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INSTALLATION AND DATA ANALYSIS OF A SMALL NETWORK OF SAR CORNER REFLECTORS IN FOGO, CAPE VERDE

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Introduction

Since early ninety's Synthetic Aperture Radar Interferometry (InSAR) has been exploited for geophysical applications. InSAR technique is capable to capture information on surface deformation and can be a useful tool for monitoring active seismic and volcanic areas. Despite the capability of SAR sensors to operate in all weather and day/night conditions, SAR signal is affected by different source of noise (e.g. water vapour or instrumental noise) [Hanssen, 2001]. These disturbing sources affect the accuracy of InSAR deformation map, especially for time series analysis, and the quality control of InSAR measurements, either standard differential interferometry and Persistent Scatterers Interferometry (PSI), is not an easy task. A fruitful solution is represented by the adoption of passive Corner Reflectors (CRs). CRs can provide point measurements with high level of confidence with sub-centimeter accuracy [Marinkovic et al, 2007], thanks to their high backscattered signal value, and representing strong persistent scatterers to be used for calibrating and validating SAR (from InSAR and PSI technique) deformation map. Indeed, CRs can maintain their interferometric phase stable during time. Additionally, CRs can also be exploited to calibrate the amplitude SAR signal, and to provide reference points for geocoding purposes.

Here we present the design, realization and installation of a small CRs network on the Fogo Volcano island, Cape Verde. This activity has been done in the framework of the European project MIAVITA, MItigate and Assess risk from Volcanic Impact on Terrain and human Activities.

1. Corner Reflectors design and realization

The design and realization of the CRs have been conducted by INGV staff of the Remote Sensing Group. Taking into account the requirements to be compliant with present C-band SAR (ENVISAT-ASAR and RADARSAT missions) and X-band SAR (COSMO-SkyMed and TerraSAR-X) and the future Sentinel-1 SAR mission of the European Space Agency (ESA), the CRs are trihedral types with a base edge length of 1.0 m (fig. 1). This shape and size allows to obtain a Radar Cross Section (RCS) suitable to have a clear, high reflective point in the SAR image [Sarabandi et la, 1995].

The size of a CR is directly proportional to the signal strength, affecting the quality of the measurement. The larger is the reflectors, the better is the precision of the measurement. CR radar reflectivity is also function of the wavelength of the SAR sensor (see eq. 1). It is required that the minimum size of the CR should give a signal that dominate all other signals coming from targets located in the vicinity (natural surfaces, rocks, house, etc.).

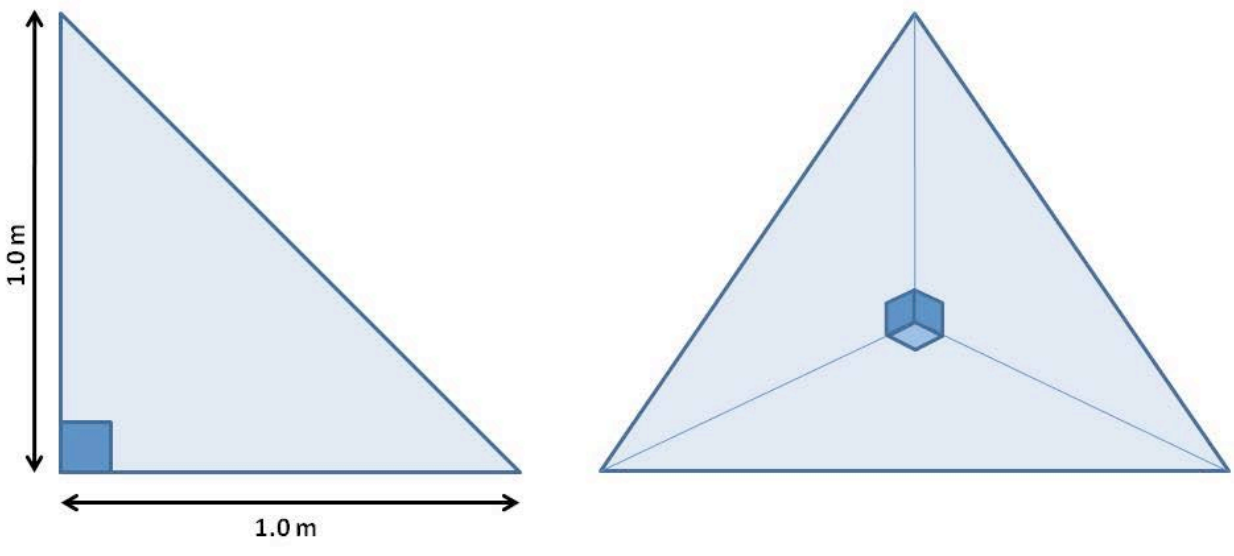

Figure 1. CR design: lateral (left) and perspective (right) views.

