Adjustment of the Classical Terrestrial Geodetic Network of Mozambique Tied to ITRF

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Key words: Geodetic networks, GPS, Adjustment

SUMMARY

In Mozambique a triangulation network with 750 geodetic points and a linear extension of about 9000Km, covering the whole country, was implemented between 1907 and 1973 by portuguese scientific and technical missions. At the beginning the precision corresponded to a 2nd order European triangulation. After 1957, the precision was upgrade to the 1st order.
After several decades this geodetic patrimony is still important for the economic, technologic and scientific development of Mozambique since it is used as the basis for the cartography produced until now. In 1991, Portugal and Mozambique established a Protocol for the revision and adjustment of the Mozambique geodetic network.
Mozambique has also a GPS network with 245 stations installed in cooperation with the Special Team Royal Engineers (UK) and the Joint Venture Norway Mapping of Mozambique. Thirty of these stations are common to the classic network.
The classic network was adjusted to the global datum WGS84/ITRF94, fixing the coordinates of those thirty points. The mean value of the error ellipses semi-axis was reduced from 2.5m to 0.5m.

SUMÁRIO

A rede geodésica de Moçambique foi estabelecida entre 1907 e 1973 por várias Missões técnico-científicas portuguesas. Está apoiada em cerca de 750 vértices e apresenta uma extensão linear de 9000 km. No início a precisão angular requerida equivalia à 2ª ordem europeia e a partir de 1953 à 1ª ordem.
Várias décadas passadas esta infraestrutura é ainda de uma importância fundamental para Moçambique pois, além de o cobrir geograficamente, é facilmente convertível nos sistemas de coordenadas usados pelos actuais sistemas de posicionamento e navegação como o GPS. Também importante o facto de permitir compatibilizar a informação geo-referenciada já adquirida com a que se venha a obter, servindo assim de estrutura de apoio aos projectos de planeamento e desenvolvimento. Em 1991 Portugal e Moçambique estabeleceram um Protocolo de Cooperação para a Revisão e Ajustamento desta Rede.
Moçambique possui igualmente uma rede GPS com 245 estações estabelecida em cooperação com o Special Team Royal Engineers (UK) e a Joint Venture Norway Mapping of Mozambique. Destas, 30 são comuns à rede clássica.
Ajustou-se então a rede clássica fixando as coordenadas GPS destes 30 pontos, no datum WGS84/ITRF94. O valor médio para o semi-eixo maior das elipses de erro passou de 2.5 m para 0.5 m.

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1. INTRODUCTION

The origin of the Tropical Research Institute of Portugal (IICT) dates from 1883 when the "Cartography Commission" was created. Since then it was replaced by institutions with different names dealing with cooperation, promoting scientific and technical research on tropical areas, namely portuguese speaking countries.

This Institute owes its existence to the large amount of data acquired, mainly in tropical regions, to the research conducted for many years on problems typical of those regions and to the technical and scientific teams available with great experience of working there. Therefore, the present facilities of the IICT makes this Institute the right body in Portugal for cooperation with similar institutions in tropical countries.

IICT includes Geodesy between its activities, that until 1974 developed intense field work carried out by scientific and technical missions, in order to perform systematic acquisition and processing of geodetic data.

These large amount of geodetic data related and their mathematical treatment carried out so far are vital to african portuguese speaking countries

The Direcção Nacional de Geografia e Cadastro (DINAGECA) is a governmental structure included in the Ministry of Agriculture and Rural Development of Mozambique. It assures the production of georeferenced information and monitor the whole process related with permission to the land use and profit rights. This institution was reorganised and is now called Direcção Nacional de Terras (DINAT).

In 1991 Portugal and Mozambique established a Cooperation Protocol to Revise and Adjust the Geodetic Network of Mozambique, through the two institutions, consisting of the the adjustment of the network, eventual re-observation of some chains, to increase its density, to concede documentation related with network elements existing at IICT or other institutions and lecturing.

2. GEODETIC NETWORK OF MOZAMBIQUE

The first institutional body devoted to geodetic work in Mozambique, Geodetic Mission of Eastern África, was created in 1907. Its activity was carried out until 1910, plenty of difficulties arising from the flatness of the areas to the covered at the time. A total number of 75 first order geodetic points was established, with 2 bases measured.

