New Chilean Reference Frame, 3 years after the Maule Earthquake

Lautaro Francisco RIVAS Reveco, Chile

Key words: GPS, reference frame, earthquake, Chile.

SUMMARY

The particular geographical situation of Chile has transformed the country into a very seismic region. Chile is located just above the subduction zone between the Nazca and the South American plate. In this zone the Nazca plate moves underneath the South American plate causing a drift of 2 cm/year in the north east direction. This physical phenomenon is the responsible for all the seismic, geological and volcanic activity that characterizes the region.

Chilean reference frame is based on the GNSS technology. A total of 66 continuous GPS stations programmed to record data every 30 seconds, for 24 hours a day and distributed all over the country has formed the skeleton of the horizontal network that provide the frame on which all the national geospatial infrastructure is developed.

The February 27 2010 Maule mega thrust earthquake involved surface displacement that range for 0.3 to 5 mt in the horizontal coordinates, meaning the total destruction of the quality of the reference frame both active and landmarks. The analysis of all the information gathered during this 3 years period has provided a clear picture of the deformation during the earthquake and specially the deformation produced after the event.

From the information and analysis of the data gathered during this period, it was possible to develop an approach to measure, process and rebuild the national reference frame. This work has contributed to the national territorial develop through the use of a standardized modern and global geodetic reference frame.

SUMMARY (Spanish)

La situación geográfica particular de Chile ha transformado este país en una región muy sísmica. Chile se encuentra sobre la zona de subducción entre las placas de Nazca y de Sudamérica. En esta zona la placa de Nazca pasa bajo la placa de Sud América, provocando un desplazamiento de 2 cm/año en dirección hacia el noreste. Este fenómeno es responsable de toda la actividad sísmica, geológica y volcánica que caracteriza esta región.

El marco de referencia chilena está basado en la tecnología GNSS. Un total de 66 estaciones GPS programados para captar datos cada 30 segundos , durante 24 horas diarias y distribuidos en todo el país, ha constituido el esqueleto de la red horizontal que proporciona el marco sobre el cual se desarrolla toda la infraestructura geoespacial nacional.

El mega-terremoto del 27 de febrero de 2010 en la Región del Maule provoco un desplazamiento en la superficie variando entre 0,3 hasta 5 metros en las coordenadas horizontales, lo que resulto en la destrucción total de la calidad del marco de referencia, tanto en los hitos activos como los pasivos. El análisis de toda la información reunida durante este periodo de 3 años ha proporcionado una visión clara de la deformación durante el terremoto y especialmente la deformación producido después del evento.

En base a la información y el análisis de los datos recopilados durante este periodo, fue posible desarrollar un método para medir, procesar y reconstruir el marco de referencia nacional. Este trabajo ha aportado al desarrollo territorial nacional mediante el uso de un marco de referencia geodésico estandarizado moderno y global.

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1. BACKGROUND: CHILE, SIRGAS AND THE RGN UP TO 2010

The geographic situation of Chile, especially its location above the subduction zone of the Nazca and South American plates has caused a great quantity of seismic events throughout the whole history of the country, including the biggest ever recorded in the world to date, that of Chillan in 1960 with a magnitude of 9.5 on the Richter scale.

While Chilean society is used to these unpredictable phenomena of nature and the consequences that this type of event involves, technological progress in reference systems and their constant increase in quality and precision have led to a change in how these phenomena are seen from the viewpoint of geodesy. How much impact a seismic event has on the geodesic structure of this country, how the quality of a geodesic site is affected or skewed, when it is considered to be destroyed and when it is time to re-measure and rebuild the network; all these are questions that the geodesic community of Chile is obliged to resolve in order to be able to provide and maintain a reliable and homogeneous geodesic national network in accordance with current practice but which also adapts and reshapes itself to the deformations in the earth's crust which Chile is exposed to.

The Military Geographic Institute (IGM) is the official organization of the State of Chile for cartographic portrayals of Chilean territory and has performed this task since the date of its creation in the year 1929. For a cartographic base covering the whole nation, first of all it is necessary to have available a network of monumented points in the field that, through a geodesic datum, links the portrayal of the terrain to a system of coordinates. Knowing this, the IGM started, at the beginning of the century, to build the National Geodesic Network (RGN). This network came to be made up of more than 12,000 points of first, second and third around the whole of the territory, the main Datums being PSAD 56 and SAD 69.

