IAG IPGH NIMA

GEOCENTRIC REFERENCE SYSTEM FOR THE AMERICAS

SIRGAS

NEWSLETTER # 6

February 2002

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EDITORIAL

I have the pleasure to present to readers the sixth edition of the SIRGAS Project Newsletter. After the last one, important project activities have occurred. Among them, it should be emphasized the SIRGAS GPS 2000 campaign, jointly planned by Working Group (WG) I "Reference System" and WG III "Vertical Datum". This campaign was carried out from May 10 to 19, 2000, with two objectives: to repeat the first GPS campaign, occurred in 1995, in order to support the computation of velocities for the SIRGAS reference network stations, and to collect GPS data for the WG III activities. Hence the stations established during the first phase of the project were re-occupied. Additional stations were established in tide gauges, with the objective of supporting the integration of the classical altimetric systems into the new unified one, and others set up close to international borders in order to facilitate the link between the national vertical systems. North America, Central America and the Caribbean participated in this campaign, establishing a geodetic network that covers the whole American continent from north to south. 184 stations were occupied during the campaign and the corresponding data is in final processing by DGFI, in Munich, and IBGE, in Rio de Janeiro. We would like to take this opportunity to thank these institutions for the enormous efforts towards processing the SIRGAS 2000 network, as well as all participants in the campaign.

During this time period, several project meetings were organized, some of them are reported here. The project members met in Birmingham, UK, during the 22nd General Assembly of the International Union for Geodesy and Geophysics, in July 1999, when the SIRGAS 2000 campaign was proposed and planned. After that, during the International Association of Geodesy (IAG) International Symposium on Vertical Reference Systems, in Cartagena, Colombia, in February 2001, a significant number of presented papers were related to the SIRGAS project. During this same meeting, the SIRGAS committee officially extended its composition to include representatives from the Central and North America and the Caribbean. The change of the meaning of the SIRGAS acronym was also proposed and officially accepted during this meeting, and since then SIRGAS stands for "Geocentric Reference System for the Americas". The last meeting occurred during the IAG Scientific Assembly, held in Budapest, Hungary, in September 2001, when the preliminary processing results of the SIRGAS 2000 campaign were discussed. In that same occasion, Eng. Roberto Luz, then president of WG III, resigned, being replaced by Eng. Laura Sanchez. We would like to take this opportunity to acknowledge Roberto Luz for all his efforts to promote and develop the WG III activities and we wish all the best for Laura Sanchez in her new role.

I would like to mention the active participation of SIRGAS representatives during the Seventh United Nations Regional Cartographic Conference for the Americas, held in

New York, USA, in January, 2001, when an important recommendation was approved. A copy of this recommendation, which proposes the adoption of a SIRGAS compatible reference system by the member countries of America, is included in this newsletter.

The next meeting in going to be held during the VII International Congress on Earth Sciences, in Santiago, Chile, from October 21 to 25, 2002 (more information with the Military Geographic Institute of Chile, email: cct2002@igm.cl, http://www.igm.cl), when the final results of the campaign will be adopted and important issues related to the project structure as well as to the WG III activities will be discussed.

I would like to invite the readers to visit the project websites, located at
http://www.ibge.gov.br/home/geografia/geodesico/sirgas/principal.htm
and
http://www.dgfi.badw.de/dgfi/SIRGAS/sirgas.html
where past newsletters and other information can be find.

Finally, I would like to take this chance to thank all SIRGAS members and colleagues for the fruitful collaboration and to wish all a Merry Christmas and a very happy, successful and peaceful New Year.

LUIZ PAULO SOUTO FORTES
President of the Committee

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The complete and updated composition of the committee, the Working Group III, the scientific council and the processing centers is presented below.

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INFORMATION ON 2nd WORKING GROUP III MEETING, HELD FROM JULY 22 TO 23, 1999, IN BIRMINGHAM, ENGLAND (prepared by the past President of WG-III, Eng. Roberto Teixeira Luz)

I. Agenda

- Opening (L. Fortes) – Project overview and status; links with IAG e other international organisms; general topics
- Information related to WG-I (M. Hoyer) – discussion of SIRGAS 2000 GPS Campaign, jointly with WG-III
- Information related to WG-II (National Representatives) – status of the integration of national geodetic networks to SIRGAS
- Discussion of WG-III activities (R. Luz) – technical document regarding the vertical reference system; WG-III databases (BIVAS, BIDAS); leveling of stations of SIRGAS 1995.4 Network; 2000 GPS Campaign
- Information on IAG VeReS 2001 Symposium (February, Cartagena,Colombia)
- Conclusions and recommendations

II. Discussions

1. during the opening of the meeting, the President of IAG, Fernando Sansó, invited representatives of South American countries to be present on the meeting of IGeS ;
2. the President of the Committee of SIRGAS Project, Eng. Luiz Paulo, opened the Meeting quoting the honours citations to SIRGAS during the Opening Session of IAG Assembly and classifying the Project as a virtual South America Sub-Commission within IAG Commission X ;
3. National Representatives of Argentina, Brasil, Chile, Colombia and Venezuela presented the status of activities concerned to the connection of the geodetic systems of their countries to SIRGAS ;
4. the preliminary version of the WG-III Technical Document (*Annex 2*) was discussed, emphasizing the proposal of including a recommendation on the adoption of normal heights. Consensus was not reached, so only a recommendation on starting of computation of geopotential numbers was made;

5. the objectives and realization of SIRGAS 2000 GPS Campaign was discussed : the reobservation of stations of 1995 Campaign and the extension of SIRGAS Reference Network allowing its vertical use. For this objective, stations must be placed at main tide gauges in each coastal country and at the borders where there is no SIRGAS 1995.4 stations. Observation will start at 0h UT of May 10, 2000, and will finish at 24h UT of May 19, totalizing 10 days of continuous observation, with 15s rate, where possible. WG-I and WG-III must produce and distribute technical specifications for data collection, preparation and transmission ; and
6. the next Meeting of SIRGAS Project will be held during the IAG International Symposium on Vertical Reference Systems, Cartagena de Indias, Colombia, February 2001. During this meeting, first results of 2000 Campaign must be presented.

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IV. Recommendations

1. start computation of geopotential numbers of leveling+gravity stations, sending report on the progress of this activity to WG-III before Cartagena Symposium ;
2. request, in the next 30 days, information on leveling+gravity status, which must be send until November 1999 ; and
3. inform SIRGAS member countries that resolutions of Santiago Meeting (1998) are still valid.

V. Resolutions

1. to perform SIRGAS 2000 GPS Campaign from May 10 to 19, 2000 ; and
2. to organize next SIRGAS Meeting in Cartagena, Colombia, February 2001.

INFORMATION ON THE 2000 GPS SIRGAS CAMPAIGN (Paper presented at IAG International Symposium on Vertical Reference Systems, Cartagena, Colombia, February 2001)

1 Introduction

The SIRGAS Project (Sistema de Referencia Geocéntrico para América del Sur) was created in 1993 during an international workshop sponsored by the International Association of Geodesy (IAG), the Pan-American Institute for Geodesy and History (PAIGH) and the US Defense Mapping Agency (DMA, now NIMA) in Asunción, Paraguay. The principal objective was to establish a unified geocentric reference system for South America (Working Group I), solving the problems caused by the proliferation of the national horizontal datums and the connections between them. One of the main steps towards that objective was the installation of the SIRGAS reference frame in May 1995. Its results, i.e., the coordinates of the 58 GPS stations of the network, were presented during the IAG Scientific Assembly in Rio de Janeiro (SIRGAS Project Committee 1997, Hoyer et al. 1998).

