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Deliverable D3.4: Description of Volcanic Early Warning System (VEW)

A deliverable of WP3: Early Warning System for Volcanic Activity

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EXECUTIVE SUMMARY

Objectives defined in the Activity 3.4 “Volcanic Early Warning (VEW) System implementation” are reported in this document which represents the third official deliverable of WP3: “Early Warning System for Volcanic Activity”.

The main goal of this document is the description of the Volcanic Early Warning System (VEW). VEW will integrate Sentinel-1 and GNSS data making use of several products partially defined in D3.1 “User Requirements” as DIM, DAM, VEW-DIM and VEW-DAM. In this technical report the methodology to generate these products is explained in detail.

This methodology as well as the products can be adapted according to changes proposed by the users and possible technical constraints.

The submission date of this deliverable has been delayed due to the necessity to analyse products included in D35 “Updated Deformation Activity Map (V0)” which was delivered first week of July 2018. Those products constitute the base of VEW.

REFERENCE DOCUMENTS

N°	Title
RD1	DoW U-Geohaz
D3.1	User Requirements
D3.2	VEW Assessment Procedure
D2.2	Updated Deformation Activity Map (V0)

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1 INTRODUCTION

IGN is the institution responsible of volcanic monitoring and alert in Spain. The IGN monitoring system has been designed to be able to detect changes in evolution of the data recorded by the surveillance networks (seismic, geodetic, geochemical, geophysical and thermal networks) and to interpret them in terms of possible changes in the eruptive process, establishing prognosis of future evolution including scenarios of different hazards.

Figure 1: IGN Volcanic Monitoring Network, El Hierro (Canary Island, Spain)

IGN has to communicate this information to the volcanic risk managers (Civil Protections), as scientific alerts, reports and personal communication. These scientific alerts triggers the activation of the Civil Protection Emergency Plans.

Deformation is one of the parameters that can reflect a change in the volcanic system, which can potentially lead to an eruption. Products generated by VEW, described in the following sections, have an important effect on improving the monitoring system of IGN as they provide an excellent spatial coverage of deformation with an updating frequency of six days.

VEW aims to generate products of deformation which integrates results coming from different geodetic techniques (InSAR, GPS mainly). These results, together with other geophysical information coming from the monitoring networks, can act as input parameters of volcanic assessment software to hold volcanic hazard and risk management.

The starting point of VEW are the deformation maps generated by InSAR techniques using Sentinel-1 data. The methodology to generate these products is the first part of this document. In a second stage, those maps are integrated with deformation data coming from IGN monitoring networks. The methodology to generate IGN products and the way they are integrated in the VEW constitute the second and third parts of this technical report.

2 METHODOLOGY TO GENERATE INSAR PRODUCTS

InSAR products generated in U-Geohaz make use of Sentinel1 images.

The Sentinel-1 mission comprises a constellation of two polar-orbiting satellites, operating day and night performing C-band synthetic aperture radar imaging, enabling them to acquire imagery regardless of the weather.Sentinel-1 work in a pre-programmed operation mode to avoid conflicts and to produce a consistent long-term data archive built for applications based on long time series. The constellation cover the entire world's land masses on a bi-weekly basis, sea-ice zones. The Sentinel-1 SAR instrument and short revisit time will greatly advance users' capabilities and provide data routinely and systematically for land monitoring and emergency response.

In particular over Tenerife, La Palma and El Hierro islands, which are the test areas for WP3, updated deformation maps can be provided every six days. This high frequency of revisiting together with the open access policy of Sentinel-1 images, make possible for the first time ever, to design an Early Warning Monitoring System based on InSAR techniques. This is the philosophy behind VEW.

The main goal of WP3 is to implement an Early Warning System based mainly on the exploitation of DAM with a 6-day temporal repeatability. Description of the first dataset processed within U-Geohaz project is described in the Technical Note 3.5 “Updated Deformation Activity Map (V0)”.

Final version of DAM, which is the core of the InSAR part of VEW, will be delivered in month eighteen. Together with DAM itself, and some other derived products, a methodology to update the baseline of deformation maps with the information of the last acquisition will be provided. This methodology is essential to guarantee updated results and move closer to real time tracking of deformation that is mandatory in volcanic monitoring tasks.

