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SIRGAS Final Report

Working Groups I and II

IBGE

Brazil 1997

Presidente da República
Fernando Henrique Cardoso

Ministro de Estado do Planejamento e Orçamento
Antonio Kandir

INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA - IBGE

Presidente
Simon Schwartzman

Diretor de Planejamento e Coordenação
Nuno Duarte da Costa Bittencourt

ÓRGÃOS TÉCNICOS SETORIAIS

Diretoria de Pesquisas
Lenildo Fernandes Silva

Diretoria de Geociências
Trento Natali Filho

Diretoria de Informática
Fernando Elyas Nóbrega Nasser

Centro de Documentação e Disseminação de Informações
David Wu Tai

UNIDADE RESPONSÁVEL

Diretoria de Geociências

Departamento de Geodésia
Luiz Paulo Souto Fortes

MINISTÉRIO DO PLANEJAMENTO E ORÇAMENTO
INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA - IBGE
DIRETORIA DE GEOCIÊNCIAS
DEPARTAMENTO DE GEODÉSIA

South American Geocentric Reference System

Final Report

Working Groups I and II

Rio de Janeiro
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INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA - IBGE
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20021-120 - Rio de Janeiro, RJ - Brasil

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José Augusto Barreiros Sampaio
Divisão de Documentação e Processos Gráficos
DIPRO/DEPIN/DGC

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CHAPTER 1

INTRODUCTION

The SIRGAS (Sistema de Referência Geocêntrico para a América do Sul) Project was initiated at the International Conference for the Definition of a South American Geocentric Datum, convened from 4 through 7 October 1993, in Asuncion, Paraguay, by invitation of the International Association of Geodesy - IAG, the Pan-American Institute of Geography and History - PAIGH and the United States Defense Mapping Agency - DMA (now, National Imagery and Mapping Agency - NIMA). Representatives of the three sponsoring organizations and of almost all South American countries participated in that Conference.

The objectives established for the project were the following:

- to define a reference system for South America;
- to establish and maintain a reference network; and
- to define and establish a geocentric datum.

The goals to be achieved were:

- to reach the defined objectives in 1997, coinciding with the Scientific Assembly of the International Association of Geodesy, with the exception of maintenance which is a longer term objective;
- to promote and coordinate the efforts of each South American country to achieve the defined objectives;
- to establish a high precision Global Positioning System (GPS) network, in accordance with the objectives of Resolution No. 2 of the 10th Meeting of the Directors of South American Geographic Institutes (DIGSA), held in La Paz, Bolivia, in 1993;
- to concentrate attention at the beginning on the Horizontal Datum; and
- to facilitate the connection of pre-existing networks.

The following definitions of the reference system and of the geocentric datum for the continent were adopted by the participants of the Asuncion Conference:

- SIRGAS reference system: IERS (International Earth Rotation Service) Terrestrial Reference Frame (ITRF);
- geocentric datum: coordinate axes based on the SIRGAS reference system and parameters of the "Geodetic Reference System (GRS) 1980" ellipsoid.

The activities of the SIRGAS Project have been designed to develop a continental reference network with a precision and accuracy compatible with modern positioning techniques, mainly those associated with GPS. Considering the proliferation of GPS utilization, it was decided that it would be, at the very least, a waste of resources to tie the new surveys to the existing geodetic structure which was based on classical survey methods (triangulation, traverse, trilateration, etc.) and for which the precision is at least ten times worse than that easily obtained with the GPS. In addition, the multiplicity of classical geodetic systems used by the South American countries made the solution of technically simple problems, such as the definition of international borders, very difficult. The adoption of the ITRF as a common reference system guarantees the homogeneity of the results within the continent and allows the consistent integration of the SIRGAS network with the networks of other continents, thus contributing more and more to the development of a global geodesy.

This report documents the accomplishments of the project and, in particular, the activities carried out by the Working Groups to achieve the objectives stated earlier.

1.1- STRUCTURE OF THE PROJECT

The organizational structure of the project is shown in Figure 1.1; the corresponding names of the members are given in the Item 1.3 of this Chapter.

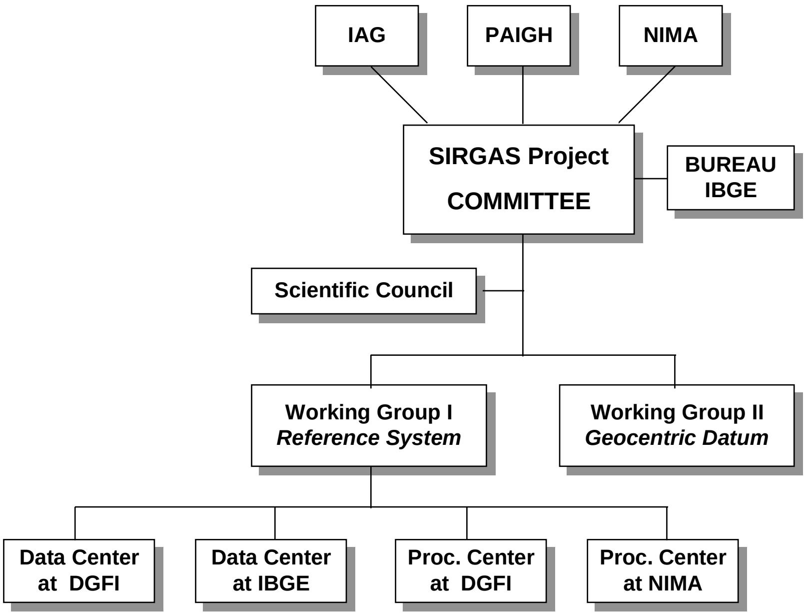


FIGURE 1.1: Organizational structure of the SIRGAS project

The Project Committee is composed of a representative from each country of the continent and one from each sponsoring organization. The Committee is responsible for establishing the direction of the project and for analyzing the results obtained by the Working Groups. The Bureau works as the Committee headquarters, furnishing support to the President of the Committee in accomplishing his tasks. The Scientific Council is composed of eminent professionals in geodesy from the international community, whose charge is to assist the Committee and the Working Groups in their analyses and decisions.

Working Group I has been responsible for the establishment of the reference system. For this purpose, it organized a continental GPS campaign, carried out from 26 May to 4 June 1995.

The processing of the data from the network established during the campaign was accomplished independently by Deutsches Geodaetisches Forschungsinstitut (DGFI) and by National Imagery and Mapping Agency (NIMA). Details of Working Group I's activities can be found in Chapter 2.

Working Group II has been in charge of coordinating the integration of the national geodetic networks of each South American country into the SIRGAS reference frame. Details about its activities are given in Chapter 3.

The Working Groups have organized the following meetings, in order to carry out their activities:

- 20-22 April 1994, Bogota, Colombia: first meeting of WG II;
- 24-28 October 1994, La Plata, Argentina: first meeting of WG I and second one of WG II;
- 5-9 August 1996, Santiago, Chile: second meeting of WG I and third of WG II;
- 8-11 April 1997, Margarita Island, Venezuela: third meeting of WG I and forth of WG II.

The official coordinates for each station of the SIRGAS Reference Network are found in Item 2.5 of Chapter 2.

The SIRGAS project has been extremely successful. This was only possible due to the high level of cooperation obtained from each participant, including the South American countries, the sponsoring organizations and the scientific consultants, representing more than 30 institutions from the Americas and Europe, all working towards the development of the South American continent.

1.2- LANGUAGES

This report is published in two versions: one in Portuguese/Spanish and another in English.

1.3- COMPOSITION OF THE PROJECT

The composition of the Committee, Working Groups and Scientific Council is presented below.

1.3.1- COMMITTEE

ENG. LUIZ PAULO SOUTO FORTES
President
IBGE/DEGED
AV. BRASIL 15671
PARADA LUCAS
RIO DE JANEIRO, RJ, BRAZIL, CEP 21241-051
FAX: 55-21-481 2747
e-mail: fortes @ ibge.gov.br

AGRIM. RUBEN RODRIGUEZ
Representative of ARGENTINA
LUIS M. CAMPOS 1521 - 6B
1426 BUENOS AIRES, ARGENTINA
FAX: 54-1-781 8901
e-mail: rubenro @ arg.siscotel.com

ENG. EZEQUIEL PALLEJA
Substitute Representative of ARGENTINA
JUNCAL 3699 PISO 10
(1425) BUENOS AIRES, ARGENTINA
FAX: 54-1-383 2935

CAP. INF. MARCO A. MONTOYA RIVERA
Representative of BOLIVIA
INSTITUTO GEOGRAFICO MILITAR
AVENIDA SAAVEDRA 2303 (ESTADO MAYOR) MIRAFLORES
CASILLA No. 7641
LA PAZ, BOLIVIA
FAX: 591-2-228329 or 591-2-226912

SOF. 1RO. JAVIER GUZMAN GALLARDO
Substitute Representative of BOLIVIA
INSTITUTO GEOGRAFICO MILITAR
AVENIDA SAAVEDRA 2303 (ESTADO MAYOR) MIRAFLORES
CASILLA No. 7641
LA PAZ, BOLIVIA
FAX: 591-2-228329 or 591-2-226912

ENG. MAURO PEREIRA DE MELLO
Representative of BRAZIL
IBGE
AV. FRANKLIN ROOSEVELT 194/GRUPO 207
CENTRO
RIO DE JANEIRO, RJ, BRAZIL, CEP 20021-120
FAX: 55-21-262 7308

PROF. MILTON DE AZEVEDO CAMPOS
Substitute Representative of BRAZIL
UNIVERSIDADE FEDERAL DO PARANÁ - UFPR
CAIXA POSTAL 19098, CURITIBA, PR, BRAZIL, CEP: 81531-970
FAX: 55-41-266 9222
e-mail: miltonac @ cce.ufpr.br

MAYOR OSCAR CIFUENTES ZAMBRANO
Representative of CHILE
INSTITUTO GEOGRAFICO MILITAR
NUEVA SANTA ISABEL 1640
SANTIAGO, CHILE
FAX: 56-2-6988278
e-mail: igm @ reuna.cl

MAYOR ENG. RODRIGO BARRIGA VARGAS
Substitute Representative of CHILE
INSTITUTO GEOGRAFICO MILITAR
NUEVA SANTA ISABEL 1640
SANTIAGO, CHILE
FAX: 56-2-6988278
e-mail: igm @ reuna.cl

ENG. ALBERTO GONZALEZ LOPEZ
Representative of COLOMBIA
IGAC
CARRERA 30 NO. 48-51
OFIC 405
SANTAFE DE BOGOTA, DC, COLOMBIA
FAX: 57-1-368 0991

ENG. SUSANA R. ARCINIEGAS
Representative of ECUADOR
INSTITUTO GEOGRAFICO MILITAR
ELDORADO, EDIFICIO DEL IGM
QUITO, ECUADOR
FAX: 593-2-569 097
e-mail: igm2 @ igm.mil.ec

DR. CLAUDE BOUCHER
Representative of FRENCH GUIANA
INSTITUTE GEOGRAPHIQUE NATIONAL
136 BIS RUE DE GRENELLE
75700 PARIS, FRANCE
FAX: 33-1-43 98 84 88
e-mail: boucher @ ign.fr

MR. ABHAI KUMAR DATADIN
Representative of GUYANA
COMMISSIONER OF LANDS AND SURVEYS
LANDS AND SURVEYS DEPARTMENT
22 UPPER HADFIELD STREET
DURBAN BACKLANDS
GEORGETOWN, GUYANA

CAP. SEV. GEOG. JUAN CARLOS TORALES
Representative of PARAGUAY
DISERGEMIL
ARTIGAS 920
ASUNCION, PARAGUAY
FAX: 595-21-213 812

CAP.ENG. JUAN MUÑOZ CURTO
Representative of PERU
INSTITUTO GEOGRAFICO NACIONAL
AV. ARUMBURU 1198, SURQUILLO
LIMA, PERU
FAX: 51-14-753075

MR. R.H. WONG FONG SANG
Correspondent of SURINAME
CENTRAAL BUREAU LUCHTKAARTERING
MAYSTRAAT 39
PARAMARIBO, SURINAME

PROF. ENG. AGRIM. ROBERTO PEREZ RODINO
Representative of URUGUAY
INSTITUTO DE AGRIMENSURA
FACULTAD DE INGENIERIA
UNIVERSIDAD DE LA REPUBLICA
AV. J. HERRERA Y REISSIG 565, CASILLA DE CORREO 30
MONTEVIDEO, URUGUAY
FAX: 598-2-715446
e-mail: rodino @ fing.edu.uy

ENG. JOSE NAPOLEON HERNANDEZ
Representative of VENEZUELA
CARTOGRAFIA NACIONAL
COORDINACION GEODESICA
EDIF CAMEJO - ESQUINA CAMEJO CSB
PISO 2 - OFIC 216
CARACAS, VENEZUELA
FAX: 58-2-5450374
e-mail: sagecan @ conicit.ve

TTE. JOSE GONZALEZ BRICEÑO
Substitute Representative of VENEZUELA
DIGECAFA - MIN. DEFENSA
FUERTE TIUNA - EL VALLE
CARACAS, VENEZUELA
FAX: 58-2-68 23405

DR. ENG. HERMANN DREWES
Representative of IAG
DGFJ, ABT. I
MARSTALLPLATZ 8
D-80539
MUENCHEN, GERMANY
FAX: 49-89-23031 240
e-mail: mailer @ dgfi.badw-muenchen.de

TTE. CRNEL. FERNANDO MIGUEL GALBAN
Representative of PAIGH
INSTITUTO GEOGRAFICO MILITAR
CABILDO 381
1426 BUENOS AIRES, ARGENTINA
FAX: 54-1-776 1611
e-mail: fernando @ mapas.igm.gov.ar

MR. JAMES A. SLATER
Representative of NIMA
NATIONAL IMAGERY AND MAPPING AGENCY
MAIL STOP A-12
8613 LEE HIGHWAY
FAIRFAX, VA 22031-2137, USA
FAX: 1-301-227 5515
e-mail: slaterj @ nima.mil

1.3.2- WORKING GROUP I: REFERENCE SYSTEM

DR. MELVIN JESUS HOYER ROMERO
President
CONSEJO NACIONAL DE CARTOGRAFIA
UNIVERSIDAD DEL ZULIA
APARTADO POSTAL 10311
MARACAIBO, VENEZUELA
FAX: 58-61-512197
e-mail: mhoyer @ europa.ica.luz.ve

MY. ENG.MIL. D. RICARDO ANTONIO TORCHETTI
Principal Member
INSTITUTO GEOGRAFICO MILITAR
CABILDO 381
1426 BUENOS AIRES, ARGENTINA
FAX: 54-1-771 0498
e-mail: public @ mapas.igm.gov.ar

ENG. KATIA DUARTE PEREIRA
Principal Member
IBGE/DEGED
AV. BRASIL 15671
PARADA LUCAS
RIO DE JANEIRO, RJ, BRAZIL, CEP 21241-051
FAX: 55-21-481 2747
e-mail: katiaduarte @ ibge.gov.br

PROF. MILTON DE AZEVEDO CAMPOS
Substitute Member
UFPR
CAIXA POSTAL 19098, CURITIBA, PR, BRAZIL, CEP: 81531-970
FAX: 55-41-266 9222
e-mail: miltonac @ cce.ufpr.br

CAP. RODRIGO MATURANA NADAL
Principal Member
INSTITUTO GEOGRAFICO MILITAR
NUEVA SANTA ISABEL 1640
SANTIAGO, CHILE
FAX: 56-2-6988278
e-mail: igm @ reuna.cl

ENG. SUSANA R. ARCINIEGAS
Principal Member
INSTITUTO GEOGRAFICO MILITAR
ELDORADO, EDIFICIO DEL IGM
QUITO, ECUADOR
FAX: 593-2-569 097
e-mail: igm2 @ igm.mil.ec

MR. HERVE FAGARD
Principal Member
INSTITUTE GEOGRAPHIQUE NATIONAL
SGN
BP 68
94160 SAINT MANDE, FRANCE
FAX: 33-1-43 988450
e-mail: herve.fagard @ ign.fr

DR. ENG. HERMANN DREWES
Scientific Consultant
DGFI, ABT. I
MARSTALLPLATZ 8
D-80539
MUENCHEN, GERMANY
FAX: 49-89-23031 240
e-mail: mailer @ dgfi.badw-muenchen.de

PROF. DR. GUNTER SEEBER
Scientific Consultant
INSTITUT FÜR ERDMESSUNG
UNIVERSITY OF HANNOVER
SCHNEIDERBERG 50
D-30167 HANNOVER, GERMANY
FAX: 49-511-762 4006
e-mail: seeber @ mbox.ife.uni-hannover.de

DR. MUNEENDRA KUMAR
Scientific Consultant
NATIONAL IMAGERY AND MAPPING AGENCY
MAIL STOP: A -20
8613 LEE HIGHWAY
FAIRFAX, VA 22031,USA
FAX: 1-703-275 5495
e-mail: kumarm @ nima.mil

1.3.3- WORKING GROUP II: GEOCENTRIC DATUM

MAYOR RODRIGO BARRIGA VARGAS
President (1996-1997)
INSTITUTO GEOGRAFICO MILITAR
NUEVA SANTA ISABEL 1640
SANTIAGO, CHILE
FAX: 56-2-6988278
e-mail: igm @ reuna.cl

MAYOR WALTER HUMBERTO SUBIZA PIÑA
President (1993-1995)
SERVICIO GEOGRAFICO MILITAR
8 DE OCTUBRE 3255
MONTEVIDEO 11600, URUGUAY
FAX: 598-2-470 868
e-mail: geografi @ seciu.uy

CAP. LORENZO A. CENTURION
Vice-president
DISERGEMIL
ARTIGAS 920
ASUNCION, PARAGUAY
FAX: 595-21-213 812

MY. ENG.MIL. HUGO RUBEN BERTOLA
Principal Member
INSTITUTO GEOGRAFICO MILITAR
CABILDO 381
1426 BUENOS AIRES, ARGENTINA
FAX: 54-1-776 1611

ENG. SONIA MARIA ALVES COSTA
Principal Member
IBGE/DEGED
AV. BRASIL 15671
PARADA LUCAS
RIO DE JANEIRO, RJ, BRAZIL, CEP 21241-051
FAX: 55-21-481 2747
e-mail: sonia @ deged.ibge.gov.br

PROF. EDVALDO FONSECA JUNIOR
Substitute Member
UNIVERSIDADE DE SÃO PAULO
EPUSP - PTR
CAIXA POSTAL 61548
CEP 05424-970 CIDADE UNIVERSITÁRIA
SÃO PAULO, BRAZIL
FAX: 55-11-818 5716
e-mail: edvaldoj @ usp.br

ENG. SUSANA R. ARCINIEGAS
Principal Member
INSTITUTO GEOGRAFICO MILITAR
ELDORADO, EDIFICIO DEL IGM
QUITO, ECUADOR
FAX: 593-2-569 097
e-mail: igm2 @ igm.mil.ec

ENG. FABIAN SANTAMARIA
Substitute Member
INSTITUTO GEOGRAFICO MILITAR
ELDORADO, EDIFICIO DEL IGM
QUITO, ECUADOR
FAX: 593-2-569 097

ENG. JOSE NAPOLEON HERNANDEZ
Principal Member
CARTOGRAFIA NACIONAL
COORDINACION GEODESICA
EDIF CAMEJO - ESQUINA CAMEJO CSB
PISO 2 - OFIC 216
CARACAS, VENEZUELA
FAX: 58-2-5450374
e-mail: sagecan @ conicit.ve

TTE. JOSE GONZALEZ BRICEÑO
Substitute Member
DIGECAFA - MIN. DEFENSA
FUERTE TIUNA - EL VALLE
CARACAS, VENEZUELA
FAX: 58-2-68 23405

MR. DON BEATTIE
Scientific Consultant
GEODETIC SURVEY OF CANADA
615 BOOTH ST.
OTTAWA, ONTARIO
K1A 0E9 CANADA
FAX: 1-613-995 3215
e-mail: beattie @ geod.emr.ca

DR. ENG. HERMANN DREWES
Scientific Consultant
DGFI, ABT. I
MARSTALLPLATZ 8
D-80539
MUENCHEN, GERMANY
FAX: 49-89-23031 240
e-mail: mailer @ dgfi.badw-muenchen.de

DR. MUNEENDRA KUMAR
Scientific Consultant
NATIONAL IMAGERY AND MAPPING
AGENCY
MAIL STOP: A -20
8613 LEE HIGHWAY
FAIRFAX, VA 22031,USA
FAX: 1-703-275 5495
e-mail: kumarm @ nima.mil

1.3.4- SCIENTIFIC COUNCIL

Scientific consultants that advise the Committee.

PROF. DR. CAMIL GEMAEL
RUA JESUÍNO LOPES, 305
SEMINÁRIO, CURITIBA, PR, BRAZIL
CEP: 80310-610

DR. KNUD PODER
GEODETIC DIVISION, KMS
RENTEMESTERVEJ 8
DK - 2400 COPENHAGEN, NV
DENMARK
FAX: 45-35-87 5052
e-mail: kp @ kms.dk

DR. IVAN MUELLER
4361 SHIRE CREEK COURT
HILLIARD, OHIO, 43026
USA
FAX: 1-614-292 2957
e-mail: mueller @ mps.ohio-state.edu

PROF. DR. HEINZ G. HENNEBERG
ESCUELA DE GEODESIA, FACULTAD DE
INGENIERIA
UNIVERSIDAD DEL ZULIA
APARTADO POSTAL 6
MARACAIBO, VENEZUELA
FAX: 58-61-516225
58-61-517252
e-mail: henneber @ europa.ica.luz.ve

DR. GALO CARRERA
GEOMETRIX
GEODETIC AND HYDROGRAPHIC
RESEARCH INC.
53 HAWTHORNE STREET
DARTMOUTH, NOVA SCOTIA
CANADA B2Y 2Y7
FAX: 1-902-466 3678
e-mail: gcarrera @ fox.nstn.ns.ca

CHAPTER 2

WORKING GROUP I: REFERENCE SYSTEM

2.1- INTRODUCTION

The definition of a geodetic geocentric reference system for South America and the establishment and maintenance of a reference frame are the fundamental objectives of the Working Group I of the SIRGAS project.

At the first workshop of the project in Asuncion, Paraguay, it was agreed that the reference system should coincide with that of the IERS - International Earth Rotation Service - and that the reference frame should be realized by means of the observation of a highly precise network of GPS stations.

The Working Group I was initially constituted by the designation of a president, representatives of three countries and three scientific consultants. Later on two more members representing two other countries were added.

The Working Group met at three workshops: La Plata, Argentina, October 1994, Santiago de Chile, August 1996, and Margarita, Venezuela, April 1997. Already before the first workshop a time schedule about the activities to be accomplished and the meetings to be held was planned. During the La Plata meeting, criteria were defined for the definitive selection of stations and the accepted GPS receivers for the observations. Technical specifications and the process of data collection and organization were discussed, too. Finally, the date of the GPS observation campaign was fixed.

The GPS observation campaign was carried out according to this schedule during ten days from May 26 to June 4, 1995. A total of 58 stations were observed. After the collection and preparation of the observation data, which was mainly done at DGFI in Munich, DGFI, IBGE, and NIMA started with the data processing.

At the workshop in Santiago the preliminary results of these three processing centers were presented and discussed. Important decisions were then made with respect to the pending computations and how they should be completed.

DGFI and NIMA presented their final results in Margarita in April 1997. At this workshop the procedure for the final, unique solution was defined, and the corresponding computations were done during the workshop.

This chapter of the SIRGAS final report is dealing with the above mentioned activities and results of the Working Group I. It includes the most important aspects of the GPS observation campaign, the preparation and archiving of observation data, detailed reports of the processing centers, and the presentation of the definitive results.

The most important activities of the Working Group I may be summarized as follows:

- collection of necessary information in each country;
- selection of stations to be observed in the GPS network;
- formulation of the technical specifications for the execution of the GPS observations;
- planning and organization of the GPS campaign;
- planning of the data collection procedure and the data processing;
- organization of the evaluation and of the procedure to derive the final results.

The evaluation of these activities and the quality of adjusted station coordinates allows the conclusion that the Working Group I accomplished completely the planned objectives. South America has at its disposal one of the most precise continental networks which will serve as a basis for the establishment of a geocentric datum. The immediate task is now to provide the adequate maintenance.

2.2- GPS OBSERVATION CAMPAIGN OF THE SIRGAS REFERENCE FRAME

The idea to observe a continental GPS station network and the planning of its configuration started from the beginning of the project at the Asuncion meeting in October 1993.

The assumed initial criterion for the selection of the stations was to include in the network all the existing LASER, VLBI, DORIS, and GPS observatories in South America. In addition one had to look for a homogeneous continental coverage of the net, to guarantee the facile access to the sites and the possibility to perform the GPS measurements. Finally there had to be some overlapping with the official geodetic network of each country.

Initially 48 preliminary stations were selected, requiring from each country detailed information about the sites and recommending the monumentation of the principal marker and the reference marks according to the requirements on its permanency.

In effect, a hard work was necessary to collect and to organize the required information provided by the different countries. This included the location of the stations and their descriptions, available instruments in the country and possible problems.

SIRGAS Working Group I, with the valuable collaboration of the scientific consultants, presented the technical specifications necessary for the GPS measurements in the SIRGAS campaign. These were elaborated taking into account all the aspects which, according the specialist's opinion, had to be included in a project like this:

I. Preparation of the equipment
II. Observation schedule
III. Tracking parameters
IV. Identification of the stations
V. Special precautions
VI. Annotations

In the same way, a form sheet was prepared to collect the necessary information of each of the stations, in order to obtain a homogeneity in the descriptions of the sites. Additionally, the instructions for the data handling were prepared.

The preliminary selection of the stations, carried out by each South American country and with the approbation of Working Group I, permitted to complete the planning of a network of 52 stations.

Before the observations, discussions were carried out and decisions were made with respect to the compatibility and availability of equipments to be used. The idea was to guarantee homogeneity in the technical generation of the instruments and to include as many geodetic GPS receivers as possible from South American institutions. On the other hand, only highly precise receivers should be employed. Four receiver types were selected for this purpose: Ashtech Z12, Leica 200, Rogue/Turbo Rogue, and Trimble SSE. This selection includes the receivers operating as part of the global IGS network in the region.

As not sufficient GPS receivers of these types were available from South American institutions, they were completed by receivers provided by some cooperating European institutions and by DMA. The distribution of receivers over the sites may be seen from Figure 2.1. A complete list of receivers and responsible institutions for each site occupation is given in Table 2.1.

A principal difference between receiver types with regard to precise positioning is the relative location of antenna phase centers. The exact location of the phase centers has to be known in the data processing in order to reduce the coordinates to the station's monument marker. If only one type of receiver and antenna is used in a campaign, the relative location of phase centers is identical in all stations and cancels in a relative positioning (with respect to a reference station or in a coordinate difference). If different receiver types are used, the variation of phase center locations between their antennae has to be corrected, i.e., the phase center corrections have to be known for each receiver type antenna.

Since the antenna phase center corrections of the employed receivers were not known in an internationally accepted way (nowadays an IGS recommendation is available), it was decided to co-locate different types of the selected receivers at several sites and to determine their exact three-dimensional distances by local tie measurements. For that reason, nine sites were occupied by two or three different receiver types. The corresponding sites may also be found in Table 2.1.

In addition to this, the handling of the observation data was organized. A data center was selected in each country, and two global data centers for the collection of the observations from all countries were established.

The observations were carried out as planned from May 26, 0:00 UT until June 4, 24:00 UT, 1995, i.e., over 10 days in total. Finally, 58 principal stations and 9 eccentric stations in 11 countries were observed:

COUNTRY	NR. OF STATIONS
Argentina	10
Bolivia	6
Brazil	11
Chile	8
Colombia	5
Ecuador	3
French Guiana	1
Paraguay	2
Peru	4
Uruguay	3
Venezuela	5
Total	58

Only few stations had some problems during the observation. We can state that the campaign was very successful, both according to the organization and the measurements.