After this major step, the further development of the project requires the unification of the vertical datums. As a consequence, immediately after the presentation of the geocentric reference frame in 1997, the SIRGAS Committee decided to create the Working Group III for the definition and realization of a unique vertical datum for South America. This WG met in Santiago, Chile, in 1998 and discussed the principal objectives involved in this task (Drewes et al. 2001). Among these are the definition of the height system (type of heights to be used and the corresponding height reference surface) and its realization by the installation of a reference frame. The latter one includes the precise height determination of some fundamental stations and the connection of the existing national leveling networks which are defined for each country by the mean sea level at different tide gauges during a certain time period.

During the IUGG General Assembly in Birmingham, England, in 1999, it was decided to perform a GPS campaign for the precise height determination of reference stations in May 2000. The countries were urged to revise their leveling networks to connect them with neighboring countries at the borders, organize the gravity data along the leveling lines, and to compute geopotential numbers as a basis for all types of physically defined heights.

In addition to the installation of the unified vertical reference system, the 1995 network had to be re-observed in order to determine the station velocities, which are essential for maintaining the reference system with respect to its time evolution. For that reason Working Groups I and III jointly organized the SIRGAS 2000 GPS Campaign.

Another matter in planning the GPS campaign was the request to extend the SIRGAS Project to Central and North America and the Caribbean. Therefore, stations in these countries were included in the network enlarging it to 184 stations spread over all the Americas (Figure 1).

2 Station Selection Criteria

The selection of stations for the GPS network forming the reference frame of the unified vertical reference system was based on the following principal criteria:

- The primary tide gauges in all the countries, i.e., those tide gauges which define the vertical datum of a classical leveling network by the mean sea level during a certain time interval (epoch) must be included.

- Other relevant tide gauges may also be included. This provides additional information about the geographical variations of the sea level (sea surface topography). Together with long term tide gauge records it may help to extrapolate the mean sea levels during the different epochs of definition of the vertical datums to a common epoch. By this means, the effects of sea level changes with time on the height systems defined at different epochs may be reduced.

- Stations at the borders between neighboring countries with known heights in both systems shall also be occupied by GPS. The eventual differences of the leveled heights in both systems include a number of effects (different mean sea levels at the primary tide gauges during the epoch of definition, missing gravity corrections, etc.) and errors (leveling errors, gravimetric correction errors, etc.). The difference between the GPS determined ellipsoidal heights and the geoid undulations provides an independent control for the leveled heights.

- Additional primary vertical control stations within the countries may also be included. This is to stabilize and to improve the design of the new vertical reference system in particular in areas far off the tide gauges. As the stations will get three-dimensional coordinates from the data processing, they may also form part of the SIRGAS geocentric reference network.
- All the sites of the SIRGAS 1995 reference frame have to be included.

Table 1 presents a summary of the stations included in the May 2000 GPS campaign, their types according to the above mentioned criteria and their distribution over the participating countries.

3 Specifications, Equipment and Performance of the GPS Observations

The GPS observations were performed from May 10, 0h to May 19, 24h, 2000, i.e., 10 days continuously. All types of GPS receivers recognized by the International GPS Service (IGS) were accepted to be employed (Table 2). Attention had to be given to all the parameters which effect the precise height determination, i.e., in particular the vertical position of the antenna (clear identification of the reference point and precise measure of the height). Preferably IGS compatible choke ring antennae should be used. If those were not available, other antennae with well documented phase center characteristics were also accepted.

The requested data collection rate was 15 s, and the minimum elevation angle 8 degrees. Detailed specifications for the site preparation and the required performance of the observations were distributed to all the participating institutions prior to the campaign. Log sheets for each station and observation day had to be filled and sent to the data center together with the data files.

4 Data Collection and Processing

The GPS observations were collected at two data centers, IBGE in Rio de Janeiro, Brazil, and DGFI in Munich, Germany. These two centers are also responsible for the analysis and processing of the observation data.

The data were sent in RINEX format and completely checked in the data centers. From all the possible observation days (184 stations ∗ 10 days = 1840 observation days) only 122, or less than 7 percent were missing.

The strategies of the processing and preliminary results were presented during the IAG Symposium on Vertical Reference Systems, Cartagena, Colombia, February 2001 (Costa et. al., 2001, Kaniuth et. al., 2001). The final results shall be discussed during the 2001 IAG Scientific Assembly in Budapest, Hungary.

Table 1. Distribution and types of stations in the countries

Country (Island)	SIRGAS 1995	New Site	Tide Gauge	Total No.
Argentina	10	7	3	20
Bermuda	-	-	1	1
Bolivia	6	3	-	9
Brazil	11	5	5	21
Canada	-	10	3	13
Chile	7	8	5	20
Colombia	5	2	1	8
Ecuador	3	3	1	7
Fr. Guiana	1	-	-	1
Guatemala	-	3	1	4
Guyana	-	2	-	2
Honduras	-	1	-	1
Jamaica	-	1	-	1
Mexico	-	13	2	15
Nicaragua	-	2	-	2
Paraguay	1	-	-	1
Puerto Rico	-	1	-	1
Saint Croix	-	-	1	1
Peru	4	3	3	10
Trinidad&Tobago	-	2	-	2
Uruguay	2	4	2	8
USA	-	12	12	24
Venezuela	5	3	3	11
Antarctica	1	-	-	1
Sum	56	85	43	184

Table 2. Equipment in the SIRGAS 2000 GPS Campaign
(* = Choke Ring Antenna)

Receiver	No	Antenna	No
AOA/Rogue			
SNR-8000	20	AOAD/M_T *	33
SNR-12	10		
BENCHMARK	2	AOAD/M_TA_NG*	2
Ashtech			
Z-XII3	56	Ash700936/701945*	28
UZ-12	14	Ashtech others	39
Javad			
JPS Legacy	4	JPS REGANT SD E	2
		JPS others	2
Leica			
CRS 1000	3		
9500 / 520	11	LEIAT 303/504 *	9
SR 299	5	Leica others	10
Topcon			
GR R1 DY	1	TOP700577	1
Trimble			
4000 SSI	28	TRM 29659.00 *	29
4000 SSE	22	Trimble others	29
4700 / 4800	8		
Total	184	Total	184

5 Future Activities

The GPS campaign for the installation of the reference network is only one step towards the establishment of the vertical reference system for the Americas. Only one type of the heights to be used (Drewes et al. 2001) is determined by this campaign, the ellipsoidal heights. To determine the other required type of heights, the normal heights, a number of activities has to be completed:

- All the reference stations have to be connected by spirit leveling to the national networks that materialize the classical height systems.
- The spirit leveling has to be reduced for the effects of the Earth's gravity field (normal reduction). For this purpose, gravimetric measurements have to be performed along all the leveling lines, if not done so far.

