CEOS Volcano Pilot Project: main results and lesson learned

Mike Poland (USGS)

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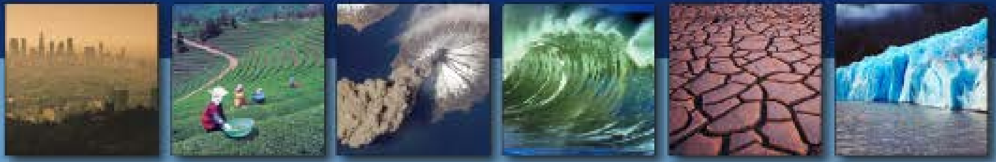
WG Disasters #8

Buenos Aires, Argentina

4–6 September 2017



PILOT TEAM: Juliet Biggs, David Arnold (*University of Bristol*), Susi Ebmeier (*University of Leeds*), Matt Pritchard, Francisco Delgado (*Cornell University*), Christelle Wauthier (*Penn State University*), Falk Amelung (*University of Miami*), Fabrizio Ferrucci (*Open University*), Mike Pavolonis (*NOAA*), Rick Wessels (*USGS*), Eugenio Sansosti (*IREA-CNR*), Elske de Zeeuw - van Dalfsen (*KNMI*)

Motivation

Merapi, Indonesia, erupting in 2010. From Pallister and others, 2013

WHAT IS MISSING?

- **up to 45% of the worlds ~ 1400 Holocene age volcanoes are not monitored**
- **What EO data are most critical for detecting changes in unrest and eruptive activity vs. different volcanism and environment?**
- **Strategy for satellite observations depending on volcanoes level of activity**

Scope

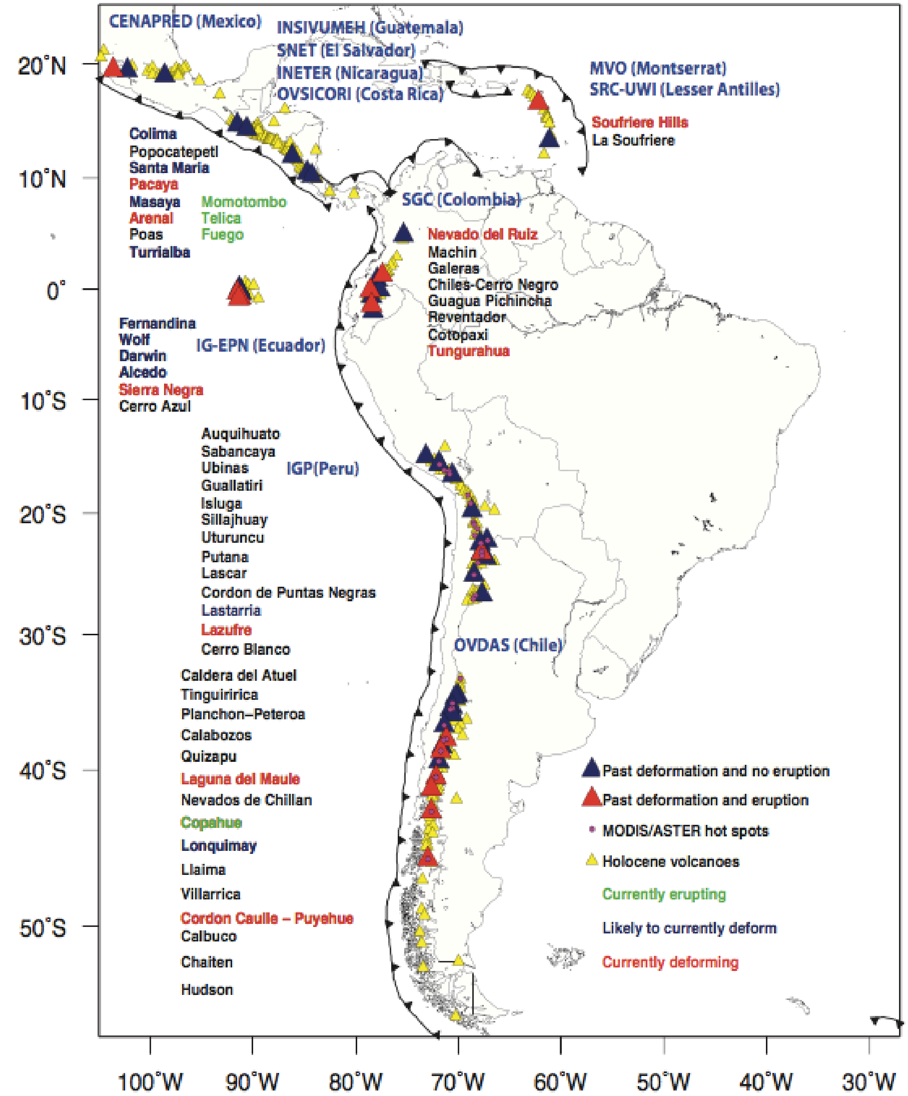
- Demonstrate the potential impact of EO data for better understand volcano hazard and reduce impacts and risks from eruptions.
- Enforce coordination between Space Agencies, value-added providers and end users to ensure that the agencies who are responsible for volcano monitoring have access to, and understanding of, those data sets that are most critical for making informed DRM decisions
- Propose a strategy for a global satellite monitoring system

Regional demonstration over Latin America

- Demonstrate potential impact of EO data: regional focus on Latin America (319 volcanoes)
- Identify volcanoes that may became active in the near future
- Track new and ongoing eruptive activity

Why Latin America?

