THE COMMON BORDER DATUM REFERENCE FRAME (CBDRF) BETWEEN INDONESIA AND TIMOR-LESTE: IMPLEMENTATION AND PROCESSING

R.M.S. Fernandes [1,2]; Djawahir Fahrurrazi[3], João Matos[4], Y. Sri Handoyo[5]

[1] Departamento de Informática, Universidade da Beira Interior, Covilhã, Portugal.
[2] Department of Earth Observation and Space systems, TUDelft, Delft, The Netherlands.
[3] Department of Geodetic Engineering, Gadjah Mada University, Yogyakarta, Indonesia.
[4] Instituto Superior Técnico, Lisboa, Portugal.
[5] Badan Koordinasi Survei dan Pemetaan Nasional, Cibinong, Indonesia.

(rmanuel@di.ubi.pt)

ABSTRACT

The accurate delineation of the border between the Republic of Indonesia (RI) and the Democratic Republic of Timor-Leste (RDTL) was a major issue after the independence of the latter country. On some segments, the uncertainty about the correct line of the border was high due to several factors (e.g., destruction of old markers, change on river courses, etc..). In addition, the accurate surveying of the entire border line in a known international reference frame was required by the two countries in order to solve any possible issue in the future.

This paper focuses on the implementation, processing and mapping of the Common Border Datum Reference Frame (CBDRF), the fiducial network created as support for the delineation field work. The CBDRF network has been observed in two different epochs. The major campaign was carried out in May 2003, where reference markers were materialized (in Timor-Leste) and observed in both sides of the border. In addition, sites observed in Indonesia side in December 2002 were also included in order to densify the entire network.

The guidelines adopted by the two governments required that the CBDRF was processed and mapped independently by the Indonesian and East-Timorese partners. Different software packages, and strategies were applied by both teams, which allow one to independently evaluate the results.

ITRF2000 (International Terrestrial Reference System, solution 2000) has been selected to map the CBDRF into a known international reference frame. The best approach on the selection of the reference stations was investigated. The comparisons that lead to the final set of reference stations (commonly agreed by all partners) are here described and analyzed.

On a final step, the coordinates independently obtained by each group were weight averaged. Small threshold values (dependent of the station order) were defined in order to detect any possible outlier. For the stations showing abnormal discrepancies, the reasons were investigated, which allowed to correct the errors for almost all cases.

The dense geometry and the quality of the final coordinates of the CBDRF network was a guarantee of the accurate delineation the border, next step of the project. Moreover, the implemented network can be used in the future for other projects (e.g., geodynamic research).

1. Introduction

1.1 – The implementation of the CBDRF network

CBDRF is the abbreviation of Common Border Datum Reference Frame for the establishment of the international terrestrial border between the Democratic Republic of Timor-Leste (RDTL) and the Republic of Indonesia (RI). It is formed by a set of geodetic control points used as reference for the subsequent delineation and demarcation surveys of the border. The observation of the CBDRF network has been carried out jointly by RI and RDTL teams using GPS observations only. The total number of CBDRF stations is 69 divided by three classes. This classification, *a priori* defined, was function of the planned number of occupations and hours of observations:

- Zero-Order – stations continuously observed during the entire period of the campaigns.
- First-Order – stations with a minimum of 2 daily sessions (each session with a minimum of 12 hours).
- Second-Order – stations observed with a minimum observational period of at least 2 hours.

Notice that for most First- and Second-Order stations, the observational period has been much larger than the minimum required. Figures 1 and 2 show the distribution of the stations of Zero-Order, and First- and Second-Order, respectively.