- A precise quasigeoid determination has to be done by a joint processing of all available gravity data in the countries. Only by this means, the GPS ellipsoidal heights can be combined with the leveled (and gravity reduced) heights of the classical systems.

All the countries are urged to complete these tasks in the near future.

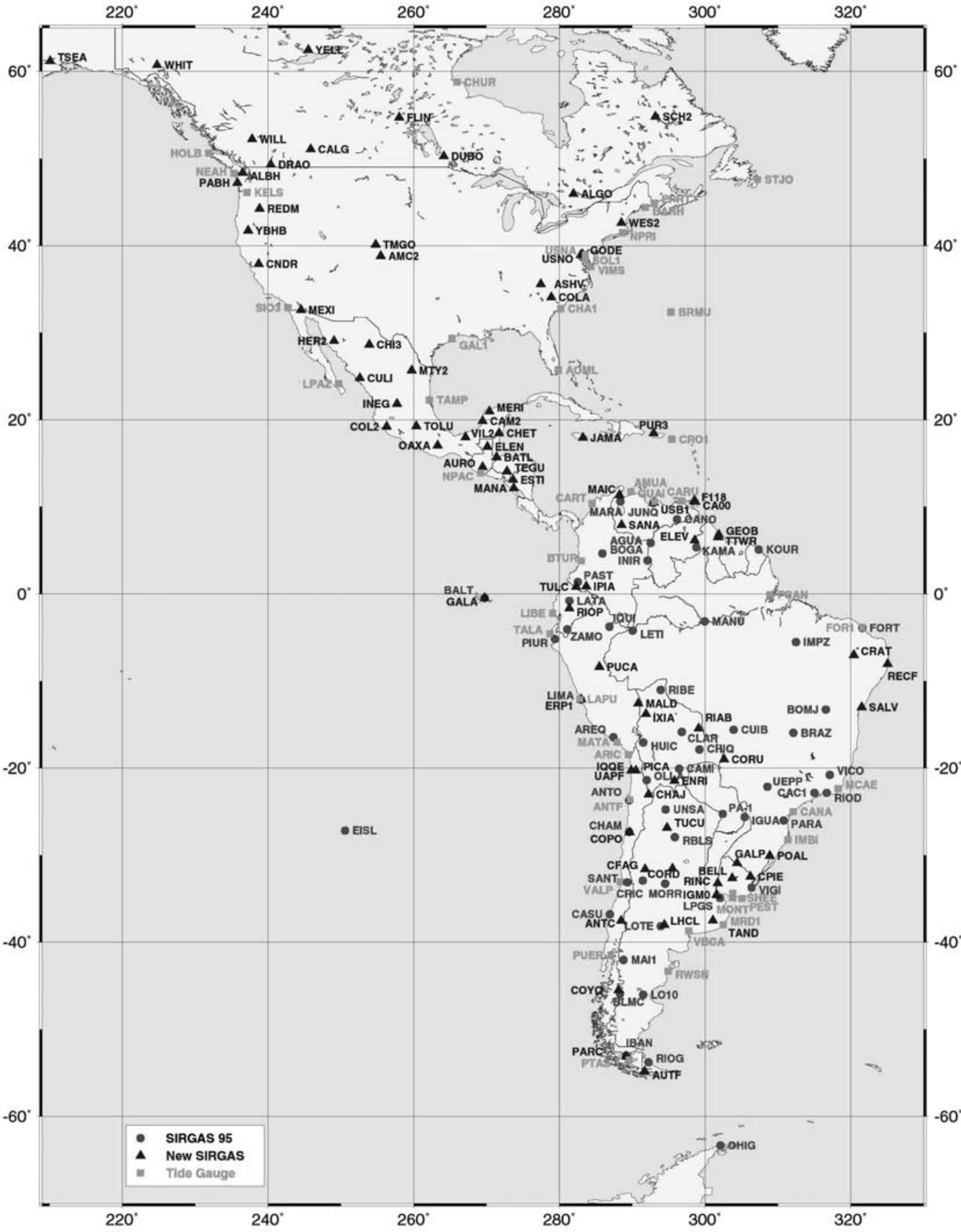

Fig. 1 Stations of the SIRGAS 2000 GPS campaign and their classification

Acknowledgement

The SIRGAS Project continues to work extremely successful. This is only possible due to the high level of cooperation provided by each participant, including all the American countries, the sponsoring organizations, the scientific consultants, as well as the data and processing centers. More than 30 institutions from the Americas and Europe are involved, all working together towards the high common goal. The extremely good cooperation was again experienced during the SIRGAS 2000 GPS campaign for the establishment of a unified vertical reference system for the Americas and as a first repetition measurement of the 1995 reference network. This is gratefully acknowledged.

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INFORMATION ON 3rd WORKING GROUP III MEETING, HELD FROM FEBRUARY 21 TO 22, 2001, IN CARTAGENA DE INDIAS, COLOMBIA

(prepared by the past President of WG-III, Eng. Roberto Teixeira Luz)

I. Agenda

- Welcome and introduction (L. Fortes)
  a. Acceptance of the agenda
  b. Proposition of SIRGAS committee's expansion to include North America, Central America and Caribbean representatives
  c. Proposition to change the meaning of SIRGAS acronym to "Americas Geocentric Reference System"
- Report from participating countries about the integration of their networks into SIRGAS and the adoption of the system in general (Representatives on SIRGAS Committee)
- Details about the SIRGAS GPS 2000 processing
  a. DGFI (K. Kaniuth)
  b. IBGE (S. Costa)
  c. discussion of the proposal on SIRGAS ellipsoidal coordinates to be officially adopted at next IAG Scientific Meeting, Budapest, September 2001
- Reports (examples) on WG III vertical data
  a. The Brazilian gravity/leveling data integration (R. Luz)
  b. South American vertical networks connection (J. N. Hernandez)
- Status of data release to WG III by participating countries (R. Luz)
- Discussion on the type of physical height to be adopted (R. Luz)
- SIRGAS time evolution (K. Kaniuth and H. Drewes)
- Next activities
- Other topics:
  a. SIRGAS in the IAG strucuture (L. Fortes)
  b. SIRGAS at the 7th UNRCCA (L. Fortes and H. Drewes)
  c. SIRGAS in PAIGH (F. Galbán)
  d. SIRGAS helping to solve Ecuador-Peru border conflict (L. Fortes)
- Conclusions and recommendations