- Range of eruption type/ages and environments
- Abundant volcanic activity
- Impact on people/air traffic
- Well established observatories
- ~202 volcanoes in the region have no ground monitoring of any type



Participants in the Pilot

CEOS Agencies:

USGS, ASI, CNES, CSA, DLR, ESA, NASA, NOAA, JAXA

Value-added providers:

University of Bristol (UK), Cornell University (US), University of Miami (US), Pennsylvania State University (US), IREA/CNR (IT), Open University (UK), NOAA, USGS

End users:

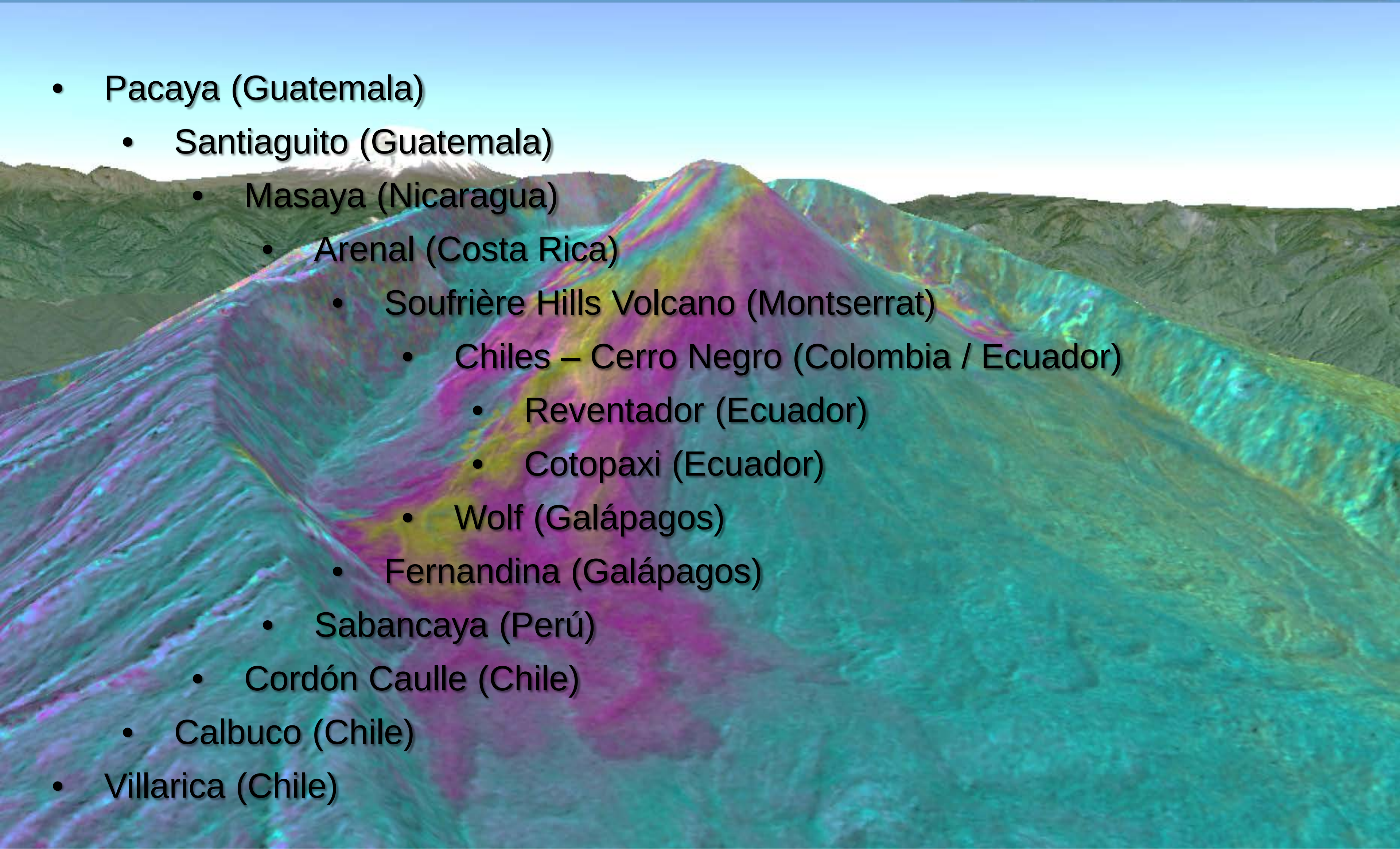
Observatorio Volcanológico de Los Andes del Sur (OV-DAS) Chile; Instituto Geofísico del Perú; Instituto Geofísico de la Universidad Nacional de San Agustín, Peru; Instituto Geofísico, Escuela Politécnica Nacional, Ecuador; Servicio Geológico Colombiano, Colombia, Buenos Aires Volcanic Ash Advisory Center, Argentina, Instituto nacional de sismología, vulcanologia, meteorología e hidrologia, (NSIVUMEH), Guatemala, Instituto Nicaraguense de Estudios Territoriales (INETER), Nicaragua

EO data

- Optical and IR data for detecting thermal anomalies, gas emissions, and ash plumes
- Radar data for ground deformation, new volcanic deposits, and topographic changes

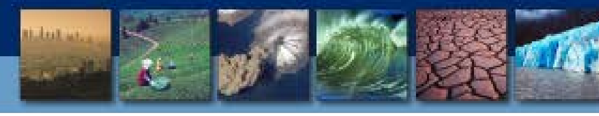
<u>FOCUS on Radar data</u> (ALOS, RADARSAT-2, COSMO-SkyMed, Terra SAR-X, Tandem-X, Sentinel 1) to understand how the entire international SAR constellation could be used for detecting and characterizing volcano behavior.