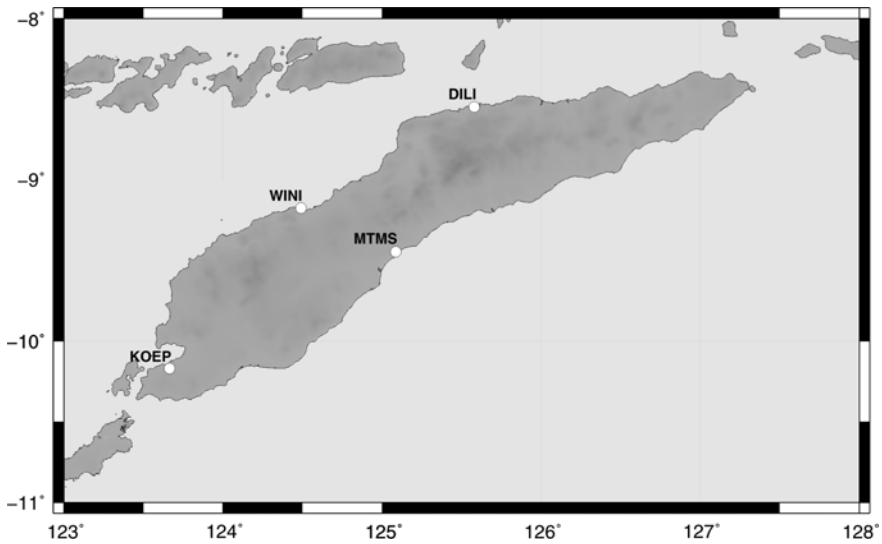

Figure 1 - Zero-Order stations of the CBDRF network (1 in Timor-Leste and 3 in Indonesia).

The stations of KOEP and DILI are continuously-operating GPS sites managed by BAKOSURTANAL (Badan Koordinasi Survei dan Pemetaan Nasional) and IST (Instituto Superior Técnico), respectively, whereas WINI and MTMS were stations operated during the campaigns only.

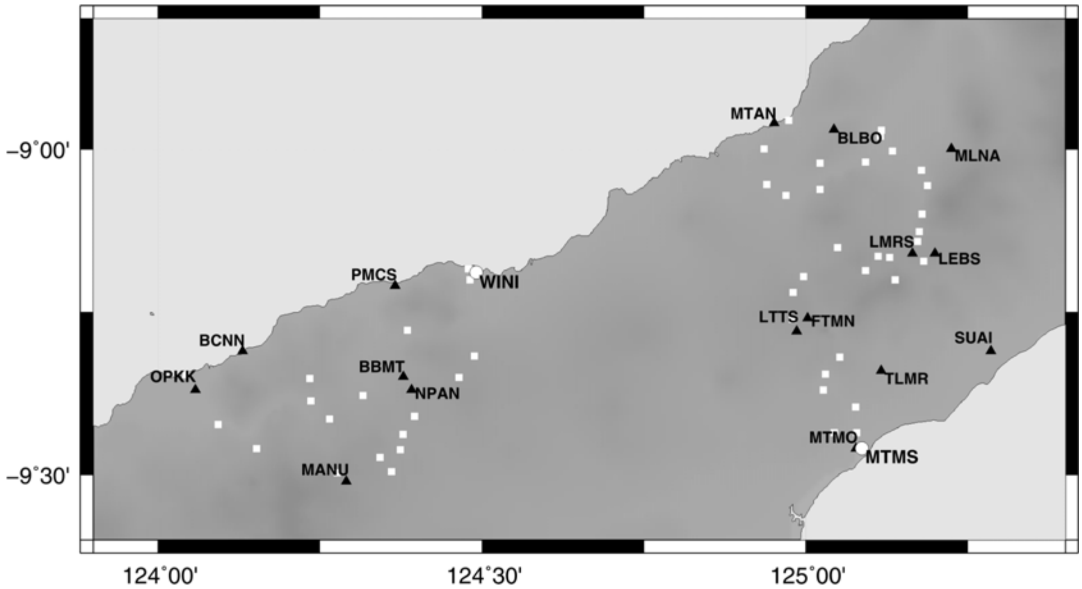

Figure 2 – First-Order (black triangles; 9 in Timor-Leste and 7 in Indonesia; labeled) and Second-Order (white squares; 10 in Timor-Leste and 39 in Indonesia) stations of the CBDRF network. Also shown the two Zero-Order stations (white circles) located close to the border

