Chapter 2

Adjustment Methodology in a Regional Densification of a Terrestrial Reference Frame

María Laura Mateo and María Virginia Mackern

Additional information is available at the end of the chapter

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1. Introduction

The measurement of geodetic networks by satellite positioning is becoming more and more common, given the advantages of this technology to solve the main problems of geodesy:

- Planimetric geo-reference to a geocentric system
- Independence of intervisibility between points
- Increase of relative precision.

The purpose of working under the Network scheme is to have superabundant observations that allow adjustment by estimating parameter (coordinates) values and precisions.

Given the versatility of the method of indirect or parametric observations, it has become the most widely used as a method of geodetic adjustment.

The Adjustment Method by Non-Conditioned Indirect Observations, also known as Method of Coordinate Variation, or Parametric Method has been widely accepted in Geodesy. by means of the use of observation equations, in which the parameters are the coordinates.

This adjustment made under the application of the method of minimum squares, estimates parameters as well as their precisions.

It allows to incorporate equations of coordinates, which are essential when introducing the reference frame and generating an external control.

In the adjustment, an appropriate management of the coordinates requires:

- The introduction of fiducial coordinates with a precision better than the precision of the network to be adjusted.
- The adoption of appropriate weights to these coordinates, in order not to create unnecessary deformations.

These objectives, as will be shown in this chapter, are strongly correlated.

The strict frame introduction by fixing the fiducial points could often result in an unfavorable option because it induces loss of precision to the network, caused by internal deformation. On the contrary it is possible to generate a free or quasi free adjustment omitting the introduction of the datum in order not to cause deformation to the network. Finally, it is possible to achieve a condition of balance by adopting the appropriate strategy, the optimum quantity and distribution of fiducial points. This solution must achieve the required precisions and the densification of the selected reference frame [2].

2. Adjustment strategy

2.1. Internal precision

Before the datum input it is necessary to estimate the internal precision of the network to be adjusted. Knowledge of network internal precision will allow the definition of tolerances when datum is introduced.

This analysis is possible because of the existence of superabundant observations that is to say in the presence of degrees of freedom. In the satellite positioning techniques the adjustment over observations made in different periods or days is very important since these observations are affected by factors that change through time such as the tropospheric and ionospheric delay, oceanic and terrestrial tides, etc. This is the reason why it is necessary to measure the points of the networks in different sessions (2 or more are recommended). The analysis of network precision is carried out on such points of over-occupation.

A "free" adjustment to the network is performed (assigning a very low a-priori weight to the coordinates of the points). This adjustment combines the total group of sessions in the so called multisession adjustment. After the application of similarity transformation (Fig.1), this result is compared with the network solution of each daily session. The internal precision of the free network is estimated from the quantification of the residuals obtained (Fig.2).

The methodology for performing the analysis on the internal accuracy is summarized in the following items and Fig. 2 outlines the procedure.

1. A free weekly adjustment is performed incorporating each of daily networks.
2. Transformation parameters are estimated between the weekly combined network and each daily networks.
3. The transformation parameters are applied to each of the daily solutions.
4. The residuals are calculated by comparing the coordinates arising from the previous processing and the coordinates of the weekly solution.
5. The obtained residuals were analyzed according to predetermined tolerances. If it is necessary stations are reduced.

The knowledge of the internal precision of the network makes possible to perform the tie of the network to a certain reference frame.

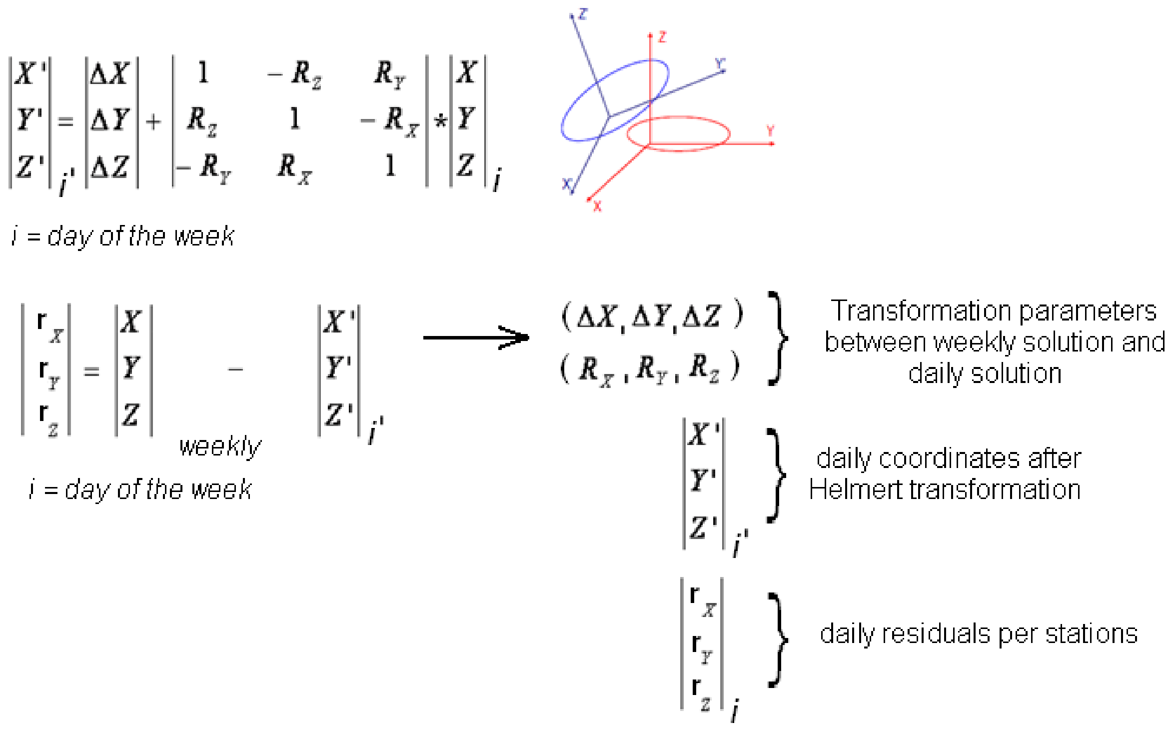

Figure 1. Similarity transformation.

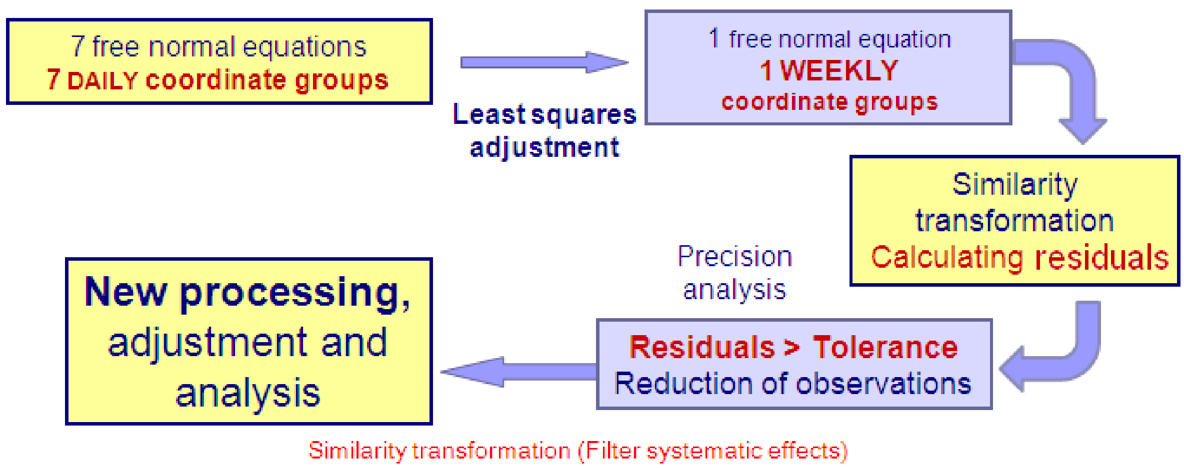

Figure 2. Analysis of the internal precision of the network.

