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ORIGINAL ARTICLE

CPLat: first operational experimental processing center for SIRGAS in Argentina

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Abstract The SIRGAS permanent GPS network which is in fact the IGS network densification for the American continent, consists today of more than 200 stations covering the continent and islands. It is currently processed by the IGS RNAAC SIR centre at Deutsches Geodätisches Forschungsinstitut producing weekly free solutions relying on IGS final orbits and EOP that contribute to the ITRF through IGS. By August 2006, the SIRGAS Working Group I had accepted five proposals for experimental processing centers within the region that would collaborate with IGS RNAAC SIR. One of them, Centro de Procesamiento La Plata (CPLat) in Argentina, began processing 60 stations on October 2006. By January 2007 CPLat reached operational capability, delivering weekly free solution SINEX files, with an internal consistency of 1.5 mm average for the horizontal components, and 3 mm in the vertical. Comparisons with IGS global and IGS RNAAC SIR weekly solutions were taken as external consistency indications, showing average RMS residuals of 1.8, 2.4 and 5 mm for the north, east, and vertical component, respectively. Analysis and comparison of adjusted solution time series from CPLat and other processing centers has proved to be highly valuable for solution QC, namely detection and identification of station anomalous behavior or modelling problems. These procedures will ensure the maintenance of the performance specifications for CPLat solutions. Action is being taken in order to guarantee the continuity of this effort beyond the experimental phase.

Keywords Experimental processing centers for SIRGAS · IGS RNAAC SIR · CPLat

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1 Introduction

The SIRGAS project was created during the International Conference for the Definition of a Geocentric System for South America, held at Asunción, Paraguay, in 1993 (http://www.sirgas.org). In 2001, the project was extended to the whole American continent and the original acronym of SIRGAS (Sistema de Referencia Geocéntrico para América del Sur) was changed to Sistema de Referencia Geocéntrico para las AméricaS (Fortes et al. 2005). The project structure includes an Executive Committee, integrated by the representatives of all participating countries and international institutions, a Directive Board, a Scientific Council, and three Working Groups: SIRGAS-WGI "Reference Systems" is in charge of the realization of ITRF (International Terrestrial Reference Frame) on the region; SIRGAS-WGII "Geocentric Datum" strives for the adoption of SIRGAS system by all participant countries. Finally, SIRGAS-WGIII "Vertical Datum" intends to establish a regional vertical reference frame.

Initially, the goal of WGI was achieved through two continental campaigns, held in 1995 (Kaniuth et al. 1998a) and 2000 (Drewes et al. 2005, Kaniuth et al. 2002) that resulted in a regional geodetic reference frame and velocity field (Drewes and Heidbach 2005).

In parallel to these actions, several international and local co-operating agencies developed a continuously operating GPS network on the region. Since 1996, the resulting observations have been weekly processed by DGFI (Deutsches Geodätisches Forschungsinstitut) as IGS Regional Network Associate Analysis Centre for SIRGAS (IGS RNAAC SIR). This IGS network densification for the American continent has grown considerably and consists today of more than 200 stations covering the continent and islands.

In 2005, SIRGAS–WGI undertook two new ambitious initiatives: to build up the capability of operationally maintaining the realization of the ITRS (International Terrestrial Reference System) in the Caribbean and Latin American countries, and to extend the use of the deployed observational infrastructure beyond reference frame maintance. In order to reach these goals SIRGAS-WGI proposed the installation of analysis centers for SIRGAS under the responsibility of Latin American institutions and also promoted the use of SIRGAS observations for atmospheric studies. With this intention, at the SIRGAS workshop in Aguascalientes, held in 2005 in México, SIRGAS-WGI established three experimental processing centers (EPCs) (http://www.sirgas.org): INEGI (Instituto Nacional de Estadística, Geografía e Informática) in Mexico, IBGE (Instituto Brasileiro de Geografia y Estadistica) in Brazil, and CPLat (Centro de Procesamiento La Plata) in Argentina. During this early experimental phase, each center would process a subset of the regional permanent GPS network to produce weekly unconstrained solutions. Within a time frame of one year, the experimental processing centers would have to be capable of producing weekly solutions following the IGS technical directives that are valid for regional associate analysis centers.