Noteworthy results



- Pacaya (Guatemala)
- Santiaguito (Guatemala)
- Masaya (Nicaragua)
- Arenal (Costa Rica)
- Soufrière Hills Volcano (Montserrat)
- Chiles – Cerro Negro (Colombia / Ecuador)
- Reventador (Ecuador)
- Cotopaxi (Ecuador)
- Wolf (Galápagos)
- Fernandina (Galápagos)
- Sabancaya (Perú)
- Cordón Caulle (Chile)
- Calbuco (Chile)
- Villarica (Chile)

Utility of data



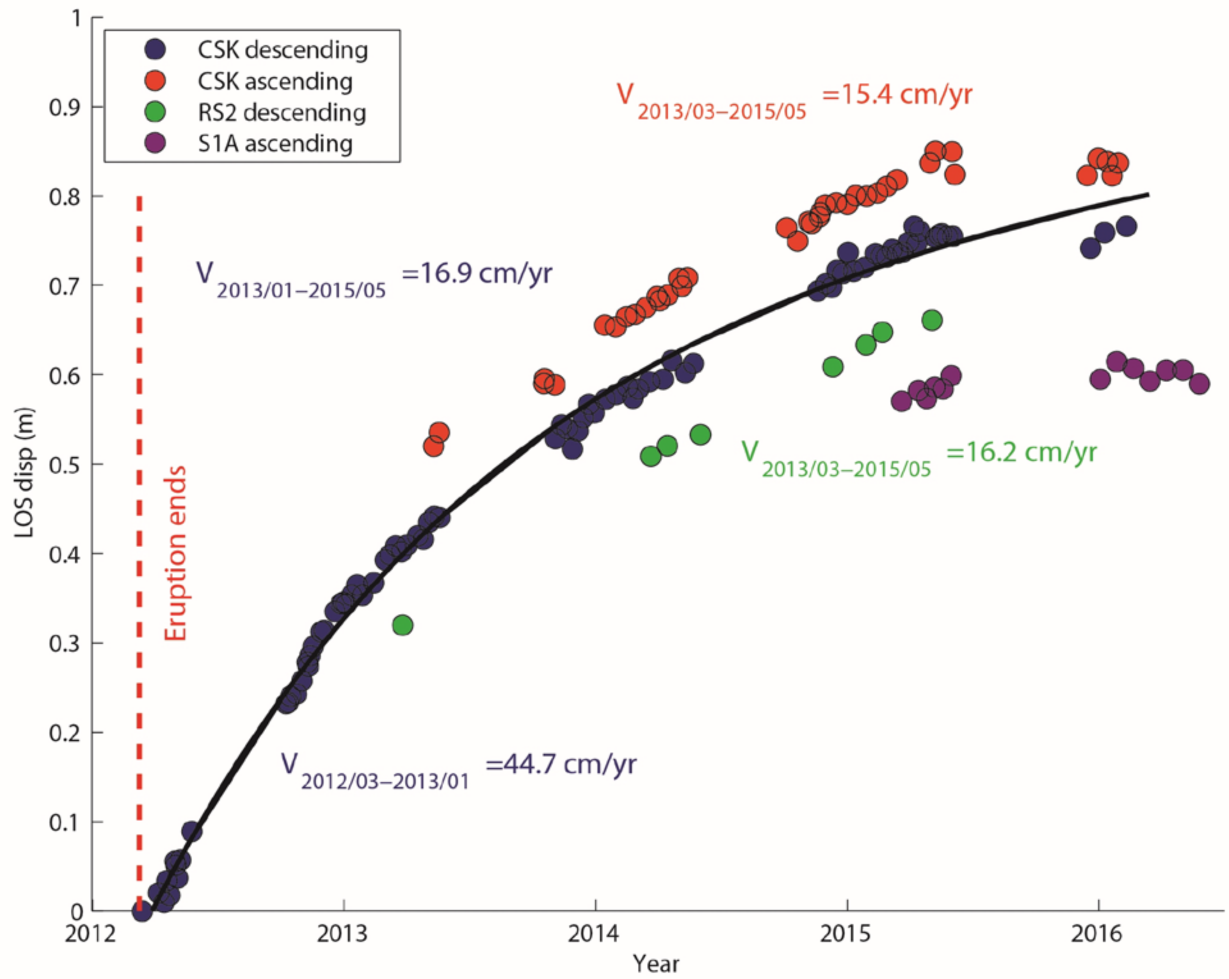
How have satellite data been useful?

- Monitored volcanoes with no ground networks and motivated installation of new sensors (*Cordon Caulle*)
- Provided data for determining alert levels (*Chiles-CN*)
- Complemented ground-based data and contributed to situational awareness during a crisis (*Chiles-CN, Calbuco*, *Villarica, Manutombo*)
- Filled "gaps" at volcanoes that have some ground-based monitoring (*Tungarahua*, *Pacaya*, *Santiaguito*)
- Provide otherwise inaccessible data (*Reventador*, *SHV*)
- Research (*Ubinas*)

Cordón Caulle, Chile

Inflation of Cordón Caulle, Chile, after the 2011-2012, has been a significant result of the pilot. This deformation would not otherwise be known without EO data.

The inflation seemed to have stopped in mid-2015.

