \end{array} \right. \qquad (3)$$

By replacing $\int_c$ by Σ, equation (3) gives

$$\left| \begin{array}{l} \sum_{k=1}^{K} m_k \vec{V}_k = \vec{0} \\ \sum_{k=1}^{K} m_k \vec{X}_k \wedge \vec{V}_k = \vec{0} \end{array} \right. \qquad (4)$$

For that purpose, the position vector X_k of a station k at date t can be expressed as :

$$X_k(t) = X_{o_k} + dX_k(t) + L_k(t) \qquad (5)$$

https://doi.org/10.1017/S0074180900119369 Published online by Cambridge University Press

where dX_k is a displacement model and L_k is an adjustable residual motion.

The model dX_k must take all possible displacements of individual station, such as Earth and ocean tides and tectonic plate motion, into account.

Possible models already used by analysis centers have to be considered.

5.3. Time-like maintenance

The final step now is precisely the temporal maintenance of the BTS. The method consists in time discretization of equations at different epochs : t_0, t_1, t_2, ... :

a) Definition of the BTS at t_0 giving X_{0_k} as coordinates

b) Definition of the BTS at t_i with 7 minimum constraints :

- one scale constraint
- 6 evolution constraints, if we approximate $\vec{V}$ by :

$$\frac{X_k^i - X_k^{i-1}}{t_i - t_{i-1}}$$

and using the following evolution equations (derived from (4)) :

$$\left| \begin{array}{l} \sum_k m_k (X_k^i - X_k^{i-1}) = 0 \\ \sum_k m_k \, X_k^{i-1} \wedge (X_k^i - X_k^{i-1}) = 0 \end{array} \right. \qquad (6)$$

6. CONCLUSIONS

It is anticipated that the time-variant model will be implemented for the next release of BTS, i.e. BTS 86. The already achieved system has an encouraging quality, but some points need to be still significantly improved : local surveys, both in quality and quantity, time information about individual solutions, exact corrections and hypotheses applied for each solution derived by analysis centers.

Finally, we are confident that this work will continue with success in the frame of the future International Earth Rotation Service, which will replace BIH as well as IPMS in 1988.

7. REFERENCES

(1) *Proceedings of the International Conference on Earth Rotation and Terrestrial Reference Frame*, 31 July - 2 August, 1985, Columbus, Ohio, USA

https://doi.org/10.1017/S0074180900119369 Published online by Cambridge University Press

(2) C. Boucher and Z. Altamimi : 'Towards an improved realization of the BIH terrestrial frame', in (1)

(3) Z. Altamimi, C. Boucher, M. Feissel : 'Directory of sites participating to the realization of the BTS for 1985', Note Interne du BIH n° 3, 1986, Paris, France

(4) C. Boucher and Z. Altamimi : 'The use of space techniques for the connection of geodetic datums', presented at the XXVIth COSPAR Meeting, July 1986, Toulouse, France

(5) C. Boucher and M. Feissel : 'Evolution of BIH activities for the definition, maintenance and dissemination of a conventional terrestrial system', GRGS, Note Technique n° 1, IGN, 1983, France

(6) *BIH Annual Report for 1984*, 1985, Paris, France

(7) *BIH Annual Report for 1985*, 1986, Paris, France

(8) B.D. Tapley, R.J. Eanes and B.E. Schutz : 'Earth rotation from laser ranging to Lageos', in (1)

(9) R. Hellings : 'Relativistic effects in astronomical timing measurements', *Astron. J. 1986*

(10) C. Boucher : 'Terrestrial and inertial relativistic reference frames', GRGS, Rapport Technique n° 3, 1986, Paris, France.

DISCUSSION

Archie Carlson: How was the origin (approximate geocenter) determined or adopted by the VLBI groups (NGS and JPL)? How was the longitude established or adopted by the VLBI group? Why was the DSN Terrestrial coordinate system not considered in the coordinate comparisons?

Boucher: (as reported by Carlson) Dr. Boucher suggested that I consult the experts in VLBI for details. For NGS and GSFC, Haystack station was held fixed at some *a priori* value. The DSN VLBI solution (TEMPO) was included in our solution.

Reply by Lambeck: The scale bias of the Texas SLR frame might be due to the fixing of both c and GM in the solution.

R. Eanes: The SSC(CSR) 84LO solution was performed with GM fixed to the MERIT Standard value. A new solution which has just been distributed uses an adjusted value of GM. The scale of the new system is closer to the VLBI results.

Kaula: Have you made, or considered, solutions that are geographically limited to test for geographically associated systematic error, particularly in the Doppler?

Reply by Boucher: We realize that there are such correlations, but have been more concerned about globally optimal solutions.