The results obtained by the three EPCs were presented during the SIRGAS WGI Workshop held in Río de Janeiro, Brazil, on August 2006. On that occasion, two new processing centers were proposed: Instituto Geográfico Agustín Codazzi (IGAC) in Colombia, and Instituto Geográfico Militar (IGM) in Argentina. Besides, new goals were established for the following stage: the whole network was divided into two parts. The data from the southern part of South America (Fig. 1) would be processed by CPLat, IBGE and IGM, while IGAC and INEGI would process the data from the northern part plus Central America and the Caribbean. In addition two combination and comparison experimental centers were established: CPLat and IBGE. For this new stage, experimental processing centers should deliver their weekly solutions to DGFI within 3 weeks following observations.

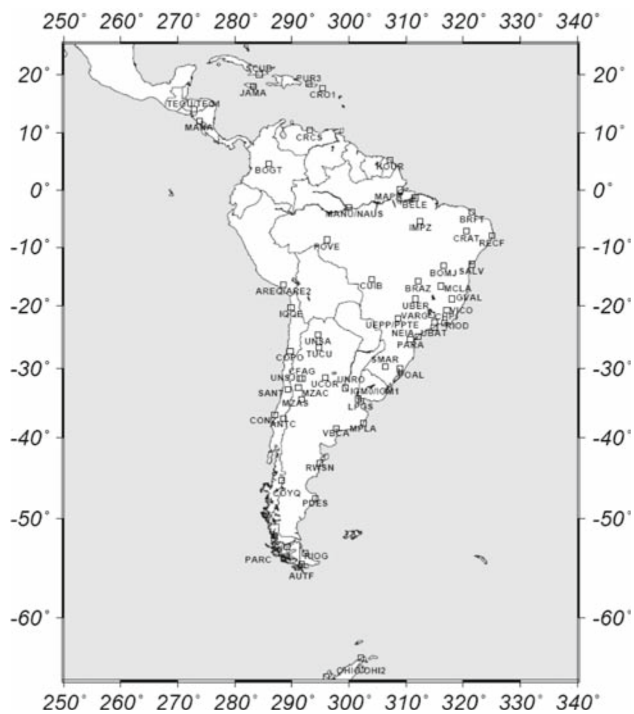


Fig. 1 SIRGAS continuously operating stations process by EPC CPLat

DGFI and the experimental combination centers should combine and analyze the solutions. The ultimate goal of this stage is to ensure the regional processing and combination centers can produce solutions that are comparable to the products of the IGS Regional Network Associate Analysis centers.

This paper presents the results from CPLat as an Experimental Processing Center for 60 stations located in South America and Antarctica from October 2006 to December 2007 (GPS weeks 1395–1453). It is divided into six sections: the first one describes the processing strategies implemented as agreed in 2006 SIRGAS WGI meeting in Río de Janeiro. The second part describes the main requirements that were fulfilled by CPLat to become operational as an EPC. The third and fourth parts show comparisons among CPLat's weekly solutions as an indication of their internal consistency and comparisons against IGS RNAAC SIR solutions and global IGS solutions as external consistency checks. The fifth part shows the time series which are useful to find anomalous behavior in the stations. On the final part we discuss future actions that would ensure the continuity of this effort.

2 GPS data processing

The computations were carried out with the Bernese GPS Software V5.0 (Hugentobler et al. 2006) using carrier phase double differences. The main characteristics of the data analysis can be summarized as follows:

- Satellite orbits, satellite clock offsets and Earth Orientation Parameters (EOP) were fixed to final combined IGS (International GNSS Service) products corresponding to solutions that include absolute receiver and satellite antenna phase center variations in the observation model.
- IGS absolute receiver and satellite antenna phase center variations were used in the carrier phase observation modelling.
- Periodic site displacements due to ocean loading were taken into account according to the GOT00.2 model.
- L1 and L2 carrier phase ambiguities were solved using the QIF (Quasi ionosphere free) (Hugentobler et al. 2006) strategy without any a priori ionospheric model. This particular strategy has been shown successful by (Kaniuth and Vetter 2005).
- As regards the treatment of the tropospheric delay, an a priori effect was obtained using the (Saastamoinen 1973) model for the zenith delay plus the mapping function by (Niell 1996) to compute the a priori slant delay. In addition, corrections to the zenith delay were estimated every 2 h (Kaniuth et al. 1998b) from the observations.
- The elevation angle cutoff was set to 3°, and a zenith distance dependent weighting $\cos^2(Z)$ was applied.
- The observations were adjusted daily, and then the corresponding normal equations were accumulated to solve for weekly solutions. All daily and weekly solutions are practically unconstrained. This means the reference frame is only loosely defined through the satellite orbits so as not to introduce any deformation into the network.

3 CPLat goes operational

As already mentioned, since 1 October 2006, SIRGAS WGI EPCs were requested to deliver their weekly solutions consistently and within no more than three weeks after observations.

Automatic downloading of observations through the Internet and the implementation of the Bernese Processing Engine (BPE) were key factors to achieving the delivery timing goal. Solution consistency between all EPCs and RNAAC SIR has been facilitated by the implementation of a mail exploder service, SIRMAIL, that timely distributes relevant station information.

Before sending the weekly solution the following QC (quality control) procedure is carried out:

First, residuals of a seven-parameter similarity transformation between daily and weekly solutions are analyzed using thresholds of 1.5 or 2.5 cm in the horizontal and vertical components, respectively, to check for outliers in all the station residuals. In these transformations all input coordinates enter with the same weight. Next, baselines related to outliers are analyzed. Finally, actions taken to eliminate the outliers can involve baseline replacement through network configuration modifications or plain elimination.

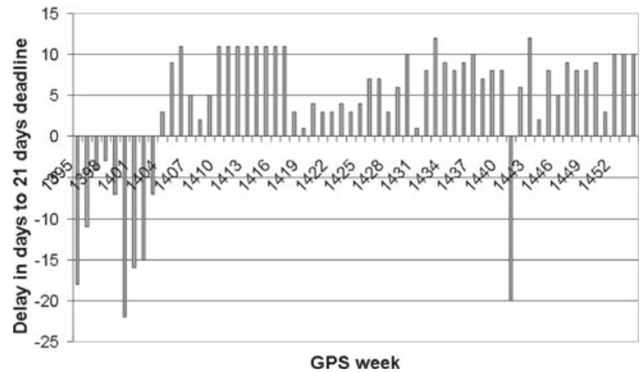


Fig. 2 Delay for delivering weekly solutions relative to 21 days deadline. The X-axis represents the GPS week and the Y-axis represents the delay in days to deliver the solution. Negative delay mean the solution was not sent in time, positive delay mean the solution was deliver on time

Figure 2 shows the evolution of the delay in the submission of weekly solutions from CPLat to the IGS RNAAC SIR. We can see delays as big as 20 days in the first 9 weeks of the experience. From week 1405 on, CPLat can be considered an operational EPC contributing to IGS RNAAC SIR.

Besides the weekly loosely constrained coordinate solutions, CPLat provides fixed weekly coordinate solutions for the maintenance of the national geodetic reference frame of Argentina. These solutions are referred to the IGS05 by applying strong weights to the IGS stations in the region. The final weight set was chosen after some testing that consisted of two steps. The first one was to analyze the deformations caused by applying different weight sets in the final adjustment. This was done by the analysis of the residuals of the seven-parameter similarity transformations between each of the different weighted solutions and the free combined one. The second step was to check the changes in the coordinates of the fiducial points with respect to its a priori values. The optimal weight set was chosen so that the residuals of the seven-parameter transformation for the corresponding weighted solution and the differences between the final and a priori coordinates of the fiducial points were not larger than the standard deviations of the individual station coordinates obtained from the daily free solution.

4 Solution quality

In this section, a series weekly of solutions is analyzed in order to show its internal consistency. In addition, some accuracy indication is given through external comparisons.