2.2. Introduction to the reference frame

Once the analysis of the internal precision of the network to be adjusted is carried out, the second adjustment, "weighted adjustment" takes place, in which the control points are selected and a-priori errors are set.

The datum input strategies are mainly based on the adhesion or not to the equations of coordinates for fiducial points. An appropriate weight is added to them in order to link to a greater or lesser extent the network vectors to the positions determined by the values of the coordinates mentioned.

The most common strategies in the adjustment of normal equations, with the objective to link the network to a certain reference frame are the followings [5][6]:

- Minimum constraint solution: this kind of solution adjusts the network by performing a roto-translation in the measured and processed network towards the reference frame desired to be used as control or Datum, materialized in the fiducial coordinate group. Similarity parameters are applied, calculated from the coordinates of fiducial points and their corresponding of the free network.
- Coordinates constrained: this strategy allows you to force the coordinates of the points taken as fiducial network to their corresponding coordinates in the reference frame. The latter should be assigned a weight according to their precisions.
- Coordinates fixed: with this option the coordinates of the selected stations are completely fixed as fiducial, accepting that they do not receive any correction.

Entering the control coordinates with a certain weight produces a double effect: it ties the network to the reference system and consequently causes certain deformation. Such effects are strongly related. A greater weight at the fiducial coordinates introduces the frame with greater accuracy at the expense of greater distortion of the network. For these reasons there is no one adjustment strategy only. Different adjustments are made by varying both the adjustment strategy as the corresponding weights. Among the various solutions will choose the optimal strategy from a careful analysis of results [3].

The choice of the solution to be adopted is based on a double analysis, aiming at a balance between the reference frame input and the minimum network deformation. This is accomplished by controlling, on the one hand, the fact that the coordinates of the support points do not vary more than the error value with which they were determined, keeping the precision of the reference frame; and, on the other hand, that this adjustment does not create deformations to the network in the points that exceed its internal precision [3].

2.2.1. Strategy for the analysis of results in the introduction of the Datum

The proposal to analyze the solutions is based, on the one hand, on the estimation of similarity transformations between the coordinates obtained from free adjustment of the network and those obtained from weighted adjustment on the other hand. The purpose of the application of this transformation to the weighted network to be assimilated to the free network is to filter the systematic effects that may be affecting it, mainly the differences between reference systems. Only the residual effects that show the type of deformation generated by the weighted adjustment are left. This deformation can be quantified by means of the calculus of the residuals between the coordinates of the weighted network and the free network transformed [4]

In order to achieve balance the analysis of these deformations must be considered on one of the sides of the scale. On the other side of the scale it is necessary to quantify the precision of the frame over the adjusted network. This is observed in the magnitude of corrections of the estimated coordinates (new coordinates minus a-priori coordinates) in the fiducial points.

They should not exceed the error value with which they were determined in order to preserve the precision of the reference frame that they intend to densify.

The steps to be followed in this analysis methodology are mentioned below.

1. A quasi free adjustment is made, by assigning a very low a-priori weight to all point coordinates.
2. A weighted adjustment is made, by selecting a weighting strategy and assigning a-priori weights to the coordinates of the control points.
3. Seven similarity transformation parameters between the coordinates of the points of the free network and the weighted network are established.
4. The similarity transformation is applied to the free network in order to take it to the reference frame of the weighted network.
5. The residuals are calculated after the application of the transformation mentioned above.
6. The calculated residuals are analyzed.
7. The extent of the estimated corrections to the a-priori coordinates of the fiducial points is analyzed.
8. The process is repeated, modifying the adjustment strategy and the weights to the fiducial coordinates. It is also repeated changing the fiducial reference frame in case there is the possibility to choose more than one.
9. The optimum weighted adjustment is selected, based on the comparison of the results obtained for each case in points 6 and 7, or decisions are taken as regards the control network to be adopted.

Figure 3 outlines the proposed analysis methodology. Where it comes to finding the balance between the distortion introduced by the reference frame to be densified and accuracy on the same network densification.

3. Example - An actual case of application

In order to present this theory in practice, the Methodology used for the processing of a regional continuous GNSS network in South America (SIRGAS-CON-D-South), is described. In this point the models used in the processing, the adjustment methodology and the result analysis are described[7].

3.1. Densification network to be adjusted

As the main objective is to obtain a high precision network, it was necessary for the observations gathered by observation GNSS permanent stations to undergo a strict processing, modeling in a precise form the physical phenomena which affect the observations and estimating those parameters that cannot be modeled [5].

The observations of 98 continuous GNSS stations were gathered and precise ephemerides were used together with Earth Orientation Parameters (EOPs) provided by IGS (International GNSS Service.)

