Status Report on Volcano Pilot Project

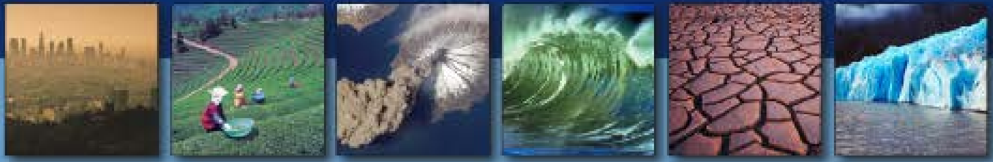
Mike Poland (USGS)

Simona Zoffoli (ASI)

WG Disasters #6

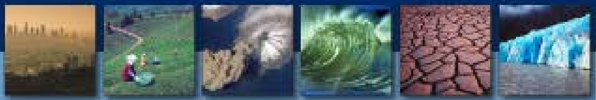
Vancouver, WA, USA

6 -8 September, 2016



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

Overview



- **Motivation and objectives**
- **Data usage**
- **New results**
- **Capacity building**
- **Sustainability**

Pilot Team

Juliet Biggs, David Arnold, James Hickey (*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*)

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.

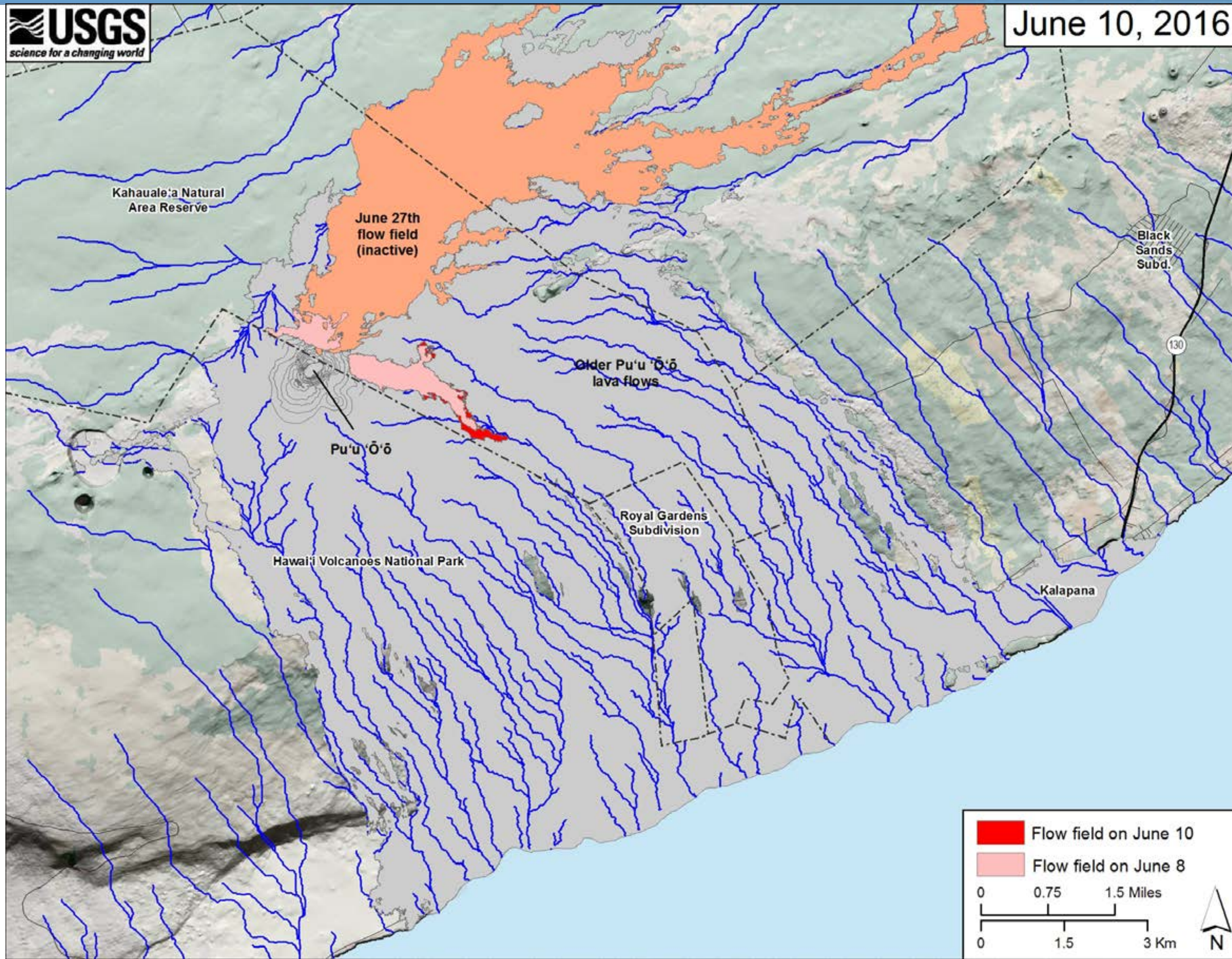
Objective C – Significant Global Event

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.