TABLE 2.1: Sites of the 1995 GPS campaign, employed instruments and institutions

Site	Lat.[°]	Long.[°]	Receiver(s)	Institutions
ANTARCTICA				
O'HIGGINS	-63.32	-57.90	Rogue	IGS
ARGENTINA				
SALTA	-24.73	-65.41	Trimble	Univ. Tucuman / GFZ
PUERTO IGUAZU	-25.61	-54.56	Ashtech + Leica	IGM Argentina / DGFI
VILLA ROBLES	-27.91	-64.12	Ashtech	Univ. Tucuman
CRICYT	-32.89	-68.88	Trimble	UAGG Mendoza
MORRO	-33.27	-65.48	Ashtech	UAGG Mendoza
LA PLATA	-34.91	-57.93	Rogue	Obs. La Plata / GFZ
LOTE 24	-38.13	-66.09	Ashtech	UAGG Mendoza
EL MAITEN	-42.01	-71.20	Leica + Trimble	Catastro Rio Negro DGFI / Univ. Dresden
LOTE 10B	-46.04	-68.47	Trimble	DGFI
RIO GRANDE	-53.79	-67.75	Rogue + Leica	Obs. La Plata / GFZ / DGFI
BOLIVIA				
RIBERALTA	-11.01	-66.07	Trimble	IGM Bolivia
CLARA	-15.82	-63.19	Trimble	IGM Bolivia
HUICHURAYA	-17.04	-68.48	Trimble	IGM Bolivia
SJ DE CHIQUITOS	-17.87	-60.77	Trimble	IGM Bolivia
CAMIRI	-20.05	-63.56	Trimble	IGM Bolivia
OLLAGUE	-21.35	-68.04	Trimble	IGM Bolivia
BRAZIL				
MANAUS	-03.12	-60.06	Ashtech	IBGE
FORTALEZA	-03.88	-38.43	Rogue	IGS(CRAAE/INPE/NOAA)
IMPERATRIZ	-05.49	-47.50	Ashtech	IBGE / IfE Hannover
BOM JESUS LAPA	-13.26	-43.42	Ashtech	IBGE
CUIABA	-15.56	-56.07	Ashtech	IBGE / IfE Hannover
BRASILIA	-15.95	-47.88	Rogue	IGS (IBGE / JPL)
VIÇOSA	-20.76	-42.87	Ashtech	IBGE / UFV
PRES. PRUDENTE	-22.12	-51.41	Trimble	IBGE / UNESP / EPUSP
CACHOEIRA	-22.69	-44.98	Trimble	IBGE
RIO DE JANEIRO	-22.82	-43.31	Ashtech	IBGE
CURITIBA	-25.45	-49.23	Trimble+Ashtech	UFPR / IfE Hannover
CHILE				
ANTOFAGASTA	-23.70	-70.42	Rogue	IGM Chile / GFZ
CHAMONATE	-27.30	-70.41	Ashtech	IGM Chile
ISLA DE PASCUA	-27.15	-109.38	Rogue	IGS
SANTIAGO	-33.15	-70.67	Rogue	IGS
CARRIEL SUR	-36.78	-73.06	Ashtech	IGM Chile
BALMACEDA	-45.91	-71.69	Ashtech	IGM Chile

CARLOS IBANEZ	-53.00	-70.85	Ashtech	IGM Chile

TABLE 2.1 (continued)

Site	Lat.[°]	Long.[°]	Receiver(s)	Institutions
COLOMBIA				
CARTAGENA	+10.39	-75.53	Leica	Agustin Codazzi
BOGOTA	+04.64	-74.08	Rogue + Leica	IGS / Agustin Codazzi
PUERTO INIRIDA	+03.85	-67.91	Leica	Agustin Codazzi
PASTO	+01.39	-77.29	Leica	Agustin Codazzi
LETICIA	-04.20	-69.94	Leica	Agustin Codazzi
ECUADOR				
GALAPAGOS	-00.46	-90.26	Ashtech	IGM Ecuador / IGN
LATACUNGA	-00.81	-78.63	Ashtech	IGM Ecuador / IGN
ZAMORA	-04.05	-78.93	Ashtech	IGM Ecuador / IGN
FR. GUIANA				
KOUROU	+05.25	-52.81	Rogue	IGS (ESA)
PARAGUAY				
M. ESTIGARRIBIA	-22.04	-60.59	Ashtech	DSGM Paraguay / DMA
ASUNCION	-25.28	-57.61	Ashtech	DSGM Paraguay / DMA
PERU				
IQUITOS	-03.73	-73.24	Leica	IGN / Univ. FAF FRG
PIURA	-05.20	-80.63	Leica	IGN Peru / DGFI
LIMA	-12.10	-77.02	Leica + Trimble	IGN Peru / DGFI / Univ. FAF FRG
AREQUIPA	-16.47	-71.49	Rogue + Leica+Trimble	IGS / IGN Peru / DGFI / Univ. FAF FRG
URUGUAY				
YACARE	-30.60	-57.42	Ashtech	SGM Uruguay /
CERRO VIGIA	-33.71	-53.58	Ashtech	/ Fac. Ingenieria
MONTEVIDEO	-34.89	-56.26	Ashtech + Leica	/ Univ. de la República
VENEZUELA				
MARACAIBO	+10.67	-71.62	Trimble + Leica	EIG Univ. Zulia / DGFI
JUNQUITO	+10.46	-67.09	Trimble	DCN
LA CANOA	+08.57	-63.86	Trimble	DCN / DIGECAFA / DGFI
AGUA LINDA	+05.89	-67.46	Trimble	DCN / DIGECAFA / DGFI
KAMA	+05.39	-61.21	Leica	DCN / DIGECAFA / DGFI

FIGURE 2.1: Sites and receiver occupations of the SIRGAS 1995 GPS campaign

2.3- PREPARATION OF OBSERVATION DATA AND DATA ARCHIVES

All the data of the SIRGAS 1995 GPS campaign were collected and stored in archives by two global data centers: one at DGFI in Munich/Germany, and an identical backup at IBGE in Rio de Janeiro/Brazil. The data were generally transformed to RINEX format by the institutions in charge of the stations or by the national data centers and then forwarded by e-mail, ftp, or diskettes to the global data center. Some 700 files with more than 1.3 GBytes of about 10 million observations were stored altogether.

In the global data center, all the files were reviewed and checked for plausibility. This included in particular the following steps (only those activities are mentioned where major problems occurred):

- Control the completeness of the received data files for each station, request for initially undelivered data;
- Prove the general compatibility of the RINEX file headers with the RINEX 1 or 2 formats; if necessary complete the headers accordingly;
- Unify the station names and - if necessary - convert them to SIRGAS or IGS conventions;
- Check the approximate positions given in the RINEX headers for blunders through day by day comparison;
- Convert receiver and antenna type names to IGS standards;
- Check the antenna heights, request missing information from the responsible agencies, reduce slant to vertical measures and refer to the defined antenna reference points (ARP).

A summary of collected data and antenna heights is given in Table 2.2. A mean antenna height above the marker is given, if the heights of different days did not differ more than a millimeter from the average. If greater discrepancies occurred, different heights are listed.

The day by day occupation of stations is shown in Table 2.3. The coverage of achieved data per day is indicated by a signature distinguishing (nearly) full coverage, more than half a day of data, and less than half a day of data. Defective data (mainly missing second frequency) are also distinguished.

All the prepared data were stored in archives and distributed by ftp to the processing centers. They are available for future use to all interested persons. The structure of the data files is as follows:

	ftp.dgfi.badw-muenchen.de				
or	ftp.deged.ibge.gov.br				
user:	anonymous				
password:	your own e-mail address				
directory:	pub/gps/sirgas				
sub-directories:	addresses	coordinates	data	events	results

TABLE 2.2: Site occupations, sampling rate, data amount, average antenna heights

Station Name	Receiver Type	Obs. Days	Rate [sec]	Amount [MByte]	Antenna H [m]
ANTARCTICA					
O'HIGGINS	Rogue	6	30	11.4	0.001
ARGENTINA					
SALTA	Trimble	9.5	30	14.9	0.046
PUERTO IGUAZU	Ashtech	9.5	30	17.1	1.444
PUERTO IGUAZU 2	Leica	9.5	15	26.9	1.554
VILLA ROBLES	Ashtech	9.5	30	15.4	0.848
CRICYT	Trimble	10	30	10.3	1.532
MORRO	Ashtech	9.5	30	16.1	1.365
LA PLATA	Rogue	10	30	15.6	0.046
LOTE 24	Ashtech	9.5	30	15.3	1.172
EL MAITEN 1	Trimble	10	15	31.3	1.005
EL MAITEN 2	Leica	10	15	24.6	1.139
LOTE 10B	Trimble	9	15	27.1	1.326
RIO GRANDE	Rogue	10	30	19.3	0.035
RIO GRANDE 1	Leica	10	30	15.0	0.256
BOLIVIA					
RIBERALTA	Trimble	10	30	18.3	1.436
CLARA	Trimble	10	30	17.0	1.100
HUICHURAYA	Trimble	10	30	17.6	1.417
S.J. DE CHIQUITOS	Trimble	10	30	17.6	1.154
CAMIRI	Trimble	10	30	17.4	1.114
OLLAGUE	Trimble	10	30	17.3	1.040
BRAZIL					
MANAUS	Ashtech	9	30	24.0	0.008
FORTALEZA	Rogue	10	30	19.3	0.643
IMPERATRIZ	Ashtech	10	30	27.0	0.078
BOM JESUS LAPA	Ashtech	9	30	22.4	0.008
CUIABA	Ashtech	9	30	22.3	0.074
BRASILIA	Rogue	10	30	17.7	0.007
VIÇOSA	Ashtech	9.5	30	22.5	0.008
PRES. PRUDENTE	Trimble	10	30	21.6	0.009
CACHOEIRA	Trimble	10	30	21.3	0.077/0.052
RIO DE JANEIRO	Ashtech	6.5	30	13.7	0.008
CURITIBA	Trimble	10	30	17.6	0.163
CURITIBA RM3	Ashtech	10	30	17.3	1.246
CHILE					
ANTOFAGASTA	Rogue	10	30	18.1	0.046
CHAMONATE	Ashtech	10	30	16.4	0.000
ISLA DE PASCUA	Rogue	10	30	16.2	0.061
SANTIAGO	Rogue	10	30	17.8	0.093
CARRIEL SUR	Ashtech	10	30	15.8	0.000
BALMACEDA	Ashtech	9	30	14.9	0.000
CARLOS IBANEZ	Ashtech	9.5	30	15.5	0.000

TABLE 2.2 (continued)

Station Name	Receiver Type	Obs. Days	Rate [sec]	Amount [MByte]	Antenna H [m]
COLOMBIA					
CARTAGENA	Leica	10	15	27.6	1.405
BOGOTA	Rogue	10	30	18.0	0.061
BOGOTA 2	Leica	9	15	18.2	1.413
PTO. INIRIDA	Leica	10	15	29.1	1.382
PASTO	Leica	10	15	26.4	1.475
LETICIA	Leica	10	15	29.7	1.468/1.450
ECUADOR					
GALAPAGOS	Ashtech	9	30	16.8	1.364
LATACUNGA	Ashtech	10	30	19.3	0.640
ZAMORA	Ashtech	9	30	14.7	1.190
FR. GUIANA					
KOUROU	Rogue	10	30	18.9	0.132
PARAGUAY					
M. ESTIGARRIBIA	Ashtech	9	30	23.3	1.447
ASUNCION	Ashtech	10	30	22.1	0.766
PERU					
IQUITOS	Leica	5.5	15	8.7	1.671
PIURA	Leica	4.5	30	7.2	1.683
LIMA	Leica	9	30	14.5	1.173
LIMA 1	Leica	10	30	15.8	1.212
LIMA 2	Leica/Trimble	10	30	17.8	1.314/1.049
AREQUIPA	Rogue	10	30	17.3	0.061
AREQUIPA 1	Trimble	2	15	4.3	1.333
AREQUIPA 2	Leica	2	30	3.3	1.420
URUGUAY					
YACARE	Ashtech	9	30	20.3	5.076
CERRO VIGIA	Ashtech	10	30	21.8	0.074
MONTEVIDEO	Ashtech	10	30	24.0	0.081
MONTEVIDEO FORT	Leica	4	30	5.3	2.039
VENEZUELA					
MARACAIBO	Trimble	10	15	34.4	0.077
MARACAIBO ASTRO	Leica	10	15	26.6	0.284
JUNQUITO	Trimble	10	30	15.7	1.402
LA CANOA	Trimble	10	30	26.1	1.016
AGUA LINDA	Trimble	9	15	33.1	1.494
KAMA	Leica	9.5	15	17.5	1.514/1.547

TABLE 2.3: Summary of day by day observation data

Station	**Id. / Day**	**146**	**147**	**148**	**149**	**150**	**151**	**152**	**153**	**154**	**155**
ANTARCTICA											
O'Higgins	OHIG										
ARGENTINA											
Salta	UNSA										
Puerto Iguazu	IGUA										
Puerto Iguazu 2	IGU2										
Villa Robles	RBLS										
Cricyt	CRIC										
Morro	MORR										
La Plata IGS	LPGS										
Lote 24	LOTE										
El Maiten 1	MAI1										
El Maiten 2	MAI2										
Lote 10B	LO10										
Rio Grande	RIOG										
Rio Grande 2	RIO1										
BOLIVIA											
Riberalta	RIBE										
Clara	CLAR										
Huichuraya	HUIC										
S.J. de Chiquitos	CHIQ										
Camiri	CAMI										
Ollague	OLLA										
BRAZIL											
Manaus	MANA										
Fortaleza IGS	FORT										
Imperatriz	IMPZ										
Bom Jesus Lapa	BOMJ										
Cuiabá	CUIB										
Brasília IGS	BRAZ										
Viçosa	VICO										
Pres. Prudente	UEPP										
Cachoeira	CACH										
Rio de Janeiro	RIOD										
Curitiba	PARA										
Curitiba RM3	CURI										
CHILE											
Antofagasta	ANTO										
Chamonate	CHAM										
Isla de Pascua IGS	EISL										
Santiago IGS	SANT										
Carriel Sur	CASU										
Balmaceda	BLMC										
Carlos Ibanez	IBAN										

Station	Id. / Day	146	147	148	149	150	151	152	153	154	155
COLOMBIA											
Cartagena	CART										
Puerto Inirida	INIR										
Bogota IGS	BOGT										
Bogota 2	BOGO										
Pasto	PAST										
Leticia	LETI										
ECUADOR											
Galapagos	GALA										
Latacunga	LATA										
Zamora	ZAMO										
FR. GUIANA											
Kourou IGS	KOUR										
PARAGUAY											
M. Estigarribia	ESTI										
Asuncion	ASUN										
PERU											
Arequipa IGS	AREQ										
Arequipa 1	ARE1										
Arequipa 2	ARE2										
Lima	LIMA										
Lima 1	LIM1										
Lima 2	LIM2										
Iquitos	IQUI										
Piura	PIUR										
URUGUAY											
Cerro Vigia	VIGI										
Montevideo	MONT										
Fortaleza Mont	FEZA										
Yacare	YACA										
VENEZUELA											
Maracaibo	MARA										
Maracaibo Astro	MAR1										
La Canoa	CANO										
Junquito	JUNQ										
Agua Linda	AGUA										
Kama	KAMA										

Legend: Availability of data

more than 20^h
12^h-20^h
6^h-12^h
data with problems
no data available

2.4- PROCESSING

2.4.1- PROCESSING OF THE SIRGAS 95 GPS NETWORK AT DGFI

2.4.1.1- ABSTRACT

The present report describes the data processing of the 1995 SIRGAS GPS campaign done at Deutsches Geodaetisches Forschungsinstitut, Abt.I (DGFI/I) using the Bernese GPS software. A total of 67 observing stations at 58 sites covering the South American mainland and some surrounding areas occupied by stations of the International GPS Service for Geodynamics (IGS) were included in the analysis. In a first step a nearly unconstrained "free network" adjustment using IGS precise (combined) orbits was done. The final station coordinates were derived by transforming the "free network" to the IERS Terrestrial Reference Frame (ITRF) by means of seven stations identical with the ITRF94 solution. The r.m.s. errors are in the sub-centimeter level for each of the three coordinate components X, Y, Z.

2.4.1.2- INTRODUCTION

In 1993 the project for the establishment of an accurate geocentric geodetic reference system for the South American continent, Sistema de Referencia Geocéntrico para América del Sur (SIRGAS), has been initiated. The first goal of SIRGAS is the realization of a reference network of some sixty stations equally distributed over the continent by performing a GPS campaign.

The Deutsches Geodaetisches Forschungsinstitut (DGFI), Dept.I, was involved in the SIRGAS project from its beginning and made the following commitments for the establishment of the SIRGAS reference frame:

- To provide its own experience gained in several international projects for the planning of the GPS campaign, and to devote considerable resources to its execution including GPS observations at several sites;

- To act as a data center by archiving and providing access to the data for the SIRGAS community through anonymous ftp;

- To act as an analysis center for the continental GPS project with the intention to process the entire data set and to provide a unique network adjustment.

This report concentrates on the latter task and summarizes the strategy applied for processing the large amount of data, the software and models used, and presents the achieved results. The processing has been performed at DGFI with some assistance from the University of La Plata, Argentina.

The following acronyms will be used frequently in this report:

IGS = International GPS Service for Geodynamics

ITRF = IERS (International Earth Rotation Service) Terrestrial Reference Frame

2.4.1.3- DATA SET

The SIRGAS GPS campaign was carried out during the period May 26 – June 04, 1995. The guidelines issued for the measurements included the following recommendations relevant to the processing of the network:

- Each station should be operated from 0^h to 23^h UT daily leaving one hour for tasks such as exchange of power supply and data dumping;
- To account for rapid ionospheric delay variations, particularly the stations in the northern part of the continent should observe at a 15 seconds sampling rate;
- The observations should include data down to an elevation cut off angle of 10°.

The majority of the stations operated almost continuously during the 10 days period 23 hours per day. Since various precise geodetic GPS receivers, available in the South American countries and available from the participating institutions, were included in the campaign, some units suffered from a poor hardware configuration creating small problems. The main departures from the envisaged schedule were:

- A few time delays occurring on the first day of the campaign due to logistic delays or problems in establishing in time the necessary infrastructure for continuous observations;
- The inability of several receivers to cope with the 15 seconds sampling rate proposal mainly due to insufficient memory;
- Some interruptions due to power supply failures mainly at stations operated unattended in remote environment;
- Loss of data at very few stations during some days of the campaign due to hardware failures.

The location of all the sites occupied during the SIRGAS campaign is displayed in Figure 2.2. Table 2.4 lists all the stations, their acronyms and GPS systems included in the network adjustment. Excluded are the measurements at two eccentric monuments at the Arequipa site which were occupied during the first two days only and experienced considerable loss of data. Moreover, station S.J. de Chiquitos (CHIQ) in Bolivia is excluded because the receiver at that site acquired almost no L2 data. The four characters abbreviation given for each station is identical with the first four characters of the RINEX file names, as available from DGFI's data archive. The receiver acronyms in Table 2.4 stand for the following GPS receiver / antenna systems:

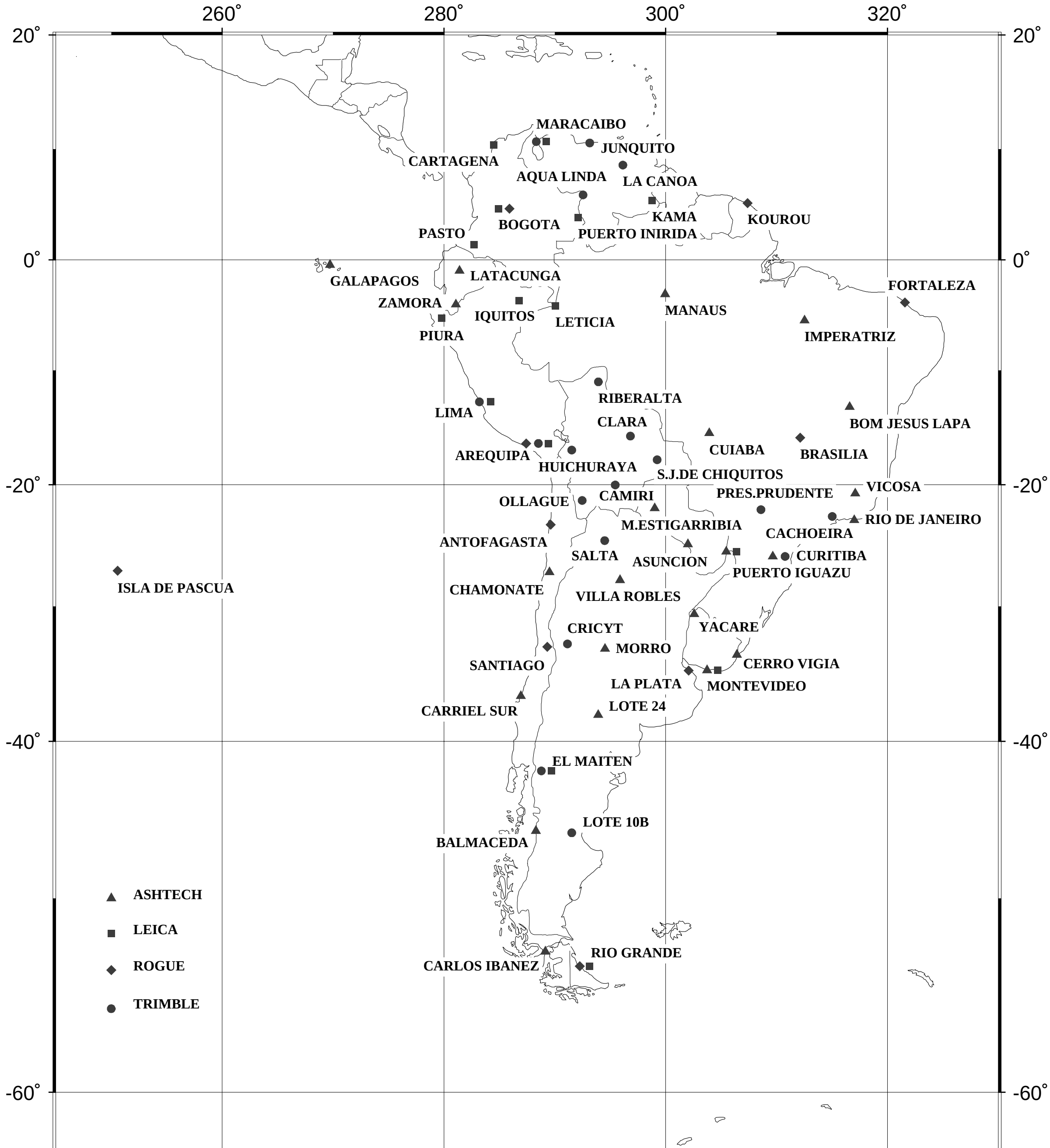


FIGURE 2.2: Location of the sites occupied during the SIRGAS 95 GPS campaign

ROG = ROGUE or TURBO ROGUE with antenna DORNE MARGOLIN B, R or T;

TRI = TRIMBLE SSE with antenna 4000 ST L1/L2 GEOD or TR GEOD L1/L2 GP;

LEI = LEICA 200 with SR 299 INTERNAL antenna;

ASH = ASHTECH Z XII with antenna GEODETIC L1/L2 P :

ASH 228 = antenna model 700 228;
ASH 718 = antenna model 700 718, large ground plane.

In early 1995 the phase center characteristics of the involved GPS antennae were not yet known precisely enough for combining different antenna types when differencing between stations. Therefore, at several sites co-locations between different receiver/antenna systems were performed enabling the combination of receiver specific sub-networks, provided the local ties are available from independent measurements. Table 2.5 displays the co-locations included in the network adjustment. Most of the stations were operated simultaneously during the whole SIRGAS campaign. These co-location stations are also included in Table 2.4.

2.4.1.4- NETWORK PROCESSING

Strategy Outline

For selecting a general strategy for the SIRGAS processing the following constraints had to be considered:

- The Bernese GPS software to be used processes single differences between stations and requires the definition of baselines;

- The number of measurements for each basic observable would probably approach a total of $1.5 \cdot 10^7$;

- The total number for parameters to be estimated in the adjustment would then amount to $2.5 \cdot 10^4$.

Based on these constraints, a procedure of distributed processing resulting in a solution identical with a one step adjustment was applied. This strategy can be outlined as follows:

- Since at the time of the SIRGAS campaign the phase center characteristics of the included GPS antenna types were not sufficiently accurate determined, no single differences between different antenna types (mixed baselines) were defined in order to avoid any accuracy degradation. Differencing between identical antennae eliminates phase center biases almost completely, provided the baselines are not too long.

- Considering the above aspect and taking into account the number of units of each of the receiver types involved in SIRGAS, receiver specific networks comprising the measurements collected during a one day session only are created; such a subset can be adjusted within a 3 hours limit on a HP 700 workstation.

TABLE 2.4: Stations included in the DGFI SIRGAS GPS processing;
ID = 4 character station identification, REC = receiver / antenna system

ID	Station Name	REC
	Antarctica	
OHIG	O'Higgins IGS	ROG
	Argentina	
UNSA	Salta	TRI
IGUA	Puerto Iguazu	ASH 228
IGU2	Puerto Iguazu 2	LEI
RBLS	Villa Robles	ASH 228
CRIC	Cricyt	TRI
MORR	Morro	ASH 718
LPGS	La Plata IGS	ROG
LOTE	Lote 24	ASH 718
MAI1	El Maiten 1	TRI
MAI2	El Maiten 2	LEI
LO10	Lote 10B	TRI
RIOG	Rio Grande	ROG
RIO1	Rio Grande 1	LEI
	Bolivia	
RIBE	Riberalta	TRI
CLAR	Clara	TRI
HUIC	Huichuraya	TRI
CAMI	Camiri	TRI
OLLA	Ollague	TRI
	Brazil	
MANA	Manaus	ASH 718
FORT	Fortaleza IGS	ROG
IMPZ	Imperatriz	ASH 718
BOMJ	Bom Jesus Lapa	ASH 718
CUIB	Cuiabá	ASH 228
BRAZ	Brasilia IGS	ROG
VICO	Viçosa	ASH 718
UEPP	Pres. Prudente	TRI
CACH	Cachoeira	TRI
RIOD	Rio de Janeiro	ASH 718
PARA	Curitiba	ASH 228
CURI	Curitiba RM3	TRI
	Chile	
ANTO	Antofagasta	ROG
CHAM	Chamonate	ASH 718
EISL	Easter Island IGS	ROG
SANT	Santiago IGS	ROG
CASU	Carriel Sur	ASH 718
BLMC	Balmaceda	ASH 718
IBAN	Carlos Ibañez	ASH 718
	Colombia	
CART	Cartagena	LEI
BOGT	Bogotá IGS	ROG
BOGO	Bogotá 2	LEI
INIR	Puerto Inirida	LEI
PAST	Pasto	LEI
LETI	Leticia	LEI
	Ecuador	
GALA	Galapagos	ASH 228
LATA	Latacunga	ASH 228
ZAMO	Zamora	ASH 228
	Fr. Guiana	
KOUR	Kourou IGS	ROG
	Paraguay	
ESTI	M. Estigarribia	ASH 718
ASUN	Asunción	ASH 718
	Peru	
IQUI	Iquitos	LEI
PIUR	Piura	LEI
LIMA	Lima	LEI
LIM1	Lima 1	LEI
LIM2	Lima 2	LEI/TRI
AREQ	Arequipa IGS	ROG
	Uruguay	
YACA	Yacare	ASH 718
MONT	Montevideo	LEI
FEZA	Montevideo Fort.	ASH 718
VIGI	Cerro Vigia	ASH 718
	Venezuela	
MARA	Maracaibo	LEI
MAR1	Maracaibo Astro	TRI
CANO	La Canoa	TRI
JUNQ	Junquito	TRI
AGUA	Agua Linda	TRI
KAMA	Kama	LEI

TABLE 2.5: Co-locations of different GPS systems included in DGFI processing

Site	Station IDs	GPS Systems
Puerto Iguazu	IGUA / IGU2	ASHTECH 228 / LEICA
Bogotá	BOGT / BOGO	TURBOROGUE IGS / LEICA
El Maiten	MAI1 / MAI2	TRIMBLE / LEICA
Curitiba	PARA / CURI	ASHTECH 228 / TRIMBLE
Maracaibo	MARA / MAR1	TRIMBLE / LEICA
Rio Grande	RIOG / RIO1	TURBOROGUE / LEICA
Montevideo	MONT / FEZA	LEICA / ASHTECH 718
Lima	LIMA / LIM2	LEICA / TRIMBLE

- Daily solutions of these sub-networks provide a means for assessing the day by day consistency and allow the identification of outliers and processing errors; in addition, in these receiver specific adjustments local parameters such as ambiguities can be pre-eliminated; the reduced normal equations are then saved for external accumulation together with all the other subsets.

- The daily adjustments are performed as totally unconstrained "free networks"; consequently, any change of datum definitions and any introduction or modification of further fiducial information such as local ties will not require a reprocessing of the normal equation subsets.

- The accumulation and solution of all the unconstrained normal equation systems is performed using an external program ACCSOL, to be described in more detail in Item 2.4.1.4 “Combination of Normal Equations”; before this final stage of the SIRGAS adjustment, no datum realizations such as ITRF positions and additional fiducial information are applied. This procedure provides a very high flexibility, e.g. for analyzing the sensitivity of the SIRGAS network to reference frame variations.

Preprocessing with the Bernese Software

As mentioned before, the data processing starting from the RINEX files up to the generation of normal equations for all daily receiver specific networks was done with the Bernese GPS software system (Rothacher et al. 1993). We have used version 3.4 although version 3.5 was available after the SIRGAS campaign. The reasons for staying with the older version were:

- The improvements realized in version 3.5 were only of minor importance for the preprocessing steps;

- On the other hand DGFI's version gpsest of the Bernese adjustment program GPSEST included a number of improvements and extensions, such as
  - the ability to define constraints for troposphere estimates at co-location sites,

– the availability of more and advanced troposphere calibration models,

– the ability to store normal equations for external accumulation using DGFI's program ACCSOL.

Further developments realized in gpsest are not as relevant to the SIRGAS project.

Figure 2.3 displays the structure of the processing with the Bernese software. Considerable effort was dedicated to the editing of the more than 700 RINEX observation files, aiming at

- checking the compatibility of the file headers with the RINEX conventions and formats,
- standardizing the station, receiver and antenna names,
- proving the antenna height and, if not yet done, reducing it from slant range to the vertical, and
- referring the antenna heights to the defined antenna reference points.

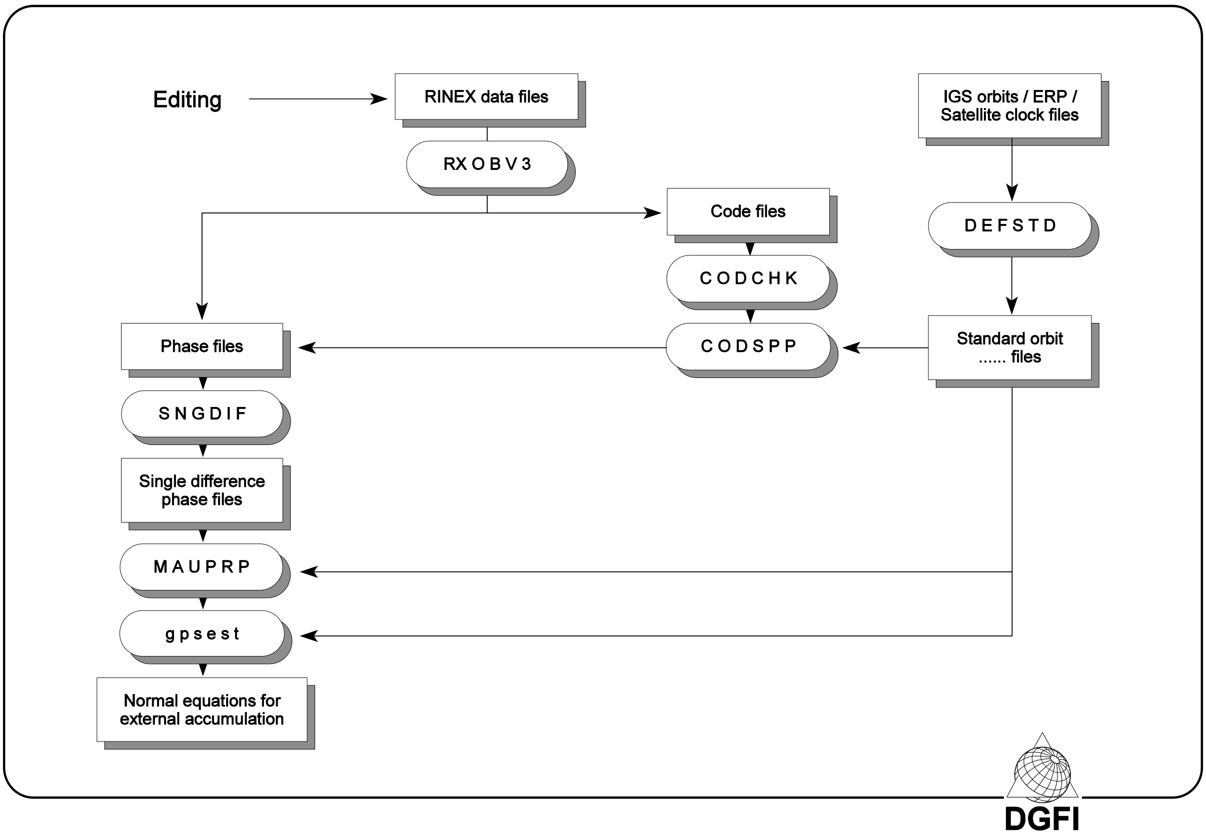


FIGURE 2.3: Generalized scheme of GPS data processing with the Bernese software

In the sequel the main characteristics of the measurements modeling, the orbit models and the parameter estimation as applied to SIRGAS are listed:

Basic observable	Carrier phase L1 and L2, code measurements only used for receiver clock synchronization; sampling rate: 30 seconds Elevation angle cutoff: 10° in preprocessing, 15° in adjustment.
Modeled observable	Double-differences, ionosphere-free linear combination L3.
Cycle slip fixing	Phase processing in a baseline by baseline mode using triple-differences; slip fixing by simultaneously checking different linear combinations of L1 and L2, optionally outlier rejection (program MAUPRP).
Ionosphere	Not modeled because first order effects are eliminated by the linear combination L3.
Troposphere	A priori calibration applying standard atmosphere surface meteorological parameters and using the Davis model, consisting of Saastamoinen's zenith delay prediction and Davis' continued fraction mapping function; Estimation of zenith delay corrections every 4 hours, applying a mapping function 1/cos (zenith distance), no constraints to a priori model.