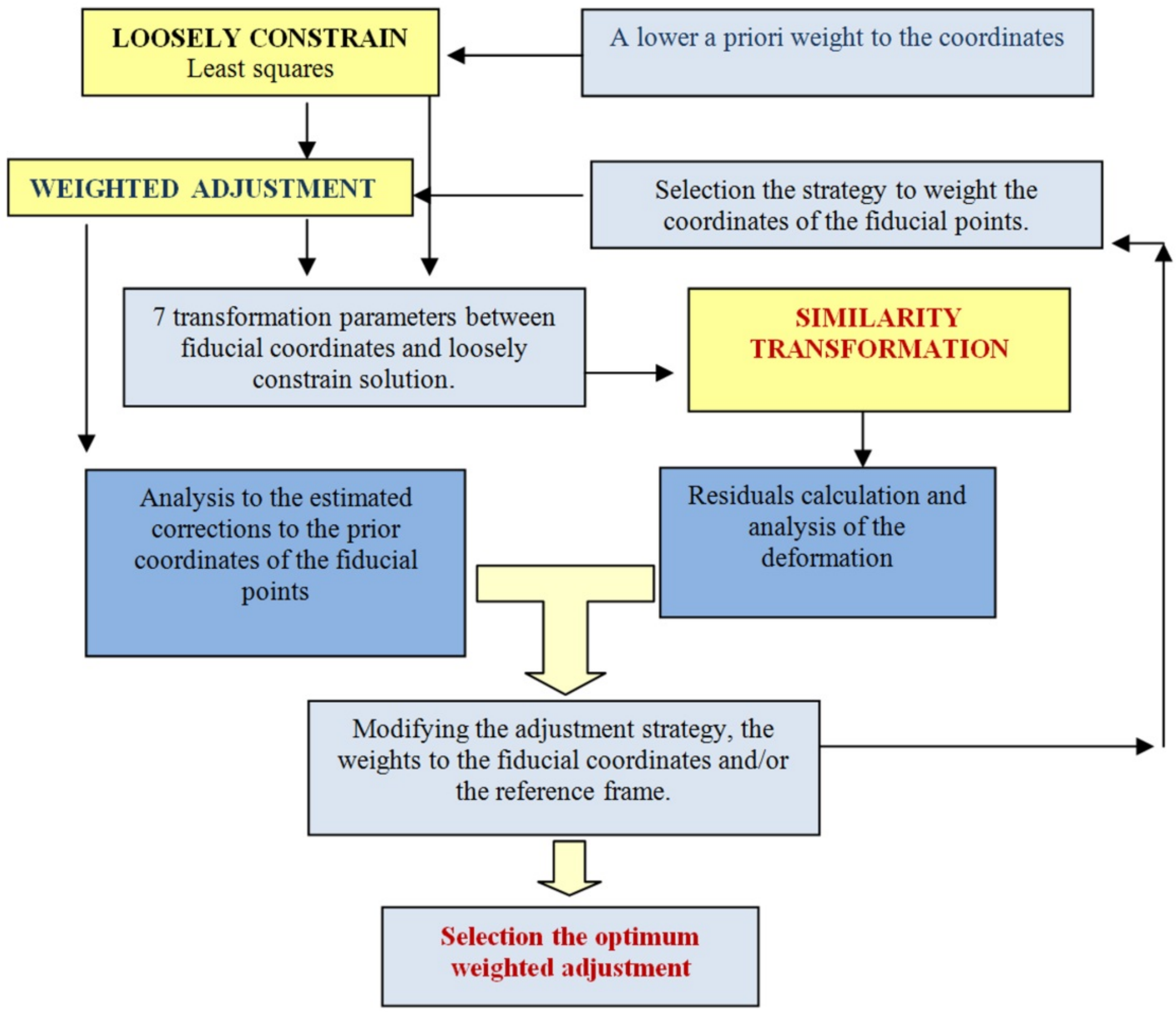

Figure 3. Methodology for analysis of results. Balance between accuracy and deformation.

The total 2.5 year-period of observation to be processed was divided into GPS weeks, witch provided data redundancy and over-occupation, in order to allow the corresponding accuracy analysis week by week and then the total that includes the whole period.

Other variables considered in the processing were: published satellite problems and maneuvers, as well as corrections to the antenna phase centers used. The latter were consistent with the offset of satellite antennas, on the one hand, and with the specific equipment (receiver, antenna, radome, off set, etc.) of each GNSS continuous station on the other. In addition, a-priori coordinates and velocities for all processed stations were incorporated to the processing.

Taking into account all these elements, a data pre-control and pre-processing were carried out, which detected outliers and inconsistencies in the data. In certain cases, it was necessary to reduce or cut data which did not comply with the required quality criteria.

Once the pre-processing was accomplished, the vectors network was constituted and also the parameters estimation was made. In this processing, models of ocean loading, gravitational attraction, nutation and precession were considered and improved by EOPs, calculated by IGS and only tropospheric parameters, ambiguities and corrections to a-priori coordinates were estimated.

The most important parameters introduced in the processing are detailed as follows [8]:

Observations	Double differenced
Sampling rate	30 sec
Elevation cutoff	03º
Baselines strategy	MAX-OBS
Observations weighting	cos Z
Orbits/EOP	IGS final - IGS08 and EOP week
A-priori Troposphere model	Niell dry component
Troposphere	Zenith delay estimated each 2 hours (12 daily corrections p/station) A-priori sigma applied with respect to Niell prediction model (wet component) -first parameter +/- 5 m absolute and +/- 10 cm relative
Ambiguities	QIF strategy, no ionosphere model applied
Ocean tide model	FES2004
Phase center variation	Absolute (IGS_08)
Coordinates and velocities	IGS05_R
Daily solution	NEQ files, free network solution (s=±1m)
Week solution	SINEX files, Free network solution (s=±1m)

Table 1. Parameters incorporated in the processing of GNSS observables

3.2. Free weekly adjustment, analysis of internal precision

The daily normal equations generated after parameter estimations, were subjected to a quasi-free weekly adjustment, with which the analysis of the internal precision of the network was performed. In this adjustment the normal equations obtained for each of the seven days of the week are combined in a single system of equations. All the point coordinates are constrained using a 1.00 meter a-priori sigma. In this way, the network is only tied to the frame established by the orbits at the moment of observation.

The solution of each of the 7 days was analyzed together with the combined weekly solution, starting from the comparison of coordinates after the application of similarity transformation. Residuals were calculated after the transformation and were verified to ensure that they were within the pre-established tolerances. This process was described in detail in point 2.1, Fig.1 and Fig.2.

It is worth noting that these tolerances of internal precision are determined in each case according to the repeatability analysis of coordinates. The latter was possible thanks to the observation redundancy and a particularly varied sampling according to the time (Fig. 4), which is relevant due to its influence on a vast quantity of factors taking part.

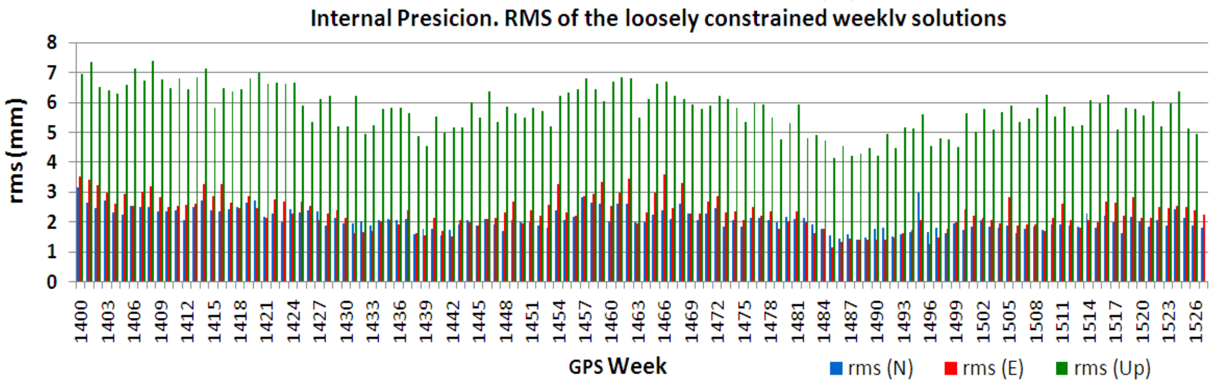

Figure 4. Internal precision. SIRGAS-CON-D-South network – Period: 127 weeks.

In the presented case these tolerances were considered for north and east components in 15 mm. and for a up component of 30 mm. For residuals larger than the tolerances, it was concluded that the main causes were: insufficient observations (shorter than 10 hours), too high offset of the receiver clock or too many outliers.

