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Deliverable D3.6: Guidelines for the Integration of VEW in CPAs

A deliverable of WP 3: Early Warning System for Volcanic Activity

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Dissemination Level		
PU	Public	
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the Consortium (including the Commission Services)	
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TN	Technical Note, not a deliverable, only internal for members of the Consortium	

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EXECUTIVE SUMMARY

The tasks performed in Activity 3.6 named "Integration of VEW in CPAs" and lead by CNIG-IGN, SCP and GOBCAN, are reported in this document, which represents the sixth official deliverable of WP3 "Early Warning System for Volcanic Activity". The main goal of this activity is to give CPAs the guidelines to integrate the products resulting from the Volcanic Early Warning System (VEW) into their workflows. These products, which integrate Sentinel 1 and GNSS data, are defined in D3.1 and D.3.4, and have been generated in D3.5. Furthermore, these products have been validated according to the procedure described in D.3.8.

REFERENCE DOCUMENTS

N°	Title
RD1	DoW U-Geohaz
D3.1	User Requirements
D3.2	VEW Assessment Procedure
D3.4	Description of Volcanic Early Warning System (VEW)
D3.5	Updated Deformation Activity Map (V0)
D3.8	VEW Validation Report

CONTRIBUTORS

Contributor(s)	Company	Contributor(s)	Company
Anselmo Fernández García	CNIG-IGN		
Elena González Alonso	CNIG-IGN		
Sergio Ligüerzana Rodríguez	CNIG-IGN		
Laura García Cañada	CNIG-IGN		

REVIEW: CORE TEAM

Reviewed by	Company	Date	Signature
Oriol Monserrat	CTTC	03/10/2019	

1 INTRODUCTION.

In Spain, as it was explained in D3.1, the responsibility and decision-making related to the volcanic risk management is shared between National and Canary Island (Autonomic) authorities, depending on the phase and situation of the declared emergency. Different emergency plans can be activated, from local to national level, depending on the increasing volcanic risk and situation. In this framework, IGN declares the scientific alert with its own data or evaluating the available data forma other institutions through the scientific committee of the corresponding Emergency Plan. Products obtained in WP3 can be useful in the evaluation and management not only of Volcanic Risk Emergencies but also in Risks Emergencies in general.

The main goal of this deliverable is to provide guidelines addressed to Civil Protection prevention departments to properly integrate, use and interpret the products obtained in WP3 as a support to early warning system for volcanic hazards.

This document is organized as follows: Section 2 describes the different products obtained in WP3. Section 3 is divided into two subsections, section 3.1 gives the guidelines for the visualization of the products described in section 2 as well as other information of interest, and section 3.2 constitutes a guide for the interpretation of these products, including an application to a real case. Section 4 discuss contributions of the project to the Early Warning System developed by IGN and those that are expected to be produced in the future.

2 DESCRIPTION OF VEW PRODUCTS.

Products obtained in WP3 have been widely described in D3.4 and D3.5. In this document we only want to give a brief explanation on each of them. These products are the following ones: DIM (Displacement Map), DAM (Deformation Activity Maps) and ADA (Active Deformation Areas). When we added GPS data for these products, VEW-DIM, VEW-DAM and VEW-ADA are obtained.

The DIM map is a deformation map which displays relative deformation (in mm) between two dates, estimated in the satellite line of sight direction. It is obtained after the phase unwrapping of the interferograms, and the transformation from phase to displacement. As it is explained in D3.5, each interferogram is separated in High Frequency (HF) component and Low Frequency (LF) component. Both components are processed separately, in order to produce different products(see Figure 2-1). HF-DIM maps are the input product for the direct integration methodology, and only contains points selected for the direct integration processing as it is explained in D3.5. HF-DIM maps can be visualized as the difference between two consecutives dates in DAM map. The analysis of LF-DIM maps is more qualitative due to they usually contain deformation but also atmospheric artifacts. This analysis must be done by experts, and if it is possible, integrating DIM maps with measurements coming from other geodetic or geophysical techniques.

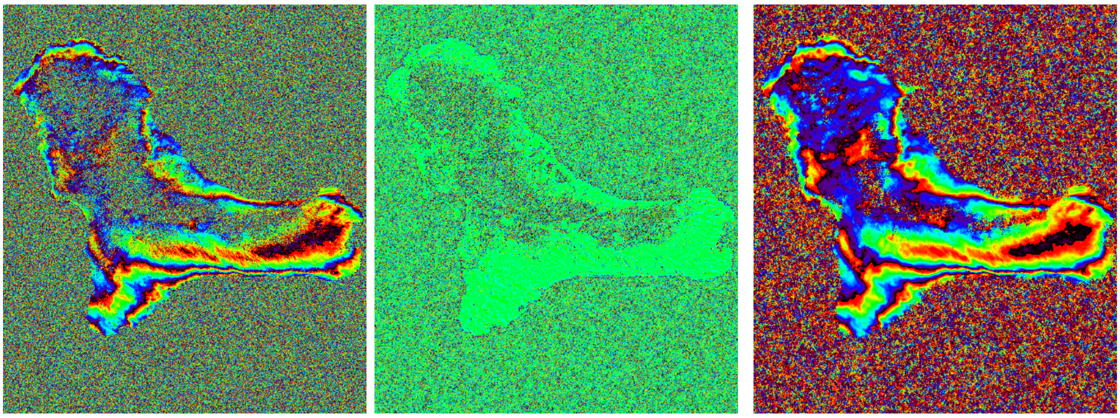

Figure 2-1 DIM products: complete interferogram (Left), HF (Centre), LF (Right).

The DAM map provides for each point, the temporal evolution of the phase with respect the first acquisition time and the mean LOS velocity (see Figure 2-2). The DAM map is the output of the direct integration and is obtained from de HF-DIM products.

The ADA map is derived from the DAM map and it shows the ADAs, groups of measured points (more than five) with same deformation behaviour whose temporal series have reliable noise (Barra et al., 2017) (see Figure 2-3). ADA map is a useful tool that eases the DAM map analysis, and both of them represents an excellent starting point to recognize long-term processes.

