THE AZORES GLOBAL POSITIONING SYSTEM NETWORK

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ARQUIPÉLAGO

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The TANGO network was established in 1988 with 12 GPS (Global Positioning System) stations located in four of the main tectonic plates: Eurasian, North American, African and Caribbean. Main goals of this project were to establish a zeroorder network for the Azores volcanic islands, located in the vicinity of the triple junction of those plates, to assess GPS capabilities to support analysis of the dynamics of this region as well as to measure continental drift, and to contribute for vertical Datum unification between Europe and America through the Azores and Bermuda islands.
In this paper we discuss different aspects for the establishment and processing of the local Azores network. Using broadcast ephemeris an internal accuracy at the 0.1ppm level was reached for baselines up to hundreds of kilometers; it is emphasized the importance of those results in the development of scientific areas of major interest for this Region of the Atlantic.

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A rede TANGO foi estabelecida em 1988 com 12 estações GPS (Global Positioning System) situadas em quatro das principais placas tectónicas: Euro-Asiática, Norte Americana, Africana e Caraíbas. Entre os principais objectivos do projecto contam-se o estabelecimento de uma rede geodésica de ordem zero para as ilhas vulcânicas dos Açores, localizadas nas proximidas da junção de três daquelas placas, a avaliação das potencialidades do GPS no estudo da dinâmica da região e da deriva dos continentes, e a contribuição para a unificação dos Data verticais entre a Europa e a América através das ilhas dos Açores e das Bermudas.
Neste trabalho são discutidos em particular os diferentes aspectos do estabelecimento e processamento da rede local no Arquipélago dos Açores. Usando as efemérides difundidas obteve-se uma precisão interna de cerca de 0.1ppm na medida de distâncias que atingem algumas centenas de quilómetros. É realçada a importância destes resultados para o desenvolvimento de outras áreas científicas de grande interesse para esta região do Atlântico.

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INTRODUCTION

The Global Positioning System (GPS) is being developed by the Department of Defense of the United States of America. The use of the System is based on the measurement of the distance between the observer and at least four satellites of the 21 satellite NAVSTAR constellation, using the L-band signals that are continuously emitted by the satellites in two frequencies L1 (1575.42 Mhz) and L2 (1227.6 Mhz). In this way, the observer is able to compute time and position (X,Y,Z) anywhere in the world, 24 hours a day.

In the last five years we have seen a very fast development of the System concerning method applications and also equipment. In 1989 the test stage was finished and there were no doubts about the great capabilities of the System to measure very accurately distances of up to thousands of kilometers (LICHTEN & al. 1989). These possibilities are of great importance not only for geodesy but also for other earth sciences, namely geodynamics.

The Azores Archipelago, located in the area where three main tectonic plates meet (Fig. 1), is a region of well known seismic and volcanic activity.

