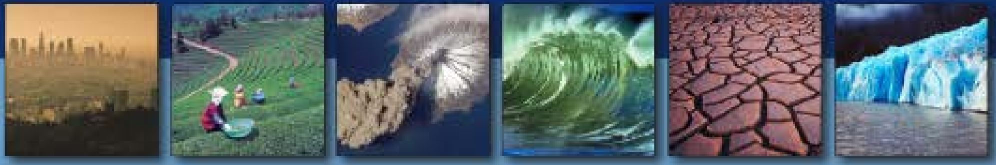
Status Report on Volcano Pilot Project

Mike Poland (USGS)
Simona Zoffoli (ASI)

WG Disasters #7
Rome, Italy
14–16 March 2017



Overview

- Pilot Background
- Supersites and large event
- Results for Latin America
- Evaluation and sustainability

Pilot Team

Juliet Biggs, David Arnold (*University of Bristol*)

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Mike Pavolonis (*NOAA*)

Rick Wessels (*USGS*)

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Elske de Zeeuw - van Dalfsen (*KNMI*)

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, using satellite EO data to track deformation as well as gas, ash, and thermal emissions.

Objective B – GSNL

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

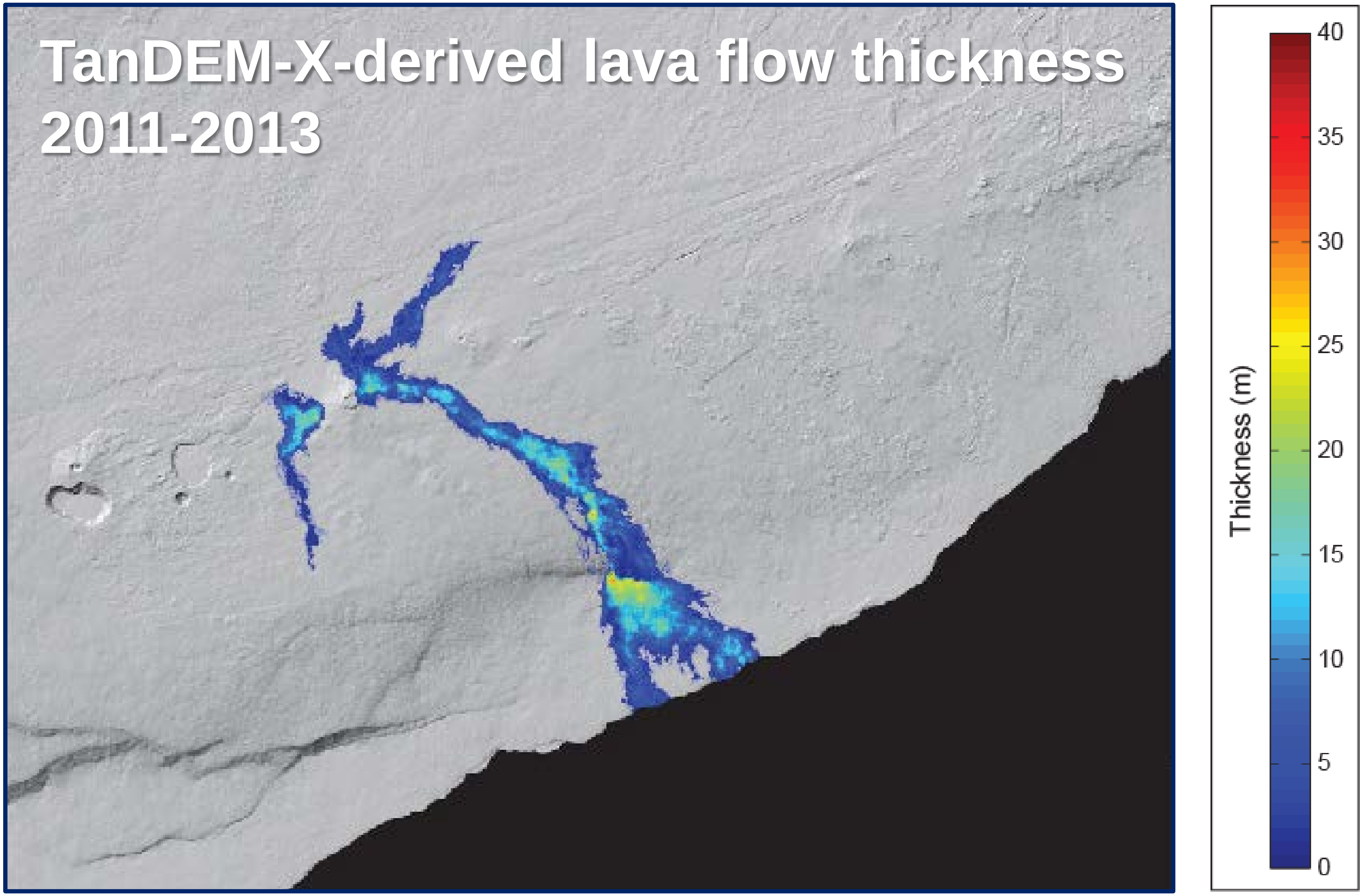
Objective C – Significant Global Event

Specific study 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, regional, and global impacts.

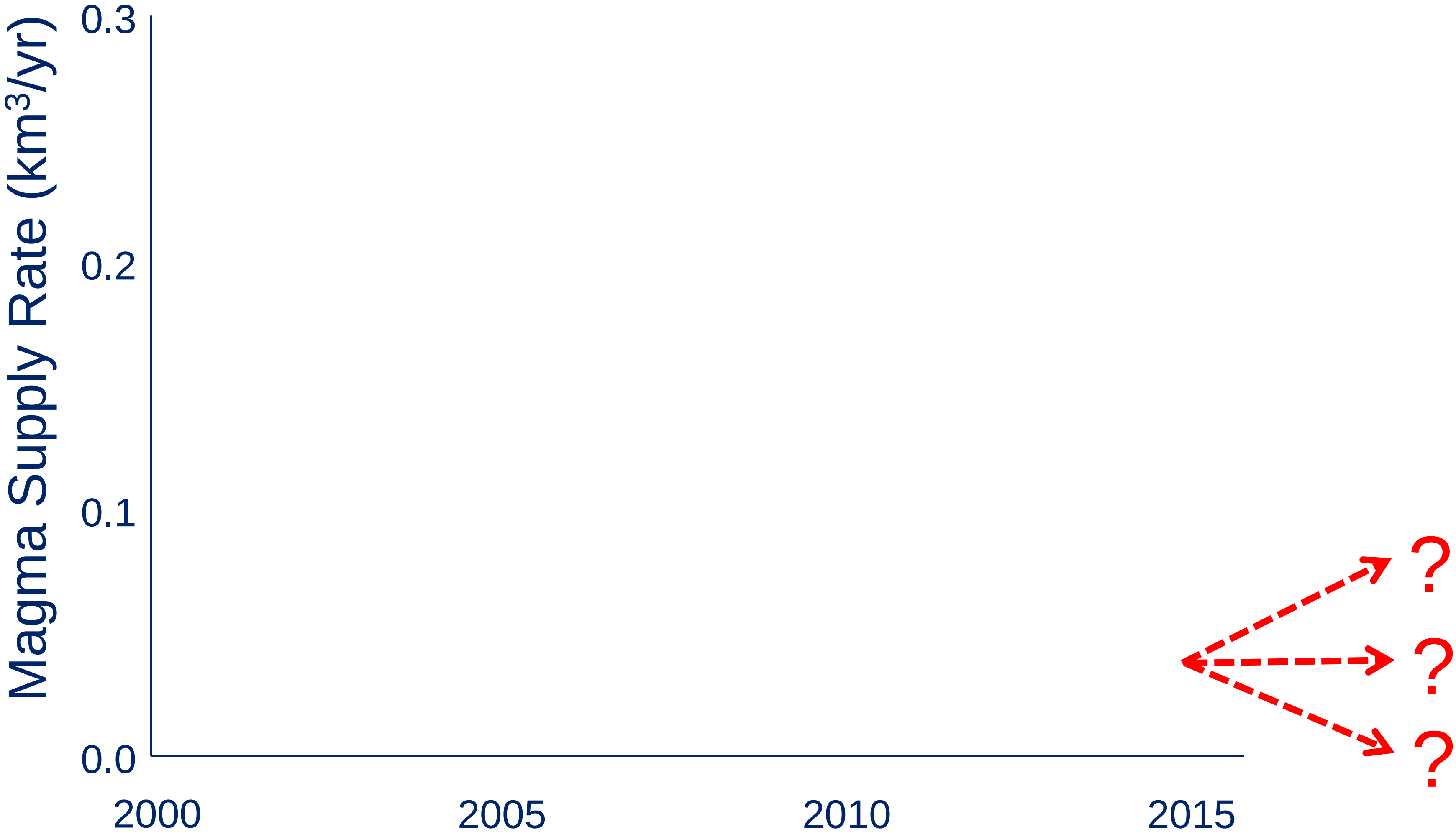
Objective B: Supersites

- 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

Objective B: Hawai‘i



Objective B: Hawai‘i



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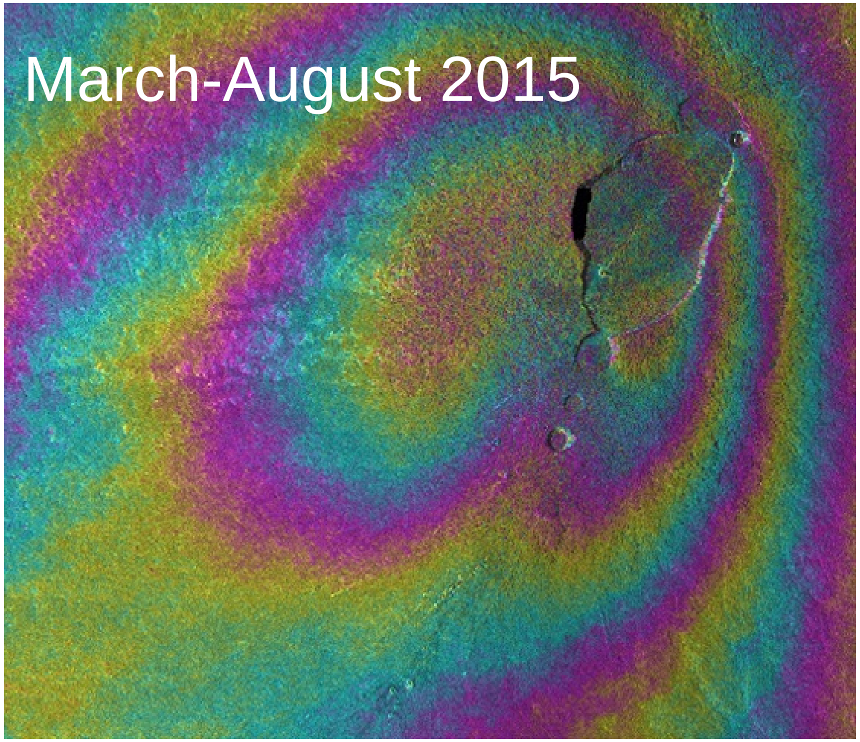
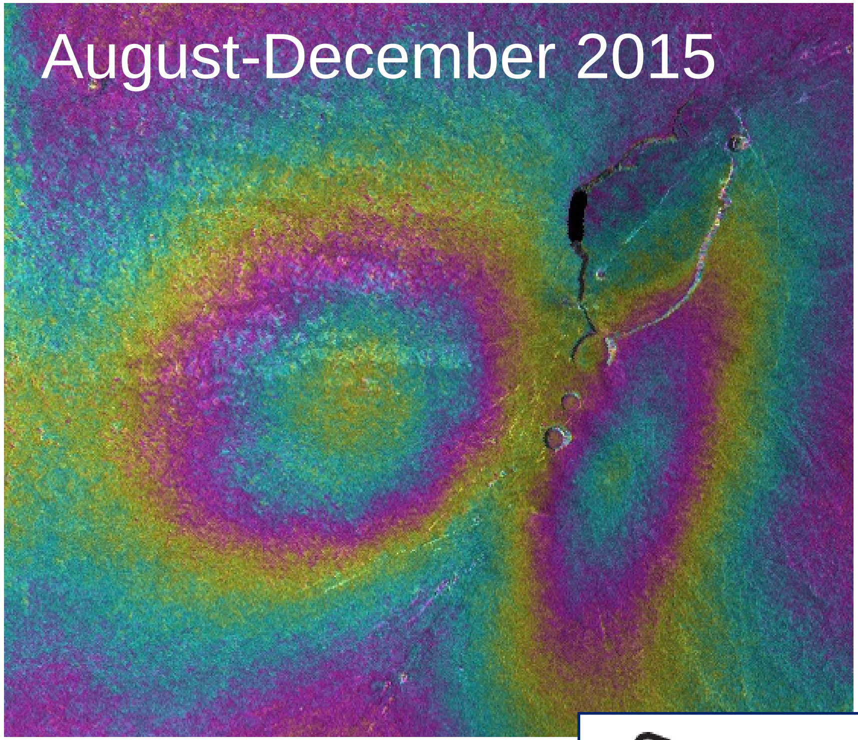
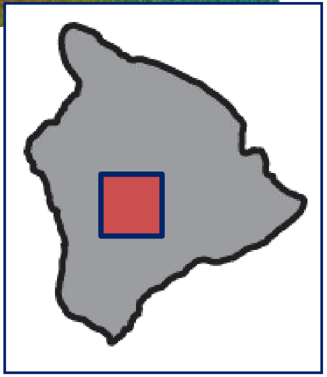
Objective B: Hawai‘i







