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Biennial report for Permanent Supersite/Natural Laboratory

Ecuador Volcanoes Supersite

History	*https://geo-gsnl.org/supersites/permanent-supersites/ecuadorian-volcanoes-supersite-new-version-2/*
Supersite Coordinator	*Patricia A. Mothes, Instituto Geofísico, Escuela Politécnica Nacional, Quito Ecuador*

Volcanoesmonitored on the Continent with InSAR.

Volcanoesmonitored in the Galápagos Islands with InSAR

1. Abstract

From 2021 until present (May 2023) the Ecuador Volcano Supersite has made significant strides in SAR imagery uptake and processing. This is in part due to collaboration with INGV which aided in providing processing software, training and computational facilities in order to have advanced capabilities in image processing of satellite imagery for volcano and tectonic monitoring. Computational facilities have also been improved at the Instituto Geofísico where satellite data is being processed with ISCE. And new servers are being purchased for installing the SarScape program, for InSAR processing and modeling.

For the IGEPN´s 24/7 volcanic and seismic monitoring imagery of 13 volcanoes is being processed weekly. These are either of Sentinel-1, TerraSar-X or Cosmo Skymed and cover the following volcanoes: Cotopaxi, Cayambe, Sangay, Antisana, Tungurahua, Guagua Pichincha, Reventador and Chiles-Cerro Negro on the mainland. For the Galapagos islands, images of Wolf, Cerro Azul, Sierra Negra, Darwin and Fernandina volcanoes are also processed weekly.

The results of the processing are shared internally at the Instituto Geofísico´s weekly meeting in which all SAR processing results are discussed in conjunction with seismic, gas, thermal, acoustic, visual or satellite data sets. If a volcano appears to be ramping up in its level of activity, the data parameters will be reported in a Special Report, and analysis will be provided of what the InSAR processing results, in combination with other data, might mean. If the activity is deemed considerably intense, a personal conversation with the head of National Risk Management (Civil Defense) takes place. At a meeting of key monitoring scientists within the IGEPN, the rate of ascent of activity is assessed and the eruptive scenarios are laid out. Such has been the case of Cotopaxi volcano, which began with a marked uptick in activity in October, 2022. A yellow alert was emplaced and continues. Daily activity reports are always given, and more frequent IGalInstante reports are prepared for ashfalls and other visible phenomenon.

Presently, Sangay volcano has a high level of superficial and internal agitation. Deformation is particularly clear on the upper NE flank. The deformation is persistent, and along with the continual seismicity, is a significant indication of continuing magma recharge into this volcano. Additionally, several volcanoes in the Galapagos have notable deformation signals and the time series are compared with seismicity counts, locations and energy release on a weekly basis.

With so many potentially active volcanoes (> 45) on the Ecuadorian mainland and in the Galapagos, the satellite monitoring is imperative. Along with the seismicity and gas detection capabilities of the IGEPN and also of satellite sensor observations, the IGEPN can give confident early-warnings of potentially hazardous, strengthening volcanic activity.

<A one-page abstract which may be used for dissemination by CEOS or GEO)

2. Scientists/science teams

Researcher/team 1	***Patricia Mothes, IGEPN, Quito Ecuador, pmothes@igepn.edu.ec, www.igepn.edu.ec*** ***Pedro Espín B., IGEPN, Quito Ecuador, pespin@igepn.edu.ec, www.igepn.edu.ec (Now at Univ. of Leeds).*** ***Marco Yépez Y., IGEPN, Quito Ecuador, myepez@igepn.edu.ec, www.igepn.edu.ec*** ***Santiago Aguaiza, IGEPN, Quito Ecuador, saguaiza@igepn.edu.ec, www.igepn.edu.ec*** ***Marco Córdova, IGEPN, Quito Ecuador, mcordova@igepn.edu.ec*** ***Maria Naranjo; IGEPN, Quito Ecuador, fnaranjo@igepn.edu.ec***
" **2**	*Falk Amelung, RSMAS, University of Miami, famelung@rsmas.miami.edu,*
" **3**	*Susanne Ebmeier, COMET, University of Leeds, Great Britain, s.k.ebmeier@leeds.ac.uk* http://www.see.leeds.ac.uk/people/s.ebmeier *Elisa Trasatti*, Istituto Nazionale di Geofisica e Vulcanologia Osservatorio Nazionale Terremoti Via di Vigna Murata 605, 00143 Rome, Italy elisa.trasatti@ingv.it; https://www.ingv.it/it/organizzazione/chi-siamo/personale/#932 *Paul Lundgren,* Jet Propulsion Laboratory California Institute of Technology, Pasadena CA, USA. paul.r.lundgren@jpl.nasa.gov

Scientists/science team issues

At the moment within the IGEPN 5 investigators work on processing and analyzing the SAR data for 13 volcanoes. These data are presented each week and discussed in a collective volcano meeting, held every Thursday. Additionally, some data is being worked up for future publication. One researcher (Pedro Espin) is working towards his PhD at COMET under direction of S.K. Ebemier and Tim Wright at Leeds University. Two other colleagues are working closely with Elisa Trasatti of INGV on projects dealing with Wolf and Guagua Pichincha volcanoes, respectively. The team leader, Patricia Mothes, is keeping close watch of deformation patterns at over-due Cotopaxi volcano.