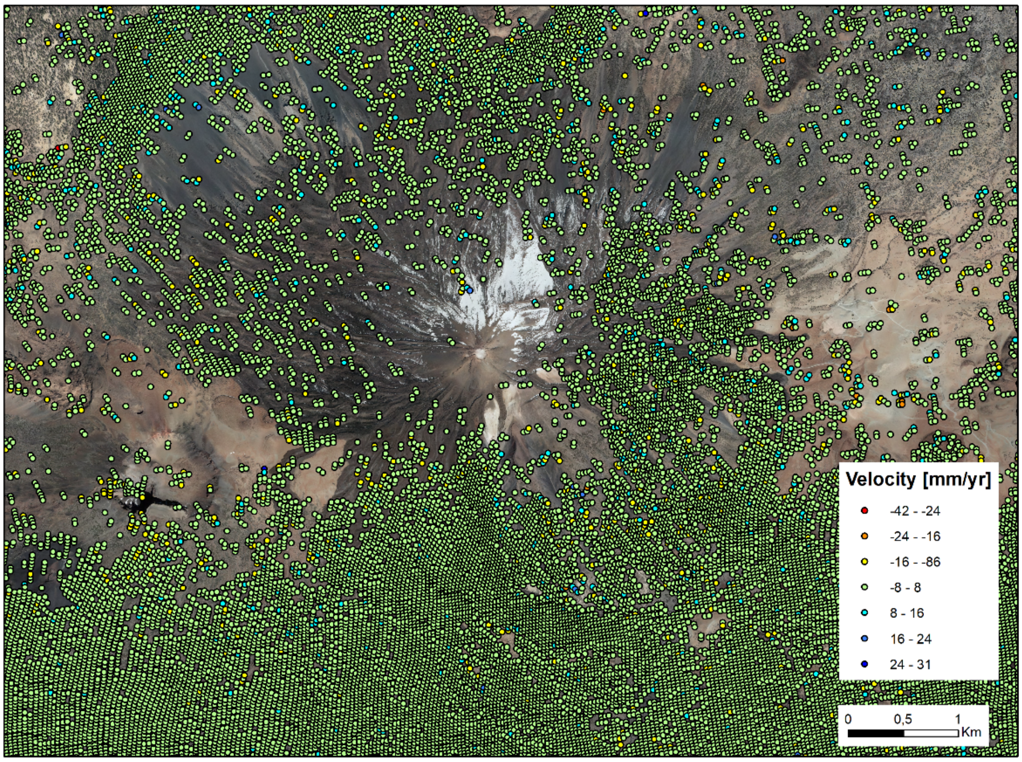

Figure 2-2 DAM map over Teide Area (Tenerife Island).

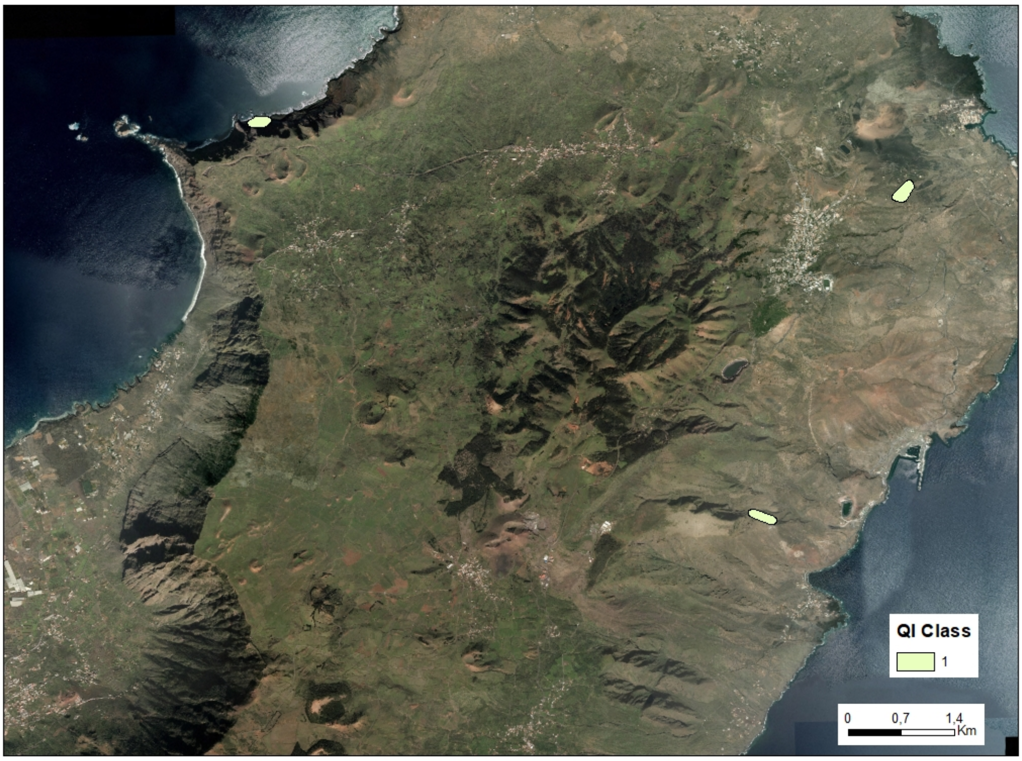

Figure 2-3 ADA Map over El Hierro Island.

As it was explained in D3.4, the main objective of VEW is the creation of products that integrate deformation from different techniques to have a broader vision of the deformation field. In this project we have integrate DIM, DAM and ADA with GPS data coming from the daily processing of the GPS network that IGN has in Canary Islands. For this integration it is necessary to project GPS date to LOS, in order to be able to compare with InSAR data. As it is explained in D3.8 the projection to LOS is done applying the equation (Hanssen, 2001):

$$d_r = d_u(\cos(\theta_{inc}) - \sin(\theta_{inc})\left\{d_n \cos\left(\alpha_h - \frac{3\pi}{2}\right) + d_e \sin(\alpha_h - \frac{3\pi}{2})\right\}$$

According to the Sentinel-1 ascending orbits used in this analysis, these parameters are:

- d_r : deformation vector in LOS direction
- d_n, d_e, d_u: deformation vectors in north, east and up directions coming from GNSS-NEU time series
- θ_{inc} : incidence angle for the area of interest (between 27.º53 and 44º28, depending on the island)
- α_h : orbit heading (~12.5º)

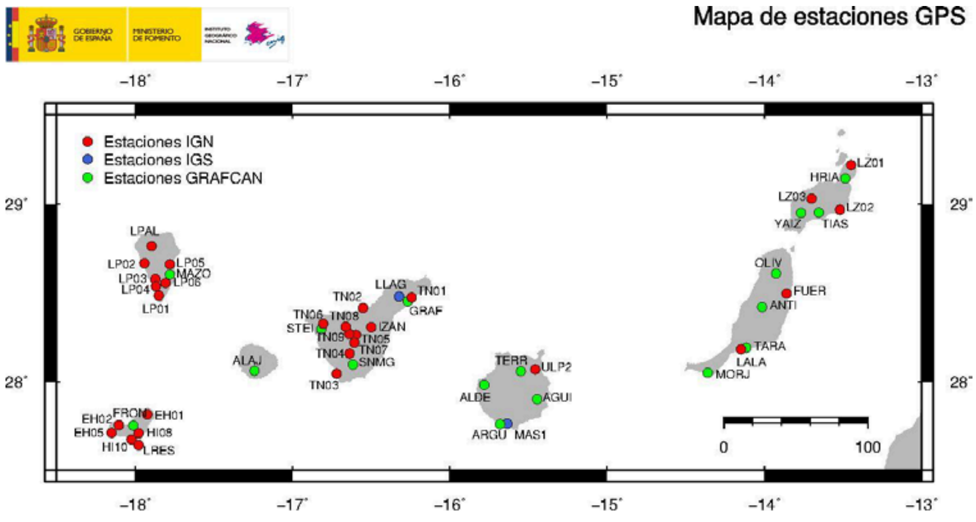

Figure 2-4 GNSS permanent networks in Canary Islands.

The products previously described are provided in shape files, and where appropriate, must be accompanied by a report performed by experts. The structure of the shape files is collected in the following tables.

The DIM shape file fields are:

Field	Description	Units
E	UTM East	[m]
N	UTM North	[m]
Lambda	WGS84 Geographic Longitude	[º]
Fi	WGS84 Geographic Latitude	[º]
Defo	Averaged deformation of the last 4 dates	[mm]

Table 2-1 DIM shapefile attributes.