There are mainly three products, generated with InSAR techniques, which will be used to create the VEW:

- DIM: Displacement Maps
- DAM: Deformation Activity Maps
- ADA: Active Deformation Areas

In the following subsections these products are explained in detail.

2.1 Displacement Map (DIM)

Displacements maps (DIM) display relative deformation between two dates. The deformation, in mm, is estimated in line of sight. Positive values represent points moving towards the satellite. Negative values represent the contrary. As a rule, all InSAR products derived in U-Geohaz show deformation in LOS with the same sign criterion. The highest temporal frequency of Sentinel-1 are six days, which mean that within a week we can have and updated displacement map. They are generated following methodology based in Devanthèry 2014.

Figure 2 shows a preliminary map obtained from two images acquired on 26th of May and first of July of 2017. It is worth noting that it is shown with illustrative purposes and that the shown movements must not be considered. The main reason is that the atmospheric contribution to the map has not been removed.

DIM maps are the base of the subsequent processing, which means that they contain less processed information. This fact has positive and negative implications. Negative are that they can contain more unwrapping errors and that the atmospheric filtering must be checked. However, they can provide key information in case of a new deformation area appear. DIM can help to warn of its existence faster than other products, as processing resources to generate DIM are less demanding. However, this capacity depends on several factors such as deformation magnitude and location and the quality of the atmospheric removal applied. These topics will be addressed in the following months during the software tuning. To conclude DIM is a key product to detect non-linear deformations.

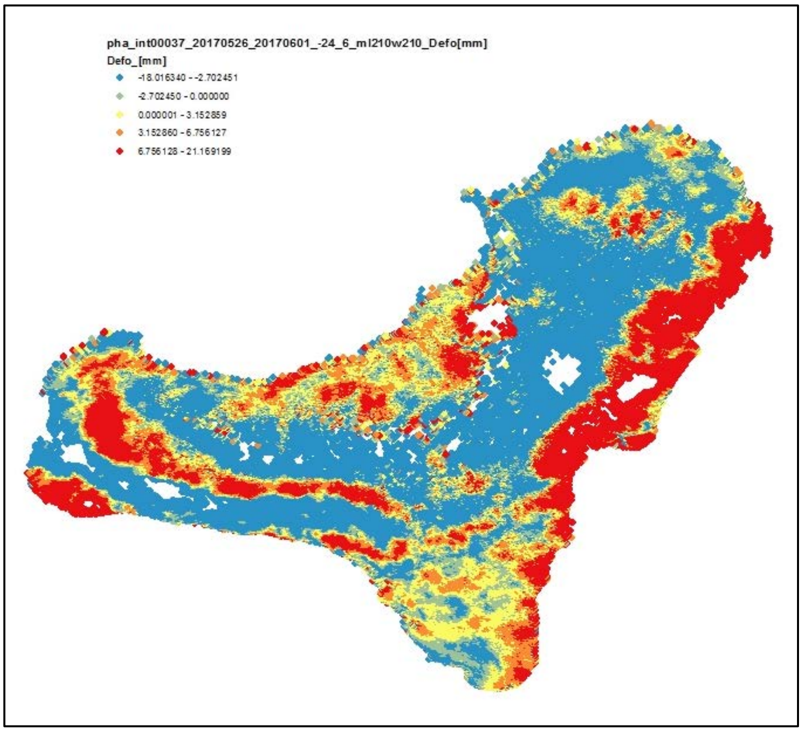

Figure 2: DIM over El Hierro Island

2.2 Deformation Activity Map (DAM)

First DAM (v0 version) over El Hierro, La Palma and Tenerife has already been delivered, technical details can be found in D3.5 “Updated Deformation Activity Map (V0)”. Methodology to generate DAM is similar to the one used in SAFETY and is explained in detail in Barra et al 2017.

DAM contain information of PS deformation and mean velocity during the study period over the test sites. Deformation of the time series is obtained respect to first image of the time interval. Reference PS are selected from stable areas with good coherence.

Some deformation areas have been detected in DAM v0 with deformation amplitudes above the noise threshold calculated empirically for every island, see figures 3 to 5. Some of these PSs show also deformation trends.