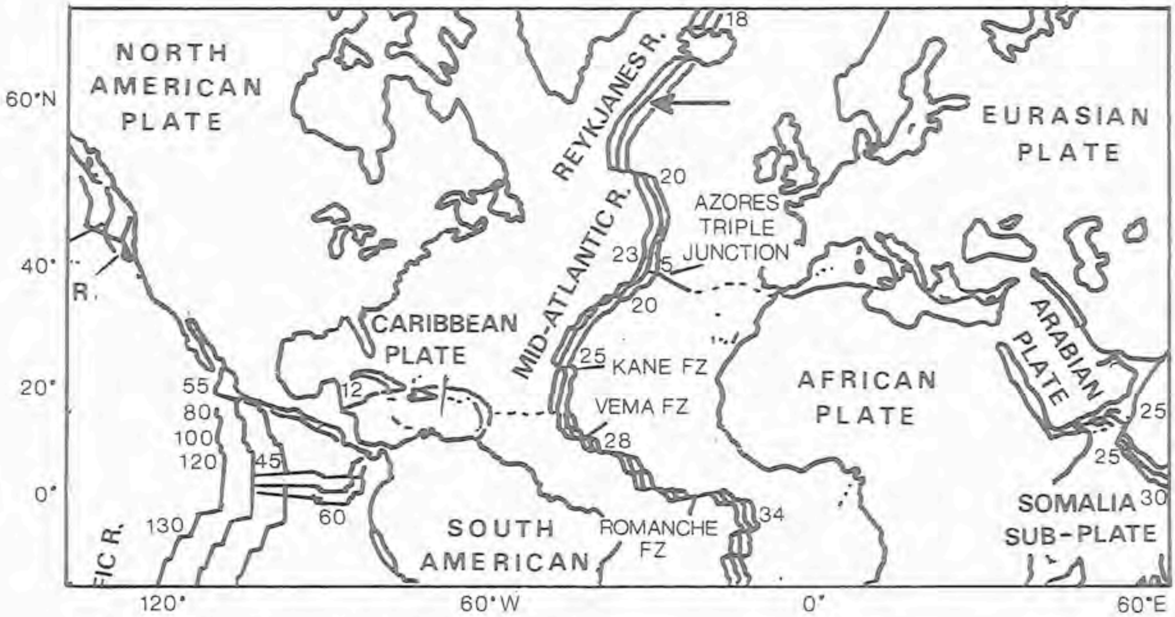

Fig. 1 - Main tectonic plates in the North Atlantic area.

The archipelago is formed by nine islands, two of them lying in the North American plate whereas the others are located in the so called Azores microplate (FORJAZ 1988).

Due to the lack of a high precision geodetic network it is difficult to validate the different theories that try to explain the dynamics of this region (KRAUSE & al. 1970, MCKENZIE & al. 1972, MACHADO & al. 1972, FORJAZ 1988 and MADEIRA & al. 1990).

One of the main purposes of the GPS campaign carried out in 1988 was exactly to assess the System potentialities for the establishment of a high precision network which should be reobserved periodically to provide the necessary information to support geodynamic studies. More specifically it was intended to know if GPS can be used to measure directly continental drift. Another important goal is Datum unification between the different groups of islands as well as its connection to the European Datum through the connection to the Portuguese continental network (Figs. 2 and 3).

Here we shall describe the details of the design of the Azores GPS network and discuss the results obtained so far.

CAMPAIGN DESIGN

The observation campaign took place in Fall 1988, between November 25 and December 5. Twelve stations were established in a network that covers all the nine islands (Fig. 4).

The station located in the Meteorological Observatory in the Terceira island was held fixed, observing during the whole campaign. The others, mobile stations, where occupied during two to four days. In Fig. 5 we resume the adopted observation schedule.

At the time of this campaign the System was still in a development stage with a space component formed by nine satellites, with only six of them operational, distributed by two orbital planes. As a consequence, the spatial coverage in the Azores region was very poor, with a four satellite visibility period of just one and a half hour (beginning near 22h, local time). Fig. 6 shows how bad the situation was at that epoch with the satellites gathered on one side of the hemisphere and with small elevation angles.

The assessement of the quality of the satellite configuration over a certain station is usually estimated by a parameter called GDOP