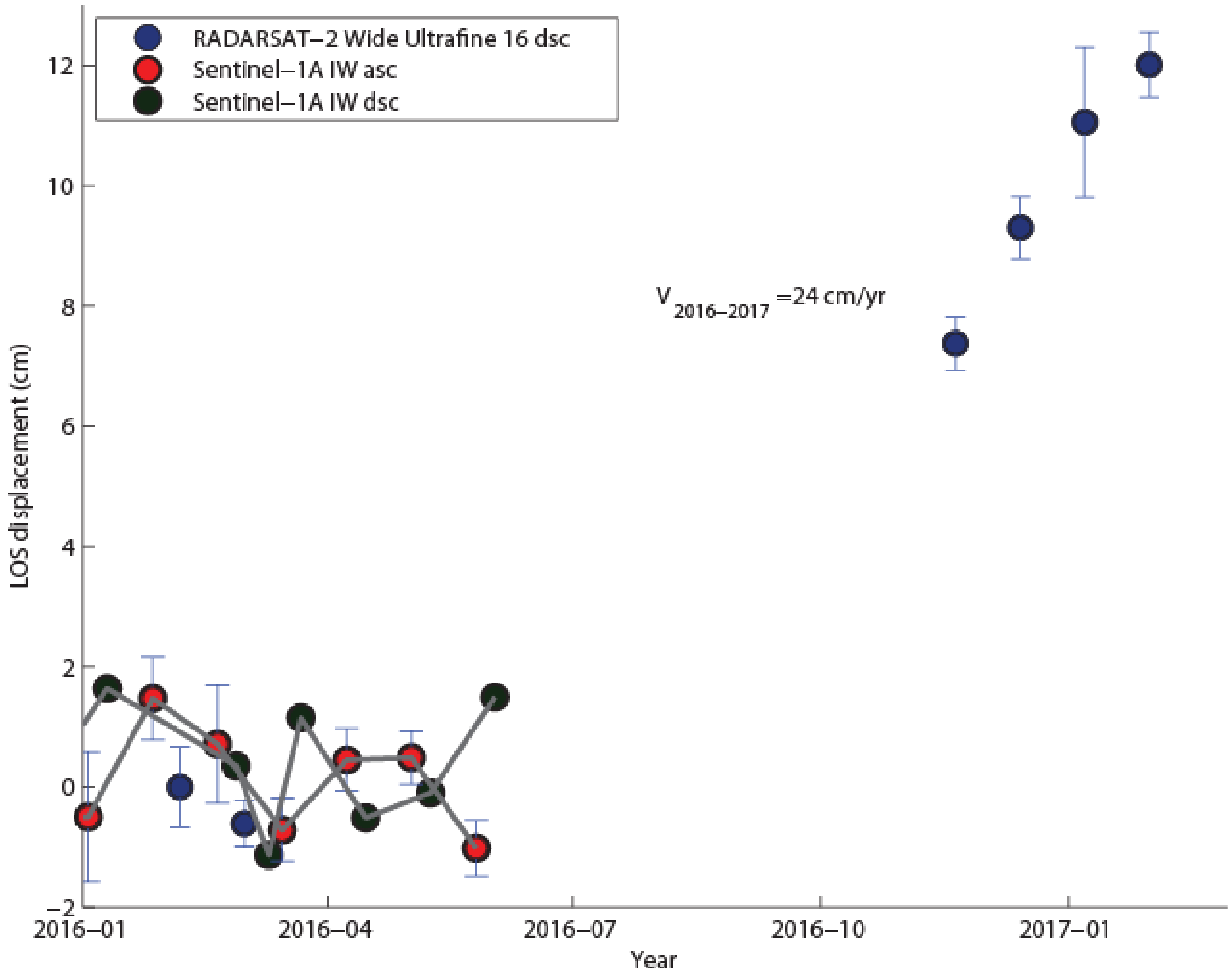


Post-eruptive uplift of up to 0.8 m between March 2012 and May 2015. The line-of-sight uplift rates reached 45 cm/yr, but the deformation was not accompanied by earthquakes

Cordón Caulle, Chile

New results indicate that inflation at Cordón Caulle resumed in mid-2016!

In response to these observations, OVDAS is installing a continuous GNSS station to establish ground-based monitoring of the volcano.



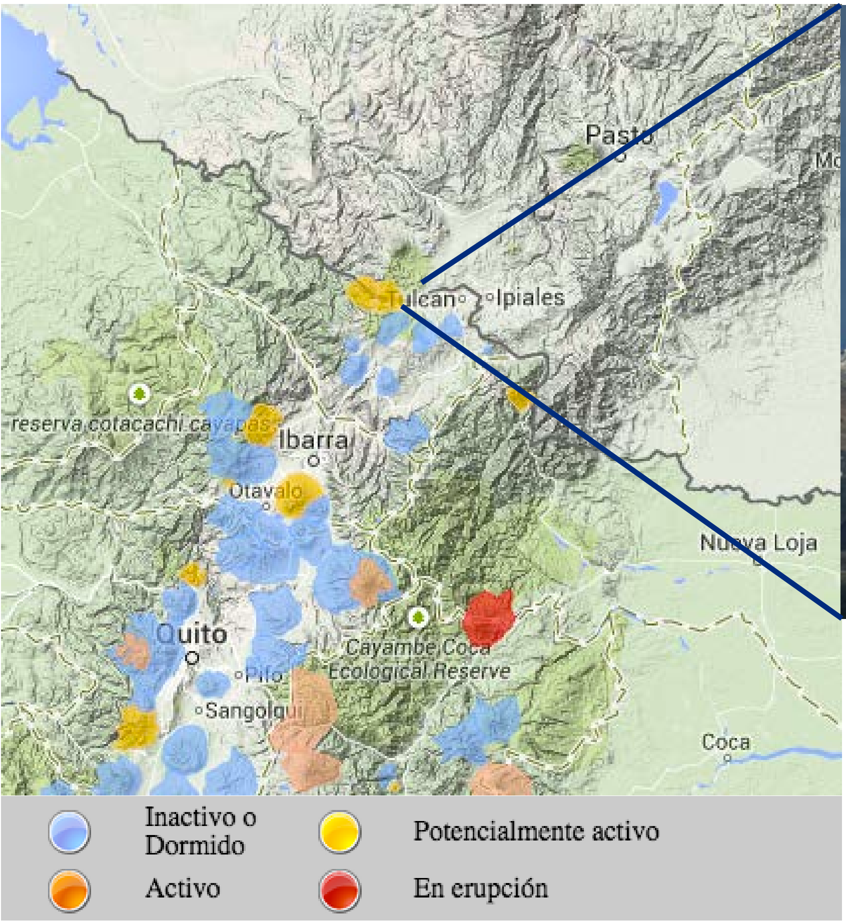
Utility of data

The project frequently responded to requests from local observatories to provide satellite data to complement ground based measurements of unrest.

Satellite observations were requested often to assess whether there is evidence of large magma accumulation during a seismic crisis or to confirm observation of deformation from a single sensor.

EO observations have showed a lack of magma driven deformation during crises at **Chiles and Cerro Negro de Mayasquer, Monotombo,Sabanacaya and Nevados de Chillan** and have consequently been instrumental in the decision not to raise the alert level.