The physical implementation of the CBDRF has been carried out differently on both sides of the border. In the RDTL side, most monuments were constructed just before the first observations (except some stations already installed by IST in the framework of previous projects in Timor-Leste), whereas in the Indonesian side, most selected markers were already part of the existing national geodetic network. This is a reason for the large number of Second-Order sites in the Indonesian site. The RI team used the CBDRF campaign carried out in 2003 to also perform a reobservation of their national pillars along the border. Conversely, the RDTL team decided to invest in the installation and observation of sites to be classified as First-Order markers in order to have a very stable network in the area, and they only setup some Second-Order sites where the logistic conditions would advise to perform such densification (*e.g.*, no access to electric power in the vicinity). Two more aspects were taking into account during the planning of the location of the sites by both partners. First, each country wanted to have an independent network on its territory. Second, the poor conditions for terrestrial (and even aerial) connections in the region were a fundamental constraint on the planning of the subsequent works in the border. Although the physical distance between the stations is short (the averaged distance between Zeroand First-Order points is around 15km in both segments of the border), the time necessary to travel between two CBDRF markers or between a CBDRF marker and the border can amount to several hours. Therefore, it was necessary to design the network in order that no segment of the border would be more than 1-2 hours distant of a CBDRF marker in each country.

1.2 – GPS Campaigns

The main campaign on the CBDRF network has been carried out jointly by the two partners between May 10th and 31st, 2003. In this campaign, 51 CBDRF points distributed by the RI territory (31 points) and RDTL territory (20 points) were observed. Previously, in 20-21 December 2002, the RI teams have observed 18 points distributed in Indonesian territory nearby the RI-RDTL borderline. It was agreed by both partners to include this campaign in the definition of the CBDRF network. In fact, all First-Order points in the Indonesian side (cf. Figure 2) have been observed in this campaign.

Table 1 summarizes the specifications for the GPS observations that have been followed:

Table 1 – Major characteristics of the GPS observations of the CBDRF network.

Method	Static
Instruments	Dual-frequency geodetic-type receivers
Observation time-span	Continuous (during the campaign) for Zero-Order; 2-4x24 hours for First-Order; and minimum of 2 hours for Second-Order
Data recording rate	15 seconds (30 seconds for some points of Zero- and First-Order)
Elevation-mask angle	10°

2. Data Processing

The RI and RDTL teams have processed the GPS data independently. To process the Zero- and First-Order CBDRF networks, the RI team used the BERNESE software package (Rothacher and Mervart, 1996), and the RDTL team used the GIPSY software package (Webb and Zumberge, 1995). For the processing of the Second-Order network, both teams used commercial software.

With respect to the Zero- and First-Order networks, which will be here discussed in more detail, the strategies applied by both partners were different. The RI team processed the network using a batch approach, *i.e.*, the entire network is processed simultaneously in one computation. Parameters to be simultaneously estimated include station-specific parameters (*e.g.*, receiver position, receiver clock bias and drift, zenith tropospheric delay) and common parameters (*e.g.*, satellite clock bias and drift; EOPs). The coordinates of one or more stations can be tightly constrained to *a priori* values in order to implement the reference frame, or, alternatively, it is possible to generate the so-called "fiducial-free" network solution. In the fiducial-free network approach only loose constraints (1m–1km) are applied to the sites. Later, the results of a fiducial free network solution are transformed into the appropriate reference frame using Helmert transformations (cf. next section for further details).

In contrast, the RDTL team made use of the PPP (Precise Point Positioning) strategy that is available using the GIPSY software package[1]. The concept of PPP is illustrated simply by considering a two-steps processing. First, a global network is used to compute the common parameters (orbit, satellite clock, and EOPs). The global coverage of the continuously-operating GPS stations has now reached the point that the addition of an extra station would do little to change the values for the global parameters (Blewitt, 1998). In a second step, these global parameters can be kept fixed to compute each set of station-specific parameters one-by-one (Zumberge et al., 1997). For a single station, which has not been processed together with the global network, the only difference for the FN approach is that this particular station does not influence the solution for the common parameters. The Jet Propulsion Laboratory (JPL) provides daily estimates of fiducial-free orbits, satellite clocks and EOPs (plus satellite eclipse information) derived from a global network. Hence, a user interested in a (small) subset of stations may go to the aforementioned step two directly. It is required to use consistent Earth models (*e.g.*, Earth tides) to avoid a degradation of the achievable accuracy. For further details, a user can check Fernandes (2004). Here, the PPP strategy was enhanced by introducing the ambiguity-fixing step. This approach allowed one to obtain slightly improvements in the daily repeatabilities for most stations.

