Research Networking Programmes

Short Visit Grant - Scientific Report

Proposal title: "Characterization of Volcano Deformation. GNSS Data Acquisition and Processing Methodologies"

Proponent Institution: Centro de Informação e Vigilância Sismovulcânica dos Açores (CIVISA), Azores University, Portugal

Host Institution: Icelandic Met Office (IMO)

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1 Purpose of the visit

The main purpose of the Short Visit Grant to IMO was to acquire knowledge about the Icelandic GNSS monitoring network and the volcano monitoring strategies used in Iceland. More specifically, the intention was to understand and discuss data acquisition schemes from IMO's permanent stations and to compare it with current procedures done in CIVISA. In addition, there was the purpose to compare and discuss about the GNSS data processing methodologies used in CIVISA and IMO. It was proposed the use of a GNSS data set from Fogo Volcano (Azores) to be processed using different software (Bernese and GAMIT/GLOBK) and to compare the results. The intention was to evaluate each processing methodology and to make a characterization and discussion about crustal deformation results from Icelandic and Azorean volcanoes regarding unrest periods (e.g. Eyjafjallajökull and Fogo volcanoes).This is particularly important for the Azores, where very few examples from volcano deformation are available. The grant was scheduled to last from 1 to 15 of September, 2014. From 22 to 29 August it was possible to participate in the NEMOH Field School, *Volcano Deformation and Magmatic Processes*, which also took place in Iceland.

Bardarbunga volcano began to show strong signs of unrest a few days before the grant period. A fissure eruption initiated NE of Dyngjujökull on the 31st August. This situation forced all the personnel of IMO to be fully involved in the monitoring tasks. As a result, a readjustment was necessary in the work plan and the visit was carried on, as an alternative, in the Institute of Earth Sciences (IES) of the University of Iceland, under the coordination of Freysteinn Sigmundsson, who works closely with IMO. An effort was done to keep, as close as possible, the initial work plan and at the same time to follow closely the evolution of Bardarbunga-Dyngjujökull ground deformation. These changes in the work plan were reported to the Chairman of the MeMoVolc steering committee Tim Druitt and received his agreement.

2 Description of the work carried out during the visit

Both campaign and continuous GNSS observations are done in CIVISA. The GNSS data from the geodetic network is currently processed using Bernese software. The results are analyzed with scripts developed internally in CIVISA but there is the need to explore other software.

Consequently, after a previous discussion and comparison between data processing methodologies used in CIVISA and both in IMO and IES, it was decided to test some strategies on GNSS data analysis during the visit to IES. The work developed will be useful for the geodesy group from CIVISA to quickly analyze results from both GNSS campaign and continuous data observations.

2.1 Development of tools for conversion of output files from Bernese to GAMIT/GLOBK format

In IES the GNSS data is processed using GAMIT/GLOBK software, the same methodology applied by IMO, and the results are usually displayed and analyzed with TSVIEW from GGMATLAB software package. The primary aim of TSVIEW is to assess the quality of time series and includes many options: to detrend the results from the tectonic displacement, to delete bad site estimated positions, to account from jumps in the time series and other options (Herring and McClusky, 2009).

However, TSVIEW software only reads GAMIT/GLOBK output files and not Bernese files. The data from the output files from both processing software is arranged in a different way.

A MATLAB script, that was named B2G, was created to convert the Bernese estimated positions and errors to GAMIT/GLOBK format and to allow the use of TSVIEW software.

The daily estimated positions of all stations processed from Bernese software are stored in daily SNX files in cartesian coordinates and the variance-covariance matrix values of the coordinates are stored in daily COV files (figure 1). From COV files the position errors can be determined. All three position components (north, east and up) are stored in the SNX files.

In GAMIT/GLOBK software the output results are not stored in daily files. The estimated positions from different days are stored in individual station files with local coordinates and corresponding errors for north component (DAT1 files), east component (DAT2 files) and up component (DAT3 files) (figure 2).