Inflation of Mauna Loa volcano, Hawai‘i

Cosmo-SkyMed

Inflation source changed location in mid-2015…

Objective C: Fogo demonstrator

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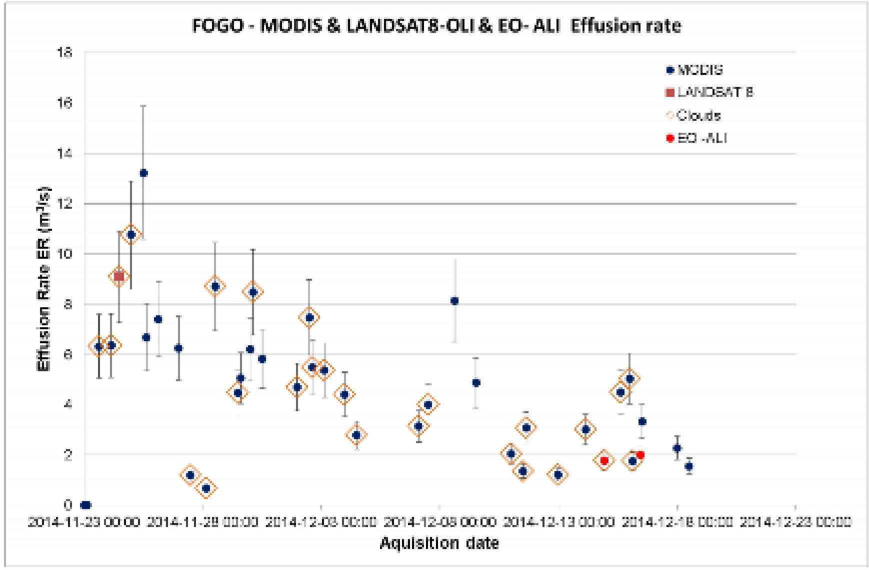
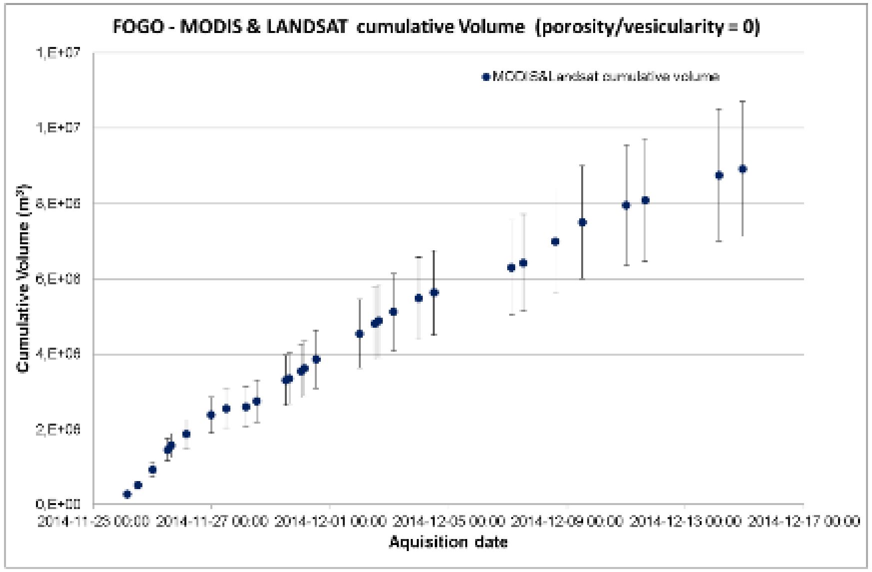
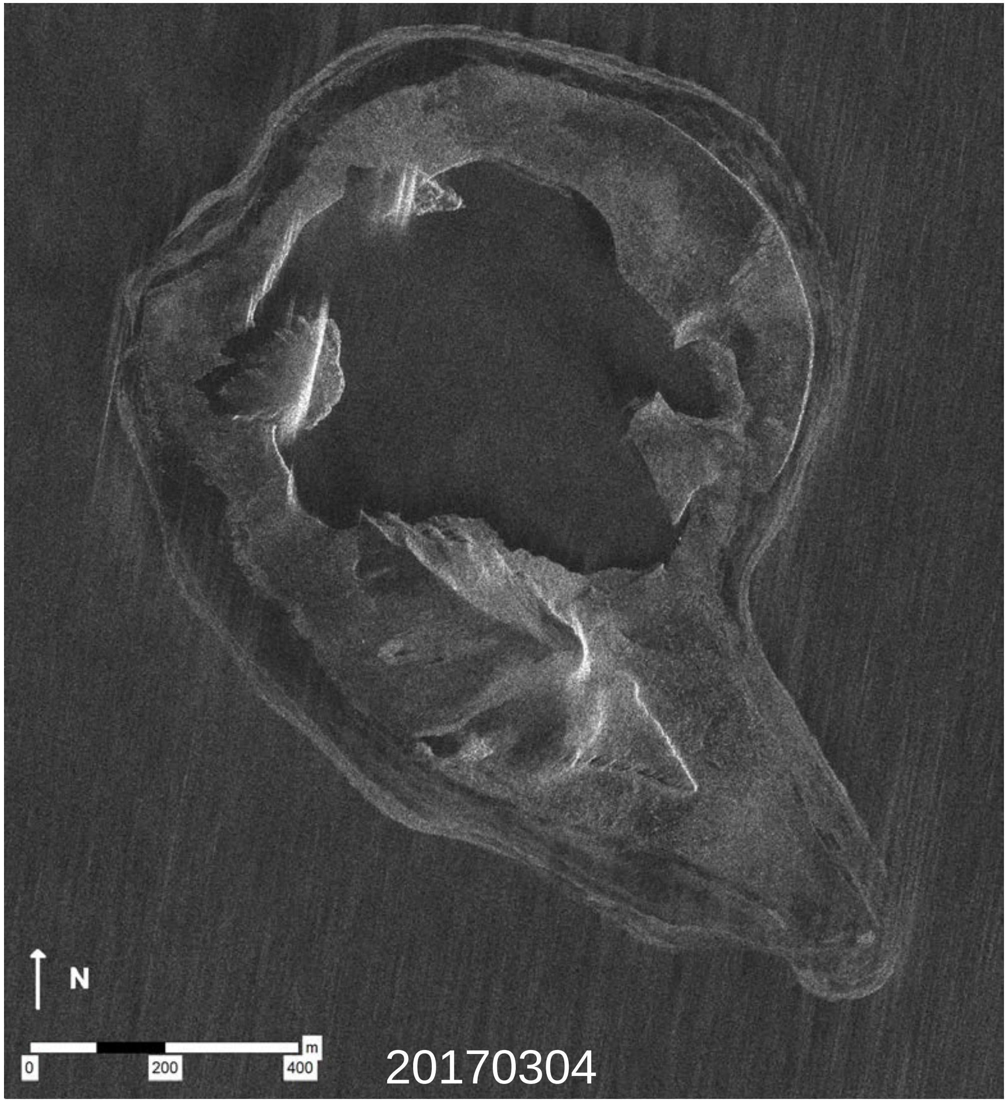
- Proposal has been submitted to ensure rapid access to data if a large volcanic event occurs
- Fogo eruption serves as a demonstration





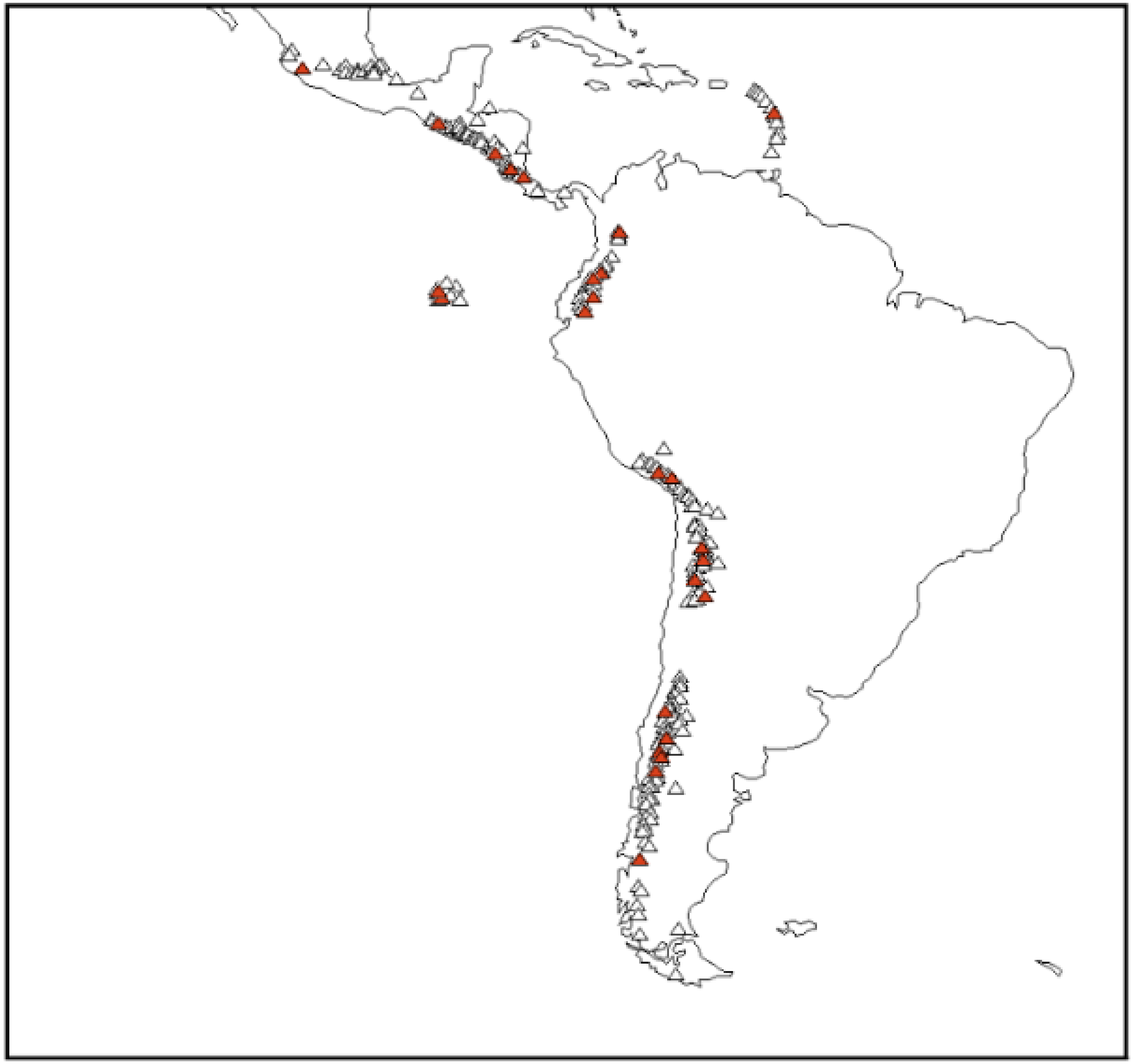
courtesy Fabrizzio Ferucci, Open University

Objective C: Bogoslof demonstrator



Objective A: Regional demonstration

- Demonstrate how EO data can be used to cost-effectively monitor all 315 volcanoes that erupted in the last 10,000 years in the region
- 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, KNMI
Southern and Austral Andes SAR	Cornell University
Galápagos SAR	IREA/CNR
Mexico SAR	University of Miami
Central America SAR	Pennsylvania State University
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	Allocated	Notes
RADARSAT-2	**270**	Quota exhausted. Coherence in HH seems to be better that that of VV with Sentinel.
COSMO-SkyMed	**900**	Baselines are sometimes poor, but large datasets thanks to background mission is very helpful.
TSX	**400**	Lack of a background mission means acquisitions are few, but interferometric pairs are always easy to find.
ALOS-2	**200**	Quota nearly exhausted. Primary value is improved coherence due to L-band frequency.
TDX (CoSSC exp.)	**150**	Exceptional value thanks to ability to map topography at any time of day or in any kind of weather.
Sentinel-1a/b	**N/A**	Reliable acquisitions, but spatial resolution limits ability to see small-scale patterns.