Satellite center of mass correction

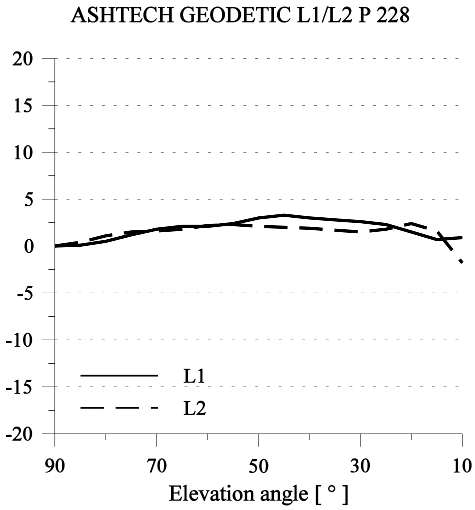
	X	Y	Z
Block I	.2100	.0000	.8540 m
Block II/IIA	.2794	.0000	1.0259 m

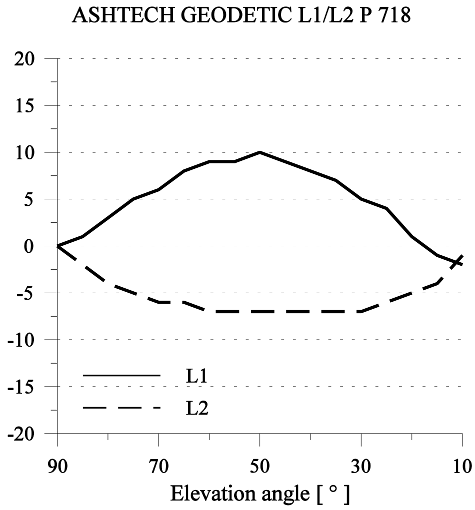
Receiver antenna phase center correction	Offsets of mean antenna phase center with respect to the defined antenna reference points according to the model IGS-01, issued on June 30, 1996; applied offsets are documented in Table 2.6; Elevation dependent range correction again according to the IGS-01 model; the corrections applied to the antennae included in SIRGAS are displayed in Figure 2.4; Both correction types are relative to the DORNE MARGOLIN T antenna.
Ambiguities	Not resolved, but pre-eliminated in each daily receiver specific normal equation system.
Orbits, satellite clock biases	Definitive combined IGS orbits and satellite clock parameter series according to files IGS 08025.SP3 → IGS 08040.SP3 .
Earth orientation	Adopted from IGS solutions compatible to the satellite orbits as given in files IGS 08027.ERP → IGS 08047.ERP .

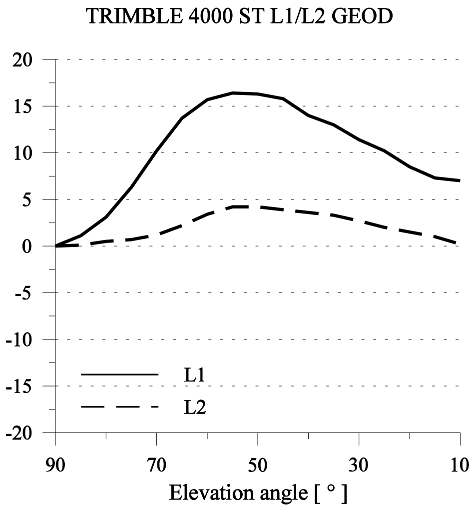
The satellite orbits generated by IGS at the SIRGAS campaign epoch refer to ITRF 93. Applying these orbits to the SIRGAS processing introduces already a loose constraint to ITRF 93. Nevertheless, at this stage the daily adjustments and saved normal equations may be considered almost unconstrained as "free networks". Therefore the terrestrial reference frame realization for SIRGAS is discussed later.

TABLE 2.6: Offsets of mean antenna phase centers [mm] in north (N), east (E) and height (H) with respect to antenna reference points (ARP) as proposed by IGS and applied to SIRGAS (model IGS-01)

Antenna	Freq.	N	E	H
ROGUE DORNE MARGOLIN B	L1	0.0	0.0	78.0
	L2	0.0	0.0	96.0
ROGUE DORNE MARGOLIN R	L1	0.0	0.0	78.0
	L2	0.0	0.0	96.0
TURBOROGUE DORNE MARGOLIN T	L1	0.0	0.0	110.0
	L2	0.0	0.0	128.0
TRIMBLE 4000 ST L1/L2 GEOD	L1	0.0	-3.0	78.0
	L2	-3.1	-1.3	74.4
TRIMBLE TR GEOD L1/L2 GP	L1	1.5	-1.2	75.1
	L2	-1.1	1.7	69.2
LEICA SR 299 INTERNAL	L1	3.1	-0.2	113.1*
	L2	1.3	-3.5	117.2*
ASHTECH GEODETIC L1/L2 P Model 700 228	L1	0.5	0.3	79.9
	L2	-1.2	0.8	79.2
ASHTECH GEODETIC L1/L2 P Model 700 718	L1	3.4	1.0	87.3
	L2	3.1	-1.3	63.4
* 91.0 mm of these height offsets already included in antenna heights				







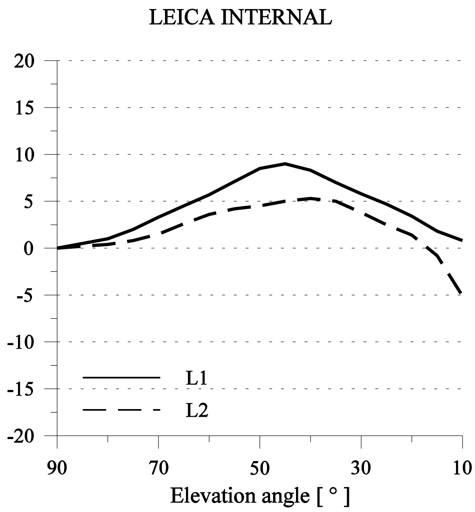


FIGURE 2.4: Elevation dependent phase center corrections [mm] of GPS antennae involved in SIRGAS relative to the DORNE MARGOLIN T antenna (Source: model IGS-01)

Combination of Normal Equations

As described in the previous section, receiver specific daily normal equation systems where generated which can be considered to represent almost unconstrained "free networks", although the application of the IGS orbits at the SIRGAS epoch establishes a loose relation to ITRF 93. For the accumulation and solution of an arbitrary number of such sets of normal equations the program ACCSOL (ACCumulate and SOLve) has been developed at DGFI. With relevance to SIRGAS, this program provides among others the following options:

- To introduce coordinates of fiducial points as additional observation equations assigning individual weights;

- To apply condition equations constraining certain pairs of troposphere estimates to equality, e.g. at co-location sites;

- To introduce local eccentricities information, e.g. at fiducial stations or for co-located receivers, as stochastic information.

The general structure of combining normal equations in ACCSOL is displayed in Figure 2.5.

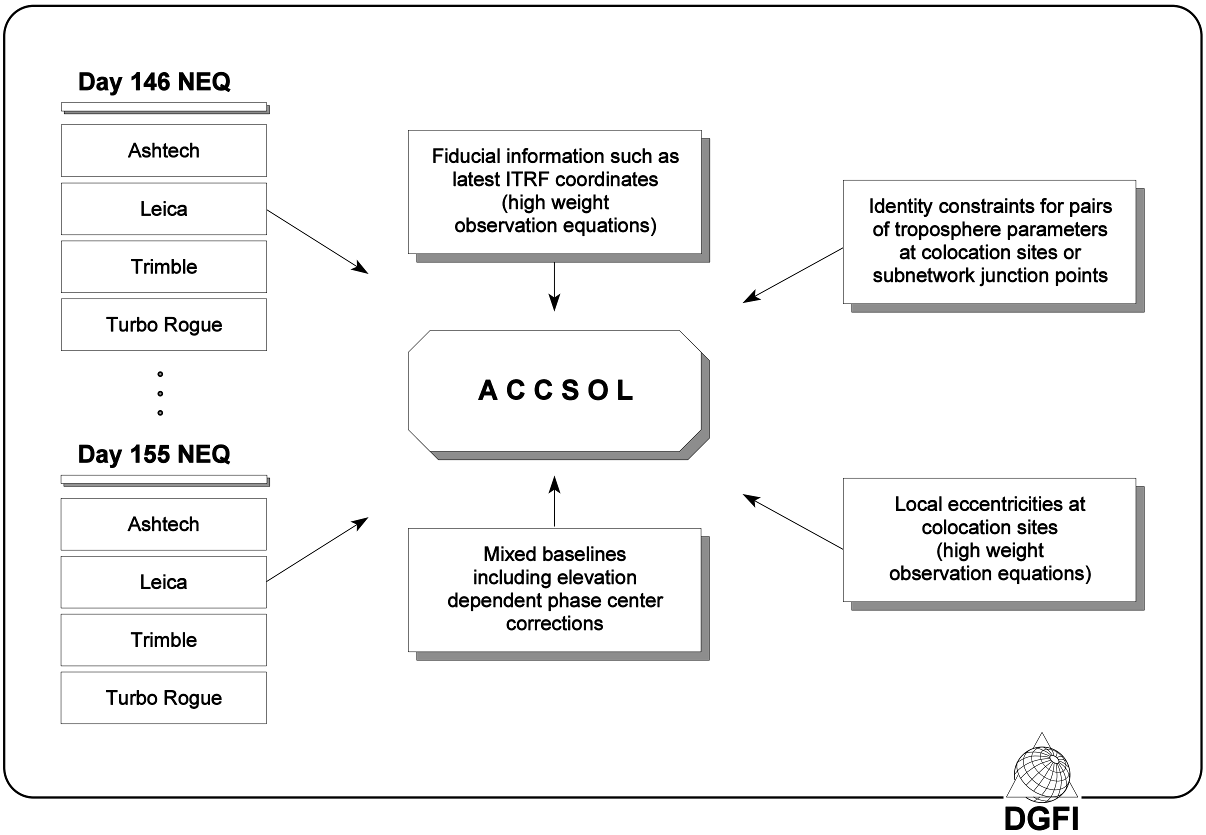


FIGURE 2.5: Combination of SIRGAS normal equations and additional information in ACCSOL

The procedure for referring the SIRGAS network to a global reference frame such as the ITRF will be discussed in item 2.4.1.5. As regards the other options for combining independent SIRGAS sub-network equations we proceeded as follows:

- Single difference L1 and L2 phase files involving different receiver systems operated at the co-location sites were introduced applying the phase center models proposed by IGS, see Table 2.6 and Figure 2.4; the sites and receiver/antenna systems are listed in Table 2.5.

- In addition to these co-location sites some local eccentricity components were applied, provided these ties were available from measurements completely independent from the SIRGAS data, including terrestrial observations such as leveling. Table 2.7 documents these local eccentricities being included in ACCSOL as observation equations with the quoted standard deviations.

- Experiencing that the application of the IGS phase center variation models increases the precision by up to 10 % and shows no remarkable biases, in addition some further mixed baselines were included for strengthening the connection between the receiver-specific sub-networks and the ROGUE network, which realizes the reference to the global network These mixed baselines are: Arequipa IGS – Huichuraya, Fortaleza IGS – Imperatriz and Santiago IGS – Carriel Sur.

2.4.1.5- RESULTS

Data Problems

As has been mentioned in item 2.4.1.3, station S.J. de Chiquitos in Bolivia was discarded already in the early stage of the SIRGAS processing because the TRIMBLE receiver operating there didn't track sufficiently on L2, and two eccentric stations in Arequipa were not included because of very few available data. No further complete failure of any other station occurred.

However, the processing of all the single difference files involving the IGS station Kourou (KOUR) operated with a TURBOROGUE caused severe problems in the sense that

- the data acquired were subject to many cycle slips compared to other receivers, and
- these slips even couldn't be fixed successfully in several cases.

As a consequence, although much effort was spent on analyzing these problems, finally only about half of the total data from Kourou remained in the adjustment.

Similar problems as with KOUR showed up when processing the other TURBOROGUE stations close to the equator, namely BOGT (Bogotá) and FORT (Fortaleza). We suppose these effects to be due to rapid ionospheric delay variations which cannot be sufficiently met by the IGS stations operated at 30 seconds sampling rate only.

TABLE 2.7: Local eccentricities between co-located receivers applied to the SIRGAS adjustment

ECCENTRICITY FILE FOR PROGRAM ACCSOL

Vector components in X, Y, Z or distance R or height difference H from station I to station II + assigned standard deviations (M)

STATION I	STATION II	COMPONENT		STAND.DEV.
EL MAITEN 1	EL MAITEN 2	X	8.627	.002
EL MAITEN 1	EL MAITEN 2	Y	-3.752	.002
EL MAITEN 1	EL MAITEN 2	Z	6.439	.002
EL MAITEN 1	EL MAITEN 2	H	0.385	.002
RIO GRANDE	RIO GRANDE 1	X	-24.700	.002
RIO GRANDE	RIO GRANDE 1	Y	-8.552	.002
RIO GRANDE	RIO GRANDE 1	Z	-0.065	.002
RIO GRANDE	RIO GRANDE 1	H	-0.810	.002
PUERTO IGUAZU	PUERTO IGUAZU 2	X	-57.953	.003
PUERTO IGUAZU	PUERTO IGUAZU 2	Y	-67.699	.003
PUERTO IGUAZU	PUERTO IGUAZU 2	Z	47.135	.003
CURITIBA	CURITIBA RM3	X	-21.354	.002
CURITIBA	CURITIBA RM3	Y	-8.371	.002
CURITIBA	CURITIBA RM3	Z	-11.352	.002
MONTEVIDEO	MONTEVIDEO FORT	X	5.834	.002
MONTEVIDEO	MONTEVIDEO FORT	Y	9.089	.002
MONTEVIDEO	MONTEVIDEO FORT	Z	8.389	.002
LIMA	LIMA 1	X	3.511	.002
LIMA	LIMA 1	Y	1.907	.002
LIMA	LIMA 1	Z	-5.010	.002
LIMA	LIMA 2	X	-5.306	.002
LIMA	LIMA 2	Y	-0.423	.002
LIMA	LIMA 2	Z	-3.635	.002
MARACAIBO ASTRO	MARACAIBO	X	21.093	.003
MARACAIBO ASTRO	MARACAIBO	Y	9.847	.003
MARACAIBO ASTRO	MARACAIBO	Z	26.032	.003
BOGOTA IGS	BOGOTA	X	118.455	.003
BOGOTA IGS	BOGOTA	Y	-14.117	.003
BOGOTA IGS	BOGOTA	Z	-150.883	.003
BOGOTA IGS	BOGOTA	H	33.7225	.005

Particular effort was also necessary when processing some of the LEICA stations in Colombia, Peru and Venezuela, which were operated also at a 30 seconds sampling rate. However, due to lack of sufficient memory space and power supply problems because of the high power consumption of the LEICA 200 system compared to the other receivers, at some of these stations departures from the envisaged observation schedule occurred:

- Data files were corrupted,
- Sessions didn't finish at midnight but extended for several hours on the following day, and
- Sessions were split into several files with sometimes large gaps in between.

All these irregularities required much more manual interaction and editing of command files, e.g. in order to adjust the troposphere modeling to the individual data distribution. Still then processing errors may occur which have to be traced carefully.

Consistency of Daily Adjustments

It is well known that the standard deviations resulting from GPS network adjustments due to the large number of data included are generally by far too optimistic; they reflect only the internal precision but not the accuracy of the solution. As already discussed earlier, at DGFI we have adjusted single day receiver specific networks. The comparison of the results did not only provide a means to detect data of processing problems but also to somehow assess accuracies. The processing of the SIRGAS project was distributed among four analyses. In addition emphasis was put on varying the baseline definition day by day, the reason for this being the fact that, although mathematical correlations are handled correctly in the software, physical correlations cannot be handled in the same way. Therefore, the design matrix was varied every day.

For these single day receiver specific networks the IGS orbits and associated Earth orientation parameters were kept fixed, but no other constraints were applied. Thus, the adjustments can be considered as almost free networks. For their comparison the numerical rank defects are removed by performing similarity transformations. In Table 2.8 the root mean square (rms) differences between the daily adjustments and the 10 days solution are documented for the ASHTECH, the TRIMBLE and the LEICA networks.

TABLE 2.8: Consistency of receiver specific networks: RMS differences in north (N), east (E) and height (H) between single day adjustments and the 10 days solutions [mm]

Day	ASHTECH Z XII			TRIMBLE SSE			LEICA 200		
	N	E	H	N	E	H	N	E	H
146	3.9	4.9	10.9	6.4	6.6	14.1	6.3	4.7	14.2
147	2.7	4.9	4.7	4.3	7.1	12.7	6.7	6.9	14.9
148	2.9	2.1	9.6	4.1	5.9	7.9	3.3	9.8	10.5
149	4.7	6.9	8.5	4.4	4.1	11.4	4.7	6.6	19.9
150	3.6	5.3	9.0	5.1	5.9	16.1	7.7	7.9	12.6
151	3.0	2.9	6.4	4.9	5.3	9.4	7.5	5.0	16.8
152	5.4	7.5	7.0	7.2	12.6	11.8	11.4	17.5	17.3
153	3.2	4.7	6.5	5.5	5.2	11.0	4.9	6.6	9.3
154	3.9	5.3	6.9	6.3	9.0	10.2	3.6	4.1	10.0
155	4.2	3.0	7.6	5.2	7.6	12.7	4.2	9.2	17.7
Average	3.7	4.8	7.8	5.3	6.9	11.7	6.0	7.8	14.3

The combination of these networks includes mixed baselines from co-locations and additional local eccentricities. The comparisons allow the following conclusions:

- Among the three receivers displayed, the ASHTECH Z XII demonstrates by far the best performance in all three components, followed by TRIMBLE SSE and LEICA 200;
- In case of the LEICA network the greater scatter in the heights is probably due to a slightly worse troposphere modeling because of the mentioned observation irregularities;
- Surprisingly, day 152 shows significantly worse results than all the other days, primarily in the horizontal position components; the effect seems to be caused by inconsistencies in the orbits, because it applies to all receivers;
- The daily consistency of the combined network ASHTECH + TRIMBLE + LEICA is slightly worse than the average of the single receiver adjustments because a very few days such as 150 suffer from some sparse co-location data.

The inclusion of the ROGUE/TURBOROGUE network through the IGS stations establishing the reference to ITRF will be discussed in the next item.

Reference to ITRF

The combined IGS orbits used in the SIRGAS adjustment refer to ITRF 93 in the sense that all IGS analysis centers in their orbit computations fixed 13 stations at their ITRF 93 positions extrapolated to the measurement epoch by applying the individual velocities. Among these 13 fixed stations is Santiago (SANT) the only one on the South American continent. At the time of the SIRGAS campaign three more South American IGS stations already included in the ITRF solutions were available: Arequipa (AREQ), Fortaleza (FORT) and Kourou (KOUR). Considering that due to their relatively short tracking history the accuracy of the ITRF positions and velocities for these stations might not be as good as in Europe or North America, we included in the processing three additional IGS stations in order to base the SIRGAS solution on as many fiducial points as possible; these are Richmond (RCM5), Easter Island (EISL) and O'Higgins (OHIG).

Table 2.9 documents the ITRF 93 coordinates of these 7 fiducial points at the SIRGAS epoch 1995.4. The given standard deviations are propagated from ITRF formal errors of the 1993.0 positions and of the station velocities. It should be mentioned that ITRF 93 does not in all cases report positions for the GPS station; for three of the seven sites coordinates referring to SLR or VLBI markers had to be centered to the GPS reference points. Table 2.10 displays these local eccentricities applied to the SIRGAS processing.

Since early 1996 the new solution ITRF 94 is available which includes observations up to the end of 1994 and should provide more accurate positions and velocities in particular for the stations of concern here. However, the reference systems underlying ITRF 93 and ITRF 94 are not totally identical. Moreover, due to a modification of the estimation concept ITRF 94 does not any more report velocities for station OHIG. On the other hand, it includes now also position estimates of the GPS reference points for the 3 sites listed in Table 2.10; thus, the application of local ties can be avoided. In order to preserve station OHIG as a fiducial point also in ITRF 94 we have adopted its position at reference epoch 1993.0 and transferred it to the SIRGAS epoch 1995.4 by simply applying the velocity estimates quoted in ITRF 93. Table 2.11 lists the coordinates of the fiducial points in ITRF 94; again the standard deviations were computed from the formal errors of ITRF positions and velocities.

In order to assess the internal consistency between the ITRF 93 and ITRF 94 solutions we have estimated a similarity transformation of one set of coordinates to the other, applying weights according to the individual standard deviations; the reference system differences should then be fully compensated by the transformation parameters. Table 2.12 displays the residuals after transformation which clearly indicate that the overall consistency is only on the 1 cm level or even worse.

TABLE 2.9: ITRF 93 coordinates and their standard deviations at epoch 1995.4 of IGS stations

Station	X [m]	Y [m]	Z [m]
AREQ*	1942826.702 ± .010	-5804070.246 ± .012	-1796893.951 ± .011
EISL	-1884951.834 ± .013	-5357595.859 ± .013	-2892890.453 ± .013
FORT	4985386.614 ± .017	-3954998.591 ± .014	-428426.485 ± .008
KOUR	3839591.407 ± .018	-5059567.552 ± .021	579956.921 ± .009
OHIG	1525872.432 ± .011	-2432481.295 ± .013	-5676146.025 ± .023
RCM5	961334.748 ± .004	-5674074.152 ± .003	2740535.147 ± .004
SANT	1769693.287 ± .006	-5044574.139 ± .006	-3468321.037 ± .007
* Based on SLR 7403 position			

TABLE 2.10: Local ties applied to center ITRF 93 positions to GPS reference points; Source: IGS site information catalogue

Site	ΔX [m]	ΔY [m]	ΔZ [m]
Arequipa SLR 7403 → AREQ	18.6152	-.5478	21.4987
O'Higgins VLBI 7245 → OHIG	39.4501	-17.6389	28.4357
Easter Island SLR 7097 → EISL	32.0162	12.4845	-37.0883

TABLE 2.11: ITRF 94 coordinates and their standard deviations at epoch 1995.4 of IGS stations realizing the reference frame for the SIRGAS adjustment

Station	X [m]	Y [m]	Z [m]
AREQ	1942826.725 ± .009	-5804070.245 ± .008	-1796894.018 ± .009
EISL	-1884951.831 ± .011	-5357595.820 ± .011	-2892890.498 ± .011
FORT	4985386.652 ± .011	-3954998.583 ± .011	-428426.523 ± .010
KOUR	3839591.454 ± .013	-5059567.548 ± .012	579956.899 ± .009
OHIG *	1525872.457 ± .014	-2432481.278 ± .017	-5676146.046 ± .028
RCM5	961334.783 ± .009	-5674074.162 ± .006	2740535.140 ± .008
SANT	1769693.312 ± .011	-5044574.130 ± .010	-3468321.076 ± .010
* Based on ITRF 94 position and ITRF 93 velocity			

TABLE 2.12: Discrepancies between ITRF 93 and ITRF 94 subsets of stations realizing the reference frame for the SIRGAS adjustment; residuals [cm] after similarity transformation ITRF 93 → ITRF 94 including (left) and excluding (right) OHIG; individual weights according to standard deviations applied

Station ID	ΔX	ΔY	ΔZ	ΔX	ΔY	ΔZ
AREQ	.27	.18	2.64	.30	.38	2.42
EISL	.00	-1.72	.96	-.30	-1.40	.69
FORT	1.45	-.96	.33	1.73	-.72	.33
KOUR	-.23	-1.13	-.77	-.01	-1.03	-.76
OHIG	.00	1.92	-2.93			
RCM5	-.30	.13	-.47	-.33	.01	-.33
SANT	-.22	.41	-.83	-.21	.77	-1.13
RMS	.58	1.14	1.61	.75	.85	1.18

Final Solution

In order to come up with the most reasonable set of coordinates we have performed several adjustments of the complete SIRGAS network using the program ACCSOL. These various solutions include the following alternatives:

- Tying the SIRGAS network rather strongly to ITRF 93 or ITRF 94 by applying very high weights allowing only some millimeters variations of the fiducial point coordinates;
- Applying individual weights to the fiducial coordinates according to their standard deviations at epoch 1995.4 as displayed for ITRF 93 and ITRF 94 in Tables 2.9 and 2.11 respectively;
- "Free network" adjustments with subsequent similarity transformation to either ITRF 93 or ITRF 94, again applying individual weights when adjusting the transformation parameters.

All the solutions aiming at constraining SIRGAS very closely to the ITRF positions produced some distortions of the network. The discrepancies among the fiducial points positions, as resulting from the ITRF coordinates at epoch 1993.0 along with the associated velocities, exceed the internal consistency of the SIRGAS network itself. Therefore, we finally decided to follow the third alternative listed above which has some further advantages over the other solutions:

- The precision estimates resulting from a "free network" adjustment of about 0.8 mm for the X and Z and 1.4 mm for the Y coordinates cannot be considered a measure of accuracy; instead, including the full transformation errors into the estimation of the standard deviations after transformation to ITRF probably provides more reliable accuracies.

- Given the resulting transformation parameters, the original "free network" solution can be reconstructed easily from the transformed set of coordinates; thus the reference to further ITRF solutions can be performed without any reprocessing.

The DGFI's final coordinates of the SIRGAS network are not included in this report, in order to avoid confusion with the official ones, but are available upon request at IBGE or DGFI. The solution refers to the ITRF94 as realized by the seven stations given in Table 2.11.

2.4.1.6- SUMMARY

We have processed the SIRGAS 95 GPS campaign which aimed at establishing a reference network of almost 70 stations distributed over the entire South American continent. The Bernese software system including some improvements implemented at DGFI has been used for this task. The main features of our processing may be summarized as follows:

- Considerable effort has been spent on editing all data files and checking the relevant entries, because the quality of the final result not only depends on the processing strategy and the software used but primarily on the measurement performance and the reliability of on site information such as the antenna heights.
- Single day receiver specific sub-networks have been processed; after the mathematically correct elimination of the ambiguities the normal equations were saved for external accumulation. This distributed data processing provides some advantages in data control and accuracy/reliability estimation.

- The receiver specific networks were processed in the "free network" mode, only the IGS orbits and the associated Earth orientation parameters were held fixed. All further information such as local ties, mixed baselines at co-location sites and fiducial point coordinates, realizing the reference frame, were applied not before the final stage of the adjustment. This last step is the accumulation of all sets of normal equations and their solution using DGFI's program ACCSOL. The selected strategy provides high flexibility in the sense that changes in the applied fiducial information does not require any data reprocessing.
- When processing the SIRGAS campaign it showed up that the internal accuracy of the network, which is demonstrated by the consistencies of daily solutions, is better than the accuracy of the seven ITRF stations available on and around the South American continent realizing the reference frame. Therefore, the final solution is based on a "free network" adjustment with subsequent weighted transformation to ITRF 94. Thus, the SIRGAS coordinates can easily be updated as soon as a better ITRF reference frame is available.
- The SIRGAS adjustment includes the latest antenna phase center variation models proposed by IGS, but it does not rely on any absolute calibration. Local ties were applied as stochastic information considering their expected uncertainties. The precision of the free network is in the order of 0.8 mm in the X and Z coordinates and 1.4 mm in the Y component. The standard deviations given with the solution include the transformation uncertainties to ITRF 94 and are probably realistic accuracy measures.

2.4.1.7- REFERENCE

ROTHACHER, M.; BEUTLER, G.; GURTNER, W.; BROCKMANN, E.; MERVART, L.. Bernese GPS Software Version 3.4 Documentation. Astronomical Institute, University Bern, 1993.

2.4.2- THE NIMA’S DERIVATION OF STATION COORDINATES FOR THE SIRGAS CONTINENTAL REFERENCE NETWORK

2.4.2.1- INTRODUCTION

This item presents the results of The National Imagery and Mapping Agency’s (NIMA) efforts to process the GPS data collected during the SIRGAS continental campaign carried out between 26 May and 4 June 1995. Ten days of data from 69 stations in 11 countries were processed using the GIPSY-OASIS II software.

Since the International Terrestrial Reference Frame 1994 (ITRF94) was chosen to be the reference frame for the SIRGAS network, final SIRGAS station coordinates are referenced to ITRF94, epoch 1995.42. Due to the time period of the SIRGAS campaign, all station positions were computed in ITRF93. Transformation parameters were applied to the ITRF93 station coordinates to obtain the desired ITRF94 station coordinates.

2.4.2.2- PREPROCESSING ACTIVITIES

Approximately 130 megabytes of RINEX data existed for each day. The Deutsches Geodaetisches Forschungsinstitut (DGFI) ensured that the RINEX files were complete and that the height of instrument (HI) measurements were correct. All files were stored, in compressed form, on the DGFI's Internet-accessible computer in Munich, Germany.