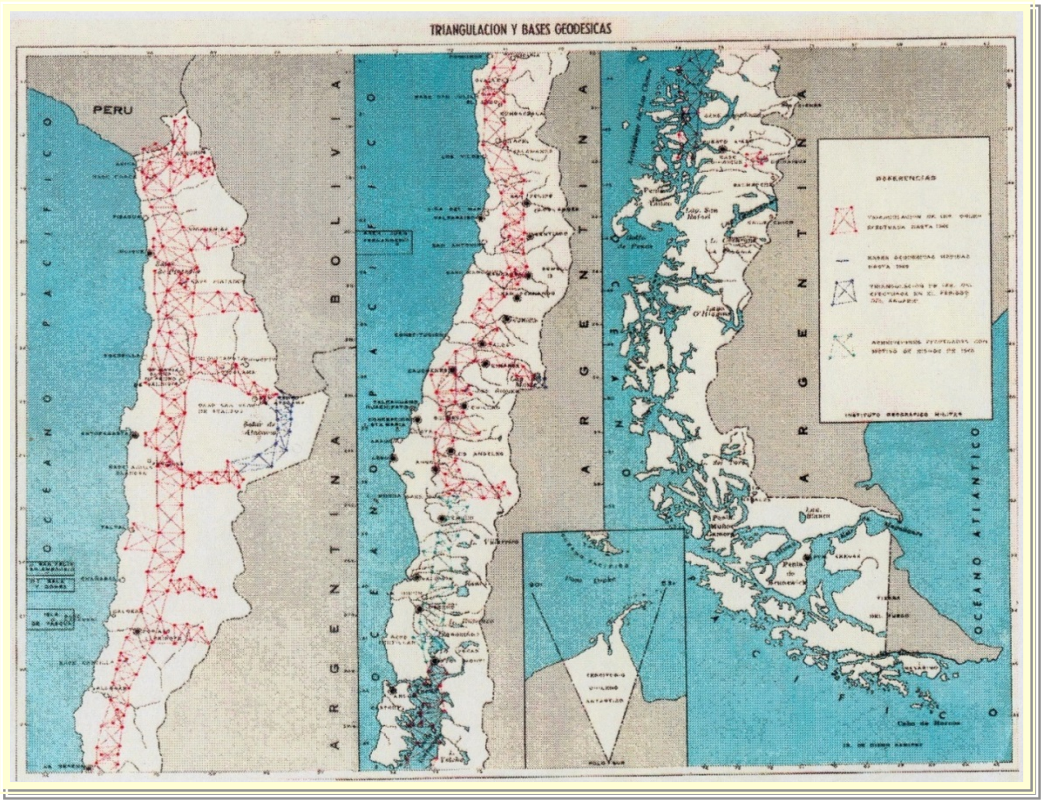

Figure 1 Old National Geodesic Network of Chile

The coming of the space age has involved great changes in the way in which geodesic datum are defined; these have slowly become less local (covering only part of the territory), being replaced by global Datums such as WGS84. The IGM has not stood aside from these technological innovations, so in the year 1993 it participated in the creation of the project for the Geocentric Reference System for the Americas (SIRGAS)

SIRGAS started within the context of the Pan-American Institute for Geography and History and had as its main objective the campaign to set up a single geodesic network for South America based on global positioning technology (GPS). Its implementation had to be in accordance with and compatible with the most precise of the world geodesic networks, including the International Terrestrial Reference Frame (ITRF). It was in the framework of this major work program that a new reference framework for Chile began to be defined.

For the Chilean community, in the year 2002 the National Geodesic Network SIRGAS CHILE 2002.0. was set up. By the year 2010 this network had built up 14 permanent stations and more than 500 point sites monumented and distributed around the whole of Chilean territory with an accuracy of 2cm for each one. This network was adjusted to the year 2002 but based on ITRF 2000, in accordance with the SIRGAS standards. This was the status of the RGN as of February 2010.