The script reads all daily SNX and COV files in a specified folder and takes the estimated north, east and up positions and variance-covariance matrix values for a given station. The MATLAB function XYZ2ENU (Mehrtash, 2013) was used to convert the Bernese cartesian coordinates (XYZ) and corresponding variance-covariance matrix values to local relative geographic coordinates (ENU). The script stores the converted local coordinates and errors in GAMIT/GLOBK format DAT1, DAT2 and DAT3.

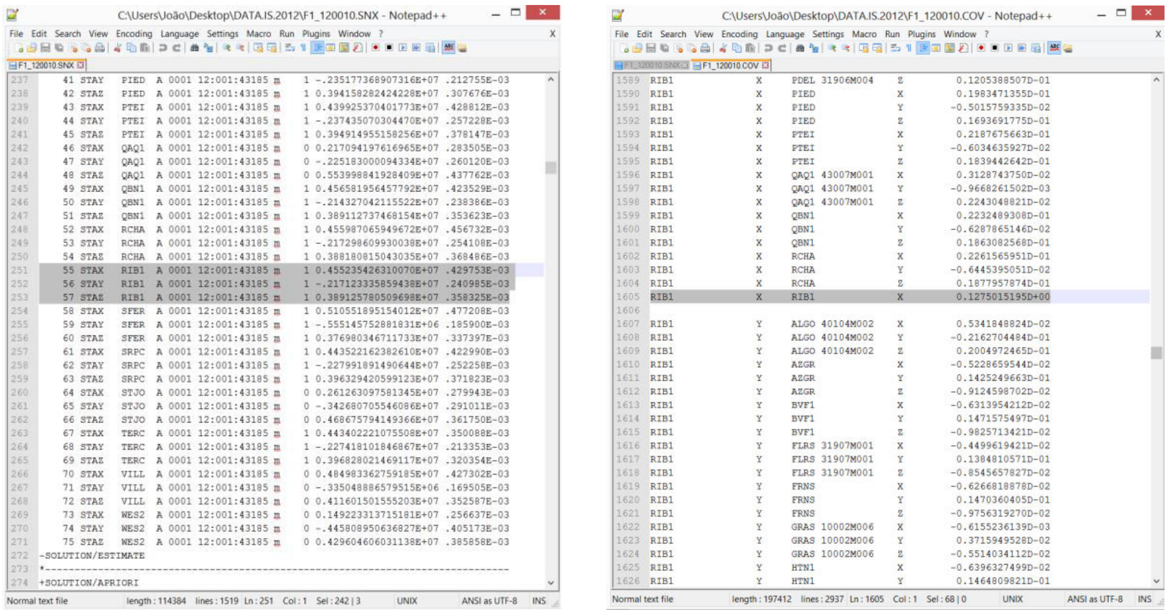


Figure 1 - Bernese SNX file with estimated positions (left) and Bernese COV file with variance-covariance values (right) for RIB1 CIVISA station.

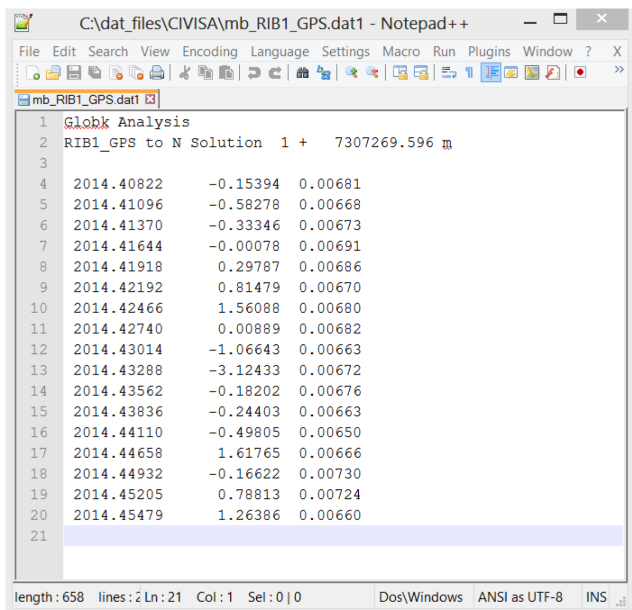


Figure 2- GAMIT/GLOBK DAT1 output file converted with B2G script with estimated north positions and errors for RIB1 CIVISA station.