We can calculate the RCS by the following expression [Sarabandi and Chiu, 1996]:

$$RCS = \frac{4}{3}\pi\left(\frac{a^4}{\lambda^2}\right) \quad (1)$$

where a is the edge length of trihedron side and λ is the wavelength of the SAR sensor we are considering. Assuming a C-band SAR, for example the ENVISAT-ASAR that operates at 5.3 GHz, i.e. with a wavelength equal to 5.6 cm, and 1.0 m of base edge length, we obtain a RCS = 1686 m^2. This value can be considered enough to have the desired reference point. Indeed, taking into account that such value is sensibly higher than other natural scatterers, it will be a visible and very bright point on the SAR image.

The three triangular faces that compose CRs are made of perforated aluminium, which allows lightness and low resistance to the wind. The three faces are linked together with L-shaped aluminium bars. Few additional aluminium profiles have been also used to strengthen the CRs structure (fig. 2a), obtaining a more mechanically stable equipment.

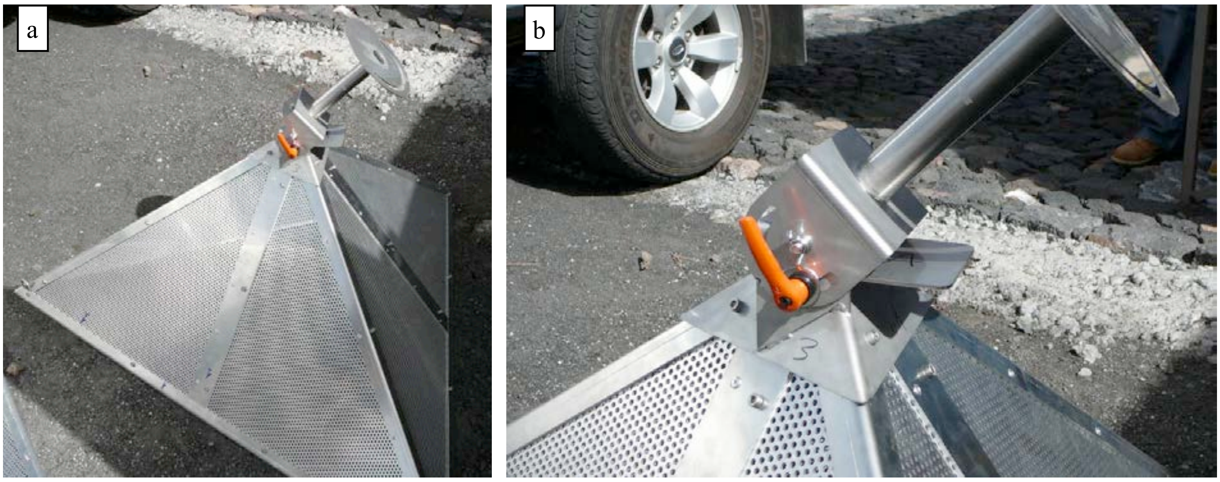

Figure 2. CR mounting: a) the CR assembling completed; b) detail of the adjustable pointing system.

The CRs are also provided of an adjustable pointing system (fig. 2b). On the vertex of the trihedron, a stainless steel mechanism is fixed, which allows to move the CR in both azimuth and elevation directions. This (not very cheap) solution has been adopted to have a flexible instrument by gaining the capability to fit CRs to various SAR on board of the present different satellite missions. Actually, thanks to this mechanism the CRs can be easily oriented to match the Line Of Sight (LOS) of any desirable SAR sensor and/or acquisition mode.

2. The installation activities in Fogo

The installation activity has began with the identification of the three possible sites, suitable from both accessibility and scientifically points of view. A preliminary evaluation for the three locations has been carried out by analysing either optical very high resolution and SAR images. Two sites have been identified inside the Fogo caldera, close to the village of Chã das Caldeiras, and one on the volcano south flank in the area close to the village of Fonte Aleixo (fig. 3).