The DAM shape file fields are:

Field	Description	Units
E	UTM East	[m]
N	UTM North	[m]
Lambda	WGS84 Geographic Longitude	[º]
Fi	WGS84 Geographic Latitude	[º]
ADA_ID	ADA id. Containing the point [-1 if it is not active point]	-
Velocity	Point displacement velocity	[mm/year]
Def_mean	Averaged deformation of the last 4 dates	[mm]
Daaammdd	Deformation value at date aaaa/mm/dd	[mm]

Table 2-2 DAM shapefile attributes.

The ADA shape file fields are:

Field	Description	Units
ADA_ID	Identity of the Active Deformation Area	-
N_APS	Number of active points in the ADA	-
X_MEAN	UTM East	[m]
Y_MEAN	UTM North	[m]
VEL_MIN	Minimum measured velocity	[mm/year]
VEL_MEAN	Averaged measured velocity	[mm/year]
VEL_MAX	Maximum measured velocity	[mm/year]
VEL_CLASS	Class of the ADA	1 if VEL_MAX > 20 mm/yr; 0 otherwise
DEF_MEAN	Averaged deformation of the last 4 dates	[mm]
TNI_CLASS	Temporal noise index	-
SNI_CLASS	Spatial Noise index	-
QI_CLASS	Quality Index of estimated velocity	-

Table 2-3 ADA shapefile attributes.

The GPS data shape file fields are:

Field	Description	Units
COD_GPS	Code of GPS station in the IGN Network	
E	UTM East	[m]
N	UTM North	[m]
Lambda	WGS84 Geographic Longitude	[º]
Fi	WGS84 Geographic Latitude	[º]
ADA_ID	ADA id. Containing the point [-1 if it is not active point]	-
Velocity	Point displacement velocity	[mm/year]
Std_dev_gps	Standard Deviation of the gps serie	[mm]
Def_mean	Averaged deformation of the last 4 dates	[mm]
Daaammdd	Deformation value at date aaa/mm/dd	[mm]

Table 2-2 VEW-DAM shapefile attributes.

3 INTEGRATION OF VEW PRODUCTS.

3.1 Visualization.

In order to analyse and integrate the previously cited products into workflows it is essential to be able to visualize them.

In section 3.1, it is briefly exposed how to visualize them in QGIS (an opensource GIS software) and in Google Earth Pro. In section 3.2, it is exposed how to load Web Map Services (WMS) in both softwares in order to have available basic geographic information (towns, infraestructures, etc) useful for the interpretation of products and for crisis management.

3.1.1 Visualization of WP3 products.

3.1.1.1 QGIS.

In QGIS, depending on the data format, there are different tools that allow to visualize the products, mainly available in the Layer → Add Layer → menu or from the Manage Layers toolbar (enabled through View → Toolbars menu). In our case all the products are vector layers, so we are going to use the option Add Vector Layer.

Another way to add a layer into a project is to use the Browser interface, following these steps:

1. Find the layer in the list.

2. Double-click its name or drag-and-drop it into the map canvas. Your layer is now added to the

Layers panel and can be viewed in the map canvas.

In order to customize data visualization, the use of the Layer Properties dialog is useful. This dialog provides for a vector layer general settings to manage appearance of layer features in the map (symbology, labeling, diagrams), interaction with the mouse (actions, map tips, form design). It also provides information about the layer.

To access the Layer Properties dialog:

• Option 1: In the Layers panel, double-click the layer or right-click and select Properties from the pop-up menu;

• Option 2: Go to Layer→ Properties menu when the layer is selected.

We recommend consulting the QGIS information available in QGIS1 and QGIS2 to have a better knowledge of these tools.

3.1.1.2 PS Time Series Viewer Plugin.

QGIS plugins add additional functionality to the QGIS application. There is a collection of plugins ready to be used, available to download in different websites. These plugins can also be installed directly from the QGIS Plugin Manager within the QGIS application.

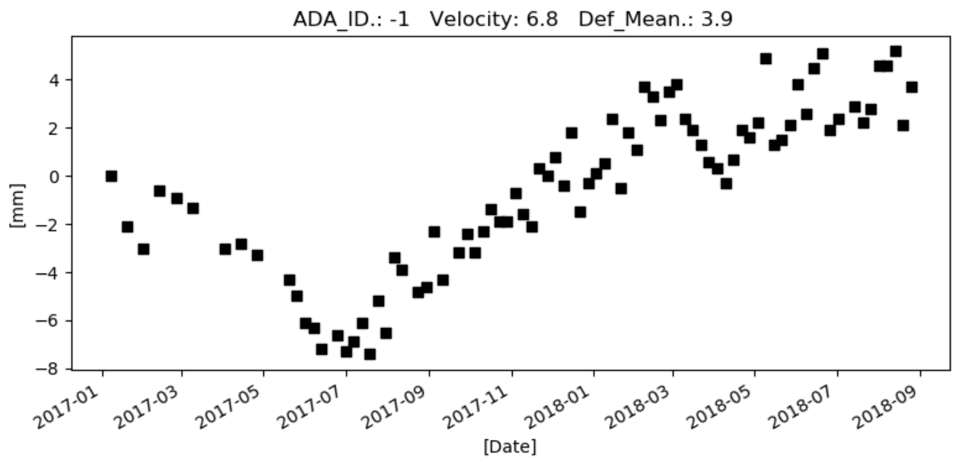

Figure 3-1 Example of the output or PS Time Series Viewer for a measured point from de DAM.

To install or activate a plugin, go to Plugins menu and select Manage and install plugins. The tabs in the Plugins dialog allow the user to install, uninstall and upgrade plugins in different ways. Each plugin has some metadata displayed in the right panel:

At the top of the dialog, a Search function helps you find any plugin using metadata information (author, name, description…).

In this case the plugin we recommend to use is "PS Time Viewer Series". Once you have installed it, an icon appears in the manager toolbar. To use it, click the icon of the plugin, select in the Layers panel the layer you want to get information about, and click in the map over one of the points of the layer. This plugin is very useful to interpret the DAM map because the output is the evolution of this point during the time, since the reference date. Next picture shows an example of the plugin's output.

3.1.1.3 Google Earth Pro.

Another other widely used software that allows to visualize shape files is Google Earth. To load a shape file in Google Earth Pro, follow the next steps:

1. File -> Import -> Select ESRI shape and point the shape file to be loaded. The corresponding .prj file must be present. If your file contains more than 2500 features, a warning message appear, asking you if you want to import a sample of the data, restrict the imported data to your current view, or to import all.
2. After that, a message will be prompted to create a Style Template. If you want to personalize the style of your data (what we recommend you), click Yes. In the Style Template Settings dialog box, you can create a style template including colors, labels, and icons. You will be prompted to save the style template for future use.

By default, the layer loaded is not activated. To display the layer, check the corresponding box in the legend. You also can enable or disable the different background and other information layers. Clicking on the different features information of the attribute table will be appear.

More information about how to import a shapefile to Google Earth is available in Google Earth.

3.1.1.4 Grafcan Viewer.

Grafcan viewer (https://visor.grafcan.es/visorweb/) allows to load shapefiles and kml files, with the limitation of 3Mb of size. This is an important limitation for U-Geohaz products. Only ADA and VEW (GPS) products can be load in this viewer. To load layers, click on layers' menu on the right side of the viewer. Clicking on the feature and selecting "Properties of the feature" information of the attribute table will be appear. The shapefiles format required is a zip file containing .shp, .shx and .dbf files.