In some cases, it was necessary to partially or completely reduce the observations of such stations. Once the control was finished, the internal precision of the network in 2 mm. was estimated for the horizontal components and for up of 4 mm. (Fig. 4.)

Two of the three strategies mentioned were used: "Coordinates constrained" and "Minimum constraint solution".

The "Fixed Coordinates" method was discarded because it is a very precise network (2mm), as expressed in the previous paragraph, not counting to the date of this adjustment with fiducial coordinates that would present an order of precision better than the mentioned one.

3.3. Reference frame selection

Among available high precision global frames this selection was performed taking into account the precision quality of the network to be adjusted.

The availability and the distribution of processed points which had coordinates in one of the ITRF [9][10] defined by the IERS or in one of the frames defined by the IGS [11] were analized.

The epoch of reference frame was also taken into account, since it is necessary to update the coordinates to the date of the observations to be adjusted [12].

Of the most recent global frames to the date of the adjustment (2008.1), ITRF2005 and IGS05, IGS05 was selected, since it presents a good availability and distribution of fiducial points over the network to be adjusted (Fig.5). In this selection, the ITRF2005 was discarded because it had been calculated with relative antenna phase centre corrections whereas IGS05 was adopted because absolute antenna phase centre corrections had been used in its calculation.

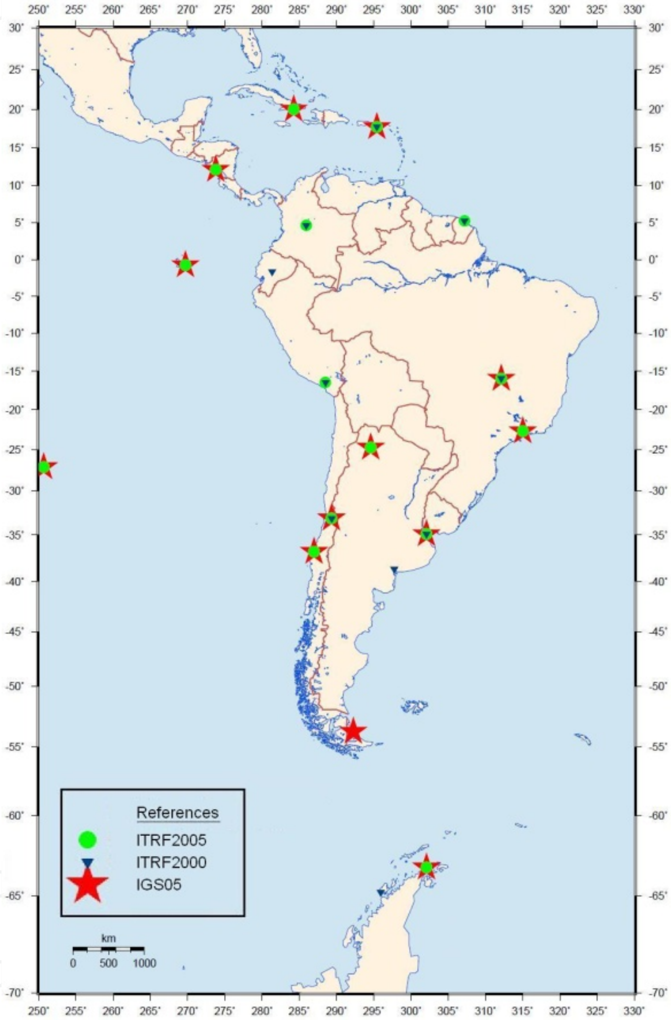

Figure 5. Stations with coordinates in ITRF00, ITRF05 and IGS05.

The possibility of adopting as frame IGS weekly solutions was also considered. IGS weekly coordinates refer to the IGS05. They coincide with the epoch of each week to adjust. In this case it was not necessary to update coordinates by velocities regardless of introducing error. The error introduced by the update coordinates for velocities is produced at the stations having in the time series of coordinates, nonlinear variations (mainly in the Up component). GNSS stations show significant seasonal position variations resulting from a combination of geophysical loading and systematic errors [2][5].

As an example (Fig. 6) shows the time series of the "up" component in the stations BRAZ and LPGS.

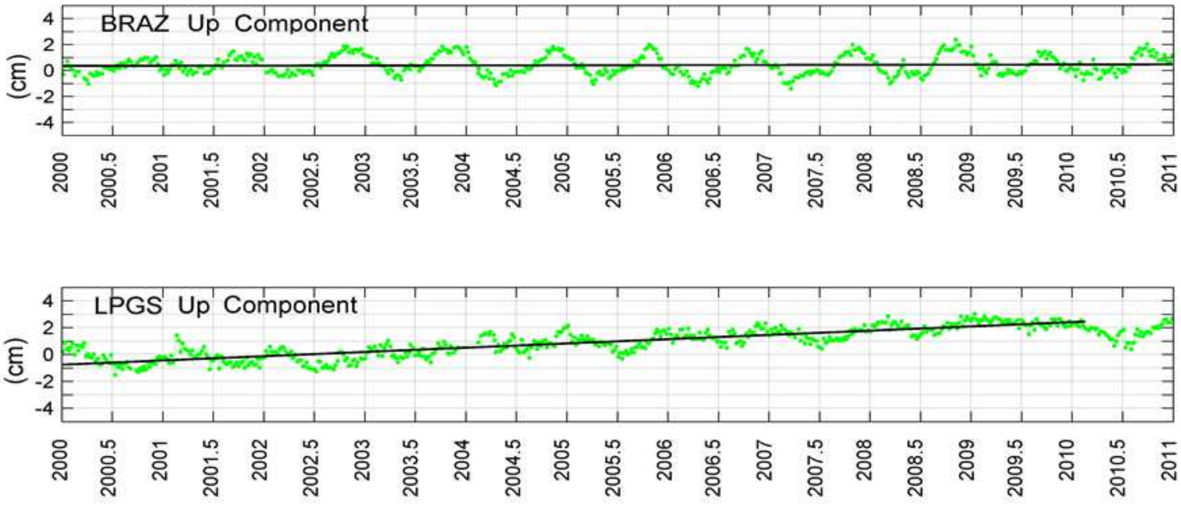

Figure 6. Seasonal position variations in the Up component. Stations: BRAZ and LPGS.

A total of 98 points made up the network to be adjusted. Of these 14 points were considered fiducial.

Summarizing, four different adjustments were calculated for each of the selected weeks:

1. "Coordinates constrained" strategy with an a-priori sigma of 0.00001 m. in fiducial coordinates and their corresponding velocities in IGS05.
2. "Minimum constraint solution" strategy, by the application Not-Net-Rotation and Not-Net-Translation, both with an a-priori sigma of 0.0000001 m without applying scale factor. Coordinates and their corresponding velocities in IGS05.
3. "Coordinates constrained" method, with an a-priori sigma of 0.00001 m, using as fiducial coordinates the weekly IGS solutions. These were obtained by a three-week delay in the site: ftp: // igscb.jpl.nasa.gov/pub/product/
4. Finally it was established as strategy of adjustment "Minimum constraint solution" with an a-priori sigma of 0.0000001 m without applying scale factor, by IGS weekly coordinates.

