Status Report on Volcano Pilot Project

Mike Poland (USGS)
Simona Zoffoli (ASI)

WG Disasters #5
Bonn, Germany
8 -10 March, 2017

Overview

- Motivation and objectives
- Data usage
- New results
- Interfacing with end users
- Milestones
- Issues

Pilot Team

Juliet Biggs, David Arnold, James Hickey, Susi Ebmeier (*University of Bristol*)

Matt Pritchard, Francisco Delgado (*Cornell University*)

Christelle Wauthier, Kendall Wnuk (*Penn State University*)

Falk Amelung (*University of Miami*)

Fabrizio Ferrucci (*Open University*)

Mike Pavolonis (*NOAA*)

Rick Wessels (*USGS*)

Eugenio Sansosti (*IREA-CNR*)

Volcano Pilot

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

WHY?

- **Over 300,000 people have been killed by volcanoes since the 1600s.**
- **Hundreds of millions live within 20 km of an active volcano today.**
- **In 2010, the Eyjafjallajökull eruption brought losses of $200m/day, and 100,000 cancelled flights.**

Volcano Pilot

Bardarbunga, Iceland, erupting in 2014.
Photo credit: M Parks

WHAT IS MISSING?

- **Large monitoring gaps exist at many hazardous volcanoes around the world**
- **Current EO data collection is not usually coordinated for volcano monitoring**
- **Need systematic observations before, during, and after volcanic events**

Pilot objectives

Objective A – Regional Demonstration

Demonstrate the feasibility of global volcano monitoring of Holocene volcanoes by undertaking regional monitoring of volcanic arcs in Latin America, stretching from Mexico to southern Chile, and including the Lesser Antilles, using satellite EO data to track deformation as well as gas, ash, and thermal emissions.

Objective B – Geohazard Supersites and Natural Laboratories

Multi-disciplinary, multi-platform monitoring of a few volcanoes that represent a diverse cross section of eruptive activity and unrest.

Objective C – Significant Global Event

Specific studies in case of a major eruption with significant regional or global impact, providing data for a comprehensive analysis of all aspects of the eruption cycle, including local (e.g., mass flows on the volcanic slopes), regional (e.g., ash emissions that may be hazardous to aircrafts), and global (e.g., volatile and aerosol emissions that may influence climate) impacts.

Objective B: Supersites

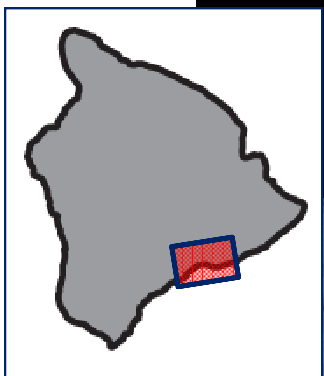
- Work continues on approved volcano Supersites:
  - Hawai‘i
  - Iceland
  - Italy
  - Ecuador
  - New Zealand
- Critical for hazards assessment and mitigation efforts and highly valued by local agencies
- Volcano supersites provide opportunities for scientific innovation due to the availability of high spatial and temporal resolution datasets

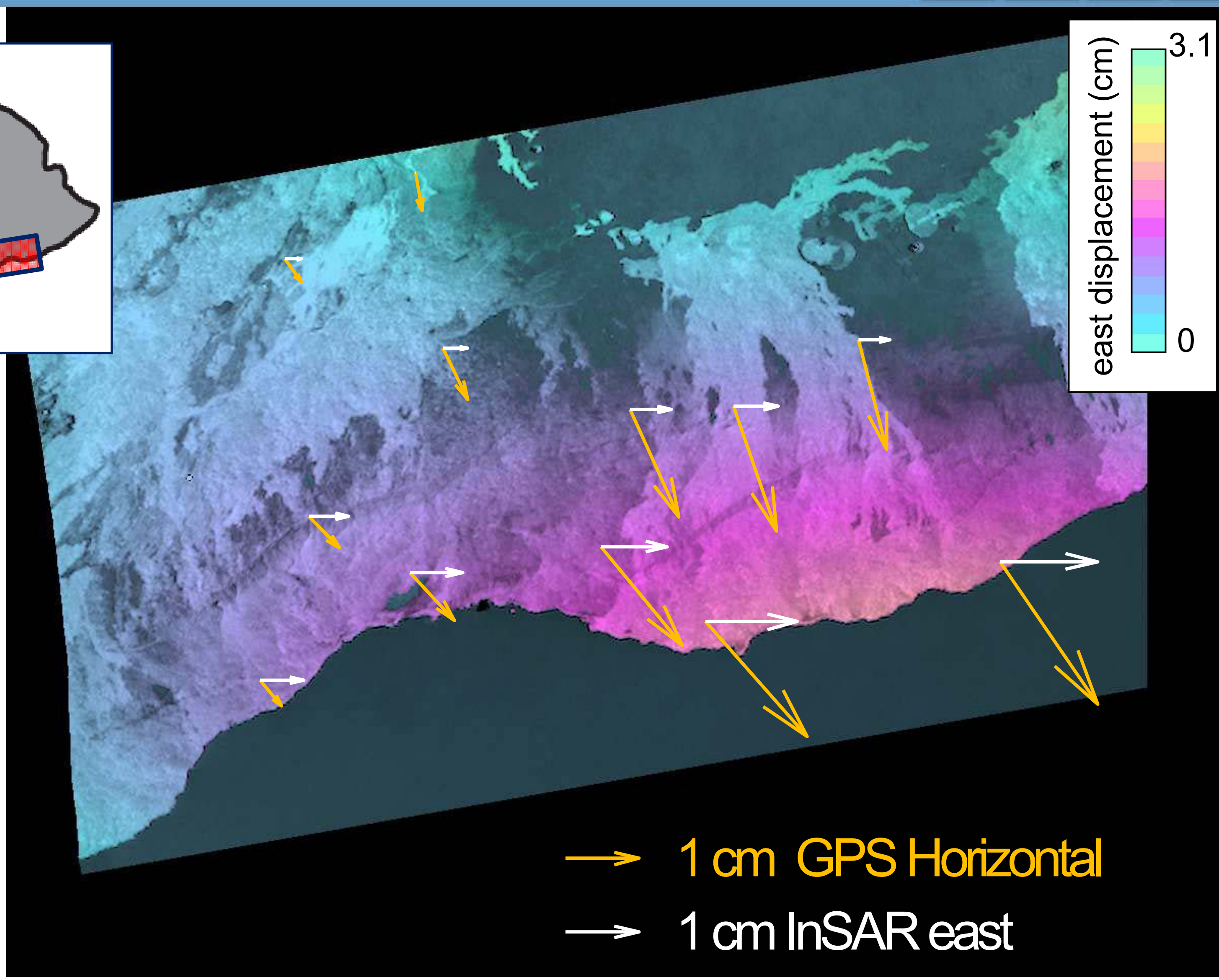
WG Disasters #5
Bonn, Germany
8-10 March, 2016

Objective B: Supersites (hazards)

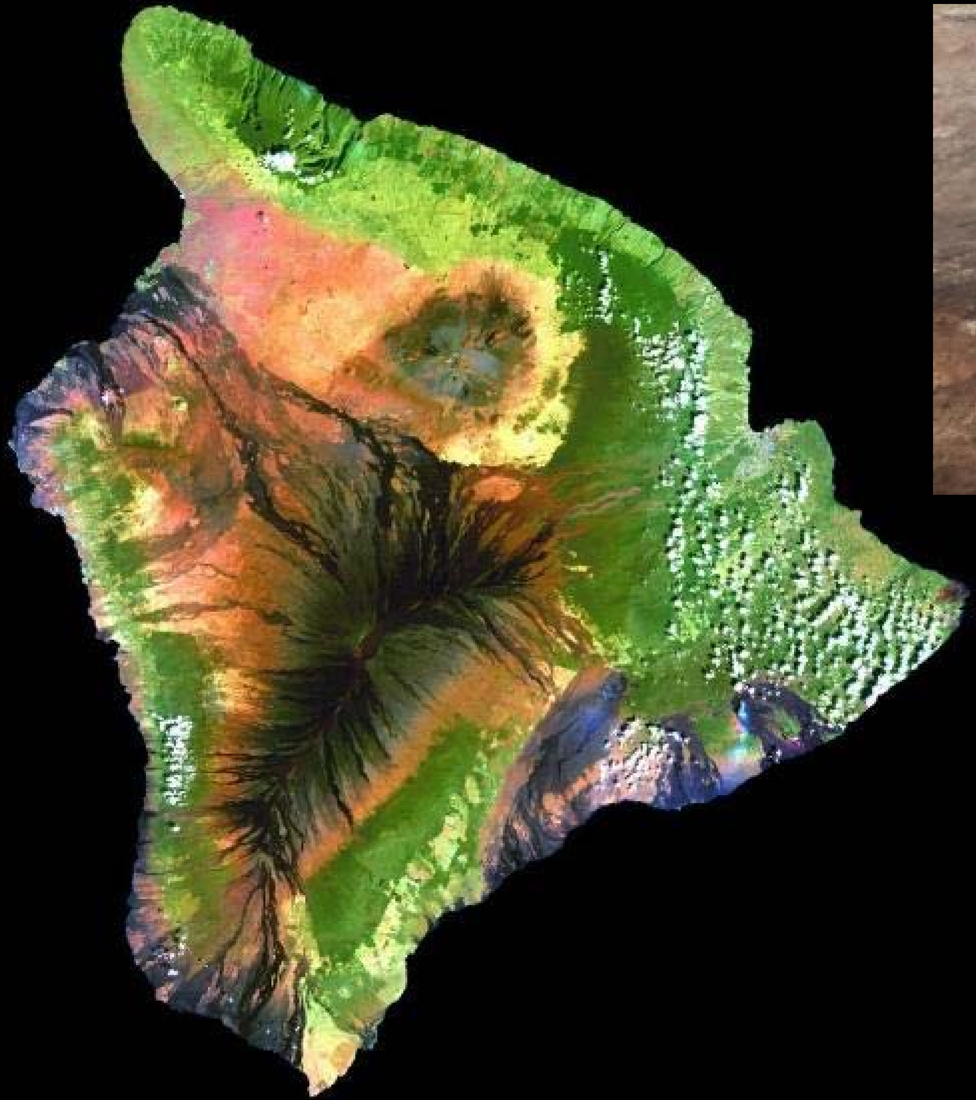
WG Disasters #5
Bonn, Germany
8-10 March, 2016

Objective B: Supersites (science)