3.1.2 Other geographic information (WMS).

Information of different types and sources can facilitate interpretation and increase the usefulness of the products of this project. Usually this information is produced and made available for the user by a lot of different organizations. Web services can facilitate access to that information.

A Web Mapping Service (WMS) is a map service hosted on a remote server. We are going to explain how to load a WMS in QGIS.

To load a WMS the procedure is similar to loading a vector file (explained in 3.1.1.1) but selecting Add WMS/WTS layer.

To create a new connection to a WMS, click on the New button.

A name and the URL of the WMS service must to be entered in the corresponding fields.

Click connect and select the layer or layers you want to add. Click add button and the layer will be appeared in your Layers Panel.

3.2 Interpretation.

Products delivered in this project have been defined in section 2. Section 3.1 provides some guidelines to open and visualize them together with other outstanding information layers which can help in the interpretation.

In this section we propose some guidelines aimed to recognize and analyse possible deformation areas by analysing ADA, DAM and GPS products generated in the project. Finally and following suggestions proposed in this document, we conclude with the evaluation of possible hazards in a real case which took place in Tenerife Island during June 2017.

3.2.1 ADA analysis

ADA map is generated from DAM following strict criteria aimed to highlight areas that show reliable displacements with time (Barra et al., 2017). So, in case local deformations exist during the study period, they should be included in the ADA map as long as their velocities are above stablished thresholds for every island (see D3.5). Therefore, in order to evaluate possible defor-

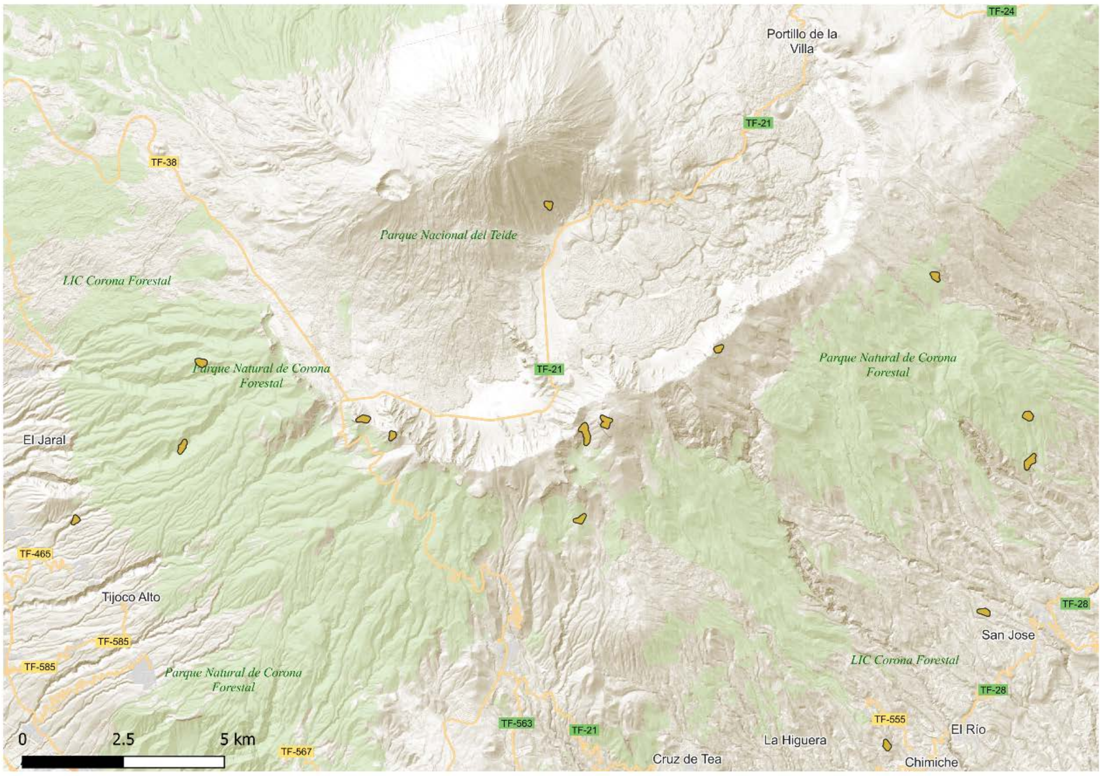

Figure 3-2 ADA selection around Teide-Pico Viejo.

mation signals, the first product to be inspected is ADA map. To help the interpretation we recommend ADA map to be displayed over a DEM, ortoimage or street map service as it has been explained in section 3.1.2.

By identifying the spatial object we can access to ADA attributes, in particular to VEL_MEAN and QI_CLASS which are averaged velocity and quality of ADA respectively. QI_CLASS considered reliable enough are numbered 1 and 2, whereas 3 and 4 need extra revision (Barra et al., 2017). On the other hand, VEL_MEAN provides magnitude of the velocity. However, to characterize the deformation and possible effects, it is important to know the direction of displacement for the purpose of risk management; in other words to know the sign of the velocity. For example a subsidence, which main part of the movement is downwards, would be translated in a negative velocity. On the contrary, an upward movement would have a positive velocity. This information is not included directly in ADA attributes but it is in the DAM map used to generate the ADA. So to interpret ADA properly it is necessary to analyse DAM.

DAM map contains all MP (measured points) which have been selected by the methodology regardless their standard deviation. To ease the analysis of ADA we recommend to filter out MP whose two times standard deviation is between the thresholds established for every island as these points are considered too noisy (see D3.5). Those thresholds are:

- Tenerife: 8.2 mm/year
- El Hierro: 11. 2 mm/year
- La Palma: 13.7 mm/year

To simplify the analysis further, and taking into account that the direction of movement can be decisive to risk management, we also recommend to separate positive and negative trends. In this way we have separate DAM map in positive and negative displacements that contain only reliable MP.

Once DAM is properly filtered, it can be displayed together with ADA. This way it is easy to know the ADA direction of movement as most of MP inside an ADA should have similar trends. Moreover, it can be useful to check temporal time series of MP inside the ADA, making use of *ps time series viewer* tool (see section 3.1.1). For example, if we want to know if a phenomenon which took place in a certain date have had an effect on deformation for a certain area, it can be checked in the time series.