3.4. Analysis of deformation introduced by Datum

In order to identify which of two adjustment strategies used and which feasible group of coordinates used to introduce the datum was turning out to be most adapted to adjust the network object of this work, a comparison of results was made. 127 weeks of observations were included, from the 1400 GPS week, (November, 2006), up to the 1527 week, (March, 2009), two and a half years of observation).

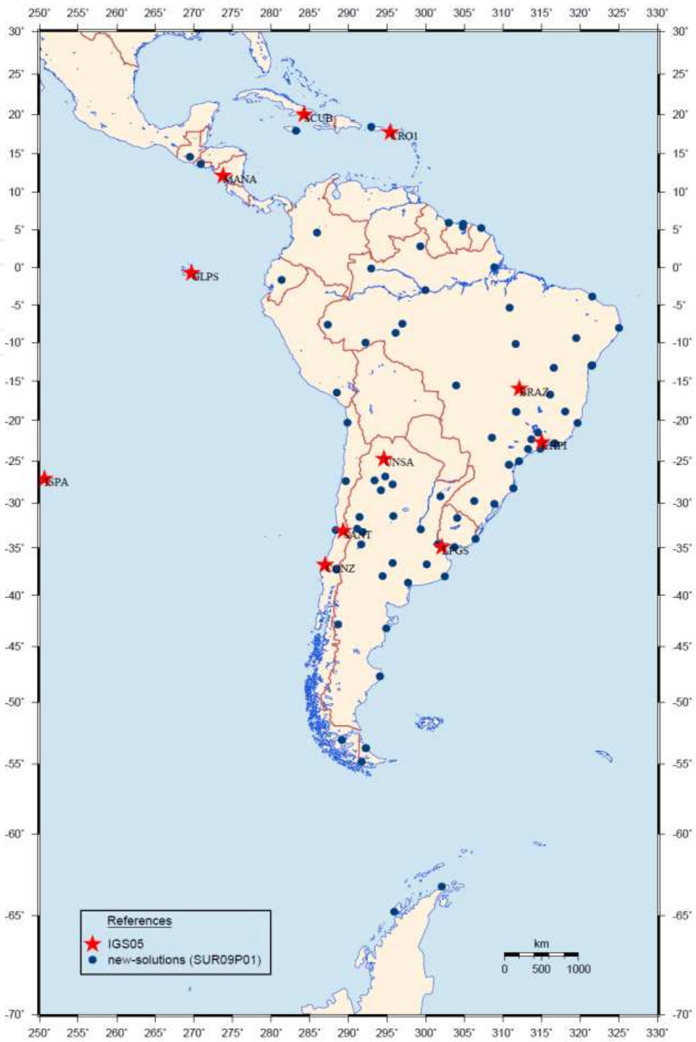

Figure 7. SIRGAS-CON-D-South and fiducial IGS stations.

The analysis was realized on the deformations caused to the loosely constrained network by the introduction of the datum. The deformations were calculated based on the quasi-free network corresponding to every week. It was considered that given the precision of this network, it was the best boss to analyze the deformations, since it is free of the systematic effects of rotation and translation introduced by the reference frame.

To estimate the deformations, each of the 4 solutions (obtained by applying the different two adjustment strategies and two frames), were compared, after the application of Helmert transformation to the quasi-free solution (2.2.1). It is to be noted that the parameters were calculated only with the groups of coordinates of the fiducial points, and then they were applied to the totality of the network for every week of calculation.

The residuals resulting from the totality of the comparisons were plotted for each of the stations, according to three components, north, east and up [5].

3.4.1. Analysis results

The major deformations were observed on the fiducial points and on the points of the contour of the network (Fig.7)

Fig. 8 and Fig. 9 show the residuals calculated in two fiducial stations, CONZ and BRAZ. In both graphs it can be observed that the strategy that produces the minimum deformation to the network is "Minimum constraint solution" (Not-Net-Rotation and Not-Net-Translation), both with IGS05 coordinates updated by velocities (in blue), and for the IGS Weekly coordinates (light blue).

In the same way, it can be observed that the strategy that major deformation offers is "Coordinates constrained" with IGS05 coordinates and velocities (red color). This response is mainly observed in those stations in which their behavior is not contemplated by a linear velocity. For example the BRAZ station is affected by seasonal variations principally in its Up coordinate. The CONZ station shows residuals in its three components, that increase as time passes (Fig. 8).

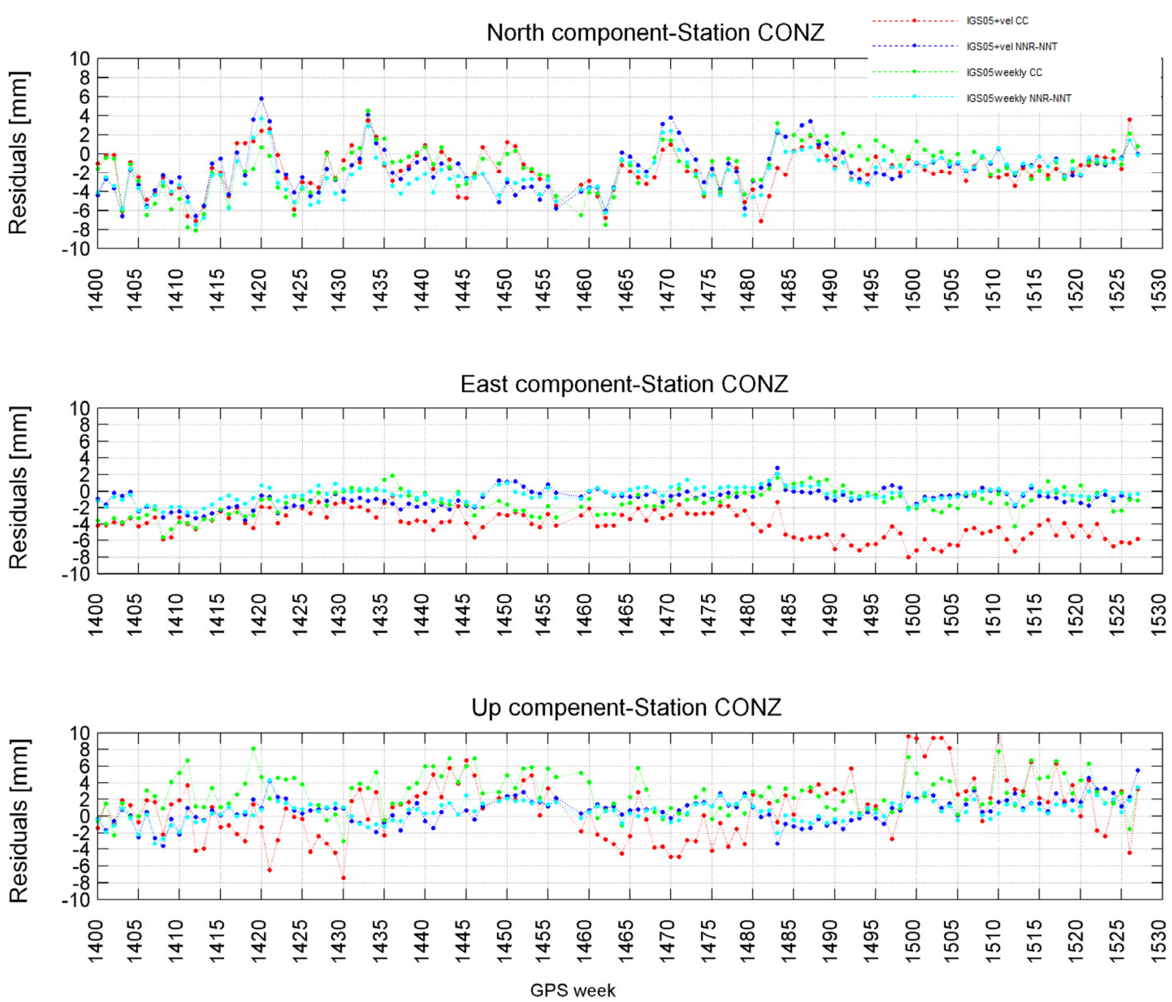

Figure 8. Residual of Helmert transformation in the fiducial station CONZ (Chile).