II. Discussions

1. the proposition of SIRGAS committee's expansion to include North America, Central America and Caribbean representatives was unanimously approved. Consequently, it was decided to change the meaning of SIRGAS acronym to Americas Geocentric Reference System. After the meeting, geodetic authorities of these countries must be invited to nominate representatives to the Committee of SIRGAS Project ;
2. the President of the Committee presented the recommendations approved by the 7th United Nations Regional Conference on Cartography in the Americas concerning SIRGAS Project (*Annex 1*), to be included soon in the web sites of the Project : http://www.dgfi.badw.de/dgfi/SIRGAS/sirgas.html and http://www.ibge.gov.br/ibge/geografia/seminario/sirgas/principal.htm
3. National Representatives presented brief reports on the status of the geodetic systems in South American countries. During these presentations, it was recommended the revision of the WG-II instructions for the national networks integration to SIRGAS (*Annex 4*). The Representatives were requested to send WG-II copy of the information presented ;
4. the Processing Centers (IBGE and DGFI) presented some details of the methodology and status of SIRGAS 2000 GPS Campaign data processing. Problems in data files were indicated, whose solutions, requested to the respective countries, must be sent until March 15, 2001. After this deadline, Processing Centers will start final computation of its own network solutions, to be presented and discussed at Budapest IAG Scientific Meeting, September 2001 ;
5. two examples on WG-III activities were presented. Representative of Brazil informed that the computation of geopotential numbers was not started yet at his Institute due to the small number of leveling stations occupied by gravity surveys. He also informed that this situation will be corrected with gravity surveys from other Brazilian institutions, whose results are already into the database of IAG Sub-Commission for Gravity and Geoid in South America ;
6. the second example of activity related to WG-III objectives was presented by National Representative of Venezuela, regarding leveling connections from his country to Colombia and Brazil. A 3,5m difference between heights referred to vertical "data" of Venezuela and Brazil was demonstrated, identifying its causes as the great lenght of leveling lines, the absence of gravity corrections, and the differences between vertical "data" of the two countries ;
7. WG-III decisions on the proposal of BIVAS and BIDAS databases were briefly reviewed (*Anex 3*), emphasizing that **no country sent** answer to this proposal nor any **information** to be included into the databases. The President of SIRGAS Committee commented that will not have any reason for including, in

the final results of 2000 Campaign, the coordinates of stations of countries that do not sent information. To break resistances and to establish a continuous data flux, the Representative of Brazil, as President of WG-III and responsible for WG-III Data Center at IBGE, will request to the National Representative of his country, immediately after the meeting, the inclusion of informations of Brazilian network. It was **recommended** the establishment of a monthly report on the inclusion of new information into the databases ; and

8. the components of WG-III agreed on the **recommendation** of adoption of normal heights, accordingly the WG-III Technical Document (*Anex 2*). This recommendation will be submitted to National Representatives, requesting their answer about it, as a way for, within few months, WG-III to know the general situation and to establish strategies towards its objectives.

III. Participants

Eng. Luiz Paulo Souto Fortes	President of SIRGAS Committee	Brazil
Eng. Roberto Teixeira Luz	President of WG.III	Brazil
Dr. Melvin Hoyer	President of WG.I and Principal Member of WG.III	Venezuela
TCL Rodrigo Maturana Nadal	National Representative in the Committee and Principal Member of WG.III	Chile
Ing. Jose Napoleón Hernández	National Representative in the Committee and Principal Member of WG.III	Venezuela
Cap. Fernando Oviedo	National Representative in the Committee	Bolivia
Ing. Roberto Perez Rodino	National Representative in the Committee	Uruguay
Cap. Ricardo Urbina	National Representative in the Committee	Ecuador
Ing. Pedro A. Sandoval	National Representative in the Committee	Colombia
Dr. Hermann Drewes	Representative of IAG in the Committee and Scientific Consultant of WG.III	Germany
TCL Fernando Miguel Galbán	Representative of PAIGH in the Committee	Argentina
Prof. Graciela Font	Substitute Member of WG.III	Argentina
Dr. Silvio Rogério C. Freitas	Substitute Member of WG.III	Brazil
Ing. Laura Marlene Sánchez	Principal Member of WG.III	Colombia
Prof. Fabian Barbato	Principal Member of WG.III	Uruguay
Cap. Eduardo Andrés Lauría	Principal Member of WG.I	Argentina
Dr. Denizar Blitzkow	Scientific Consultant of WG.III	Brazil

Ing. Klaus Kaniuth	Processing Center at DGFI	Germany
Eng. Sonia Maria A. Costa	Processing Center at IBGE and Principal Member of WG.II	Brazil
Ing. Wolfgang Seemüller	Observer	Germany
Ing. Gustavo Acuña	Observer	Venezuela
Dr. Heinz Henneberg	Observer	Venezuela
Eng. Valéria M. Guimarães	Observer	Brazil
Dr. Claudio Brunini	Observer	Argentina
Angel R. Daal	Observer	Venezuela
Jorge Faure	Observer	Uruguay
Fanery Valencia	Observer	Colombia
William Martínez	Observer	Colombia
Wilfredo Rubio	Observer	Chile

IV. Recommendations

1. Review of recommendations on integration of national networks to SIRGAS, prepared by WG-II in 1996 *(Anex 4)* ;
2. Distribution of monthly reports on the informations received by WG-III Data Centers (databases BIVAS and BIDAS), starting with informations of countries where these data centers are established ; and
3. Adoption of normal heights in the definition of SIRGAS vertical reference system in each country.

V. Resolutions

1. Extension of SIRGAS Committee to include representation of countries of Central America, the Caribean and North America ;
2. Change of meaning of “SIRGAS” to “Geocentric Reference System for the Americas” ; and
3. Presentation of final results of processing of SIRGAS 2000 GPS Campaign observations in each Processing Center, and discussion of strategies for the integration of these results, during the IAG Scientific Assembly in Budapest, September 2001.

INFORMATION ON THE MEETING OF PROCESSING CENTERS, HELD ON SEPTEMBER 06, 2001, IN BUDAPEST, HUNGARY (prepared by the past President of WG-III, Eng. Roberto Teixeira Luz)

I. Agenda

- Introduction (L. Fortes)
- Presentation of the final results of the SIRGAS 2000 GPS Campaign by the Processing Centers
  a. DGFI, Germany (K. Kaniuth)
  b. IBGE, Brazil (S. Costa)
- Discussion of strategies to integrate the processing centres' results to generate a combined final solution
- Status of data release to WG-III by participant countries (R. Luz)
- Other topics
- Conclusions , recommendations , future work

II. Discussions

1. announcement of the new WG-III President, Eng. Laura Marlene Sánchez Rodríguez, substituting Eng. Roberto Teixeira Luz ;
2. presentation of some results of the processing of 2000 Campaign observations at both Processing Centres, emphasizing the time consumed with data "cleaning", due to the excessive number of problems in station and observation reports. It was also emphasized the need to interrupt the long process of integrating new stations to the network, caused by the delays in data sending, allowing the continuation of final computation towards the integration of Processing Centres results. Moreover, it was pointed out the impossibility of precise determination of site velocities to non-permanent stations occupied in 1995 and 2000 ;
3. discussion of aspects of the integration of the Processing Centres results in a combined solution, without a clear definition of strategies for such an integration. It was recommended the evaluation of ITRF-2000 main stations quality, and also the inclusion of all the 2000 Campaign stations in the final solution ;
4. information on the status of the WG-III databases, emphasizing the fact of only Argentina sent information and, again, the objectives each country must reach and the activities they must perform towards those objectives, in accordance with decisions of past meetings ; and

5. announcement of next Project Meeting to be held on October 2002, during the International Congress on Earth Sciences), in Santiago do Chile.