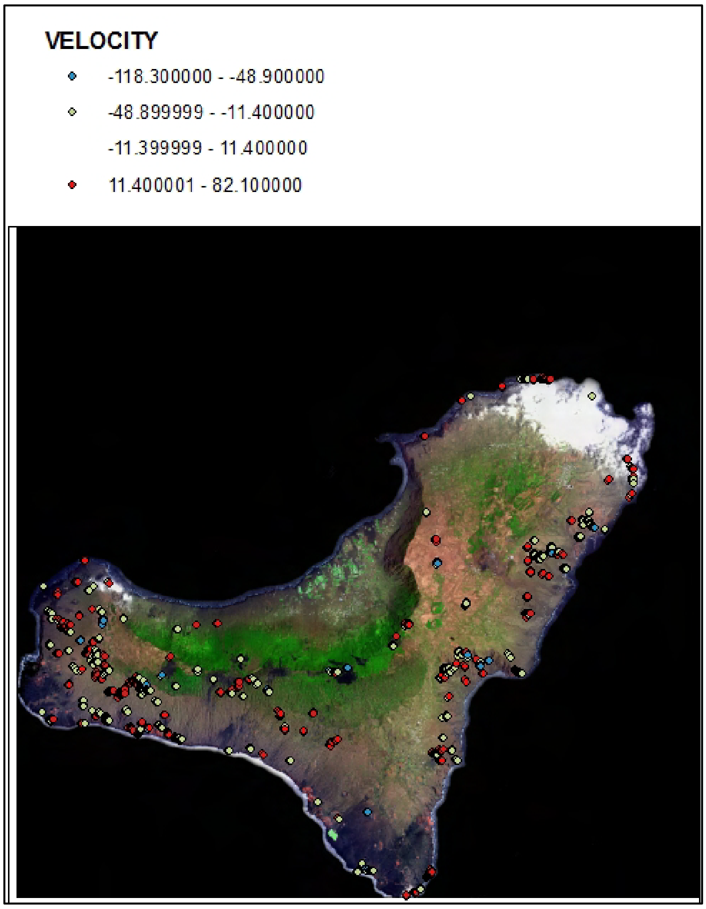

Figure 3: Mean velocities [mm/y] derived from DAMv0 over El Hierro. Stability threshold is 11.4 mm/y so PS inside these values are not shown.

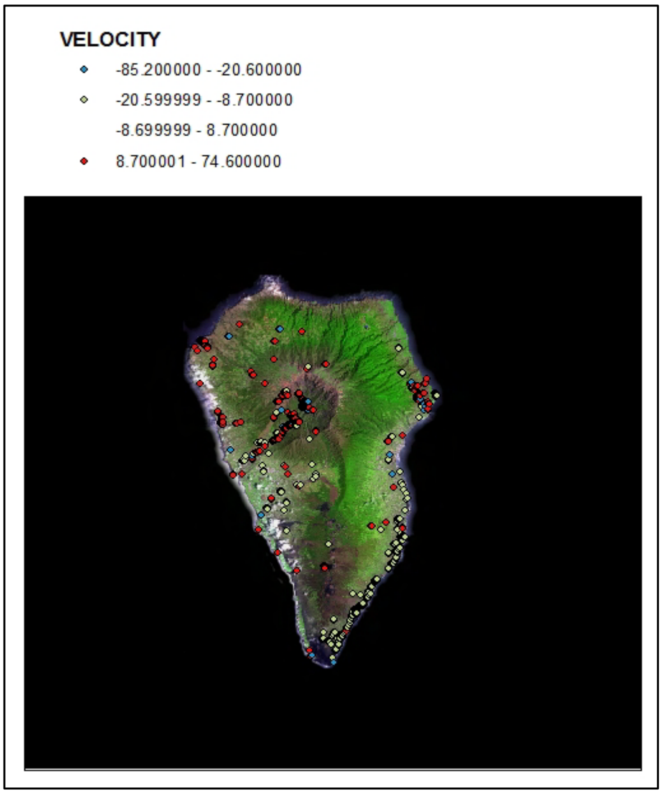

Figure 4: Mean velocities [mm/y] derived from DAMv0 over La Palma. Stability threshold is 8.6 mm/y so PS inside these values are not shown.