To restart the suspended work, at the 13th of July 1932, the Geographic Mission of Mozambique (MGM) was created. Reorganised in 1934, it maintained intense activity, until 1973 when the last campaign took place, executing successive annual campaigns of field work in Mozambique, with average 6 months duration, with office work in Lisbon between them. In 1983 the MGM was integrated into the Geodesy Centre of IICT.

The triangulation network of Mozambique (Figure 1) involves a linear development of 9000 Km covering the whole territory with a wide net appropriated for 1:250 000 cartography. It is supported by 644 1st order 644 points, 77 2nd order points and 209 of lower orders.

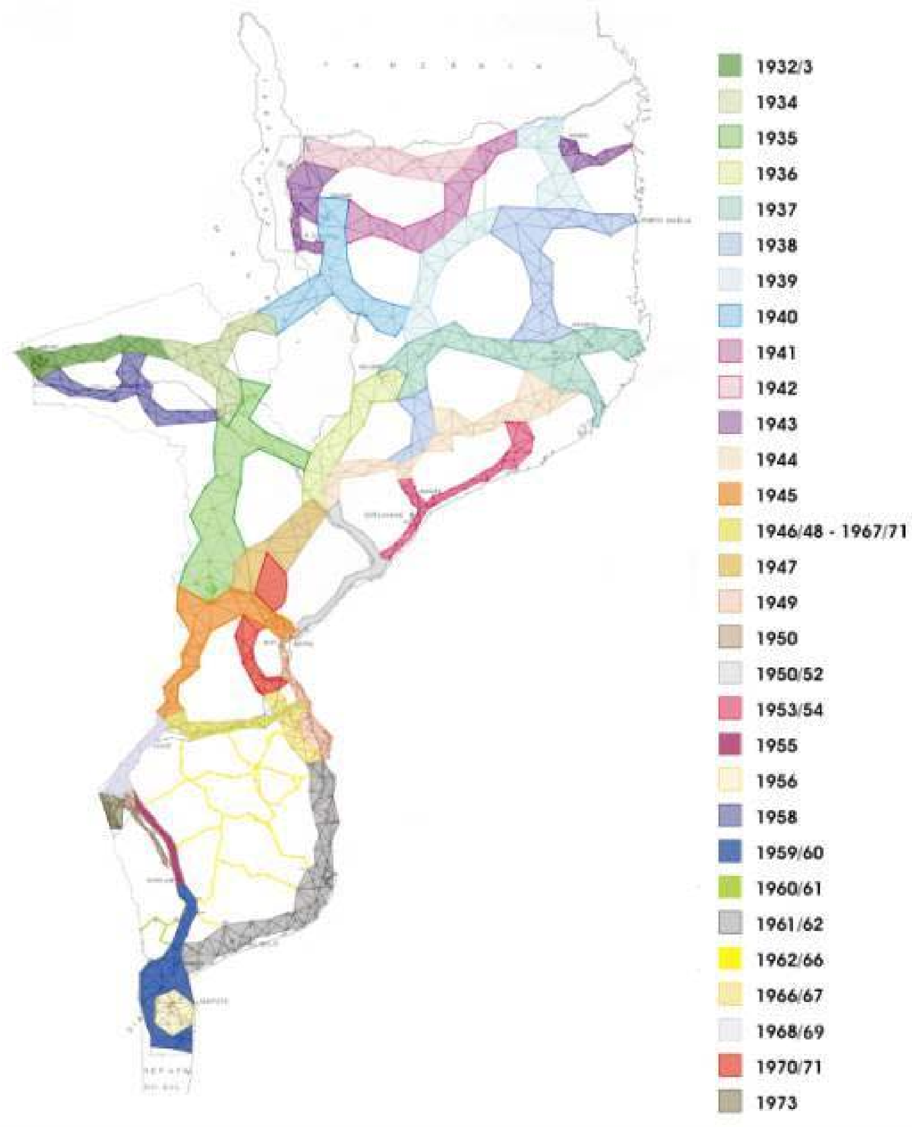

Figure 1: Mozambique triangulation network (The colours represent the year when each chain was observed)

The triangulation chains were developed along the parallels and meridians of odd order, linked to each other every two degrees. The existing exceptions were motivated by terrain constrains.