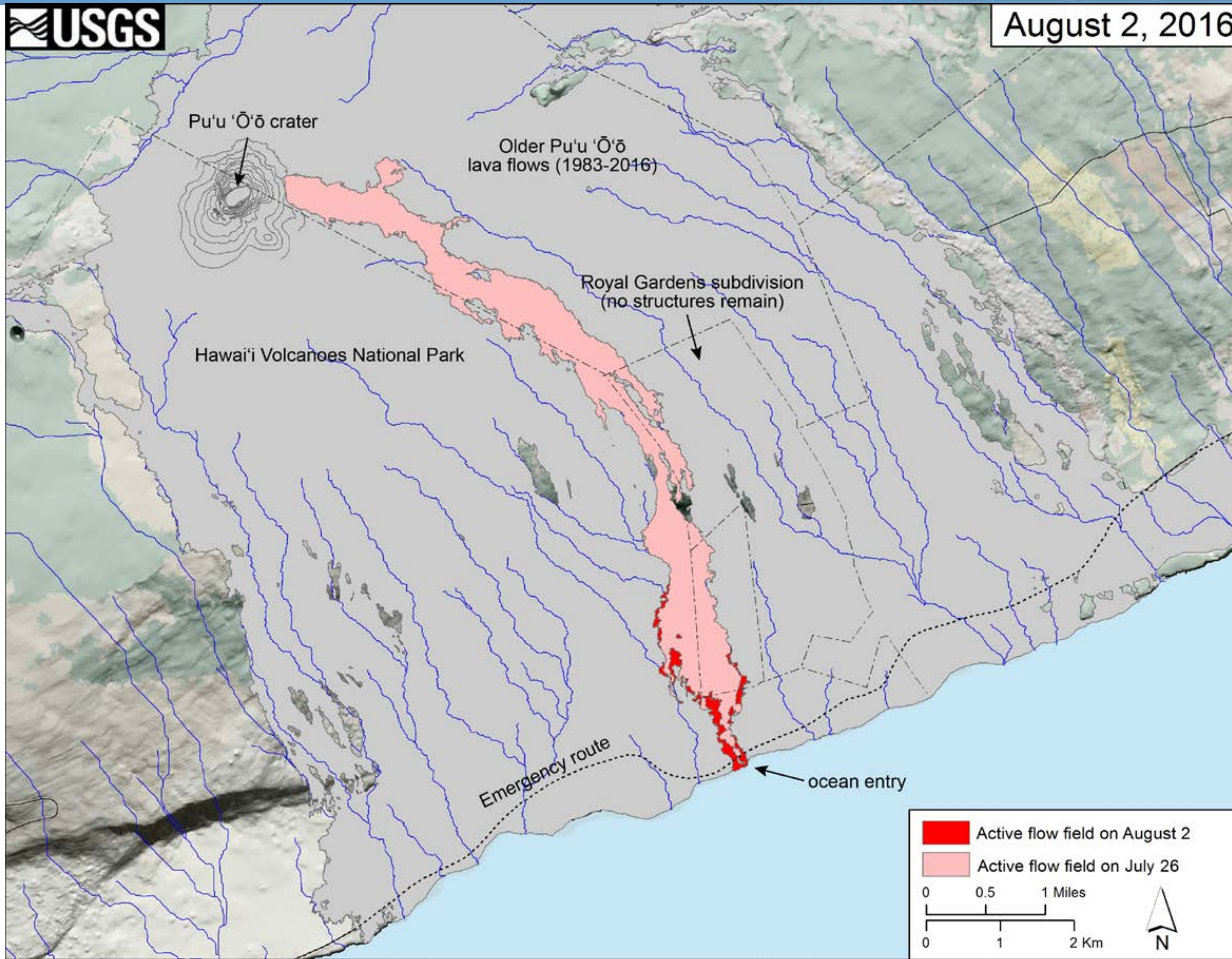
Objective B: Supersites

- 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

Objective B: Hawai‘i

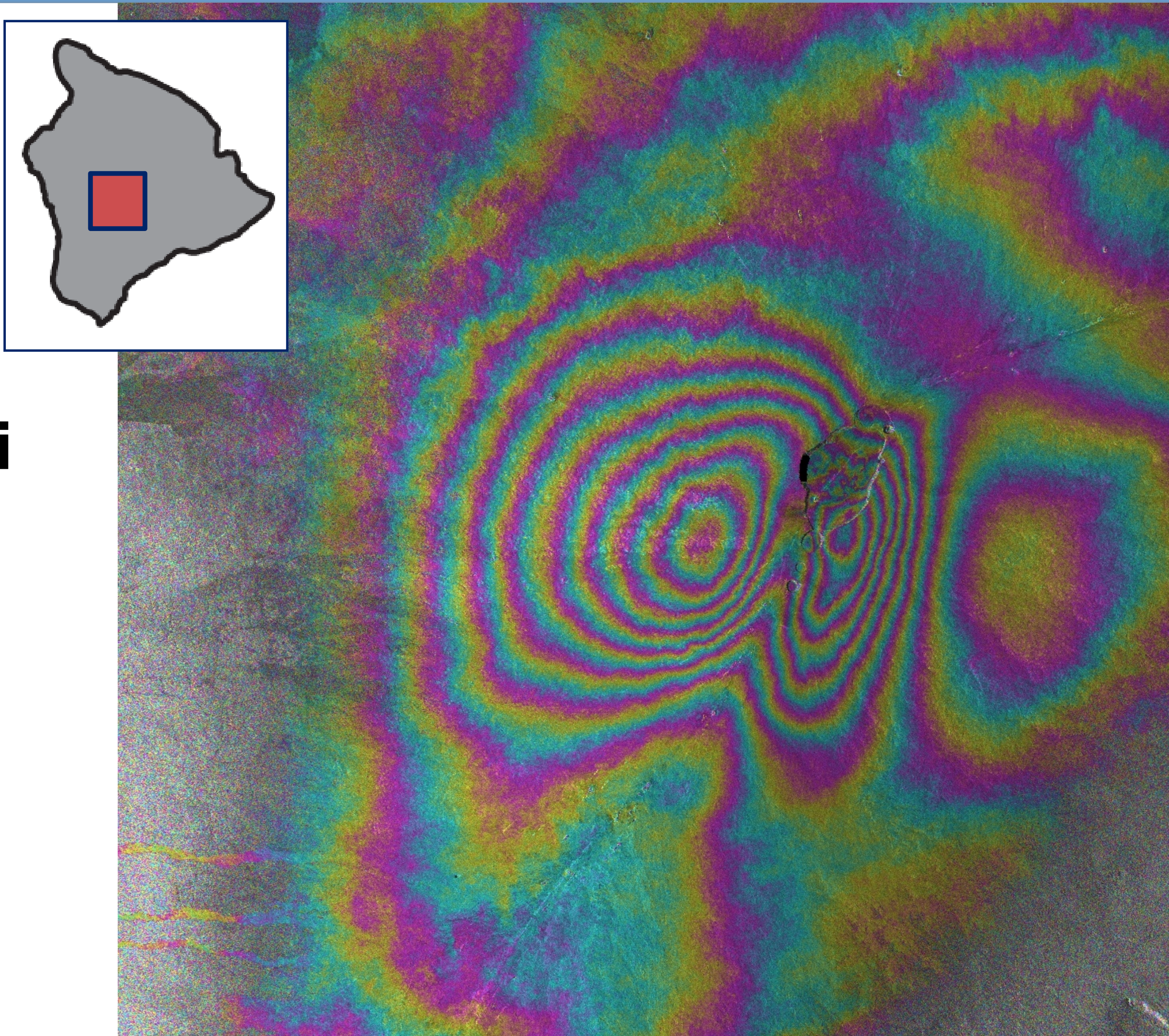