The limiting factor is processing speed, storage and improved techniques. These issues are being resolved gradually.

The team works together with good collaboration and is in contact with specialists (F. Amelung, S. Ebemier, Stefano Salvi, Elisa Trasatti, Tim Wright, Mike Poland, Paul Lundgren and Maurizio Battaglia) when questions arise about procedures or results.

1. In situ data

Type of data	Data provider	How to access	Type of access
e.g. seismic waveforms, GPS time series, gas measurements, etc.	*IGEPN*	*Link to Web portal´s data repository or description of procedure for data access*	*E.g. unregistered public, registered public, limited to GSNL scientists, etc.*
Seismic traces, locations Energy release,	*IGEPN*	*https://www.igepn.edu.ec/solicitud-de-datos*	*Written request*
GPS	*IGEPN*	*https://www.igepn.edu.ec/solicitud-de-datos*	*Written request*
Gas_So2 & CO2	*IGEPN*		

In situ data issues

The IGEPN has significant collaboration with foreign researchers. These are carried out by IGEPN researchers working collaboratively with interested individuals on a certain deformation topic that involves sets of data gathered by IGEPN ground-based networks.

2. Satellite data

Type of data	Data provider	How to access	Type of access
TerraSAR X	*DLR,*	*Link to data repository or description of procedure for data access*	*Limited to GSNL scientists*
COSMO-SkyMed,	*ASI*		*Limited to GSNL scientists*
Sentinel-1	*ESA*		*Unrestricted, open data*
…	*…*	*…*	*…*

Satellite data issues

*The **TerraSAR X** data is available and we have download it for Cotopaxi and Chiles-Cerro Negro. There are no processing issues.*

***COSMO-SkyMed** imagery is downloaded from ASI, via the portal without problems and is processed for Cayambe and Guagua Pichincha volcanoes. The data however, is often be blurry and may not have the precision that we need.*

***Sentinel-1** imagery is easy to access and we download it every week for processing. We are very happy with the results.*

3. Research results

Publications

Peer reviewed journal articles

1. **Silvana Hidalgo, Francisco Vasconez, Jean Battaglis, Mario Ruiz & 13 others *Sangay volcano (Ecuador): the opening of two new vents, a drumbeat seismic sequence and a new lava flow in late 2021*. October 2022**
DOI: 10.30909/vol.05.02.295311
https://www.researchgate.net/figure/Results-of-deformation-monitoring-analysis-obtained-using-InSAR-for-the-two-years_fig3_364329068

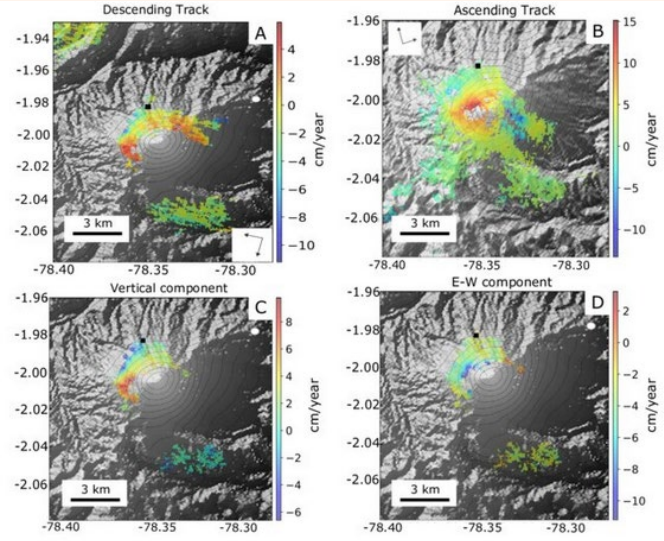
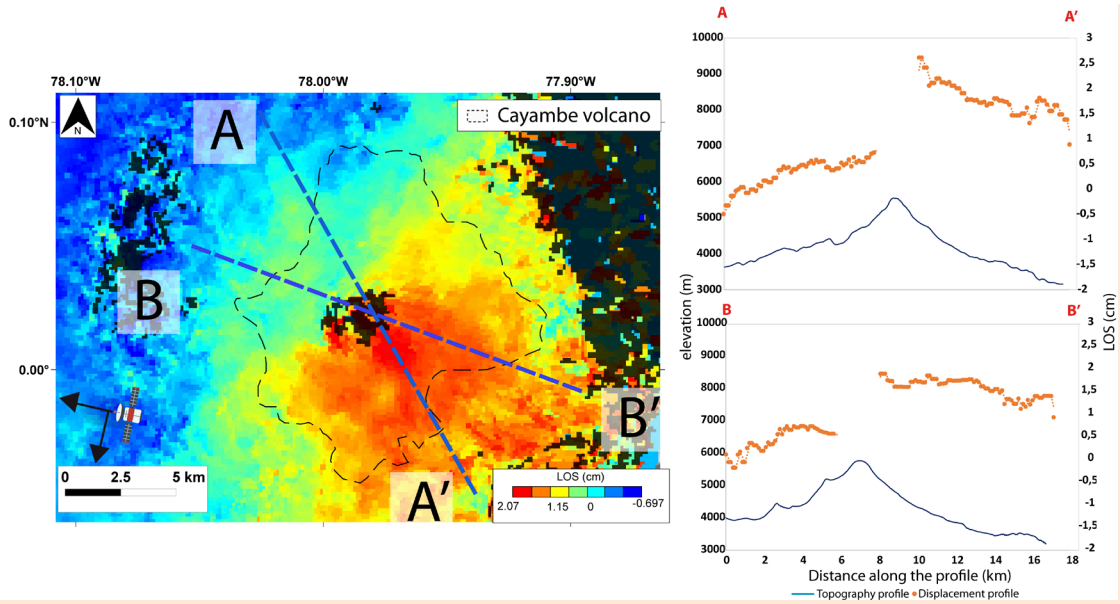