At north the triangulation developed usually in squares and other simple figures with sides with 30 to 40 Km medium length. Towards south entering the flat areas of Sofala and South of Save the sides decrease to an average length of 15-20 Km.

The location of some network points was chosen in order to be used by other services, in particular, hidrographic work. This is the case of the points situated on the last dune of the coast or in other dominant locations by the coast.

A geodetic basis was measured between each 250 Km, a total of 16, 15 were measured using invar wires and one using the tellurometer MRA-2.

In the sequence of the work performed by MGM and according to the previously referred protocol, the computation and adjustment of the network using the variation of coordinates method was performed.

According to the precisions established by U.S. Coast and Geodetic Survey and considering the triangles closure, the North zone of Mozambique has a second order angular precision and in the south zone the east part has a first order angular precision, while the chains at west side reach a second order.

During these computations it was verified that some directions presented corrections that exceeded the established tolerance for the first and second order, so they were removed from those computations. In Buzi-Zimuala chain, where some azimuthal directions showed errors superior to several minutes, supposly due to stations or targets which excentricity was missing or badly documented, the rejection of those directions caused descontinuities in the chain. Besides, its connection with the south chain was assured just for a first order direction, so that Mozambique considered its re-observation a priority which took place in October 2000.

2.1 The Buzi-Zimuala chain

This chain (Figure 2) is located between the south latitude parallels 19º40’ and 21º30’ and the east longitude meridians 34º10’ and 35º10’. It covers a 100 Km by 200 Km area and it is based on 45 points. According to the recognisement performed by DINAGECA, nine disappeared and three were re-built at a neighbouring location, so that the re-observed chain does not exactly correspond to the observed by the MGM.

In a general way it can be considered that the chain is well preserved with exception of two bent and one buried geodetic marks.

