SIRGAS Combination Centre at DGFI
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1. Introduction

The densification of the ITRF in Latin America and the Caribbean is the SIRGAS Continuously Operating Network (SIRGAS-CON). This network comprises two hierarchy levels (Brunini, Sánchez 2008): a core net (SIRGAS-CON-C) providing the primary link to the global ITRF; and a densification net (SIRGAS-CON-D) containing all the fundamental stations of the national reference frames. The densification network is further divided into three sub-networks covering the northern part, the middle part, and southern part of the SIRGAS region (Figure 1). The core network ensures the long-term stability of the continental reference frame, and the densification sub-networks improve the geographical density of the reference stations facilitating the accessibility to the reference frame in local levels. This operational infrastructure is possible thanks to the active participation of many Latin American and Caribbean institutions, who not only make available the measurements of their stations, but also are hosting SIRGAS Analysis Centres in charge of processing the observational data on a routine basis.

As responsible for the IGS Regional Network Associate Analysis Centre for SIRGAS (IGS RNAAC SIR), DGFI has to deliver loosely constrained weekly solutions for the SIRGAS-CON network to the IGS (International GNSS Service). These solutions are combined together with those generated by the other IGS Global and Regional Analysis Centres to form the IGS Polyhedron. The processing of the SIRGAS-CON network in the frame of the IGS RNAAC SIR also includes the computation of weekly coordinate solutions fitted to the current ITRF realization and accumulative position and velocity solutions for estimating the kinematics of the network. Until 31 August 2008 (GPS week 1495), DGFI processed the entire SIRGAS-CON network. Afterwards, with the introduction of the core network and the densification sub-networks within SIRGAS-CON, as well as the installation of SIRGAS Processing Centres under the responsibility of Latin American institutions, DGFI is now responsible for processing the SIRGAS-CON-C core network, for combining this core network with the densification sub-networks, and for making available the official SIRGAS products, i.e. loosely constrained weekly solutions for the IGS polyhedron, weekly solutions fitted to the ITRF for the users in Latin America, and multi-annual solutions (coordinates + velocities) for applications requiring coordinate time-dependence.

According to this, the present report summarizes the activities carried out by DGFI as SIRGAS Combination Centre since August 31, 2008. Activities related to the SIRGAS Processing Centre at DGFI and the determination of the latest multi-year solution (SIR09P01) for the SIRGAS-CON network are described in Seemüller and Sánchez (2009) and Seemüller et al. (2009), respectively.