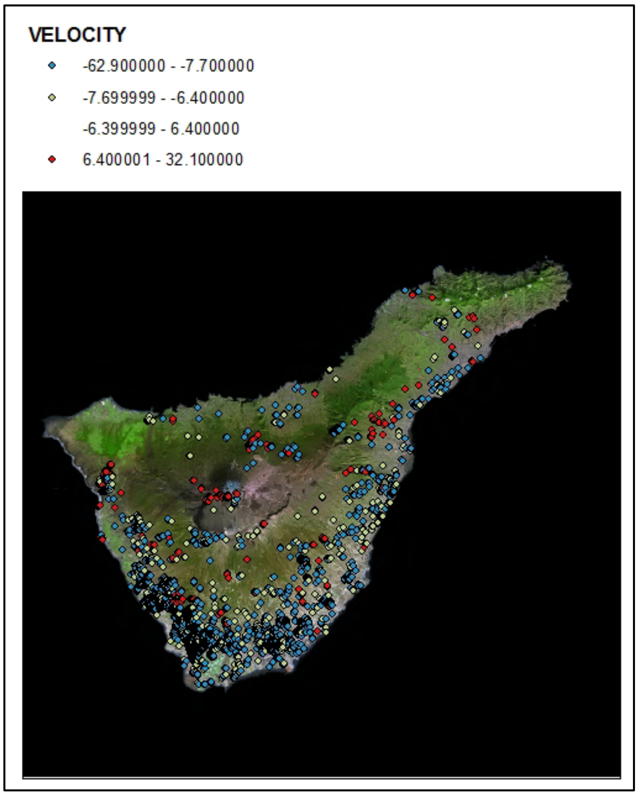

Figure 5: Mean velocities [mm/y] derived from DAMv0 over Tenerife. Stability threshold is 6.4 mm/y so PS inside these values are not shown.

DAM improves DIM in some senses. It contains an explicit selection of good pixels, called PS, with an estimated level noise for every island over which deformations are considered reliable. DAM allows to create and analyse temporal series of deformation for every PS.

PS density provided by DAM over the test sites improves the capacity of IGN Volcanic Monitoring System to detect slow deformation linked to volcanic processes. Thus, DAM will be integrated as a fundamental part of VEW.

2.3 Active Deformation Areas (ADA)

ADA (Active Deformation Areas) is the most evolved product generated from InSAR techniques at U-Geohaz project. It is derived from DAM following, with minor changes, the methodology described in Barra et al 2017. The ADAs constitute groups of PS (more than five) with same deformation behaviour whose temporal series have reliable noise.

Although main InSAR products of VEW are the DIM maps, DAM and ADA represents an excellent starting point to recognize long-term processes. Thus, they will be integrated in VEW. Note that ADA was nor originally included in User Requirements (D3.1). However, it is worth noting, that the ADA maps are a powerful tool to detect areas of interest that can be analysed more in detail exploiting both the DIM and the DAM maps. The first version of ADA has been delivered in D35 "Updated Deformation Activity Map (V0)". Some ADAs have been detected for every island during the study period. Further analysis is needed to determine its behaviour and causes as time series are still too short.