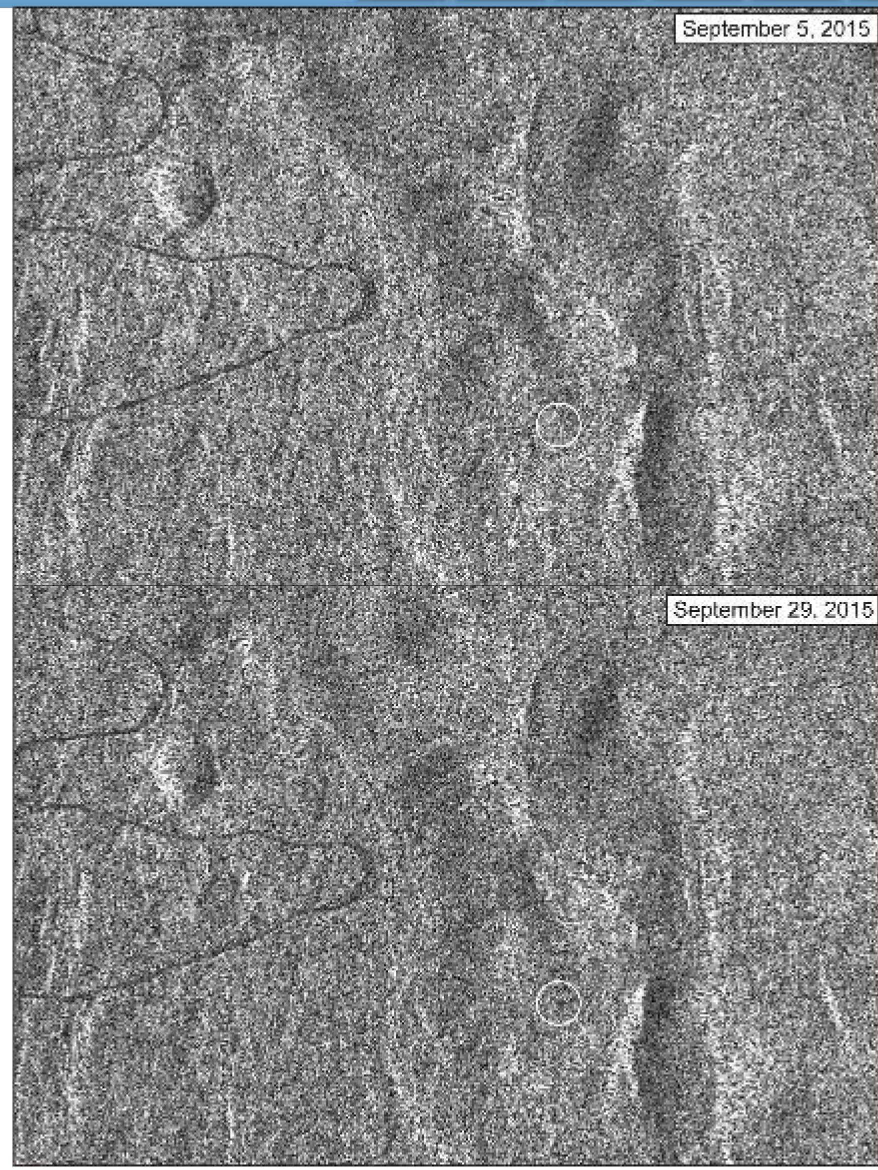
Objective B: Supersites (both!)



Mauna Kea

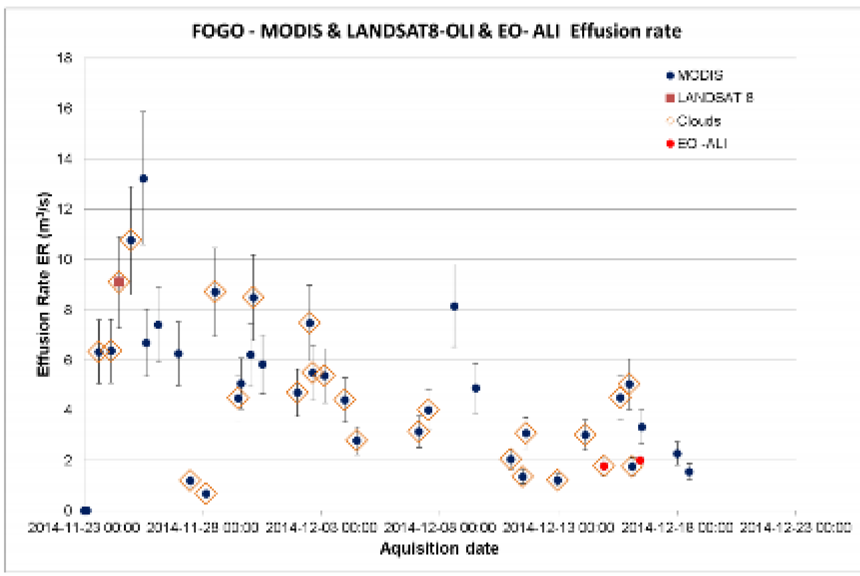
Home to several world-class telescopes

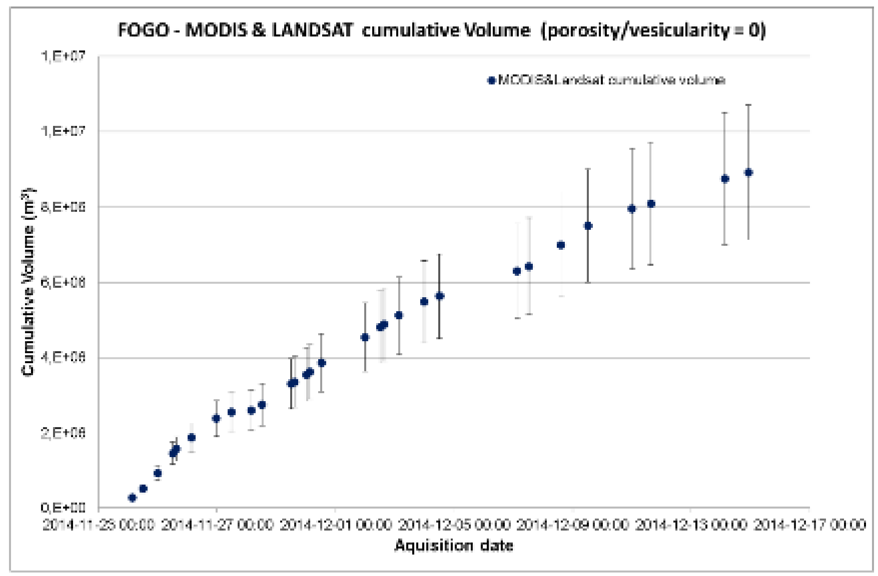
Objective B: Supersites (both!)



Objective C: Large event

- Proposal has been submitted to ensure rapid access to data if a large volcanic event occurs
- Fogo eruption serves as a demonstration





courtesy Fabrizzio Ferucci, Open University

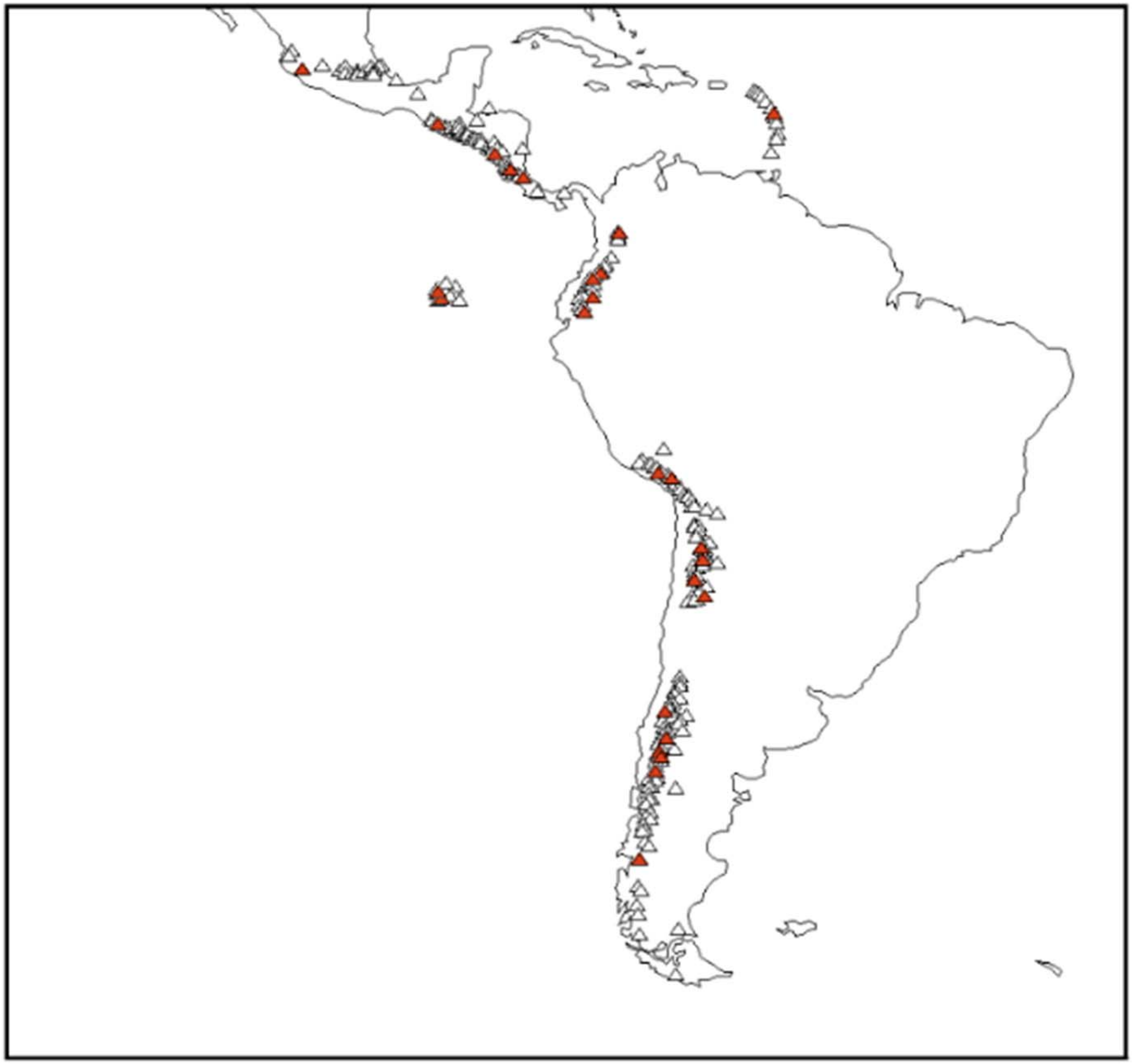
WG Disasters #5
Bonn, Germany
8-10 March, 2016

Objective A: Regional demonstration

- Demonstrate how EO data can be used to cost-effectively monitor all 315 volcanoes in the region that erupted in the last 10,000 years
- Identify volcanoes that may became active in the near future
- Track new and ongoing eruptive activity

Why Latin America?

- Diversity of environments
- Abundant volcanic activity
- Benefits to local users
- 64% of volcanoes in the region have no ground monitoring of any type



Objective A Efforts by Partner

Topic/region	Value Added Partner
Northern Andes and Lesser Antilles SAR	University of Bristol
Southern and Austral Andes SAR	Cornell University
Galápagos SAR	IREA/CNR
Mexico SAR	University of Miami
Central America SAR	Penn State, University of Bristol
Detection of ash plumes and thermal anomalies	NOAA
Development and testing of EO-based methodology for improved monitoring of surface deformation	All
Capacity-building and training activities in countries that do not currently have access to abundant EO data and/or the ability to process and interpret such data	All
Collect feedback from users	All

SAR Data Usage

Mission	Ordered / Allocated	Noteworthy results
RADARSAT-2	**235 / 270**	Cordon Caulle, Pacaya, Villarica
COSMO-SkyMed	**381 / 600**	Cordon Caulle, Chiles – Cerro Negro, Villarica
TSX	**135 / 400**	Chiles – Cerro Negro, Ubinas
ALOS-2	**84 / 200**	Momotombo, Santiaguito
TDX (CoSSC exp.)	**14/150**	Reventador, Soufriére Hills Volcano

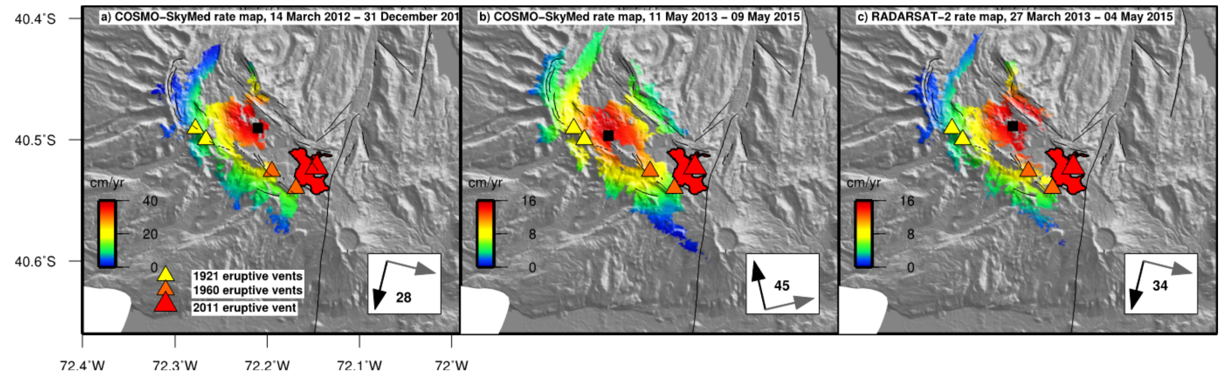
*Sentinel-1A data have not been included, since those data are distributed at no cost and with no restrictions.