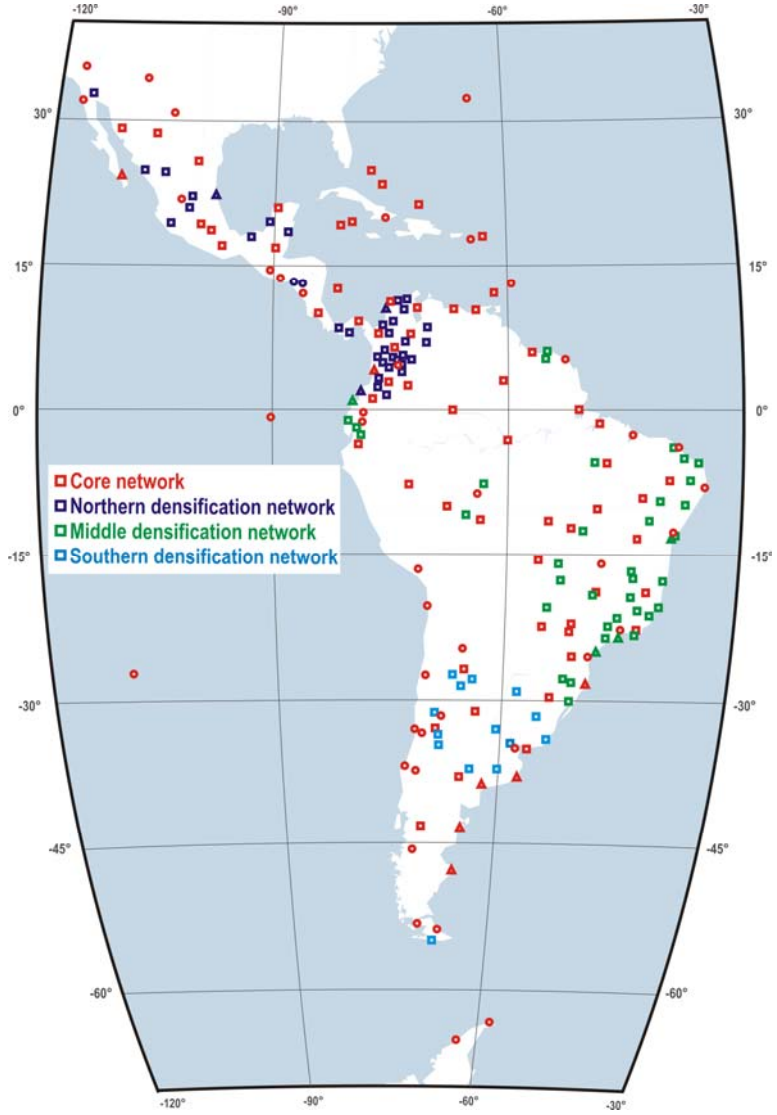

Figure 1. *SIRGAS-CON-C core and SIRGAS-CON-D densification sub-networks.*

2. DGFI combination strategy

The SIRGAS Processing Centres DGFI, CIMA, IBGE, and IGAC deliver loosely constrained weekly solutions for the assigned SIRGAS-CON sub-network. In these solutions, satellite orbits, satellite clock offsets, and Earth orientation parameters are fixed to the final weekly IGS values and coordinates for all sites are loosely constrained to ±1 m. These individual contributions are integrated in a unified solution by the SIRGAS Combination Centres: DGFI and IBGE. The processing strategy applied by DGFI for the combination of the individual SIRGAS-CON sub-networks applies the Bernese Software V.5.o (Dach et al. 2007) and corresponds to:

1) Individual solutions are reviewed/corrected for possible format problems, station inconsistencies, utilization of erroneous equipment, etc.;

2) Constraints included in the delivered normal equations are removed;

3) Sub-networks are individually aligned to the IGS05 reference frame by applying the NNR + NNT conditions. The included IGS05 reference stations are those with

available coordinates in the IGS constrained weekly combinations, i.e. files igs*yy*P*wwww*.snx (*yy* = year, *wwww* = GPS week);

4) Coordinates obtained in (3) for each processing centre are compared to the IGS weekly values and to each other to identify possible outliers;

5) Stations with large residuals (more than 10 mm in the north or east components, and more than 20 mm in the Up component) are reduced from the normal equations. Steps (3), (4), and (5) are iterative;

6) Variances obtained in the final computation of step (3) are analyzed to estimate scaling factors for relative weighting of the individual solutions (see below Item 4.1.4).

7) Once inconsistencies and outliers are reduced from the individual free normal equations, a combination for a loosely constrained weekly solution for station coordinates (all station coordinates constrained to ±1 m) is computed. This solution is submitted to IGS for the global polyhedron.

8) Finally, a weekly solution aligned to the IGS05 reference frame is computed based on the IGS weekly coordinates (igs*yy*P*wwww*.snx) of the IGS05 stations used in (3). The weights of the reference coordinates are inversely proportional to the internal precision of the GPS measurements (±1E-04 m in the Bernese Software). This solution provides the final SIRGAS-CON coordinates for further applications.

9) Resulting files of these procedure are:

   SIR*wwww*7.SNX: SINEX file for the loosely constrained weekly combination.
   SIR*wwww*7.SUM: Report of weekly combination.
   siryyP*wwww*.snx: SINEX file for the constrained weekly combination.
   siryyP*wwww*.crd: Final SIRGAS-CON coordinates for week *wwww*.

   The loosely constrained combinations as well as the weekly SIRGAS-CON coordinates are available at ftp://ftp.dgfi.badw-muenchen.de/pub/gps/SIRGAS/ or at http://www.sirgas.org/index.php?id=153.