III. Participants

Eng. Luiz Paulo Souto Fortes	President of SIRGAS Committee	Brazil
TCL Rodrigo Barriga Vargas	President of WG.II and Substitute Member of WG.III	Chile
Ing. Laura M. Sánchez R.	President of WG.III	Colombia
Ing. Jose Napoleón Hernández	National Representative in the Committe and Principal Member of WG.III	Venezuela
Dr. Hermann Drewes	Representative of IAG in the Committee and Scientific Consultant of WG.III	Germany
Tcl Fernando Miguel Galbán	Representative of PAIGH in the Committee	Argentina
Eng. Roberto Teixeira Luz	Principal Member of WG.III	Brazil
Dr. Silvio Rogério C. Freitas	Substitute Member of WG.III	Brazil
Cap. Eduardo Andrés Lauría	Principal Member of WG.I	Argentina
Dr. Zuheir Altamimi	Scientific Consultant of Committee	French
Dr. Denizar Blitzkow	Scientific Consultant of WG.III	Brazil
Ing. Klaus Kaniuth	Processing Center DGFI	Germany
Eng. Sonia Maria A. Costa	Processing Center IBGE and Principal Member of WG.II	Brazil
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Dra. Maria Cristina Pacino	Observer	Argentina
Dr. Daniel Del Cogliano	Observer	Argentina
Ing. Wolfgang Seemüller	Observer	Germany
Dr. Eugen Wildermann	Observer	Venezuela
Ing. Gustavo Acuña	Observer	Venezuela
Dr. Wolfgang Bosch	Observer	Germany
Dr. Heinz Henneberg	Observer	Venezuela
Cap Alvaro Hermosilla J.	Observer	Chile
Dr. Michael Craymer	Observer	Canada
Dr. Marc Veronneau	Observer	Canada
Dr. Daniel R. Roman	Observer	USA
Dr. Ramón V. Garcia	Observer	Mexico
Dr. João Francisco Galera M.	Observer	Brazil
Dr. Remi Ferland	Observer	Canada
Ing. Detlef Angermann	Observer	Germany

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7TH UNRCCA RECOMMENDATIONS ON SIRGAS PROJECT (New York, January 22 to 26, 2001)

The Conference,

Recognizing the importance of high quality tri-dimensional position data referred to a unique global geodetic reference system for spatial data infrastructure,

Noting that there are large differences between existing national geodetic datums,

Considering the achievements obtained by the South American Geocentric Reference System (SIRGAS) Project with respect to a unified geodetic datum,

Bearing in mind that the SIRGAS reference frame is based on the International Terrestrial Reference Frame (ITRF), and noting that the World Geodetic System of 1984 (WGS84) is practically identical to ITRF,

Also bearing in mind that SIRGAS is supporting the participating countries in terms of knowledge transfer and training,

1. *Recommends* that the member countries of the Americas integrate their national geodetic reference systems into a reference system compatible with SIRGAS;

2. *Also recommends* that the member countries of the Americas provide to SIRGAS gravity data for computation of the geoid as the reference surface of the vertical (height) system;

3. *Further recommends* that the member countries of the Americas correct their leveling by gravimetric observations in order to compute geopotential numbers and connect the leveling networks with neighboring countries, making all these information available to SIRGAS.

TECHNICAL DOCUMENT ON VERTICAL REFERENCE SYSTEM FOR SOUTH AMERICA (prepared by Hermann Drewes, Laura Sánchez, Denizar Blitzkow and Silvio Freitas in 1998)

The recent determination of the SIRGAS datum (SIstema de Referencia Geocéntrico para América del Sur) enables to solve the problem of existing discrepancies between the different national geodetic reference frames in South America. Its main advantage is the establishment of a common platform for the horizontal datums. However, the disparity persists when comparing the classical vertical positions between neighboring countries. This circumstance obligates that the definition of a vertical system be added to the maintenance of SIRGAS. The vertical system has not only to satisfy the requirements of the cartographic representation, but also the demands of the current geodetic control and the homogeneization at international level. It should allow a consistent combination of the leveled heights, the gravity data, the ellipsoidal heights obtained by GPS observations and the geoid. Its determination includes four fundamental aspects: Definition of the type of heights to be used, determination of the surface to which these heights are referred, materialization by means of the reference frame and, finally, its change through time.

Considering these aspects and the Resolution No. 4 of SIRGAS Working Group III, this document presents the physical and geometric concepts involved in the definition of the height system, its reference surface and the most convenient way to realize the reference frame in South America.

I. Types of Heights

The height of a point on the surface of the Earth is the distance between this point and a specified reference surface. It is obtained by geometric, barometric, trigonometrical, or spaceborne methods. Due to the influence of the gravity field in the measuring process, the initially obtained results have to be reduced by gravimetric corrections.

In the conventional process of height determination (spirit leveling), the telescope of the leveling instrument is tangent to the local equipotential surface, and the plumb line coincides with the gravity vector which is perpendicular to this surface. The leveled height differences do not only reflect the topographical variations but they also include the effects of the Earth's gravity disturbances. The deviations that these disturbances generate on the measured heights can be discribed and quantified in accordance with appropiate physical concepts. By this means, the heights used in Geodesy are classified according to their determination procedure, their application and the mathematical or physical models considered in their definition. In principal, we distinguish two types of heights: geometric heights (leveled and ellipsoidal) and physical heights (dynamic, normal and orthometric).

1. Geometric Heights

1.1 Leveled heights

These are those heights obtained by spirit leveling (Figure 1). The observed height differences vary according to the local gravity field.

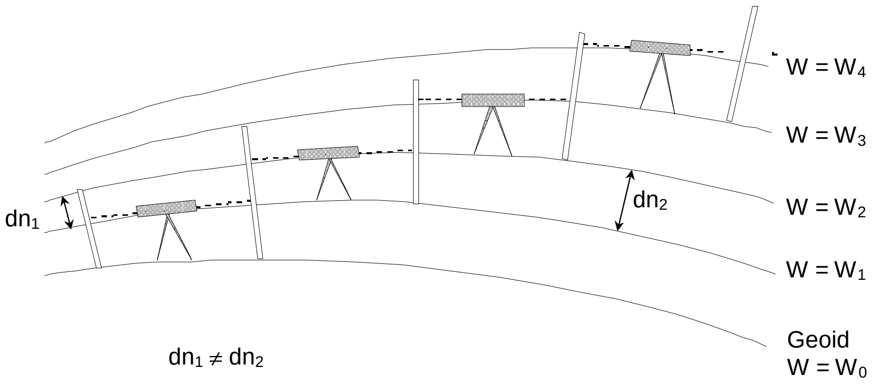

Figure 1. Leveled heights

The original measurements (dn) are the distances between the equipotential surfaces of the Earth's gravity field. The sum of dn along the leveled line provides the total height difference between the connected points. Nevertheless, due to the ellipsoidal figure of the Earth and due to the irregular distribution of its internal masses, the equipotential surfaces are not equidistant. The distances between them vary according to the trajectory of the leveling.

As these heights thus depend on the geographical route of leveling, there can easily be obtained different heights for the same point. Therefore, the leveled heights can be used only in small areas where neither the ellipsoidal figure of the Earth nor the variations of its gravity field have to be considered. Their practical application is thus restricted to local networks with approximately 10 km extension.