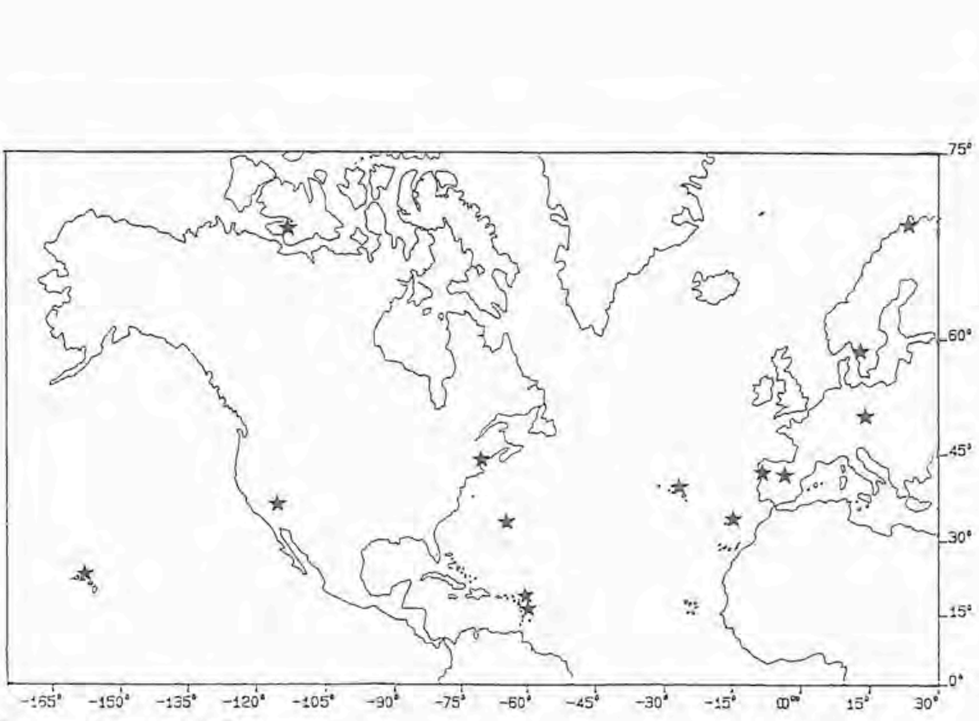

Fig. 2 - Stations of the TANGO network.

Fig. 3 - GPS stations in the continent and islands.

(Geometric Dilution Of Precision), (JORGENSEN 1980), which, in good conditions, should not be far from 3. In the particular case of this campaign that value has never been less than 6. We have to keep this in mind when evaluating the results obtained because the geometric configuration plays an important role in the the final precision.

In order to minimize the effect of the poor geometry we decided to observe during several hours whenever we had the means to do it. Fig. 5b shows the observation plan.

REDUCTION PROCEDURE

The processing of GPS observations is usually done in two steps:

i) In the first step we evaluate the quality of the measurements isolating the detected