The compressed data were downloaded from the DGFI over the Internet. All data were then separated by day and processed on an IBM RS6000 with GIPSY II. Station data files (RINEX) with multiple sessions during the day were combined to form one session of approximately 23 hours. Some station receivers were not started and stopped at 0000 h Universal Time (UT). These RINEX files were split and recombined in order to obtain session durations within the 24 hour UT day.

Nine of the sites had more than one receiver:

- Arequipa, Peru - Station code names AREQ, ARE1 and ARE2.
- Bogota, Colombia - Station code names BOGO and BOGT.
- Curitiba, Brazil - Station code names CURI and PARA.
- Fortaleza, Uruguay - Station code names FEZA and MONT.
- Puerto Iguazu, Argentina - Station code names IGUA and IGU2.
- Lima, Peru - Station code names LIMA, LIM1 and LIM2.
- El Maiten, Argentina - Station code names MAI1 and MAI2.
- Maracaibo, Venezuela - Station code names MARA and MAR1.
- Rio Grande, Argentina - Station code names RIOG and RIO1.

The data from each of these receivers were processed independently with GIPSY-OASIS II.

2.4.2.3- COMPUTATIONS AND ANALYSIS

GPS Absolute Point Positioning

The GIPSY II software was used to produce absolute point positions for the SIRGAS stations. GIPSY II models solid earth tides, ocean loading, pole tides and uses a Lanyi mapping function (1984) to model the troposphere.

All available data except for outlier and problem sessions were used to establish the final station coordinates. Two to 10 sessions were processed for all of the SIRGAS stations (refer to Table 2.20 for the number of sessions processed for each station). Each station session was computed at a 10° elevation cutoff angle, except in special circumstances where poor quality results occurred. A 20° cutoff angle was the highest value used. A 300 second (5 minute) sampling interval was used for data processing.

Precise Orbits and Clocks

Precise satellite orbits and clock estimates computed by NASA's Jet Propulsion Laboratory (JPL) were used for the SIRGAS reduction, and obtained via FTP. JPL precise orbits and clock values were held fixed during the processing.

JPL precise orbits and clocks were used due to the benefits of using accurate satellite clock estimates when processing data with GIPSY II. Satellite clock values were available with the International GPS Service for Geodynamics (IGS) precise orbits but they did not appear to be as reliable as the clock values generated by JPL in conjunction with its orbits when using GIPSY. JPL is one of seven processing centers that submit precise satellite orbits and clocks to the IGS. The IGS heavily weights JPL's orbits and clocks in determining the final IGS orbits. For the time period of the SIRGAS campaign, the mean transformation parameters from IGS to JPL orbits are minimal (refer to Table 2.13). JPL precise orbits and clocks are referenced to ITRF93 but because of the subtle difference in orbits they will be referred to as JPL/ITRF93.

TABLE 2.13: Mean transformation parameters between IGS and JPL orbits (IGS-JPL)

	Translation (cm)			**Rotation (.001")**			**Scale (10^{-8})**
GPS WEEK	**TX**	**TY**	**TZ**	**RX**	**RY**	**RZ**	**S**
802	1	4	1	-0.6	-0.02	0.19	0.2
803	1	5	2	-0.65	-0.11	0.17	0.2

Antenna Phase Center (LC) Offsets

The phase center of L1 and L2 will be referred to as the LC phase center offset. The LC offset is the vertical distance from the antenna reference point (ARP) to the LC phase center. The equation below, provided by the IGS, was used to compute the LC vertical offset of each antenna used.

$$LC = k \cdot L1 - (k-1) \cdot L2 \text{ where } k = \frac{154^2}{154^2 - 120^2}$$

Or equally:

$$LC = 2.546 \cdot L1 - 1.546 \cdot L2$$

Antenna LC offsets, with respect to the ARP, were applied to the station antenna heights as specified by the IGS June 1996 (refer to Table 2.14).

TABLE 2.14: Antenna LC offsets (IGS, June 1996)

Antenna	Model	LC Offset
Ashtech	Geodetic L1/L2 P, Model 700228	0.085 meter
Ashtech	Geodetic L1/L2 P, Model 700718 Large Ground Plane	0.124 meter
Leica	Internal	0.016 meter
Rogue	Dorne Margolin B Allen Osborne Design	0.050 meter
Rogue	Dorne Margolin R JPL Design	0.050 meter
Rogue	Dorne Margolin T Allen Osborne Design	0.082 meter
Trimble	TR GEOD L1/L2 GP	0.084 meter
Trimble	4000ST L1/L2 GEOD	0.084 meter

Quality Analysis

GIPSY II computes one sigma errors for all daily solutions. GIPSY II then performs a least squares fit to the multiple daily solutions for each station to produce a final station solution. The resulting combined solution has one sigma errors and repeatabilities associated with it. Residuals of daily solutions are also calculated with respect to the estimated values from the resulting least squares fit. All of the above were used in identifying problem stations and solution outliers.

Problem Stations and Outlier Solutions

- Station BALMACEDA - High daily residuals were experienced throughout the 10-day campaign.

- Station CRICYT - Only the first three days were processed due to a decreasing amount of L2 measurements with time.

- Station LA PLATA - Sessions after Day 95/150 were not able to be processed. The RINEX data files after Day 95/150 had many breaks in them with many collection epochs only containing 1 to 3 satellite measurements.

- Station CACHOEIRA - The sessions on Days 95/150 and 95/155 produced outlier solutions and were not included in the final solution computation (refer to Table 2.15). The residuals produced from these two sessions differed from the other eight sessions by 0.5 m horizontally and over 3.0 m vertically and produced higher one sigma errors. Possible reasons for this include antenna height or monument changes, equipment changes or equipment malfunctions which resulted in very little collected data (Note that the antenna heights used during processing were those reported on the station log forms). The RINEX data files for Days 95/150 and 95/155 were of the same size as the other eight sessions. According to the agency that occupied the site and the station logs, the antenna was not moved, so at this time the cause of the poor solutions is undetermined.

TABLE 2.15: Daily residuals (cm) for station CACHOEIRA

Day	Latitude		Longitude		Ellipsoid Height	
	Residual	Formal Error	Residual	Formal Error	Residual	Formal Error
95/146	-0.18	0.05	-0.61	0.15	2.36	0.37
95/147	-0.10	0.06	0.00	0.16	0.61	0.37
95/148	0.52	0.06	1.04	0.17	2.75	0.40
95/149	0.01	0.06	-0.64	0.16	0.59	0.36
95/150	-5.91	0.58	45.12	1.32	-314.97	2.31
95/151	-0.91	0.09	-3.03	0.29	5.50	0.67
95/152	0.23	0.06	-0.34	0.16	2.08	0.36
95/153	0.05	0.05	-0.06	0.16	2.38	0.35
95/154	-0.22	0.07	0.06	0.21	4.61	0.71
95/155	-9.99	0.57	34.67	1.19	-364.28	3.31

- Station PRES. PRUDENTE - This station is similar to CACHOEIRA in that two days appear to be shifted from the other eight. PRES. PRUDENTE differs from CACHOEIRA in that the one sigma errors are significantly lower on Days 95/150 and 95/152 than the other eight days (refer to Table 2.16). The position computed using Days 95/150 and 95/152 produces a shift of about 0.3 m horizontally and 1.5 m vertically from the position computed using the other eight days (Note that the antenna heights used during processing were those reported on the station log forms). All RINEX data files were of the same size. Three positions for station PRES. PRUDENTE were provided. One position includes all 10 sessions and the other two will be subsets of these sessions. The second position was computed with sessions on Days 95/150 and 95/152 and the third position included the remaining 8 sessions. No conclusions can be drawn from the results as to which position is correct. It will be recommended that station PRES. PRUDENTE be reoccupied.

TABLE 2.16: Daily residuals (cm) for station PRES. PRUDENTE

Day	Latitude		Longitude		Ellipsoid Height	
	Residual	Formal Error	Residual	Formal Error	Residual	Formal Error
95/146	9.75	0.31	26.03	0.66	149.39	1.83
95/147	6.11	0.35	9.41	0.74	190.30	1.32
95/148	6.17	0.27	24.82	0.58	123.53	0.99
95/149	2.52	0.25	26.60	0.46	108.32	0.88
95/150	-1.04	0.06	-7.39	0.16	-48.07	0.36
95/151	5.18	0.29	20.00	0.59	138.23	0.95
95/152	0.14	0.05	-7.90	0.14	-49.06	0.33
95/153	5.64	0.20	29.80	0.45	98.91	1.39
95/154	4.78	0.21	30.99	0.45	93.76	1.03
95/155	3.61	0.21	30.61	0.50	65.59	0.84

- Station IQUITOS - The session on Day 95/154 was not included in the final solution computation. The session was less than ten hours and produced high residuals and errors.

- Station SALTA - The session on Day 95/155 was not included in the final solution computation. The session produced only 270 phase and range measurements resulting in poor residuals and errors.

2.4.2.4- TRANSFORMATION PARAMETERS

The SIRGAS station coordinates computed using GIPSY II were referenced (by default) to JPL/ITRF93. A transformation was needed to convert the JPL/ITRF93 coordinates to ITRF94.

The only high accuracy stations in South America with independently determined ITRF94 coordinates were five IGS stations whose data were collected as part of the SIRGAS campaign. The International Earth Rotation Service (IERS) had computed ITRF94 coordinates for these IGS stations for a 1993.0 epoch date. DGFI propagated these positions to the epoch of observation (refer to Table 2.17), 1995.42, using the IGS station velocities. The IGS stations' ITRF94 positions were then verified at NIMA. Two sets of coordinates for each of the IGS stations now existed -- the IERS-derived “true” ITRF94 coordinates and the NIMA-derived JPL/ITRF93 coordinates. These were used to derive a set of transformation parameters for the IGS sites that then could be used to convert all the SIRGAS station coordinates from JPL/ITRF93 to ITRF94. Unfortunately, the number of degrees of freedom available from five stations is very small. This certainly affects the accuracy of the transformation parameters. On the other hand, the IGS stations do have large geographic separations which is good with regard to their applicability to the continent as a whole. Figure 2.6 shows the geographic distribution of the IGS stations.

TABLE 2.17: IGS ITRF94 control station coordinates, epoch 1995.42

Station	Code	X (m)	Y (m)	Z (m)
Arequipa, Peru	AREQ	1942826.725	-5804070.245	-1796894.018
Isla de Pascua, Chile	EISL	-1884951.831	-5357595.820	-2892890.498
Fortaleza, Brazil	FORT	4985386.652	-3954998.583	-428426.523
Kourou, French Guiana	KOUR	3839591.454	-5059567.548	579956.899
Santiago, Chile	SANT	1769693.312	-5044574.130	-3468321.076

A seven parameter similarity transformation was computed using NIMA software called ‘SIMTRAN’ and GIPSY II’s utility ‘Transform’. The transformation parameters solved for include translation in X, Y and Z (TX, TY, TZ), rotation about X, Y and Z (RX, RY, RZ) and a scale factor (S). Control station positions in both reference frames, JPL/ITRF93 and ITRF94, and their one sigma positional errors were used as input to determine the transformation parameters.

Transformation parameters were computed for three (AREQ, KOUR and SANT), four (AREQ, FORT, KOUR and SANT) and five station (AREQ, EISL, FORT, KOUR and SANT) sets. The two programs, SIMTRAN and Transform, produced the same results. The differences between transformed coordinates using the parameters derived from four stations and three stations are below 5 millimeters (refer to Figure 2.7). Centimeter-level differences arise when comparing the transformed coordinates based on parameters derived from five stations to those of four, and three stations (refer to Figures 2.8 and 2.9 respectively). The transformation parameters derived from using the five IGS stations are shown in Table 2.18.

The only viable alternative to the above procedure was to apply the global ITRF93-to-ITRF94 transformation parameters computed by the IERS to the South American stations.

Transformation parameters for epoch 1995.42 were computed as prescribed in [Boucher and Altamini, 1996], and are shown in Table 2.19. These transformation parameters were applied to the JPL/ITRF93 SIRGAS station coordinates to obtain ITRF94 coordinates. The differences between transformed coordinates based on parameters derived from the 5 IGS stations and the IERS global parameters are below 5 centimeters (refer to Figure 2.10). Due to these small differences, the SIMTRAN transformation parameters (derived from the 5 IGS stations) were used for computing the final ITRF94 coordinates (refer to Table 2.18).

TABLE 2.18: Transformation parameters from JPL/ITRF93 to ITRF94, epoch 1995.42, using IGS stations AREQ, EISL, FORT, KOUR and SANT

Translation (cm)			**Rotation (.001")**			**Scale (10^{-8})**
TX	**TY**	**TZ**	**RX**	**RY**	**RZ**	**S**
3.680 ± 1.47	-2.100 ± 1.53	1.240 ± 2.36	-1.720 ± 0.86	-0.804 ± 0.383	-0.434 ± 0.563	-0.288 ± 0.161

TABLE 2.19: Global ITRF93-to-ITRF94 transformation parameters, epoch 1995.42

Translation (cm)			**Rotation (.001")**			**Scale (10^{-8})**
TX	**TY**	**TZ**	**RX**	**RY**	**RZ**	**S**
1.5518	0.2032	0.9064	1.2062	0.6098	0.5890	-0.04

2.4.2.5- RESULTS

Absolute point positions and their corresponding one sigma errors are provided for all 69 stations occupied during the SIRGAS campaign. These results are not included in this report, in order to avoid confusion with the official ones, but are available upon request at IBGE or NIMA. Table 2.20 lists the names of the stations, codes and number of sessions processed.

Standard deviations computed by GIPSY for the station coordinates are less than or equal to 2 mm in X, Y and Z for all stations except AREQUIPA ARE1, BALMACEDA and S.J DE CHIQUITOS. Station AREQUIPA ARE1 had only two sessions (one 23 hour and one 4 hour session). AREQUIPA ARE1, BALMACEDA and S.J DE CHIQUITOS have standard deviations of 6 mm or less in X, Y and Z.

2.4.2.6- RECOMMENDATIONS

PRES. PRUDENTE (UEPP) is the only station of 69 that we cannot provide a confident solution for. The site did not provide good residuals and accuracies over the ten day period. The statistics indicate that days 95/150 and 95/152 produce the most confident solution. Due to the small number of acceptable sessions, it is recommended that PRES. PRUDENTE be reoccupied to establish an accurate solution for the station.

2.4.2.7- REFERENCE

BOUCHER, C. and ALTAMINI, Z.. International Terrestrial Reference Frame. *GPS WORLD*, Volume 7, Number 9, pp. 71-74, September 1996.

TABLE 2.20: Number of sessions processed by NIMA for each station

STATION	CODE	Sessions Processed
AGUA LINDA	AGUA	9
ANTOFAGASTA	ANTO	10
AREQUIPA	ARE1	2
AREQUIPA	ARE2	2
AREQUIPA	AREQ	10
ASUNCION	ASUN	10
BALMACEDA	BLMC	9
BOGOTA	BOGO	9
BOGOTA	BOGT	10
BOM JESUS LAPA	BOMJ	9
BRASILIA	BRAZ	10
CACHOEIRA	CACH	8
CAMIRI	CAMI	10
LA CANOA	CANO	10
CARTAGENA	CART	10
CARRIEL SUR	CASU	9
CHAMONATE	CHAM	10
S.J DE CHIQUITOS	CHIQ	3
CLARA	CLAR	10
CRICYT	CRIC	10
CUIABA	CUIB	8
CURITIBA	CURI	10
ISLA DE PASCUA	EISL	10
M ESTIGARRIBIA	ESTI	10
FORTALEZA MONT	FEZA	4
FORTALEZA	FORT	10
GALAPAGOS	GALA	9
HUICHURAYA	HUIC	10
CARLOS IBANEZ	IBAN	10
PUERTO IGUAZU	IGU2	10
PUERTO IGUAZU	IGUA	10
IMPERATRIZ	IMPZ	10
PTO. INIRIDA	INIR	10
IQUITOS	IQUI	5
JUNQUITO	JUNQ	10
KAMA	KAMA	10
KOUROU	KOUR	10
LATACUNGA	LATA	10
LETICIA	LETI	10
LIMA	LIM1	10
LIMA	LIM2	10
LIMA	LIMA	8
LOTE 10B	LO10	10
LOTE 24	LOTE	10
LA PLATA	LPGS	5
EL MAITEN	MAI1	10
EL MAITEN	MAI2	10
MANAUS	MANA	8
MARACAIBO	MAR1	9

TABLE 2.20 (continued): Number of sessions processed by NIMA for each station

STATION	**CODE**	**Sessions Processed**
MARACAIBO	MARA	10
MONTEVIDEO	MONT	10
MORRO	MORR	10
O'HIGGINS	OHIG	9
OLLAGUE	OLLA	10
CURITIBA	PARA	10
PASTO	PAST	10
PIURA	PIUR	5
VILLA ROBLES	RBLS	10
RIBERALTA	RIBE	10
RIO GRANDE	RIO1	10
RIO DE JANEIRO	RIOD	7
RIO GRANDE	RIOG	10
SANTIAGO	SANT	10
SALTA	UNSA	8
VIÇOSA	VICO	10
CERRO VIGIA	VIGI	10
YACARE	YACA	9
ZAMORA	ZAMO	9

FIGURE 2.6: Geographic distribution of the IGS stations used to derive the transformation parameters from ITRF93 to ITRF94

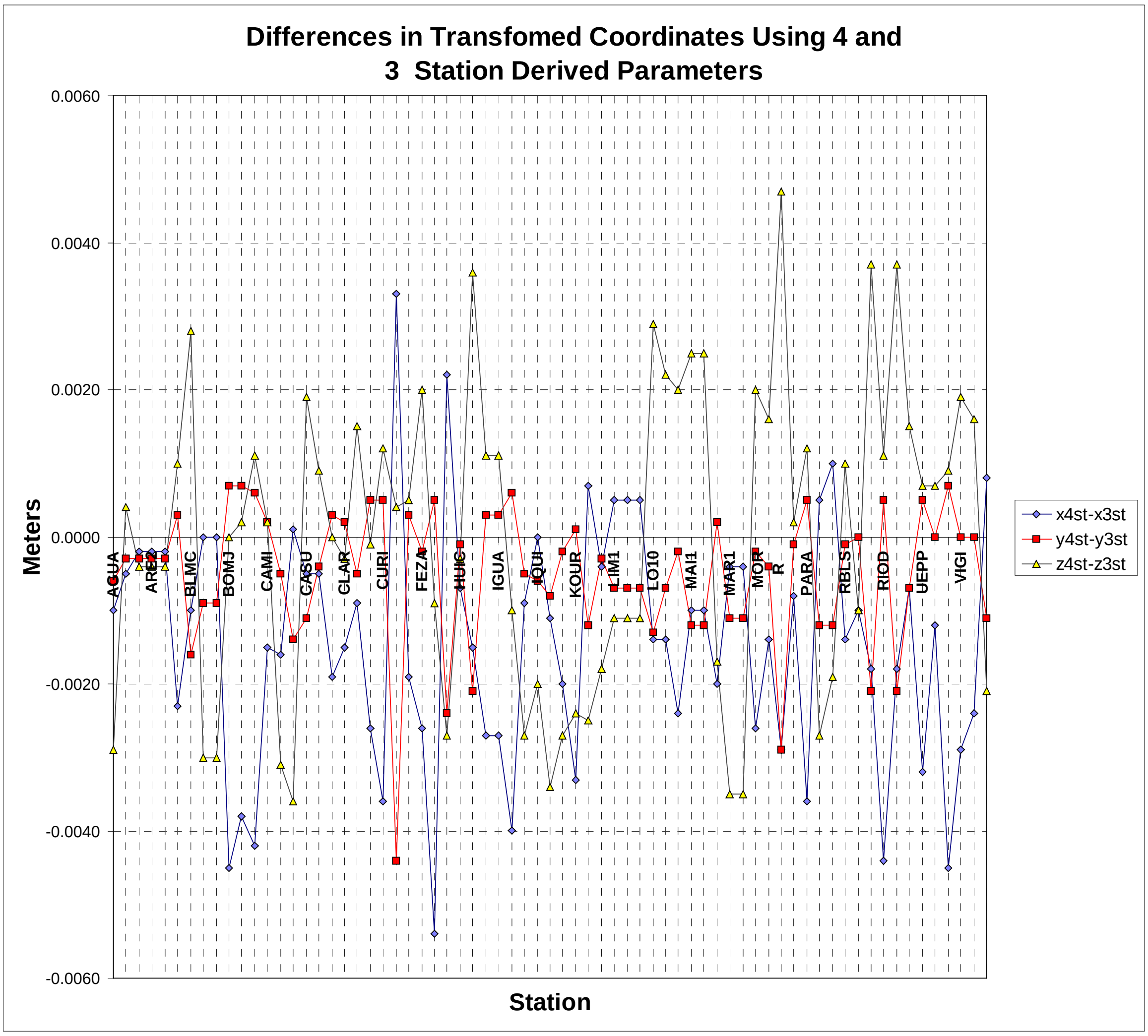


FIGURE 2.7: Graphic representation of the differences in transformed coordinates using parameters derived from 4 stations (designated as x4st, y4st and z4st) and 3 stations (designated as x3st, y3st and z3st). Stations are listed, from left to right, in the same order as Table 2.20

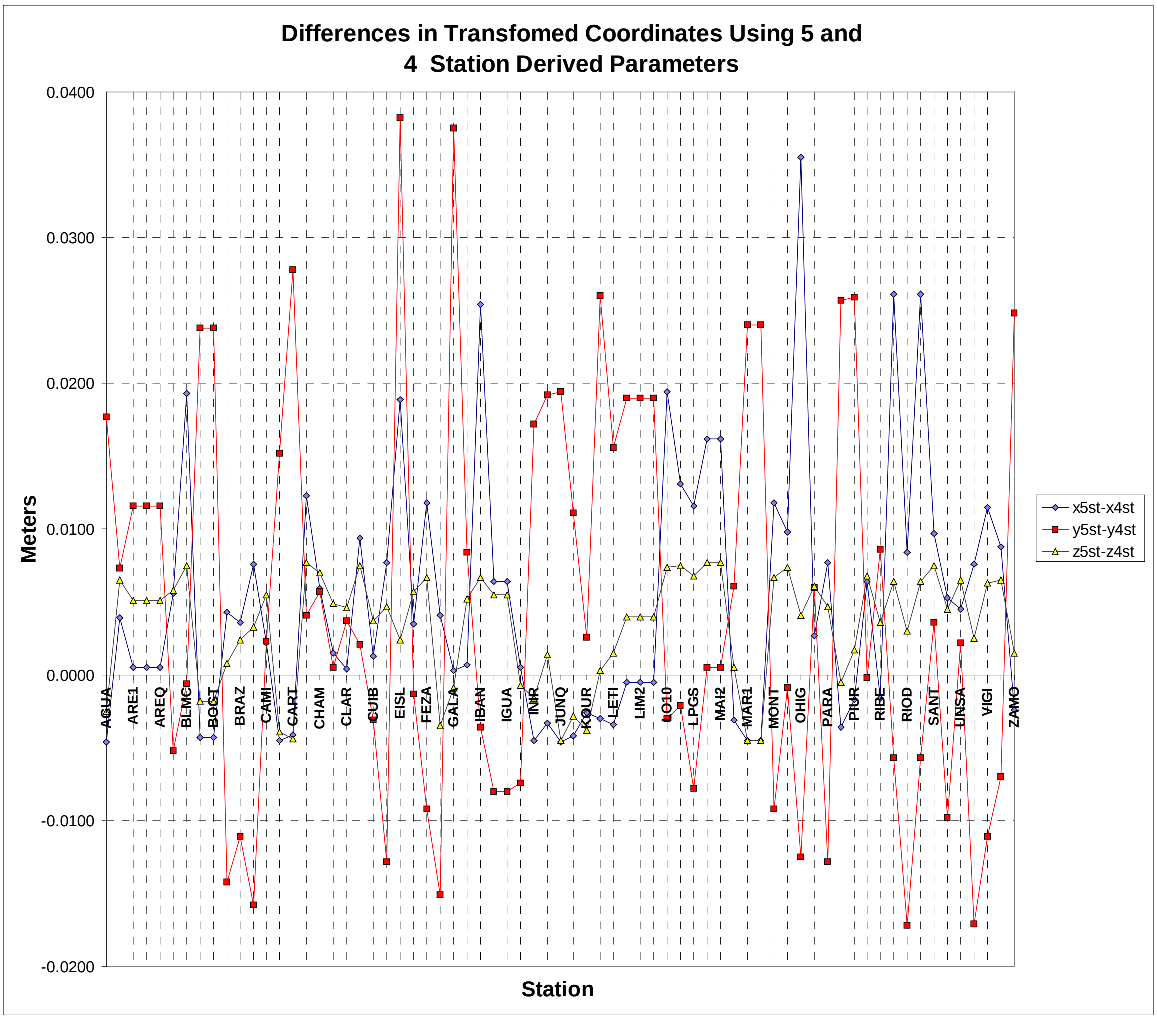


FIGURE 2.8: Graphic representation of the differences in transformed coordinates using parameters derived from 5 stations (designated as x5st, y5st and z5st) and 4 stations (designated as x4st, y4st and z4st). Stations are listed, from left to right, in the same order as Table 2.20

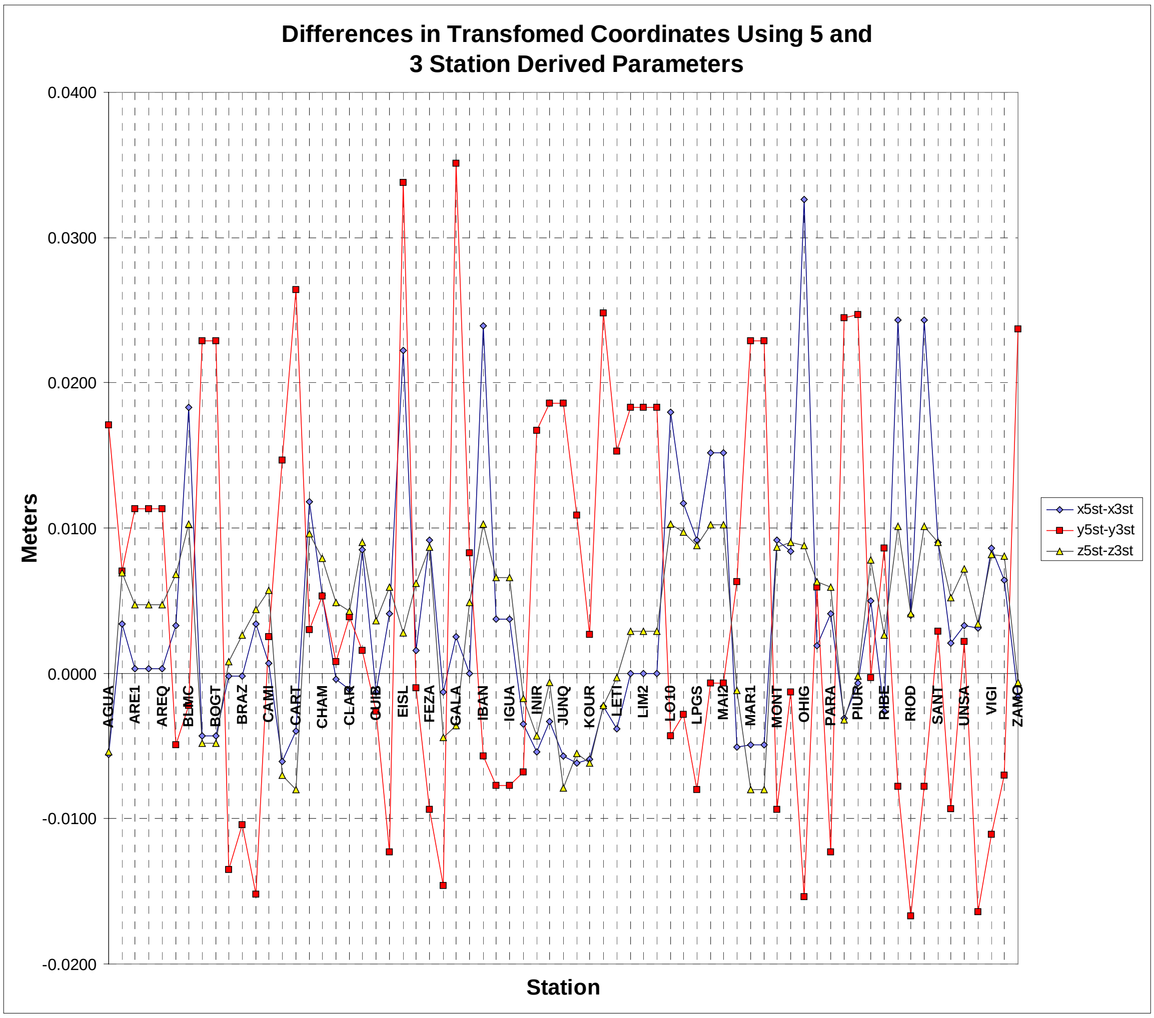


FIGURE 2.9: Graphic representation of the differences in transformed coordinates using parameters derived from 5 stations (designated as x5st, y5st and z5st) and 3 stations (designated as x3st, y3st and z3st). Stations are listed, from left to right, in the same order as Table 2.20

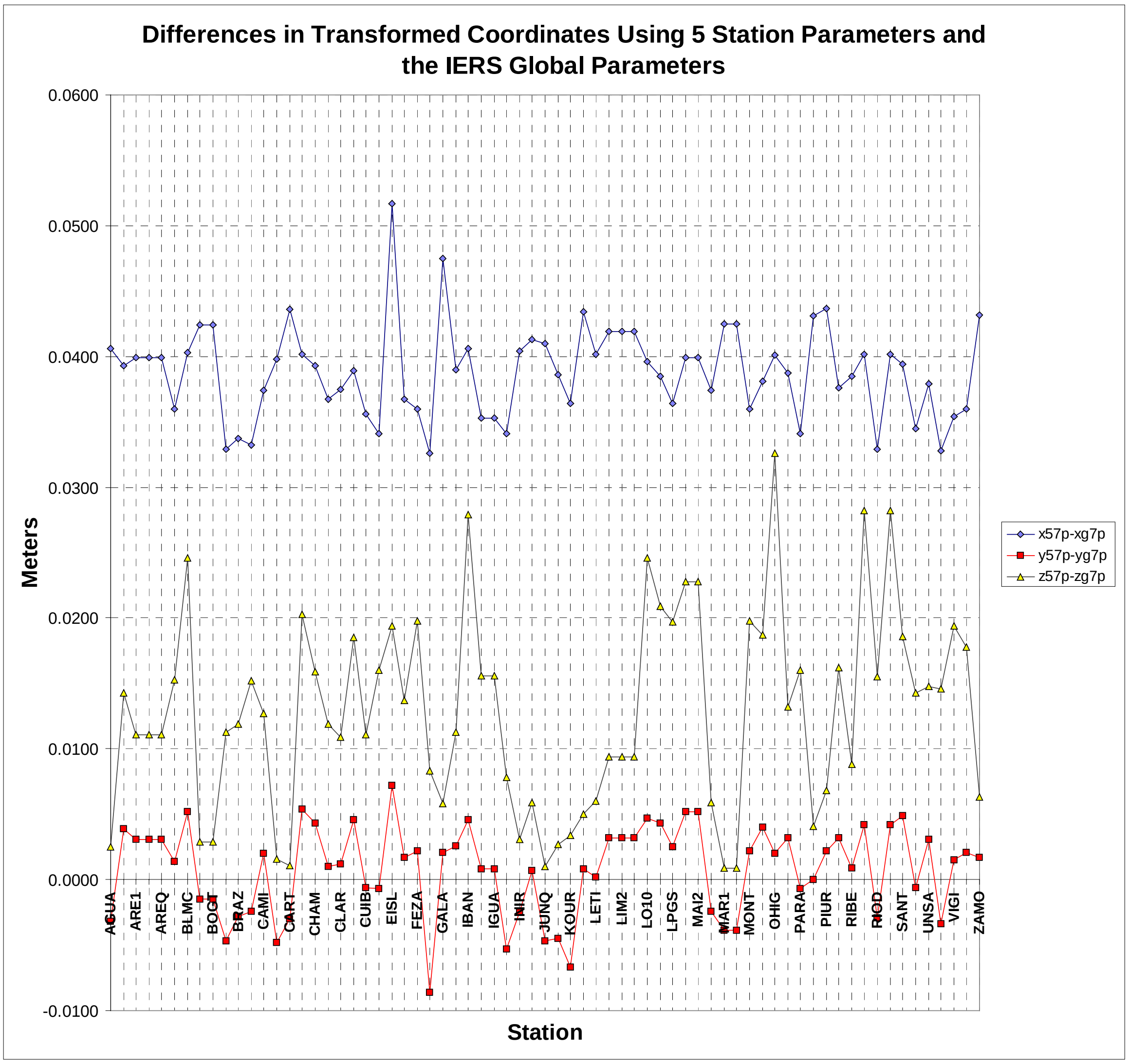


FIGURE 2.10: Graphic representation of the differences in transformed coordinates using parameters derived from 5 stations (designated as x57p, y57p and z57p) and the IERS global parameters (designated as xg7p, yg7p and zg7p). Stations are listed, from left to right, in the same order as Table 2.20

2.5- FINAL COORDINATES OF THE SIRGAS 1995.4 REFERENCE FRAME

Independent coordinate solutions of the SIRGAS May/June 1995 GPS campaign (referred to as epoch 1995.4) were computed by Deutsches Geodaetisches Forschungsinstitut (DGFI) and by National Imagery and Mapping Agency (NIMA). DGFI used the Bernese software version 3.4 with some modifications implemented at DGFI, and NIMA used the GIPSY-OASIS II software. The station coordinates computed in the first step by DGFI and by NIMA are nearly unconstrained solutions and refer to the IERS (International Earth Rotation Service) Terrestrial Reference Frame 1993 (ITRF93) epoch 1995.4 by fixing the satellite orbits in this frame. DGFI used the International GPS Service (IGS) precise combined orbits and clock offsets while the NIMA results were computed with the JPL orbits and clock parameters. After applying a seven parameter similarity transformation (Helmert transformation), the maximum difference between the DGFI and NIMA coordinates was 3.5 cm. The rms differences between the solutions were ± 1.0 cm in X, ± 1.4 cm in Y and ± 0.7 cm in Z.