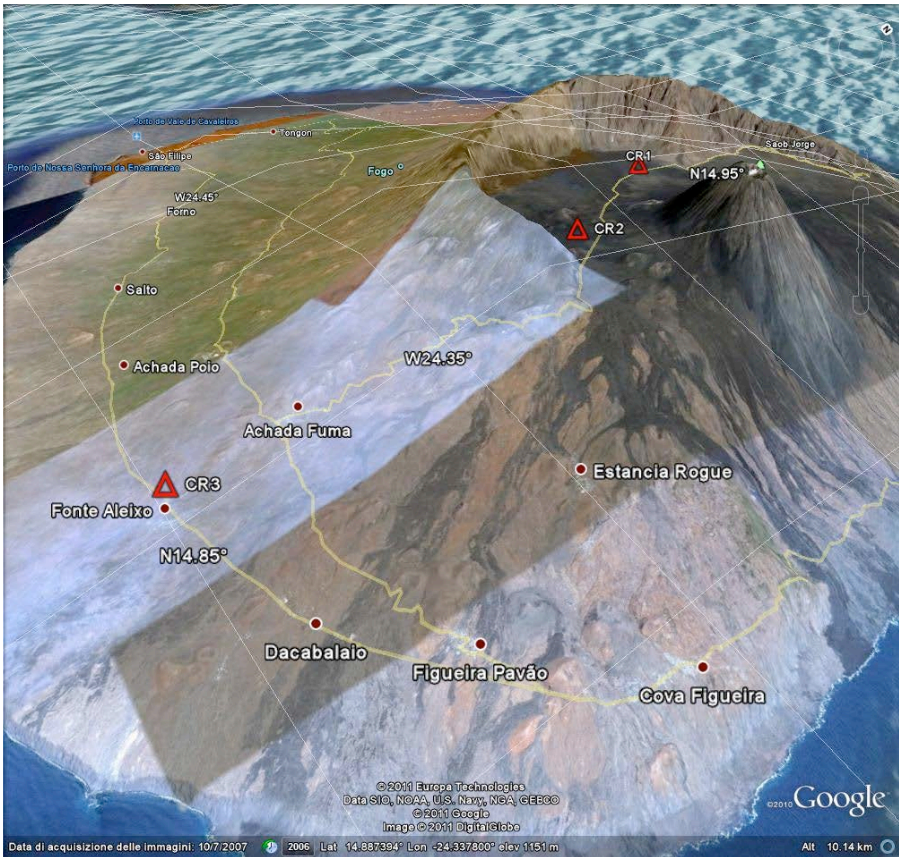

Figure 3. The three **s**ites selected for the CRs installation (red triangles).

The installation campaign started on September 26, 2011. The preliminary locations have been surveyed to find the exact positions of the three CRs. On each of the selected site, the same assembling procedure has been adopted. First a 1m depth hole has been excavated on the soil. Four steel rods, are fixed to the base of the CR (fig. 4) to obtain four small pillars to be inserted in the hole, and then the hole is filled up with cement (fig. 5) and the final positioning of the CR base is achieved.

Figure 4. Preparation of the CR base.

Figure 5. CR base positioning on the ground. Left figure highlights the four rods drowned in the cement, right figure shows the final positioning of the base.

The final step of the CR setup consists on the insertion of the thrihedron on its base and on the CR pointing. It is worth to note that the accuracy of CR orientation respect to the satellite Line Of Sight (LOS) is quite critical, otherwise we cannot reach the expected performances. We must take into account the orbital path with respect to north and the incidence angle of the electromagnetic wave transmitted by the SAR. In our case, we considered the SAR on board of ENVISAT mission. To set the orientation of the CR with the reflecting surface perpendicular to the LOS, it is necessary to account for about 16° between the north direction and the orbital ascending path and about 15° between the north and the descending orbit. The incidence angle is of about 40°, for IS6 acquisition mode presently working on ENVISAT SAR[1]. If on one hand the elevation pointing has been set easily by using an electronic level, on the other hand the azimuth setting was much less accurate, because we used a magnetic compass to set up the azimuth. This last procedure has two main sources of inaccuracies. First, the true North was found using the magnetic declination given by the IGRF model (see for example http://www.ngdc.noaa.gov/geomag-web/#declination), and not the magnetic declination computed in situ. Second, and the main source of inaccuracy, it is not possible with more sophisticated instruments to take in account the magnetic anomalies due the heterogeneities brought by volcanic rocks and very irregular topography. However, other observations in the field (for example comparing azimuth given by a GPS receiver and by a magnetic compass), enables to estimate the inaccuracy to be +/-5º.