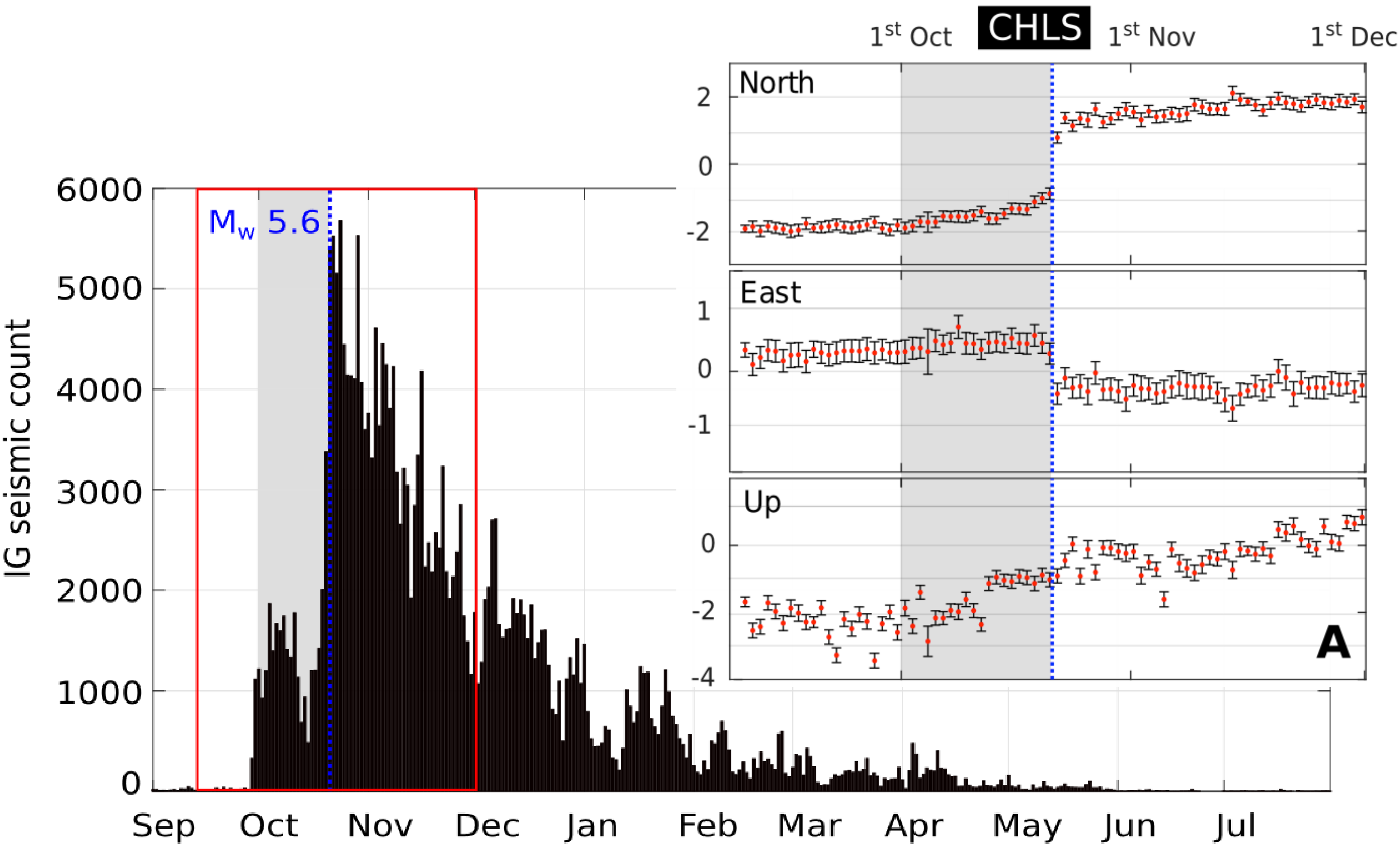
Chiles – Cerro Negro, Ecuador-Colombia border