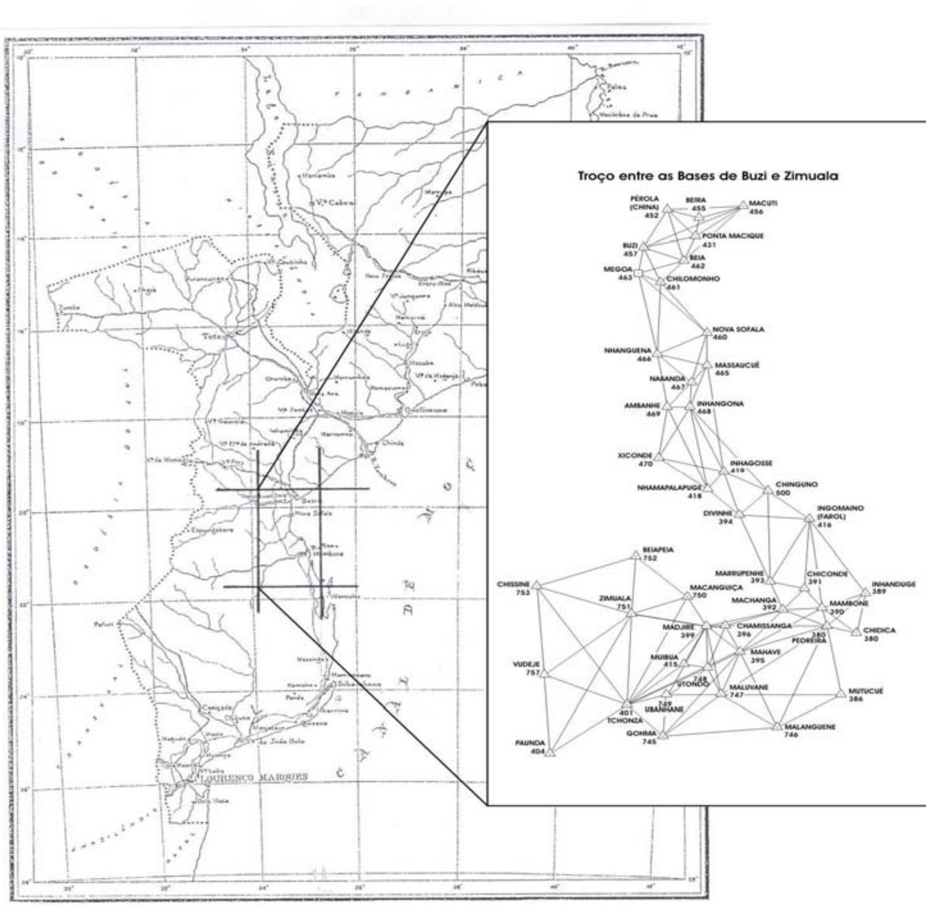

Figure 2: Buzi-Zimuala Chain

2.1.1 GPS re-observation of Buzi-Zimuala chain

The field work took place between 21st of October and 10th of November 2000. Taking into account the financial, human and logistic resources as well as the characteristics of the area to be observed, a thirteen days field work period was considered.

Six Trimble 4000 SSI receivers belonging to DINAGECA were used. Two 4 hours sessions had been planned with a common vector between each section. However, the time to go between stations, varying between 30 minutes and 3 hours and the access itself made impossible the move from one point to another between two sessions. Therefore only a single 6 to 8 hours session took place.

Besides, petrol had to be economised since the petrol stations were rare and distant and not always had petrol available. Reducing travelling made also possible to assure work continuity even when the cars broke. However, in some stations it was possible to execute the two predicted sessions.

To minimize the errors related with relative positioning, 3 stations were selected taking into account its position within the chain, no obstructions and the state of conservation of geodetic marks. Forced centering systems were implemented to guarantee greater rigor and that was where the 24 continuous hours sessions were performed during a 4 days minimum period.

2.1.2 Field Data processing

The field data were processed with Bernese V.4.2 (Hungentoble et al, 2001) and GPSurvey V.2.35 (Trimble, 1999) softwares.

A daily data processing took place. For each session (n-1) linearly independent vectors were obtained, with n being the number of receivers, so that each station had a minimum of 2 independent vectors defining it and with the other sessions, closed polygons were formed in order to be able to detect errors. 55 linearly independent vectors were computed, involving 37 stations.

The free ionosphere combination L_c and the Saastamoinen model for the tropospheric refraction were used as well as the QIF strategy (Hugentobler *et al*, 2001) to solve the ambiguities.

To assure a better precision, and specially to reference to ITRF97, the network was connected to the geodetic world reference through the Hartebeesthoeck (HRAO) station in South Africa and 3 sations of Buzi-Zimuala chain where 24 hours sessions were performed. It was also intended to used the Malindi (MALI) station in Quénia, however, for the referred period, there were no observations in L_2, probably due to intense ionospheric perturbation. Due to the vectors dimension defined by these two stations, the precise orbits were computed by IGS and referenced to ITRF97 were used.

The multi-station solutions of each day were combined using the ADDNEQ (Hugentobler et al, 2001).

Figure 3 shows the semi-axis values of the error ellipses computed multiplying the variance--covariance matrix by the ratio between the variance obtained from the comparison of coordinates associated with the solutions of each session and the variance of the weight unit derived from the combination of solutions, thus obtaining more realistic error ellipses. Excluding the PUGE (Nhamapalapuge) and PERO (Pérola do Chamba) stations, the major and minor semi-axis vary between 3.0 mm and 7.5 mm and 1.5 mm and 6.0 mm respectively, indicating that the network has a good precision. The high values for PUGE and PERO points are due to the fact that these do not have good observation conditions. Nhamapalapuge geodetic mark is almost obstructed by a baobab tree. The Pérola do Chamba is located below big mango trees with dense foliage and it was positioned under strong precipitation. One of the Joint Venture Norway Mapping of Mozambique (JVNMM) recommendations is to avoid campaigns during rainny season since the quality of the phase measurements can be distorted due to the impact of the tropospheric noise (JVNMM, 1998).