2.2 Development of tools to calculate displacement velocities between GNSS campaign observations

Another script, that was named CALCDISP, was developed to support IES and CIVISA fast determinations of displacement velocities between campaign GNSS surveys. The script estimates the weighted average position of a given station in different campaign surveys. This is done using the weights of the errors of each campaign observation.

Giving n measurements of quantity x with their corresponding uncertainties:

$$x_1 \pm \sigma_1 \,;\, x_2 \pm \sigma_2 \ldots\ x_n \pm \sigma_n$$

The best estimate of the mean of these values is the weighted average (Taylor 1997):

$$x_{wei} = \frac{\sum w_i\, x_i}{\sum w_i}$$

The sum is done over all n measurements (i = 1,…n) and the weight w_i of each measurement is the reciprocal square of the corresponding uncertainty:

$$w_i = \frac{1}{\sigma_i^2}$$

The uncertainty of the weighted average is:

$$\sigma_{wei} = \frac{1}{\sqrt{\sum w_i}}$$

Using this approach the less precise observations contribute much less to the estimated average, resulting in more precise position estimation.

This method is to be applied in campaign observations, when the number of observations in each campaign is low and the campaign surveys are separated by long periods of time, and not in continuous data observations.

This second script was done as a MATLAB function with input and output parameters. This way the task can be applied very quickly for any station and number of campaigns. The inputs of the function are:

- Directory of the observation files
- File name of the station
- Vector with first days of each campaign
- Vector with last days of each campaign

The outputs of the function are:

- Displacement velocities in north, east and up components
- Velocity errors in north, east and up components

As an example, SVAD station from IES was used. It has 3 sets of points corresponding to 3 GPS campaigns:

- Between 2008.56967 and 2008.57787 (4 days)
- Between 2010.60685 and 2010.61233 (3 days)
- Between 2011.57123 and 2011.57671 (3 days)

The function CALCDISP was done for GAMIT/GLOBK and not Bernese output results. However, Bernese output results can be converted to GAMIT/GLOBK format using the first script developed during this short visit grant and then the CALCDISP function can be used.

3 Description of the main results obtained

The first script - B2G script - was applied for a GNSS data set from Fogo Volcano (Azores) - RIB1 station - that was processed with Bernese software and the time series were successfully visualized with TSVIEW (figure 3).

The time series from RIB1 station were then analyzed with TSVIEW functions including: detrending from linear displacements, edition of breaks and estimation of exponential and logarithmic functions to fit the data. The software can be further explored with longer time series from other CIVISA stations.

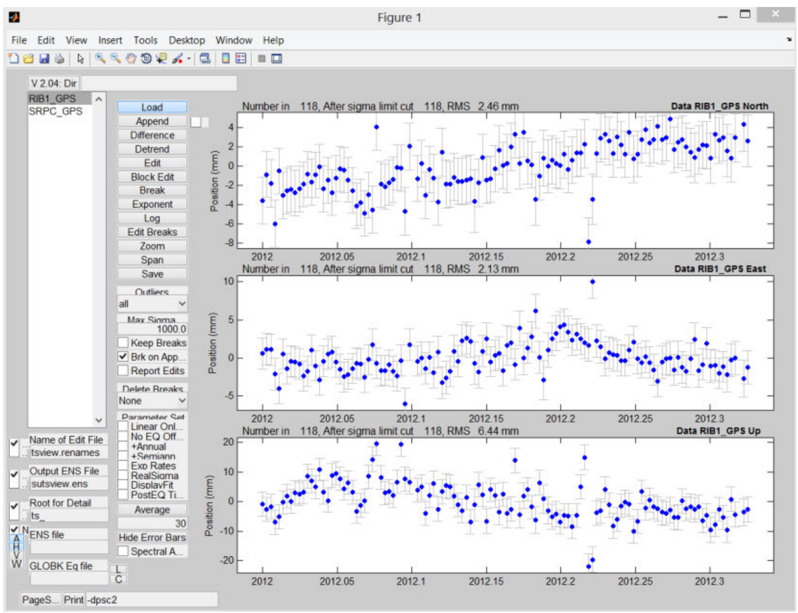


Figure 3- Time series of RIB1 station visualized in TSVIEW software.