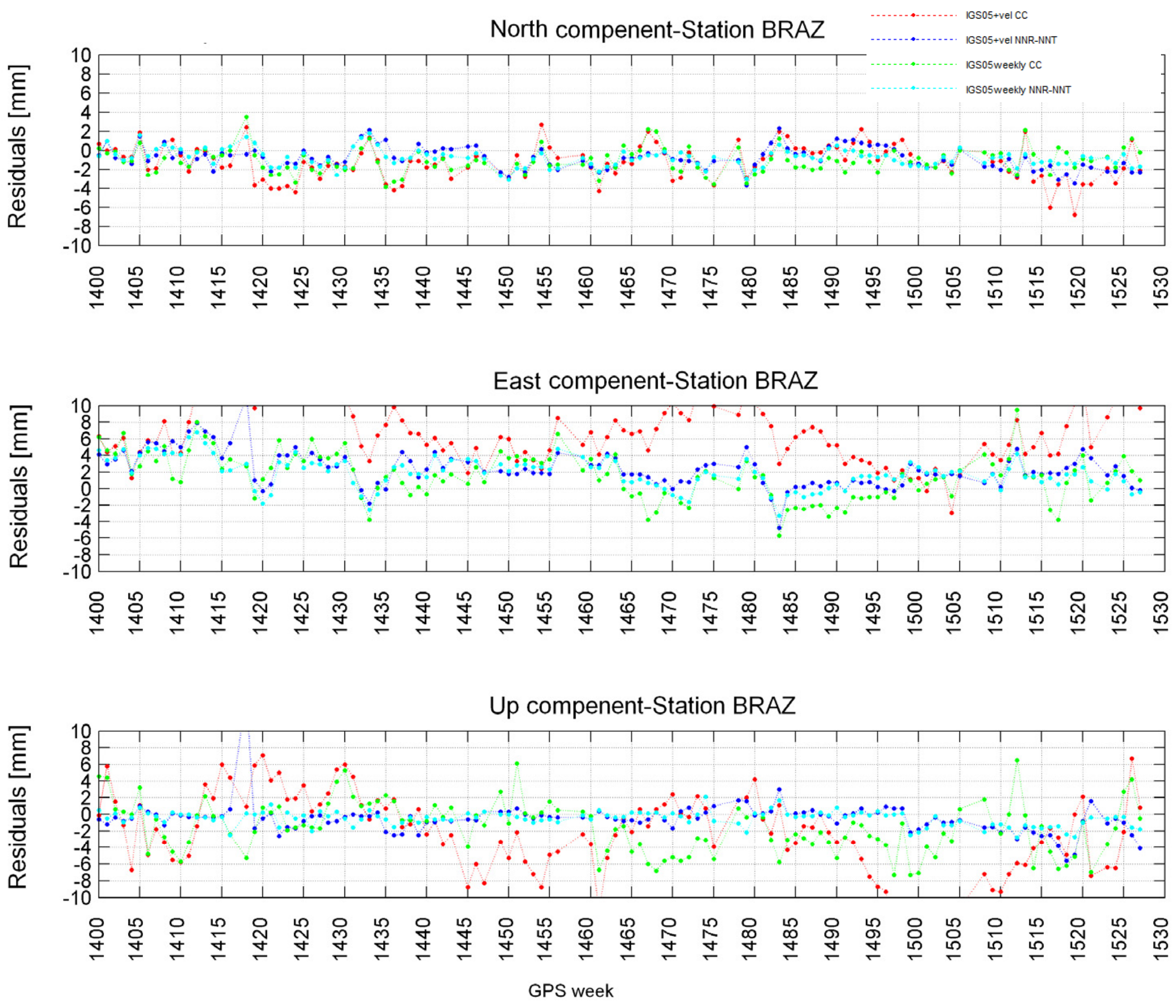

Figure 9. Residual of Helmert transformation in the fiducial station BRAZ (Brasil).

In the results, the behaviors observed in the variation of the coordinates it wasn´t linear. Which allowed to conclude in the need to calculate velocities determined in precise form and that they accompany on the real movement of the coordinates answering to a model defined with better precision.

In order to realize a quantitative analysis there were calculated the average values of these residuals by every station of reference for 127 analyzed weeks, in each of four strategies (table 2 and Fig.10).

Finally there was calculated the average value of these residuals for the whole network according to the strategy, with its corresponding standard deviation (table 1 and Fig. 11.). It is necessary to mention that the residuals in north and east components have combined in a residual called "Horizontal".

It was concluded that the strategy that minor deformation was causing to the network was “Minimum constraint solution” since this type of adjustment tries to support the quasi-free original network without deforming it and only torn it moves trying to accommodate to the frame of reference, producing of this form the minor residuals.

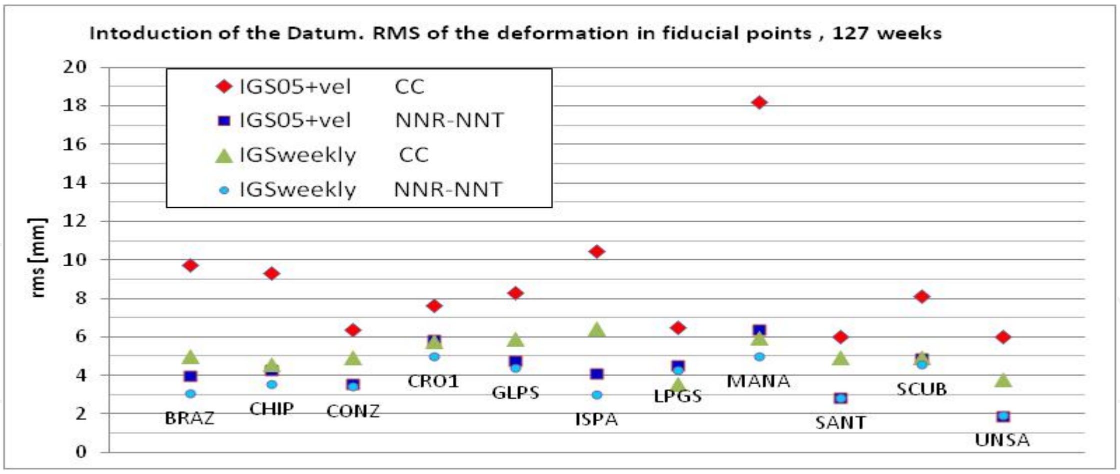

Figure 10. RMS in the reference points according to strategy of adjustment.