The installation operations successfully ended on September 28, 2011.

Figure 6 shows the three CRs in their final configuration. The top image shows the CR installed on the northern area of Fogo caldera; the middle image refers to the CR located in the southern part of the caldera; the bottom figure shows the CR close to Fonte Aleixo. The first two CRs are set for SAR acquisition on descending orbit while the one in Fonte Aleixo is for descending ones. Table I, reports the location of the 3 CR.

Label	Latitude	Longitude
CR1	14.956805	-24.369447
CR2	14.928406	-24.356823
CR3	14.851053	-24.359602

Table I. Geographical coordinates of the three CRs.

[1] At the time of the installation campaign, September 2011, ENVISAT satellite was regularly operating. Unfortunately, since April 2012 the space platform is out of working.

Figure 6. The three CRs successfully installed. Upper, middle and bottom images refer to the two CRs close to Chã das Caldeiras and the one close to Fonte Aleixo, respectively.

3. SAR data measurements

In order to test the effectiveness of the installation campaign a couple of SAR data images from ENVISAT satellite have been requested to ESA. One images was taken on 30 October 2011, on ascending orbit, and a second scene was acquired on 4 November 2011, on descending orbit. We received SAR data in Single Look Complex format. In order to extract the backscattering coefficient from the images, the data were radiometrically corrected. Finally the images were geocoded by using the SRTM DEM to locate the expected position of the three bright points corresponding to the CRs. The geocoded products are images with a pixel size equal to 12x12 m on ground, value close to the resolution of the acquisition mode of ENVISAT.

Looking at the two images in the areas were the installations were carried out, it is easy to find the three bright points that corresponds to the three CRs. Figures 7 to 9 show the SAR backscattering images related to the small portion where the CRs are installed.

After this first qualitative check, a more quantitative analysis has been performed to evaluate the CRs backscattering value. Looking at the maximum value of the pixels corresponding to each CR in the SAR calibrated images (in azimuth and ground range geometry), we found 9.2 dB for CR1 and 9.7 dB for CR2, for the descending orbit image, and 10.7 dB for CR3 for the ascending orbit image. They show a higher SAR response than the surrounding natural scatterers (between -11 and -6.6 dB for the three sites, within an area of 200m radius), which means that they are clearly visible and can be still used as references for SAR product, being strong and stable point scatterers.