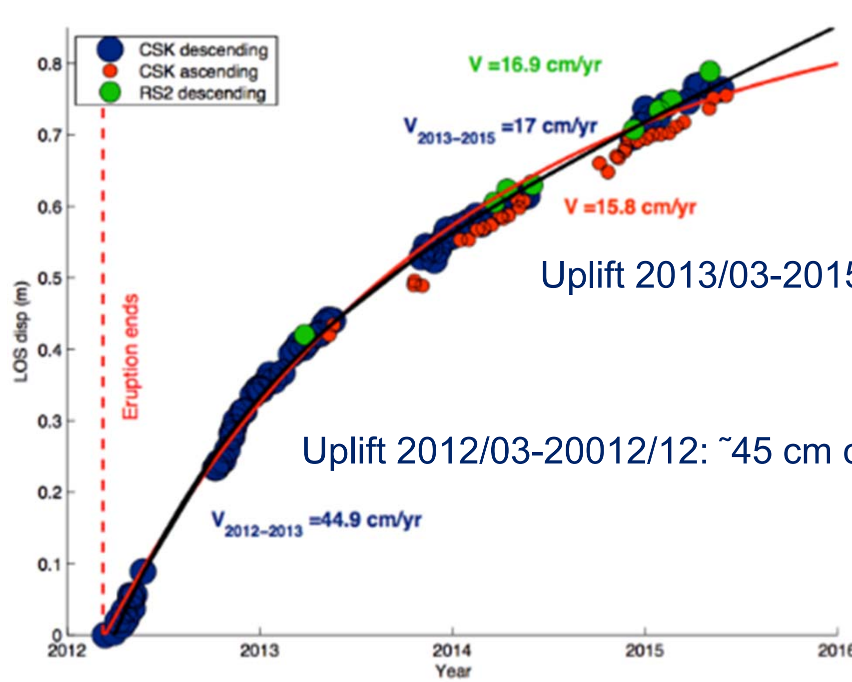
How have satellite data been useful?

- 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 (*Calbuco*, *Momotombo*)
- Filled “gaps” at volcanoes that have some ground-based monitoring (*Tungarahua*, *Pacaya*, *Santiaguito*)
- Provide otherwise inaccessible data (*Reventador*, *SHV*)
- Research (*Ubinas*)

Results: Cordón Caulle

- Rapid uplift following end of 2011-2012 eruption
- Uplift is aseismic (no associated earthquakes)
- OVDAS **wants** to deploy a GPS based, but had to postpone due to the Villarrica and Calbuco eruptions in 2015
- Recognition of uplift motivated NOAA to increase detection sensitivity for ash and thermal anomalies



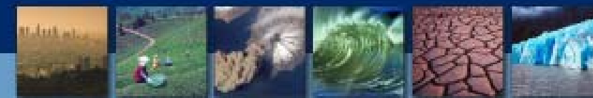


Uplift 2013/03-2015/06: ˜16 cm/yr uplift

Uplift 2012/03-20012/12: ˜45 cm cm/yr

CEOS
WG Disasters #5
Bonn, Germany
8-10 March, 2016

Results: automated alerts



CIMSS » Volcanic Cloud Monitoring » Event Alerts » 2016-02-21

Volcanic Cloud Monitoring — NOAA/CIMSS (BETA)

Home | Satellite Imagery | Alerts | Coverage Map | Tutorials | Logout (rwessels@usgs.gov)

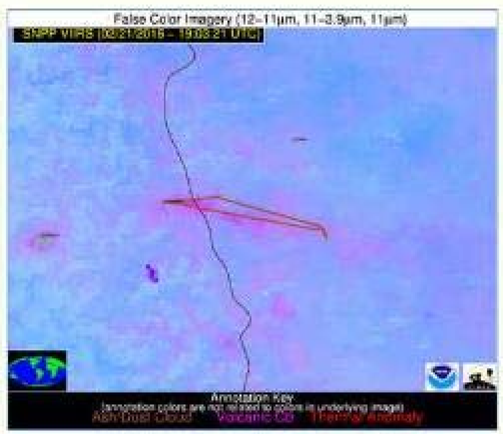
Volcanic Cloud Alert Report

DATE:	2016-02-21
TIME:	19:03:21
Production Date and Time:	2016-02-21 21:47:39 UTC
PRIMARY INSTRUMENT:	NPP VIIRS

More details ▼

Possible Volcanic Ash Cloud

False Color Image (12-11, 11-8.5, 11) [zoomed-in]



False Color Image (12-11, 11-3.9, 11) [zoomed-in]

Basic Information

Volcanic Region(s)	South America
Country/Countries	Chile-Argentina
Volcanic Subregion(s)	Central Chile and Argentina
VAAC Region(s) of Nearby Volcanoes	Buenos Aires
Mean Object Date/Time	2016-02-21 19:03:21UTC
Radiative Center (Lat, Lon):	-37.860 °, -71.180 °
Nearby Volcanoes (meeting alert criteria):	Copahue (0.00 km) Callaqui (24.50 km) Trolon (27.70 km) Mariñaqui, Laguna (46.70 km) Antuco (52.20 km)
Maximum Height [AMSL]	2.50 km; 8202 ft
90th Percentile Height [AMSL]	2.10 km; 6890 ft
Mean Tropopause Height [AMSL]	16.40 km; 53806 ft

Show More ▲ | View all event imagery »

courtesy Mike Pavolonis, NOAA

CEOS

WG Disasters #5
Bonn, Germany
8-10 March, 2016

Results: automated alerts

CIMSS » Volcanic Cloud Monitoring » Event Alerts » 2016-02-23

Volcanic Cloud Monitoring — NOAA/CIMSS (BETA)

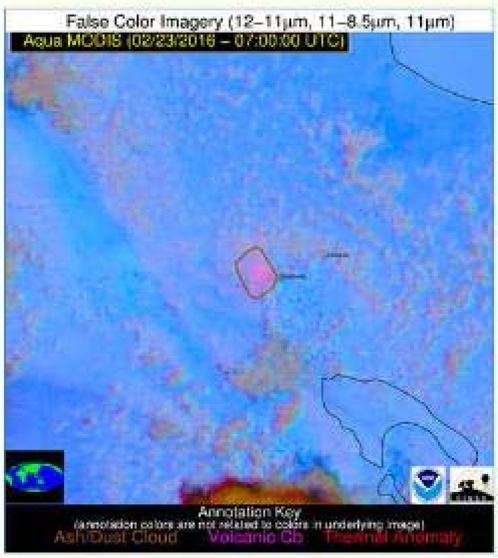
Home | Satellite Imagery | Alerts | Coverage Map | Tutorials | Logout (rwessels@usgs.gov)

Volcanic Cloud Alert Report

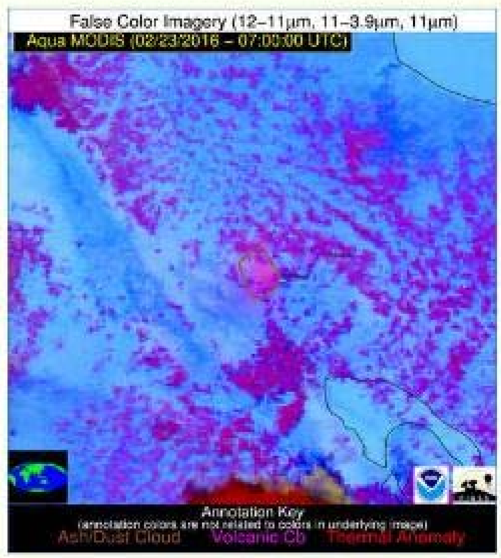
DATE:	2016-02-23
TIME:	07:00:00
Production Date and Time:	2016-02-23 08:31:58 UTC
PRIMARY INSTRUMENT:	Aqua MODIS

More details ▼

Possible Volcanic Ash Cloud



False Color Image (12-11, 11-8.5, 11) [zoomed-in]



False Color Image (12-11, 11-3.9, 11) [zoomed-in]

Basic Information

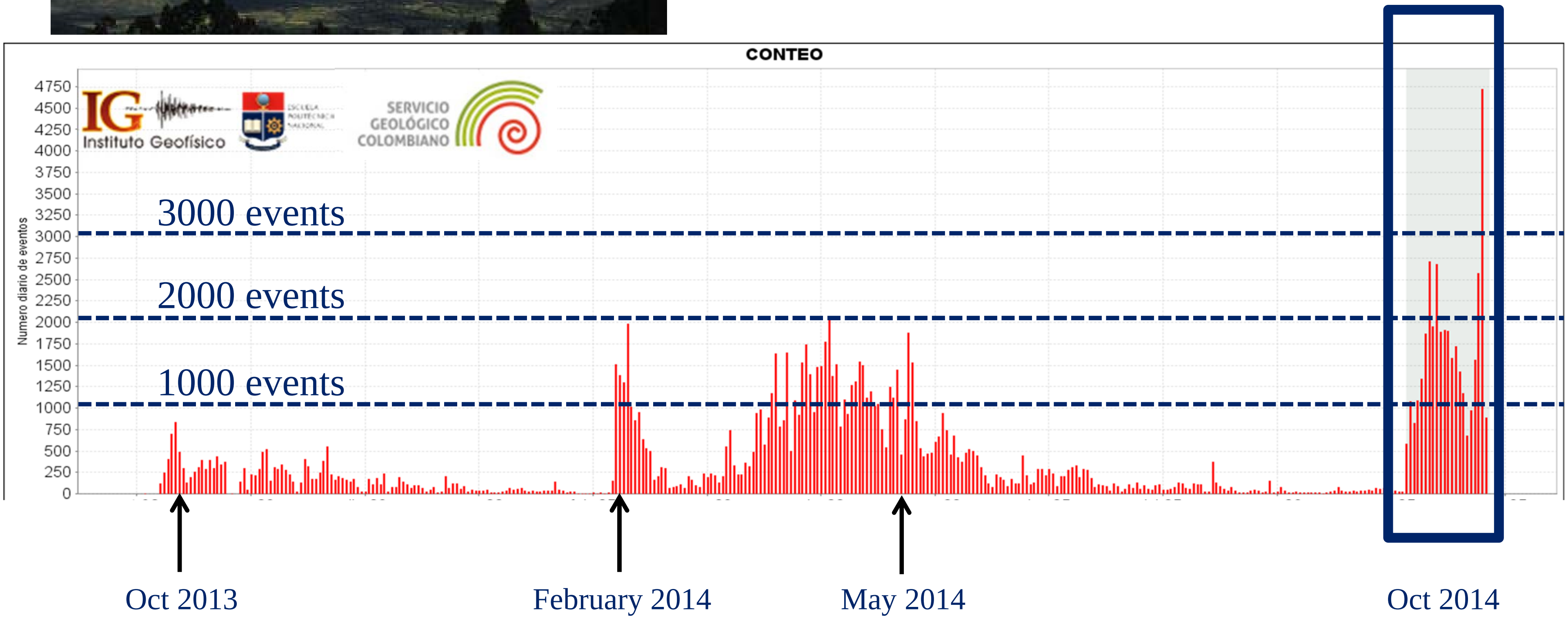
Volcanic Region(s)	Indonesia
Country/Countries	Indonesia
Volcanic Subregion(s)	Sumatra
VAAC Region(s) of Nearby Volcanoes	Darwin
Mean Object Date/Time	2016-02-23 07:00:00UTC
Radiative Center (Lat, Lon):	3.170 °, 98.390 °
Nearby Volcanoes (meeting alert criteria):	Sinabung (0.00 km) Sibayak (15.70 km) Toba (81.80 km) Kembar (110.80 km) Imun (127.60 km)
Maximum Height [AMSL]	6.20 km; 20341 ft
90th Percentile Height [AMSL]	5.60 km; 18373 ft
Mean Tropopause Height [AMSL]	16.90 km; 55446 ft