RMS (127 weeks)								
Station	IGS05+vel CC (mm)		IGS05+vel NNR-NNT		IGSweekly CC		IGSweekly NNR-NNT	
	Horizontal	Up	Horizontal	Up	Horizontal	Up	Horizontal	Up
BRAZ	7,916	5,686	3,487	1,930	3,569	3,438	2,878	0,999
CHPI	7,470	5,531	3,862	1,757	3,704	2,711	3,402	1,054
CONZ	5,179	3,692	3,133	1,685	3,461	3,543	3,142	1,379
CRO1	5,795	4,980	5,314	2,429	4,224	3,894	4,620	1,886
GLPS	4,388	7,013	4,012	2,491	4,589	3,664	4,163	1,375
ISPA	7,694	7,064	3,643	1,848	5,105	3,904	2,696	1,344
LPGS	4,561	4,639	3,670	2,560	2,708	2,281	3,515	2,366
MANA	15,239	9,955	4,515	4,485	4,680	3,636	4,391	2,365
SANT	3,660	4,787	2,545	1,229	3,298	3,631	2,634	1,046
SCUB	6,892	4,318	4,495	1,893	3,503	3,450	4,341	1,387
UNSA	4,169	4,302	1,621	0,891	2,315	3,018	1,712	0,818
Mean value	6,633	5,633	**3,663**	**2,109**	3,741	3,379	**3,408**	**1,456**
Standard deviation	3,235	1,790	1,002	0,938	0,846	0,507	0,907	0,530

Table 2. RMS in the reference points according to strategy of adjustment.

Analyzing the average values of residuals, they confirm that the minor values obtain in both cases in which there was applied the strategy Minimum constraint (NNR-NNT). Between these two options the one that minor deformation produces is the one that uses the IGS weekly coordinates (last column, table 1 and Fig.11.). It presented an average residual of 3.40 mm in horizontal component and 1.45 mm in height.

The solutions obtained by means of coordinates constrain linking to the weekly coordinates of the IGS also they present minimal deformations. The strategy that should have discarded was CC with coordinates IGS05 updated by speeds, since in this case they were duplicating and even they were trebling the values of introduced deformation.

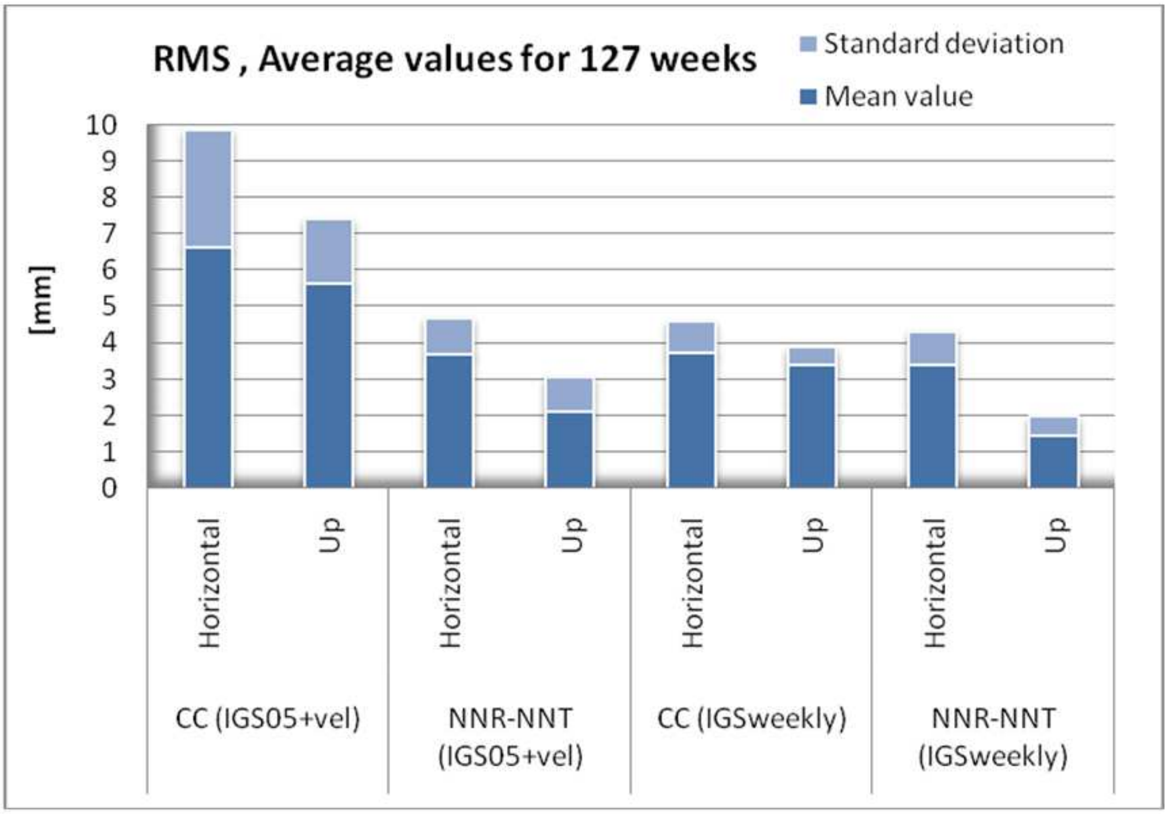

Figure 11. Deformation of the network according to the strategy of adjustment.

3.5. Frame accuracy

In the previous section we arrived at the solution that allows us to deform as little as possible the network. However, this solution will not be adequate if the accuracy of the frame is lost. It's time to reach equilibrium in the balance. Finding the point at which the chosen solution provides lower distortion and greater accuracy

In order to quantify the accuracy of the frame over the adjusted network, the extent of estimated corrections of the coordinates (new coordinates - prior coordinates) in the fiducial points were analyzed. They should not exceed the error value with which they were determined in order to preserve the precision of the reference frame that intend to densify.

The estimated corrections were analyzed for each of the four strategies of adjustment used. In each case they were compared to the a-priori error of fiducial coordinates and the optimum solution was selected together with the analysis of deformation. In the above mentioned solution 80% of the fiducial points presented accuracy to the reference frame within 0.005m., thus complying with the objective pursued. (Fig.12).

Final result was selected as better strategy of adjustment to link the network SIRGAS-CON-D-South to the strategy "Minimum constraint" adopting as reference coordinates the correspondents to the IGS weekly solution.