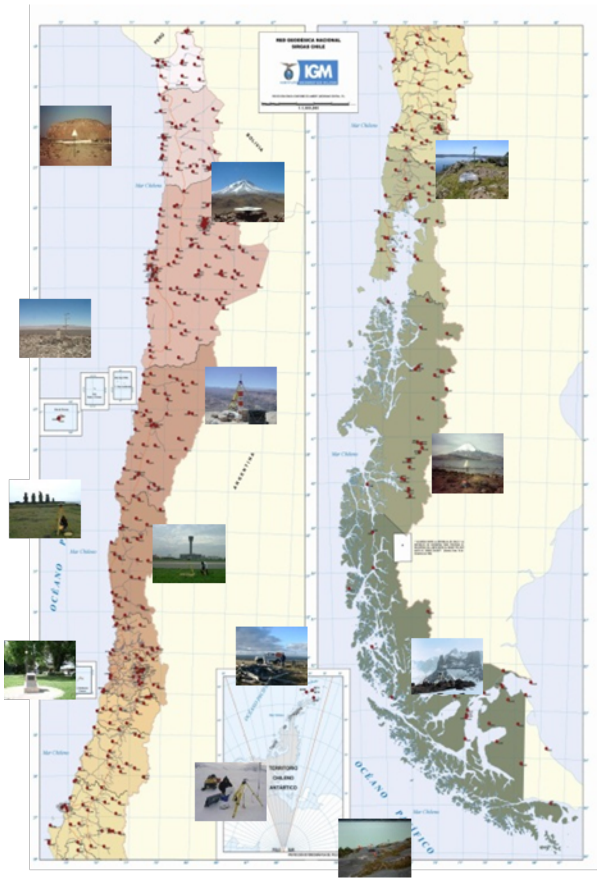

Figure 2. Passive Network.

2. EARTHQUAKE OF 2010

The seismic event of the 27th of February in the year 2010 was the fifth largest in all recorded history, with a magnitude of 8.8 Mw (Moment Magnitude Scale). The major impact was on territory from La Ligua to Temuco, that is, more than 700 km long and affecting 13 million people, which constitutes 80% of the total population of Chile. Movements of the surface of up to 5 m approximately were recorded. From the geodesic point of view, an event of this nature means the total destruction of the quality of the geodesic points in the zone affected.

At this moment the questions stated above began to play a major role, above all in relation to the substantial demands placed on the geodesic structure by the organizations responsible for the tasks of rebuilding the infrastructure affected by the earthquake. This meant that there was a high demand for information, so as to know about the movements that took place at the moment of the earthquake (coseismic displacement) and, just as important, also the movements coming after the earthquake (postseismic displacement).

3. REBUILDING AND MEASURING THE MOVEMENTS

It is in this context that a campaign was started, run jointly between the IGM and various organizations, both Chilean, such as Concepción University, and from other countries such as the State University of Ohio (USA), among others, with the aim of setting up quickly and in time a large number of permanent GPS stations along all of the zone affected, in order to obtain a homogeneous coverage of stations that would enable reliable data to be captured promptly, concerning the movements that the earth's crust has undergone up to the current date.

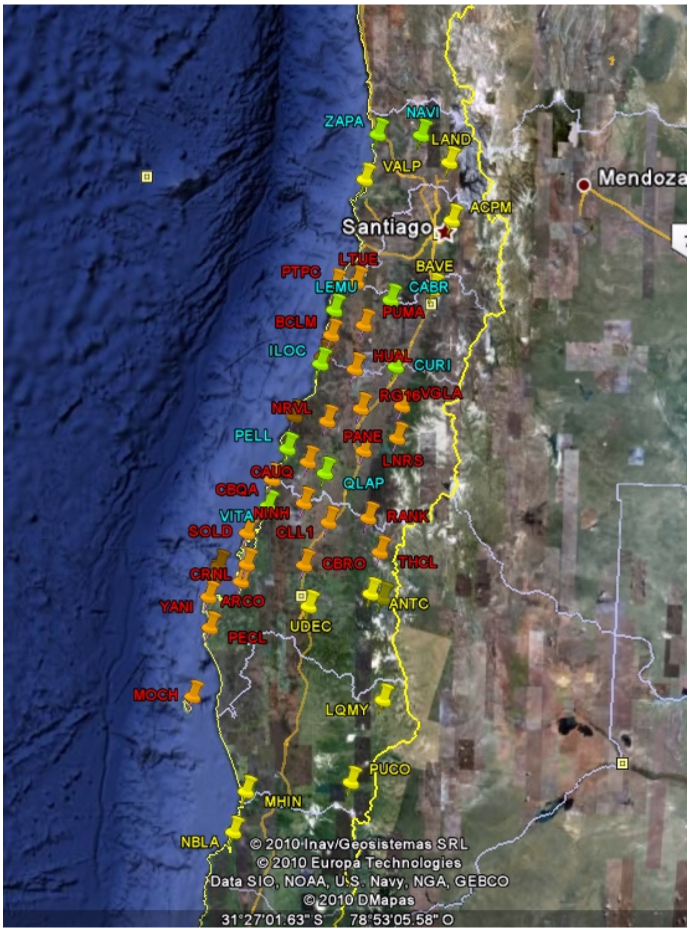

Fig 3 instalación de estaciones terremoto 2010.