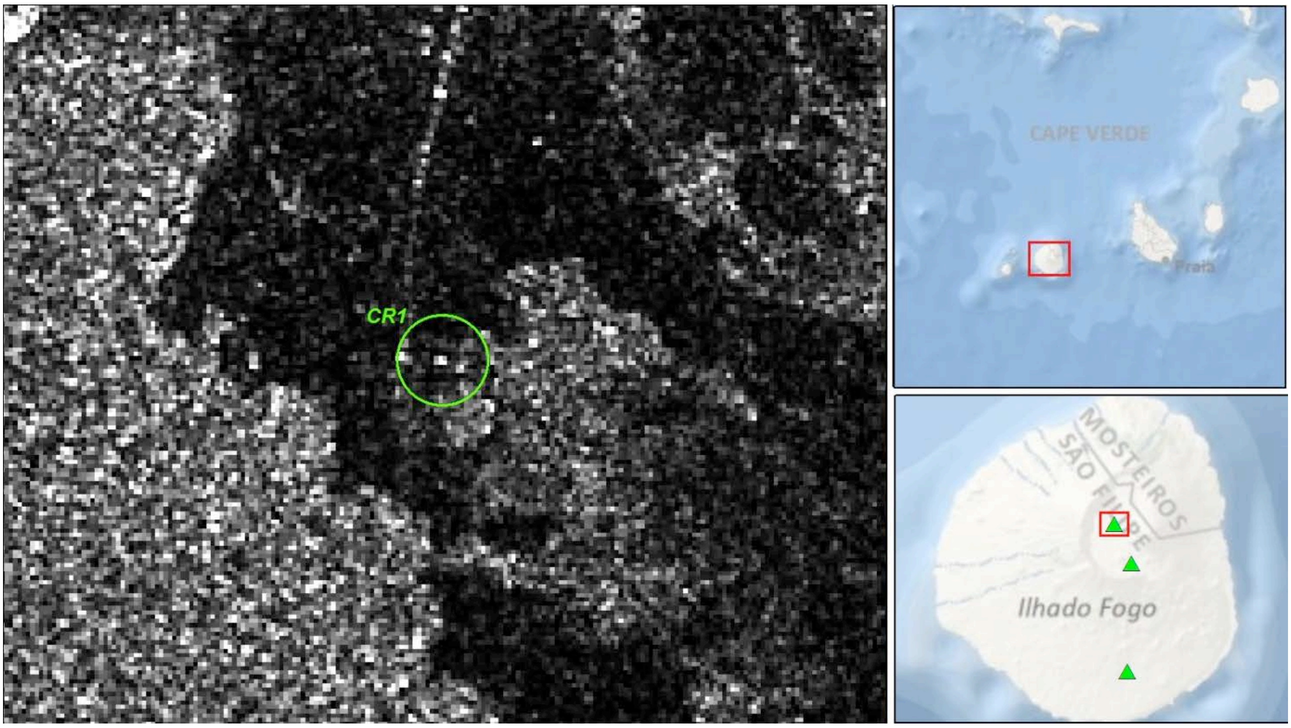

Figure 7. SAR image detail of the area where the CR1 was installed. The clear bright point inside the green circle is the SAR response of the CR.

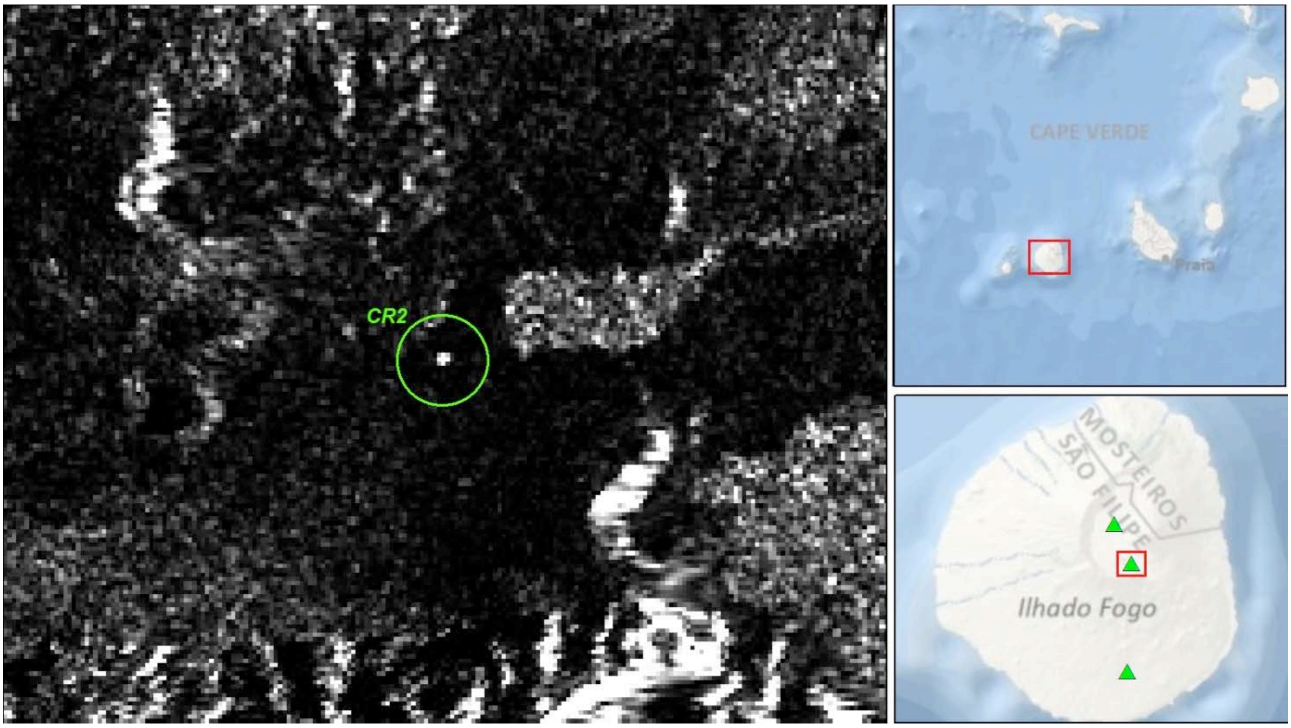

Figure 8. SAR image detail of the area where the CR2 was installed. The clear bright point inside the green circle is the SAR response of the CR.