Figure 3: Results of deformation monitoring analysis obtained using InSAR, for the two years preceding the new northern lava flow onset. [A] Deformation along the LOS direction, Descending track between 05/01/2020 and 07/12/2021, [B] Deformation along the LOS direction, ascending track between 02/01/2020 and 04/12/2021. Components of motion: [C] Vertical component and [D] Horizontal component at Sangay volcano. The black square represents the reference point.

2. **Pedro Alejandro Espín Bedón, Laurence Audin, M.-P. Doin, Daniel Alejandro Pacheco, etc (2022). Unrest at Cayambe Volcano revealed by SAR imagery and seismic activity after the Pedernales subduction earthquake, Ecuador (2016). May 2022, Journal of Volcanology and Geothermal Research 428(6192):107577.**

DOI: 10.1016/j.jvolgeores.2022.107577



Conference presentations/proceedings

FRINGE-2023: InSAR Contributions to Continuous Volcano Monitoring in Ecuador. Patricia A. Mothes, M.Yepez, Espín Bedón, Pedro Alejandro, Andrea Córdova, Daniel Pacheco, Lourdes Narváez Medina, Darío Arcos & Maurizio Battaglia. (Scheduled for Sept., 20223)

Variable ground deformation rates since May 2022 at Chiles-Potrerillos Volcanoes, Ecuadorian-Colombia border.

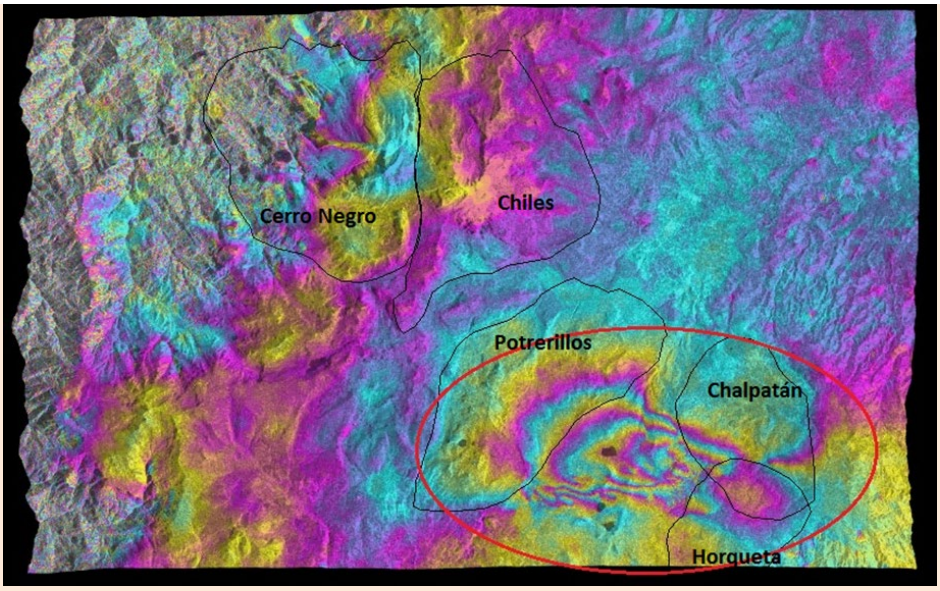
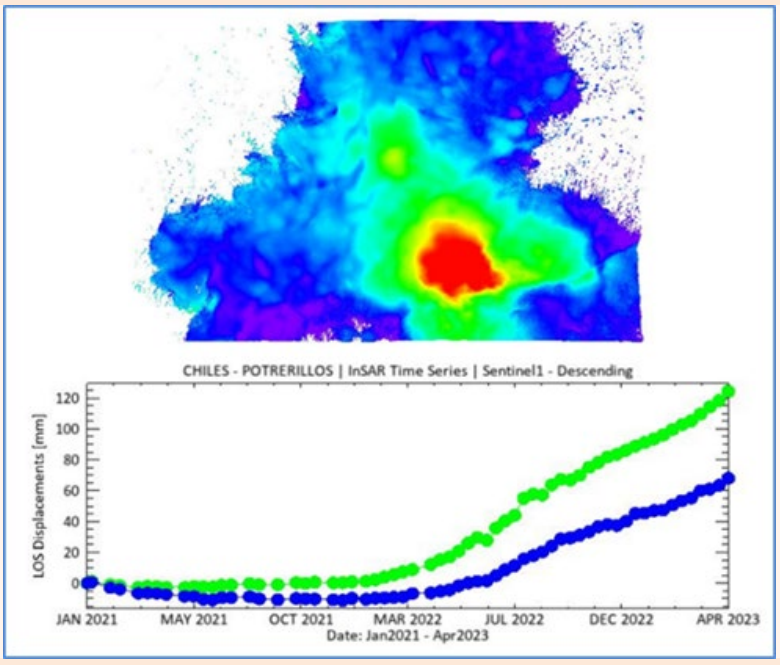