From this effort, it was possible to obtain valuable information about what had happened during and after the earthquake. It was determined that the coseismic movements had a magnitude of between 60 cm and 5 metres within the whole zone affected and moving in a south-westwards direction, completely the opposite of the normal movement that the South American plate undergoes, which is usually about 15 mm going north-eastwards. This confirmed the initial assessment that the RGN had ceased to exist totally in that region from the point of view of geodesy.

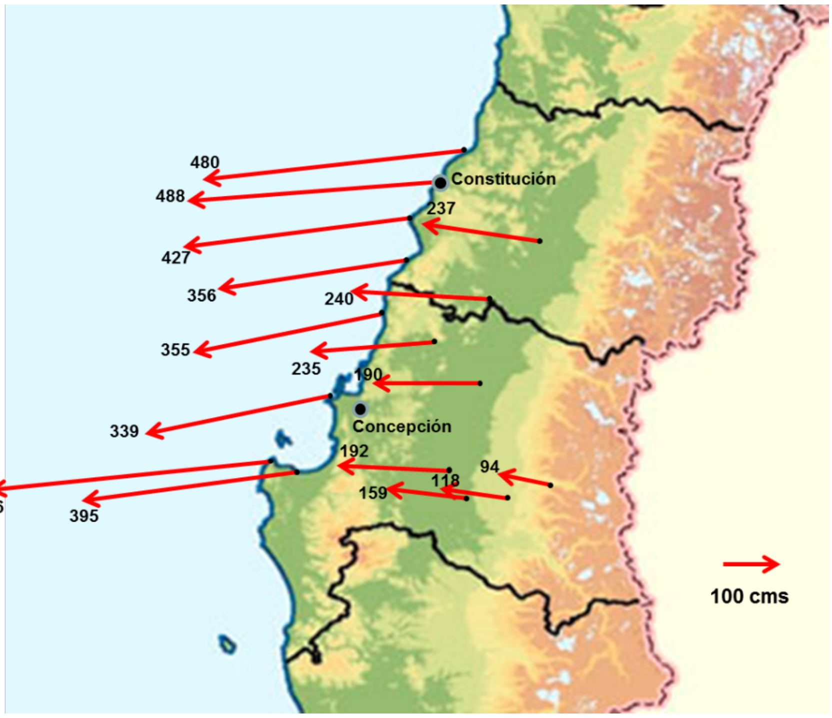

Fig 4: Coseismic movement with the Maule earthquake in 2010.

However, it provided valuable information about the postseismic movements. This information was vital for determining the moment when the network may be remeasured, because while the earth's surface continues to move in an irregular way in terms of its magnitude and direction, it was going to be impossible to survey for the new network, because it would not be able to sustain that network over time in the face of such deformations.