Regarding the second script - CALCDISP - it was possible to calculate the velocities between SVAD campaign surveys using the estimated weighted averages of the positions and the mean times between the campaign surveys. The weighted averages of the positions estimated for each campaign survey are set as red points in figures 4, 5 and 6.

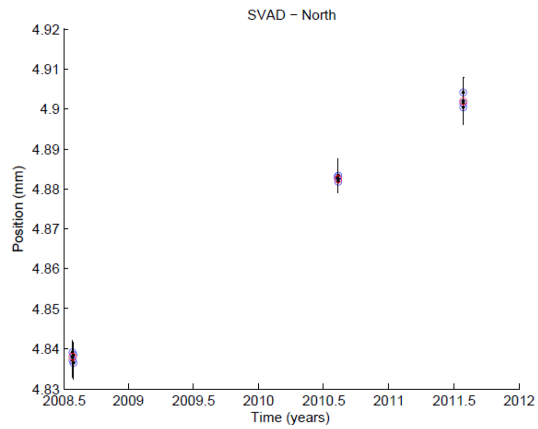


Figure 4- Time series of SVAD north component (blue) and weighted averages (red).

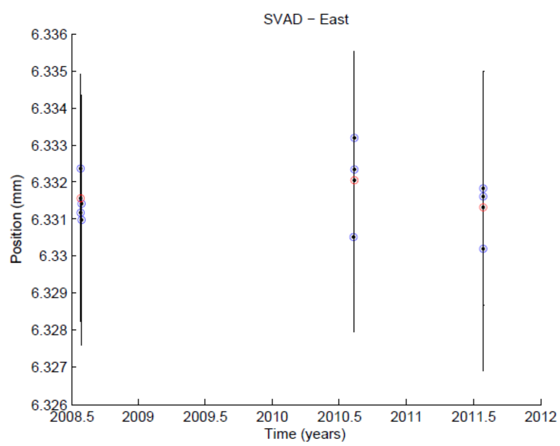


Figure 5- Time series of SVAD east component (blue) and weighted averages (red).

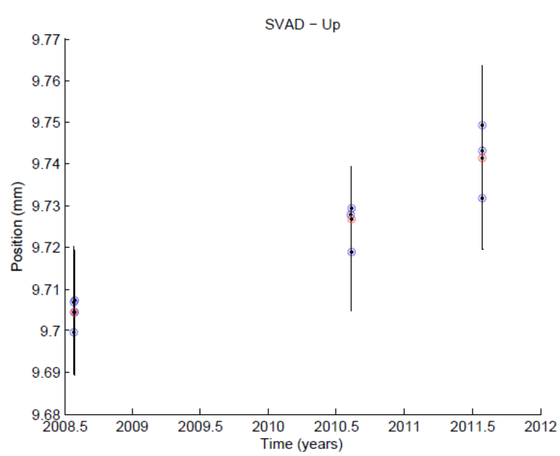
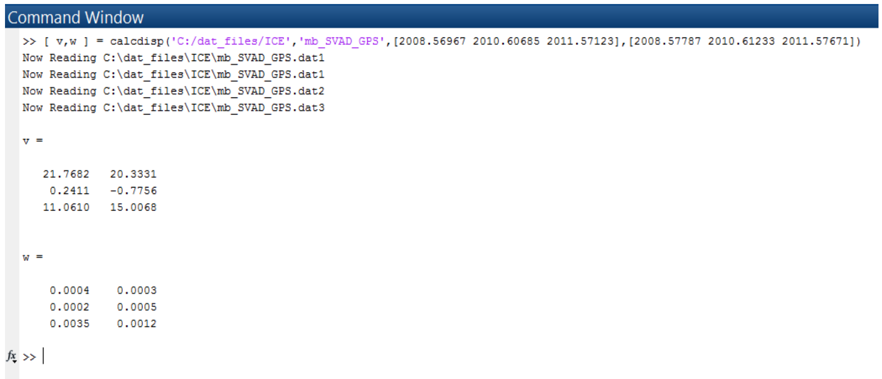