Before the weekly combinations computed by DGFI for the SIRGAS-CON network are published or made available for users, a quality control is carried out to guarantee consistency and reliability of the SIRGAS products. This quality control is described in Section 4 of this Report.

3. Evaluation of the SIRGAS Experimental Processing Centres by DGFI

SIRGAS promotes the installation of more Processing Centres hosted by Latin American institutions. Motivation for this are:

1) SIRGAS member countries are qualifying their national reference frames by installing an increasing number of continuously operating GNSS stations and each country shall be able to process the data of its own stations;

2) Since there are not enough Local Processing Centres, the required redundancy in the analysis of the SIRGAS-CON network is not fulfilled: not all SIRGAS-CON stations are included in the same number of individual solutions and they are unequally weighted in the weekly combinations. As an optimum, each SIRGAS-CON station shall be processed by the same number of Processing Centres (at least three).

In this frame, institutions interested to install a SIRGAS Processing Centre shall pass a test period of one year. In this period, they have to align their processing strategies to the SIRGAS guidelines and satisfy the punctuality on delivering their weekly solutions. DGFI as a SIRGAS Combination Centre is responsible for evaluating the weekly solutions delivered by the SIRGAS Experimental Processing Centres, analysing not only their accuracy and compatibility with the official SIRGAS products, but also reviewing if operational aspects related with the punctuality on making available their SINEX files, the observance of the SIRGAS guidelines, accordance with the log files information, etc. are fulfilled. The evaluation of the solutions produced by the SIRGAS Experimental Processing Centres is carried out following the same procedure applied for the SIRGAS Official Processing Centres. Details of evaluation and results are presented in the following Section.

4. Quality control carried out by DGFI in the weekly combinations for the SIRGAS-CON network

The generation of the weekly SIRGAS-CON products (i.e. loosely constrained combinations and station coordinates fitted to IGS05) at DGFI includes a quality control at two levels: Firstly, the individual solutions delivered by the SIRGAS Processing Centres (official and experimental) are analysed to establish their quality and consistency. This includes a survey about date of delivering, processed stations, log file observance, etc. Once the individual solutions are reviewed and free of inconsistencies, their combination is carried out by applying the procedure summarized in Section 2. Then, the second quality control concentrates on the results of this combination. Here, the main objective is to ascertain the accuracy and reliability of the weekly solutions for the entire SIRGAS-CON network. It should be mentioned that the DGFI combinations made available for users include the solutions provided by the SIRGAS Official Processing Centres only. Combinations including solutions delivered by the SIRGAS Experimental Processing Centres are for internal control. The procedures, analysis, and conclusions contained in this report are based on the weekly solutions summarized in Table 1.

Table 1. *Solutions delivered by the SIRGAS Processing Centres.*

Id	Processing Centre	First week	Latest week	Sub-network	No. stations
SIRGAS Official Processing Centres					
CIM	Instituto de Geodesia y Geodinámica at the Universidad Nacional del Cuyo (IGG-CIMA, Argentina))	1495	1538	Southern sub-network	50
DGF	Deutsches Geodätisches Forschungsinstitut (DGFI, Germany)	1495	1538	Core network	107
IBG	Instituto Brasileiro de Geografia e Estátistica (IBGE, Brazil)	1495	1538	Middle sub-network	94
IGA	Instituto Geográfico Augustín Codazzi (IAGC, Colombia)	1495	1538	Northern sub-network	94
SIRGAS Experimental Processing Centres					
ECU	Instituto Geográfico Militar of Ecuador (IGM, Ecuador)	1513	1538	Selected stations of the northern and middle sub-networks	31
LUZ	Laboratorio de Geodesia Física y Satelital at the Universidad del Zulia (LGFS-LUZ)	1520	1538	Northern sub-network	94
URY	Servicio Geográfico Militar of Uruguay (SGM, Uruguay)	1526	1538	Selected stations of the southern and middle sub-networks	44