Volcán Chiles

Very limited monitoring
Potentially Active
Inaccessible

Chiles – Cerro Negro



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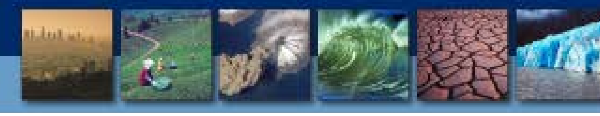
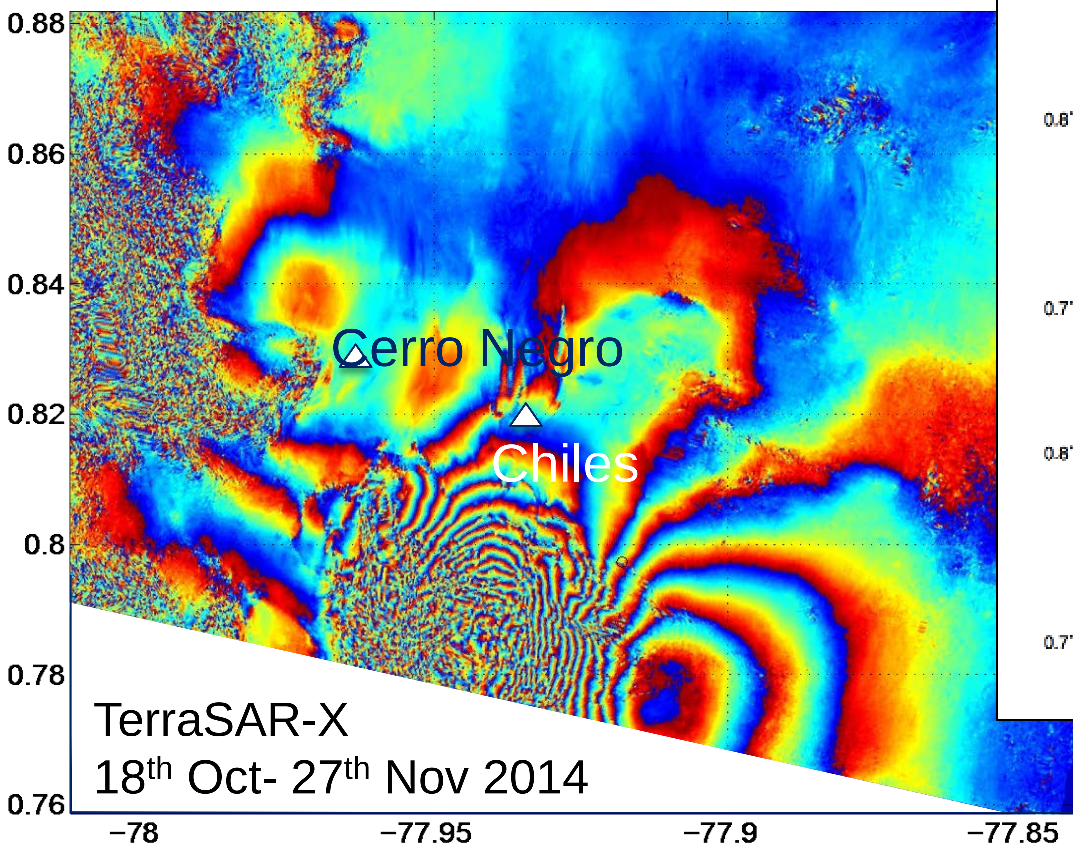
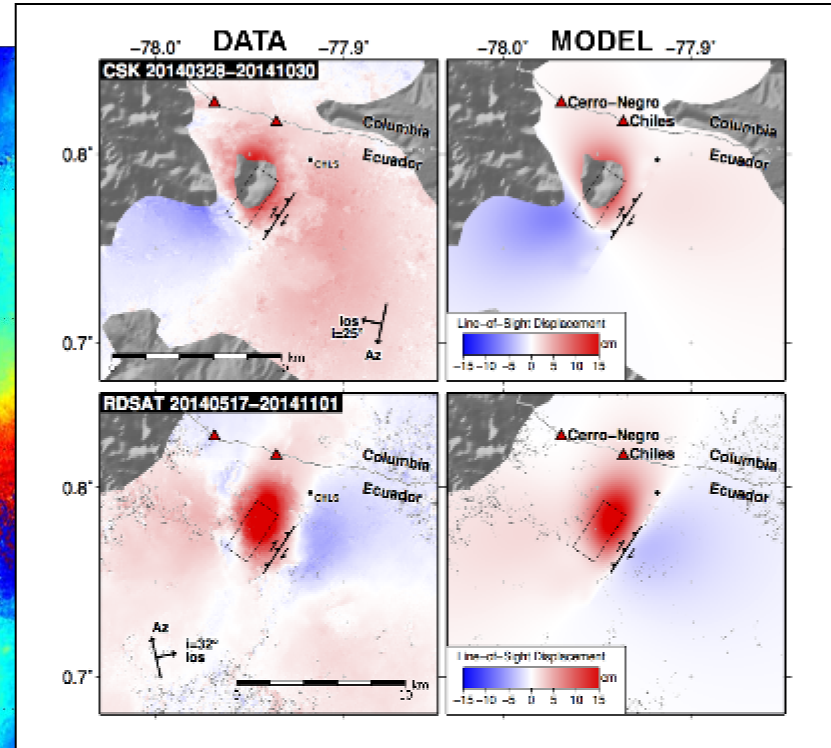
Chiles – Cerro Negro, Ecuador-Colombia border



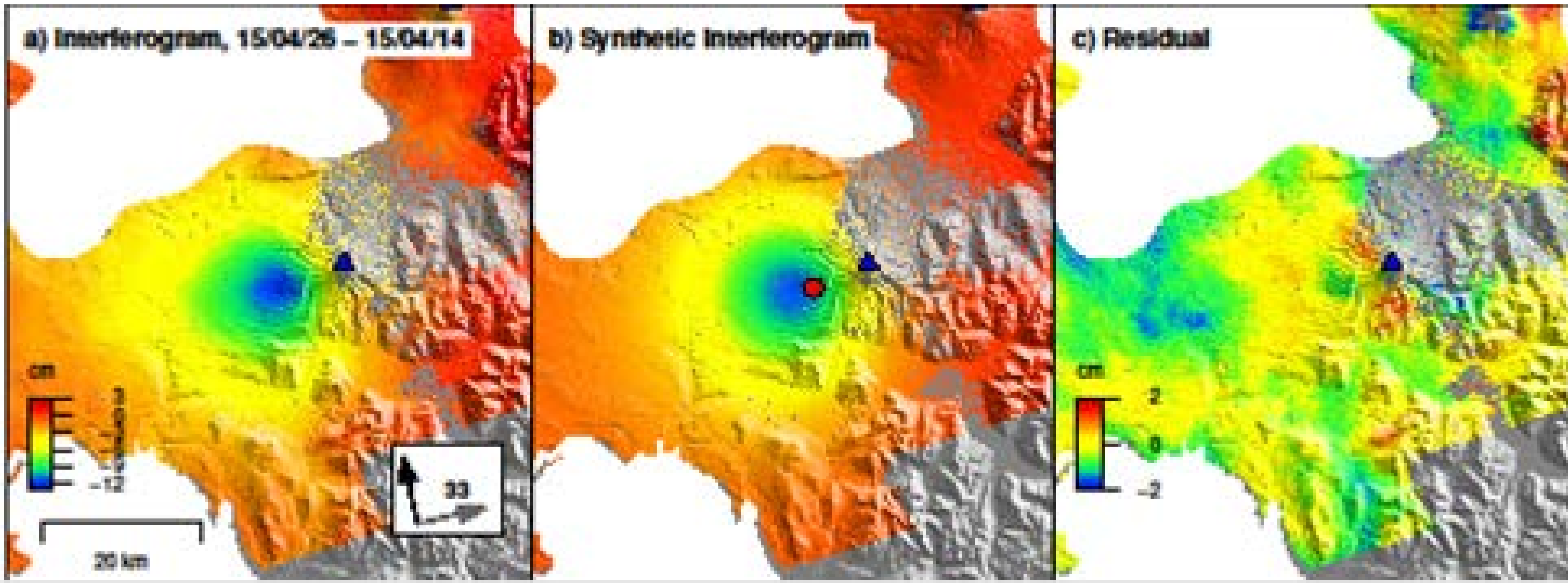




Ground deformation – is it magma or “just” the earthquake?