Objective B: Hawai‘i



Objective B: Hawai‘i

Inflation of Mauna Loa volcano, Hawai‘i

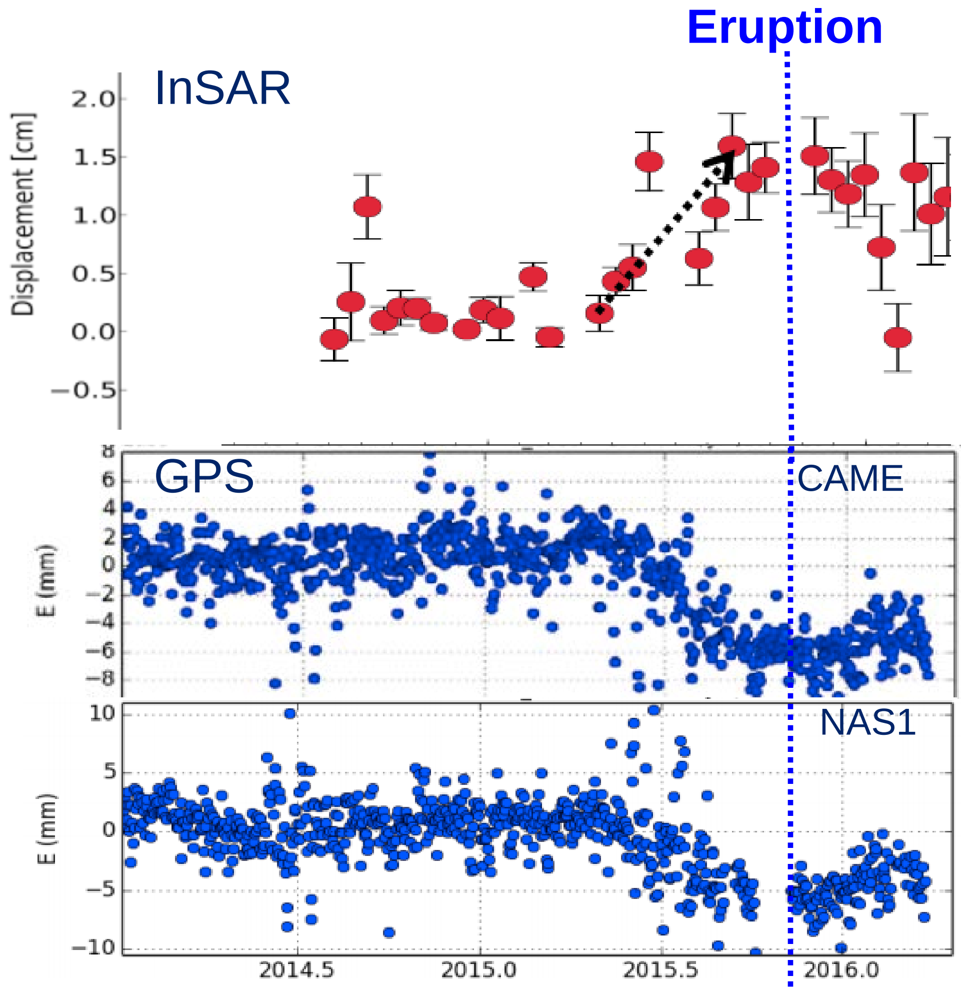


Cosmo-SkyMed

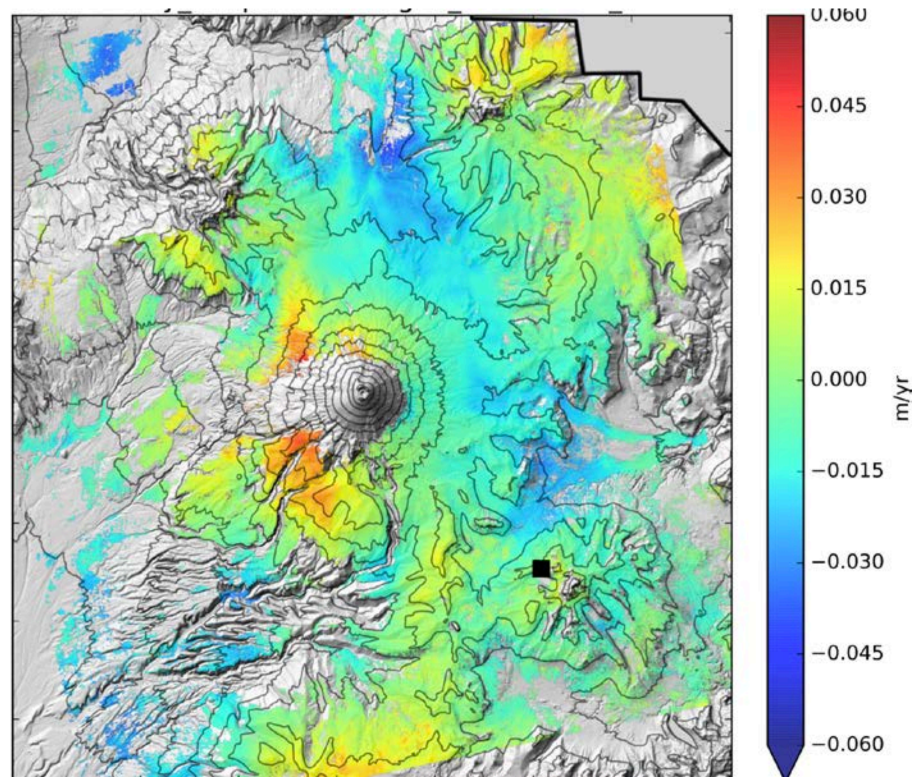