Figure 4: Interferogram of rupture area of 25 July 2022, 5.6 Mw earthquake adjacent to the Potrerillos Plateau and the Chalpatán caldera. Sentinel-1 descending orbit track. Two frames: 17 July 2022 and 29 July 2022 were used. Refer to Fig. 3 for coordinates.



Evidence of Notable deformation at Chiles-Porterrillos volcanoes, since May 2022. Descending Track, Sentinel-1. Courtesy, Marco Yepez.

Research products

Type of product	Product provider	How to access	Type of access

Ground deformation time series, source model, etc.	*Name of scientist(s)*	*Link to publication, research product repository or description of procedure for access*	*E.g. public, registered, limited to GSNL scientists, etc.*
Time series, maps and Modeling results are all discussed at weekly volcano meetings	*Mothes, Espin, Yepez and Aguaiza*	*If activity on volcano is significant, special reports are prepared and published on IG website www.igepn.edu.ec*	*Each scientists can be reached via email to discuss data results. Also, 4 publications are being prepared which will cover volcanoes and tectonic areas.*
…	*…*	*…*	*…*

Research product issues

4. Dissemination and outreach

We provide frequent information to the public via social media (1.6 million followers on Twitter). The public and authorities are aware that the volcanoes are being monitored with satellite data and that the processing is on-going at the IGEPN. Plots of time-series and interferograms are published when activity warrants.

5. Funding

Funding for training in Sarscape program processing and use of a powerful server was made available by INGV. Funding for other computational systems is being provided by local funding. The doctoral student (P. Espin) has a scholarship to Leeds.

6. Stakeholders interaction and societal benefits

The stakeholders are the citizens who can potentially be affected by eruptions. At the moment with Sangay volcano, we are trying to correlate the gas outputs with InSAR time-series patterns to be able to anticipate before an eruption occurs of VEI 1-2 size. While the InSAR has clearly been suggestive that magma recharge is occurring, it doesn´t have the sensitivity to know within a few hours that an eruption will be forthcoming.

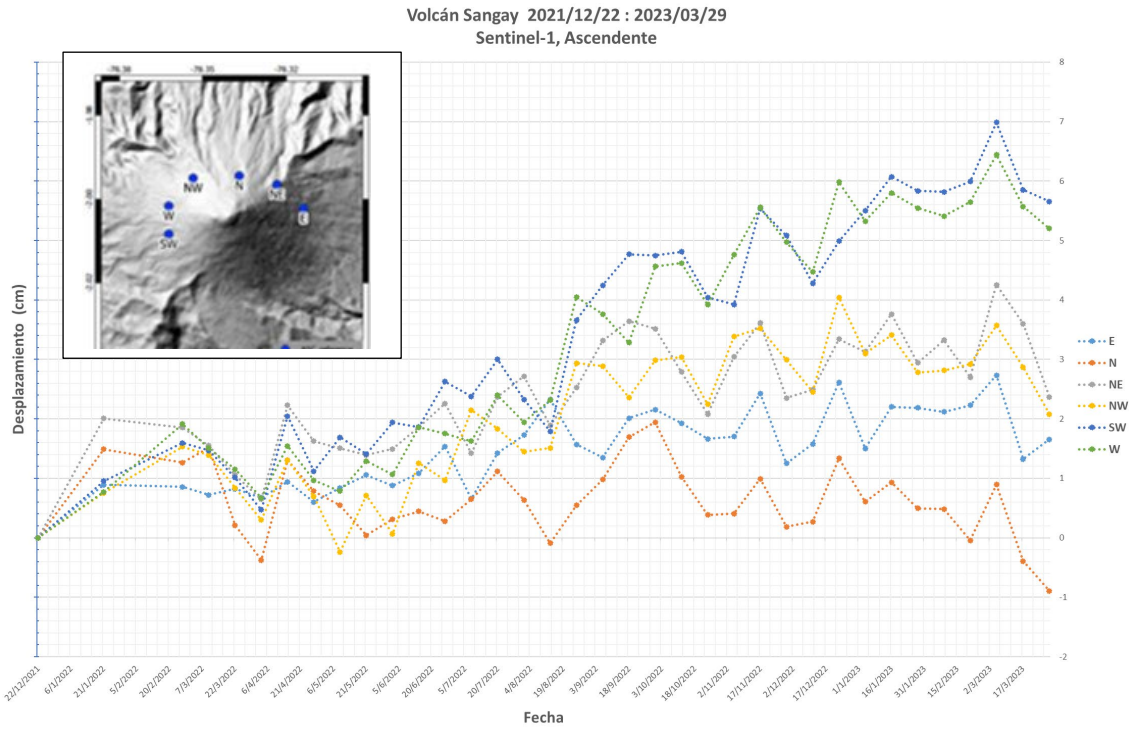
The local civil defense, (Secretario de Gestion de Riesgos) is in constant communication with us via radio, telephone and WhatsApp. They are truly the most continual group that has uptake of our real-time volcano monitoring information and use it to anticipate the level of affectation of crops, livestock, infrastructure that might occur when ash or lahars