CEOS data indicated about 30 cm of ground movement associated with the earthquake, but no deformation indicative of magma accumulation or transport. The lack of deformation in INSAR images played a key role in the decision to reduce rather than elevate the alert level of volcano.

Calbuco, Chile



Observed (left), modeled (center), and residual (right) deformation (from Sentinel-1a, spanning April 14–26, 2015) due to an eruption at Calbuco, Chile, on April 22, 2015. A model of the deflation indicates that the source is located about 5 km SW of the volcano's summit at a depth of 9.3 km beneath the surface.

Confirmed single ground base sensor co-eruptive and showed post eruptive sensor unreliable.

OVDAS used this source model to validate their tilt meter records

Calbuco, Chile

Feedback from Buenos Aires VAAC manager on May 3, 2015:

"I thank you and congratulate you for the excellent work in making available of all images and products that allow us to significantly improve the tasks of detecting and tracking volcanic eruptions and clouds and ash, since we only have GOES13 and some polar satellites images."

In the wake of the explosive eruption of Calbuco, the Buenos Aires VAAC used the products to help brief aviation stakeholders

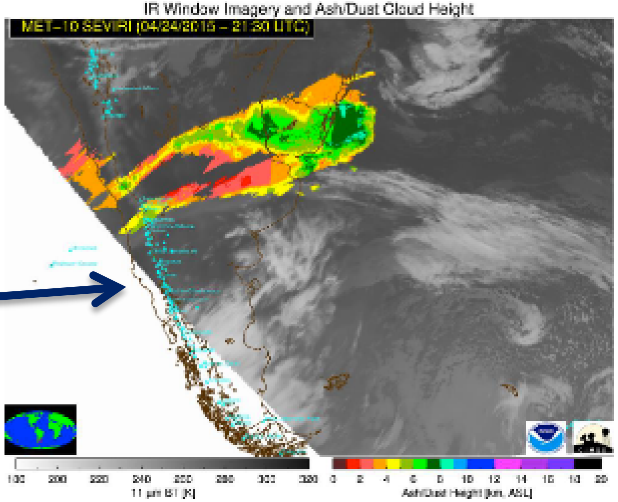
SERVICIO METEOROLÓGICO NACIONAL

sobre la franja central de Córdoba, el norte de San Luis, y el sur de San Juan. Esta banda se estima en una altura que varía entre los 10 y 12 km. Una segunda banda se orienta siguiendo la línea San Rafael – Mar del Plata, y se extiende por el sur de la provincia de Buenos Aires, La Pampa y Mendoza, con desplazamiento hacia el Noreste.

Reportes de visibilidad de 18 HOA: En el centro y norte de la provincia de Buenos Aires se reportan visibilidades superiores a los 8km. Hacia el sur de la provincia se reportan visibilidades, menores, de 2 km (en Mar del Plata) y 4 km (en Bahía Blanca). Mientras tanto, las estaciones meteorológicas Bariloche y Neuquén reportan visibilidades de 5 km y 1200 metros, respectivamente.

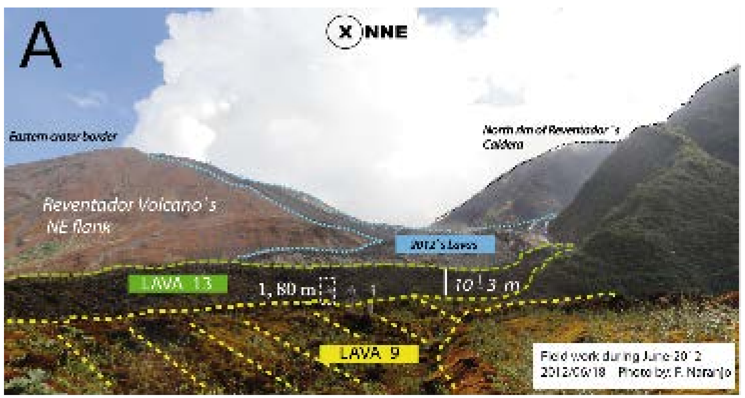
Para conocimiento de la situación regional se adjuntan imágenes EXPERIMENTALES de: a) estimación de altura de nube volcánica y b) estimación de carga de masa