Figure 6- Time series of SVAD up component (blue) and weighted averages (red).



```
Command Window
>> [ v,w ] = calcdisp('C:/dat_files/ICE','mb_SVAD_GPS',[2008.56967 2010.60685 2011.57123],[2008.57787 2010.61233 2011.57671])
Now Reading C:\dat_files\ICE\mb_SVAD_GPS.dat1
Now Reading C:\dat_files\ICE\mb_SVAD_GPS.dat1
Now Reading C:\dat_files\ICE\mb_SVAD_GPS.dat2
Now Reading C:\dat_files\ICE\mb_SVAD_GPS.dat3

v =

   21.7682   20.3331
    0.2411   -0.7756
   11.0610   15.0068


w =

    0.0004    0.0003
    0.0002    0.0005
    0.0035    0.0012

>>
```

Figure 8- MATLAB Command Window with CALCDISP function outputs (velocity array v and error array w) from SVAD station example.

The north velocities are higher than the east and up velocities (table 1). Also, the east velocities are much lower than the north and up velocities and the east velocity between the second and third campaigns is negative i.e. it has west direction. In all other cases the velocities are “positive”. This analysis can be confirmed from figures 4 to 6.

Table 1- North, east and up velocities and errors between the first and second campaigns (P1-P2) and between the second and third campaigns (P2-P3).

	P1-P2		**P2-P3**	
	Velocity (mm/year)	**Error (mm/year)**	**Velocity (mm/year)**	**Error (mm/year)**
north	**21,7682**	**0,0004**	**20,3331**	**0,0003**
east	**0,2411**	**0,0002**	**-0,7756**	**0,0005**
up	**11,061**	**0,0035**	**15,0068**	**0,0012**

The quick velocity estimation is very important to check if the displacement of GNSS stations vary in time and, thus, it can help identify possible deformation signals from volcanic or other activity and to analyze its evolution.

4 Other Comments

4.1 Following of the unrest period and eruption in Bardarbunga-Dyngjujökull

The visit was a very rewarding experience because it was coincident with the start and ongoing eruptive activity in Bardarbunga-Dyngjujökull. It was possible to attend and participate in daily meetings since the 15th August (during the participation in NEMOH summer school and also in IES) about the state of activity on the volcano and to follow the changes in the deformation rates and seismic activity related with the lateral migration of magma from Bardarbunga volcano. The fruitful discussions about crustal deformation results favoured a better understanding of its relation with magma processes.

4.2 Meeting at IMO

A revision of the work produced was done in IMO on 12 September with Benedikt Ofeigsson. This meeting allowed the comparison of methodologies used both in IMO and CIVISA and resulted on insights about possible improvements on the methodologies currently applied in CIVISA. By comparing and discussing the problems that occur with the acquisition, processing and analysis procedures that are carried out in both institutions new ideas emerged to surpass some of the difficulties that still exist. With the visit to IMO, knowledge about the Icelandic GNSS monitoring network and volcano monitoring strategies was acquired.

Overall, this short visit grant was very useful to share knowledge on ground deformation monitoring and to develop research methodologies for better understanding of the geodynamic processes and for the improvement of CIVISA response to volcanic unrest crises using GNSS crustal deformation monitoring technique. Future collaborations are envisaged to strengthen the capabilities of both institutions on the interpretation of volcano deformation and magmatic processes.

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