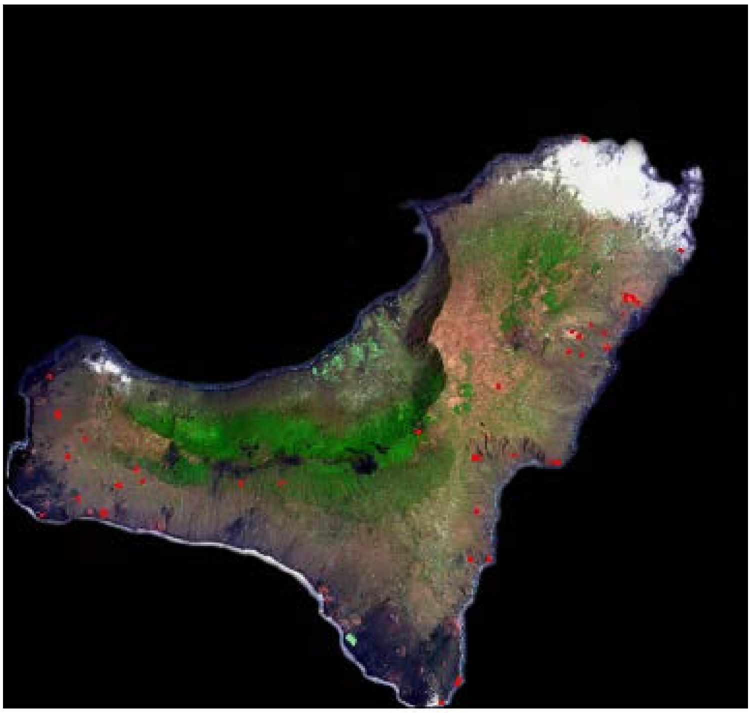

Figure 6: ADAv0 (red polygons) located over El Hierro

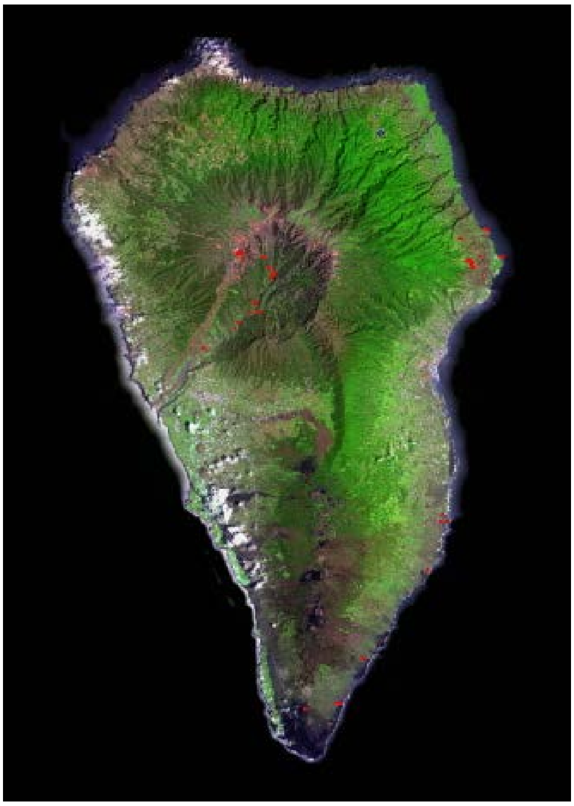

Figure 7: ADAv0 (red polygons) located over La Palma

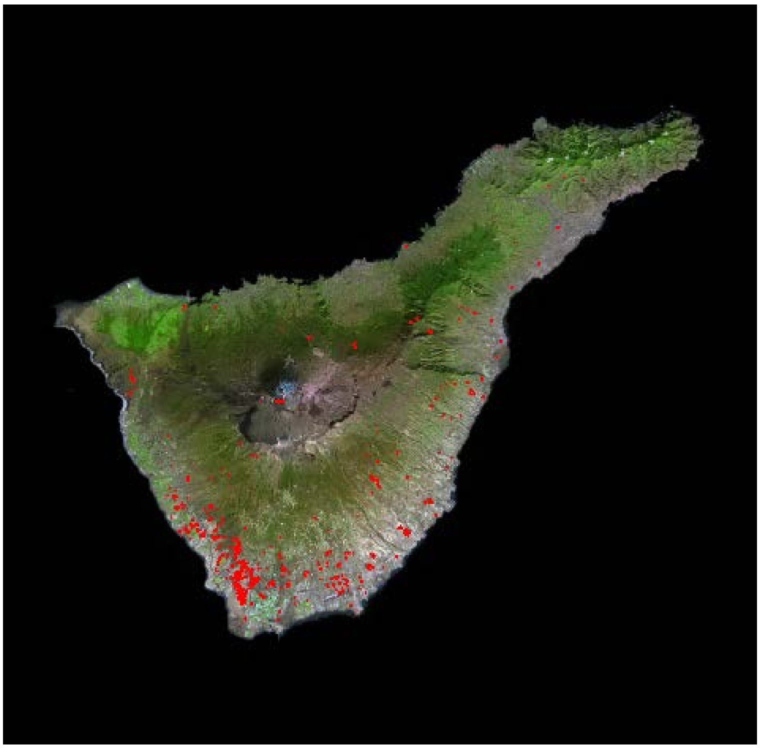

Figure 8: ADAv0 (red polygons) located over Tenerife

3 METHODOLOGY TO GENERATE GPS PRODUCTS

A network of more than forty continuous GPS (CGPS) stations was operating in the Canary Island since 2007. Regarding test sites of U-Geohaz, IGN operates nine permanent stations in Tenerife, six in El Hierro and six in La Palma. Networks are always open to be enlarged based on new necessities. For example, La Palma GPS network is currently being densified.