Show More ▲ | View all event imagery »

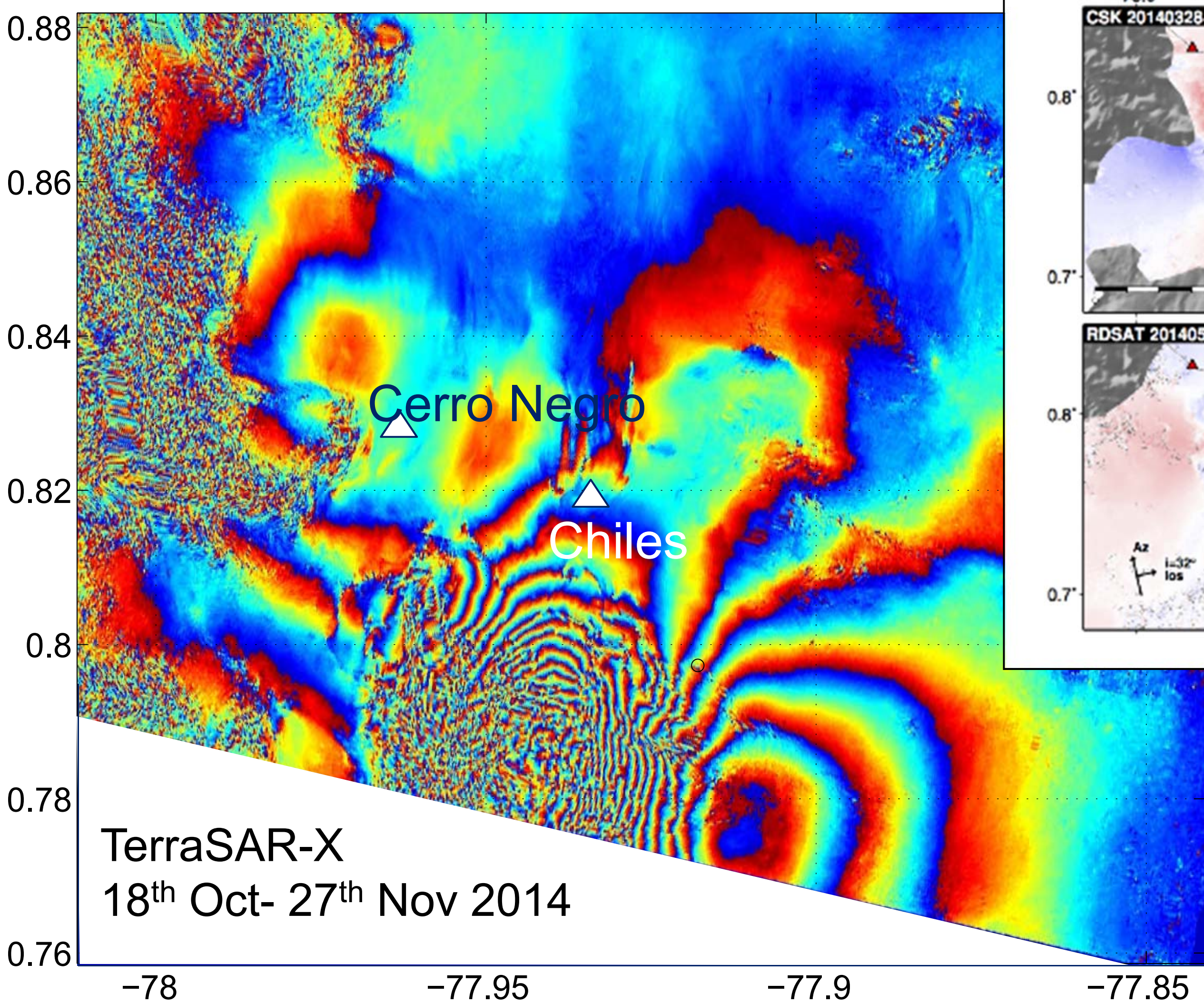
courtesy Mike Pavolonis, NOAA

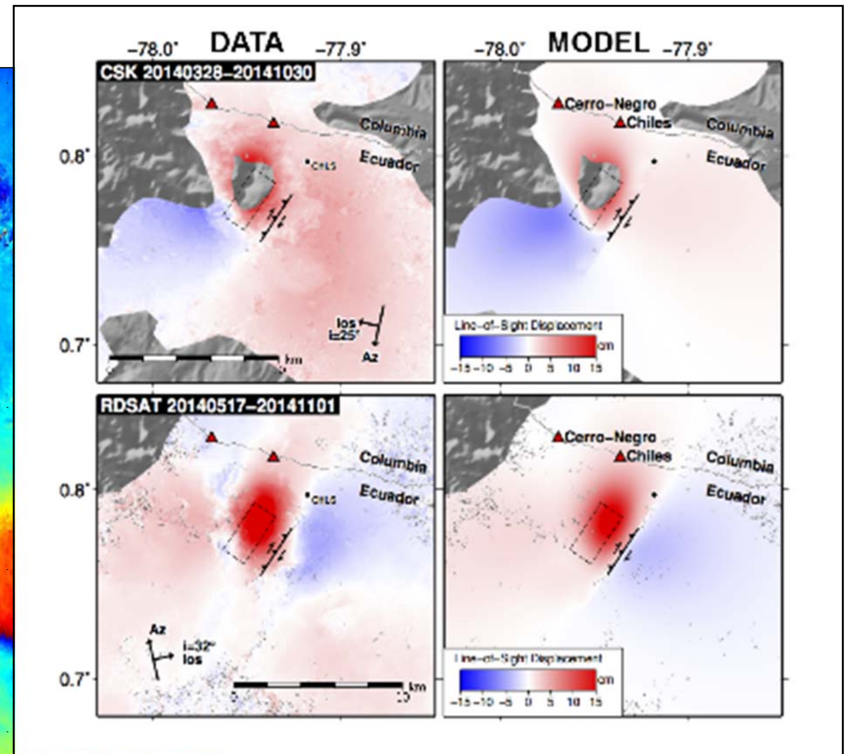
Results: Chiles – Cerro Negro

Seismic unrest 2013-2014



Results: Chiles – Cerro Negro



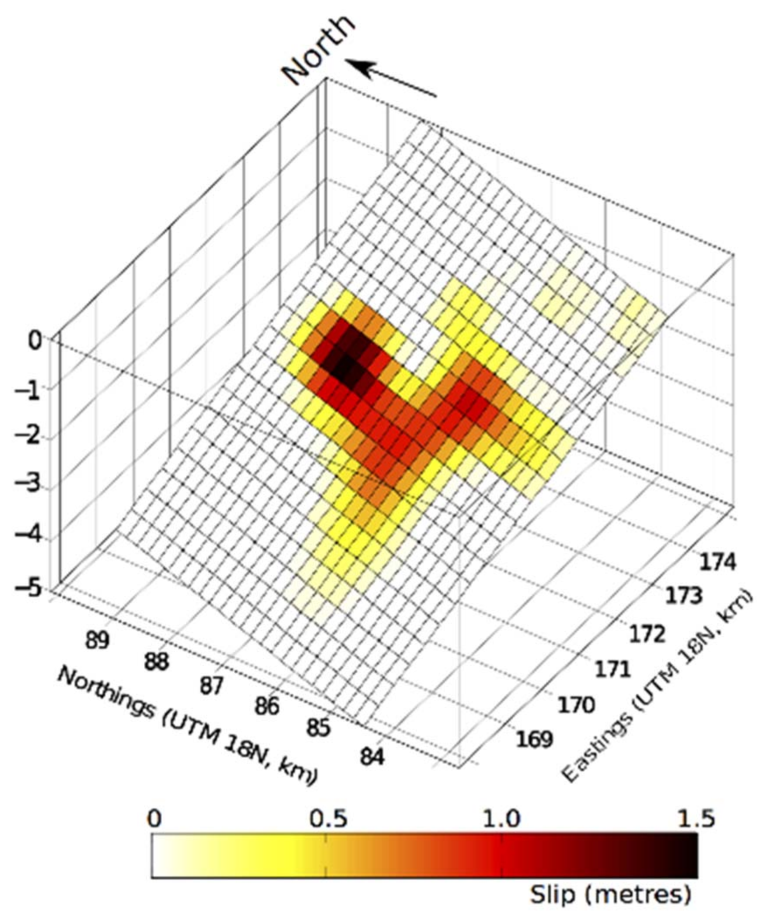


Ground deformation – is it magma or "just" the earthquake?

WG Disasters #5
Bonn, Germany
8-10 March, 2016

Results: Chiles – Cerro Negro

- **Modeling of InSAR data indicate it was "just" the EQ!**
- **Regular CSK and TSX acquisitions were processed as part of the CEOS pilot, and interferograms were provided to the Instituto Geofisico (Ecuador) and Servicio Geologico (Colombia) every ~6 days.**
- **Interferograms, with GPS and decrease in seismic events, were "*in helping us arrive to the decision to lower the alert level from orange to yellow.*" (P. Mothes, IG)**



Results: Calbuco

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

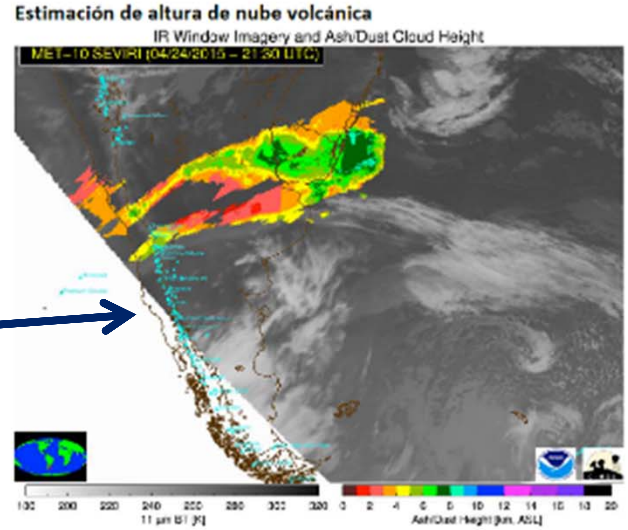
SERVICIO METEOROLÓGICO NACIONAL

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.