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)

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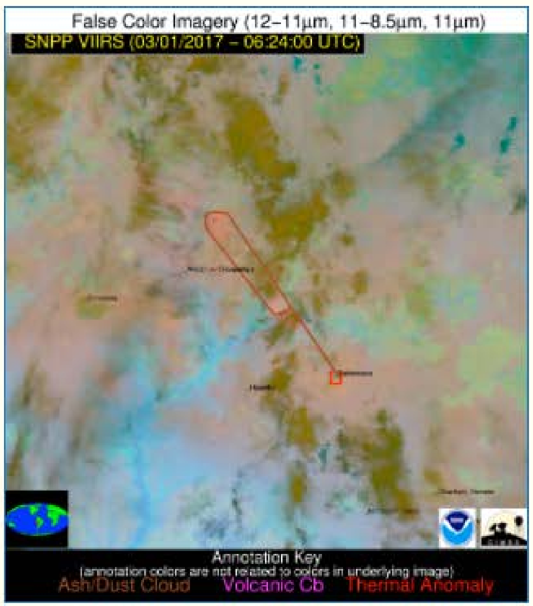
Detection of volcanic plumes

Volcanic Cloud Alert Report

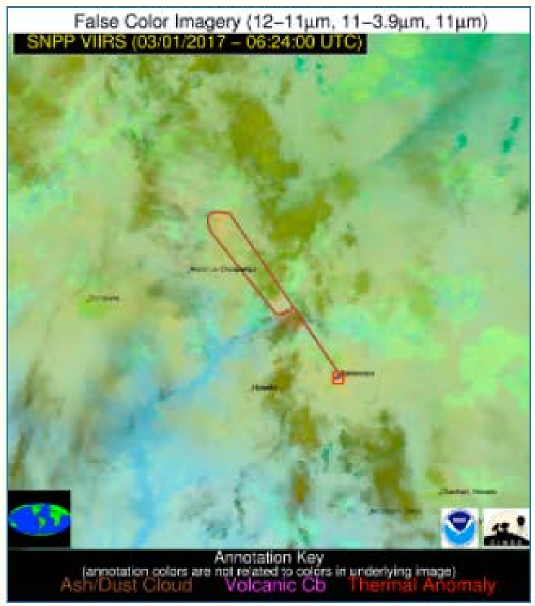
Date:	2017-03-01
Time:	06:24:00
Production Date and Time:	2017-03-01 08:56:07 UTC
Primary Instrument:	NPP VIIRS

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	Peru
Volcanic Subregion(s)	Peru
VAAC Region(s) of Nearby Volcanoes	Buenos Aires
Identification Method	Plume
Mean Object Date/Time	2017-03-01 06:29:00UTC
Radiative Center (Lat, Lon):	-15.780°, -71.850°
Nearby Volcanoes (meeting alert criteria):	Sabancaya (0.00 km) [Thermal Anomaly Present] Huambo (30.50 km) Nicholson, Cerro (54.20 km) Chachani, Nevado (57.10 km) Andahua-Orcopampa (65.20 km)
Maximum Height [AMSL]	8.70 km ; 28543 ft
90th Percentile Height [AMSL]	8.00 km ; 26247 ft
Mean Tropopause Height [AMSL]	16.50 km ; 54134 ft

Show More ▲ View all event imagery »

The Buenos Aires VAAC receives volcanic thermal anomaly and ash cloud alerts from the NOAA VOLcanic Cloud Analysis Toolkit (VOLCAT).

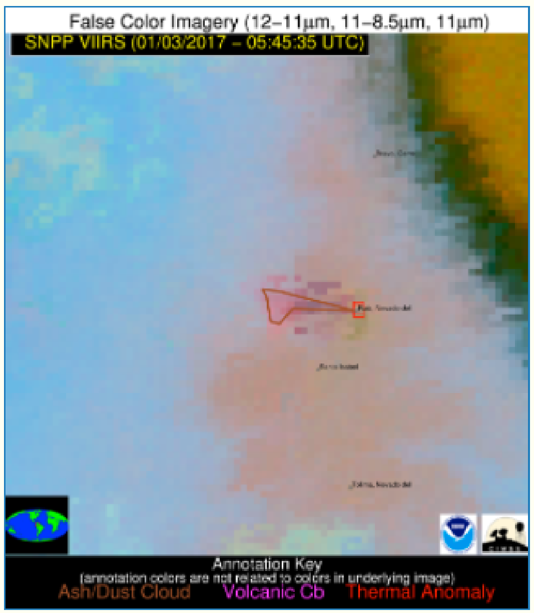
Detection of volcanic plumes

Volcanic Cloud Alert Report

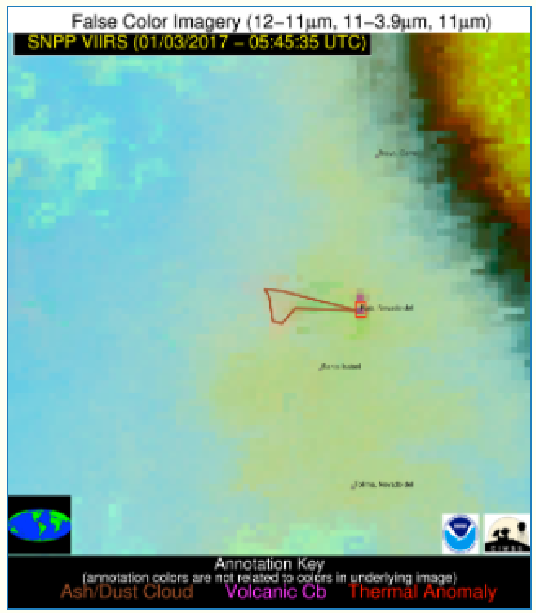
Date:	2017-01-03
Time:	05:45:35
Production Date and Time:	2017-01-03 13:00:44 UTC
Primary Instrument:	NPP VIIRS

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]

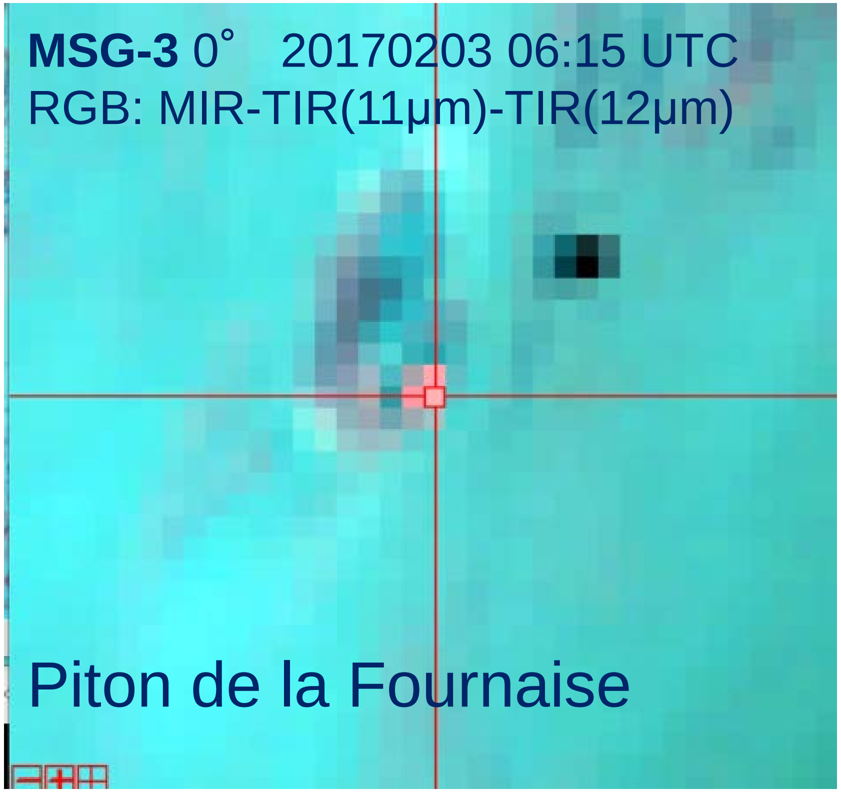
Basic Information

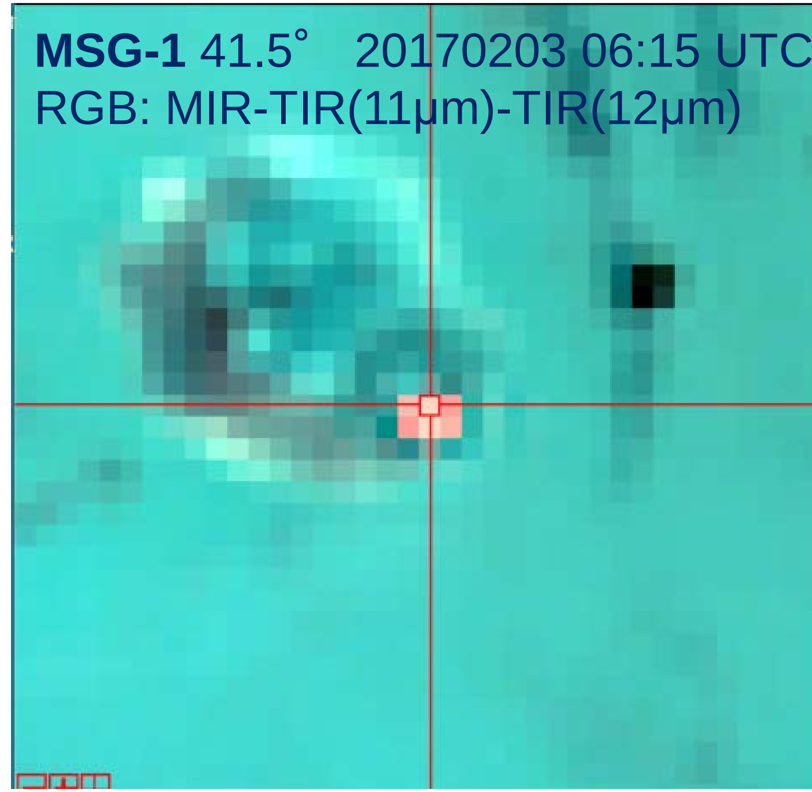
Volcanic Region(s)	South America
Country/Countries	Colombia
Volcanic Subregion(s)	Colombia
VAAC Region(s) of Nearby Volcanoes	Washington
Identification Method	Plume
Mean Object Date/Time	2017-01-03 05:45:35UTC
Radiative Center (Lat, Lon):	4.890°, -75.320°
Nearby Volcanoes (meeting alert criteria):	Ruiz, Nevado del (0.00 km) [Thermal Anomaly Present] Santa Isabel (9.90 km) [Thermal Anomaly Present] Bravo, Cerro (22.10 km) Tolima, Nevado del (25.10 km) Romeral (34.90 km)
Maximum Height [AMSL]	6.60 km ; 21654 ft
90th Percentile Height [AMSL]	6.30 km ; 20669 ft
Mean Tropopause Height [AMSL]	16.90 km ; 55446 ft

Show More ▲ View all event imagery »

The Washington VAAC issues advisories for many volcanoes in Latin America, and it receives volcanic thermal anomaly and ash cloud alerts from VOLCAT.

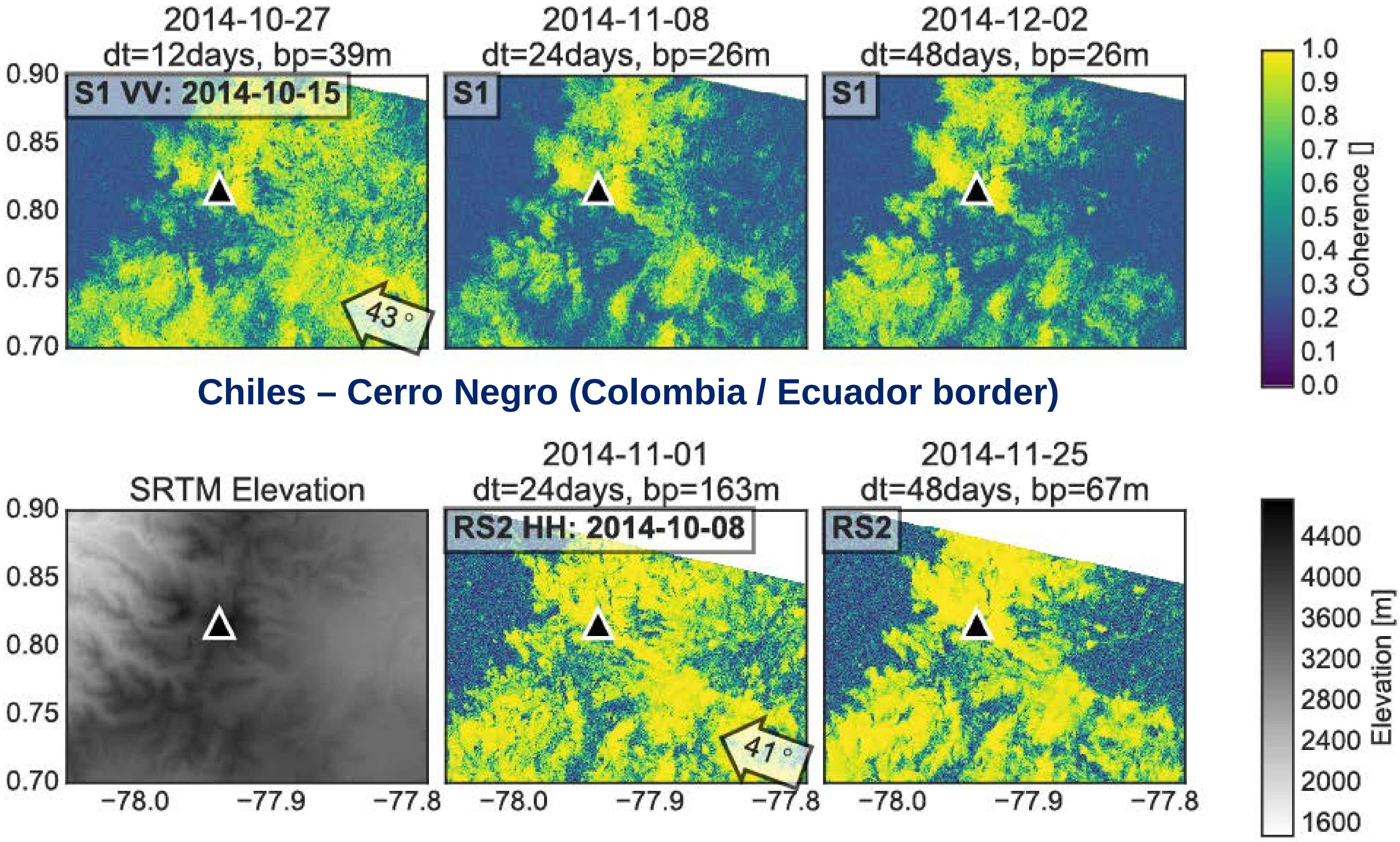
Thermal, ash, and gas emissions





Thermal anomalies are excellent for tracking eruptions due to the high revisit frequency of geostationary weather satellites. Effectiveness of SO_2 measurements is challenged by infrequent revisits due to a lack of geostationary sensors capable of detecting gas emissions.