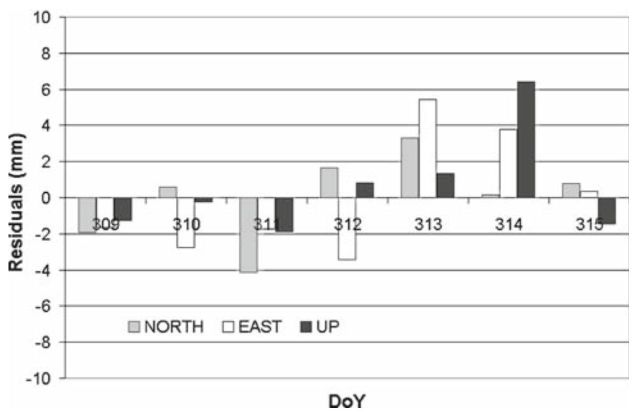


Fig. 3 Residuals of a seven-parameter similarity transformation between each daily solution and the weekly combined solution for the station MZAC, week 1400

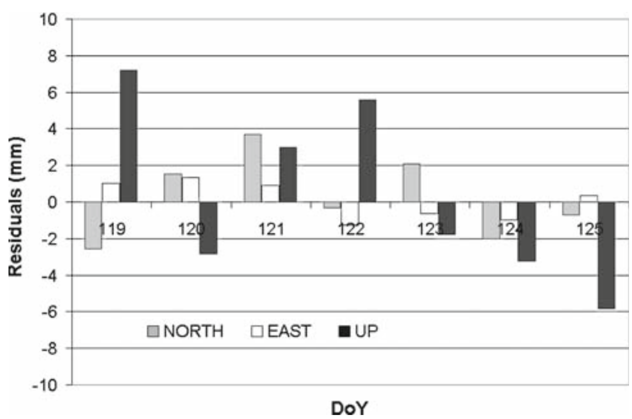


Fig. 4 Residuals of a seven-parameter similarity transformation between each daily solution and the weekly combined solution for the station CONZ, week 1425

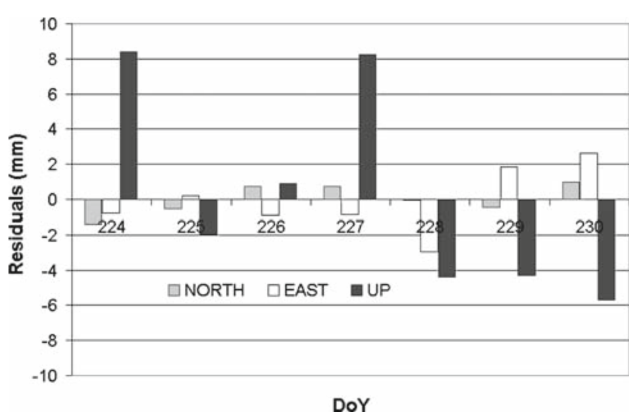


Fig. 5 Residuals of a seven-parameter similarity transformation between each daily solution and the weekly combined solution for the station RWSN, week 1440

The internal consistency of CPLat's weekly solutions is shown. Figures 3, 4 and 5 are representative examples of coordinate repeatability after applying the processing strategy described in Sect. 2 for solutions corresponding to GPS week

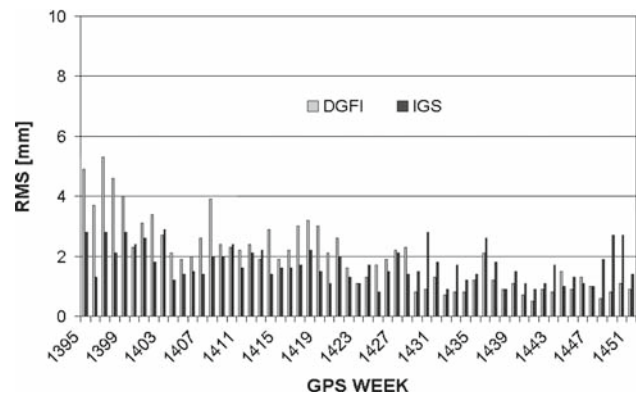


Fig. 6 RMS from seven-parameter similarity transformations between CPLat versus DGFI and IGS weekly solutions, North Component