4.1 Evaluation of individual solutions

4.1.1. Punctuality on delivering weekly solutions

According to the SIRGAS 2008 Resolutions (Brunini, Sánchez 2008), the SIRGAS Processing Centres shall deliver to the IGS RNAAC SIR their weekly solutions in the third week after observation. In the same way, the SIRGAS Combination Centres shall report their results in the fourth week after observation. In general, these punctuality requirements are satisfied. Figure 2 shows the corresponding statistics classified in three main timetables: on time (solutions delivered according to the SIRGAS agreement), delayed (solutions delivered during the following week after deadline), and late (solutions delivered after two o more weeks after deadline).

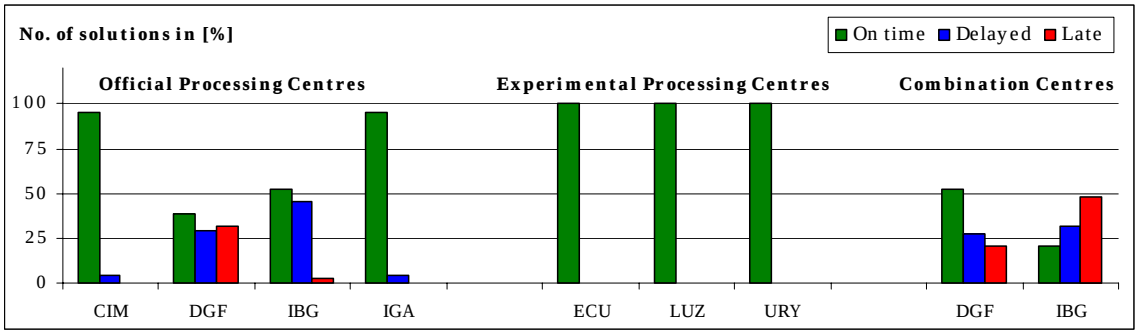

Figure 2. *Percentage of solutions delivered on time, delayed, or late by the SIRGAS Analysis Centres (GPS weeks 1495 to 1538).*

4.1.2 Compatibility with log files

The SIRGAS-CON stations included in the individual solutions shall be identified by the 4-character code together with the IERS domes number and the station information (receiver, antenna, height of the antenna, etc.) shall precisely correspond to the station information contained in the log files. In general, all Processing Centres satisfy these requirements. The few inconsistencies found under this topic were appropriately corrected.

4.1.3 Identification of outliers

To avoid deformations in the combined network, those stations with very large outliers (more than 50 mm in any component) are reduced from the weekly normal equations. The identification of these outliers is carried out by transforming the contributing normal equations to identical a-priori values and generating time series for station coordinates. The loosely constrained weekly solutions delivered by each Processing Centre are aligned by means of a 7-parameter similarity transformation to the IGS05 positions at observation epoch. After that, coordinate time series are generated for each station included in the individual solutions. In this way, if one station is processed by three Processing Centres, there will be available three different time series for the same station. By comparing the time series amongst one to another, it is easier to identify outliers and their possible causes: if outliers, jumps, or interruptions are identifiable in the different series, the problems may be individually associated to the station (tracking deficiencies, equipment changes, failure of the data submission, earthquakes, etc.). If outliers, jumps, or interruptions are not present in all time series, the deficiencies may

be associated to administrative issues (neglecting of stations, incomplete download of RINEX files, disagreement with the log files, etc.). In this step, a few outliers were identified and the corresponding stations were reduced from the normal equations before combination.