DGFI's solution includes a correction for the elevation angle dependent phase center variation of each type of used receiver antennae as proposed by IGS (model IGS-01). This correction is not included in the NIMA solution. The error caused by not including this correction reduces in principal to a constant coordinate (mainly height) offset for each antenna type because of the (nearly) 24 hours permanent observations and consequently full coverage of the satellite passes under all elevation angles. It was therefore decided to combine the two solutions in the following manner:

1. Compute a separate seven parameter similarity transformation between the DGFI solution and each of the five receiver antenna type sub-networks (Ashtech P 700228, Ashtech P 700718, Leica SR299, Trimble 4000ST/TR GP, Dorne Margolin) of the NIMA solution. This will account for the small differences in the antenna corrections as well as the small reference frame differences.

2. Apply the transformation to the five antenna type subsets of the NIMA coordinates. The rms differences between the DGFI coordinates and the transformed NIMA coordinates reduce then to ± 0.7 cm in X, ± 0.9 cm in Y and ± 0.6 cm in Z.

3. Compute the mean of the DGFI coordinates and the transformed NIMA coordinates to produce a combined set of coordinates in the ITRF93.

The final coordinates should be given in the ITRF94 (the most recent realization of the ITRF up to date) according to a previous decision of the SIRGAS Committee. In order to accomplish this, a subset of SIRGAS stations identical with global stations independently determined in the ITRF94 is required. Using these stations, transformation parameters can be computed to convert the SIRGAS coordinates from ITRF93 to ITRF94.

Only four stations (Arequipa, Fortaleza, Kourou and Santiago) on the mainland of South America are included in the official ITRF94 solution of the IERS with station coordinates at epoch 1993.0 and velocities to extrapolate to epoch 1995.4. This was considered too few to derive a good seven parameter transformation. Two nearby SIRGAS stations with IERS-determined ITRF94 coordinates and velocities (Easter Island and O'Higgins) outside the mainland may be added to increase the number of stations identical with the SIRGAS reference frame. Doing so, however, considerable distortions were found in the network.

The International GPS Service (IGS) is computing station coordinate and velocity solutions in the ITRF more frequently than the IERS. At the time of the final SIRGAS computations, two 1996 solutions of the IGS Analysis Centers CODE (Berne) and JPL (Pasadena), respectively, were available, both referring to the ITRF94 and including three additional SIRGAS stations on the South American mainland (Bogota, Brasilia and La Plata). The CODE and JPL solutions are computed with the Bernese and GIPSY software, respectively. Since this software is almost identical with that used by DGFI and NIMA, respectively, it was decided to use the average CODE and JPL station coordinates (referring to ITRF94 and extrapolated to epoch 1995.4) as fiducial coordinates. The maximum component differences between the CODE and JPL coordinates for the nine stations are 3.6 cm in Bogota and Easter Island and 3.8 cm in Santiago. Table 2.21 shows the CODE and JPL coordinates at epoch 1995.4.

The final SIRGAS solution was computed by a seven parameter similarity transformation between the mean CODE/JPL coordinates in ITRF94 at epoch 1995.4 and the combined DGFI/NIMA coordinates using the nine IGS stations. The transformation parameters were then applied to the combined DGFI/NIMA coordinates to produce the final SIRGAS coordinates in ITRF94 at epoch 1995.4. The result is given in Table 2.22 and Table 2.23.

TABLE 2.21: IGS solutions used for SIRGAS transformation to ITRF94

1. CODE Global Solution / South America Subset at Epoch 1995.4

Station	Name	X (m)	Y (m)	Z (m)
Kourou	KOUR	3839591.4394	-5059567.5478	579956.9204
Bogota	BOGT	1744399.1020	-6116037.8616	512731.6066
Fortaleza	FORT	4985386.6253	-3954998.5699	-428426.4967
Easter Island	EISL	-1884951.8559	-5357595.8164	-2892890.4748
O'Higgins	OHIG	1525872.4699	-2432481.3126	-5676146.0936
Santiago	SANT	1769693.3142	-5044574.1362	-3468321.0558
Arequipa	AREQ	1942826.7156	-5804070.2441	-1796893.9806
Brasilia	BRAZ	4115014.1083	-4550641.5325	-1741444.0740
La Plata	LPGS	2780102.9819	-4437418.8639	-3629404.5978

2. JPL Global Solution / South America Subset at Epoch 1995.4

Station	Name	X (m)	Y (m)	Z (m)
Kourou	KOUR	3839591.4431	-5059567.5364	579956.8960
Bogota	BOGT	1744399.1381	-6116037.8340	512731.5910
Fortaleza	FORT	4985386.6514	-3954998.5708	-428426.5246
Easter Island	EISL	-1884951.8538	-5357595.8460	-2892890.5113
O'Higgins	OHIG	1525872.4584	-2432481.2891	-5676146.1154
Santiago	SANT	1769693.3174	-5044574.1386	-3468321.0935
Arequipa	AREQ	1942826.7299	-5804070.2525	-1796894.0139
Brasilia	BRAZ	4115014.1111	-4550641.5159	-1741444.1036
La Plata	LPGS	2780102.9739	-4437418.8473	-3629404.6230

TABLE 2.22: SIRGAS final coordinates (ITRF94, epoch 1995.4)

Station	X (m)	Sigma	Y (m)	Sigma	Z (m)	Sigma
ANTARCTICA						
O'HIGGINS IGS	1525872.458	0.006	-2432481.304	0.006	-5676146.102	0.006
ARGENTINA						
SALTA	2412830.370	0.003	-5271936.696	0.003	-2652209.146	0.003
PUERTO IGUAZU	3337066.730	0.003	-4688978.550	0.004	-2740427.110	0.003
PUERTO IGUAZU 2	3337008.782	0.003	-4689046.261	0.004	-2740379.965	0.003
VILLA ROBLES	2462064.885	0.003	-5074756.607	0.003	-2967964.511	0.003
CRICYT	1932215.193	0.004	-5001352.644	0.004	-3444510.828	0.003
MORRO	2216022.790	0.004	-4857391.581	0.004	-3479484.155	0.003
LA PLATA IGS	2780102.979	0.004	-4437418.845	0.004	-3629404.604	0.004
LOTE 24	2035975.384	0.004	-4592847.631	0.004	-3916827.408	0.004
EL MAITEN 1	1529296.195	0.004	-4493524.883	0.004	-4247352.584	0.004
EL MAITEN 2	1529304.823	0.004	-4493528.637	0.004	-4247346.142	0.004
LOTE 10B	1627558.482	0.004	-4126035.190	0.005	-4569051.335	0.004
RIO GRANDE	1429907.729	0.005	-3495354.729	0.005	-5122698.707	0.005
RIO GRANDE 2	1429883.026	0.005	-3495363.268	0.005	-5122698.772	0.005
BOLIVIA						
RIBERALTA	2539620.472	0.004	-5723487.984	0.003	-1210304.560	0.004
CLARA	2769004.289	0.003	-5478490.464	0.003	-1727517.058	0.003
HUICHURAYA	2239251.534	0.003	-5678506.612	0.003	-1858125.455	0.003
SJ DE CHIQUITOS	2965510.326	0.003	-5299418.003	0.003	-1945242.100	0.003
CAMIRI	2669199.492	0.003	-5368719.469	0.003	-2173298.384	0.003
OLLAGUE	2223873.553	0.003	-5515451.363	0.003	-2309233.470	0.003
BRAZIL						
MANAUS	3179009.385	0.004	-5518662.101	0.004	-344401.888	0.004
FORTALEZA IGS	4985386.661	0.005	-3954998.585	0.005	-428426.515	0.005
IMPERATRIZ	4289656.485	0.004	-4680884.940	0.004	-606347.402	0.004
BOM JESUS LAPA	4510195.859	0.004	-4268322.294	0.005	-1453035.370	0.004
CUIABA	3430711.398	0.003	-5099641.528	0.004	-1699432.996	0.003
BRASILIA IGS	4115014.106	0.004	-4550641.513	0.004	-1741444.086	0.004
VIÇOSA	4373283.325	0.004	-4059639.008	0.005	-2246959.796	0.004
PRES. PRUDENTE	3687624.310	0.003	-4620818.571	0.004	-2386880.407	0.004
CACHOEIRA	4164684.609	0.004	-4162401.036	0.004	-2445011.067	0.004
RIO DE JANEIRO	4280294.892	0.004	-4034431.192	0.005	-2458141.455	0.004
CURITIBA	3763751.639	0.004	-4365113.768	0.004	-2724404.755	0.004
CURITIBA RM3	3763730.301	0.004	-4365122.141	0.004	-2724416.116	0.004
CHILE						
ANTOFAGASTA	1958449.007	0.003	-5505640.820	0.003	-2547545.258	0.003
CHAMONATE	1901401.818	0.003	-5343947.505	0.003	-2907705.533	0.003
ISLA PASCUA IGS	-1884951.849	0.006	-5357595.833	0.007	-2892890.495	0.006
SANTIAGO IGS	1769693.314	0.004	-5044574.146	0.004	-3468321.077	0.003
CARRIEL SUR	1489934.459	0.004	-4893088.153	0.004	-3797571.442	0.004
BALMACEDA	1396400.014	0.004	-4220505.197	0.005	-4559036.927	0.004
CARLOS IBANEZ	1261898.966	0.005	-3633641.363	0.005	-5070719.386	0.005
COLOMBIA						
CARTAGENA	1567576.223	0.005	-6075260.774	0.006	1142666.328	0.005
BOGOTA IGS	1744399.102	0.005	-6116037.852	0.005	512731.597	0.005
BOGOTA 2	1744517.537	0.005	-6116052.016	0.005	512580.716	0.005
PUERTO INIRIDA	2393740.675	0.004	-5896617.064	0.005	424900.162	0.004
PASTO	1402942.266	0.004	-6221912.708	0.005	153379.854	0.005
LETICIA	2181609.154	0.004	-5975453.400	0.004	-463617.196	0.004

TABLE 2.22 (continued): SIRGAS final coordinates (ITRF94, epoch 1995.4)

Station	X (m)	Sigma	Y (m)	Sigma	Z (m)	Sigma
ECUADOR						
GALAPAGOS	-28822.438	0.005	-6377927.538	0.006	-50938.985	0.005
LATACUNGA	1258247.886	0.004	-6255142.665	0.005	-90040.863	0.005
ZAMORA	1221570.888	0.004	-6244846.756	0.005	-448051.413	0.004
FR. GUIANA						
KOUROU IGS	3839591.438	0.005	-5059567.532	0.005	579956.906	0.005
PARAGUAY						
M. ESTIGARRIBIA	2904892.131	0.003	-5152575.382	0.003	-2378537.612	0.003
ASUNCION	3091071.036	0.003	-4873340.751	0.004	-2707075.517	0.003
PERU						
IQUITOS	1835340.202	0.004	-6094433.069	0.004	-412696.117	0.004
PIURA	1034520.169	0.004	-6267349.145	0.005	-573960.395	0.004
LIMA	1401316.079	0.004	-6077986.653	0.004	-1328579.858	0.004
LIMA 1	1401319.591	0.004	-6077984.752	0.004	-1328584.859	0.004
LIMA 2	1401310.782	0.004	-6077987.093	0.004	-1328583.484	0.004
AREQUIPA IGS	1942826.727	0.004	-5804070.249	0.003	-1796893.994	0.004
URUGUAY						
YACARE	2959094.220	0.003	-4630116.948	0.004	-3227701.620	0.003
MONTEVIDEO	2909132.981	0.004	-4355451.209	0.004	-3627801.306	0.004
MONTEVIDEO FORT	2909138.813	0.004	-4355442.113	0.004	-3627792.918	0.004
CERRO VIGIA	3153246.746	0.004	-4273958.035	0.004	-3519881.481	0.004
VENEZUELA						
MARACAIBO	1976117.082	0.005	-5948895.246	0.006	1173592.101	0.005
MARACAIBO ASTRO	1976095.996	0.005	-5948905.112	0.006	1173566.073	0.005
JUNQUITO	2442530.154	0.005	-5779900.001	0.006	1150758.506	0.005
LA CANOA	2778756.644	0.005	-5662504.745	0.005	943998.865	0.005
AGUA LINDA	2432526.685	0.005	-5859980.898	0.005	649900.202	0.005
KAMA	3058874.046	0.004	-5566111.193	0.005	595136.405	0.004

REMARKS

ANTOFAGASTA : coordinates refer to position before 1995 earthquake
BALMACEDA : based on DGFI solution only
BOGOTA IGS : based on NIMA solution only
PRES. PRUDENTE : based on DGFI solution only
SJ DE CHIQUITOS : based on NIMA solution only including 3 days of observations

The given rms errors (sigma) are mainly resulting from the transformation errors of the seven parameters (Helmert) transformation.

TABLE 2.23: SIRGAS final coordinates (transformed ellipsoidal coordinates in GRS80)

Station	Latitude [° ′ ″]	σ[″]	Longit. [° ′ ″]	σ[″]	Height [m]	σ[m]
ANTARCTICA						
O'HIGGINS IGS	-63 19 14.6052	.0002	-57 54 1.2284	.0002	30.680	.006
ARGENTINA						
SALTA	-24 43 38.8473	.0001	-65 24 27.5176	.0001	1257.793	.003
PUERTO IGUAZU	-25 36 42.4710	.0001	-54 33 40.2665	.0001	192.455	.004
PUERTO IGUAZU 2	-25 36 40.7866	.0001	-54 33 43.3656	.0001	191.523	.004
VILLA ROBLES	-27 54 42.5691	.0001	-64 7 9.2298	.0001	193.237	.003
CRICYT	-32 53 36.4993	.0001	-68 52 35.5183	.0001	858.974	.004
MORRO	-33 16 8.1598	.0001	-65 28 36.2638	.0001	1000.942	.004
LA PLATA IGS	-34 54 24.2868	.0001	-57 55 56.2773	.0001	29.859	.004
LOTE 24	-38 7 41.4754	.0001	-66 5 33.5196	.0001	293.177	.004
EL MAITEN 1	-42 0 50.0779	.0001	-71 12 17.4606	.0001	897.413	.004
EL MAITEN 2	-42 0 49.7854	.0001	-71 12 17.1582	.0001	897.807	.004
LOTE 10B	-46 2 32.7031	.0001	-68 28 21.7818	.0001	736.102	.004
RIO GRANDE	-53 47 7.7034	.0001	-67 45 4.0261	.0001	32.024	.005
RIO GRANDE 2	-53 47 7.7425	.0001	-67 45 5.4515	.0001	31.220	.005
BOLIVIA						
RIBERALTA	-11 0 42.0239	.0001	-66 4 20.0219	.0001	161.832	.003
CLARA	-15 49 6.4814	.0001	-63 11 11.4235	.0001	394.903	.003
HUICHURAYA	-17 2 17.1172	.0001	-68 28 43.6543	.0001	4305.179	.003
SJ DE CHIQUITOS	-17 52 24.9991	.0001	-60 46 8.3487	.0001	542.279	.003
CAMIRI	-20 2 53.2392	.0001	-63 33 52.3039	.0001	1739.485	.003
OLLAGUE	-21 21 6.0096	.0001	-68 2 25.1467	.0001	4205.162	.003
BRAZIL						
MANAUS	-3 6 58.1436	.0001	-60 3 21.7098	.0001	40.177	.004
FORTALEZA IGS	-3 52 38.8070	.0001	-38 25 32.2037	.0001	19.495	.005
IMPERATRIZ	-5 29 30.3607	.0001	-47 29 50.0434	.0001	105.041	.004
BOM JESUS LAPA	-13 15 20.0125	.0001	-43 25 18.2455	.0001	419.413	.004
CUIABA	-15 33 18.9491	.0001	-56 4 11.5191	.0001	237.428	.004
BRASILIA IGS	-15 56 50.9135	.0001	-47 52 40.3270	.0001	1106.027	.004
VIÇOSA	-20 45 41.4042	.0001	-42 52 11.9609	.0001	665.962	.004
PRES. PRUDENTE	-22 7 11.6594	.0001	-51 24 30.7216	.0001	430.945	.004
CACHOEIRA	-22 41 13.0605	.0001	-44 59 3.4351	.0001	620.300	.004
RIO DE JANEIRO	-22 49 4.2423	.0001	-43 18 22.5946	.0001	8.647	.004
CURITIBA	-25 26 54.1291	.0001	-49 13 51.4368	.0001	925.759	.004
CURITIBA RM3	-25 26 54.5685	.0001	-49 13 52.2108	.0001	923.785	.004
CHILE						
ANTOFAGASTA	-23 41 46.8414	.0001	-70 25 7.2198	.0001	54.676	.003
CHAMONATE	-27 17 51.2227	.0001	-70 24 51.1223	.0001	329.358	.003
ISLA PASCUA IGS	-27 8 53.5518	.0002	-109 22 59.8656	.0002	114.530	.007
SANTIAGO IGS	-33 9 1.0430	.0001	-70 40 6.8020	.0001	723.062	.004
CARRIEL SUR	-36 46 35.4231	.0001	-73 3 52.6469	.0001	25.652	.004
BALMACEDA	-45 54 52.6813	.0001	-71 41 33.5085	.0001	537.013	.004
CARLOS IBANEZ	-53 0 7.4753	.0001	-70 50 55.6651	.0001	46.099	.005
COLOMBIA						
CARTAGENA	10 23 22.7500	.0002	-75 31 54.3584	.0002	-4.460	.006
BOGOTA IGS	4 38 24.2573	.0001	-74 4 51.3831	.0001	2577.065	.005
BOGOTA 2	4 38 19.2421	.0001	-74 4 47.8153	.0001	2610.816	.005
PUERTO INIRIDA	3 50 43.5774	.0001	-67 54 18.8355	.0001	95.051	.005
PASTO	1 23 12.6606	.0001	-77 17 35.5918	.0001	1841.733	.005
LETICIA	-4 11 47.1293	.0001	-69 56 35.1830	.0001	95.617	.004

TABLE 2.23 (continued): SIRGAS final coordinates (transformed to GRS80)

Station	Latitude [° ′ ″]	σ[″]	Longit. [° ′ ″]	σ[″]	Height [m]	σ[m]
ECUADOR						
GALAPAGOS	-0 27 38.4376	.0001	-90 15 32.1232	.0001	60.448	.006
LATACUNGA	-0 48 50.2237	.0001	-78 37 35.3902	.0001	2941.238	.005
ZAMORA	-4 3 17.1494	.0001	-78 55 55.1269	.0001	926.353	.005
FR. GUIANA						
KOUROU IGS	5 15 7.8481	.0001	-52 48 21.4529	.0001	-25.769	.005
PARAGUAY						
M. ESTIGARRIBIA	-22 2 22.2088	.0001	-60 35 12.4512	.0001	185.642	.003
ASUNCION	-25 16 43.7807	.0001	-57 36 49.6439	.0001	92.858	.004
PERU						
IQUITOS	-3 44 5.3642	.0001	-73 14 25.1186	.0001	111.507	.004
PIURA	-5 11 51.5298	.0001	-80 37 37.1561	.0001	71.839	.005
LIMA	-12 6 10.8495	.0001	-77 1 1.1465	.0001	156.557	.004
LIMA 1	-12 6 11.0159	.0001	-77 1 1.0192	.0001	156.566	.004
LIMA 2	-12 6 10.9701	.0001	-77 1 1.3205	.0001	156.573	.004
AREQUIPA IGS	-16 27 55.8518	.0001	-71 29 34.0500	.0001	2488.934	.003
URUGUAY						
YACARE	-30 35 53.4227	.0001	-57 25 2.9022	.0001	145.696	.004
MONTEVIDEO	-34 53 17.9507	.0001	-56 15 35.5758	.0001	158.083	.004
MONTEVIDEO FORT	-34 53 17.8077	.0001	-56 15 35.1859	.0001	149.738	.004
CERRO VIGIA	-33 42 38.1770	.0001	-53 34 50.8216	.0001	165.691	.004
VENEZUELA						
MARACAIBO	10 40 26.3189	.0002	-71 37 27.9533	.0002	28.424	.006
MARACAIBO ASTRO	10 40 25.4701	.0002	-71 37 28.7141	.0002	26.272	.006
JUNQUITO	10 27 38.3983	.0002	-67 5 29.5734	.0002	2016.965	.006
LA CANOA	8 34 5.8707	.0001	-63 51 41.2668	.0001	153.365	.005
AGUA LINDA	5 53 15.2317	.0001	-67 27 22.5248	.0001	89.947	.005
KAMA	5 23 20.6412	.0001	-61 12 31.9163	.0001	1116.734	.005

REMARKS

The used ellipsoidal parameters are: a = 6378137.000 m, f = 1 : 298.2572221
The given heights are ellipsoidal heights.

2.6- FUTURE USE OF THE SIRGAS REFERENCE FRAME COORDINATES

2.6.1- INTRODUCTION

One of the principal objectives of the SIRGAS project is to establish and to maintain a continental reference network realizing the geocentric reference system by a frame of precisely positioned stations. The main reason for this objective is the application of global satellite techniques (e.g. GPS) in geodetic positioning. The determination of terrestrial station positions from geodetic satellite observations requires the consistency between the terrestrial and the satellite reference systems. As the satellite orbits are generally given in the IERS Terrestrial Reference Frame (ITRF, which is nowadays practically identical with the actualized WGS84), we need the coordinates of terrestrial fiducial points in the same system. This requirement is in principal fulfilled by providing the SIRGAS coordinates in the ITRF.

The SIRGAS reference network was observed in May/June 1995 (epoch t_0 = 1995.4). The station coordinates refer thus to this specific epoch. The materialized stations at the Earth's surface, however, are moving due to recent crustal movements. As a consequence the terrestrial station coordinates are not valid for any other epoch than 1995.4. On the other hand, the satellite orbits are not affected by the crustal movements, i.e., the terrestrial reference frame is diverging from the satellite reference frame. In the global ITRF network this fact is taken into account by providing a station velocity for each station along with the station coordinates for a defined reference epoch. The precise satellite orbits are computed from the observations at global tracking stations with their coordinates at the actual observation time derived from the reference epoch coordinates plus the motion until the observation epoch (velocity multiplied by time interval).

The maintenance of the SIRGAS reference frame includes therefore - besides the physical maintenance of the monumented sites - also the time evolution of the coordinates in order to guarantee the consistency between the terrestrial (SIRGAS) and the satellite reference system. For this purpose, station velocities $\underline{V}$ (i.e., coordinate changes dX/dt, dY/dt, dZ/dt) are required for each station. These velocities may either be derived from repeated observations and coordinate determinations, or from crustal deformation models.

2.6.2- STATION VELOCITIES FROM REPEATED OBSERVATIONS

The stations of the International GPS Service for Geodynamics (IGS) included in the SIRGAS network are equipped with permanently operating GPS receivers. The observation data sets are routinely evaluated providing station coordinates on a weekly basis. The organization of the IGS distinguishes between two levels of stations (IGS 1997): IGS global stations and IGS regional stations. The observations of the global stations are processed by seven Analysis Centers (AC) and combined to one common solution by three Global Network Associate Analysis Centers (GNAAC); observations of the regional stations are processed by six Regional Network Associate Analysis Centers (RNAAC). All the sets of data, global and regional, are combined to a so-called polyhedron solution (P-SINEX) by two GNAAC's including presently more than 120 stations.

For South America, the RNAAC SIR (i.e. SIRGAS) operated by Deutsches Geodaetisches Forschungsinstitut (DGFI) is processing all the available data from the existing permanently observing stations in this region. These include presently (May 1997) fourteen SIRGAS stations. The result is then combined with others by the GNAAC's to the global polyhedron solution. In this way we get weekly coordinates for all the included permanently observing SIRGAS stations in the ITRF and can thus derive station velocities. It is strongly recommended to join this procedure by installing as many permanent GPS receivers as possible at SIRGAS sites. More information may be requested from IGS or the RNAAC SIR.

To derive the velocities of stations not equipped with permanent GPS receivers we need at least one (better more than one) repetition measurement (GPS campaign) at time t_i for another coordinate determination. From coordinate changes $\underline{\Delta X}$ $(\Delta X, \Delta Y, \Delta Z) = \underline{X}\ (t_i) - \underline{X}\ (t_o)$ divided by the time interval Δt we then get the velocities $\underline{V}$ (V_X, V_Y, V_Z):

$$\underline{V} = \Delta\underline{X} / \Delta t \ . \qquad (1)$$

To improve the accuracy of velocity estimations, the time interval between the campaigns should not be too short. Five years seems to be a reasonable time span.

2.6.3- STATION VELOCITIES FROM CRUSTAL DEFORMATION MODELS

As long as there has been no repetitive coordinate determination, station velocities cannot be estimated empirically. In order to propagate the coordinate changes with time, approximation models have to be used. A very familiar model is that of plate tectonics. The global crustal deformations are in a first approximation described by the motions of rigid plates (i.e., spherical segments of the globe). These motions can be expressed for each point of a plate by the rotation on a sphere with the geocentric rotation vectors Ω $(\Omega_X, \Omega_Y, \Omega_Z)$. The station velocity $\underline{V}$ (V_X, V_Y, V_Z) for a station with the coordinates X, Y, Z is then

$$\begin{aligned} V_X &= \Omega_Y \cdot Z - \Omega_Z \cdot Y \\ V_Y &= \Omega_Z \cdot X - \Omega_X \cdot Z \\ V_Z &= \Omega_X \cdot Y - \Omega_Y \cdot X \ . \end{aligned} \qquad (2)$$

The IERS adopted the kinematic plate model NNR NUVEL-1A for all the stations for which the velocity has not yet been determined in the ITRF (McCarthy 1996). The South American mainland is covered by two plates in this model: South America and Caribbean plates. The Pacific islands (SIRGAS stations Galapagos and Isla de Pascua) are situated on the Nazca plate and O'Higgins on the Antarctic plate. The rotation parameters of these plates are given in Table 2.24.

TABLE 2.24: NNR NUVEL-1A rotation vectors for SIRGAS (from McCarthy, 1996)

Plate Name	Ω_X[rad/10^9a]	Ω_Y[rad/10^9a]	Ω_Z[rad/10^9a]
South America	-1.038	-1.515	-0.870
Caribbean	-0.178	-3.385	1.581
Nazca	-1.532	-8.577	9.609
Antarctica	-0.821	-1.701	3.706

It has to be stated that the hypothesis of rigid plates is only an approximation for the modeling of recent crustal movements, i.e., the modeled station velocities may differ from the real station motions. This holds in particular along the plate boundaries where we have considerable regional deformations, i.e., the plate boundaries cannot be modeled as rigid bodies. Figure 2.11 shows the global plate pattern with the known plate boundary zones. We clearly identify all the western part of the South American continent along the Andes mountain range as an extended deformation zone. In this region one cannot use the rotation pole given for the South American plate in Table 2.24. A better approximation is a regional rotation vector derived from space geodetic observations (Drewes 1996).