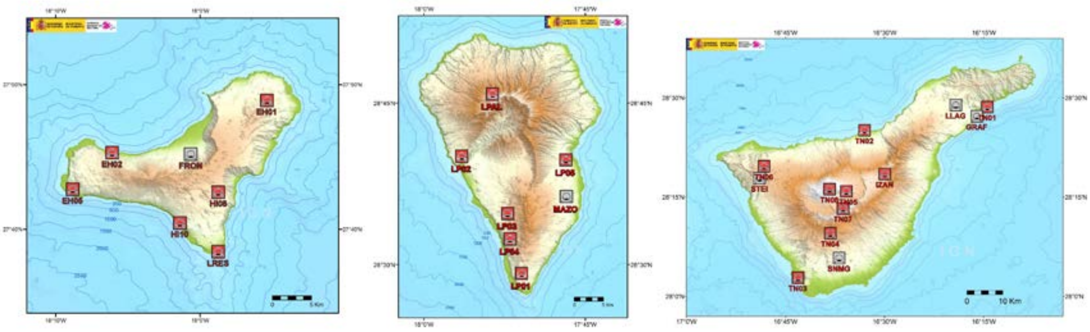

Figure 9: GPS networks over El Hierro, La Palma, Tenerife. Grey statios belong to other networks (GRAFCAN, IGS).

The 30-second sampling rate data are processed using Bernese software version 5.2 (Dach et al., 2015) to obtain daily coordinates solutions. These data are processed in the framework of a GPS network consisting of more than 30 CGPS stations located in the Canary Islands, Azores, south of Spain and north of Africa. Reference frame ITRF2014 was determined using minimum constrains to an IGS core site group of five stations. The ocean-loading model FES2004 (Lyard et al., 2006) was applied and the IGS absolute antenna phase centre model is used for satellite and stations antennas. Precise satellite orbits from the IGS are also used (Kouba, 2009). North, east and vertical deformation components (n,e,u) are daily calculated from the coordinates obtained in the process. Moreover, GPS results can be used to validate InSAR in areas around GPS location. These validations will be included in D3.8 « VEW validation report ».

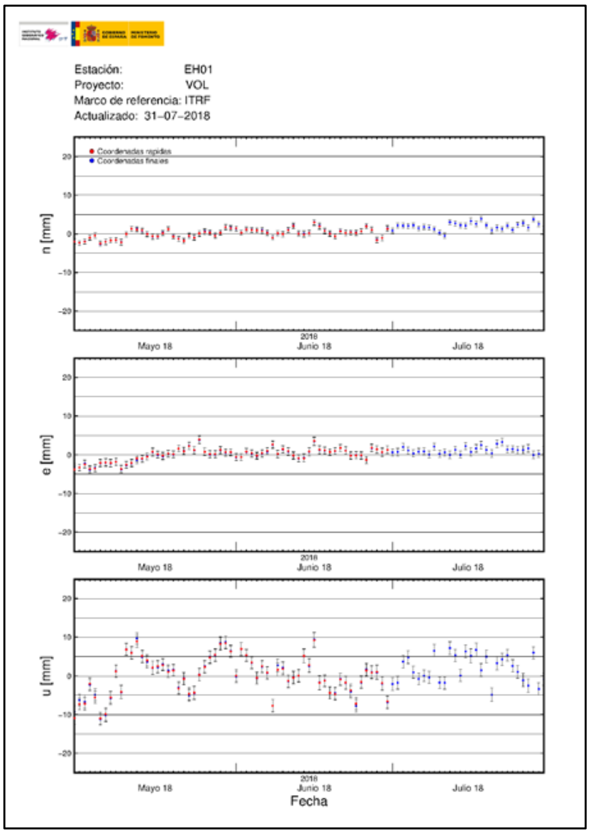

Figure 10: Daily (n,e,u) components for EH01 station (El Hierro) during the last ninety days.