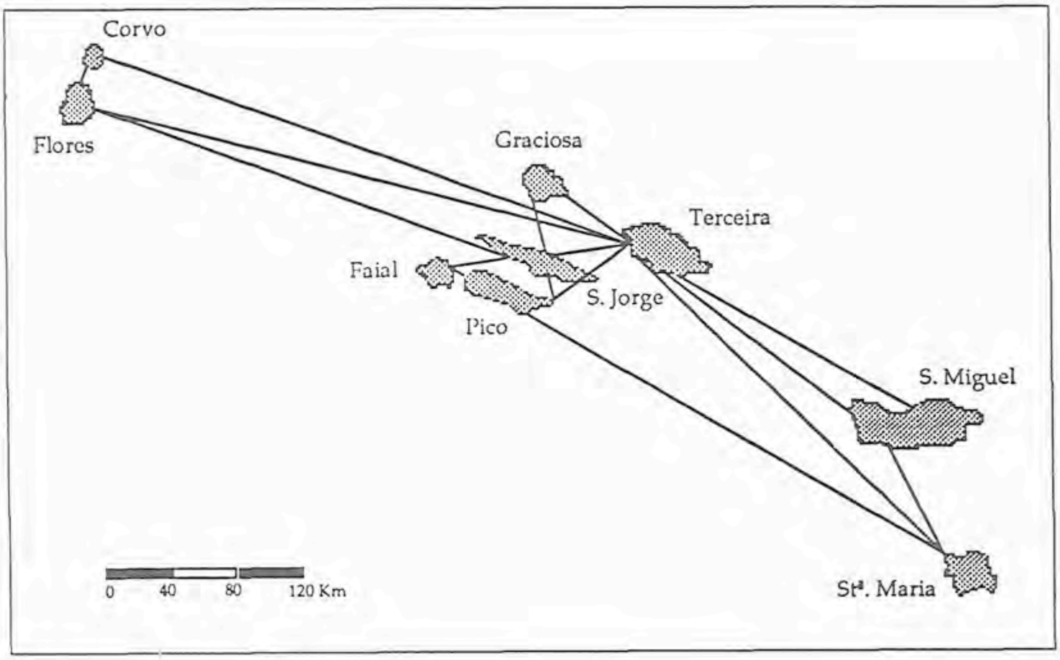

Fig. 4 - The Azores GPS network

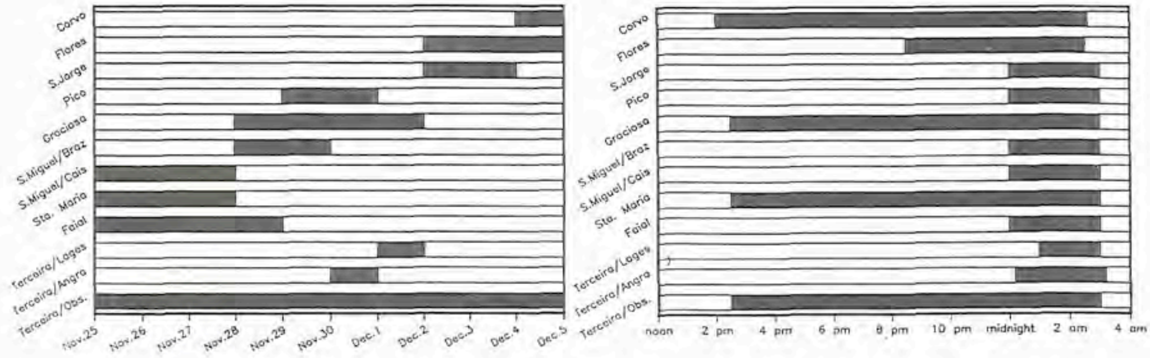

Fig. 5. - a) Daily station occupation. b) Observation time for each station.

anomalies. At this stage we try to correct any cycle slips in the phase in order to get continuous phase measurements (BASTOS & al. 1988). Phase measurements have the potential to give the most accurate results with GPS;

ii) In the second step the threedimensional coordinates of the observing stations are computed.

In this reduction process the TOPAS

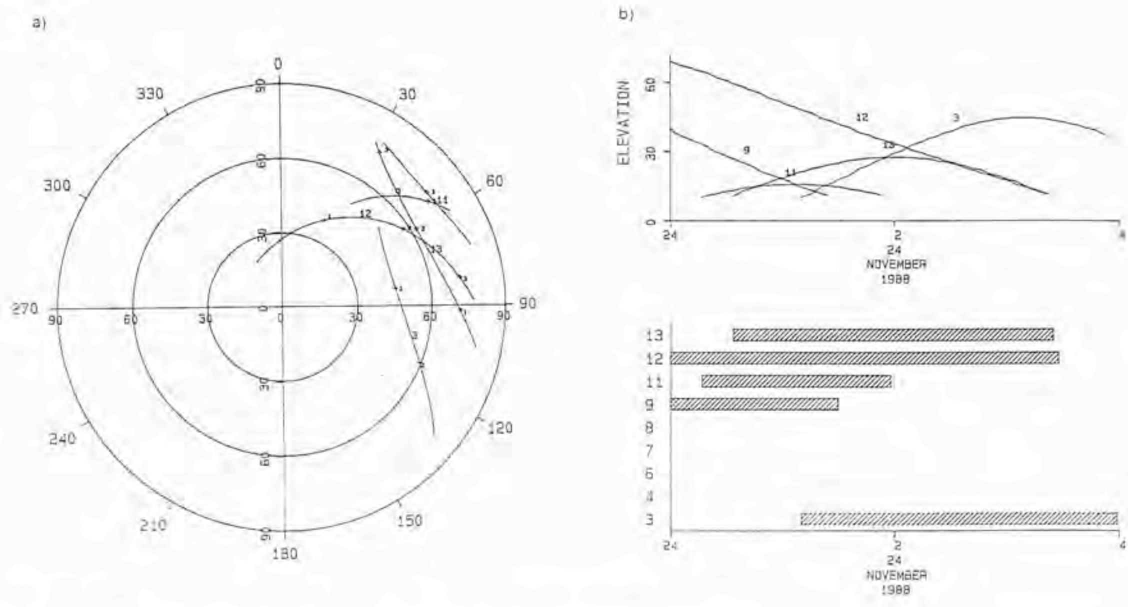

Fig. 6 - a) Satellite geometry for 4-satellite configuration. b) Elevation angles.

software was used. This is a multistation/multisession software which allows the combination of phase and code measurements from several stations in different days in one programme run to provide a final solution. The algorithm is based in the use of an extended Kalman filter in U-D mechanization to allow recursive estimation of all the parameters envolved (LANDAU 1988).