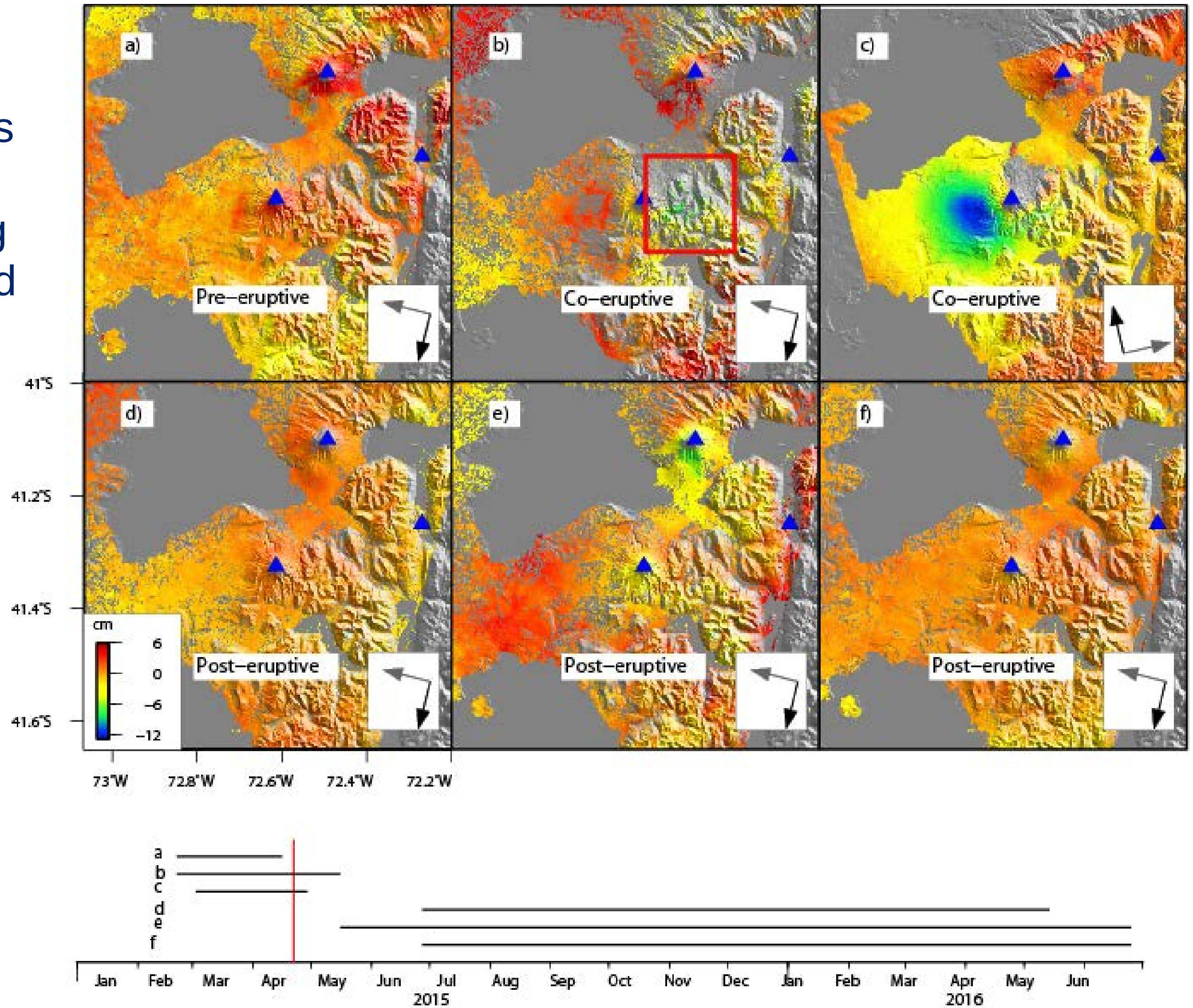
Coherence: RSAT vs. Sentinel



Chiles – Cerro Negro (Colombia / Ecuador border)

Calbuco, Chile

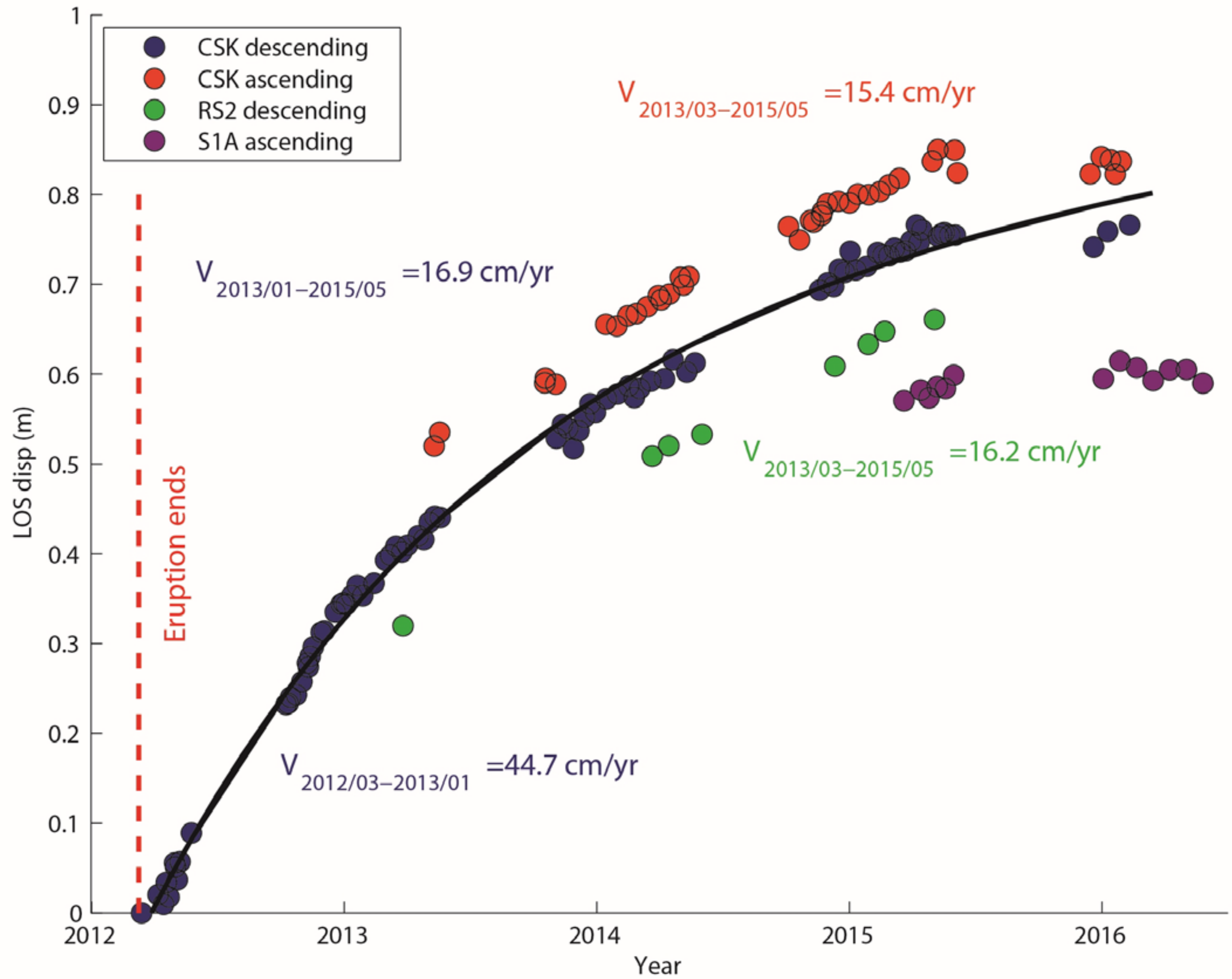
ALOS-2 interferograms are very coherent, excellent for assessing deformation associated with 2015 Calbuco eruption



Cordón Caulle, Chile

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

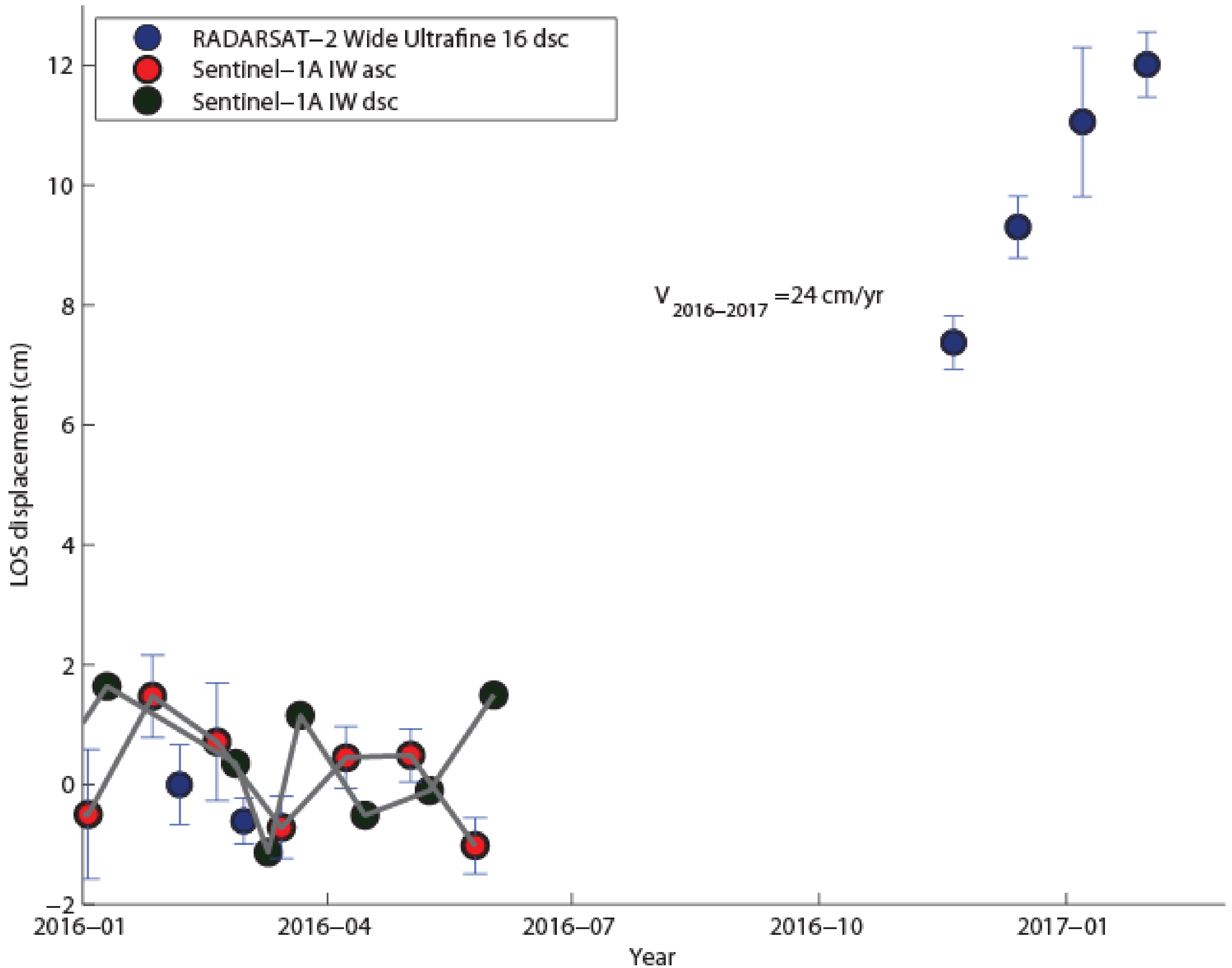
The inflation seemed to have stopped in mid-2015.