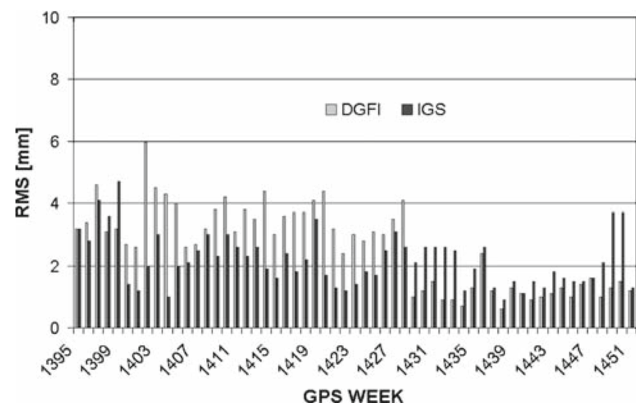


Fig. 7 RMS from seven-parameter similarity transformations between CPLat versus DGFI and IGS weekly solutions, East Component

1400, 1425, and 1440. Each figure shows the residuals of a seven-parameter similarity transformation between each daily solution and the corresponding weekly combined one. In every case, residuals in the horizontal components fall bellow 3 mm and 8 mm in the vertical component. For the same transformations it can be seen that the RMS residuals in horizontal components average 1.5 mm, while they reach 3 mm in the vertical component.

Comparison between CPLat's weekly solutions, IGS RNAAC SIR (ftp://dgfi.badw.muenchen.de/gps/sir), and global IGS solutions (ftp://cddis.gsfc.nasa.gov/pub/gps/products) for 58 weeks are depicted in Figs. 6, 7 and 8. These figures show, respectively, the RMS residuals for north, east, and up component from seven-parameter similarity transformations between loosely constrained weekly solution from different sources: DGFI versus CPLat (gray bars) and IGS versus CPLat (black bars).

Figures 6 and 7 show that the RMS residuals always fall below 5 mm for the horizontal components. Figure 8 shows values up to 10 mm for the up component. It can also be seen on the comparison with DGFI solutions that RMS residuals on the three components have some noticeable trend.

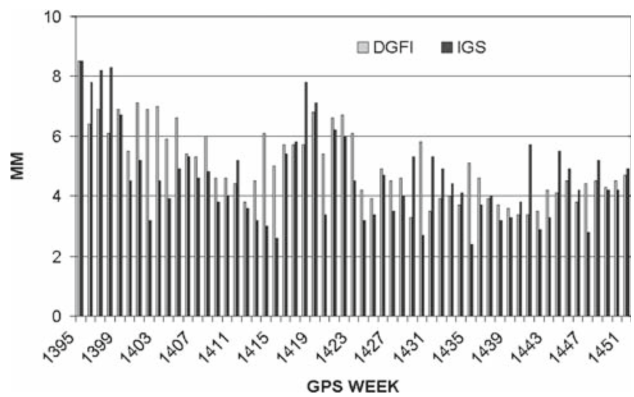


Fig. 8 RMS from seven-parameter similarity transformations between CPLat versus DGFI and IGS weekly solutions, UP Component

Horizontal component RMS residuals go from 3 mm in the beginning of the series to approximately 1 mm at the end. The behavior of the up component is similar, going from 6 mm to 4 mm. When comparing with IGS global solutions, similar trends are observed, but they are smaller for the three components.