1.2 Ellipsoidal heights

The ellipsoidal heights (h) represent the distance between the topographical surface of the Earth and the reference ellipsoid. This distance is defined along the straight line perpendicular to the ellipsoid (Figure 2).

Starting from the cartesian geocentric coordinates (X, Y, Z), the ellipsoidal heights are computed with respect to a reference ellipsoid (e.g., the Geodetic Reference System 1980, GRS80, or the World Geodetic System 1984, WGS84, which in practice are nowadays identical). Today they are obtained using modern techniques, such as satellite positioning.

Due to the increasing use of GPS techniques, it is essential to include this type of heights in the official data bases as directly observed quantities. However, as the Earth's gravity field is not considered in their determination, they may yield identical height values in points at different levels, or vice versa. This reduces its practical application to a minimum. As a consequence it is necessary that these heights be supplemented by another type that considers the gravity field.

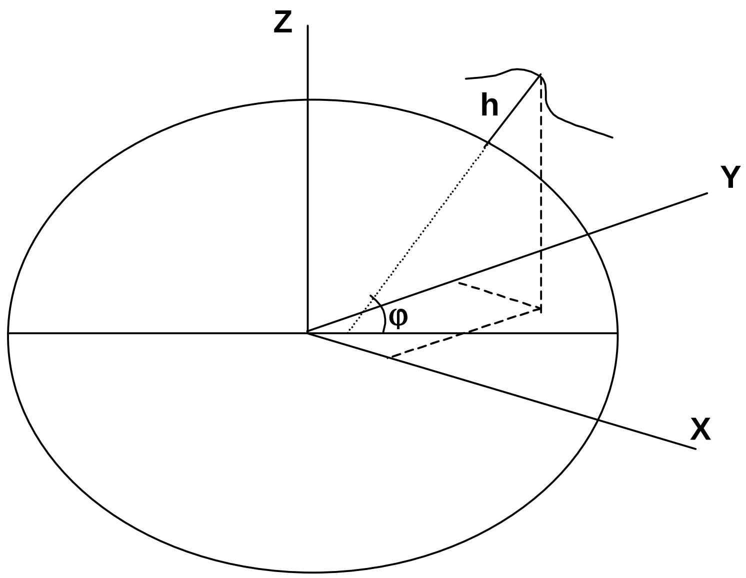

Figure 2. Ellipsoidal heights

2. Physical heights

A way to determine the real distances between the level surfaces is to start from their potential differences. In a closed circuit the sum of these differences will always be zero, independently of the chosen trajectory. This is because the potential values are univocal and they only depend on the position. In practice, their differences correspond with the results of spirit leveling reduced by gravimetric corrections. The potential difference between an observed point and the geoid (main equipotential surface of the Earth's gravity field) is known as the geopotential number:

$$\int_0^A g\,dn = W_0 - W_A = C \qquad (1)$$

being g the observed point gravity, dn the leveled height difference, W_o the potential of the geoid and W_A the potential of the surface that passes through the point. The dimension of the geopotential numbers is $[m^2/s^2]$. As this is not a longitude dimension, its use in practice is not convenient. The numbers can be expressed in distance units dividing them by conventional gravity values:

$$\textit{height (H) = geopotential number (C) / gravity value (G)} \qquad (2)$$

The heights (H) obtained by formula 2 depend on the type of gravity (G) involved. If G corresponds to the mean value of the theoretical (normal) gravity between the station and the reference surface, the calculated height is called normal. If G is a constant value of the theoretical gravity for an arbitrary point, H is known as dynamic height. Finally, if G is equal to the value of the real gravity between the geoid and the observed station, the height is called orthometric.

2.1 Dynamic heights

The dynamic heights are calculated dividing the geopotential numbers by a constant gravity value (γ_{cte}):

$$H_{(din)} = \frac{C}{\gamma_{cte}} \qquad (3)$$

The advantage of the dynamic heights is that identical values of these represent an equipotential surface of the gravity field. This means that an undisturbed water surface in any elevation over the geoid always has the same dynamic height. These heights are obtained from the leveled ones by applying the corrections which express the distance variations between the level surfaces generated by a constant gravity value.

The main disadvantage of this type of heights is that due to the convergence of the equipotential surfaces (especially in north-south direction, see Figure 1) the geometric distance between them varies considerably (5×10^{-3} units from the equator to the poles), without changing its dynamic height. For example, if two equipotential surfaces are considered whose geometric distance is 100 m in the equator, its equivalence in the poles will be of 99.5 m, while its dynamic height will always be constant.

2.2 Normal heights

The normal heights are obtained from the geopotential numbers by not dividing them by a constant gravity value (like in the equation 3) but by the mean normal gravity between the reference surface (denominated quasi-geoide) and the point in consideration (γ')(Figure 3):

$$H_{(norm)} = \frac{C}{\gamma'} \qquad (4)$$

γ' is computed by the formula of the Earth's normal gravity field, which is only a function of the geographical latitude of the point.

The normal corrections applied to the leveled heights are smaller than those of the dynamic heights, since γ' considers the convergence of the equipotential surfaces.

In accordance with the above, these heights can be obtained from the ellipsoidal heights if the undulations of the quasi-geoid, the so-called height anomalies (ζ) are subtracted:

$$H_{(norm)} = h - \zeta \qquad (5)$$

ζ is obtained from the geoid determinations by gravimetric or satellite methods.

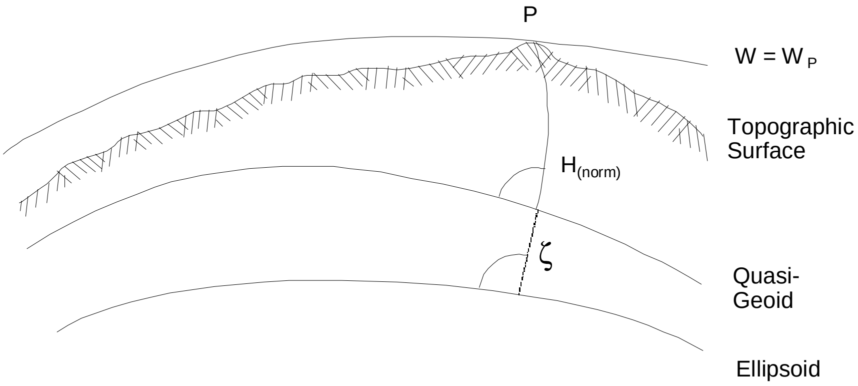

Figure 3. Normal heights

2.3 Orthometric heights

The calculation of the orthometric heights is similar to that of the normal ones with the difference that the geopotential numbers are divided by the mean value of the true gravity (g') between the evaluated point and the corresponding reference surface (geoid) (Figure 4).

$$H_{(ortom)} = \frac{C}{g'} \qquad (6)$$

The inconvenience that these heights present is based in the fact that the value g' cannot be known. Usually, the real gravity is measured on the topographic surface. For the downward continuation along the plumb line, a model of the density distribution of terrestrial masses is required. In this way, the calculated values of orthometric heights depend on the hypotheses used in the modeling of the density distribution. The most common methods in the determination of orthometric heights correspond with the hypotheses of Helmert, Vignal, Baranov and Free Air.