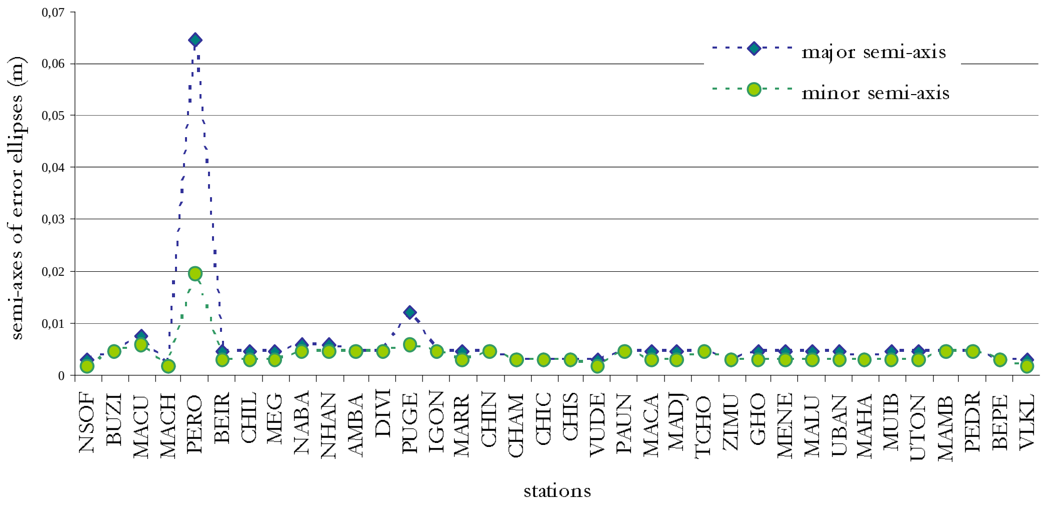

Figure.3: Major and minor semi-axis error ellipses values (Santos, 2004)

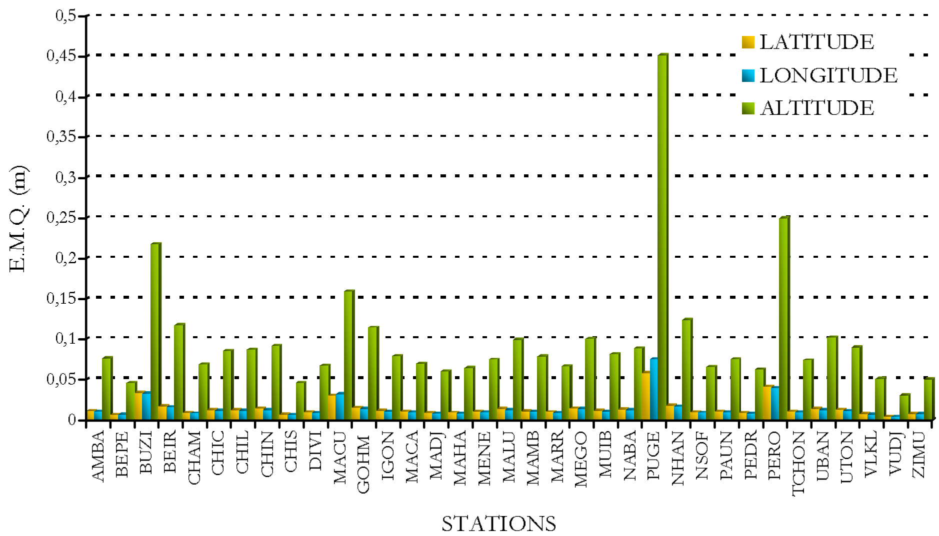

Figure 4: Quadratic mean error in the latitude, longitude and altitude components for each station (Santos, 2004)

The higher values for the quadratic medium error in the latitude and longitude components (Figure 4) are verified at the PUGE station and the lower at the VUJD (Vudje, permanent station) and are 0.058 m, 0.075 m, 0.452 m and 0.004 m, 0.004 m, 0.030 m. In a general way the vertical component is 6 times less precise than the horizontal when that value usually varies between two and three. A possible explanation could be that it was not possible to model the tropospheric refraction as well as it would be desirable. Another reason can consist of the fact that the majority of the points are located in flat zones, surrounded by vegetation,

making difficult the reception of signal from satellites and in particular from the ones with lower elevation.
Identified and corrected the eventual errors in Buzi-Zimuala chain it was then possible to perform the first order adjustment.

3. ADJUSTMENT OF MOZAMBIQUE TRIANGULATION NETWORK TO THE DATUM TETE

The triangulation network was adjusted using the Trimnet Plus software and the Clarke 1866 ellipsoid, datum Tete (oficial Mozambique datum).