**August 22, 2014 –
August 27, 2016**

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

Objective B: Cotopaxi



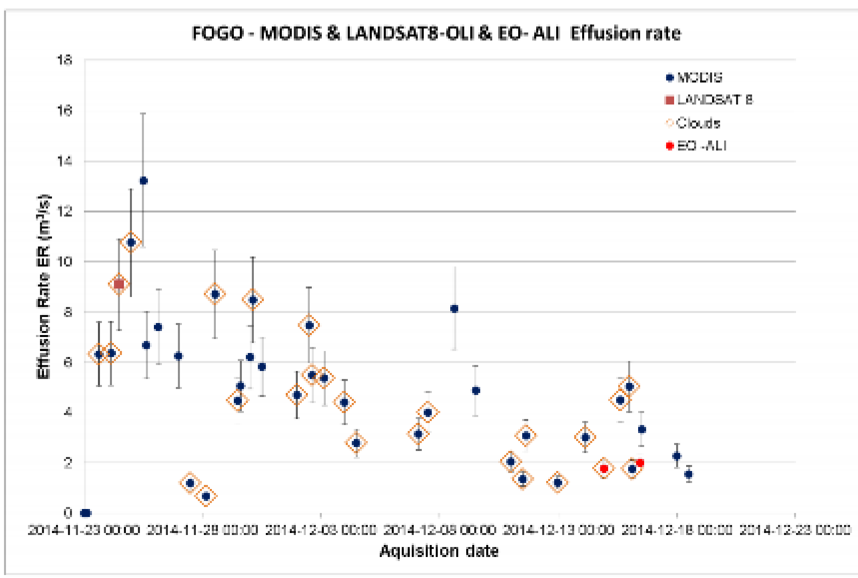
Mean LOS Velocity
April – July 2015