are present. They also use the information to activity mobilize the population, should that be necessary.

Also, governors, mayors and prefecturas are continuously in contact with the IGEPN for updates on volcanic activity, ie Cotopaxi, since it can affect so many provinces.

The media and press use our information to report on the television or in newspapers and on the radio as to the status of on-going activity at a volcano.

When volcanologists give frequent interviews all the data is talked about as a collective of information which is analyzed together. So, the InSAR imagery, seismic traces, energy levels, the gas flux and visual observations are all treated as necessary inputs to make a decision as to where eruptive activity is headed on a particular volcano.



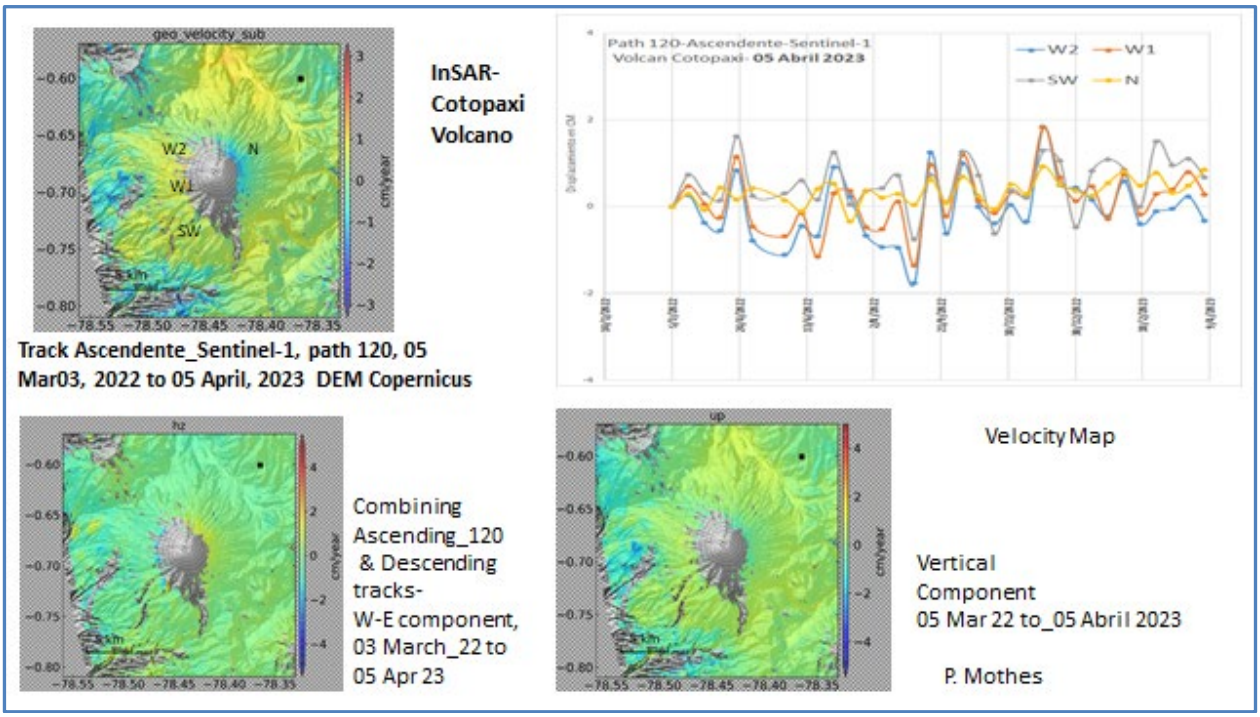
7. Conclusive remarks and suggestions for improvement

I feel tremendously grateful that we have been able to have the SuperSite collaboration so that the IGEPN researchers could receive training in processing, have access to a really good program and also servers for data processing. Now that those hurdles are overcome, we will be more concentrated on pulling out results. Published results, but also our weekly InSAR products, should be given greater visibility to the public and local authorities.