Due to the bad observation conditions, results of geodetic interest could not be obtained without fixing the phase ambiguities (BASTOS & al. 1989). This was accomplished by applying the so-called "wide/narrow laning" which combines phase and code measurements in both frequencies (LANDAU 1988).

DISCUSSION

To obtain the final solution we first try to fix the ambiguities, computing a day by day solution and applying the above mentioned technique. Afterwards all the information of the ten days observation was combined in a multistation multissession procedure to obtain the definite solution which we present in Table 1.

In this reduction no orbit improvement was made and the solution was obtained using the broadcast ephemeris directly from the navigation message.

In this table the standard deviations (σ) resulting from the resolution of the observation equations are expressed in meters. The position of the permanent station in Terceira was held fixed in the computation.

As we can conclude the accuracy of the relative positions between stations is of the order of 0.1 to 0.3 ppm even for the longer baselines ($\approx$350 km).

In Fig. 7 the corresponding error ellipses for the horizontal coordinates of the different stations are shown.

The larger errors obtained for the shorter baselines reflect difficulties in fixing the corresponding ambiguities. This can be explained by the presence of multipath interference near the antenna (BASTOS 1990).

The reported level of accuracy is also confirmed by comparing the results obtained for the

Table 1

ESTAÇÕES		X (m)	σ (m)	Y (m)	σ (m)	Z (m)	σ (m)
TERCEIRA:	Stª Maria	185469.155	0.011	118086.227	0.006	-146593.367	0.005
	S. Miguel Braz	117151.149	0.015	93413.940	0.015	-80530.025	0.014
	Faial	-49459.431	0.012	-112373.768	0.009	-11212.146	0.009
	S.Miguel Caís	117271.115	0.012	108106.692	0.009	-72488.022	0.008
	Graciosa	-57922.827	0.006	-49575.414	0.005	35134.983	0.004
	Pico	-17725.427	0.015	-70037.803	0.010	-21143.986	0.012
	Terceira Angra	544.310	0.024	-134.260	0.022	-796.275	0.027
	Terceira Lages	-2693.695	0.020	13349.060	0.022	10586.388	0.016
	S.Jorge	-41685.271	0.009	-75884.868	0.015	2141.288	0.009
	Flores	-213017.015	0.008	-268087.858	0.004	68140.942	0.005
	Corvo	-225790.033	0.016	-257402.148	0.014	88405.667	0.013
FAIAL:	Graciosa	-8463.396	0.013	62798.354	0.010	46347.130	0.010
	Pico	31734.004	0.019	42335.965	0.013	-9931.840	0.014
	S. Jorge	7774.160	0.015	36488.900	0.018	13353.435	0.013
GRACIOSA:	Pico	40197.400	0.014	-20462.389	0.010	-56278.790	0.012
	S. Jorge	16237.556	0.011	-26309.454	0.016	-32993.695	0.010
STª MARIA:	S.Miguel Braz	-68318.006	0.018	-24672.287	0.016	66063.343	0.014
PICO:	S. Jorge	-23959.844	0.018	-5847.065	0.018	23285.275	0.013
FLORES:	Corvo	-12773.018	0.014	10685.710	0.013	20264.726	0.012