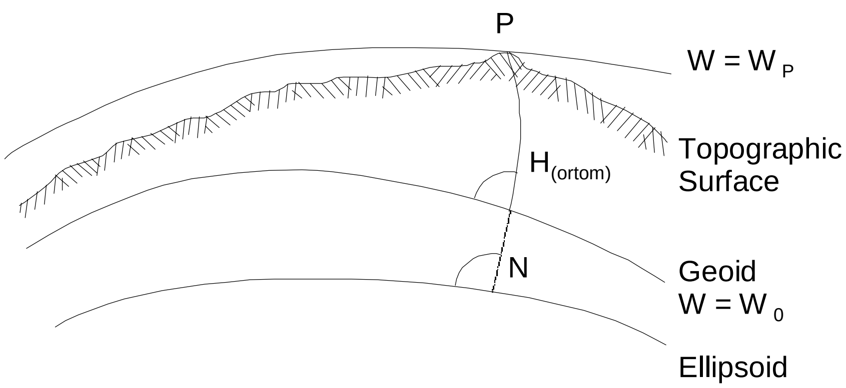

Figure 4. Orthometric heights

The orthometric corrections applied to the leveled heights are in the same order as those for the normal ones. However, the difference between orthometric and normal heights (and by this means also between the geoid and the quasi-geoid) depends on the difference between the modeled true gravity by some hypothesis and the normal gravity. It may come up to decimeters.

The orthometric heights can be computed from the ellipsoidal ones by subtracting the geoid undulations N:

$$H_{(orthom)} = h - N \qquad (7)$$

In the determination of N, as well as in the calculation of g' (equation 6) and in the estimation of the orthometric corrections, a hypothesis on the density distribution of the masses inside the Earth is required, This has to be the same for the three calculations, if it is not, a homogeneous set of orthometric heights will not be obtained, and their combination is problematic.

II. Reference surface for the definition of heights

All classic leveling starts from a reference point (vertical datum), which is determined by the observation of the mean sea level over a certain time period. It is assumed that this mean sea level coincides with the geoid. However, due to ocean dynamics, the oceans have different levels which depend on the variations of the sea surface with time (atmospheric pressure, oceanic temperature, etc.) and on the geographical position (ocean currents, density of the water, etc.). The mean sea level may differ up to two meters between several tide gauges.

To overcome the inconveniences in the vertical datum definition obtained by tide gauges, it is necessary to find a surface that constitutes a global reference independent of the observed sea level. The fundamental problem in Geodesy is to determine the equipotential surface of the Earth’s gravity field that coincides (as a first approximation) with the undisturbed mean sea level. This surface depends on the characteristics of the gravity field, especially its deformation caused by the internal density inhomogeneities. Its determination is subject to several theoretical assumptions which conduce to two principal concepts:

a. Geoid: equipotential surface of the Earth’s gravity field. Its estimation requires the formulation of a hypothesis on the density distribution of the topographic masses.

b. Quasi-geoid: non equipotential surface, very close to the geoid. Its determination does not require geophysical hypotheses; it is based on the mathematical model of the normal gravity field.

To the orthometric heights corresponds, as the reference surface, the geoid, while to the normal heights corresponds the quasi-geoid. The ellipsoidal heights are referred to the geometric figure (revolution ellipsoid), which implicitly is described by an equipotential surface of the normal gravity field.

III. Realization of the vertical reference frame

Once having defined the type of heights and their corresponding reference surface, it is necessary to materialize this system by the establishment of a set of stations (reference network) that constitute the basis for the vertical control. This set should include those tide gauges that serve as a base for the classical height system. In this way it is linked to the new system, and the validity of the heights defined by the classic method is maintained.

The stations that form the basic vertical network have to be connected by spirit leveling, reduced by gravimetric corrections and observed with GPS (referred to the SIRGAS datum). By this procedure, completed by the determination of the geoid (quasi-geoid) for South America, the vertical reference frame can be realized.

IV. Maintenance of the vertical reference system

In the same way as the horizontal geodetic networks are deformed by geodynamic processes, the vertical systems are affected, too. The changes of the vertical positions of the topographic surface are mainly due to:

a. Changes of the reference surface (geoid or quasi-geoid) as a consequence of the variations of the internal mass distribution, e.g., by plate tectonics.

b. Variation of the reference surface by changes of the mean sea level, e.g., caused by polar melting and oceanic temperature.

c. The vertical movements generated by crustal deformations, sedimentation and other topographic modifications.

These three aspects demand for a continuous monitoring of the vertical reference frame, in order to detect its variations and to maintain the validity of the determined heights by means of their permanent actualization.

V. Conclusions and recommendations

According to the above, it is recommended that the definition of the South American vertical reference system be based on two types of heights: the ellipsoidal and the normal heights. The arguments are summarized as follows:

The ellipsoidal heights enable to define a precise vertical reference frame. Nevertheless, being these only geometrical, they have to be complemented by physical heights to satisfy the practical requirements.

Among the physical heights there are the normal and the orthometric heights. The normal heights are preferred, since, in spite of having similar practical application as the orthometric ones, their determination does not require the formulation of a hypothesis or geophysical models of the topographic density distribution. This facilitates their determination using the geopotential numbers and the normal gravity field.

The normal heights use the quasi-geoid as a reference surface. This is usually calculated by gravimetric and satellite methods, while the geoid, as the reference surface of the orthometric heights, requires the formulation of geophysical models for its determination. If the applied model is modified, the orthometric heights are changed.

The normal heights are easier obtained from GPS measurements than the orthometric ones. This is due to the fact that the ellipsoidal heights are reduced by quantities calculated mathematically (height anomalies of the quasi-geoid). On the other hand, the quantities used to reduce the orthometric heights (the geoid undulations) require a geophysical hypothesis.

The normal heights facilitate the combination with heights obtained from GPS positioning with those calculated by means of geometric leveling with normal gravity correction. This guarantees a more homogeneous extension of the vertical control in the different South American countries without neglecting the consistency of an unique vertical reference frame.

The reference surface should be defined according to the selected type of heights. In this case, it corresponds with the quasi-geoid. This should be done in a coordinated way for all the South American countries.

Finally, in order to link the classic vertical reference systems, it is necessary to determine the normal heights of those tide gauges that constitute the different height datums. For that purpose, GPS observations, satellite altimetry and height anomalies should be combined.

DATABASES FOR SOUTH AMERICAN VERTICAL NETWORKS (proposed by Laura Sanchez in 1998)

According Resolution No. 3 from the Meeting of SIRGAS Working Group III, held on Santiago de Chile August 9-14, 1998, follow below two structures for the instrumentation and maintaining of a database containing the main characteristics of vertical information determined on South America.

The main objective on the design of these models was to build a database which shows a wide perspective of the up-to-date situation of national vertical systems. The first one (BIVAS, spanish/portuguese acronym for South America Vertical Information dataBase) will contain the general characteristics of the levelling networks, using each country as main key. The other (BIDAS, for South America Detailed vertical Information dataBase) collects particular characteristics of each one of the levelling stations, and its structure assumes one record for each height value.