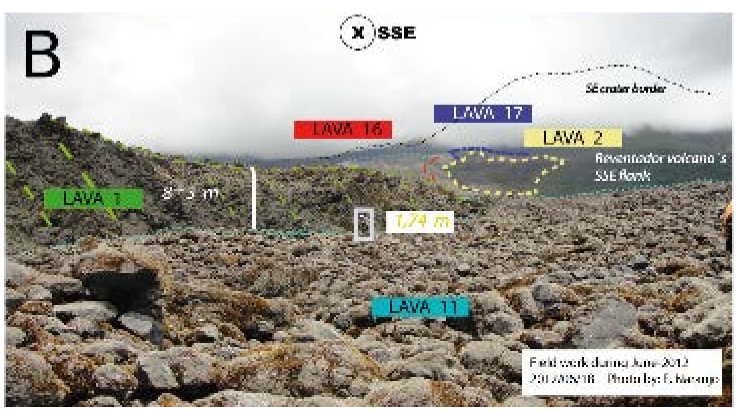
Estimación de altura de nube volcánica

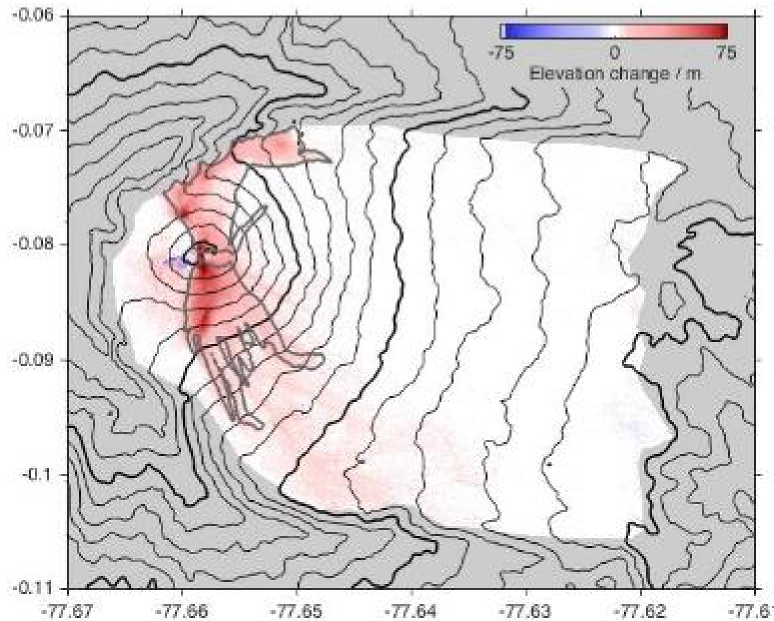


Results: Reventador

IG monitors lava effusion rate using field measurements and photos from overflights (irregular sampling and dependent on clear weather)







Thickness of new lava flows between 2011 and 2014 from TDX CoSSCs

- InSAR data provide independent measure of effusion rates. Recent data from CoSSCs have imaged activity that was unknown to IG

- Interferograms provide the only source of deformation measurement, important for assessing whether magma is accumulating

User Feedback

- **Patricia Mothes**, Geophysicist, Instituto Geofísico (Ecuador)
- **Luis Lara, Director**, Observatorio Volcanológico de los Andes del Sur (OVDAS, Chile)
- **Carlos Andrés Laverde**, Geohazards Direction team, Colombian Geological Survey (Colombia)
- **Gustavo A. Chigna**, volcanologist, INSIVUMEH (Guatemala)
- **Lourdes Narvaes Medina**, volcanologist, Observatorio Vulcanologio y Seismologico de Pasto (Colombia)
- **John Pallister**, Chief, Volcano Disaster Assistance Program, U.S. Geological Survey (USA)
- **Ing. Victor Aguilar Puruhuaya**, Jefe de Sismología, Instituto Geofísico, Universidad Nacional San Agustin de Arequipa (Perú)
- **Armando Saballos**, Dirección Gral. de Geología y Geofísica, INETER (Nicaragua)
- **Christina Neal**, Scientist-in-Charge, Hawaiian Volcano Observatory, U.S. Geological Survey (USA)

Lessons learned

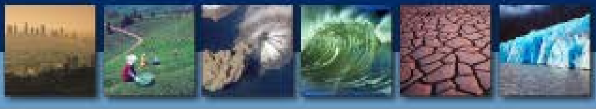
6 principles for SAR component of a global satellite monitoring system:

- A volcano monitoring system must involve **multiple space agencies and satellite platforms** to make the most of each satellite system, to get nearly daily coverage when needed and to have updated high resolution topographic maps
- **Data quotas** should be assigned for a) systematic background observations using the needed observing mode (spatial resolution, polarization, etc.), b) case studies requiring dense datasets and c) flexible response to unrest and eruption.
- A **systematic background mission** using ascending and descending passes should take into account both the level of activity at each volcano and the temporal and spatial baselines required to form coherent interferograms and observe deformation transients

Lessons learned

- **Acquisition plans need to be flexible** to accommodate changes in activity, evolving methods and improved understanding of data types
- **Near real-time data access** is vital for decision making, requiring frequent overpasses, rapid tasking and short data latency
- **Coordination between space agencies, scientists and volcano observatories is crucial** in order to provide an operational response and avoid conflicting requests for satellite tasking or interpretations of satellite observations to observatories.

References



RESEARCH

Towards coordinated regional multi-satellite InSAR volcano observations: Results from the Latin America pilot project

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Abstract
Within Latin American, about 315 volcanoes have been active in the Holocene, but 202 of these volcanoes have no seismic, deformation or gas monitoring. Following the 2012 Santorini Report on satellite Earth Observation and Geohazards, the Committee on Earth Observation Satellites (CEOS) developed a 3-year pilot project to demonstrate how satellite observations can be used to monitor large numbers of volcanoes cost-effectively, particularly in areas with scarce instrumentation and/or difficult access. The pilot aims to improve disaster risk management (DRM) by working directly with the volcano observatories that are governmentally responsible for volcano monitoring as well as with the international space agencies (ESA, CSA, ASI, DLR, JAXA, NASA, CNES) to make sure that the most useful data is collected at each volcano following the guidelines of the Santorini report that observation frequency is related to volcano activity. Here we highlight several examples of how satellite observations have been used by volcano observatories to monitor volcanoes and respond to crises. Our primary tool is measurements of ground deformation made by Interferometric Synthetic Aperture Radar (InSAR) but thermal and outgassing data have been used in a few cases. InSAR data have helped to determine the alert level at these volcanoes, served as an independent check on ground sensors, guided the deployment of ground instruments, and aided situational awareness. We describe several lessons learned about the type of data products and information that are most needed by the volcano observatories in different countries. We propose a strategy for regional to global satellite volcano monitoring for use by volcano observatories in Latin America and elsewhere.

Keywords: Remote sensing; Latin America; InSAR

Introduction

Unlike most other types of geohazards, many volcanic eruptions are presaged by volcanic unrest lasting a few hours to months (e.g., Passarelli and Brodsky, 2012; Phillipson et al., 2013). Pre-eruptive unrest has been measured by satellite observations in the months to years before several eruptions and has included changes in surface temperature, ground deformation, and variations in the flux of gases from the volcano (e.g., Biggs et al., 2014; Chaussard et al., 2013; Dehn et al., 2002; Delgado et al., 2014b; McCormick et al., 2012; Pieri and Abrams, 2005). These space-based observations are critical for discovering unrest at otherwise un-

A summary publication describes the Latin America aspect of the pilot project, lessons learned, and potential future applications (submitted to Journal of Applied Volcanology).

Thank you