3. Mapping into ITRF2000

An initial decision agreed by both countries was to determine the borderline with respect to an international reference system, namely the International Terrestrial Reference System (ITRS). Consequently, the latest realization of this system, ITRF2000 (Altamimi et al., 2002), has been adopted as reference frame. However, because ITRF2000 is a dynamic frame due to the tectonic plate motions, it was also necessary to define a reference epoch, which was selected to be 21st May 2003 (the mean day of the CBDRF campaign).

If no significant deformations occur in the network, the reference epoch is only fundamental to connect the observed network to an external reference frame. Internally, the coordinates of the reference sites can be fixed for the future. However, the island of Timor is located close to the convergence zone between the Australian plate and a complex assemblage of tectonic blocks (Michel et al., 2001). Some authors consider the island

---

[1] A similar strategy is now also available on BERNESE.

located in the center of a tectonic stable block (cf. Figure 6 in Bird (2002)) since no significant seismic activity occurred recently. This fact allowed to connect the two campaigns carried out (see next section for further details). However, it is important to carry further reobservations of the CBDRF network in the future to accurately evaluate the effect of the geodynamic processes on the network.

In order to map the CBDRF network into ITRF2000, six IGS (International GPS Service) stations were also processed by the two teams together with the CBDRF network, namely BAKO, KARR, TID2, TOW2, USUD, and YAR2 (cf. Figure 3). These stations were selected after several configurations, using a total of 24 stations, have been tested. Most of the stations of the initial set were removed due to several reasons: (1) no available data in the campaign periods; (2) large residuals in the three components or in the vertical component (*e.g.*, due to co-seismic signals); and (3) weak ITRF2000 solution.