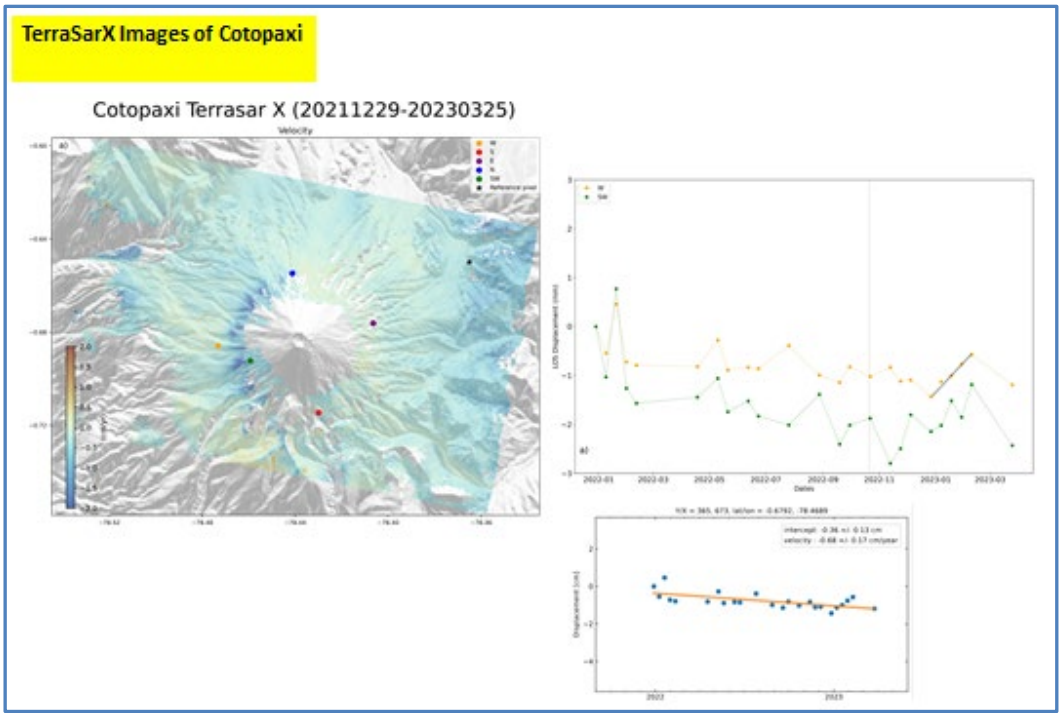
Therefore, I believe with the ongoing eruptive status of several of our volcanoes, that there are good opportunities to give some limelight to the products of InSAR processing and thus

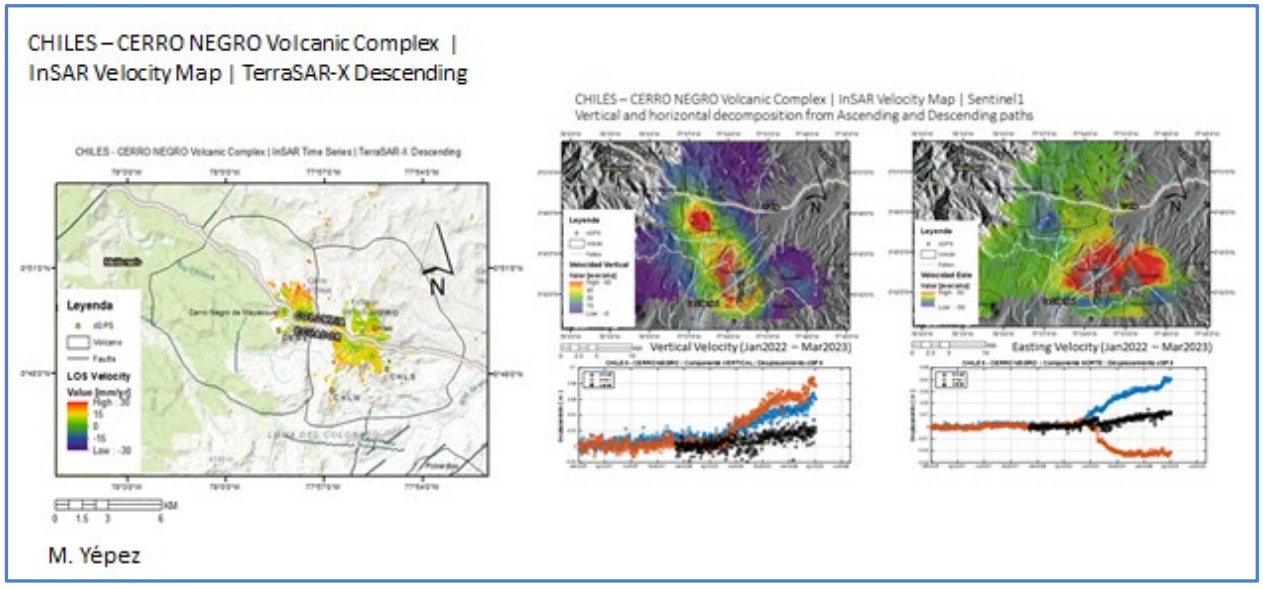
provide due credit to the Ecuador Volcano Supersite, which is benefactor of the imagery provided by DRL, ASI and ESA.