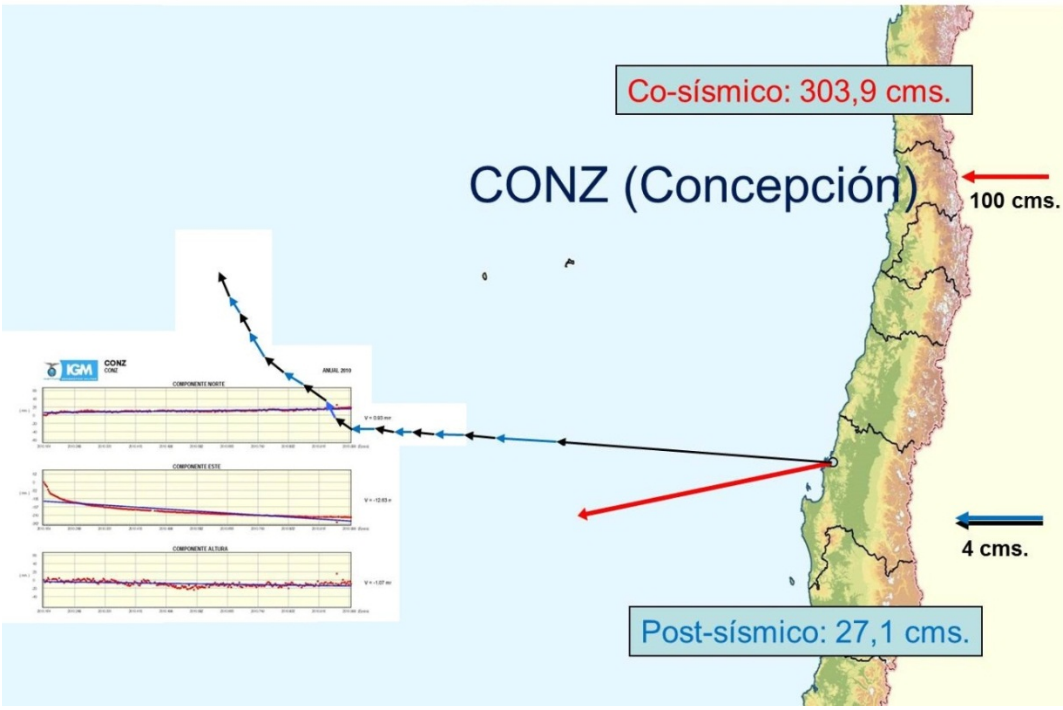

Fig 5. Post-seismic movement of CONZ station in Chile up to the year 2013.

4. THE NEW RGN AND FUTURE DEVELOPMENTS

Thus, given the data gathered by the stations deployed in the field and the analysis and conclusions reached through processing the GNSS data at the IGM, the decision was taken to re-measure the whole of Chilean territory so as to be able to set up a new epoch after the earthquake, which would give as its result a new network. The year selected for this work was 2013, during which a total of 29 geodesic reference points were measured throughout all of Chile, using the parameters and standards for measurement recommended by SIRGAS and in accordance with current techniques in geodesy.

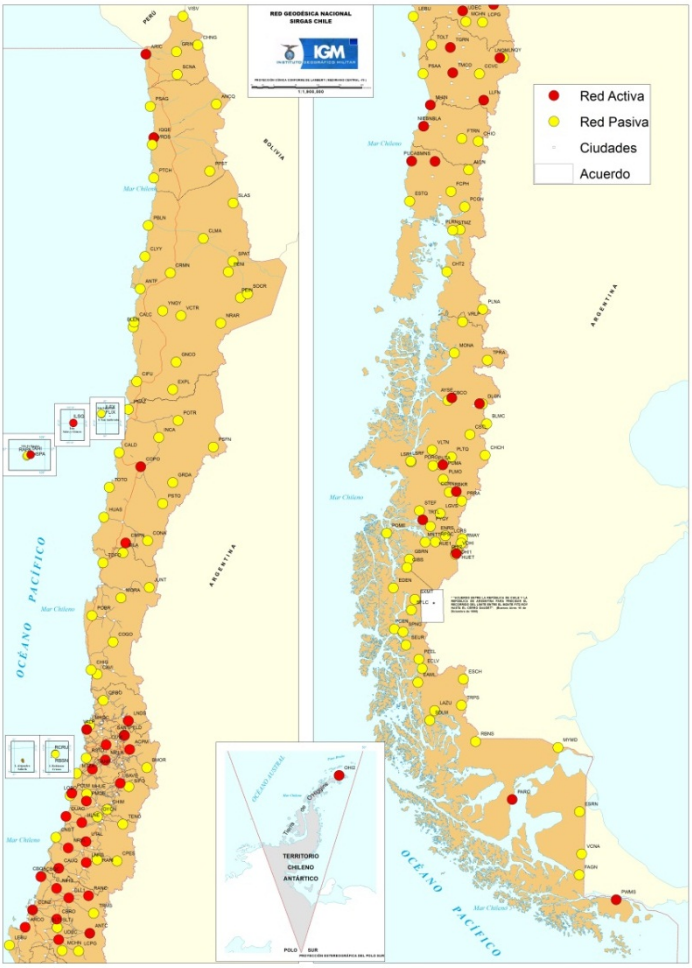

Fig 6. Geodesic sites re-measured during the year 2013

Once all the measurements had been obtained, 13 stations of the ITRF international reference framework that, at the same time, are part of the SIRGAS-CON continental network, were selected so that they could serve as support for the new adjustment. The choice of these stations was made applying the criteria of a homogenous distribution, distance, the stability of the station and the reliability of the data. Using the ITRF 2008 reference framework and again following the guidelines issued through SIRGAS, which constituted the main source of advice throughout the whole process of planning, execution, processing and control of this new network. The adjustment process was started using the software tool called “BERNESE”.