This information can be found at IGN public website: http://www.ign.es/web/ign/portal/vlc-gps

4 DESCRIPTION OF VEW PRODUCTS

The methodology to integrate InSAR derived products, described in section 2, with GPS solutions, described in section 3, is explained in this section.

Main objective of VEW is the creation of products that integrate deformation from different techniques to have a broader vision of the deformation field.

VEW derived products will provide an excellent view of the deformation field over the test sites that will be interpreted along with other geophysical information. In subsequent stages, they can be used as input of hazard and risk assessment software and numerical modelling to infer depth, volume and shape of volcanic sources.

4.1 Database structure associated to VEW products

According to DIM, DAM and ADA database (D35) we propose the following general structure for GPS derived products for every test site:

	Lat	Lon	E	N	H	ADA_ID	Vel_mean	Q_vel	Def_mean	Def1	...	Defm
GPS1												
...												
...												
...												
GPSn												

Table 1: Database structure associated to VEW products

Where GPS1,.., GPSn are GPS located at every test site.

Fields are:

- Lat : WGS84 geographic latitude [º]
- Lon : WGS84 geographic longitude [º]
- E : UTM east [m]
- N : UTM north [m]
- H : Ortometric height [m]
- ADA_ID: if GPS belongs to an ADA this field will contain the ADA_ID according to D35. In case it is not contained in any ADA the field ADA_ID will be -1.
- Vel_mean : lineal velocity estimated for the time interval considered [mm/y]
- Q_vel : Quality Index of estimated velocity
- Def_mean : Mean of the deformation for the time interval considered [mm]
- Defi : deformation projected to LOS and calculated with respect to the reference point and date [mm]

This database will be daily updated as soon as GPS solutions are available.

According to project requirements, this database will follow the user requirements established in D3.1. It will be also INSPIRE compliant.

4.2 VEW-DIM

VEW-DIM is a product which show relative deformation between two dates projected to LOS and referenced to a reference point inside the area of interest.

For every delivered DIM and by operating over Defn fields in the previous database, we can obtain relative deformation in the GPS points between two dates projected to LOS. This information can now be displayed in the same scale and interpreted along with DIM. A shape file will be created for every DIM containing:

- Lat : WGS84 geographic latitude [º]
- Lon : WGS84 geographic longitude [º]
- E : UTM East [m]
- N : UTM North [m]
- H : Ortometric height [m]
- Def_i : LOS deformation with respect to the reference point and date [mm]

We can also compute possible differences around GPS stations though the usage of buffers in ArcGis: selecting all PS inside an area of a defined extension centered in a GPS location, we calculate the PS average and compute the difference relative to the GPS values. The results of this comparison are useful to validate DIM. Differences between DIM and GPS can answer to long wavelengths captured by GPS or differences in atmospheric removal.

4.3 VEW-DAM

DAM contain all existing PS during the monitored time interval. For each PS are provided the accumulated LOS deformation at every acquisition date; the mean LOS velocity and the mean accumulated deformation. VEW-DAM pretends to include this information also for GPS stations.

The final DAM product will consist in a shape file that will contain all the fields specified in 4.1. This will allow querying to the database to obtain mean velocities, mean deformations, deformations at a given date for PS and GPS. A tool to plot time series of any PS will be developed.

The DAM will be updated together with the DIM updating.

4.4 VEW-ADA

ADA represent areas of several PS which show clear deformation by a careful analysis of its temporal series. VEW-ADA pretends to integrate here GPS time series.

In case a GPS is included in any ADA, a shape file with the following fields for every ADA will be created:

- Lat : WGS84 geograhic latitude [º]
- Lon : WGS84 geograhic longitude [º]
- E : UTM east [m]
- N : UTM north [m]
- H : Ortometric height [m]
- Vel_mean : lineal velocity estimated for the time interval considered [mm/y]
- Q_vel : Quality Index of estimated velocity

- Def_mean : Mean of the deformation for the time interval considered [mm]

GPS deformation could help to redefine an ADA as GPS act as a PS with a more precise deformation time series. By including GPS in ADA definition new ADA could be defined and also ADA quality index could be redefined. This would involve changes over the methodology to define ADA stablished in Barra et al, 2017 which would need to be studied carefully.

GPS can also help to interpret the direction of deformation as, although we are using deformations projected to LOS to be able to compare with InSAR, GPS is originally projected to north, east and up directions.

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