Cordón Caulle, Chile

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

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



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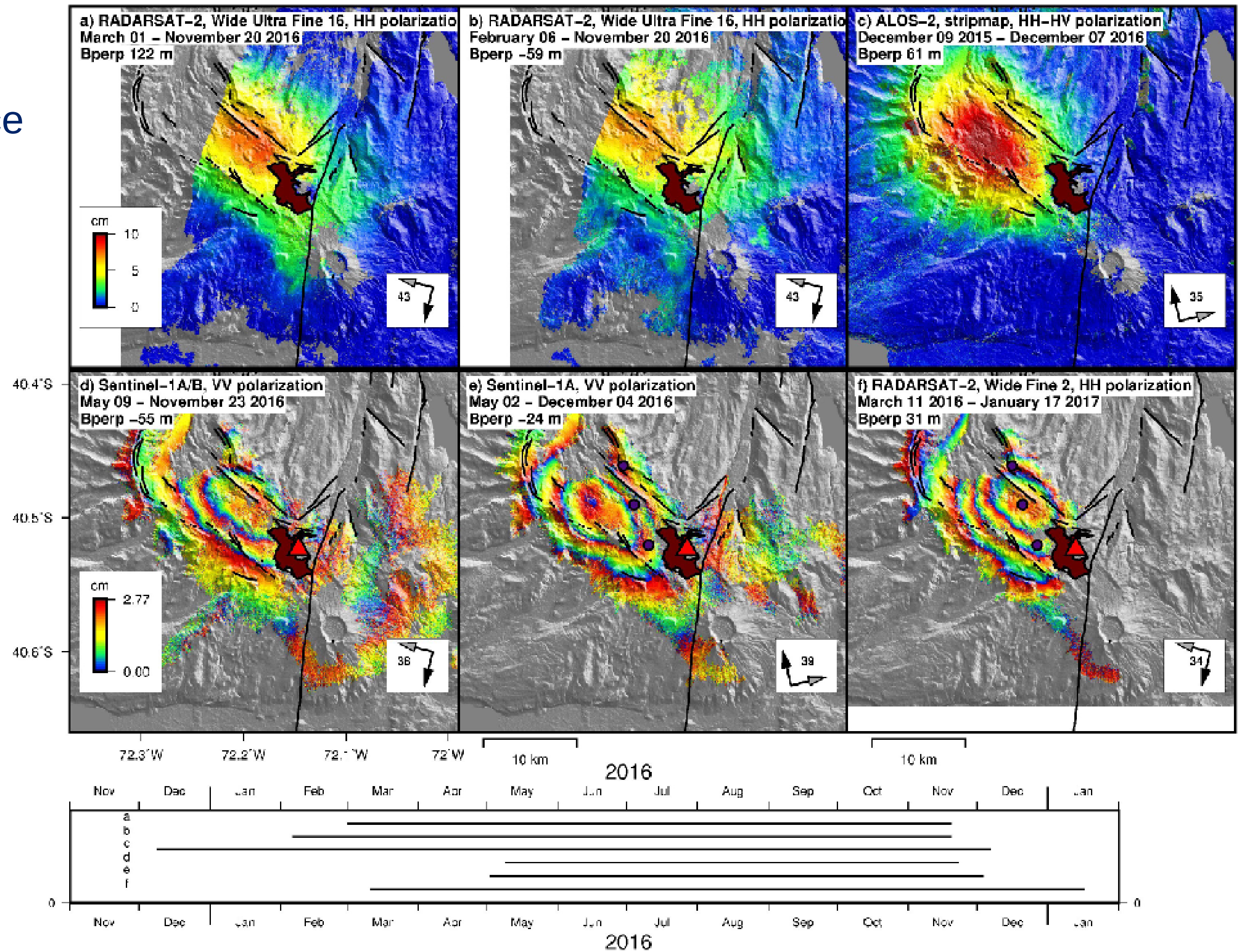
Cordón Caulle, Chile

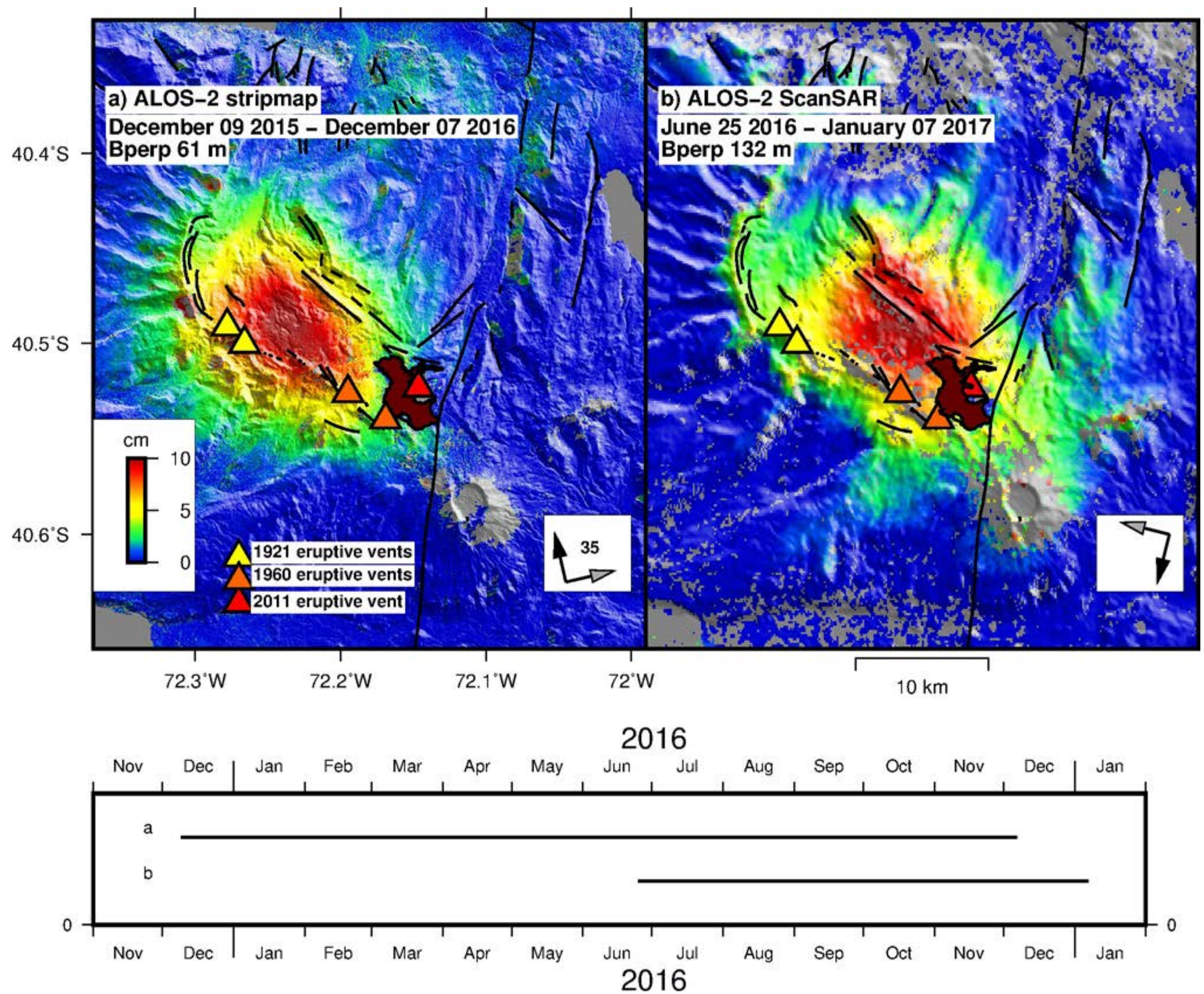
L-band coherence makes a difference at Cordón Caulle.



Cordón Caulle, Chile

ALOS-2 wide-swath vs. stripmap

Exceptional coherence!



Santiaguito, Guatemala

X and C-band InSAR: correlation limited to the lava flow and upper flanks

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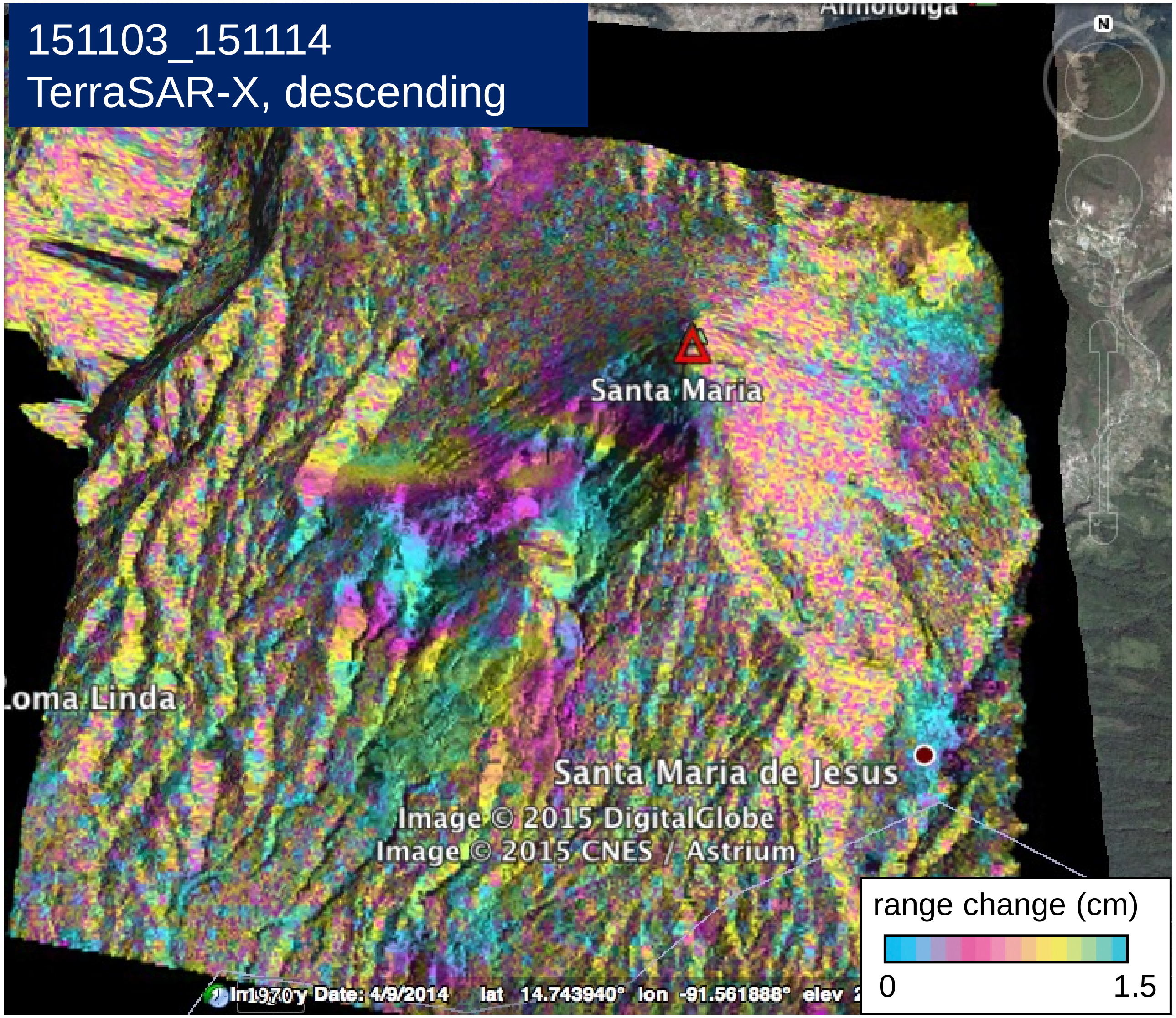
Santiaguito, Guatemala

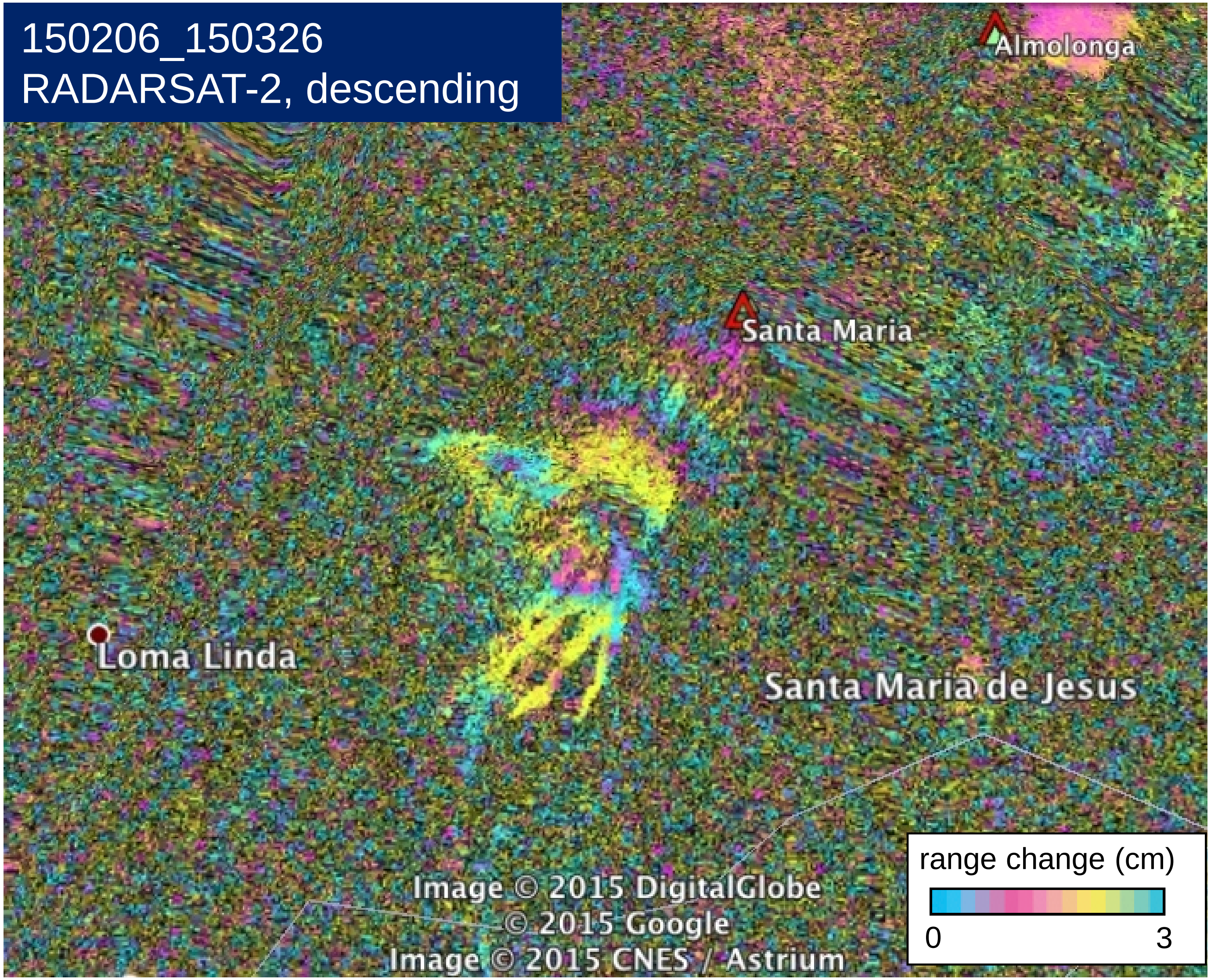
X and C-band InSAR: correlation limited to the lava flow and upper flanks



Santiaguito, Guatemala

Same signals visible on RADARSAT-2 interferogram!