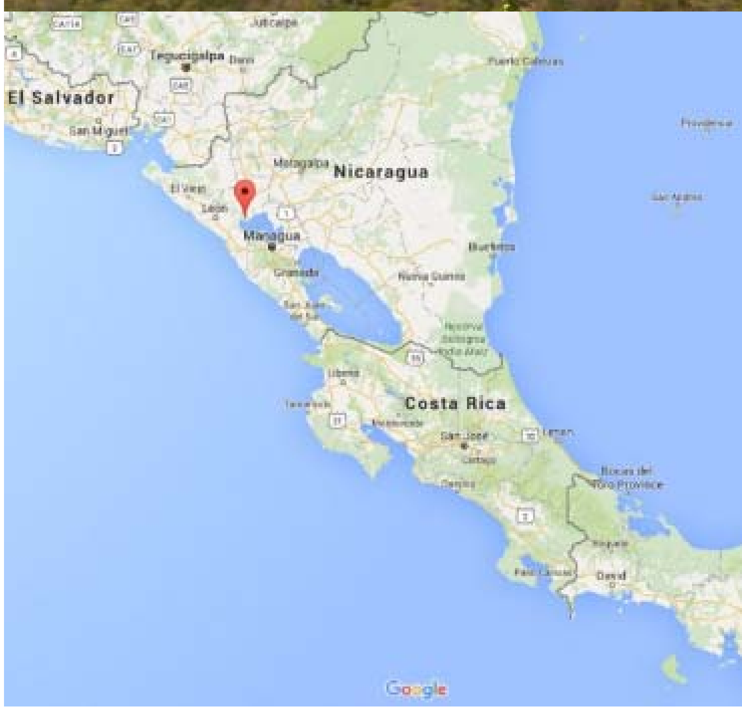
Para conocimiento de la situación regional se adjuntan imágenes EXPERIMENTALES de: a) estimación de altura de nube volcánica y b) estimación de carga de masa

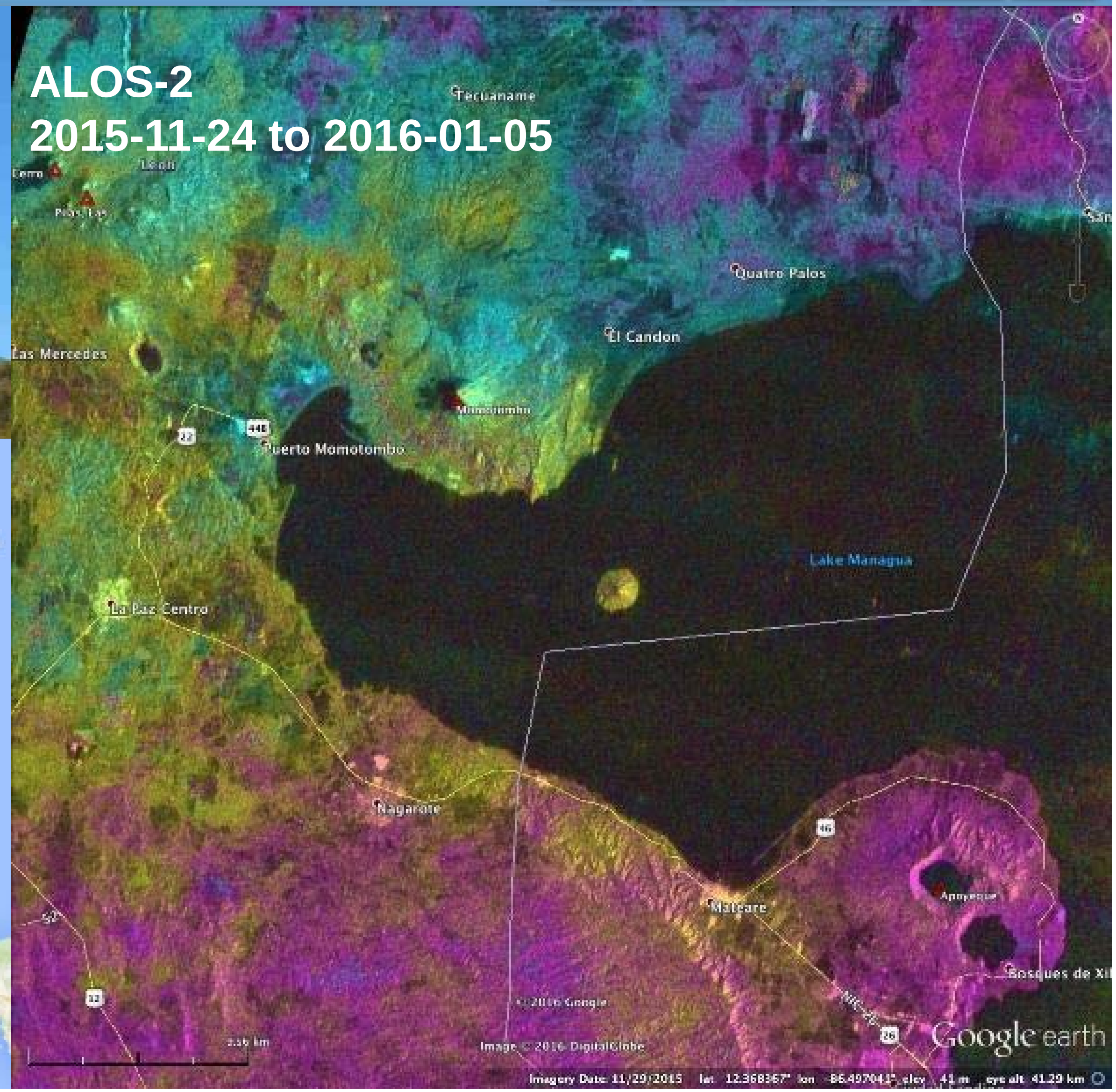
Estimación de altura de nube volcánica



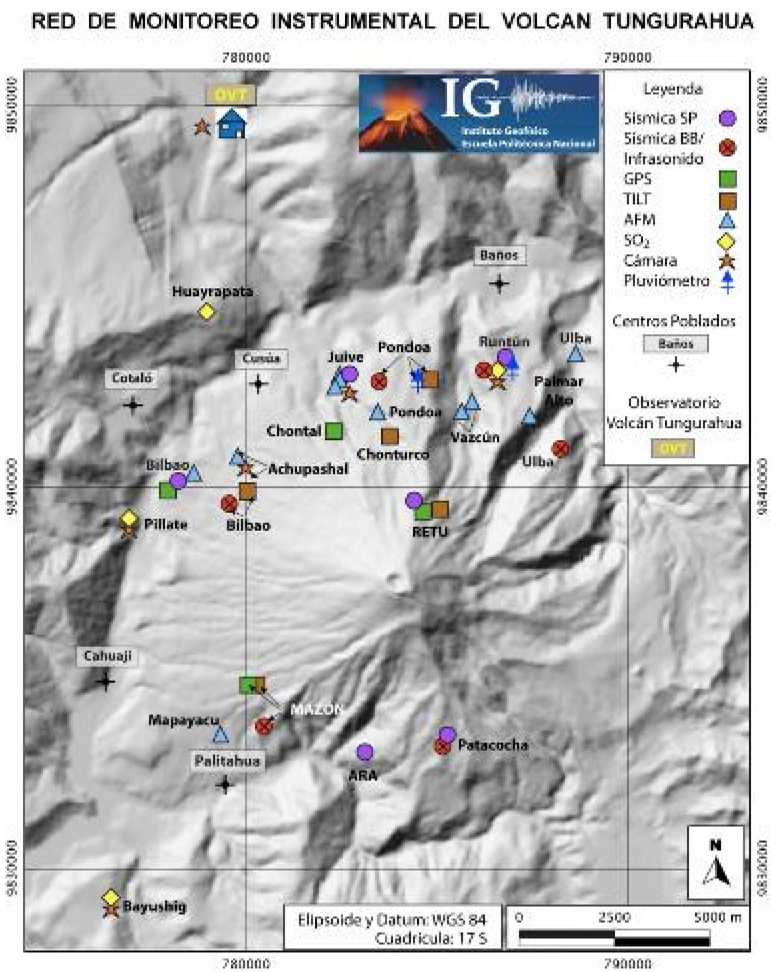
WG Disasters #5
Bonn, Germany
8-10 March, 2016