4.1.4 Validation of the stochastic models

The relative weighting of individual solutions by means of variance factors is necessary to compensate possible differences in the stochastic models of the SIRGAS Processing Centres. To validate the stochastic models we compare mean standard deviations of coordinates derived from solving the normal equations with mean RMS values derived from the time series of station coordinates. The latter ones reflect the real accuracy of the weekly coordinate solutions. If the relation between the standard deviations of the different Processing Centres is the same as the relation between the RMS values, the stochastic models are comparable and it is not necessary to apply relative weighting factors. To ensure that the RMS values are not dominated by individual stations that are not included in all solutions, they are computed in three different ways (items a, b, c). The computation of the RMS values and standard deviations was done as follows:

a) Evaluation of the individual weekly repeatability (RMS of the time series) of station coordinates for each Processing Centre. This indicates the consistency between the individual solutions from week to week;

b) Comparison of the individual weekly solutions with respect to the final weekly combination;

c) Comparison of the individual weekly solutions with respect to the weekly IGS Global Network combination (files igs*yy*P*wwww*.snx);

d) Determination of mean standard deviations based on minimum datum conditions (NNR and NNT) with respect to the IGS05 stations. These mean standard deviations represent the formal errors of the individual solutions.

Table 2 summarizes the mean values for the described approaches over the total analyzed period (Table 1 shows the number of GPS weeks included per Processing Centre). The variance factors are calculated with respect to the DGFI values, since they correspond to the major SIRGAS-CON-C core network. In general, the variance factors derived from the different RMS values (criteria a, b, c) is very similar and can be averaged. These mean values are then compared with the variance factors derived from the standard deviations (criteria d). They agree quite well. Keeping in mind that all the Processing Centres are applying the same analysis strategy (double differences), the same software (Bernese), the same satellite orbits, satellite clock offsets, and Earth orientation parameters (final IGS products), as well as the same observations (RINEX files) for the common stations (Table 3), we can conclude that the parameters estimated by each of the contributing solutions are at the same accuracy level (i.e. there are no differences in the stochastic models) and a relative weighting of the Processing Centres is not necessary.

Table 2. *Variance factors (with respect to DGF values, i.e. SIRGAS-CON-C core network) for the individual normal equations generated by each SIRGAS Analysis Centre.*

Processing centre / component		Approach				Variance factors				
		a) RMS residuals for weekly repeatability [mm]	b) RMS residuals wrt combined solution [mm]	c) TMS residuals wrt IGS weekly solutions [mm]	d) Mean standard deviation [mm]	a)	b)	c)	Mean of a, b, c	d)
CIMA	N	1,9	0,7	2,1						
	E	1,6	0,6	2,4						
	Up	3,8	1,5	4,6						
	Total	4,7	1,8	5,7	1,7	1,3	1,1	0,9	1,1	0,9
DGFI	N	2,2	0,7	1,9						
	E	2,2	0,7	2,2						
	Up	5,0	1,6	4,2						
	Total	6,1	1,9	5,2	1,6	1,0	1,0	1,0	1,0	1,0
IBGE	N	2,6	0,8	2,0						
	E	2,6	1,0	2,1						
	Up	5,3	1,6	4,7						
	Total	6,8	2,1	5,6	1,7	0,9	0,9	0,9	0,9	0,9
IGAC	N	1,9	0,5	1,6						
	E	2,1	0,6	1,9						
	Up	4,2	1,3	4,5						
	Total	5,2	1,6	5,2	1,5	1,2	1,2	1,0	1,1	1,0
ECU	N	1,5	0,8	2,0						
	E	1,4	0,7	2,0						
	Up	4,1	2,4	4,8						
	Total	4,7	2,7	5,7	1,4	1,3	0,7	1,1	1,0	0,9
LUZ	N	1,4	0,6	1,6						
	E	1,5	0,7	2,0						
	Up	3,5	1,8	4,7						
	Total	4,6	2,1	5,4	1,6	1,3	0,9	1,0	1,1	1,0
URY	N	1,6	0,8	1,4						
	E	1,2	0,6	1,3						
	Up	3,6	1,5	2,9						
	Total	4,5	1,9	5,1	1,3	1,4	1,0	1,2	1,1	1,0

Table 3. *Number of common stations processed by the SIRGAS Analysis Centres.*

Processing Centre	CIM	DGF	IBG	IGA	ECU	LUZ	URY
CIM	50	36	21	15	9	15	31
DGF		107	49	56	17	56	22
IBG			94	17	22	17	22
IGA				94	20	94	5
ECU					32	20	3
LUZ						94	5
URY							44