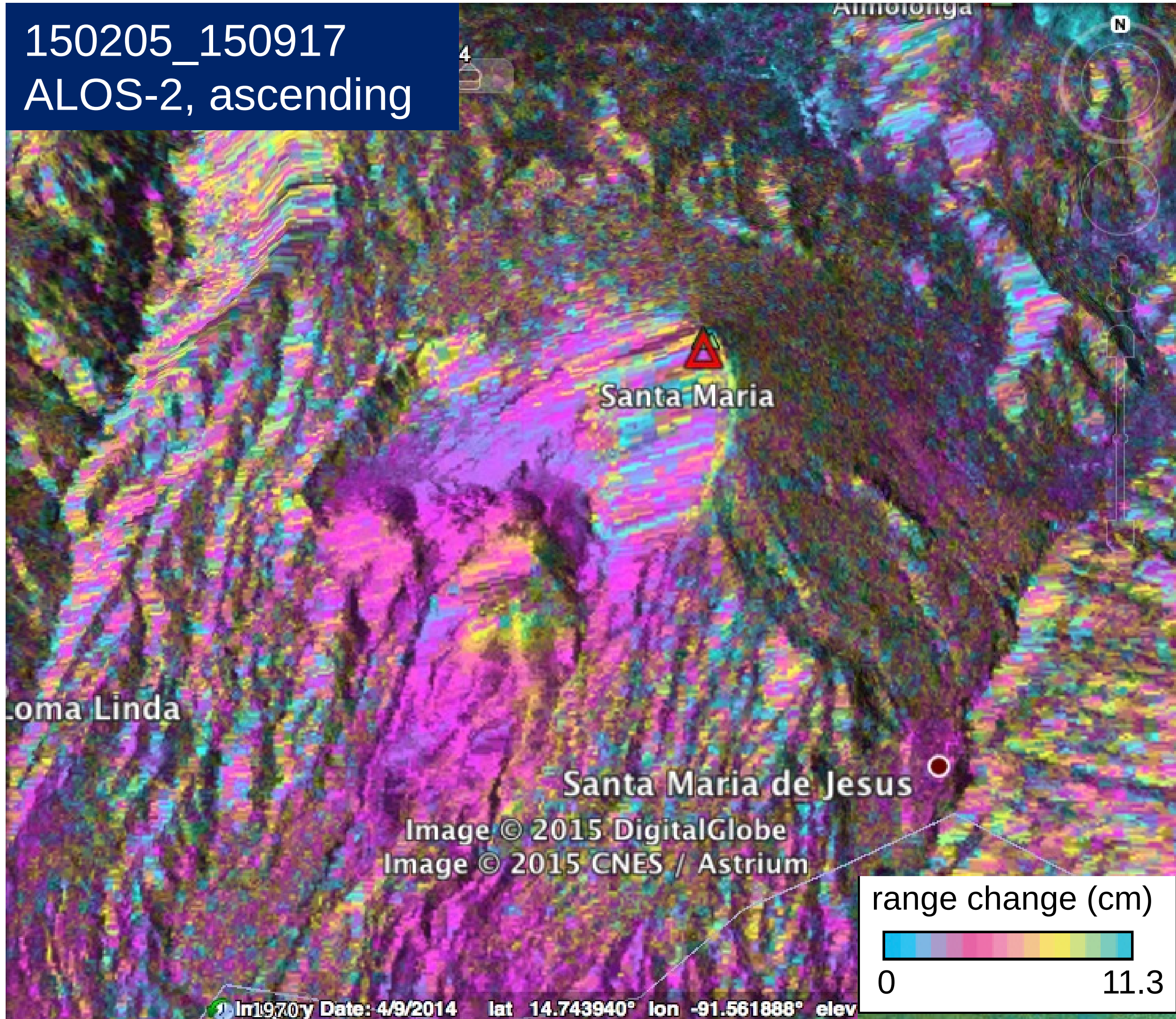
Deformation? Ash plume?



Santiaguito, Guatemala

L-band InSAR: signal correlation more extended!

LOS subsidence of Caliente's southern flank?



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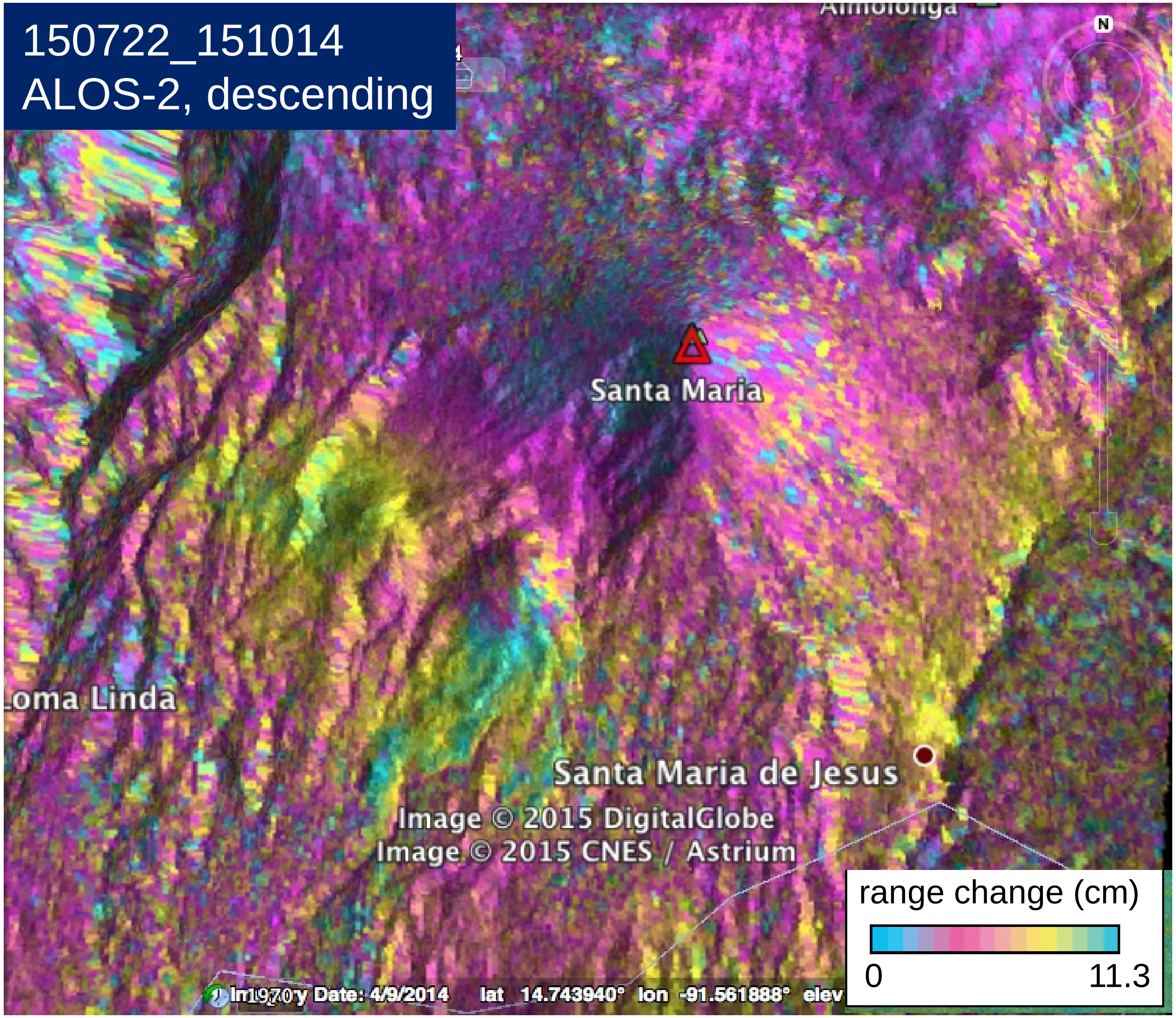
Santiaguito, Guatemala

L-band InSAR: signal correlation more extended!

LOS subsidence of Caliente’s southern flank + other subsiding areas?



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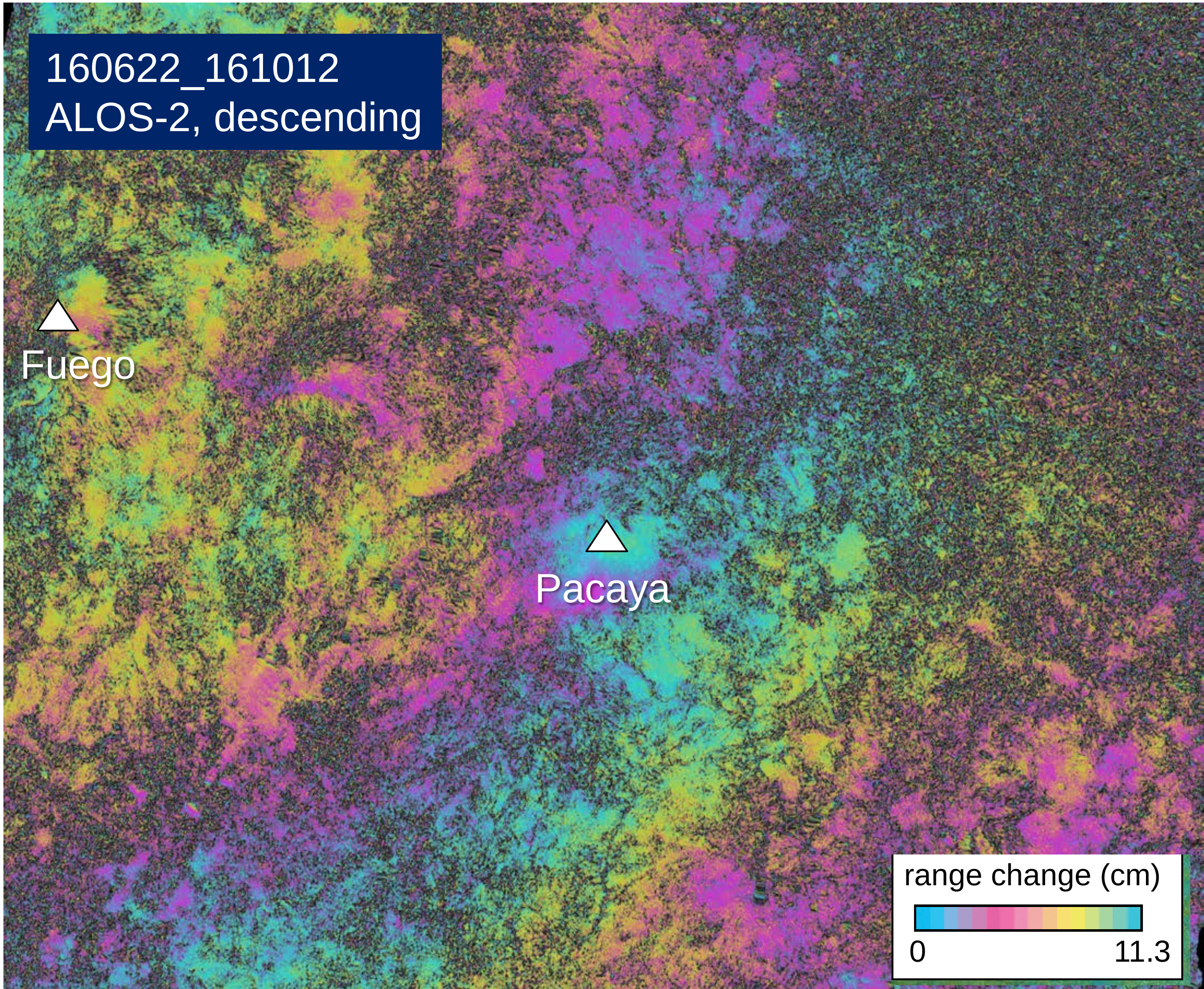
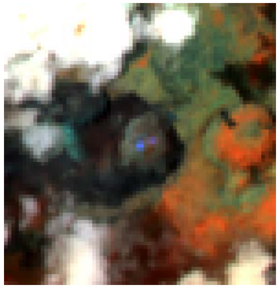
Fuego and Pacaya, Guatemala

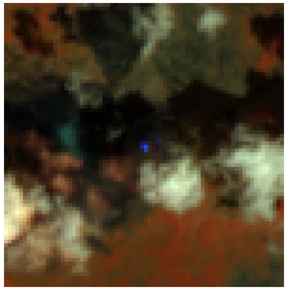
Good coherence with ALOS-2 on both Pacaya and Fuego, Guatemala.