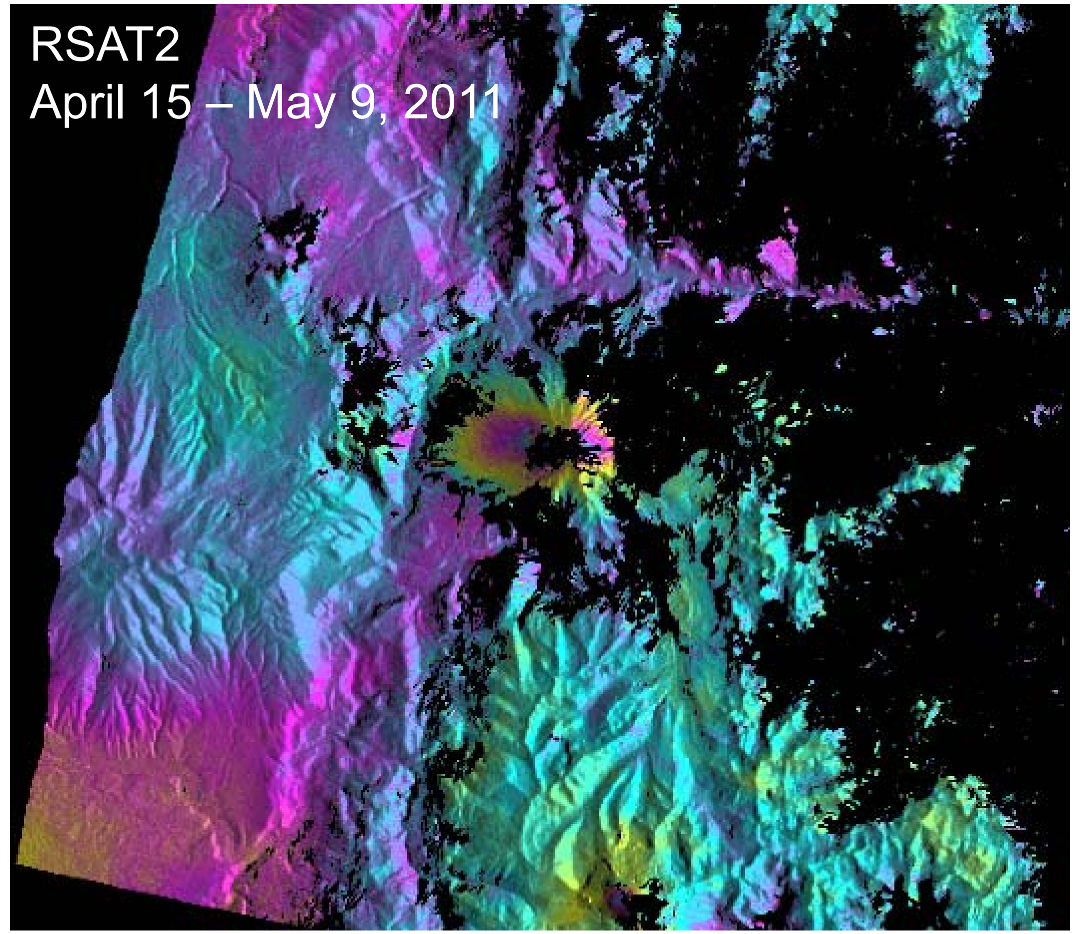
Results: Momotombo





Results: Tungaraua

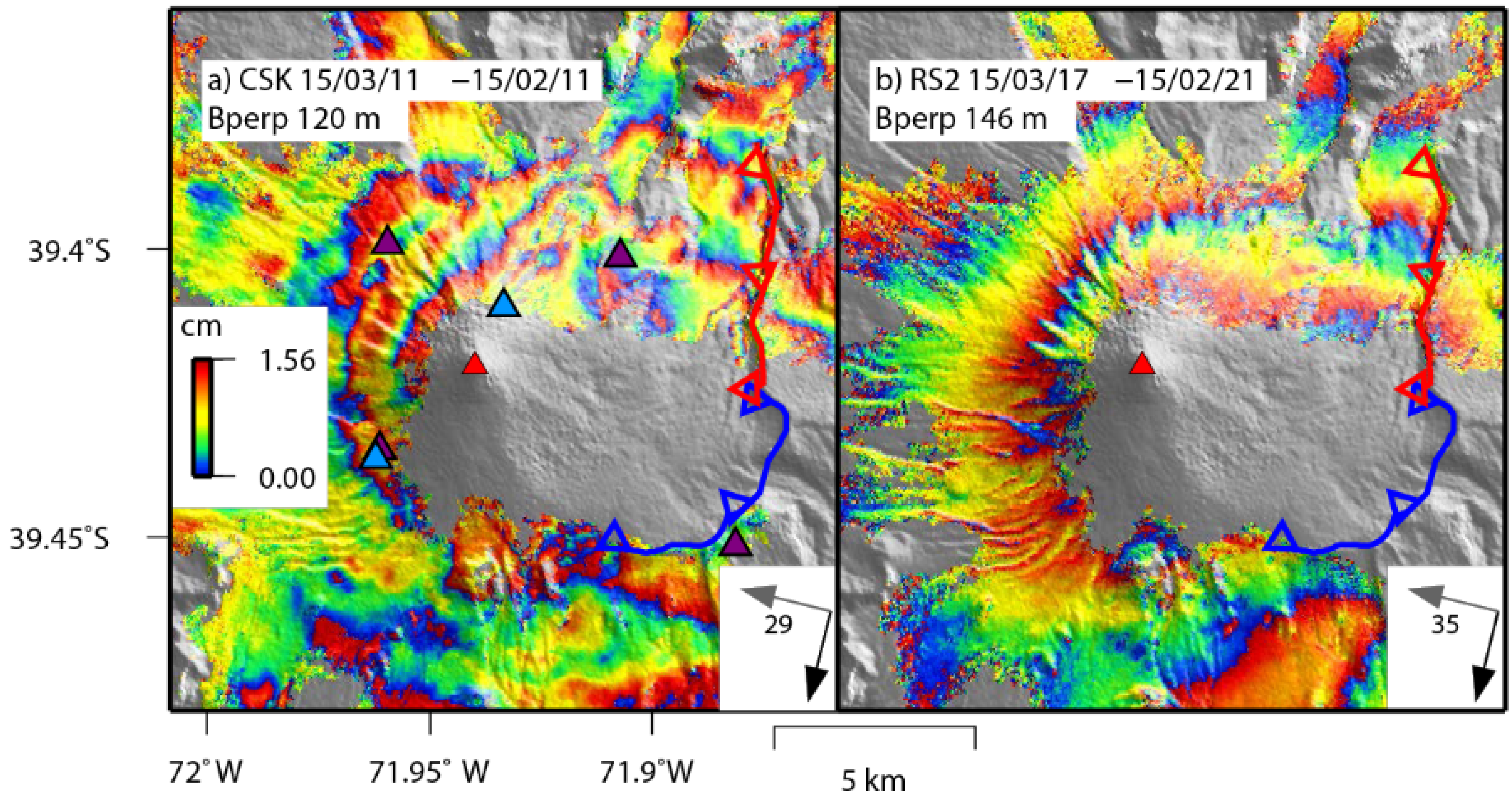




Outcome of CEOS pilot investigation:

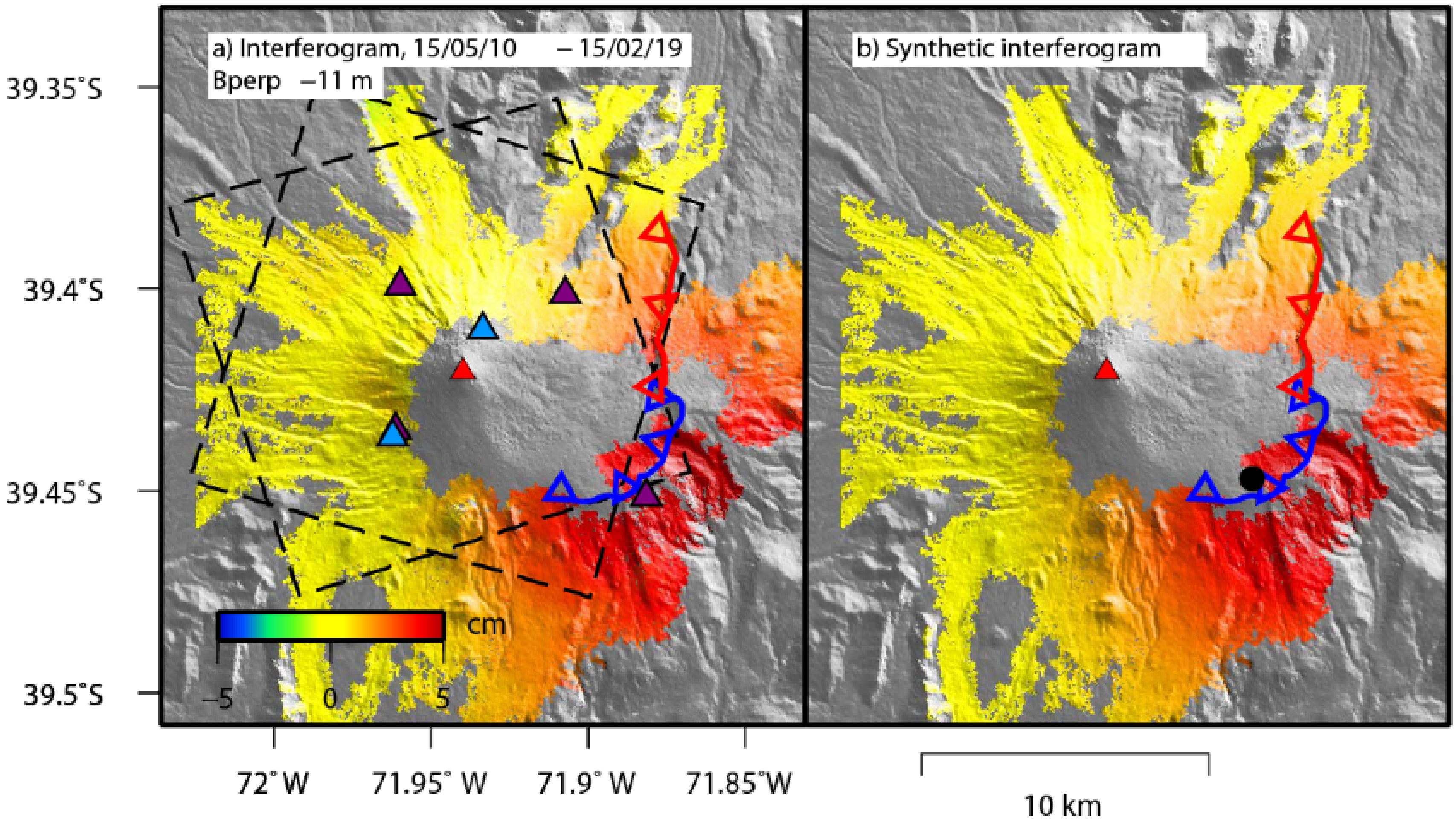
IG installs new ground sensors in monitoring gap

Results: VIllarica



Most dangerous volcano in the southern Andes, experienced a small eruption in March 2015. No clear evidence of co-eruptive deformation from InSAR, GPS (purple triangles), or tilt (blue triangles).

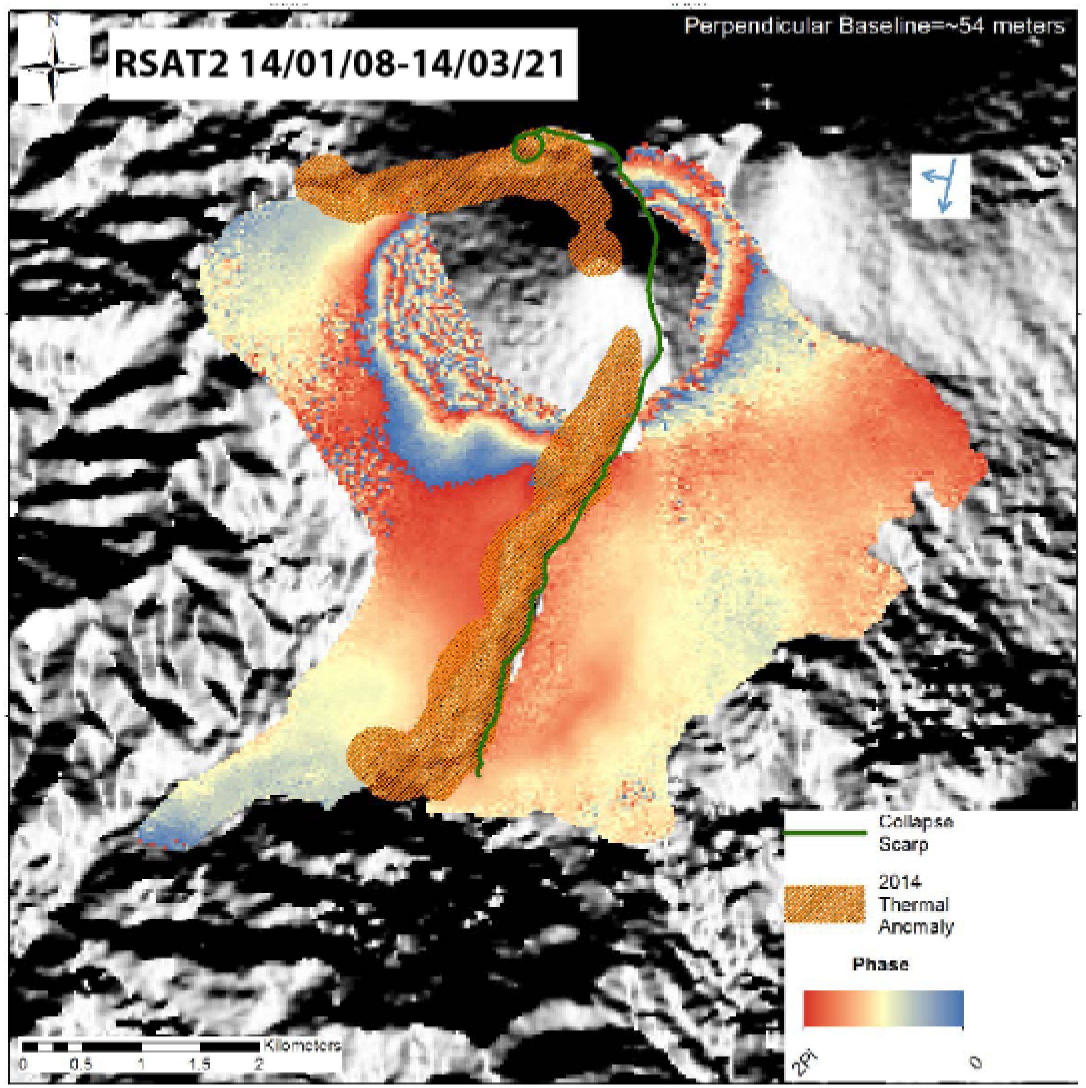
Results: VIllarica



One GPS station (purple triangle) suggested deformation in May 2015. This result was corroborated by InSAR (CSK), and resulted in an increase in the volcano’s alert level.