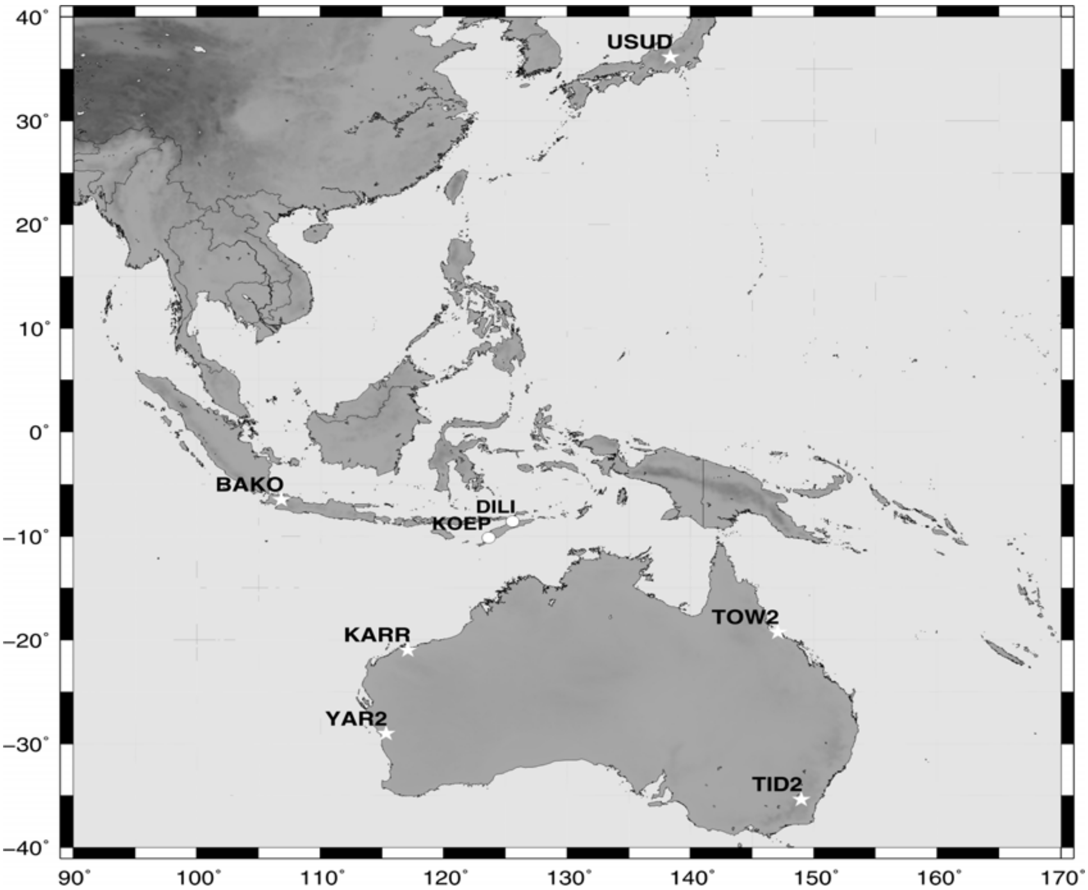

Figure 2 – IGS stations (white stars) used to map the CBDRF network into ITRF2000. The continuously-operating stations (white circles) in Timor are also shown.

The RI team tied the CBDRF network to ITRF2000 by fully constraining the Zero-Order network to the coordinates and velocities of the six IGS stations. First-Order network was then fully constrained to the Zero-Order network. The RDTL team has processed simultaneously the Zero- and First-Order networks together with the six IGS stations, and then, the entire network was projected into the ITRF2000 positions of the IGS stations by using a seven-parameters transformation. After, in both processings, the Second-Order network was fully constrained to the Zero- and First-Order networks.

Table 2 shows the weighted r.m.s. of the residuals (estimated minus predicted ITRF2000 solution) obtained by the RDTL team in the mapping of the two campaigns. It is also shown the number of outliers, *i.e.*, coordinate stations that were not considered for the mapping since their residuals were larger than the threshold criteria: 8mm, 12mm and 20mm for North, East and Up components, respectively. The only station that was considered to be an outlier in the three components was TID2 in December 2002 (only the East residual was larger than the criterion, but in the case of a horizontal outlier, the entire solution is removed). These results can be considered satisfactory attending to the lack of stations with reliable ITRF2000 solutions in this region. Most are concentrated in Australia, with an absence of stations in Northeast direction (cf. Figure 3). Furthermore, as a consequence of the adopted processing approaches (see previous section), the RI team required that no more than six stations were used in the mapping processing. This disabled the use of a global mapping approach.

Table 2 – Weighted r.m.s. of the of the residuals in the three components in the mapping into ITRF2000. The number of coordinate solutions detected as outliers (in the three components or only in the vertical component) is also shown.

Campaign	Residuals (mm)			Outliers
	North	East	Up	3D (Vertical)
December 2002	2.2	5.6	12.0	1 (2)
May 2003	3.8	5.3	4.4	0 (3)

4. Combination of Solutions

The solutions produced by the two teams have been combined in several steps. First, the solutions for both campaigns (December 2002 and May 2003) have been normalized in order that the associated formal errors were similar for both datasets. Although both software packages produced results with similar quality, the different constraints applied in the processing lead to formal errors of different magnitude. This has been carried out by multiplying the RI covariance matrixes by a scalar factor equal to the ratio between the sums of the variances in both data sets.

The solutions for each campaign have been combined using the associated uncertainties as weights. In order to have all stations referenced to the same epoch (21st May 2003), it has been decided that no internal deformations between December 2002 and May 2003 would be accounted for (see previous section). Therefore, the coordinates of the December 2002 network has been translated to the reference frame of the May 2003 network by fixing the coordinates of KOEP (the only station in Timor with estimated coordinates in both epochs; cf. Figure 1).

The analysis of the quality of the results was done by evaluating the coordinate discrepancies between the RI and RDTL solutions. For each CBDRF point of the Zero- and First-Order networks, the discrepancies in the horizontal, vertical, and 3D-geometric distance were computed. These values were compared with the threshold criterion values, which are shown in Table 3. These values were proposed by the RI team, based on their internal criteria for the Indonesian national geodetic network, and agreed by the RDTL team.