Andes Zone: Ω_X = - 1.0 rad/10^9a, Ω_Y = - 4.0 rad/10^9a, Ω_Z = 1.4 rad/10^9

The difference between computed station velocities in the central Andes using this rotation vector instead of the rotation vector for South America (Table 2.24) is 2 cm/a, i.e., in five years we get a coordinate difference of 10 cm. It is therefore strongly recommended to determine the true station velocities in this area from repeated coordinate determinations (see above).

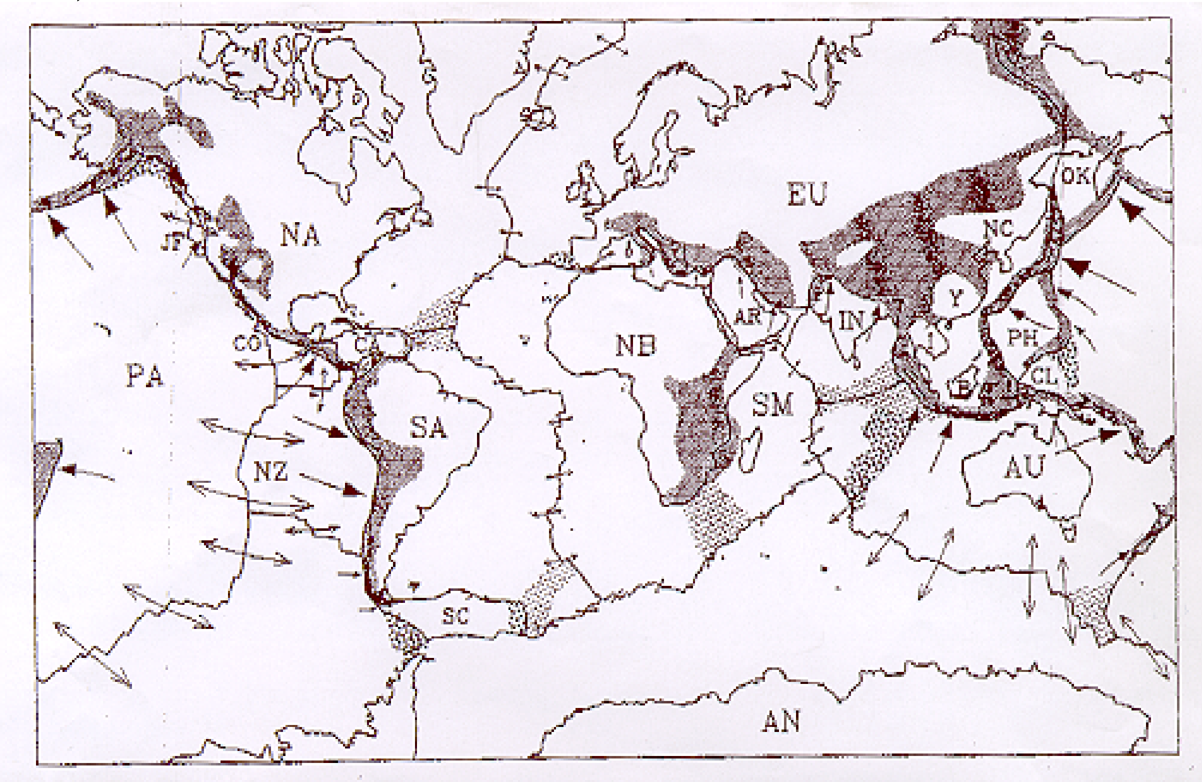


FIGURE 2.11: Global lithospheric plates and plate boundary deformation zones (from Gordon 1995)

Besides the continuous deformations we also have to consider discontinuous motions of the ground, e.g., produced by earthquakes. An example is the July 30, 1995 Antofagasta (Chile) earthquake (two months after the SIRGAS GPS campaign) where horizontal displacements up to 70 cm have been observed (Ruegg et al., 1996). The SIRGAS coordinates have to be corrected because of such motions before using them as a reference frame.

2.6.4- THE USE OF SIRGAS COORDINATES AS A REFERENCE FRAME

In the following we shall summarize the recommendations for the use of SIRGAS coordinates as fiducial stations in precise geodetic positioning in South America using space techniques (e.g. GPS). It is assumed that an observation campaign has been performed at time t_i occupying new stations and SIRGAS stations simultaneously. The result of the data processing ought to be coordinates of the new stations in the SIRGAS reference system, e.g., for national densification of the SIRGAS (= ITRF) reference frame.

The following steps have to be done when using SIRGAS coordinates in the data processing:

1. Propagate the SIRGAS coordinates of stations S used as fiducials (connecting points) from epoch 1995.4 to observation epoch t_i with station velocities $\underline{V}_S$ derived either from repeated observations or from deformation models:

   $$\underline{X}_S(t_i) = \underline{X}_S(1995.4) + \underline{V}_S \cdot (t_i - 1995.4).$$

2. Perform the coordinate adjustment using the observations at epoch t_i in connection with the SIRGAS coordinates $\underline{X}(t_i)$.

3. Transform the coordinates of the stations N from observation epoch t_i back to reference epoch t_0 = 1995.4 in order to get a homogenous coordinate set at the SIRGAS epoch:

   $$\underline{X}_N(1995.4) = \underline{X}_N(t_i) - \underline{V}_N \cdot (t_i - 1995.4).$$

   As the velocities $\underline{V}_N$ of new stations are normally not known, they have to be derived from deformation models.

In particular the last mentioned problem demonstrates the necessity of the inclusion of a crustal deformation model in the SIRGAS reference system. If we don't reduce new coordinates (valid for their observation epoch t_i) to the reference epoch t_0, we will get an unhomogenous set of coordinates referring to different epochs. The difference is 1 to 2 cm per year time interval from the reference epoch 1995.4. To perform the reduction we need a continuous deformation model for the entire continent. It is strongly recommended to support the projects for monitoring and modeling crustal deformations in South America.

2.6.5- REFERENCES

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CHAPTER 3

WORKING GROUP II: GEOCENTRIC DATUM

3.1- INTRODUCTION

Working Group II (WG II), "GEOCENTRIC DATUM", is part of the "SOUTH AMERICAN GEOCENTRIC REFERENCE SYSTEM" (SIRGAS). The mission assigned to WG II is designed to establish a Geocentric Datum through the extension of the GPS SIRGAS network, and the "Geodetic Networks" of each participating South American country, which was all created in the spirit of "Global Geodesy". In this sense it was determined that a System of Coordinated Axes based on the SIRGAS reference system, with the "GEODETIC REFERENCE SYSTEM (GRS) of 1980" ellipsoid parameters, should be considered for the geocentric datum. It was also established that the SIRGAS reference system would be based on the IERS (INTERNATIONAL EARTH ROTATION SERVICE) TERRESTRIAL REFERENCE FRAME (ITRF).

With this in mind, WG II undertook the task of diagnosing each member nation's specific situation, thereby detecting very different situation as well as different interests and intentions on how to integrate the "Geodetic Networks" to the SIRGAS reference frame. Based on this information, a series of meetings and coordination sessions was held with the intention of achieving WG II's final objective. Recommendations and resolutions were issued during each of these encounters, which each country complied according to their capacity and interest.

Finally, in August 1996, during a meeting held in Santiago de Chile, it was concluded that the best course of action to achieve the integration of each country's "Geodetic Networks", and thereby obtain a South American Geocentric Datum, is that each country individually implement said integration, however under the coordination and technical recommendations formulated by WG II, which in very general terms involve methods of obtaining, integrating, processing, and analyzing geodetic data, orienting these suggestions towards the use of the Global Positioning System (GPS).

3.2- CONTRIBUTIONS OF INDIVIDUAL COUNTRIES

3.2.1- ARGENTINA

3.2.1.1- INTRODUCTION

The current reference frame for Argentina, known as POSGAR 94, consists of 127 points. These points are centers of circles with a 200 km radius covering the entire territory of which approximately 50% coincide with the local geodetic system known as Inchauspe 69. This duality of values for the two systems' common points is what allows for the transformation of parameters.

The GPS observation campaigns which created POSGAR took place in 1993 and 1994. At the beginning of 1995, the network calculation was finalized for POSGAR 94. A manufacturer software was used for this and a precision of between 1 (one) and/or 0.5 (zero point five) ppm was reached, resulting in the WGS-84 system with a margin of error of 1 (one) meter.

3.2.1.2- ACCOMPLISHMENT OF THE OBJECTIVES ACCORDING TO THE RECOMMENDATIONS OF THE SANTIAGO MEETING IN AUGUST 1996

- Individually integrate the POSGAR National Network into SIRGAS.
- Integrate new surveys to POSGAR.
- Coordinate the needs of the country with regard to the adjustment and transformation of the coordinates.
- Find the appropriate solution to define the classical network coordinates to the new system according to WG I specifications.

3.2.1.3- MAP OF THE NATIONAL GEODETIC NETWORK

See Figure 3.1.

3.2.1.4- DESCRIPTION OF THE INTEGRATION INTO SIRGAS

A new calculation of the totality of the POSGAR network has been underway since August 1996, using Bernese software, version 3.5, and following the recommendations of the SIRGAS Working Group II. The task will be done entirely in the country, with the scientific assistance of the DGFI from Munich, Germany.

Observations were made over two periods: one between February and May 1993; the other between February and April 1994. Each lasted approximately 6 (six) hours, even though the observations from the CAP (CENTRAL ANDES PROJECT; UNAVCO/NF, USA) geodynamic project, measured simultaneously with POSGAR in 1993, were grouped in 22-hour sessions. Geodetic squaring receivers were used: TRIMBLE SST and TOPCON GP R1D.

The observable selected for the calculation is the ionospheric-free linear combination, always using floating ambiguities' solutions. Precise ephemerides from the CENTER FOR ORBITAL DETERMINATION FOR EUROPE (CODE) are used. The tropospheric effect is corrected by using an *a priori* model evaluated with a standard atmosphere, and estimating the zenith delay correction parameters per station, valid for a maximum interval of 6 (six) hours. A detailed editing of the data is carried out in order to correct for cycle slips.

Sessions are processed one by one, taking into account the correlations between the different vectors that comprise it. The initial coordinates used are from POSGAR 94, and are assigned a very low weight. This allows a set of almost free sub-networks to be obtained, the normal equations of which are kept for a subsequent adjustment. During this phase, the ambiguities

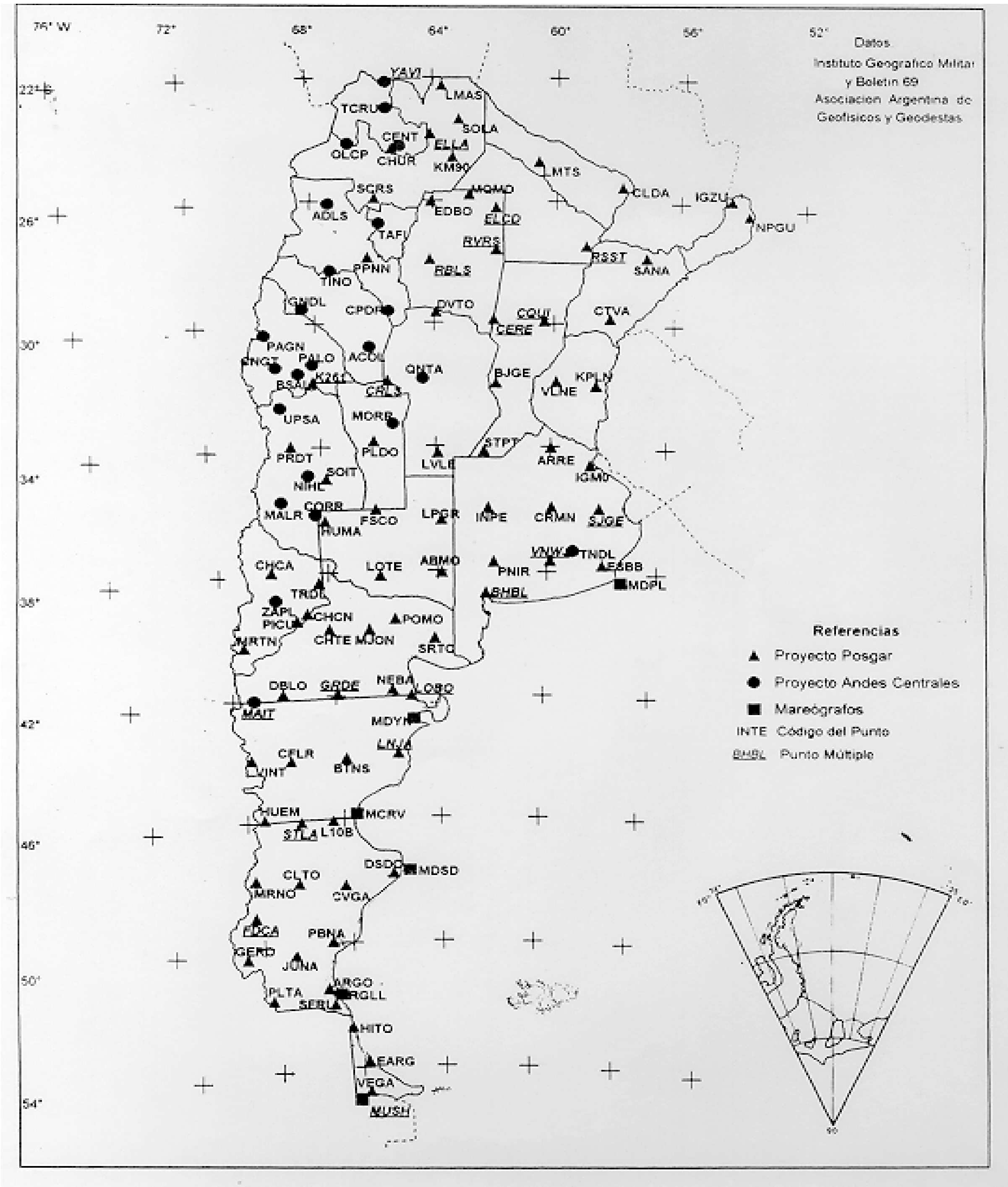

FIGURE 3.1: Map of the geodetic network of Argentina

will be eliminated from the normal equations, and only station coordinates and tropospheric corrections will be estimated.

The strategy to be used to define the reference system in the final adjustment of the network has not yet been analyzed.

Argentina has 10 (ten) SIRGAS points, 6 (six) of which belong to the POSGAR network, while the remaining 4 (four) (CRICYT, UNSA, IGZU, LPGS) must be tied to the same.

At the present time, the observations to tie CRICYT, IGZU, and LPGS points have been made, with only UNSA point remaining. The calculation of these ties will be performed with the same software and strategies mentioned before.

3.2.1.5- STATUS OF THE REALIZATION

Currently, 70% (seventy percent) of the reduction of the raw data has been completed, and it is estimated that this phase will be finalized in July 1997. During the second half of this year, the best way to execute the final adjustment will be examined, and once it is done, the results will be analyzed. It is estimated that the work could be completed by mid 1998. Due to the research on the use of the Bernese program by specialists at the National University of Astronomical and Geophysical Sciences in La Plata, a cooperation agreement was signed between that academic center and the Military Geographic Institute in order to obtain the POSGAR 98 according to previous schedule.

3.2.2- BOLIVIA

3.2.2.1- INTRODUCTION

According to agreements between members of the “SIRGAS” project, Bolivia’s contribution to this project was to establish six stations, which were satisfactorily adjusted by NIMA, as well as by the DGFI, except for San José de Chiquitos whose values are only obtained by the adjustment performed by NIMA.

3.2.2.2- ACCOMPLISHMENT OF THE OBJECTIVES

Bolivia's individual contribution to the project can be summarized as follows:

Integration of the whole country’s class “A” basic geodetic network to the SIRGAS network.

In line with this work, another class “B” network has been implemented throughout the national territory per request by the “National Mining Cadastre Service”.

The first network has a 12-hour observation time, having occupied the same station at least twice and using two known points in order to establish a true vector in each session.

The second network has been observed for 1.5 hours, having occupied each station at least twice, and using two known points in each session.

3.2.2.3- MAP OF THE NATIONAL GEODETIC NETWORK

See Figures 3.2 and 3.3.

3.2.2.4- DESCRIPTION OF THE INTEGRATION INTO SIRGAS

Currently there are two GPS control networks. The first belongs to class "A" fundamental geodetic network, and the second to class "B" Mining Geodetic network.

Both networks have been tied to the continental geodetic network, SIRGAS. In the future, these networks will be used to update all the work performed by the IGM. It should also be noted that there are coordinates referred to the WGS-84 and PSAD-56 systems, which the country has been using to date.

3.2.2.5- STATUS OF REALIZATION

The status of realization of the class "A" geodetic network is at 85% completion with compliance with the entire network designed by the Military Geographic Institute schedule for the course of this year.

The geodetic mining network has been completed, with all WGS-84 and PSAD-56 systems data available, in both geodetic coordinates as well as CUTM.

3.2.2.6- SCHEDULE FOR FINAL RESULTS

The Bolivian Geographic Military Institute is currently performing the complementary works for the determination of the orthometric heights in the SIRGAS stations. This work will be finished by the end of the year.

The complete data from the class "A" geodetic network will be available by mid-November.

The data from the Geodetic Mining network have been available since last November.

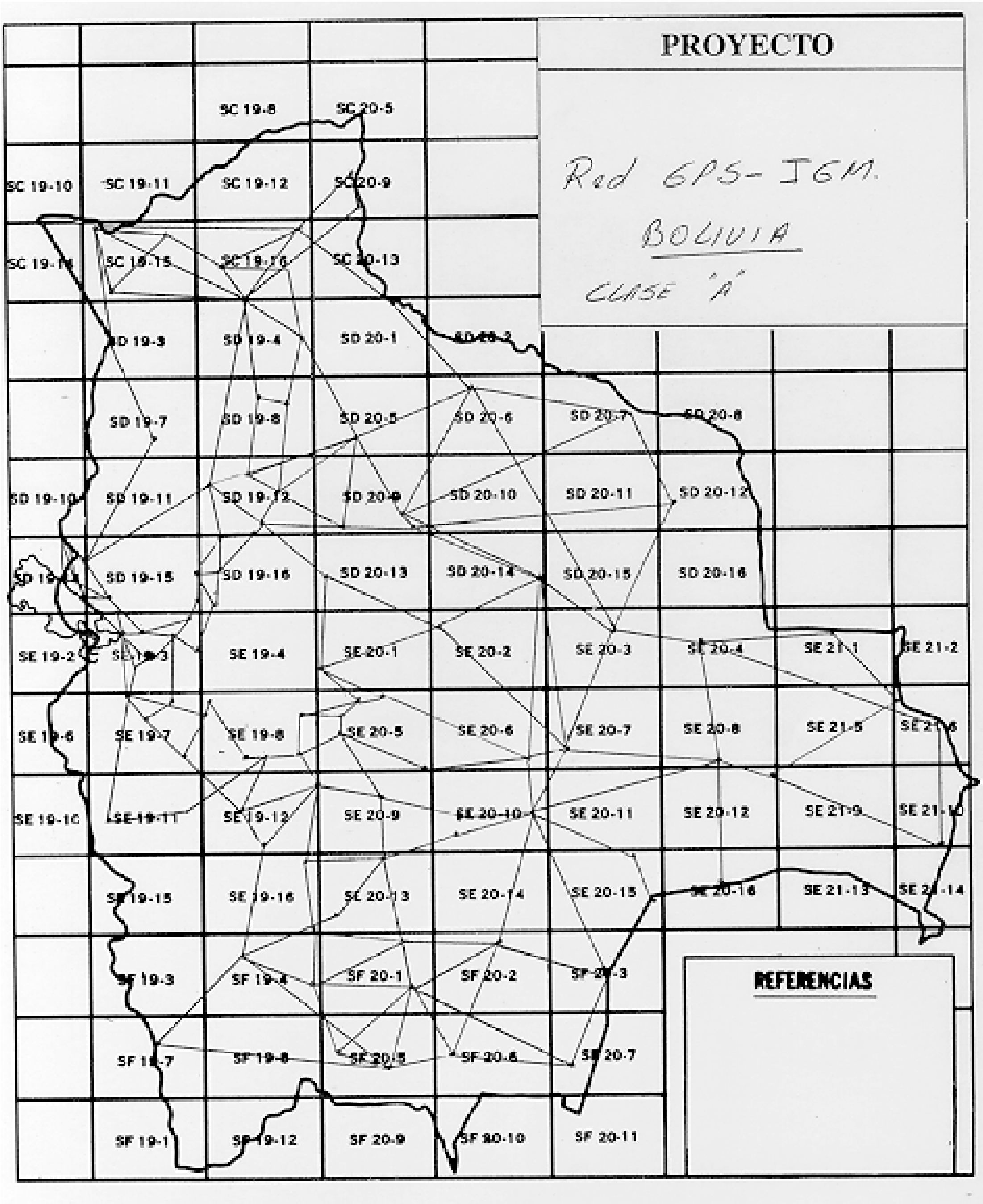

FIGURE 3.2: Map of the geodetic network of Bolivia (Class A)

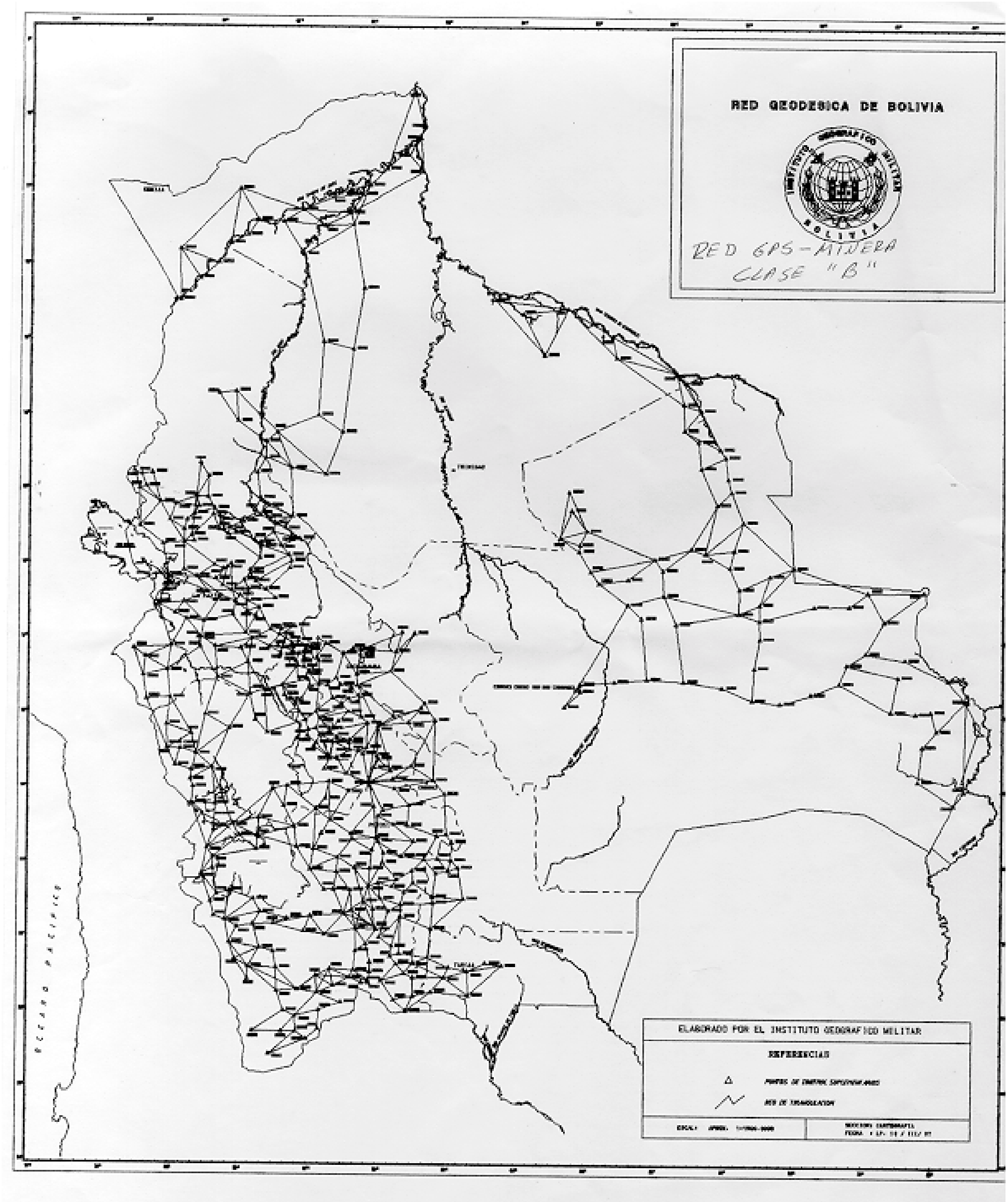

FIGURE 3.3: Map of the geodetic network of Bolivia (Class B)

3.2.3- BRAZIL

3.2.3.1- INTRODUCTION

The Brazilian Institute of Geography and Statistics (IBGE) is the institution in charge of Geodetic and Cartographic activities in Brazil and was selected as the central bureau for the SIRGAS Project with the objective of presenting its contribution to geodesy in the continent. With this aim in mind since the beginning of the project, Brazil has been actively participating in its activities and campaigns and is in charge of the Database and compliance with recommendations and technical cooperation.

In order to obtain a gradual and homogenous improvement of the Brazilian Geodetic Network, and considering its subsequent integration into SIRGAS, a Planimetric Network Readjustment Project (REPLAN) was launched during the last decade. In this manner, all the observations that form the network, be them of terrestrial or space nature, were included for the first time in a global and simultaneous adjustment. This project was completed in September 1996 and, as a result, new coordinate values were generated for 4,939 geodetic high precision stations.

This year, all efforts are being carried out towards the integration of the Brazilian Geodetic Network to the SIRGAS and, with this objective, 11 (eleven) SIRGAS stations in the Brazilian territory are already connected to classical network stations or GPS network stations in the region. In addition, 30 (thirty) GPS campaigns have been measured over the 1994-1997 period and are being included in the new adjustment. It is expected that this will be completed by December of this year.

3.2.3.2- ACCOMPLISHMENT OF THE OBJECTIVES ACCORDING TO THE RECOMMENDATIONS OF THE SANTIAGO MEETING

In order to contribute the maximum to the development of the SIRGAS Project, Brazil actively participated in the SIRGAS 95 campaign, with eleven stations in Brazilian territory, nine of which are already plani-altimetrically connected to the existing high precision networks. The nine Brazilian stations currently belong to the Brazilian Network for Continuous Monitoring of GPS (RBMC) which are considered to be one of the first active geodetic networks in South America.

Accepting the resolutions established in the Santiago meeting, Brazil will incorporate and integrate all the observations used in the REPLAN Project to the SIRGAS, that is the Classical First Order Network, DOPPLER, and GPS observations. The GPS observations from 1994 received a more refined treatment through the use of precise orbits in the processing with scientific software. In order to show the current level of integration of the Brazilian Geodetic Network into SIRGAS, a paper will be presented at the IAG meeting in September of this year.

Using the experience acquired in REPLAN and in the processing of GPS networks with scientific software, Brazil is also providing technical advice to Uruguay through GPS networks processing and is cooperating with the integration of the Uruguayan network to the SIRGAS.

3.2.3.3- MAP OF THE BRAZILIAN GEODETIC NETWORK

See Figure 3.4.

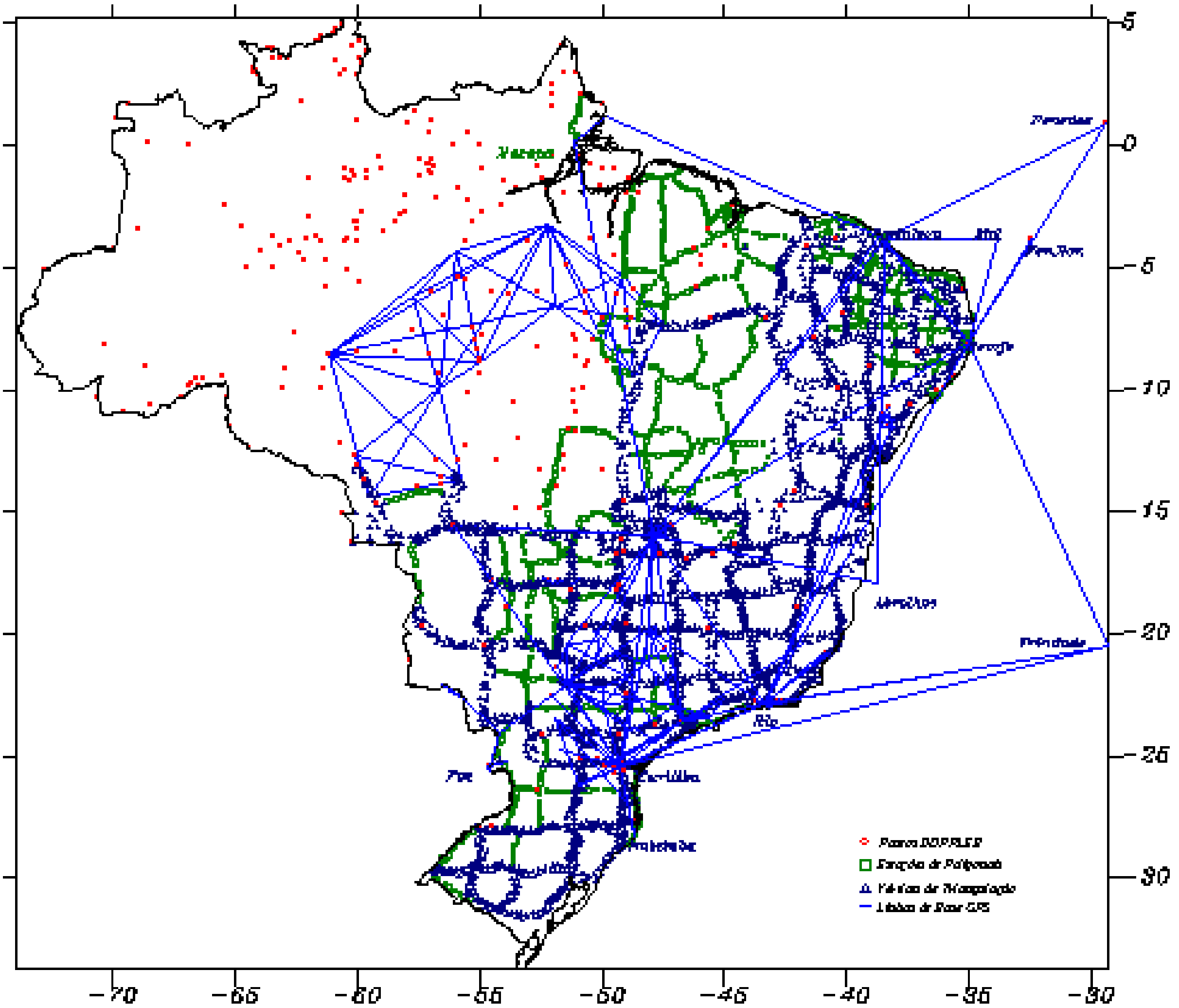

FIGURE 3.4: Map of the Brazilian geodetic network

3.2.3.4- DESCRIPTION OF THE INTEGRATION OF THE NATIONAL GEODETIC NETWORK INTO SIRGAS

The initial step for the systematic development of the geodesy in Brazil took place during the 1940s with the establishment of the planimetric network of the Brazilian Geodetic System. Currently, the planimetric network has 3,498 triangulation stations, 1,158 traverse stations, 26 trilateration (HIRAN) points, 1,143 DOPPLER stations, and 250 GPS stations, totaling 6,075 stations, the coordinates of which had been determined before the REPLAN project through various adjustments.