It envolved 726 vertices (triangulation, traverse) 3731 azimuthal directions, 163 azimuthal angles, 16 Laplace azimuths, 15 geodetic basis measured with invar wires, a basis measured with a tellurometer and 90 sides of traverse measured with a tellurometer. Figure 5 presents the EMQ obtained for the latitude and longitude components.

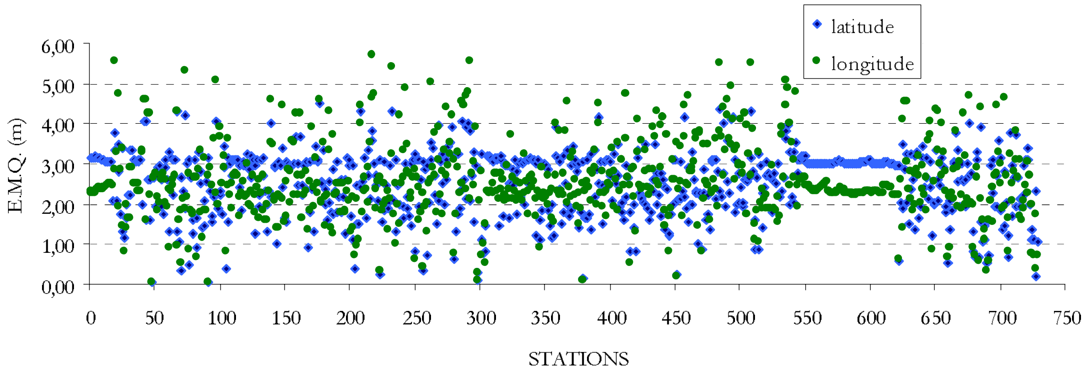

Figure 5. Mean square error for the latitude and longitude components (Santos, 2004)

Figure 6 represents the respective error ellipses. Those with a dimension superior to 3 m reveal zones where errors can eventually be found, such as at the north coast.

4. ADJUSTMENT OF THE MOZAMBIQUE GEODETIC NETWORK TO THE WGS84/ITRF94 DATUM

4.1 The GPS network

The Mozambique GPS network is constituted by 245 stations with a 100 km to 150 km spacing in the country and 1 km to 10 km in the major cities (JVNMM, 1998).

This network was observed by two different teams who worked with DINAGECA: the 19 Special Team Royal Engineers and the Joint Venture Norway Mapping of Mozambique.

The GPS network, MOZNET, was observed in 1995 and 1996 and it is constituted by a fundamental network with 8 absolute stations which were used to make the connection to the

ITRF94 and 237 relative stations forming a first order network with 96 stations and various second order chains (Gaza and Sofala with 29 stations, Maputo, 31, Beira,19, Quelimane, 18, Nampula, 24 and Pemba 20). The Moznet network has a 1 cm to 5 cm precision (JVNMM, 1998).

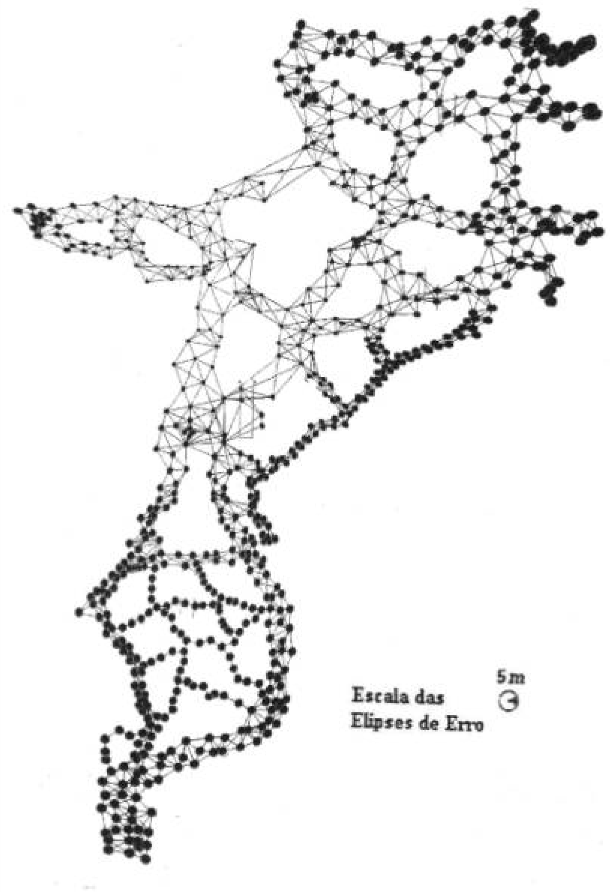

Figure 6: Error ellipses of Mozambique network

DINAGECA made the MOZNET coordinates available.