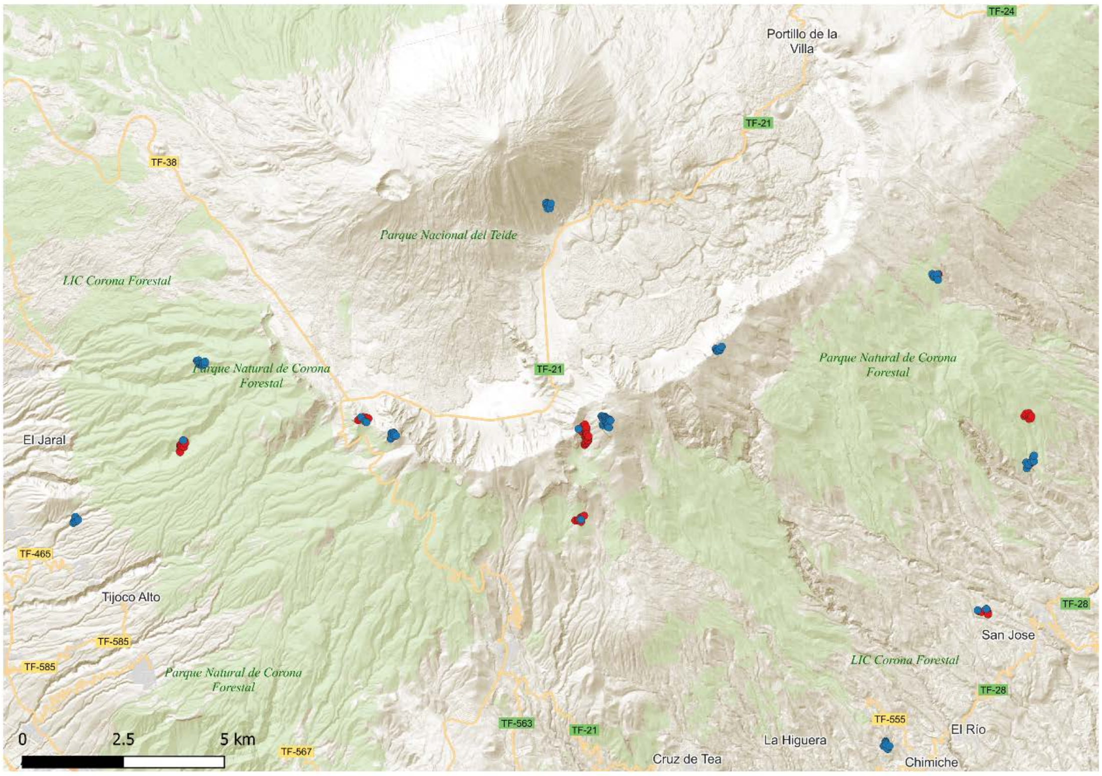

***Figure 3-3* Selection of MP with velocities over 8.2 mm/year in Teide-Pico Viejo. Red MP show positive trends, blue ones show the opposite.**

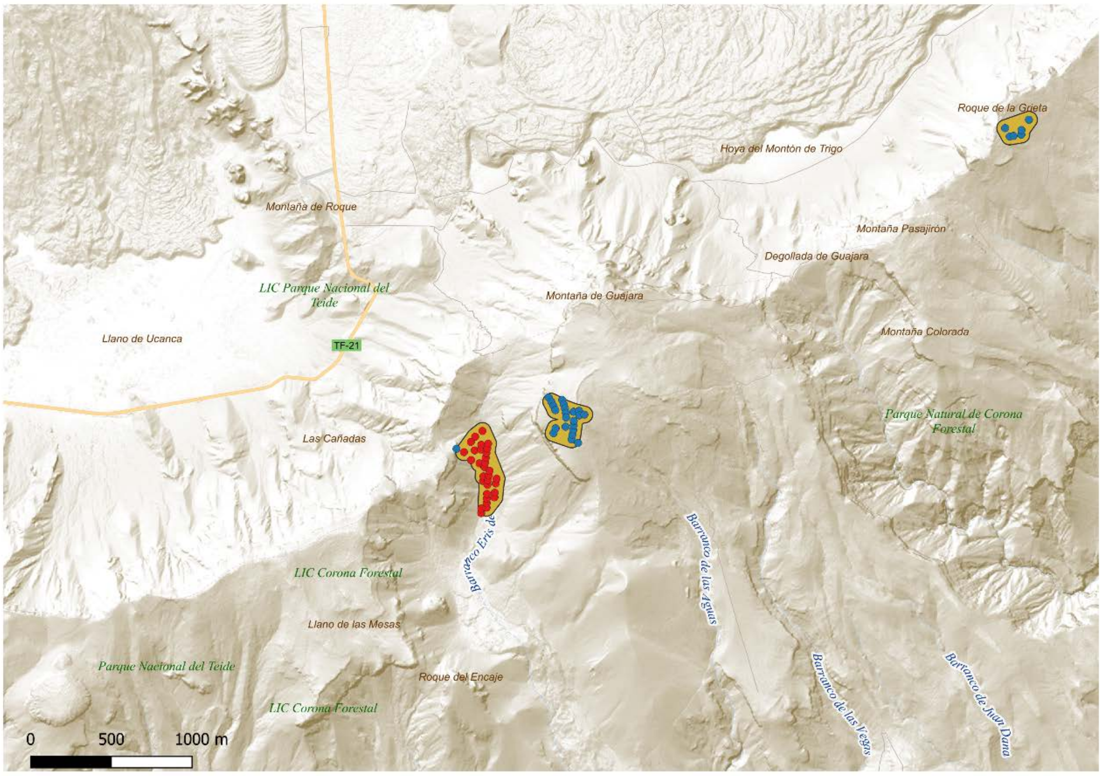

***Figure 3-4** MP inside ADA located in Guajara Mountain, inside Parque Nacional del Teide. Color codes are the same as in Figure 3-3.*

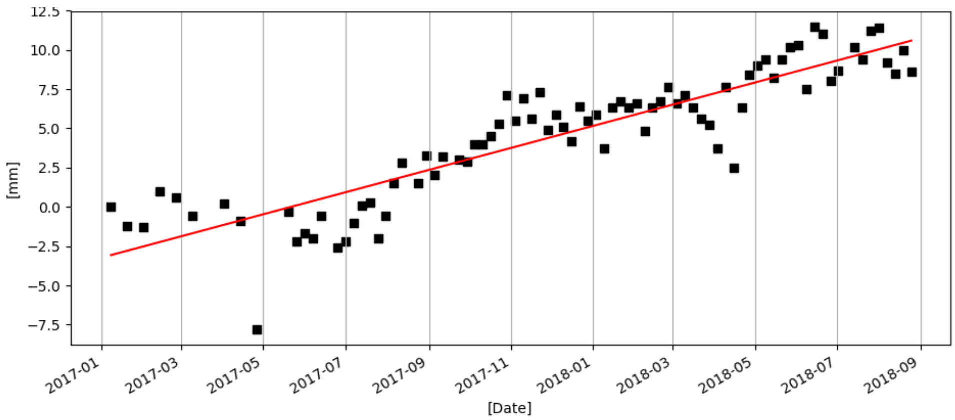

***Figure 3-5** Time Series of a MP inside positive ADA from Figure 3-4.*

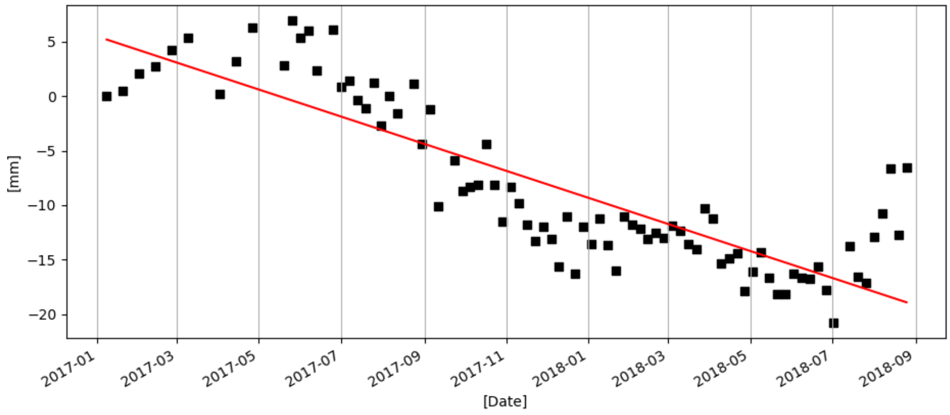

***Figure 3-6** Time Series of a MP inside negative ADA from Figure 3-4.*

3.2.2 DAM analysis

We can also be interested in a certain area which is not an ADA. This situation demand direct DAM analysis. For example, it is possible that there are areas with movements under the selected threshold which would not constitute an ADA but even so, we can be interested in. It is also likely that there are several MP with meaningful velocities, however they do not fulfil the vicinity conditions to be an ADA.