As previously stated, the REPLAN Project arose from the need of providing a homogenous and refined treatment of the stations which form the Brazilian Planimetric Network. In the first phase these were threatened and criticized through various programs designed for this purpose. This phase of the project took almost five years and only in the second half of 1992 the adjustment of the Triangulation Network began. The first global adjustment of the planimetric network was performed with GHOST software, developed by Geomatics of Canada for NAD83 adjustment. The project also had the valuable advice of Mr. Don Beattie, contributing to the conclusions of some phases.

Of the 1,143 DOPPLER point positions, only the ones which were connected to triangulation network stations and reprocessed with precise ephemerides were included in the REPLAN. The GPS networks established before 1993 were processed with broadcast ephemerides, while the networks established from 1994 onward are being processed with precise ephemerides.

The following observations will be used for integration to the SIRGAS:

- Horizontal directions (Theodolite T3): 16,913
- Astronomic azimuths (Theodolite T3/T4): 389
- Astronomic stations (Components of the deflection of the vertical): 378
- Geodetic Baselines (Triangulation - Geodimeter and Invar tape): 257
- Geodetic Baselines (Traverse - Telurometer): 1,277
- DOPPLER point positioning processed with precise ephemerides: 179
- GPS Baselines (included until September 1996, covering 400 GPS stations): 1,198.

In line with the activities for integration to the SIRGAS, the transformation parameters related to the local datum officially adopted in Brazil, South American Datum 1969 (SAD-69), are already being determined. Five geographically distributed SIRGAS stations with coordinates in both systems are being used for this calculation.

3.2.3.5- SCHEDULE FOR PRESENTATION OF FINAL RESULTS

See Table 3.1.

TABLE 3.1: Schedule for presentation of final results of the Brazilian geodetic network's integration into SIRGAS

ACTIVITIES	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
PROCESSING OF 1994-1997 GPS CAMPAIGNS												
PROCESSING OF SIRGAS LINKS												
INCLUSION OF GPS CAMPAIGNS IN ADJUSTMENT FILE												
ADJUSTMENT OF ALL GPS CAMPAIGNS												
INCLUSION OF GPS CAMPAIGNS IN THE TERRESTRIAL OBSERVATIONS FILE												
SIMULTANEOUS ADJUSTMENT OF ALL NETWORK OBSERVATIONS												
ANALYSIS OF RESULTS												
REPORT ON FINAL RESULTS												

3.2.4- CHILE

3.2.4.1- INTRODUCTION

The Chilean Geographic Military Institute, acting as the directing agency at the national level with regard to geography and national surveying, has established and maintained a "NATIONAL GEODETIC NETWORK OF I, II, AND III ORDER", over the last five decades, covering the whole national territory with chains of geodetic triangulations.

This conventional national geodetic network established by classical geodetic astronomic systems and Doppler satellite systems, has been forced to adopt various ellipsoid and reference datum for the development of national cartography. Therefore, the PSAD 56, SAD 69, WGS 72, and NWL 9D ellipsoids have been adopted. Lately, with satellite technological advancement and development of equipotential models based on terrestrial gravity, the modern global GPS satellite positioning system, which is referenced to the World Geodetic System (WGS-84), has been created. This satellite datum has substituted the systems mentioned above and has been adopted and recommended by the entire South American community since it allows for the rapid structuring and homogenization of all the network values with high precision.

The IGM, aware of the advantages of this new satellite technology, agreed to install this new and modern geodetic reference system in Chile and has signed significant international scientific collaboration agreements to implement a new "National GPS Geodetic Network", with the objective of establishing the accurate and permanent geodetic control of the deformation that is occurring in the Andes, thereby discarding the use of the conventional positioning system for the aforementioned reasons.

The geodetic GPS measurements for this new network at the national level have been developed during the last five years (1992-1997) and consist of a series of simultaneous geodetic measurements' activities of this new and modern "National GPS Geodetic Network".

To date, a total of approximately 184 "GPS stations" (period 1992-1997), located in different geographic areas throughout the twelve regions that comprise the nation, from the Antarctic region to the oceanic islands, have been measured.

In order to maintain this new National GPS Geodetic Network with updated information, a "Network of Active and Permanent Stations" (EAF) was created, with 13 (thirteen) stations throughout the country, combined with another 3 (three) already existing in the national territory and managed by the International GPS Service for Geodynamics (IGS) located on Easter Island, Santiago (Peldehue), and O'Higgins Base (Antarctic Chilean territory).

The new EAF, like the 184 fixed GPS stations, has been installed and operated by the IGM in conjunction with the University of Hawaii in the United States, and the Geoforchungzentrum Postdam (GFZ) of Germany. The participation of these two international organizations occurred through permanent scientific cooperation agreements with the IGM in order to determine the conditions and technical requirements of installation, permanent functioning, and joint financing of the 13 GPS "Fixed and Active Stations" (EAF) which comprise this new “Active National Geodetic Network” (RGNA) of “continuous tracking”. This network has been scientifically and strategically defined in different regions of the country for its daily operation, through the continuous tracking of the NAVSTAR-GPS satellite constellation, which will soon be integrated, along with the network of 184 fixed GPS stations, to the current “GPS SIRGAS NETWORK”, established in Chile with 4 fixed stations (Copiapó, Concepción, Balmaceda, and Punta Arenas).

3.2.4.2- ACCOMPLISHMENT OF THE AGREEMENT OBJECTIVES

The IGM has established the integration of the “National GPS Geodetic Network” to the current SIRGAS-GPS network in Chile as its first priority.

For this reason, a work program was created with a two-year development period (1997-1998), which, in short, is intended to create and integrate all the SIRGAS stations (4) in just one network with the “Fixed Stations” (184) and “Fixed and Active Stations” (13) GPS geodetic networks.

In order to process the GPS integration data of these new GPS networks to the SIRGAS network, collaboration with those entities which signed the agreements will be sought, such as the University of Hawaii and the Geoforchungzentrum (GFZ) of Germany; help was also offered by the United States National Imagery and Mapping Agency (NIMA).

3.2.4.3- GENERAL MAP OF THE NATIONAL GPS GEODETIC NETWORKS

Attached is a figure with a general map of the nation, with the approximate individualization and geographic location of the GPS stations which comprise the current “National Geodetic Network of Fixed GPS Stations” along with the “National Geodetic Network of Active Fixed Stations (EAF)”, which will be integrated to the current national geodetic SIRGAS network.

Note: the IBAN, BLMC, CASU, and CHAM stations correspond to the network of GPS SIRGAS fixed stations.

See Figure 3.5 and Table 3.2.

3.2.4.4- DESCRIPTION OF THE INTEGRATION INTO THE SIRGAS NETWORK

The following phases have been developed for the technical development at the office:

- The processing and calculation of geographic positioning values will be executed in two sets of data (EAF and SIRGAS stations). The coordinate values for the SIRGAS stations will be fixed, and the coordinate values obtained from the EAF will be calculated and adjusted.

- Once the definitive coordinate values for the EAF are obtained and adjusted to the SIRGAS network, the reprocessing of the coordinate data for the 184 fixed stations of the national GPS network, remeasured during the joint IGM/UH and IGM/GFZ campaigns during 1996, will begin.

3.2.4.5- STATUS OF THE REALIZATION

According to the work program for the integration of the networks detailed in the preceding item, the plan of action is as follows:

a) In August of this year, the first GPS remeasurement campaign of the SIRGAS stations will begin. They will be measured for 48 hours simultaneously with the seven continuous tracking active and fixed stations (EAF). The aim of these measurements is to link and integrate the EAF located in Antofagasta (region II), Copiapó (region III), Antuco (region IX), Puerto Montt (region X), Punta Arenas (region XII), and the Presidente Frei Base (region XII and the Chilean Antarctic), to the 4 SIRGAS stations in Chile.

b) To implement the work program in the field towards the integration of the aforementioned networks, a period of approximately 18 months was established, depending on available resources and the priorities of the works planned during this year in the technical work plans of the Military Geographic Institute for 1997. Notwithstanding, the project is categorized as a priority due to its national and international importance.

c) In addition to the development of the aforementioned terrestrial missions, the IGM plans the following technical activities:

   - Acquisition of new GPS processing software for the processing of GPS data in large regions (at the national level), such as, for example BERNESE, SKY, GIPSY II, or others.

   - The training of personnel involved in the processing of GPS data and software handling and analysis.

   - Along with the software acquisition, the data will be processed simultaneously by various organizations: the University of Hawaii (UH), Germany's GFZ, and NIMA, in order to make comparisons and analyze the results obtained through these agencies.

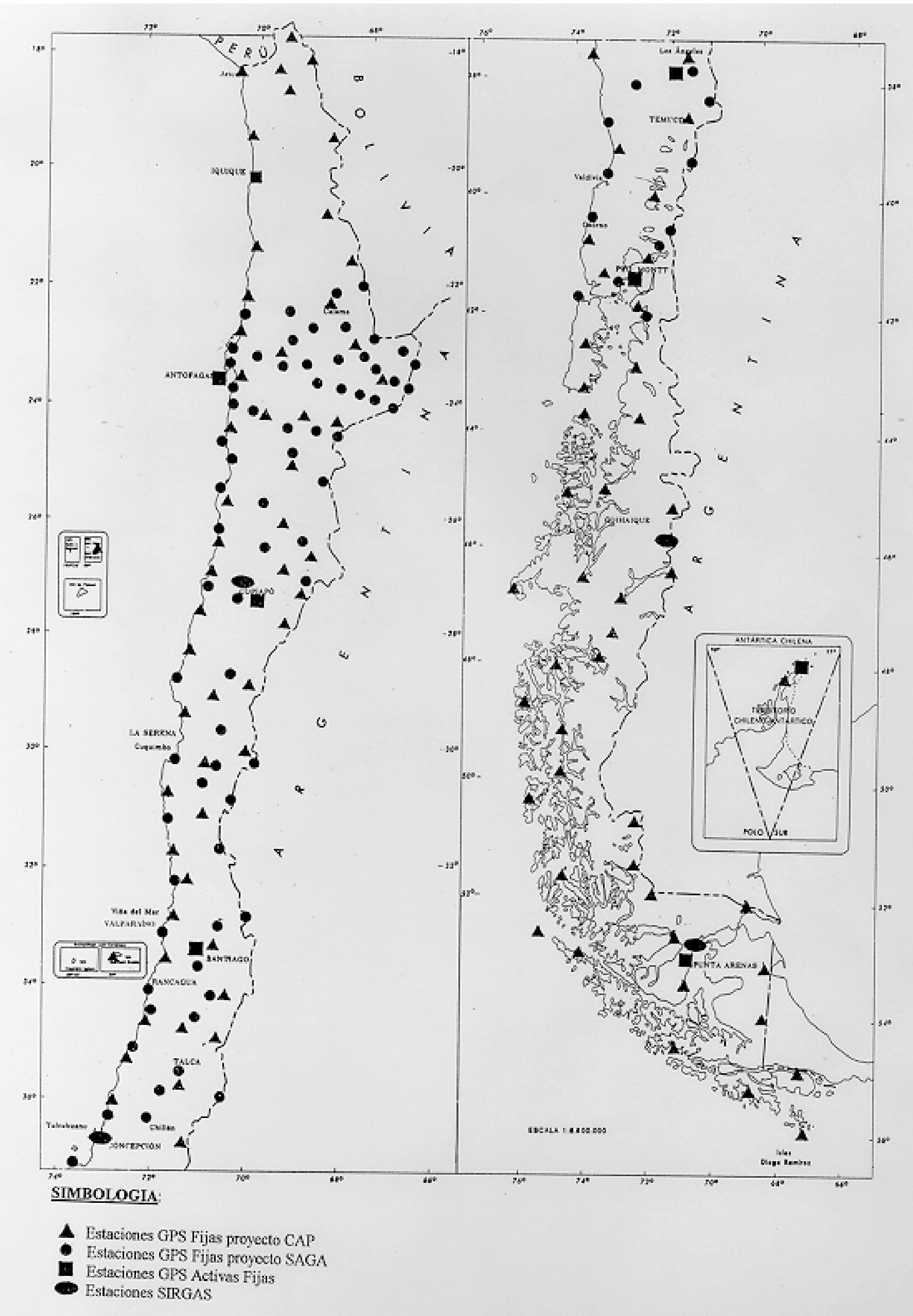

FIGURE 3.5: General map of the national GPS geodetic networks of Chile

TABLE 3.2: Active and fixed stations (EAF) of the national active geodetic network of Chile

NUMBER	STATION NAME	EAF CODE	AGREEMENT/ PROJECT
1	IQUIQUE	IQQE*	IGM-UH/CAP
2	ANTOFAGASTA	ANTO*	IGM-GFZ/SAGA
3	COPIAPO	COPO*	IGM-UH/CAP
4	ISLA ROBINSON CRUSOE	RCRV	IGM-GFZ/SAGA
5	ISLA SAN FELIX	SFEL	IGM-UH/CAP
6	ANTUCO	ANTC*	IGM-UH/CAP
7	PUERTO MONTT	PMON*	IGM-GFZ/SAGA
8	COHIAIQUE	CQUE	IGM-UH/CAP
9	CAMPO DE HIELO SUR	GUAR	IGM
10	PUNTA ARENAS	PARC*	IGM-UH/CAP
11	ARICA	ARCA	IGM-UH/CAP
12	PUERTO WILLIAMS	PUWI	IGM-UH/CAP
13	BASE FREI TERRITORIO CHILENO ANTARTICO	FREI*	IGM-UH/CAP

NOTE: the asterisk * indicates active stations

3.2.5- COLOMBIA

3.2.5.1- NEW NATIONAL GEODETIC NETWORK WITH GPS

The horizontal Colombian network was started in the 1940s and was extended throughout the national territory with the conventional method (geodetic triangulation with theodolite and standardized metric tapes). The process took more or less 45 years and covered the three mountain chains and part of the Eastern Plains.

It was impossible, nonetheless, to reach the regions of Orinoquía and Amazonía with geodetic triangulation due to the sylvan characteristics of these two regions which prevents adjacent stations to see one other (intervisibility).

The conventional network, referred to today as the “old network”, consists of points (geodetic vertices) located in the highest parts of the Andes, in order to make out extensive areas of land. The points are marked with 0.3 meters by 0.3 meter square concrete monuments of 0.8 meters in depth. The identification is stamped on a bronze plate and generally corresponds to the same name where the station is located.

By joining the points, according to the intervisibility among them, a series of geometric figures, made up of triangles, is obtained (the most common one is the quadrilateral). The set of all these figures is known as the Geodetic Triangulation Network.

This network has geodetic coordinates (latitude and longitude) for each of its vertices; that is, there is a large number of points of reference where the coordinates are measured for all cartographic, geodetic, and topographic projects in the country.

The vertical network extends throughout the national territory forming a large net of leveling lines with points of known heights, separated by about 1 kilometer, and marked with concrete monuments of the same size as those used at the vertices of the horizontal network, but with a consecutive numeration to identify the points on a line.

The two described networks represent the supporting geodetic infrastructure for the execution of all national cartography.

Before the appearance of the GPS satellite system, the determination of the horizontal network was a supremely difficult and expensive task, with unavoidable obstacles which prevented total national coverage. For this reason, the partial execution took many years of difficult field work.

3.2.5.2- THE NEED FOR A NEW NETWORK

Because of the modernization of the Institute, the Geodesy Division of the Subdepartment of Cartography changed its old theodolites (pioneer instruments in the country's geodesy) for modern high precision satellite receivers (Wild GPS System 200, by Leica) and total stations with the best technology. It also replaced the mechanical levels used to determine the vertical network with easy-to-use automatic levels.

With all this available technology, it was necessary to think about a new infrastructure of geodetic support with higher precision, more coverage, and easier access.

The Subdepartment of Cartography presented its new network project in 1994 at the IGAC (Instituto Geográfico "Agustin Codazzi") installations, where the second work meeting on the SIRGAS Project was being held.

The first draft of the GPS network contemplated the occupation of vertices of the old network: the difficult access to these points would limit its utility.

The definitive project (see Figures 3.6 and 3.7) came at the end of 1993 from the Calculations Unit of the Geodesy Division and it contemplated location of high security such as are the installations of the various national airports.

The execution phase was planned in 1994, and the nation was divided into four geographic zones.

Three of them - south, center, north - were observed that year with the GPS receivers and thanks to the participation of the seven regional offices.

In 1995, the implementation of the fourth part was planned (Orinoquía and Amazonía), the most difficult in the country due to its difficult access and lack of communications in the area (Barrancominas, San Felipe, La Chorrera, Araracuara...).

3.2.5.3- REALIZATION OF THE PROJECT

With great optimism and under the direction of the Chief of the Geodesy Division, the group of engineers started programming the last phase. The simultaneity of observations performed on a certain date makes necessary to plan the shift to the sites.

That is how field observations were performed from September 12 to October 5, with a three-day delay. This was considered a success since finally the National Geodetic Network with GPS was completed, including the most difficult part which had never had geodetic support before.

The new network can be used with GPS receivers and with the conventional method, because each main vertex has another point (azimuth signal) located at a distance of approximately 1000 meters.

Currently, there are preliminary coordinates adjusted with SKI software. It is anticipated that at the end of this year there will be a final adjustment using scientific software.

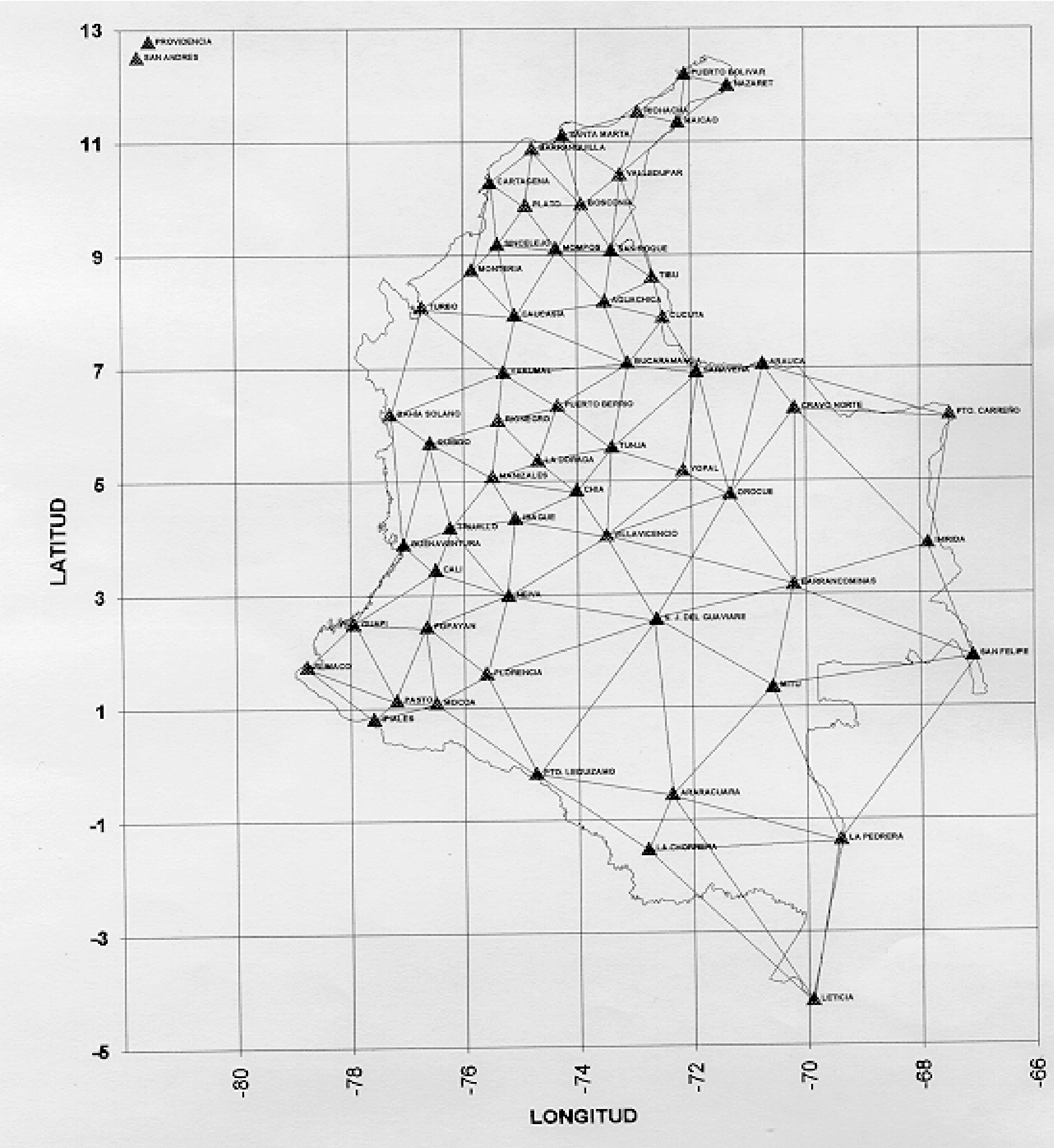

FIGURE 3.6: Map of the new national GPS geodetic network of Colombia

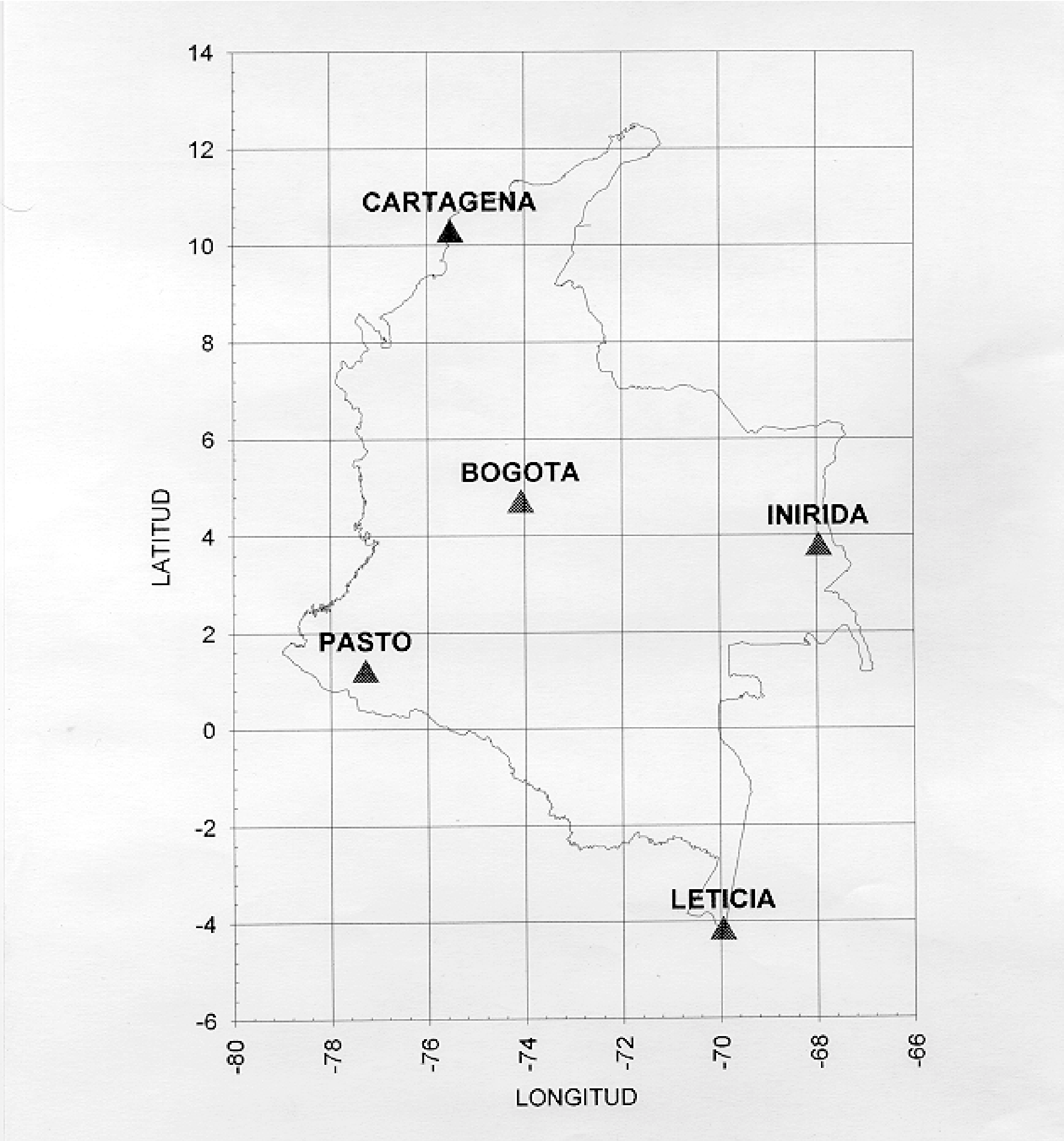

FIGURE 3.7: Map of the SIRGAS stations in Colombia

3.2.6- ECUADOR

No information.

3.2.7- FRENCH GUIANA

3.2.7.1- INTRODUCTION

Since French Guiana is an overseas region of France, the “Institut Géographique National” (IGN) is in charge of the establishment and maintenance of its geodetic network. A new geodetic network, called “Réseau Géodésique Français de Guyane” (RGFG), was established in French Guyana in May 1995. Its coordinates, that were published before the final SIRGAS solution was available, are based on the ITFR93, epoch 1995.0 coordinates of the IGS station Kourou, which are very close to the SIRGAS coordinates of this station.

3.2.7.2- DESCRIPTION OF THE GEOCENTRIC DATUM OF FRENCH GUIANA AND ITS INTEGRATION INTO SIRGAS

The RGFG consists of (see Figure 3.8):

- The reference point of the network, which is the IGS permanent station at Kourou, the only SIRGAS point in French Guiana,
- The network called “Réseau de Base Français de Guyane” (RBFG), consisting of 23 points divided into the two following subnetworks:
  - The RBFG1 (7 points),
  - The RBFG2 (16 points) is a densification of the RBFG1 in the coastal area.

The observations were carried out using Ashtech Z-12 receivers and processed with Ashtech’s software GPPS, using IGS orbits. After running a first adjustment with Geolab in order to detect errors, the final weighting and adjustment were performed with softwares developed by IGN.

The solution obtained by fixing the ITRF93 coordinates (epoch 1995.0) of the IGS station “KOUR“, is labeled RGFG95. The RGFG95 coordinates have been published as geographical coordinates on the GRS80 ellipsoid. The coordinates used for KOUR were:

ϕ = 5° 15’ 7.84786” λ = - 52° 48’ 21.45401” h = - 25.772 m

The discrepancy with the final SIRGAS coordinates for this point is 0.7 cm on the latitude, 3.4 cm on the longitude and 0.3 cm on the height component.

A 7-parameter transformation has been computed between the new datum (RGFG95) and the former datum called CSG67, using the coordinates of 21 common points. This transformation has been computed so that the CSG67 coordinates of the fundamental point (Diane) remain unchanged, with the resulting set of transformed coordinates making up a new realization of the old datum, labeled CSG67(IGN95).

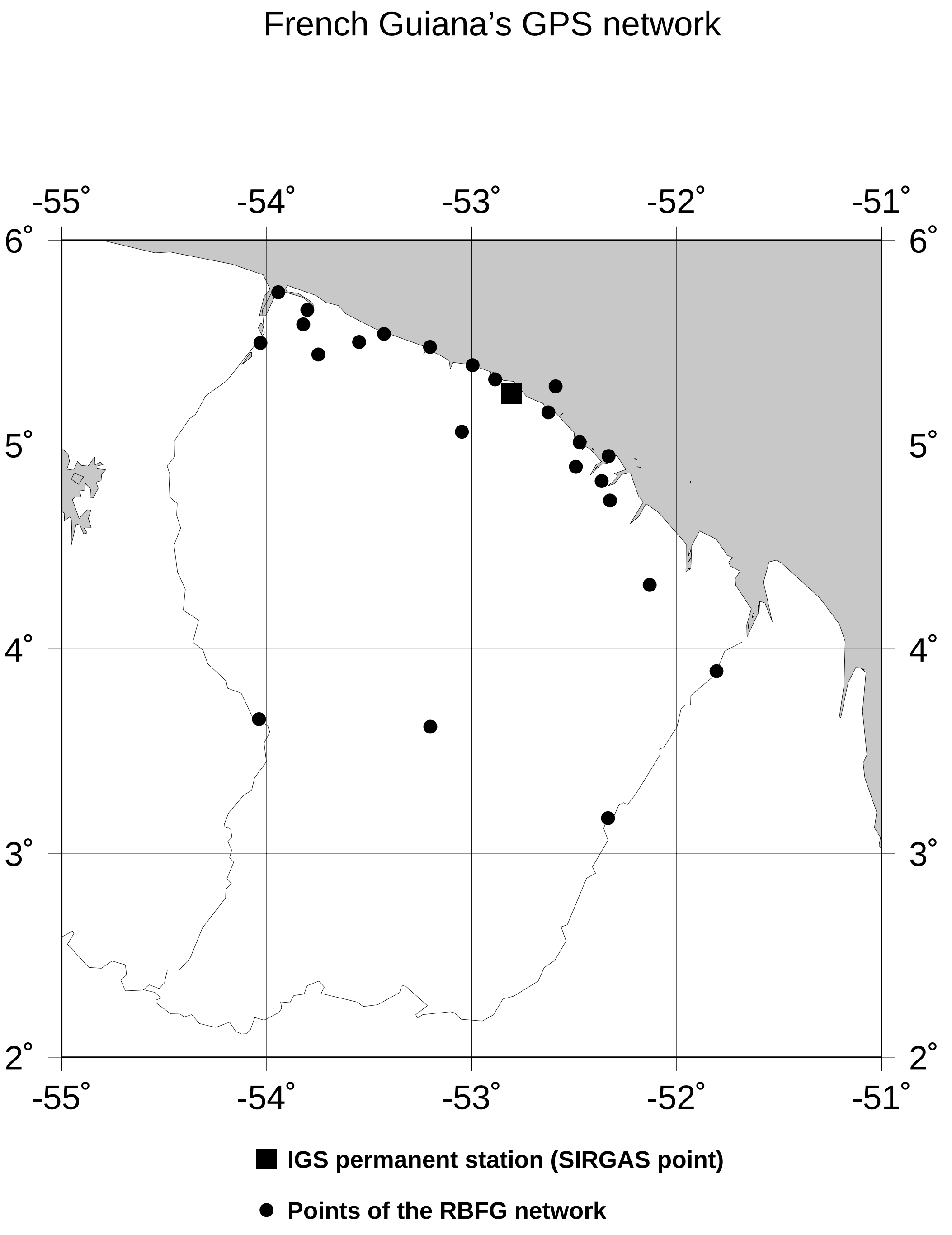

FIGURE 3.8: Map of the French Guiana's GPS network

3.2.7.3- ACCOMPLISHMENT OF THE OBJECTIVES ACCORDING TO THE RECOMMENDATIONS OF THE SANTIAGO MEETING

Because the small difference in the coordinates for Kourou between the SIRGAS and the RGFG95 solutions is consistent with the precision of the RGFG network, we propose to regard the RGFG95 solution as being expressed in the SIRGAS system.