Table 3 – Threshold values for acceptance/rejection of the CBDRF station coordinates based on the differences between the RDTL and RI solutions.

Threshold values(cm)	Horizontal	Vertical	3D-geometric
Zero-Order	3.0	7.5	8.1
First-Order	4.0	10.0	10.8

The comparison between the values in Table 3 and in Table 4 allows one to immediately conclude that all coordinate station solutions were within the tolerances defined *a priori*. Therefore, all stations of the Zero-Order and First-Order networks were accepted as CBDRF stations.

Table 4 – Maximum and averaged (between parentheses) differences between the RDTL and RI solutions.

Threshold values(cm)	Horizontal	Vertical	3D-geometric
Zero-Order (4 stations)	1.0 (0.5)	4.7 (2.4)	4.8 (2.5)
First-Order (16 stations)	2.2 (1.1)	3.3 (1.4)	3.3 (1.8)

With respect to the Second-Order network, the averaged 3D-geometric discrepancy was 6cm. For these stations, only the 3D-geometric differences were compared using a tolerance value of 13.5cm. Initially, there were several stations that shown discrepancies larger than the threshold criteria. However, after analysing the reasons that cause the differences (*e.g.*, wrong antenna height) only 4 stations were not accepted as part of the CBDRF network.

5. Conclusions

The autonomous approaches, using different software packages (Bernese by Indonesia and Gipsy by Timor-Leste) and mapping methodologies, allowed a more reliable assessment of the quality of the final solutions.

The results show that the stations of the CBDRF, in particular, the Zero- and First-Order stations have very robust solutions with respect to ITRF2000. In this way, the accurate connection of the points of the borderline between Timor-Leste and Indonesia with respect to a global reference frame is possible. Furthermore, the derived solutions can be used in the future for other type of projects (*e.g.*, geodynamic studies or definition of national geodetic networks).

Acknowledgments

The Portuguese authors would like to thanks UNMISET (United Nations Mission in East-Timor) for the permanent support in the field works and OAUP (Observatório Astronómico da Universidade do Porto) that provided invaluable collaborators. They also wish to thank the East-Timorese collaborators for their dedication during the campaigns.

References

Altamimi, Z., P. Sillard, and C. Boucher (2002): ITRF2000: A New Release of the International Terrestrial Reference Frame for Earth Science Applications, J. Geophys. Res., B10, 2214, doi:10.1029/2001JB000561.

Bird, P. (2003): An updated digital model of plate boundaries, Geochem. Geophys. Geosyst., 4 (3), 1027, doi:10.1029/2001GC000252.

Blewitt, G. (1998): GPS Data Processing Methodology: From Theory to Applications, in GPS for Geodesy, vol. 60 of Lecture Notes in Earth Sciences, edited by A. Kleusberg and P.J.G. Teunissen, pp. 231–270, Springer, 2nd edition.

Fernandes, R.M.S. (2004): Present-day kinematics at the Azores-Gibraltar plate boundary as derived from GPS observations, isbn 90-407-2557-8, 202 pp., DUP, Delft University of Technology, The Netherlands.

Michel G., Y. Yu, S. Zhu, C. Reigber, M. Becker, E. Reinhart, W. Simons, B. Ambrosius, C. Vigny, N. Chamot-Rooke, X. LePichon, P. Morgan and S. Matheussen (2001): Crustal motion and block behavior in SE-Asia from GPS measurements, Earth and Planet. Sci. Lett., 187, 289-291

Rothacher, M., and L. Mervart (1996): The Bernese GPS software version 4.0, Astronomical Institute, University of Berne.

Webb, F., and J. Zumberge (1995): An introduction to GIPSY/OASIS-II, JPL D–11088, California Institute of Technology, Pasadena, California.

Zumberge, J., M. Heflin, D. Jefferson, M. Watkins, and F. Webb (1997): Precise Point Positioning for the efficient and robust analysis of GPS data from large networks, J. Geophys. Res., 102, 5005–5017.