4.2 Evaluation of combined solutions

The weekly combined solutions are aligned to the IGS05 reference frame by constraining the coordinates to the IGS05 stations included in the IGS weekly combinations (igs*yy*P*wwww*.snx). The applied constraint corresponds to a weight inversely proportional to the internal precision of the GPS measurements (1E-04 m in the Bernese Software). The quality evaluation of the DGFI combined solutions is based on the following criteria:

a) Mean standard deviation for station positions after aligning the network to the IGS05 reference frame indicates the formal error of the final combination;

b) The weekly coordinate repeatability after combining the individual solutions provides information about the internal consistency of the combined network;

c) Time series analysis for station coordinates allows to determine the compatibility of the combined solutions from week to week;

d) Comparison with the IGS weekly coordinates (igs*yy*P*wwww*.snx) indicates the consistency with the IGS global network;

e) Comparison with the IBGE weekly combination (ibg*yy*P*wwww*.snx) fulfils the required redundancy to generate the final SIRGAS products. This comparison is carried out with the final coordinate values (no 7-parameter similarity transformation is applied here).

Table 4 presents mean values of the different applied criteria for the period covering the GPS weeks 1495 - 1538. The mean standard deviation of the combined solutions agrees quite well with those computed for the individual contributions (Table 2), i.e. the quality of the individual solutions is maintained and their combination does not deform or damage the internal accuracy of the entire SIRGAS-CON network. The coordinates repeatability in the weekly combinations provides an estimate of the accuracy (internal consistency) of the weekly combinations of about ±0,8 mm in the horizontal component and about ±2,5 mm in the vertical one. The RMS values derived from the time series for station coordinates and with respect to the IGS weekly coordinates indicate that the reliability of the network (external precision) is about ±1,5 mm in the horizontal position and ±4,3 mm in the height. The differences respect to the weekly IBGE combinations are a bit larger, considering that DGFI and IBGE apply the same input normal equations for combination. This can be a consequence of the dissimilar combination strategies, especially the methodology for the datum realization. A description about the IBGE combination strategy is available at ftp://geoftp.ibge.gov.br/SIRGAS.

Conclusions

DGFI as a SIRGAS Combination Centre reviews, evaluates, and combines on a weekly basis the individual solutions delivered by the SIRGAS Analysis Centres: four Official Processing Centres (CIM, DGF, IBG, IGA) and three Experimental Processing Centres (ECU, LUZ, URY). The official SIRGAS products (i.e. loosely constrained weekly solutions for the IGS polyhedron and weekly solutions aligned to the IGS05) released by DGFI include the individual solutions of the Official Processing Centres only. Analyses including contributions from the Experimental Processing Centres are for internal control. The analyzed period corresponds to the GPS weeks 1495 - 1538. The results permit to conclude that all Processing Centres (official and experimental) satisfy the administrative and quality processing

requirements defined in the SIRGAS guidelines. Their weekly solutions are at the same accuracy level with respect to each other and with respect to final weekly combinations. In general, the accuracy (internal consistency) of results is ~ ±0,8 mm for the horizontal position and ~ ±2,5 mm for the vertical one, while the realization accuracy with respect to the IGS05 frame (external precision) is about ±1,5 mm for the horizontal components and ±4,3 mm for the vertical one.

Table 4. *Evaluation of DGFI weekly combinations (mean values for the period 1495 – 1538).*

Criteria	Component	Value in [mm]
Mean standard deviation		1,64
Mean RMS residuals for coordinate repeatability in the weekly combination	N	0,61
	E	0,87
	Up	2,51
	Total	2,73
Mean RMS residuals derived from time series	N	1,50
	E	1,36
	Up	3,80
	Total	4,33
RMS residuals wrt IGS weekly solutions	N	1,39
	E	1,75
	Up	3,69
	Total	4,35
RMS residuals of station coordinate differences between DGFI and IBGE combinations	N	1,10
	E	1,10
	Up	1,40
	Total	2,20

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