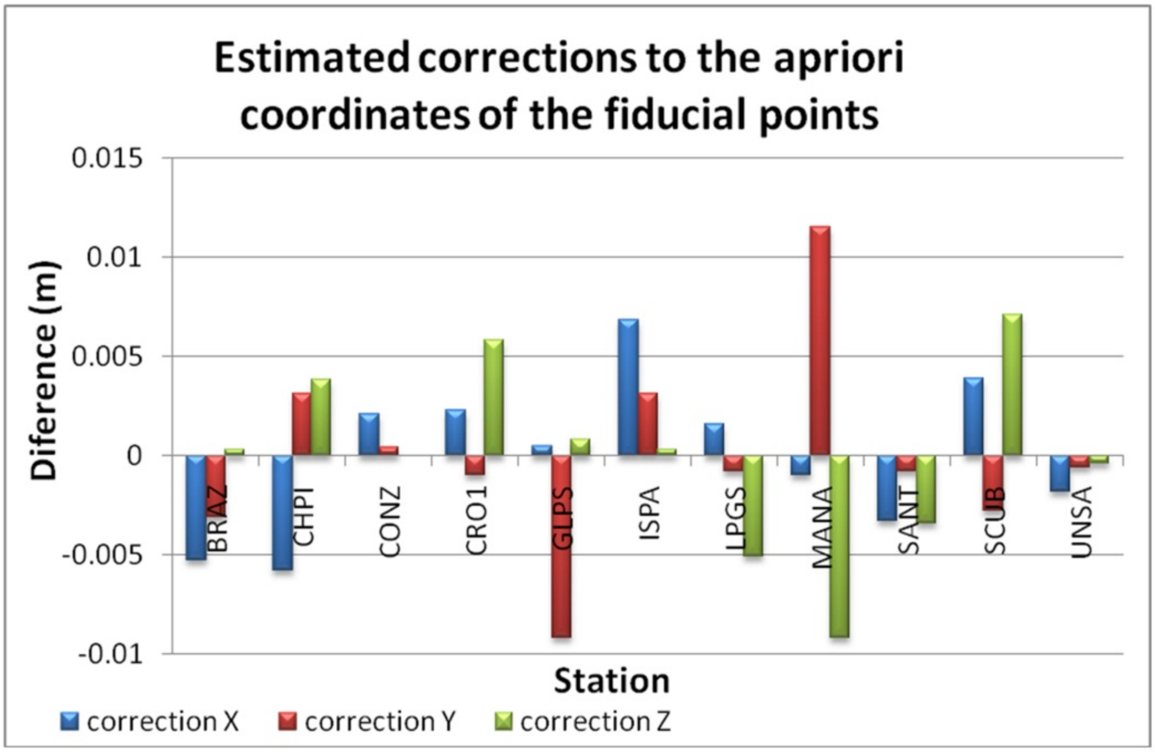

Figure 12. Frame accuracy. Estimated corrections in the fiducial points.

4. Conclusions

The absence of result analysis in the adjustment can bring about one of the following problems: the adoption of an inappropriate frame, its loss of accuracy, or an unnecessary loss of the precision if the Network to be adjusted

To ignore seasonal variations at reference stations can introduce systematic errors in the datum realization and the networks can be significantly deformed [13].

These effects are larger in regional networks than in the global net, especially in regions with strong seasonal variations such as Latinamerica [2].

The geometry of the quasi free network is always deformed, when the geodetic datum is introduced. This deformation is specifically larger at the remote sites of the network, and in fiducial points

Updating strategies based on the linear movement of the reference stations introduce important errors into the station positions, mainly at the reference stations. This is a consequence of constraining a seasonal signal to be a linear trend [13].

It is necessary that the reference frame definition include, together with the usual linear terms, seasonal variations in order to improve the modelling of the reference site motions and to make it more reliable.

In the mean time, weekly solutions of regional reference frames shall be aligned to IGS frames by constraints to the IGS weekly coordinates [5].

Author details

María Laura Mateo
Instituto Argentino de Nivología, Glaciología y Cs Ambientales – CONICET, Argentina
Facultad de Ingeniería -Universidad Nacional de Cuyo, Argentina

María Virginia Mackern
Facultad de Ingeniería -Universidad Nacional de Cuyo, Argentina
Facultad de Ingeniería -Universidad Juan Agustín Maza, Argentina

5. References

[1] Drewes, Hermann (2009). Reference Systems, Reference Frames and the Geodetic Datum – basic considerations. Sideris, M.G. (Ed.): Observing our Changing Earth, IAG Symposia, Vol. 133, 3-9, Springer 2009.

[2] Sanchez L. and Mackern M.V. (2009), Datum realization for the SIRGAS weekly coordinates, Geodesy for Planet Earth, IAG Scientific Assembly 2009; Buenos Aires, Argentina.

[3] Mackern, M. V and Brunini, C. (2004). "El ajuste de Redes en la Geodesia del siglo XXI." Tópicos de Geociencias. Un volumen de estudios Sismológicos, Geodésicos y Geológicos en homenaje al Ing. Fernando Séptimo Volponi. VOL. 1. PAG 115 – 142. EDIT. EFU. Fundación Universidad Nacional de San Juan. ISBN N° 950-605-340-5. San Juan. Argentina.

[4] Mackern, María Virginia (2003). Materialización de un Sistema de Referencia Geocéntrico de alta precisión mediante observaciones GPS. Tesis Doctoral, Universidad Nacional de Catamarca. Argentina .

[5] Mateo M.L. (2011). Tesis doctoral: Determinación precisa de velocidades en las estaciones GNSS de medición continua de América Latina, Red SIRGAS. Facultad de Ingeniería – Universidad Nacional de Cuyo, Mendoza, Argentina.

[6] Dach, R., Hugentobler, U., Fridez, P. and Meindl, M.: Bernese GPS Software version 5.0, Astronomical Institute, University of Berne, Switzerland, 2007.

[7] Brunini, C.; Sánchez, L.; Mackern, M.V.; Mateo, M.L.; Martínez, W.; Luz, R. (2010). SIRGAS: the geodetic reference frame in Latin America and the Caribbean. IAG Commission 1 Symposium 2010 Reference Frames for Applications in Geosciences. Marne la Vallee, Francia. Octubre de 2010.

[8] Mateo, M. L.; Calori, A. V.; Mackern, M. V. and Robin, A. M.. (2010). Evolución de la red SIRGAS-CON-D-Sur. Aportes del centro de procesamiento CIMA. Reunión SIRGAS (Sistema de Referencia para las Américas) 2010. Lima, Peru. Noviembre 2010.

[9] Altamimi, Z., Collilieux, X., Legrand, J., Garayt, B., Boucher, C.(2007): ITRF2005: A new release of the International Terrestrial Reference Frame based on time series of station positions and Earth Orientation Parameters, Journal of Geophysical Research, 112, B09401,x. doi:10.1029/2007JB004949.

[10] Altamimi, Z., (2010) ITRF2008 and the IGS Contribution. IGS Workshop 2010 – Newcastle, UK

[11] Ferland, R. (2006). [IGSMAIL-5447]: Proposed IGS05 Realization. http://igscb.jpl.nasa.gov/mail/igsmail/2006/msg00170.html.

[12] Drewes, Hermann (2005). Deformation of the South American Crust Estimated from Finite Element and Collocation Methods. Springer Berlin Heidelberg, Volume 128, pag. 544-549. 2005

[13] Mackern, M. V.; Mateo, M. L.; Robin, A. M. and Calori, A. V. (2009): A Terrestrial Reference Frame (TRF), coordinates and velocities for South American stations: contributions to Central Andes geodynamics. Adv. Geosci., 22, 181–184, 2009. www.adv-geosci.net/22/181/2009/