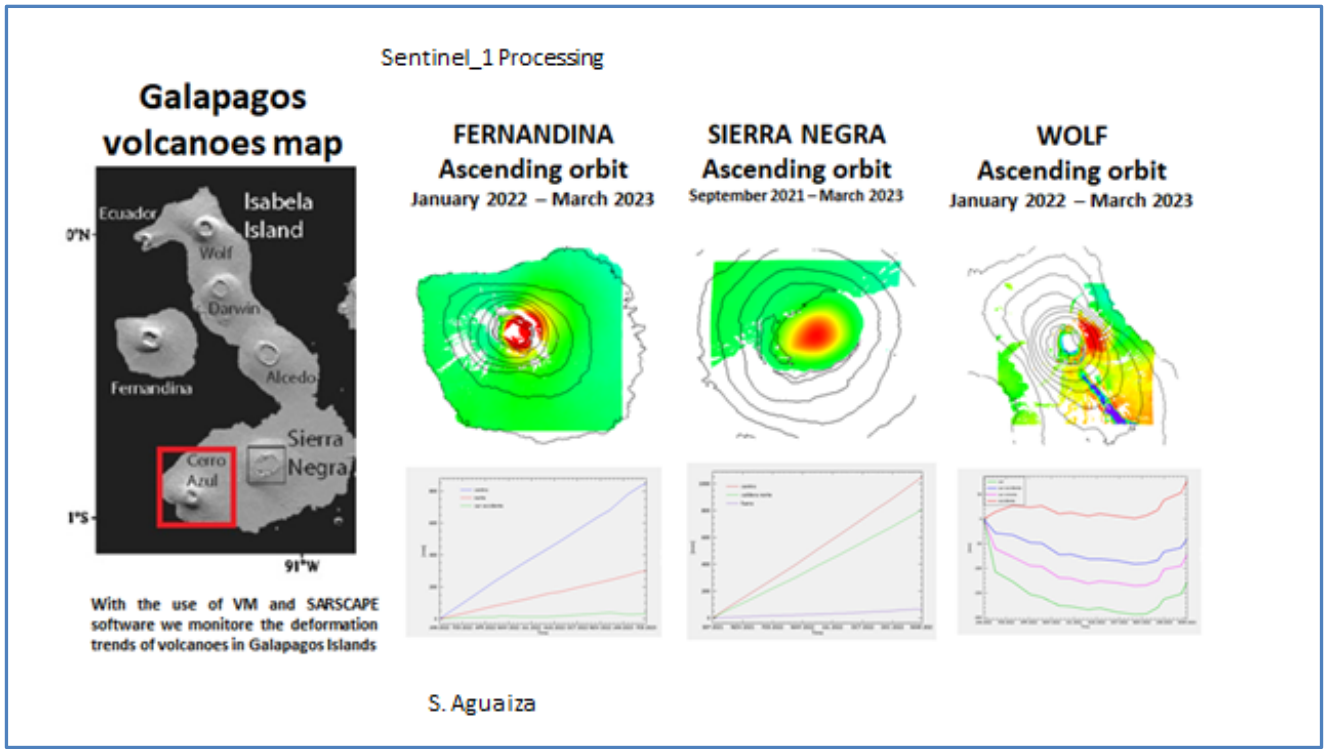
8. Dissemination material for CEOS (discretionary)