In those cases we can open DAM map, filtered by direction of movement would be advisable, and apply a colour scale based on velocity. We likely see clusters of points with a spatial pattern, if they exist. We can also query the MP time series with ps time series viewer.

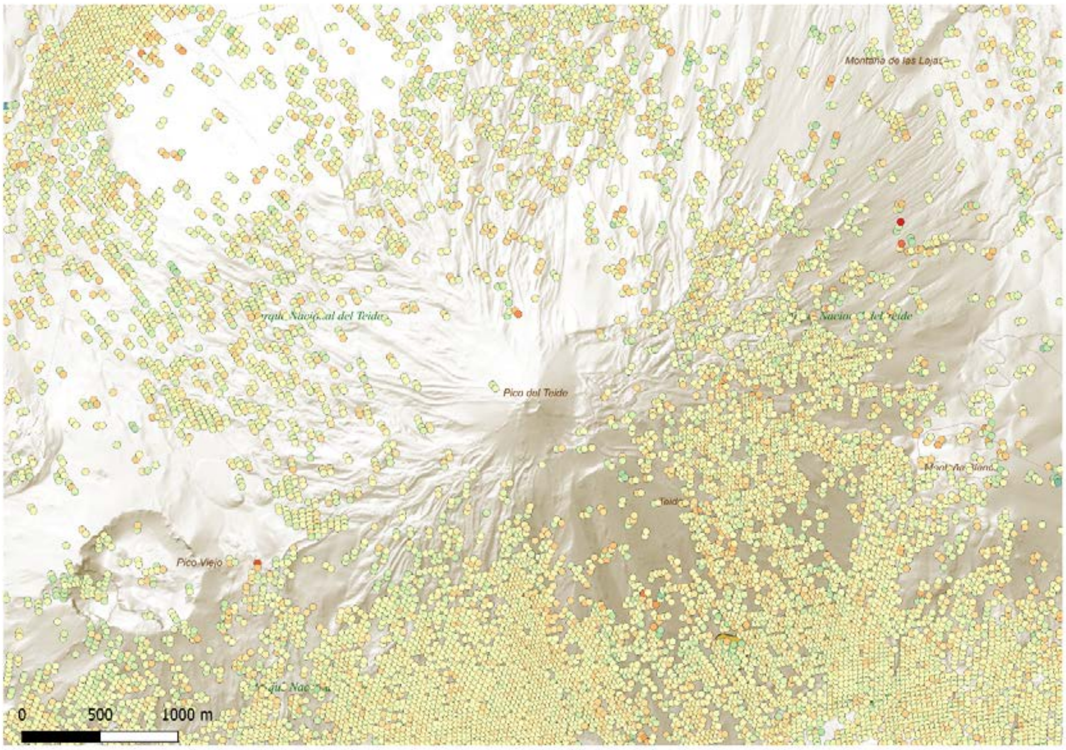

***Figure 3-7** DAM represented with a color scale (same codification as previous images) around Teide-PicoViejo*

3.2.3 DIM analysis

According to the description done in section 2, DIM-HF products are transformed to DAM through direct integration methodology.

As far as DIM-LF is concerned, as it contains both deformation and atmospheric signals, the analysis is quite complex. Best recommendation in this case is to be advised by an expert to interpret possible deformations.

3.2.4 GPS analysis

DAM and ADA maps are the result of applying InSAR techniques, however products provided in this deliverable also include GPS time series. GPS results are referred to the location where the equipment is installed, so its spatial coverage is punctual, but the precision of the measurement is generally better than achieved by InSAR techniques. Then, we can consider GPS time series as a very precise recording of a point movement. This fact is useful in several senses when trying to interpret ADA or DAM products. For example, in case there are several MP inside an ADA with different trend, so the behaviour of the entire ADA it is not clear, GPS direction of movement can be decisive to point out the real trend. Analogous situation can take place in case we are analysing areas of DAM not included in ADA map.

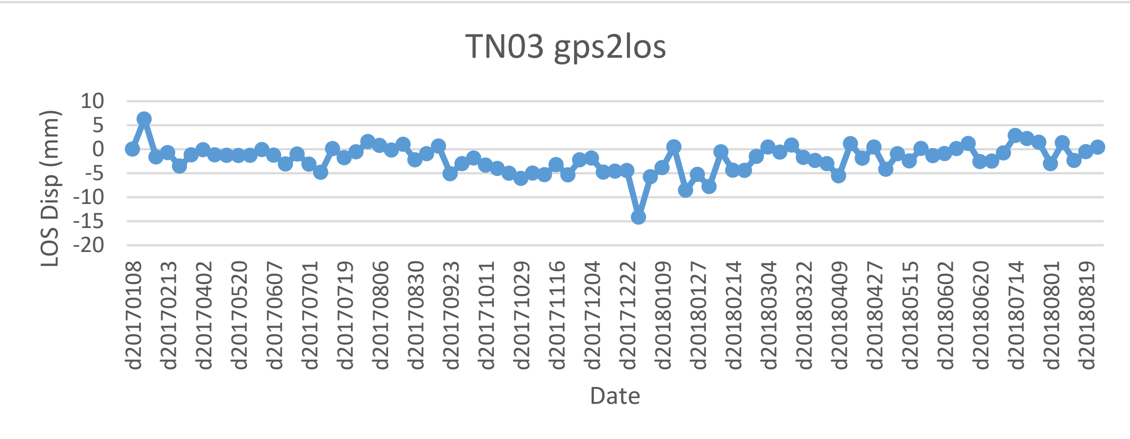

Figure 3-8 TN03 GNSS time series projected to LOS

3.2.5 *__Application to a real case:__* ***Volcanic Early Warning System products interpretation during a seismic swarm in Tenerife island.***

In the last years tens of volcanic alerts have been declared in The Canary Islands always accompanied by anomalous seismicity and sometimes by other geophysical parameters, as they are deformation and geochemical signals.

In this section we want to show the way U-Geohaz products are interpreted, together with other data coming from IGN networks to declare and track volcanic alerts, as well as evidence the added-value of these products for the volcanic early warning system.

IGN is the institution in charge of generating volcanic alerts to Civil Protection Authorities in Spain (RD 953/2018). Continuously, we analyse data coming from geophysical networks stablished in active volcanic areas. This allow us to detect anomalous activity and characterize it, being also able of stablish its evolution. The ability of interpreting volcanic activity from different techniques is essential to characterize the event.

During 2017 a singular episode took place in Tenerife island. Seismic networks detected twelve low magnitude swarms in the vicinity of Teide volcano between 7-19 km depth (https://www.ign.es/web/resources/volcanologia/pdf/20170609_Tenerife_IGN.pdf) Commonly, seismicity is the technique which warns the other parts of volcanic system about the existence of anomalous activity. However deformation is a fundamental parameter to stablish changes in the volcanic system related with a possible pressure increase. U-Geohaz products are based in GPS and InSAR techniques which provide DIM, DAM and ADA, so the information derived from them is valuable to stablish a volcanic alert. To show the importance of U-Geohaz products to the system we are going to analyse the way we would have interpreted the deformation contained in the maps during the mentioned episodes on 9 June 2017.