3.2.8- GUYANA

No information.

3.2.9- PARAGUAY

3.2.9.1- INTRODUCTION

The Military Geographic Service Office and the Defense Mapping Agency (DMA) executed the densification of 165 points in the Primary Geodetic Network between June and December of 1992, within the Project for the Rationalization of the Use of the Land, National Cadastre Project, in order to:

- Produce Digital Orthophotocharts and to later tie to another more precise network in America.

- Basically, two types of stations were classified in the Control Network, a point used as a fiducial one and points positioned relative to the fiducial point.

- The computation of measurement data was done in Paraguay and the DMA offices in Cheyenne, Wyoming, and St. Louis, Missouri, in the United States. The adjustment was executed by DMA and National Geodetic Survey.

- The resulting vectors are within the specifications established by the US Federal Geodetic Control Committee - "B-ORDER".

- All the measurements in this Control Network have their respective descriptions, graphs, and relative positions in the Operational Charts.

- These control stations were established referred to the 1984 World Geodetic System.

3.2.9.2- ACCOMPLISHMENT OF THE OBJECTIVES ACCORDING TO THE RECOMMENDATIONS OF THE SANTIAGO MEETING - CHILE - AUGUST/1996

Paraguay has a relatively new Primary Network Control (densified in 1992). All raw data and final computations are at the DMA offices in the USA. The data (vectors) are ready to be used immediately for its linkage to the SIRGAS.

The establishment of SIRGAS stations No. 100050 ASUNCION and No. 1000120 ESTIGARRIBIA has led the way to compliance with the Santiago - Chile August 1996 recommendations.

The technical procedures and software will be the same ones used by the NIMA center of computations, according to the final derivations of the SIRGAS coordinates of the stations defined in **TECHNICAL MEETING V OF THE SIRGAS PROJECT**, held in Isla Margarita, Venezuela, from April 8-11 of this year.

3.2.9.3- PRIMARY NETWORK STATIONS WHICH WILL BE INTEGRATED INTO THE SIRGAS NETWORK

See Figure 3.9.

3.2.9.4- DESCRIPTION OF THE INTEGRATION INTO SIRGAS

The 165 points shown on the map are included in the integration of the primary network to the SIRGAS network, two of which correspond to the SIRGAS stations established in South America.

The classical geodetic networks will not be included in the integration of the Primary Network to the SIRGAS because they are too old and the required data is not available.

3.2.9.5- STATUS OF REALIZATION

Paraguay is coordinating the scientific and technological support needs with the National Imagery and Mapping Agency (NIMA) for the transformation and the adjustment of the national network to the SIRGAS network.

3.2.9.6- SCHEDULE FOR OBTAINING FINAL RESULTS

The final results are subject to the planning of NIMA activities and the Military Geographic Service Office, within the schedule which will be established in the Cartographic Agreement signed by Paraguay and the United States.

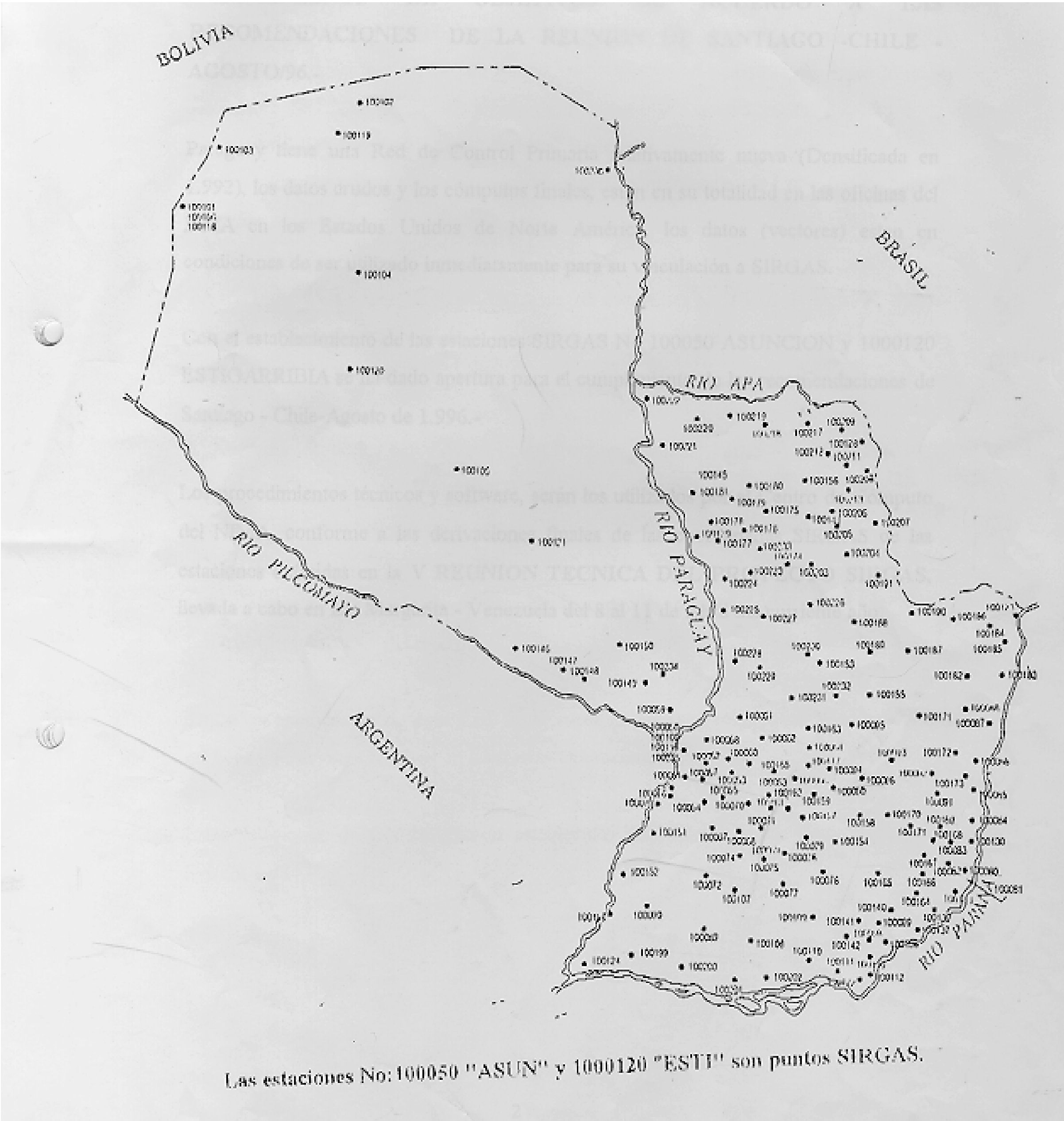

FIGURE 3.9: Map of the primary network stations of Paraguay which will be integrated into the SIRGAS network

3.2.10- PERU

3.2.10.1- INTRODUCTION

The National Geographic Institute, as the main cartographic entity in Peru, has been working on the consolidation of its parameters of reference in order to improve the classical geodetic network. It has also been establishing a geodetic geocentric reference system in Peru with the technical assistance and cooperation program offered by the Geodetic Institute of the University of the Armed Forces of Germany (IGUNIBWN).

The use of advanced technology instruments like GPS allow for more precise results to be obtained and, with the use of some stations from the classical geodetic Peruvian network, will allow for the determination of divergences from the PSAD 56 and WGS 84 coordinate systems.

The establishment of the GPS network to be used to determine the coordinates in the WGS-84 coordinate system offers us better cartographic possibilities to be used in various technical-scientific activities in Peru.

3.2.10.2- ACCOMPLISHMENT OF THE OBJECTIVES

The development of the SIRGAS project directs its activities towards the adoption of a reference system with a precision which is compatible with the current techniques of positioning, primarily those associated with the GPS.

The program established by the SIRGAS Working Group II, and the coordination done by Professor Engineer ALBERT SCHODLBAUER and the Geodetic Institute of the University of the Armed Forces of Germany, have created a plan of action based on the following:

a) In the annual IGN 1995 work plan, geodetic terrestrial control of four high precision GPS points to comply with the SIRGAS project activities in the cities of Piura, Iquitos, Arequipa, and Lima was performed between May 26 and June 5, 1995, through the use of four (04) terrestrial control brigades for the establishment of the Geocentric Datum and the high precision GPS points for South America. This consisted of a 24-hour permanent data record for 6 days, and it was synchronized by 10-second epochs simultaneously.

b) In the annual IGN 1996 work plan, terrestrial control of 28 geodetic precision points was performed in compliance with the "SIRGAS PERU" project in the localities of: Locumba, San Juan, Andahuaylas, Anta, Puerto Maldonado, Juliaca, Pisco, Huacho, Chimbote, Ayacucho, Huancayo, Cerro de Pasco, Pucallpa, Talaya, Puerto Esperanza, Trujillo, Chiclayo, Chachapoyas, Tumbes, Imacita, San Lorenzo, Tarapoto, Andoas, Curarey, Gueppi, Estrecho, Caballococha, and Angamos, between August 20 and September 7, 1996, with four terrestrial control brigades to establish primary geodetic stations, with a register of data in each for 72 hours, and synchronized in epochs of 10 seconds, supported by the SIRGAS stations in Arequipa, Lima, Piura, and Iquitos, with permanent tracking during the programmed campaign, employing GPS equipment with double frequency, for which coordinates were permanently established with the Geodetic Institute of the

University of the Armed Forces of Germany, which committed its participation and technical advice for the development of the campaign of the "SIRGAS PERU" project, which was carried out without news.

c) In the annual IGN 1997 work plan, terrestrial control of the basic GPS network is planned, with the determination of 120 second order stations, tied to high precision points of the SIRGAS project. It consists of a data record every 24 hours and is synchronized in 10-second epochs simultaneously through the use of five terrestrial control brigades. It uses double frequency state of the art GPS equipment, which will constitute the geodetic structure in Peru with determinations of WGS-84 coordinates.

3.2.10.3- MAP OF THE NATIONAL GEODETIC NETWORK

See Figure 3.10.

3.2.10.4- DESCRIPTION OF THE INTEGRATION INTO SIRGAS

The integration to the geocentric reference system for the South America SIRGAS began with the determination of (04) four high precision GPS stations with a simultaneous data record in South America and Peru; stations were established in Arequipa, Lima, Piura, and Iquitos.

The work was done between May and June of 1995 with the participation of IGN personnel and technical personnel from the Geodetic Institute of the University of the Armed Forces in Germany.

The SIRGAS PERU project continued in 1996 with the establishment of 28 first order stations to create the new geodetic GPS network in Peru, and to comply with the agreement of technical cooperation, which was established by the National Geographic Institute of Peru and the Geodetic Institute of the University of the Armed Forces of Germany. This was done following the SIRGAS Working Group II suggestions on the general instructions for GPS measurements.

The 28 stations are placed in easily accessed areas, and some of the stations from the classical network, such as the bases of Ayabacas, Anta, Sama, Marcona, Las Salinas, Huancayo, Cerro de Pasco, Atalaya, and Chimbote, were considered; these are Laplace stations that will allow us to determine clearer the difference in transformation parameters from one system to another (delta x, y, z) obtained in WGS-84 with reference to PSAD 56.

In 1997, with its desire to complete the GPS geodetic network, the National Geographic Institute has planned the determination of 120 stations of second order throughout all of Peru; through this network, we expect to cover the geodetic-cartographic expectations with coordinates in the WGS-84 system.

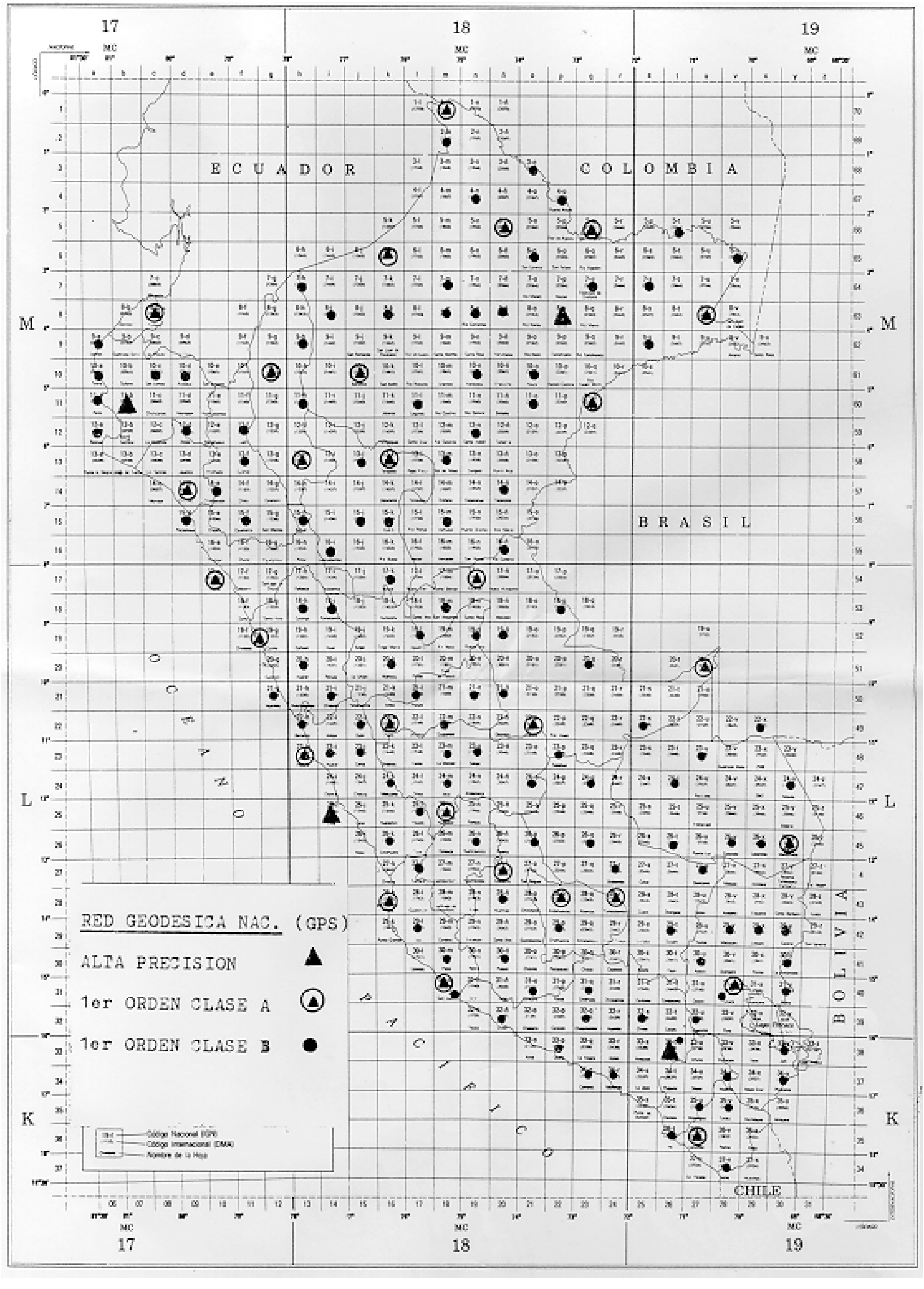

FIGURE 3.10: Map of the national geodetic network of Peru

3.2.10.5- STATUS OF THE REALIZATION

The status of realization in 1997 for the SIRGAS project is as follows:

a) Four (04) high precision stations determined with GPS measurements in the differential method.

b) Twenty-eight (28) first order stations determined with GPS measurements in the differential method.

c) One hundred and twenty (120) second order stations planned for the basic network.

3.2.10.6- SCHEDULE FOR OBTAINING FINAL RESULTS

The schedule for obtaining final results is as follows:

a) Results of the observations of SIRGAS network 1995 for South America: AUG 97.

b) Results of the observations of SIRGAS-PERU network 1996 at the national level: NOV 97.

c) Results of the observations of the SIRGAS-PERU network's densification: DEC 97.

3.2.11- SURINAM

No information.

3.2.12- TRINIDAD AND TOBAGO

No information.

3.2.13- URUGUAY

3.2.13.1- INTRODUCTION

The Republic of Uruguay has actively participated in the development of the SIRGAS project since its inception in 1993.

In the country, the project was undertaken as a collective challenge, and several institutions, led by the Military Geographic Service (SGM, responsible for national cartography), and the Institute of Land Surveying (IA, main institute for geodetic education), joined efforts, knowing that it would pragmatically result in regional and continental integration. These institutions and other organizations specializing in national transport and cadastre, offered the necessary elements in equipment and personnel to execute the campaign and the densification of the stations at the national level.

3.2.13.2- ACCOMPLISHMENT OF THE ESTABLISHED OBJECTIVES

Uruguay established three SIRGAS stations during the May/June campaign of 1995. The three were measured by the SGM with Ashtech Z-12 receivers. Likewise and taking advantage of the campaign, the GPS stations were densified, measuring 5 additional ones with Leica receivers by the IA with the support of different national organizations. In 1996 and 1997, different baselines were established on vertices of the geodetic network. In April 1997, 4 more GPS stations were added, completing the observation on the Laplace points and on important intersections of the classical network, with the future integration to the SIRGAS in mind.

According to the resolutions established in the Santiago meeting in August of 1996, it was decided at the national level to implement the readjustment of the first order geodetic network, consisting of around 420 stations of classical triangulation within the framework of the three SIRGAS stations, and incorporating about 10 densification stations and GPS baselines. These stations and lines were measured during the SIRGAS campaign in May and June of 1995 and thereafter.

This integration strategy allows the easily accessed existing geodetic network, with a destruction percentage of less than 30%, to be used, obtaining, at the same time, transformation parameters for big scale cartography. To execute the integration project called “the redefinition of the national geodetic network within the SIRGAS framework”, there was a national and international joining of SGM, IA, the Brazilian Institute of Geography and Statistics (IBGE), along with consultation by the Canadian Geological Service.

3.2.13.3- STATISTICS FROM THE NATIONAL GEODETIC NETWORK TO BE ADJUSTED

See Figure 3.11.

a) CLASSICAL NETWORK

- 422 triangulation stations
- 27 geodetic baselines and electronic measurements
- 12 Laplace stations and astronomic azimuths

b) TRIDIMENSIONAL STATIONS

- 3 SIRGAS stations, ITRF 1995.4 coordinates
- 9 additional stations, baselines to be reprocessed and determined (about 60 lines)

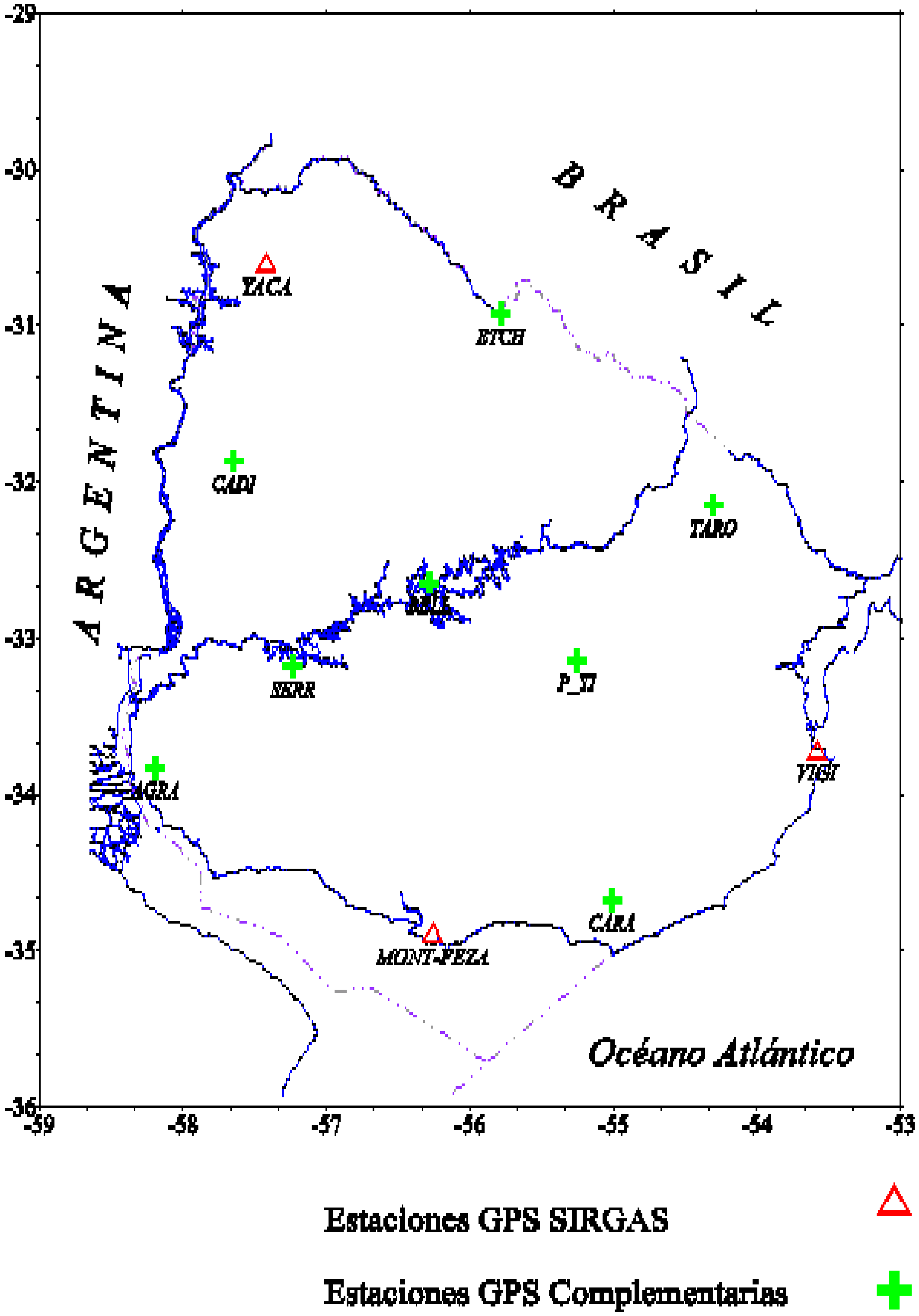

FIGURE 3.11: Map of the Uruguayan national geodetic network's tridimensional stations

3.2.14- VENEZUELA

3.2.14.1- INTRODUCTION

The National Autonomous Service for Geography and Cartography, under the Ministry of Environment and Natural Renewable Resources, is the main entity for geodesy and cartography in Venezuela.

With this aim in mind, during 1994 and at the beginning of 1995, the establishment of a new geodetic network was planned for the country. The result was REGVEN, the Venezuelan GPS network, which was measured from May 20 to June 16, 1995, coinciding with the SIRGAS measurement campaign of May 26 to June 4, 1995. REGVEN was processed by the German Institute of Geodetic Investigations, DGFI, using BERNESE software and precise ephemerides.

3.2.14.2- INTEGRATION OF THE NATIONAL NETWORKS INTO SIRGAS

REGVEN consists of 67 vertices connected to the SIRGAS network in the stations of Maracaibo (3), Junquito (34), Agua Linda (49), Canoa (59), and Kama (71).

REGVEN will form part of the new Venezuelan geodetic control, integrated to the SIRGAS.

With regard to our classical triangulation network, we are working on the transformation parameters between PSAD 56 and the SIRGAS, to transform all coordinates to the SIRGAS.

With regard to the southern region of the country, (states of Amazonas and Bolivar), a new GPS network was established in 1992 and 1993 in southern Venezuela. We are now calculating the network again and connecting it to the SIRGAS with the common stations (Agua Linda, Canoa, and Kama), and with the REGVEN stations, Canaima (69), Guardia (66), Mata de Maza (68), and Dorado (70).

3.2.14.3- MAP OF THE NATIONAL GEODETIC NETWORK

See Figure 3.12.

3.2.14.4- STATUS OF THE NETWORK'S REALIZATION

With the determination of the coordinates of the SIRGAS network, and its approval at the V SIRGAS Meeting on Margarita Island in April 1997, REGVEN has already been calculated, while the recalculation of the GPS network in the South of Venezuela will be finished in August 1997. By that date we will have obtained the SIRGAS-PSAD 56 transformation parameters, and by this way transform the entire triangulation network to SIRGAS.

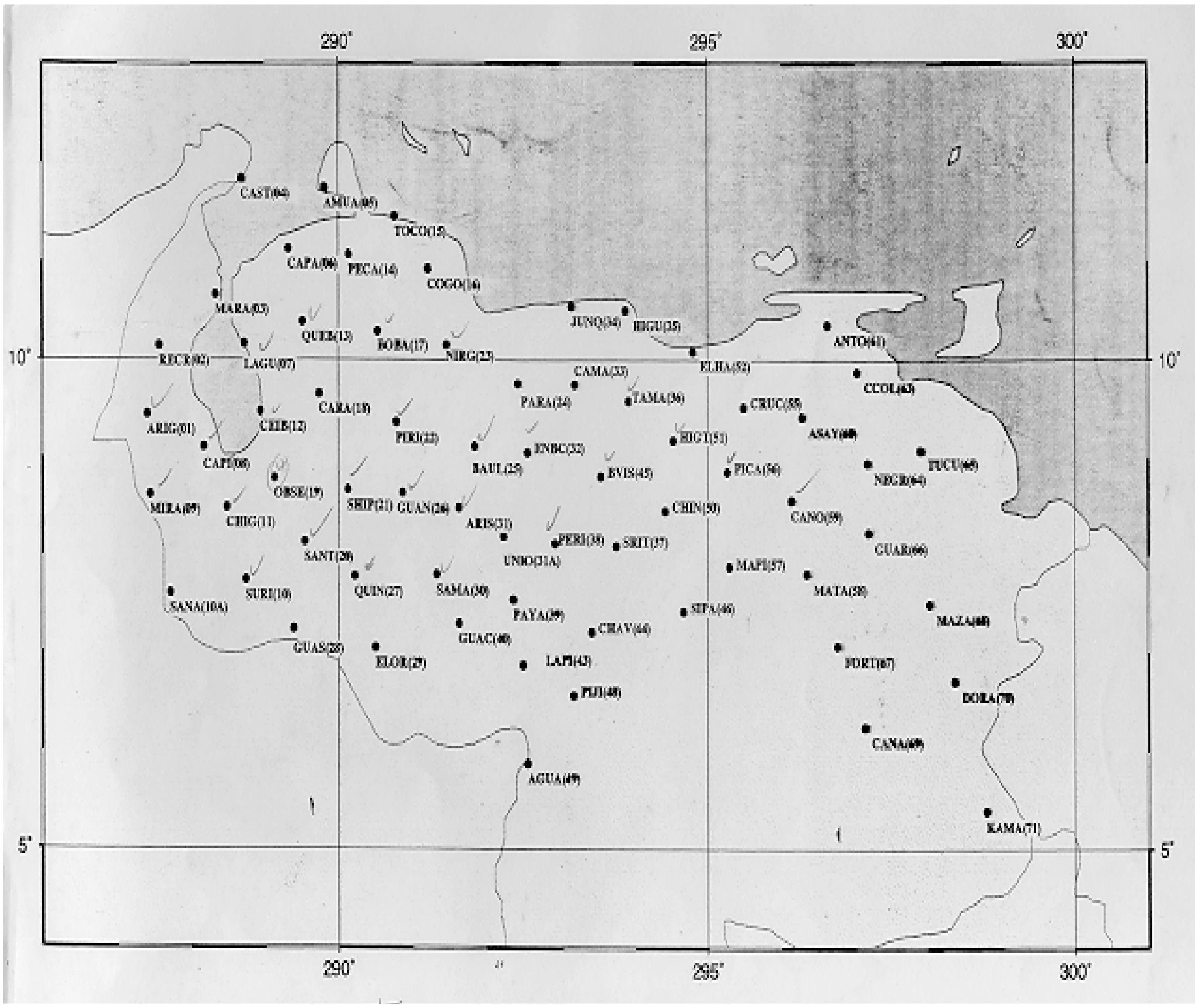

FIGURE 3.12: Map of REGVEN, the Venezuelan GPS network

3.2.14.5- DEADLINE FOR OBTAINING FINAL RESULTS

In September of 1997, all the coordinates of geodetic vertices in Venezuela will be established in the SIRGAS system, available to users on that date.

Sistema de Referência Geocêntrico para a América do Sul

Relatório Final

Grupos de Trabalho I e II

Iniciado na Conferência de Assunção, com a participação dos países sul-americanos, este projeto tem como objetivo principal definir um sistema de referência e um *datum* geocêntrico para a América do Sul.

Nesta publicação são apresentadas a estrutura e composição do projeto, as atividades desenvolvidas pelos grupos de trabalho visando ao cumprimento dos objetivos e à contribuição individual dos países-membros.

A publicação, editada em duas versões, português/espanhol e inglês, é ilustrada com tabelas e figuras.