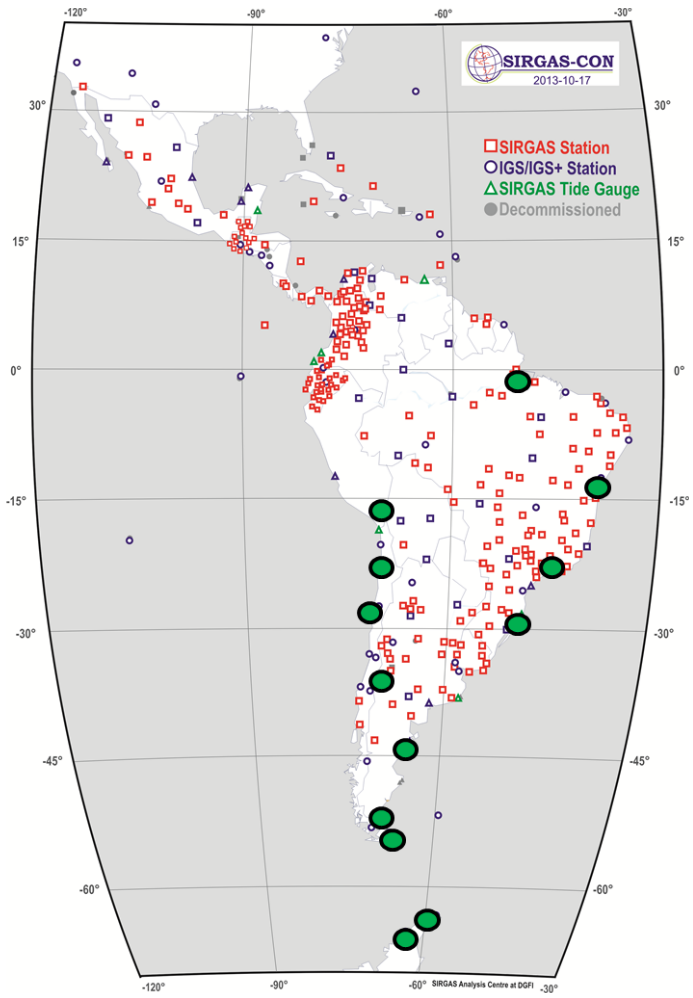

Fig 7 ITRF fiducial stations.

As a result of this work, a new adjustment epoch was obtained for the RGN of Chile in 2013. During the validation process, the standard deviation determined for the total adjustment of the network was 3 mm horizontally and 10 vertical mm, which is acceptable for the purposes of providing to users in society a reliable, sturdy and permanent network.

In the future, it remains to create the models that will link together the data based on the older measurements from before the earthquake of 2010 and the new reference framework. In other words, it is intended to create a velocity model that would connect both reference systems. Given that, to date, there are still changes in the velocities of the stations that are permanently monitoring the terrain, it is judged that the model will not be lineal, unlike traditional models. For this purpose, work is being done in conjunction with Dr. Herman Drewes through the SIRGAS Project in order to develop an approach that makes it possible to give shape to the model. This is the work which currently is still being performed.

5. CONCLUSIONS

Over time, we have learned that the earth is a long way from being a rigid and static body; to the contrary, the dynamics of its tendencies are sometimes astounding. Far from trying to remove these effects in geodesic networks, we should learn from them, in order to be able to adapt these networks to the activity of the earth's crust.

It is fundamental to have available a large amount of reliable and accurate information, promptly, for the whole area being studied, in order that, through these means, the methodologies enabling this adaptability can be developed.

A non-linear velocity model is an essential element in the maintenance of a reference framework under these conditions, as it makes it possible to model the changes in velocity at the stations, which thus adapts even more to the reality of the movements of the earth's crust in zones affected by seismic events.

CONTACT

Title:	Major and Military Polytechnic Engineer
First Name:	Lautaro
First Surname:	RIVAS
Second Surname:	Reveco
Institution:	Instituto Geografico Militar (Military Geographic Institute)
Address:	Nuva Santa Isabel 1640
City:	Santiago
Country:	Chile
Tel.	(56) – 2 - 4109312
Email:	lrivas@igm.cl
Web site:	www.igm.cl