BIVAS: South America Vertical Information dataBase

This structure collects the general information about altimetric stations existent in South America. Its main objective is to provide a quick statistic on the up-to-date vertical situation. In this database the number of records will be same as the number of countries.

field	description	attributes	format	length
PAIS	name of the country	Argentina Bolivia Brasil Etc.	character	30
ESTT	total number of stations with known height value		numeric	8
EST1	number of first order altimetric stations		numeric	8
EST2	number of sedcond order altimetric stations		numeric	8
EST3	number of third order altimetric stations		numeric	8
ESTO	number of low precision altimetric stations		numeric	8
TDAV	classic vertical datum	corresponding tide gauge	character	60
TALT	Type of the heights (height system)	levelled orthometric normal dynamic other	character	20

TGRA	number of altimetric stations with known gravity value		numeric	8
TDAG	gravity datum	Postdam IGSN71 IAGBN	character	20
GEOP	number of altimetric stations with computed geopotential number		numeric	8
TCOO	number of altimetric stations with known geodetic coordinates		numeric	8
TDAH	horizontal geodetic datum	national SIRGAS other	character	60
TELI	number of altimetric stations with known ellipsoidal height value		numeric	8
GEOD	geoid model	national regional global	character	60
CONS	percentage of non-destroyed altimetric stations		numeric	3
REOC	percentage of relevelled altimetric stations		numeric	3
ACTL	reference date		date YYYY/ MM/DD	10
OBSV	comments		character	300

BIDAS: South America Detailed vertical Information dataBase

This model collects as much as possible information regarding existent altimetric stations in each country from South America. It will contain as many records as known height values. So, if one altimetric station has levelled height, orthometric height and ellipsoidal height, it must appear three times in the database with the attributes corresponding to each height type. The definition of BIDAS is based in a entity-relationship model, allowing the link between different attributes from fields of additional bases.

Besides generating BIVAS, the main advantage of this database is its use as structure for the storage of information about SIRGAS vertical reference network, composed by reference tide gauges and basic vertical stations defined in each country.

field	description	attributes	format	length
CodEst	station code		character	12
NMP	station name		character	30
CodPas	country code		numeric	5
FECHA	levelling date		date YYYY/MM/DD	10
TLAT	station latitude		numeric 00° 00’ 00,000”	10
TLON	station longitude		numeric 00° 00’ 00,000”	10
TMETH	horizontal coordinates determination method	1001 doppler 1002 GPS 1003 astronomy 1004 triangulation 1005 trilateration 1006 traverse 1007 bissection 1008 cartographic interpolation 1009 other	numeric	4
TPRH	precision of horizontal coordinates		numeric 00,000”	6
TDAH	geodetic datum	national SIRGAS other	character	20
ORDEN	station classification according its precision	2001 first 2002 second 2003 third 2004 other	numeric	4
ALTT	height value		numeric 0000,0000 m	9
TALT	height type	3001 levelled 3002 orthometric 3003 normal 3004 dynamic 3005 ellipsoidal 3005 geoidal	numeric	4
TMEDV	height determination method	spirit levelling trigonometric levelling GPS levelling geophysical hypothesis Etc.	character	60
TPRV	height precision		numeric 00,0000 m	7

TDAV	vertical datum type	national tide gauges local geoids regional geoids global geoids other	character	60
TGRAV	observed gravity value		numeric 000 000,0000 mgal	12
TPGR	observed gravity precision		numeric 0,0000 mgal	6
TDAG	gravity datum	Postdam IGSN71 IAGBN other	character	60
TEST	up-to-date station status	4001 active 4002 obsolete 4003 destroyed	numeric	4
TLOP	station localization		character	100
TDES	station description		character	300
TCRO	station croquis		graphic	
ACTL	reference date		date YYYY/MM/ DD	10
OBSV	comments		character	300

RECOMMENDATIONS FOR THE INTEGRATION OF NATIONAL GEODETIC NETWORKS INTO SIRGAS SYSTEM (prepared and distributed in 1996 by WG-II)

Objective of the recommendations

These recommendations have two main objectives :

1. To set minimal procedures that guarantee for the South American countries the highest possible precision of their fundamental geodetic GPS networks. Compatibility in this context means that the networks should all be integrated into the IERS Terrestrial Reference Frame (ITRF) which is realized by the SIRGAS network on the continent, thus leading to a uniform continental network.

2. To establish the minimum contents of the reports to be addressed to SIRGAS Working Group II by every country referring to the processing of their national networks.

1. Procedures

Observations :

National geodetic networks should only include GPS observations with double frequency receivers.

Processing guidelines :

The use of software packages allowing multisession-multistation processing is highly recommended. Doing so will, among many other advantages, make feasible correct observation correlation handling. Among the packages having the stated advantage, the use of Bernese, GIPSY or GEONAP would be advisable because those are the packages used by DGFI, DMA and IBGE, respectively.

For those networks entirely observed later than 1994.0, the use of precise ephemeris from the IGS is advisable. In case of including measurements from epochs prior to that, the use of precise ephemeris from a source of widely acknowledged quality is recommended. For 1993 individual precise orbits are available from several IGS analysis centres, such as CODE, EMR, GFZ, JPL, SIO.

The implementation of precise satellite clock information compatible with the used precise orbit is advisable in case of being available. Precise and compatible earth orientation and rotation parameters should also be used.

As a general rule for processing, it would be advisable to process the observations starting from known coordinates good to the meter level imposing no restrictions (free network) which means no fixing nor weighting any station coordinates. Only in the final adjustment the correspondingly transformed SIRGAS coordinates should be introduced to establish the reference frame. Among the advantages of this approach it should be mentioned that a great percentage of the work can be done before the availability of the official SIRGAS coordinate set which is intended to be released in March 1997.

The utmost care should be taken when introducing the fiducial SIRGAS coordinates because they should be transformed to the same reference system and epoch in which the orbits are expressed. Moreover, SIRGAS fiducial coordinates should not be set as fixed (errorless) but should be introduced into the final adjustment with a high weight corresponding to their individual rms errors.

In this sense, the countries should take the output of the final adjustment as the official set of coordinates for their national networks. However, in the case of points coincident with the SIRGAS points, the official SIRGAS coordinates should be taken.

Finnaly and in order to assure a better integration of the national networks throughout the whole continent in a homogeneous system, conversion of the final national results to the SIRGAS reference frame for epoch 1995.42 is recommended.

2. Results e related information to be addressed to SIRGAS Working Group II

Network :

- Final coordinates of the national network stations with the variance-covariance matrix or at least their corresponding standard deviations.

- Network design.

Observation schedule :

- Sessions
- Stations
- Observation periods
- Receivers employed

Processing : software package used

Processing strategy description :

- Set of used a-priori coordinates
- Used satellite ephemeris/clocks information and earth rotation/orientation parameters
- Elevation mask
- Combination strategy used with L1 and L2
- Tropospheric delay handling
- Ambiguity handling
- Set of coordinates used to realize the reference system
- Problems detected during the processing sequence
- Quality estimations for the processing
- Information about the people that actually performed the calculations, institutes they work for and the scientific consultants that could eventually have participated