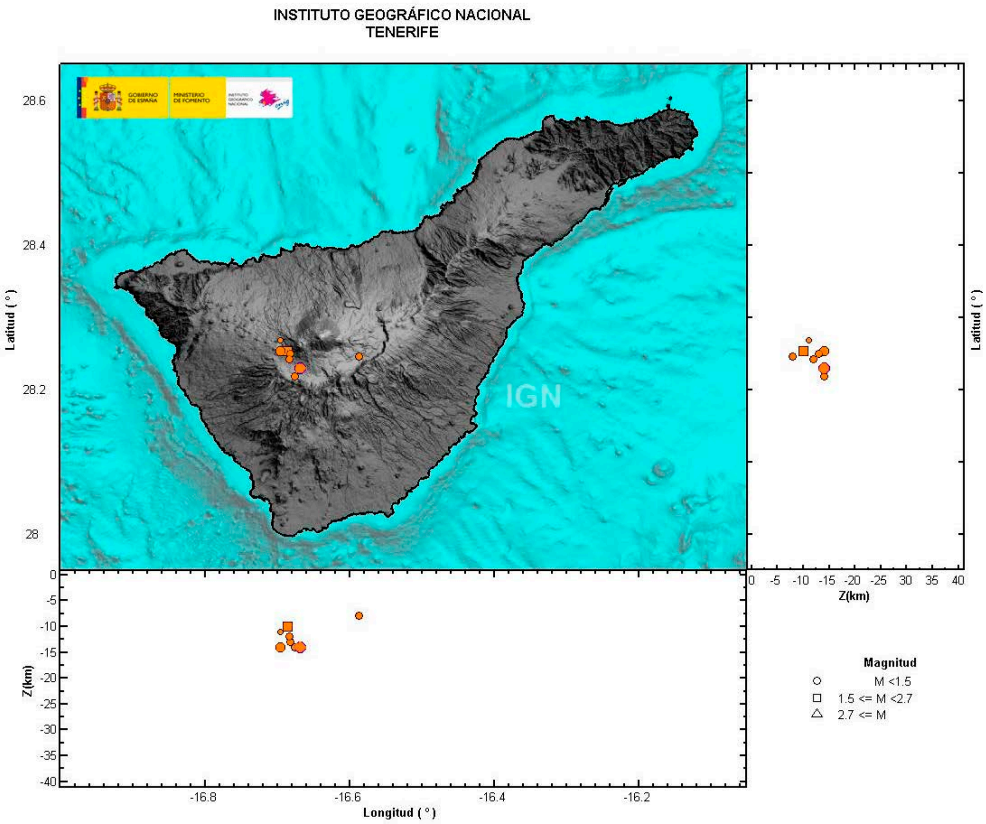

***Figure 3-9** Location of 9 June 2017 events*

Events were located inside Parque Nacional del Teide, west of Teide-Pico Viejo volcanic complex. Although in this case depth and magnitude of seismicity did not pointed out to a detectable source of deformation its existence could not be rejected. So, the kind of signals we are looking for are positive in DAM, ADA and GPS, consistent with an overpressure source. DIM could also provide information, although its interpretation is be more complex. To provide an evaluation to Civil Protection Authorities, we propose the following actions:

- **ADA map general inspection in the surrounding of Teide-Pico Viejo complex**:

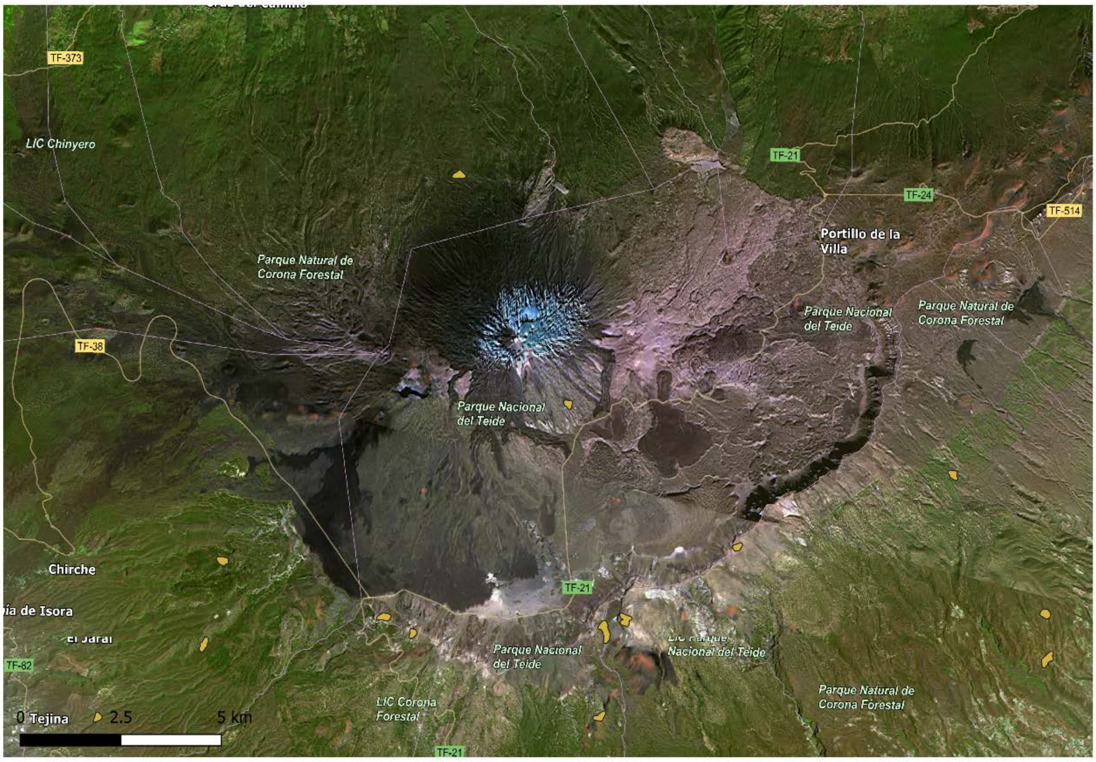

***Figure 3-10** Selection of ADA in Teide-Pico Viejo area*

We conclude that there are some ADAS, close to seismicity, which deserve further analysis

- **Analysis of DAM with positive trends inside the ADA close to epicentres:** We filter DAM map to select points above the fixed threshold only with positive trends, which could be involved with a change pressure.

Once we have selected ADA with positive trends above 8.2 mm/year, we analyse the time series of the MP inside to check if there are changes around 9 June 2017.