In spite of using the same designation, the majority of those coordinates did not correspond to the classic network points.

Network adjustment

Once the common points were identified, a hypothesis would be to introduce GPS vectors (Figure 7) in the classic network, fixing Tete or the IGS stations (HRAO, MALI). However, there were only six vectors available, not presenting enough strength by themselves to adjust a network with so many points.

Therefore, it was decided to fix the coordinates of the 30 GPS points (Figure 8) and adjust the network to ITRF94.

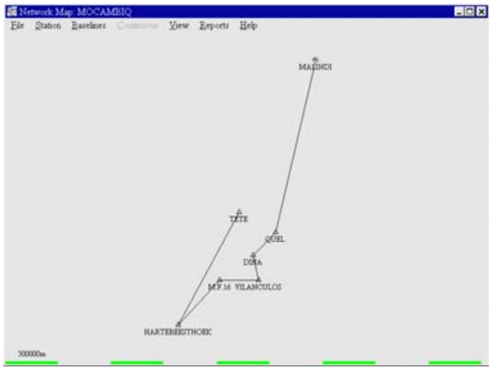

Figure 7: Available GPS vectors

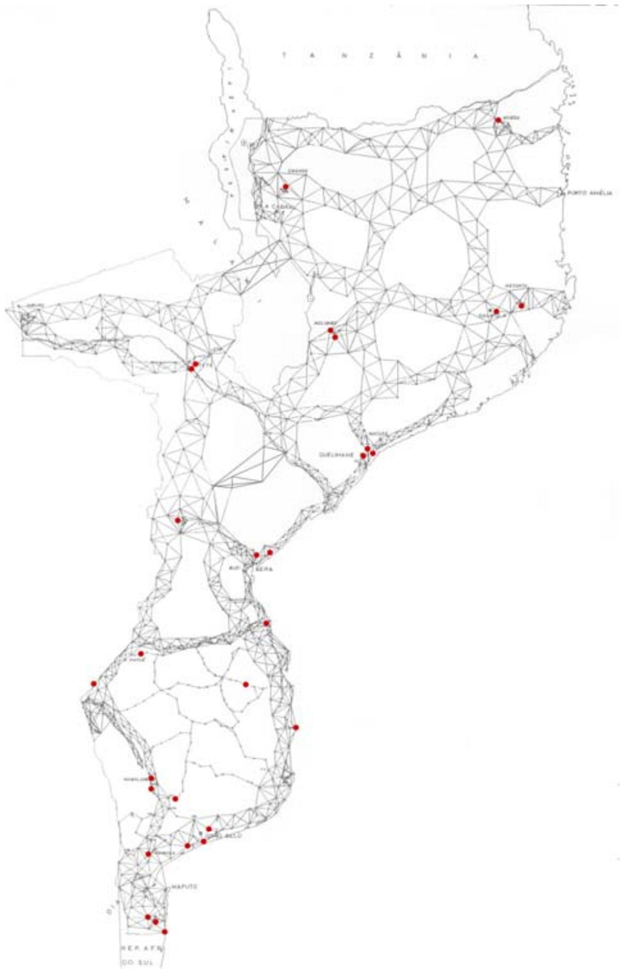

Figure 8: Scheme of the 30 points (red dots) common to the classic network and the MOZNET