Sentinel-1 interferograms are not coherent at either volcano



Masaya, Nicaragua


September 16, 2015


November 3, 2015

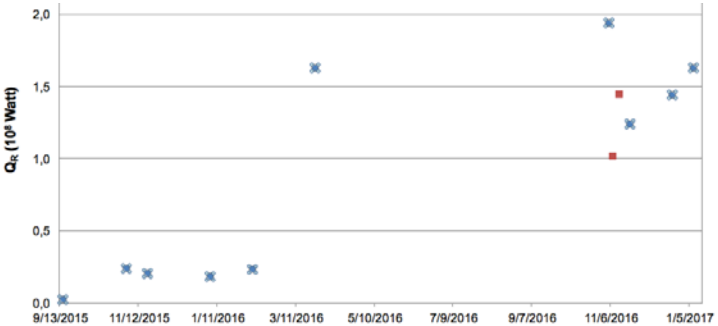

November 19, 2015


January 6, 2016

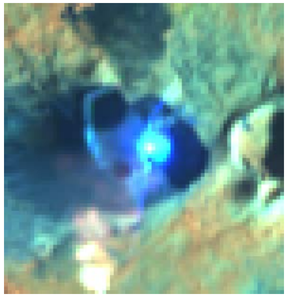

February 7, 2016

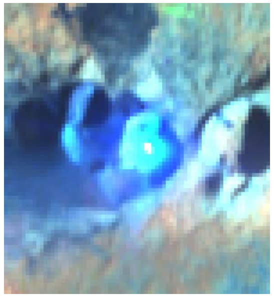

March 26, 2016

Masaya lava lake
September 2015 - January 2017

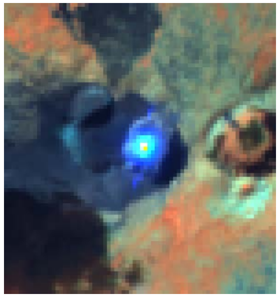


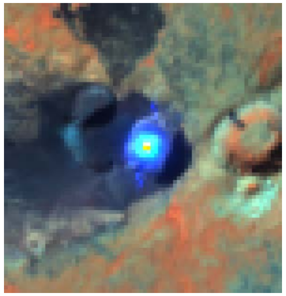

November 5, 2016


November 8, 2016


November 13, 2016


November 21, 2016

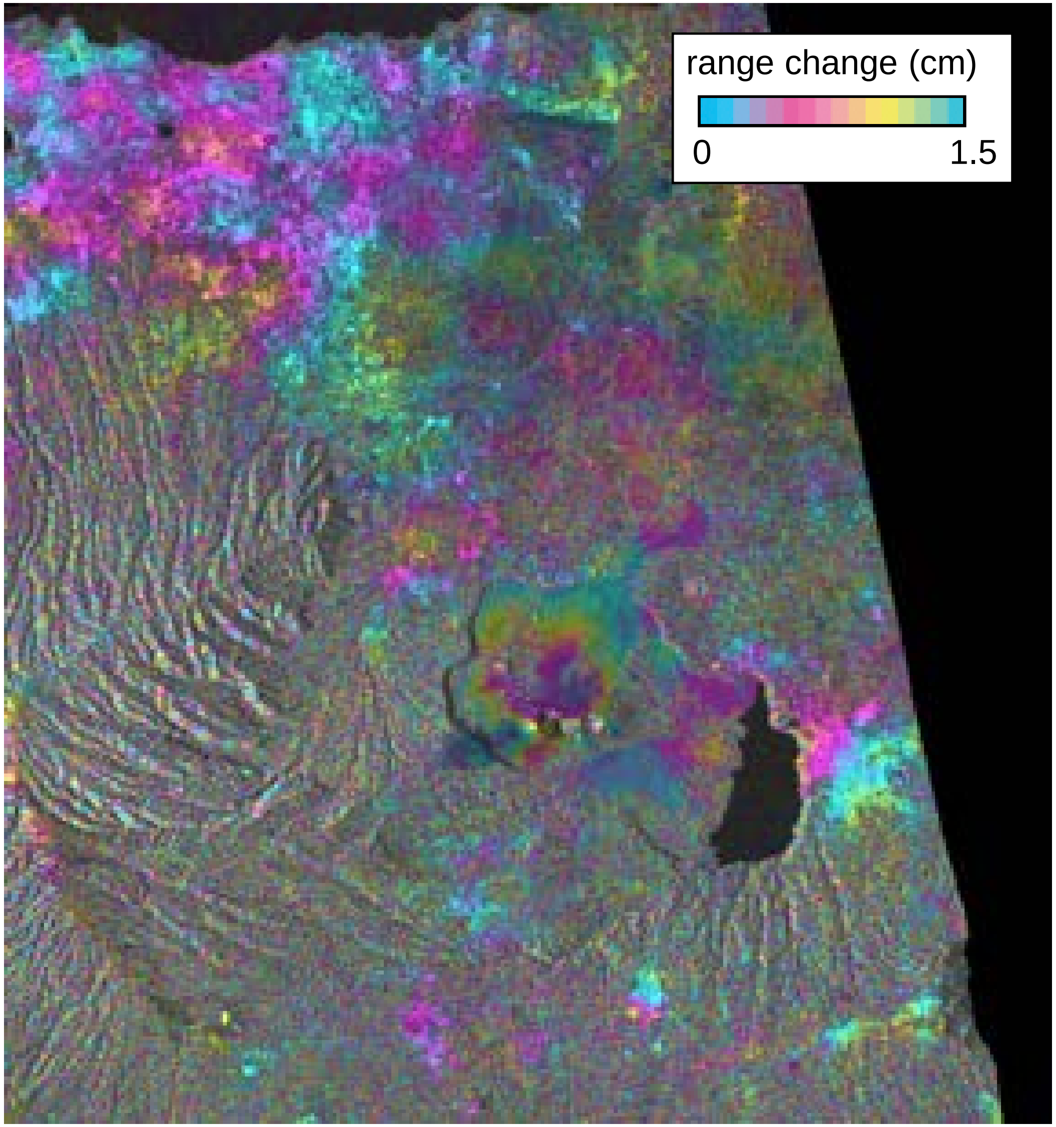

December 23, 2016


January 8, 2017

Masaya, Nicaragua

CSK
2015-11-18 to 2015-12-16

Inflation of the crater area of Masaya coincident with an increase in levels of activity and rise in lava lake height in late 2015.