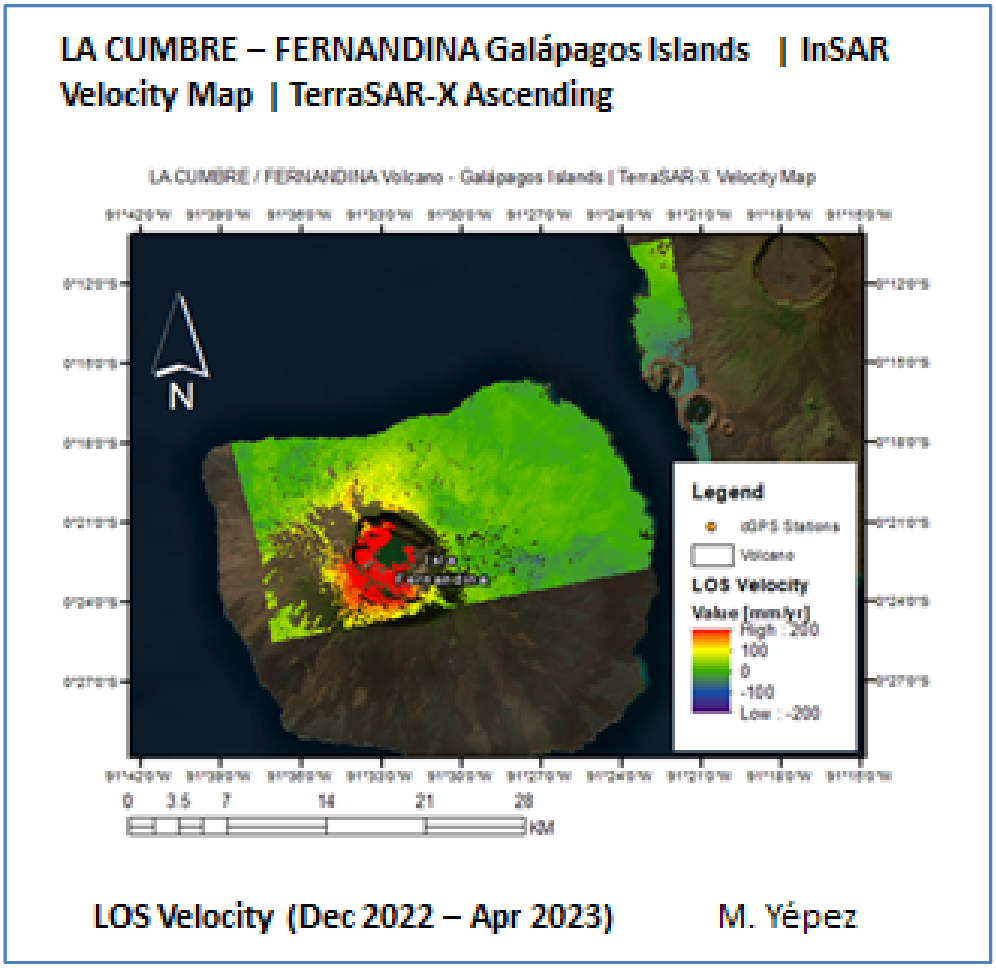


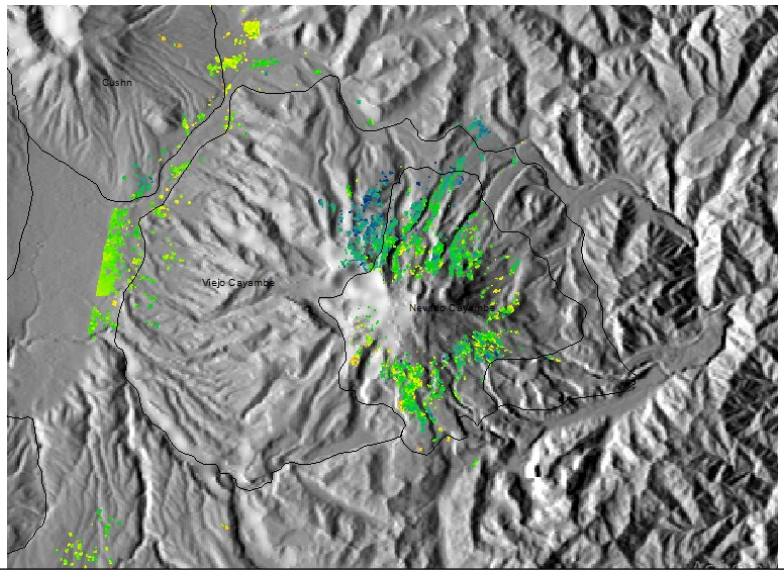
Both Tracks & InSAR Velocity_29 April 2021, Sentinel-1, Cotopaxi Volcano, upto April, 2023.


TerraSarX Images of Cotopaxi
Cotopaxi Terrasar X (20211229-20230325)


CHILES – CERRO NEGRO Volcanic Complex |
InSAR Velocity Map | TerraSAR-X Descending
CHILES – CERRO NEGRO Volcanic Complex | InSAR Velocity Map | Sentinel1
Vertical and horizontal decomposition from Ascending and Descending paths
Leyenda
LOS Velocity
Vertical Velocity (Jan2022 – Mar2023)
Easting Velocity (Jan2022 – Mar2023)
M. Yépez


Sentinel_1 Processing
Galapagos volcanoes map
Ecuador
Isabela Island
Wolf
Darwin
Fernandina
Alcedo
Sierra Negra
Cerro Azul
0°N
1°S
91°W
With the use of VM and SARSCAPE software we monitore the deformation trends of volcanoes in Galapagos Islands
FERNANDINA
Ascending orbit
January 2022 – March 2023
SIERRA NEGRA
Ascending orbit
September 2021 – March 2023
WOLF
Ascending orbit
January 2022 – March 2023
S. Aguaiza


LA CUMBRE – FERNANDINA Galápagos Islands | InSAR Velocity Map | TerraSAR-X Ascending
LA CUMBRE / FERNANDINA Volcano - Galápagos Islands | TerraSAR-X Velocity Map
N
Legend
dGPS Stations
Volcano
LOS Velocity
Value [mm/yr]
High : 200
100
0
-100
Low : -200
0 3.5 7 14 21 28
KM
LOS Velocity (Dec 2022 – Apr 2023)
M. Yépez



Velocity map of Cayambe volcano. Obtained by InSAR-SBAS (Cosmo-SkyMed, descending track), up through March 2023. Map courtesy of M. Yépez Y.

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