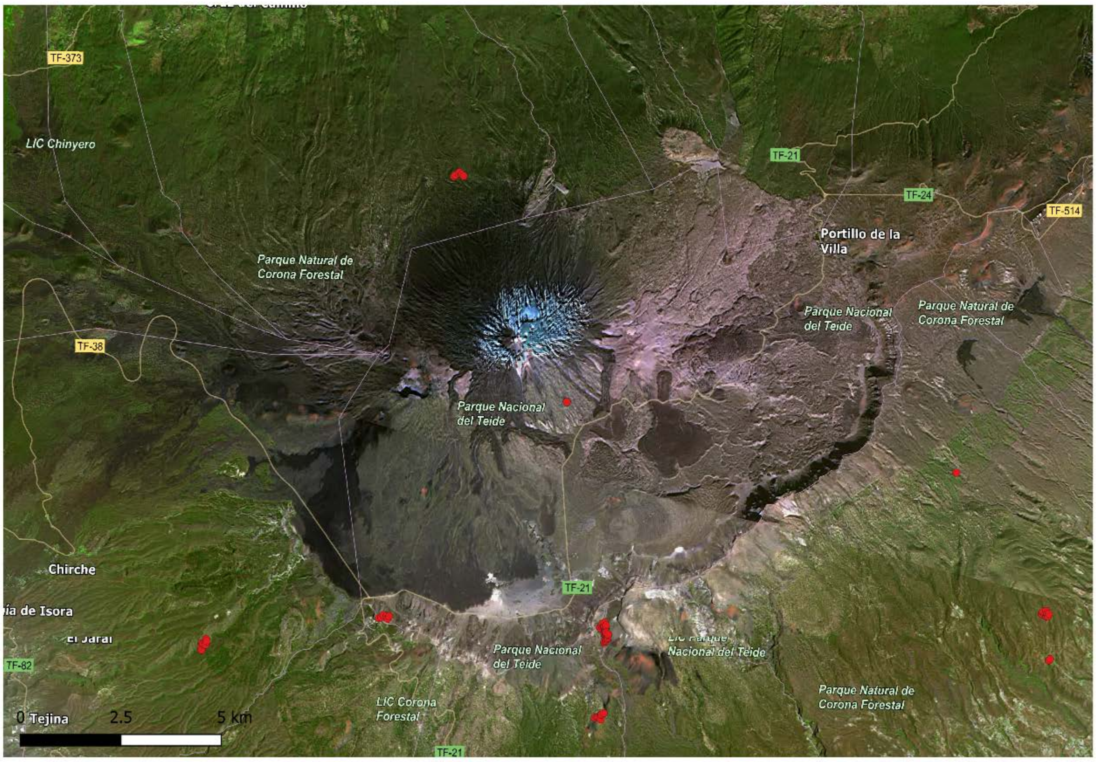

Figure 3-11 MP showing positive trends inside DAM in the area of study.

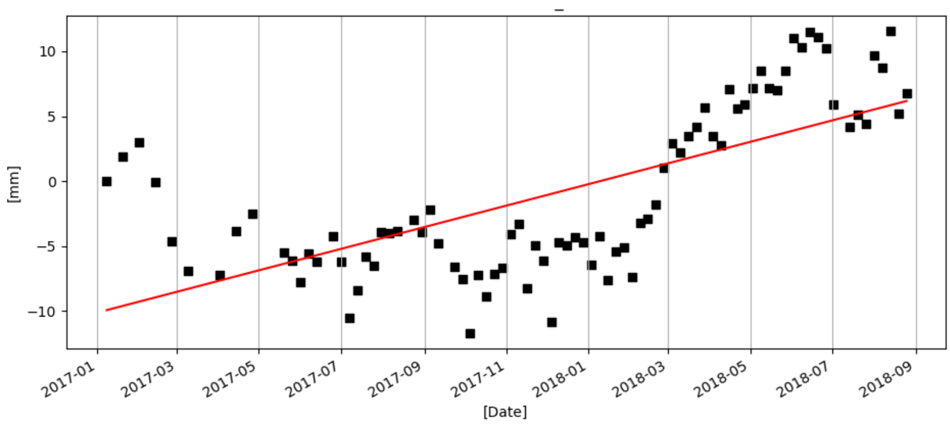

***Figure 3-12** Time series of a MP inside ADA_ID number 9, located a few kilometres to the epicentres*

Results do not show meaningful changes in deformation related to the swarm (see Figure 3-12). Slope variation which takes place on March 2018 seems to be related to other causes.

- **Detailed DAM analysis in Teide-Pico Viejo:** Although ADA do not show deformation changes related to the swarm, a good practice is to analyse the complete DAM, filtered to show only positive trends, as the expected deformation can be difficult to observe and close to the background noise.

Figure 3-13 ***DAM positive velocities around Teide-Pico Viejo***

Results do not show clusters of points with velocities close to the active thresholds that can be interpreted as low magnitude deformation areas.

- **Interpretation of DIM-LF:** In case a volcanic source exists, its expected deformation can be larger than several squared kilometres which mean that the signal would not appear neither DAM nor ADA but in DIM-LF. However, as DIM-LF contain possible deformation and atmospheric effects, the last cannot be removed properly with the current methodology, so only a partial and qualitative interpretation could be done.

- **GPS time series analysis**: We would check GPS time series in a similar way we have inspected DAM time series. Relevant difference between GPS and derived InSAR time series is precision which means that GPS could see changes that DAM time series could not.

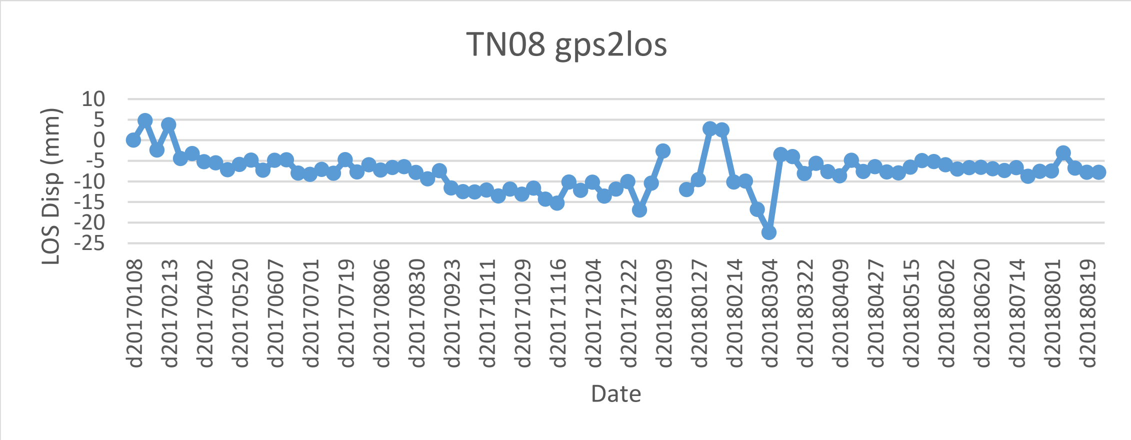

Figure 3-14 TN08 GNSS time series projected to LOS

Analysis conclude that there is no deformation related to the swarm in the GPS stations of the area.

Similar analysis of other geophysical parameters (gravimetry, gas and water analysis) did not point to a volcanic intrusion.

With this analysis we would conclude that the registered swarm was not accompanied by deformation or geochemical changes in the volcanic system, so the scientific alert level would remain low.

3.3 VEW-DAM Web Map Service.

One aspect that is currently being worked on is the possibility of generating WMS services to make some of the products in this workpackage available. The CNIG is the organization that manages the Spanish SDI, and the possibility of generating these WMS with them has already been discussed. The availability for the generation of this service is total and will be subject to an analysis of the possibilities offered by the products at the end of the project and the utility that the services may have for the different partners.

4 REFERENCES.

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