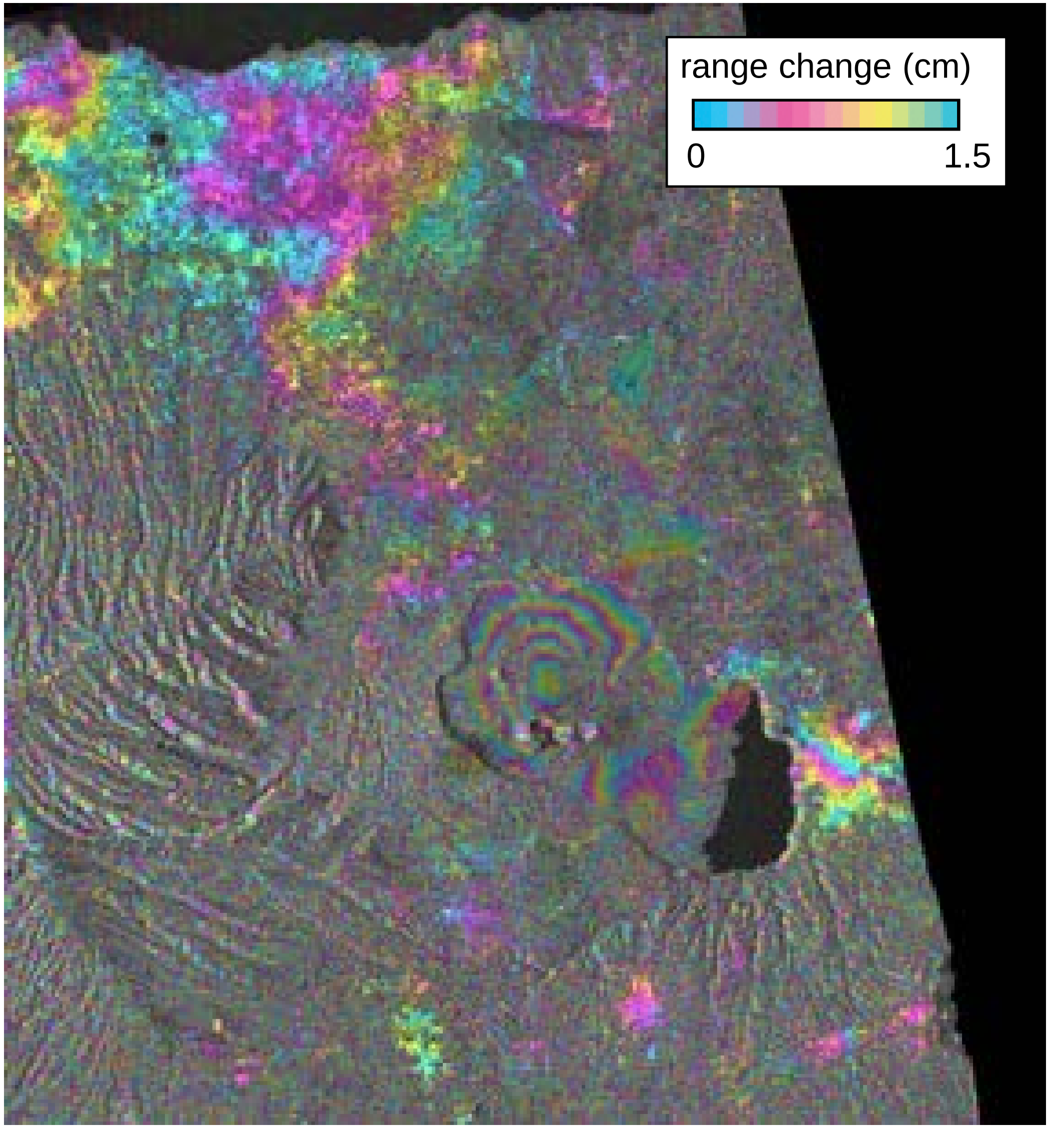


Masaya, Nicaragua

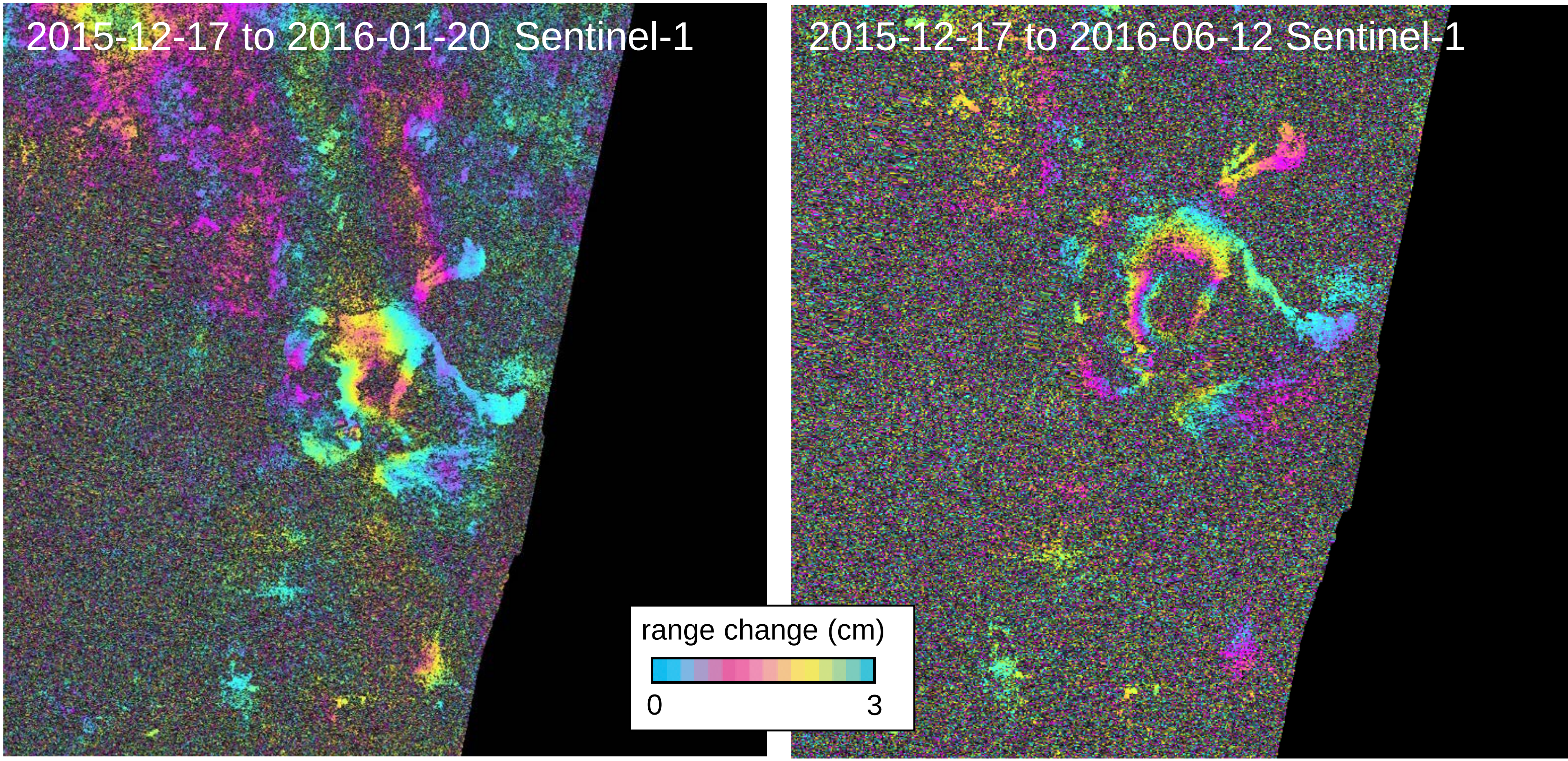
CSK
2015-10-17 to 2016-03-09

Deformation does not appear after April 2016

CSK time series analysis is in progress

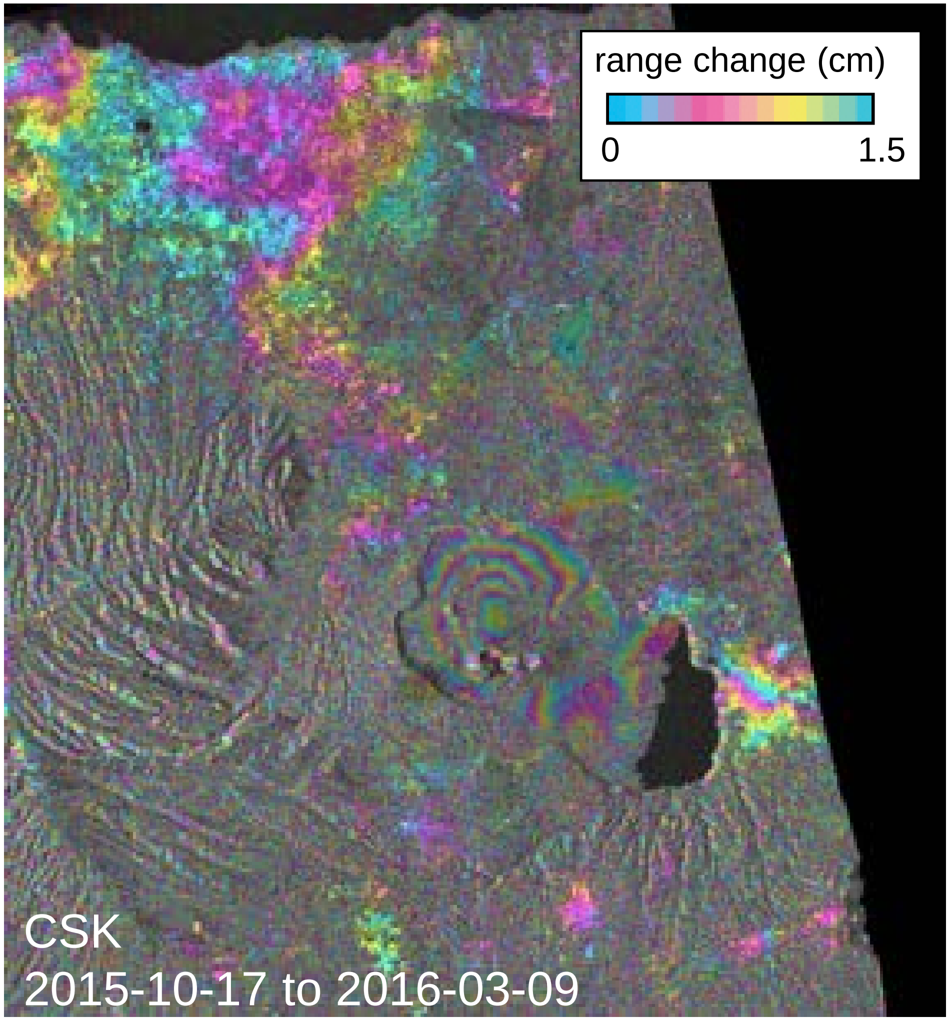


Masaya, Nicaragua



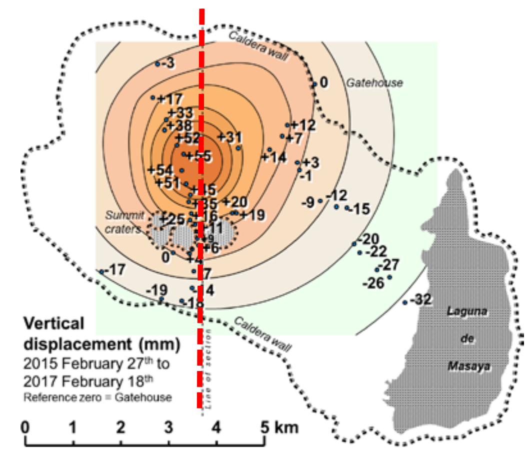
Masaya inflation also appears in Sentinel interferograms. Modeling of these data suggest a pressure increase at ~1.5 km beneath the surface.

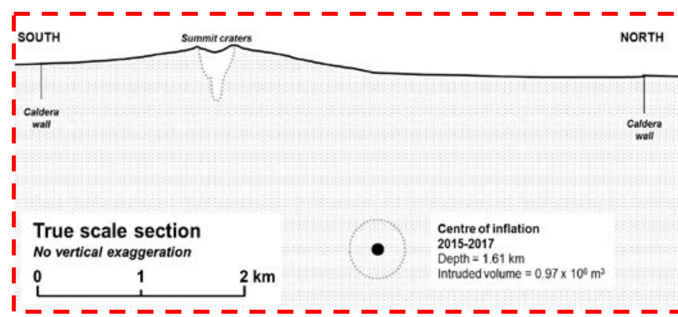
Masaya, Nicaragua



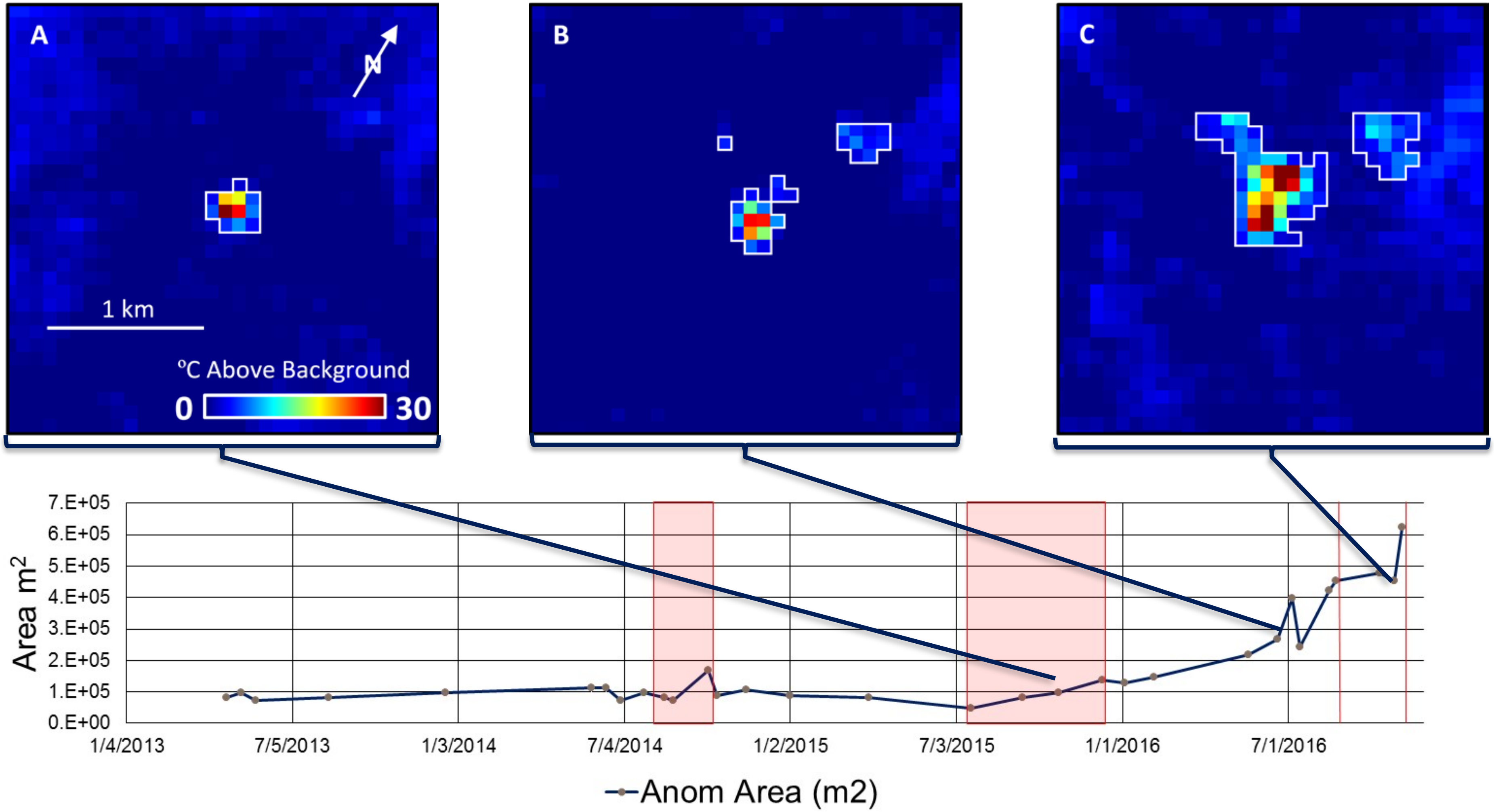
The Open University

Levelling route. Data, processing and model JB Murray, OU, 2017©





Sabancaya, Peru



Results: Lessons learned

- L-band data are critical for coherence in vegetated areas
- HH RSAT-2 interferograms seem to offer better coherence than VV Sentinel-1 interferograms. The reason for this difference is not clear.
- A “background mission” that acquires data over active volcanoes has great value for when a system becomes restless
- Poor baselines for interferometry can be compensated for to a degree by numerous acquisitions
- Low data latency is important for crisis situations
- Topographic data are critical

Publications

- Ebmeier, S. K., J. Biggs, C. Muller and G. Avard (2014). Thin-skinned mass-wasting responsible for edifice-wide deformation at Arenal Volcano, Frontiers in Earth Science, 2, 35, doi:10.3389/feart.2014.00035.
- Jay, J. A., F. J. Delgado, J. L. Torres, M. E. Pritchard, O. Macedo, and V. Aguilar (2015). Deformation and seismicity near Sabancaya volcano, southern Peru, from 2002 to 2015. Geophysical Research Letters, 42(8), 2780–2788, doi:10.1002/2015GL063589.
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- Delgado, F., M. Pritchard, D. Basualto, J. Lazo, L. Cordova, and L. Lara (2016). Rapid re-inflation following the 2011–2012 rhyodacite eruption at Cordón Caulle volcano (Southern Andes) imaged by InSAR: Evidence for magma reservoir refill. Geophysical Research Letters, 43(18), 9552–9562, doi:10.1002/2016GL070066.
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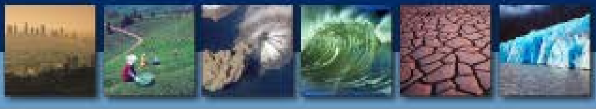

RESEARCH

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 is in preparation and will describe the pilot project, lessons learned, and potential future applications.

Evaluation criteria

1) Identification of new areas of unrest through regional InSAR monitoring.
2) Uptake by Latin American volcano monitoring agencies of EO-based methodologies for tracking deformation, as well as gas, thermal, and ash emissions.
3) Utilization of EO data for operational monitoring by volcano observatories at Supersite targets.
4) Interest expressed by volcano community to broaden approaches adopted in pilot (especially regional monitoring and new methodologies for EO-based monitoring) through representative bodies such as IAVCEI, WOVO or GVM.

Sustainability: Paths forward

Option 1—status quo: No dedicated FTE. Space agencies provide limited access to data for regional (or global?) monitoring. Coordination on a best-effort basis (through IAVCEI commission?). Need to identify a coordinator for this work.

Option 2—dedicated effort: FTE hired to coordinate satellite volcano monitoring and connect space agencies, academic researchers, and end users (VDAP could house this position). Space agencies provide access to data. Organized response to crises and capacity-building efforts.

Challenges to sustainability

- **Hiring freeze in USA currently prohibits bringing on new FTE for dedicated EO volcano-monitoring efforts, but ASI is hiring 2 researchers that might contribute**
- **Unclear how space agencies will respond to requests for more data**
- **Limited funding for academic researchers (voluntary participation is not viable in the long term and will hamper efforts to educate students)**
- **NOAA/NESDIS volcanic activity alerts are generated on a best-effort basis; long-term sustainability is an open question**

Coming Up…

- Journal of Applied Volcanology article describing pilot results and value to end users submitted in 2017
- Powell Center (2017–2019)
  - ~20 volcano remote sensing experts
  - Global in scope
  - USGS sponsored
  - Use existing databases to understand the best satellite indicators of potential eruptions
  - Provide feedback to space agencies on needed data
  - Provide guidance on how to communicate with VOs
- IAVCEI Scientific Assembly workshop (August 2017)
- IAVCEI Commission on Volcano Geodesy

Thank you