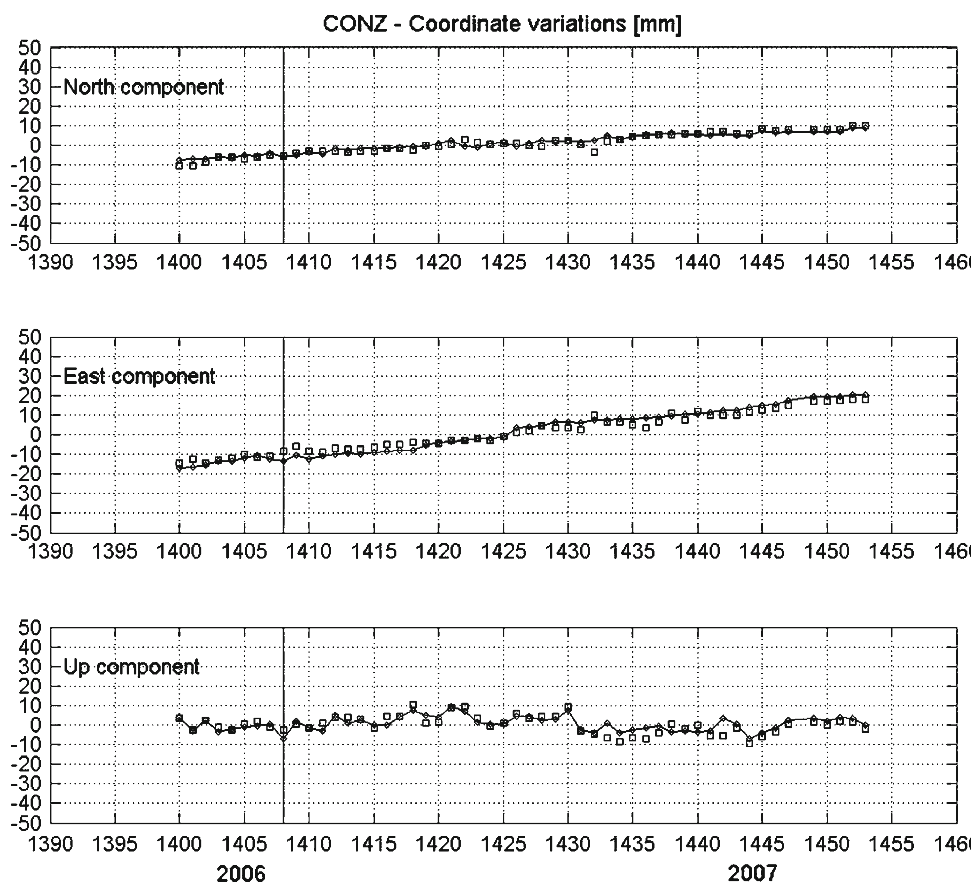
The different behavior observed when comparing to DGFI and IGS might be due to the fact that the IGS comparison involves always a relatively small group of very stable stations with a long history of continuous observation. This group added only one station within the period analyzed. When comparing with DGFI solutions, we are including a 'dynamic' network of young stations that incorporated 25 stations during the same period. The fact that trends can be seen on both comparisons could also indicate CPLat processing procedures have improved during these 58 weeks. Considering that the observation modelling has remained the same through the whole period, the improvement should be related to better solution QC strategies.

5 Time series

Time series start in the GPS week 1400, because before relative PCVs were applied in IGS RNAAC SIR solutions.

Analysis of coordinate time series coming from constrained weekly solution is a highly valuable tool to detect problems coming from anomalous station behavior or modelling problems. Since expected geological station position variations are in the cm/year range and are continuous, any anomalous behavior such as jumps or fast variation deserves special attention. Besides, time series involving the same stations and coming from different processing centers may allow to isolate real station movements from modeling errors.

Fig. 9 Time series for station CONZ (*squares* CPLat solutions, *diamonds* DGFI solutions)