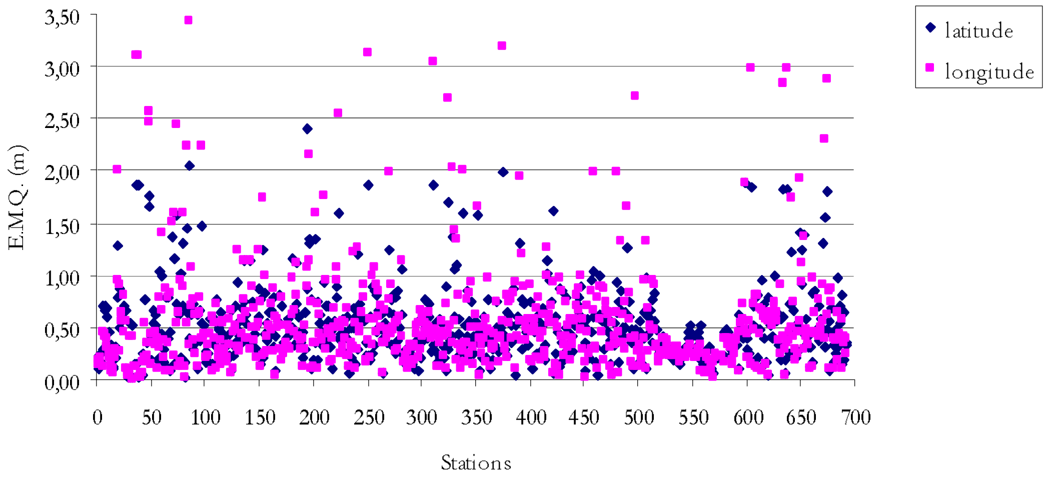

Figure 9: Mean square error in planimetric components (Santos, 2004)

Comparing Figure 5 and Figure 9, it can be verified that the root mean square error changed from 2.5m to 0.5m.

5. CONCLUSION

The 1st order Mozambique geodetic network still presents zones with low precision, such as the north coast. The conjunction of GPS and terrestrial observations of well distributed points within the territory would be a good solution to improve the quality of this network.

The prediction of re-observation of more than 30 well distributed points within the whole territory using GPS, in order to obtain a valid group of vectors is included in the Portugal and Mozambique cooperation protocol. This will make the conversion to ITRF94 datum more consistent and will allow the integration of all networks in the same system.

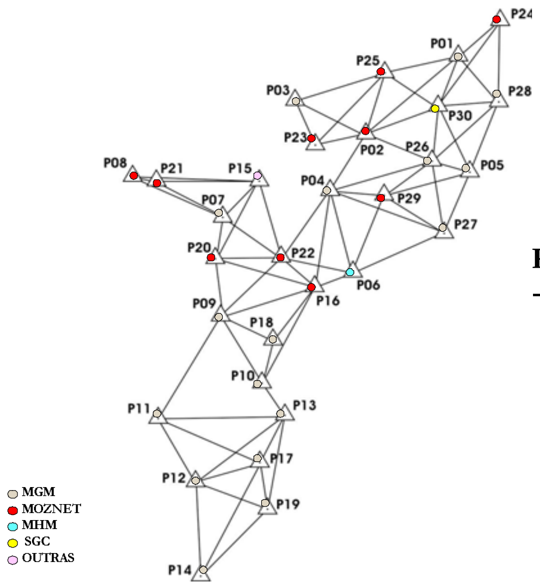

Figure 10: Selected points to be re-observed with GPS in Mozambique

REFERENCES

Hugentobler U.; Shaer and Fridez, P. (2001): *Bernese GPS Software Version 4.2*. Astronomical Institute, University of Berne.

JVNMM, (1998): *Guidelines Report for Network Adjustment in Mozambique*. Joint Venture Norway Mapping of Mozambique.

Santos, P., (2004): *Aplicações Geodésicas nos Países de Língua Oficial Portuguesa*. Dissertação para provas de acesso à categoria de investigador auxiliar. Instituto de Investigação Científica Tropical, Junho de 2004.

Trimble (1999), GPSurvey V. 2.35 User´s Manual. Trimble Navigation Ltd, Sunnyvale, California, EUA.

BIOGRAPHICAL NOTES

Paula Santos, PhD in geodesy, IICT 2005, graduate in geographical engineering, Faculty of Science of the University of Lisbon, 1991. She works as researcher at Geodetic Centre of IICT since 1991. Her main activity is in geodesy particularity in geodetic networks processing and adjustment using GPS and classic geodetic techniques.

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