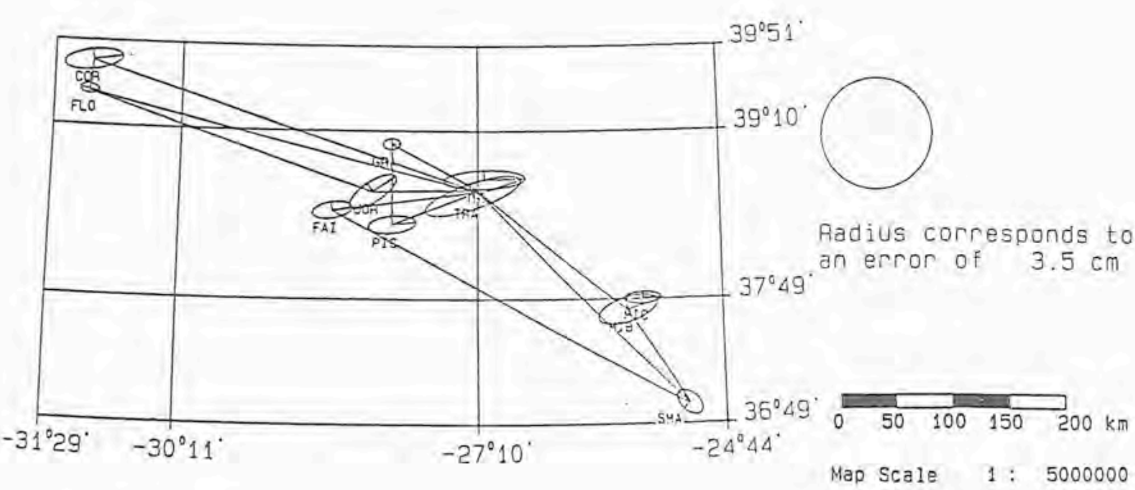

Fig. 7 - Error ellipses

distances Terceira-Flores and Terceira-S.Jorge computed with the observations of the December 1988 campaign and with the observations of another international campaign in June 1989. Table 2 shows the result of that comparison.

CONCLUSIONS AND FUTURE WORK

The results obtained so far are promising and show that undoubtly GPS can be used to measure distances between islands with an error of a few centimeters. Keeping in mind the poor satellite coverage at the time of the campaign we can expect a significant improvement in the precision in the reobservation of the whole network scheduled for September/October 1991.

In Fig. 8 we can see the satellite configuration which will be available at that epoch, for the same time interval to which Fig. 6 is referred.

As can be seen it will then be possible to observe more satellites during a longer period and with a much better spatial distribution. The cor-

Table 2

Baseline	Epoch	Length	σ
Terceira/S.Jorge	Dec	86606.871	0.047
	Jun	86606.882	0.048
Terceira/Flores	Dec	349128.270	0.011
	Jun	349128.337	0.043

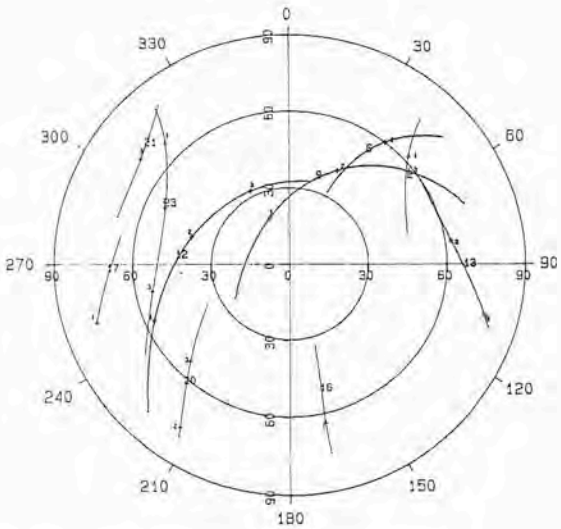

Fig. 8 - Satellite geometry for September 1991 between 0h and 4h UTC.

responding GDOP values are between 2 and 6, significantly better than in the previous campaign. It can be expected that in the next campaign the error in the measured distances will not exceed 1cm. As a consequence, GPS is confirmed as the most promising geodetic tool to support geodynamic studies in this region of the Earth. It will allow direct measure of the drift rate between the European and American plates.

The possibility of measuring distances with very high accuracy and to accomplish Data unification in a three dimensional frame is of utmost importance in an area with significant seismic and volcanic activity. Vertical Datum unification through the connection of the tide-gauges opens new possibilities for oceanographic studies, another important area of application in this region of the Atlantic. For this purpose, a high precision gravimetric network is also expected to be established in the Archipelago already in 1991.

All that information will allow a more precise definition of the geoid and the detection of the tectonic movements that may occur in the region.

Concerning the geodetic connection of the Archipelago to the Continent, a similar accuracy has been reached, some parts in 10^7 (BASTOS & al. 1990), and this will certainly be improved in the next campaign.

As shown in Fig. 9 the network will include some more stations, located in North Africa and the Canary Islands, in the African plate.