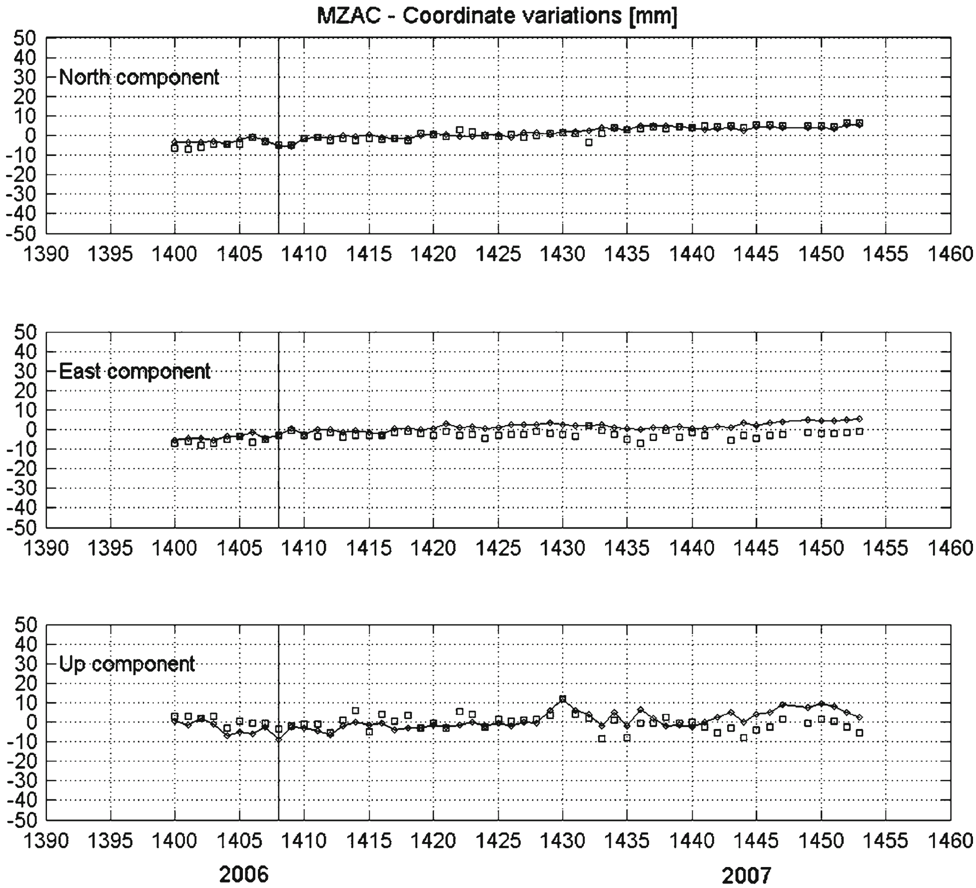


Fig. 10 Ttime series for station MZAC (*squares* CPLat solutions, *diamonds* DGFI solutions)

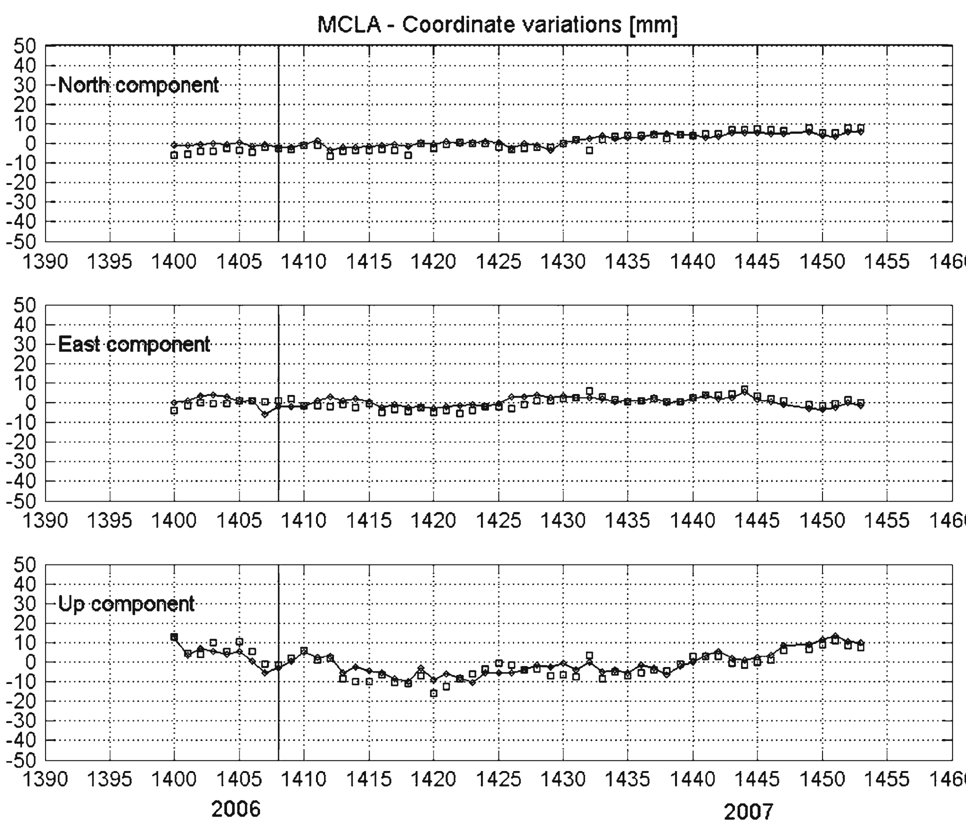


Fig. 11 Time series for station MCLA (*squares* CPLat solutions, *diamonds* DGFI solutions)