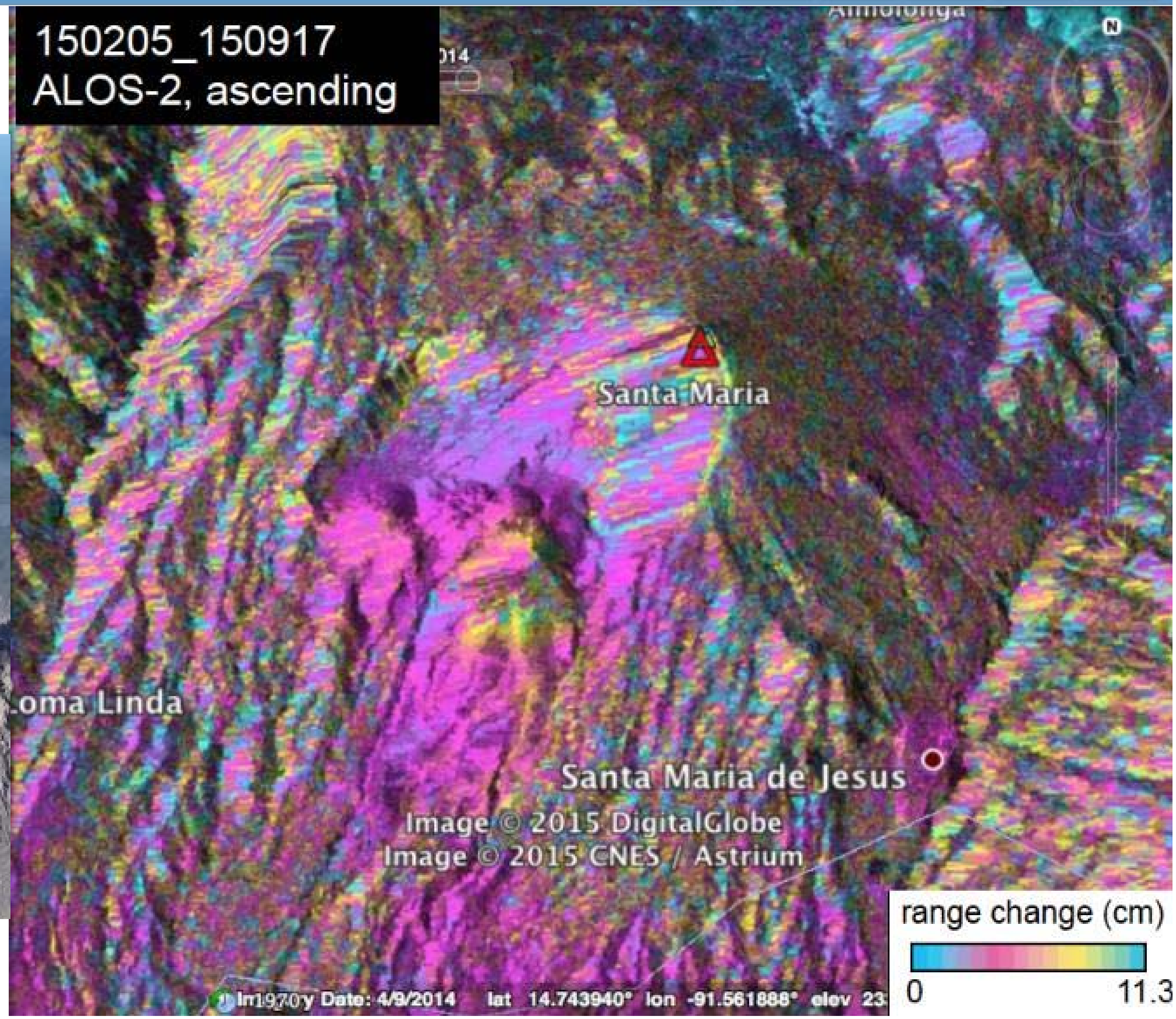
WG Disasters #5
Bonn, Germany
8-10 March, 2016

Results: Pacaya



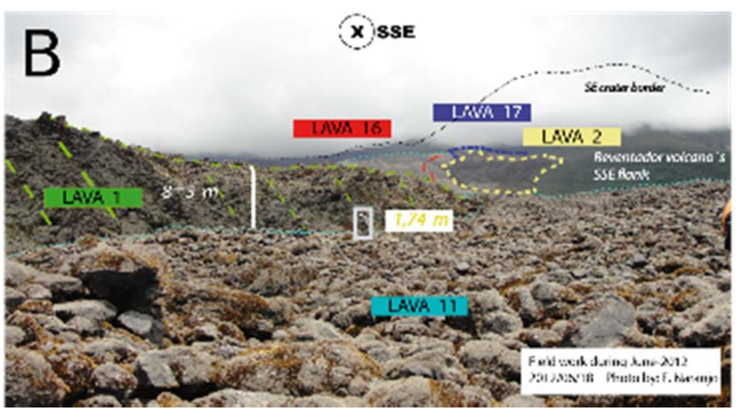
Interferogram spanning the 2014 eruption shows deformation that is likely magmatic in origin on the NE flank, while deformation on the SW flank resembles that from other time periods and is probably related to flank instability.

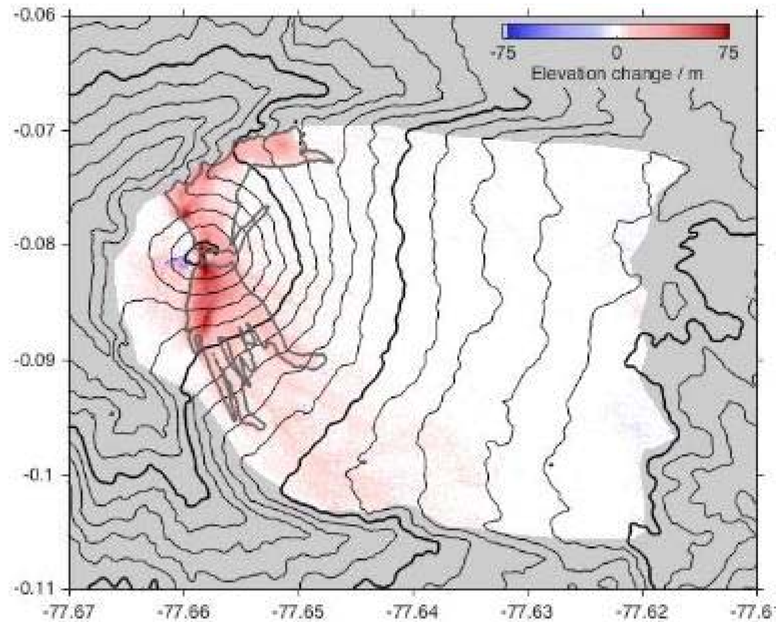
Results: Santiaguito



Results: Reventador

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

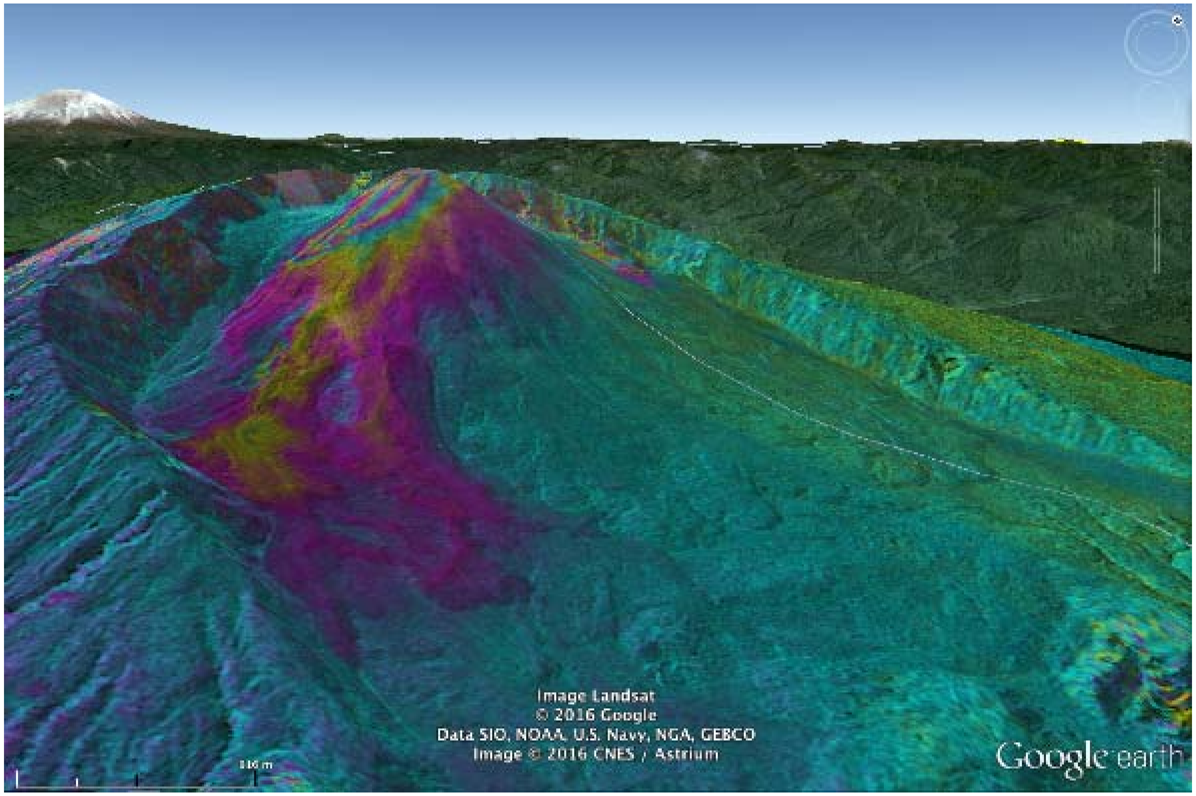




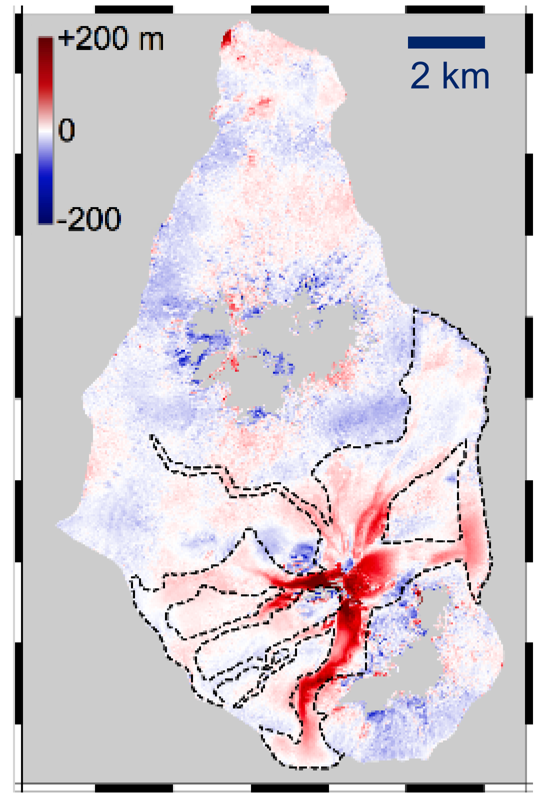
Thickness of new lava flows between 2011 and 2014 from TDX CoSSCs