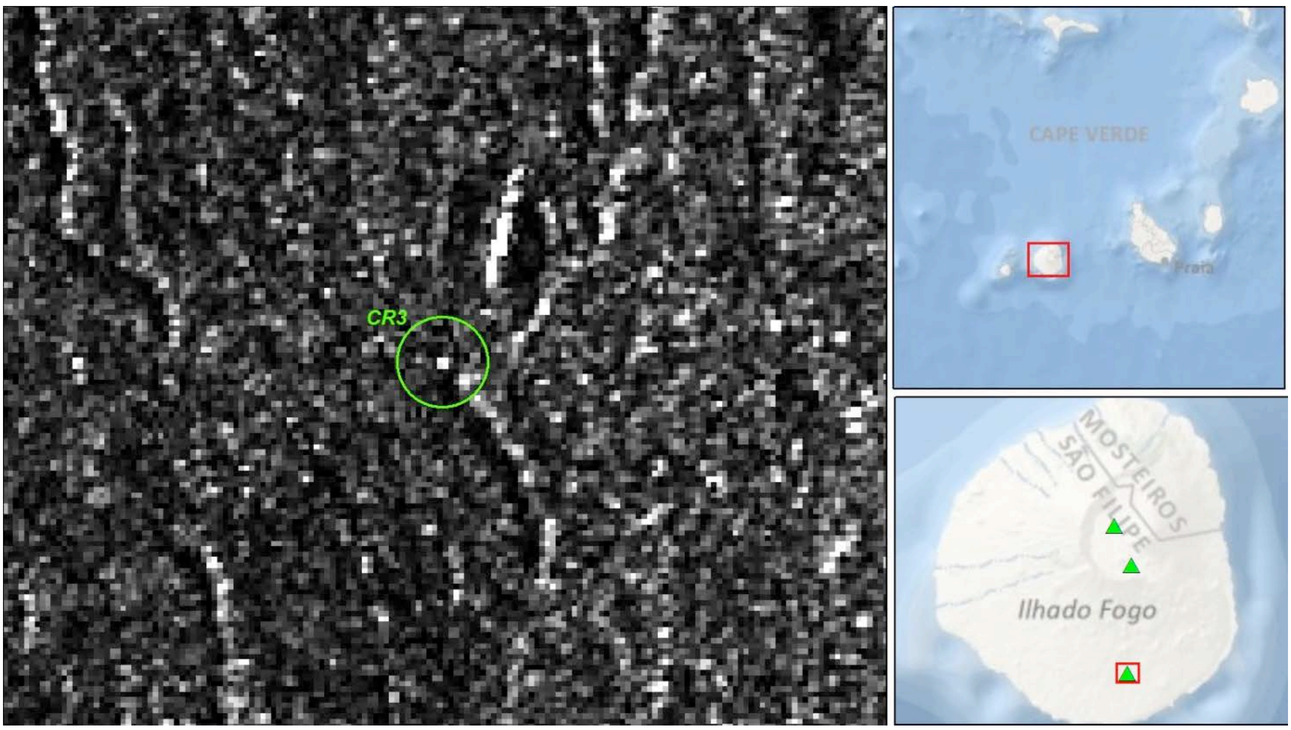

Figure 9. SAR image detail of the area where the CR3 was installed. The clear bright point inside the green circle is the SAR response of the CR.

4. Conclusions

In this work we presented the outcomes of the installation of a small network of SAR corner reflectors. This network has been set up to provide useful reference point to analyse and to validate SAR deformation Product. Three corner reflectors have been installed on Fogo volcano, Cape Verde, assuming the CRs configuration suitable for ENVISAT SAR acquisition. After three days of working the set up was successfully completed. Few weeks later, ENVISAT satellites acquired two images, one on ascending and one on descending orbit. The analysis of the SAR data confirm the pretty good precision of the CRs pointing.

Acknowledgments

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