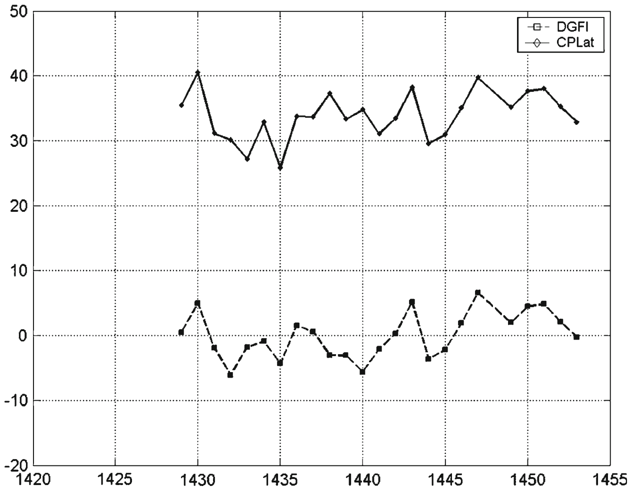


Fig. 12 Residuals of the up component, station MZAS. CPLat take into account the radome, while DGFI did not. This caused a bias of approximately 35 mm

Figures 9, 10 and 11 show some examples of station coordinate variations from the solutions generated by CPLat (squares) and IGS RNAAC SIR (diamonds). This comparison between EPC's time series allows identifying outliers, jumps, or interruptions in the stations. The problems may be associated with the station, for example, tracking problems and equipment changes. If the jumps are present in all time series (of all stations), this might be a problem in the realization of the reference frame, that can be shown in a translation or scale factor. If outliers, jumps or interruptions are not present in all time series, the problems may be associated with administrative issues such as neglecting of station and erroneous log files.

The most common discrepancies between different processing centers are due to errors in the GPS antennas type indication for the modelling of one or several station's observations. Example of this problem is station MZAS, DGFI which did not take into account an actually present radome, while CPLat did it. This caused a bias of 35 mm in the up component (Fig. 12). Similar results are shown in http://www.sirgas.org/index.php?id=176.

6 Conclusions and future work

The results shown here demonstrate the capability of the EPC CPLat to produce weekly solutions for a regional network covering Central, South America and Antarctica with 1.5 mm average internal consistency for the horizontal components, and 3 mm in the vertical. Comparisons with IGS global and ISG RNAAC SIR weekly solutions were taken as external consistency indications. They show average RMS residuals of 1.8, 2.4, and 5 mm for the north, east, and vertical component, respectively. These results are the best estimates of the achievable accuracy when realizing ITRS with this regional geodetic infrastructure.

It took CPLat center nine weeks to meet SIRGAS WGI proposed requirement for the weekly solutions. This condition would enable IGS RNAAC SIR to include EPC results into its weekly combinations.

Analysis of the time series is a powerful tool to detect anomalous behavior in the stations or modeling problems. The latter are almost always related to some failure in the process of station change events acknowledgment, dissemination, and implementation. Action should be taken in order to ensure that (a) Log files do include always the correct denomination for the equipment, (b) Changes in the station equipment are reported on time, and (c) Once informed to the processing centers, station changes have to be incorporated into the processing models.

Point (b) is mostly solved by the SIRMAIL. Points (a) and (c) will require a sustained effort from responsible people both on observation stations and EPCs.

The sustainability of this effort in the medium and long term is as important as the goals reached so far. Actions are being taken to get the necessary funding and human resource base to maintain CPLat's contribution to the SIRGAS community.

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