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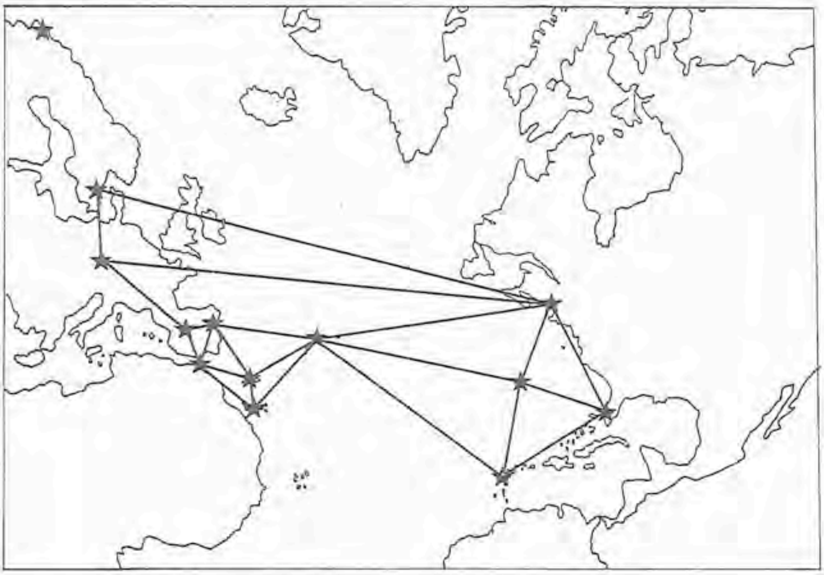

Fig. 9 - Extended TANGO network to be observed in 1991.

of the whole campaign in the scheduled time.

REFERENCES

BASTOS, L. & H. LANDAU 1988. Fixing Cycle Slips in Dual-Frequency Kinematic GPS-Application Using Kalman Filtering.- *Manuscripta Geodaetica* 13 (4): 249-256.

BASTOS, L., J. OSÓRIO, H. LANDAU & G. HEIN 1989. Preliminary Results of the TANGO Campaign - *Proceedings of the 5th International Symposium on Satellite Positioning*, Las Cruces, New Mexico: 536-544.

BASTOS, L., J. OSÓRIO, H. LANDAU & G. HEIN 1990. Transatlantic GPS experiment: results of the TANGO Campaign - *Proceedings of the International Symposium "GPS 90"*, Ottawa (Canada). Pp. 343-355

BASTOS, L. 1990. *Aplicação do Sistema Global de Posicionamento em Geodesia e Geodinâmica. Perspectivas na Modelação de Efeitos de Propagação.*- Dissertação para Doutoramento, Faculdade de Ciências do Porto. 183 pp.

FORJAZ, V. 1988. Azores study tour. Field trip guide. - *Seminar on the Prediction of Earthquakes. Economic Commission for Europe* - UN, Lisbon, 26 pp.

JORGENSEN, P. 1980. *Navstar/Global Positioning System 18-Satellite Constellation*. - Global Positioning System, Vol. II, The Institute of Navigation, Washington, 1984.

LANDAU, H. 1988. Zur nutzung des global positioning systems in geodasie und geodynamic: modellbildung, software-entwicklung und analyse. - *Schriftenreihe-Studiengang Vermessungswesen, Universität der Bundeswehr München*, Publikation no. 36, Neubiberg. 284 pp.

LICHTEN, S. & W. BERTIGER 1989. Demonstration of a Sub-Meter GPS Orbit Determination and 1.5 Parts in 108 Three-Dimensional Baseline Accuracy - *Bulletin Geodésique* 63.

MACHADO, F., J. QUINTINO & J. MONTEIRO 1972. Geology of the Azores and the Mid-Atlantic Rift. - *Proceedings of the 24th International Geology Congress*, Montreal: 134-142.

MADEIRA, J.& A., RIBEIRO 1990. Geodynamic model for the Azores triple junction: a contribution from tectonics - *Tectonophysics* 184: 405-415.

McKENZIE, D. 1972. Active tectonics of the Mediterranean region. - *Geophysical Journal of the R. A. S.* 30: 109-185.

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