- 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

Results: TDX for Topography

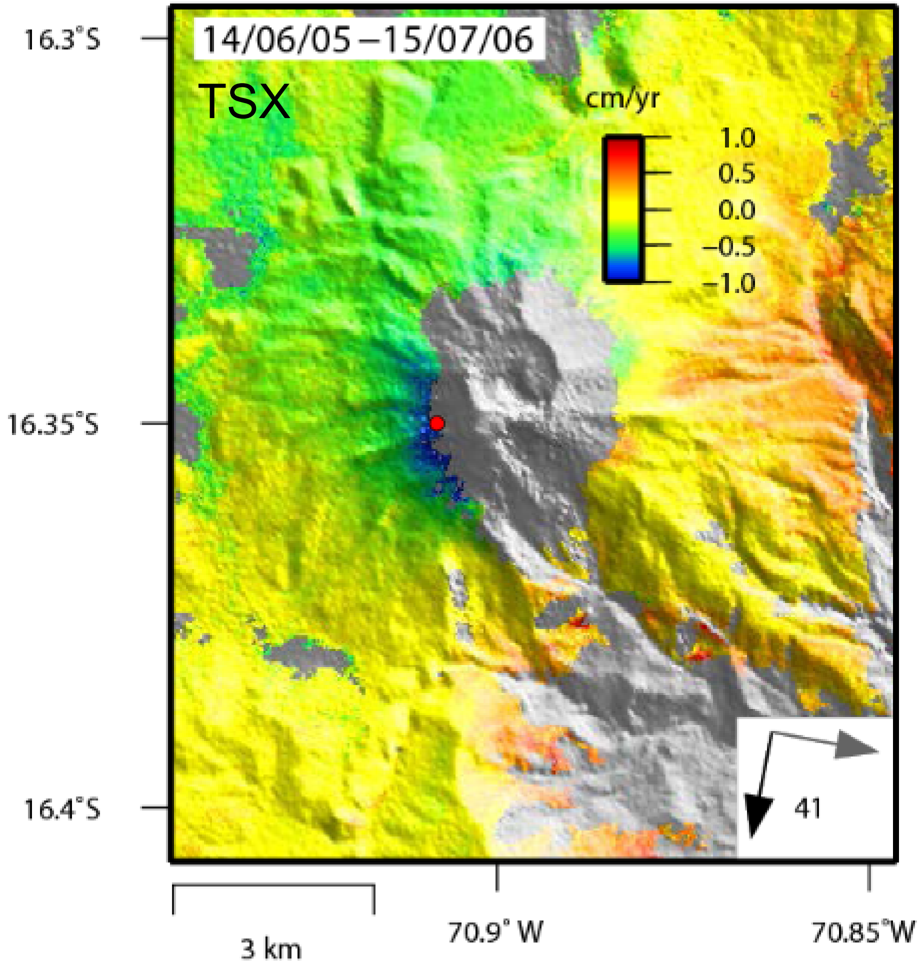


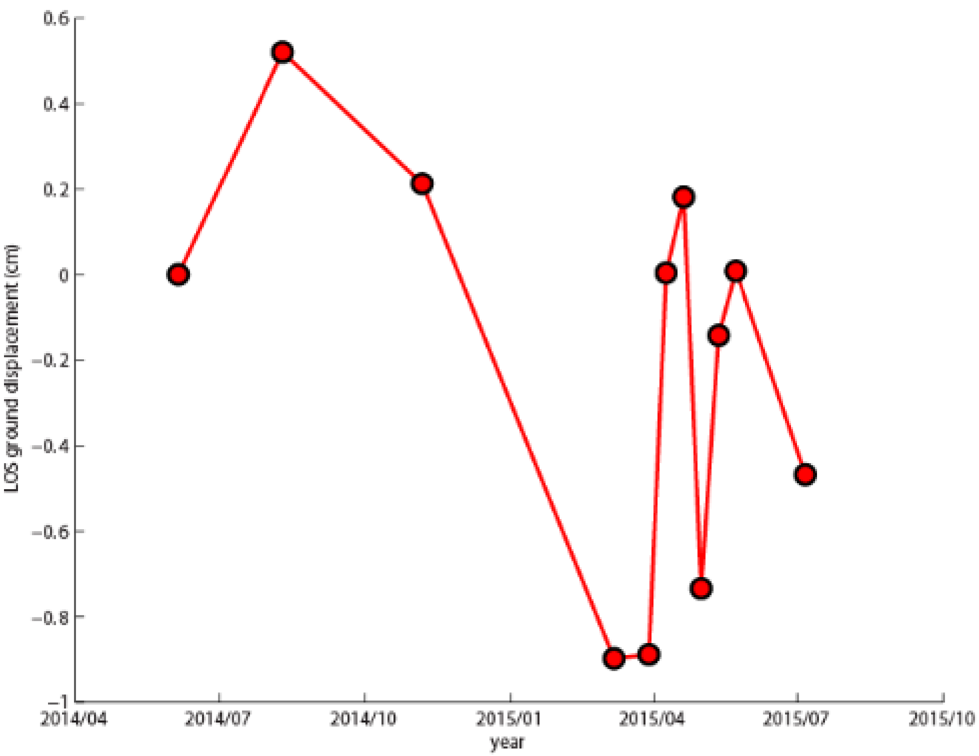
Topographic fringes from a TanDEM-X image pair showing thickness of new lava flows at Volcán Reventador, Ecuador. One complete color cycle corresponds to 25 m of new lava. Images like these supplement limited ground based measurements and allow volcano observatories to see how the rate of eruption is changing over time.



Thickness of volcanic deposits on Montserrat measured by TanDEM-X. These results can be used to update DEMs and improve hazard maps and geophysical models

Results: Ubinas





Most active and dangerous volcano in Peru and in a state of continuous unrest since 2013, with several small eruptions. But no evidence of deformation!

Users—who are they?

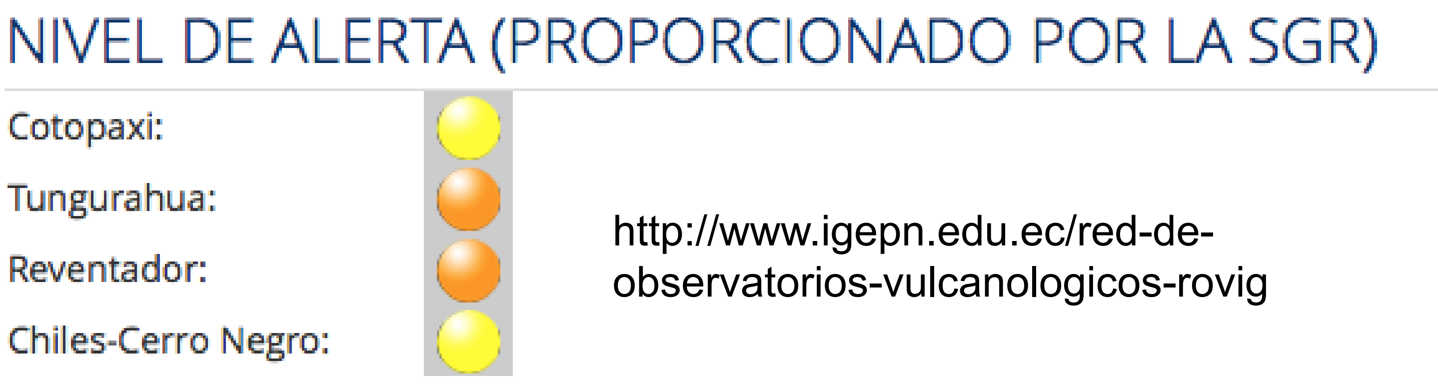
- **End-users are scientists in volcano observatories or VAACs who interface with local government officials**

Users – who are they?

[HAZARD] Volcano observatories are the experts that are governmentally mandated to monitor volcanic hazards and usually set alert levels.

[RISK] The authorities (local or national governmental bodies) have the final decision on response (e.g. evacuation) and have the responsibility to advise the local communities etc.

[ALERTS] In practice, response and communication is directly linked to the alert level. Thus when a volcano observatory changes the alert level, a pre-defined response is triggered and in almost all cases, the recommendations of the volcano observatories are followed.



http://www.igepn.edu.ec/red-de-observatorios-vulcanologicos-rovig

If the CEOS pilot were to communicate directly with the local decision makers and communities, it would potentially undermine the authority of the observatories and bypass the alert system. The technical information would likely be either not used or misunderstood.

User feedback

1.Name of your organization and brief statement of mandate.

2.What satellite data were provided to you as part of the CEOS volcano pilot project? How was the data used? (For example, images used in staff meetings, discussions of volcano alert levels, strategies for deploying ground sensors used in making figures for internal or external distribution, etc.)?

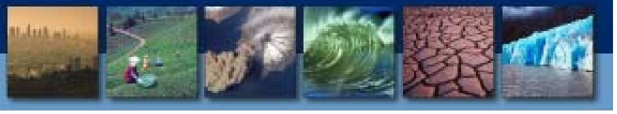
3. Were the data useful? If so, please describe in a few lines what level of products was most useful:

(For example, raw data, interferograms, google earth files, a written summary of the significance of the data, etc.).

If not, how could we improve on the use of satellite data for your needs? For example, by sending data in a more timely manner or in a different format.

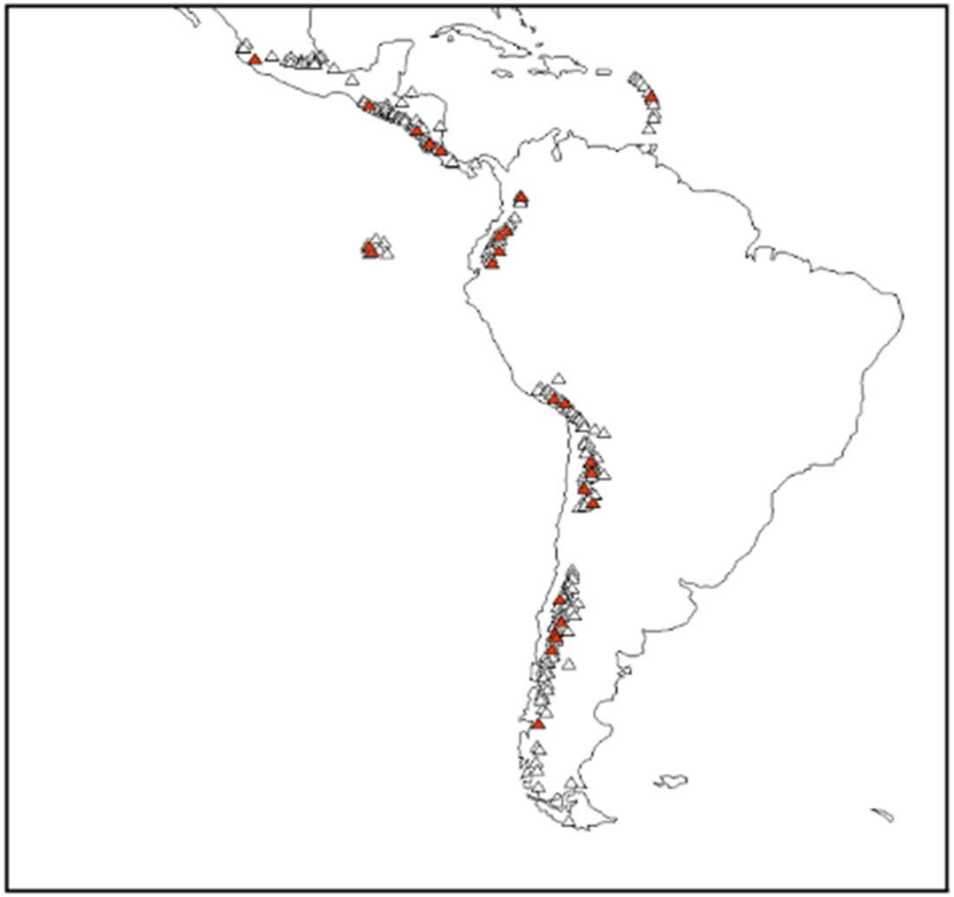
4. Looking to the future, would your organization like increase the use satellite of observations and what do you think is needed to make that happen?

User Feedback



Interviews conducted with users in:

- **Guatemala**
- **Costa Rica**
- **Columbia**
- **Ecuador**
- **Peru**
- **Chile**



What do end users want?

- Data provided as Google Earth and/or ArcGIS files, and some interpretation of imagery
- More frequent data (in terms of volume and latency between tasking, acquisition, processing, and interpretation) for use in regular reports
- Graduate-level training for students (short courses are valuable, but will not train remote sensing experts)

Peru provides a good example of how remote sensing data are used and what is needed in the future.

Upcoming milestones

2016

- Achieve monitoring of Latin American volcanoes
- Continue to provide products and collect feedback from end users
- Evaluate results from site-specific studies
- Prepare a Journal of Applied Volcanology article describing the results of our work, focusing on the value to end users

2017

- Develop broader space-based EO strategy using insights from pilot

Strategy for volcano EO

- **SAR observations of Holocene volcanoes**
  - **ALOS-2 and Sentinel-1 can provide broad “routine” wide-area coverage (based on environment)**
  - **High spatial- and temporal-resolution sensors (CSK, TSX) focus on specific targets of concern/interest**
  - **Flexible sensors (RSAT-2) for challenging problems**
- **Visible and thermal monitoring is already somewhat mature (for example, MODVOLC, NOAA system)**
- **Coordinate systems for alerting one another (already done in some cases with visible/thermal systems)**
- **Dedicated FTE, capacity building, data acquisition**

Strategy for interfacing with users

- **Proximity**

  (What is the current status of the volcano?)

- **Integrity**

  (What is the status of ground-based monitoring? How will EO products be used?)

- **Comprehensibility**

  (Products versus data; ability to process/interpret data)

- **Materiality**

  (What is needed at the volcano? What features are of greatest interest?)

Issues

- **ACQUISITION**

  Consistent acquisition strategy for volcanoes (background TSX program?)

- **COMMUNICATION**

  Improve dialogue to avoid conflicts in data acquisition

- **INTEGRATION**

  SAR versus visible/thermal wavelengths, better use of Geohazards Exploitation Platform

- **EXPANSION**

  Resources for expanding to global monitoring will be extreme (student case-study projects do not constitute a sustainable capability—PhD students have other demands on their time!)

WG Disasters #5
Bonn, Germany
8-10 March, 2016