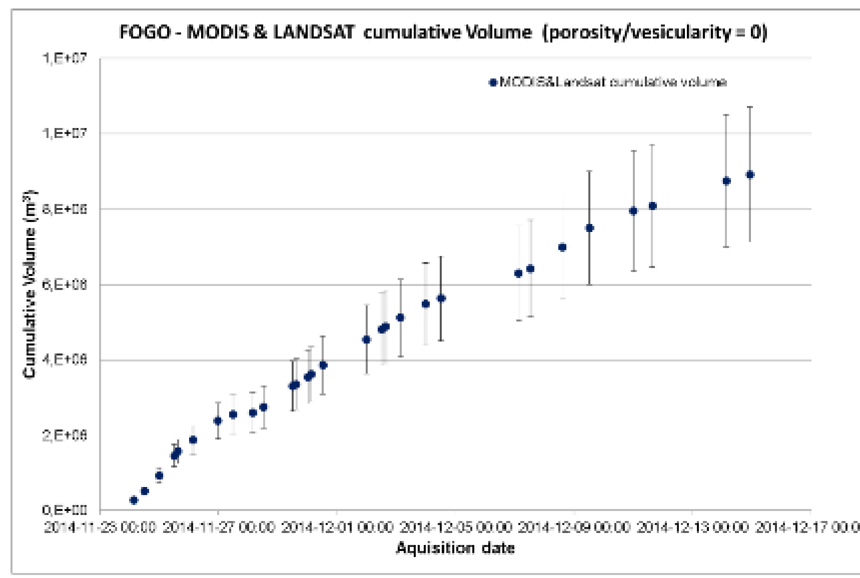


InSAR shows ~1.5 cm LOS decrease from April to August 2015, correlating with GPS

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





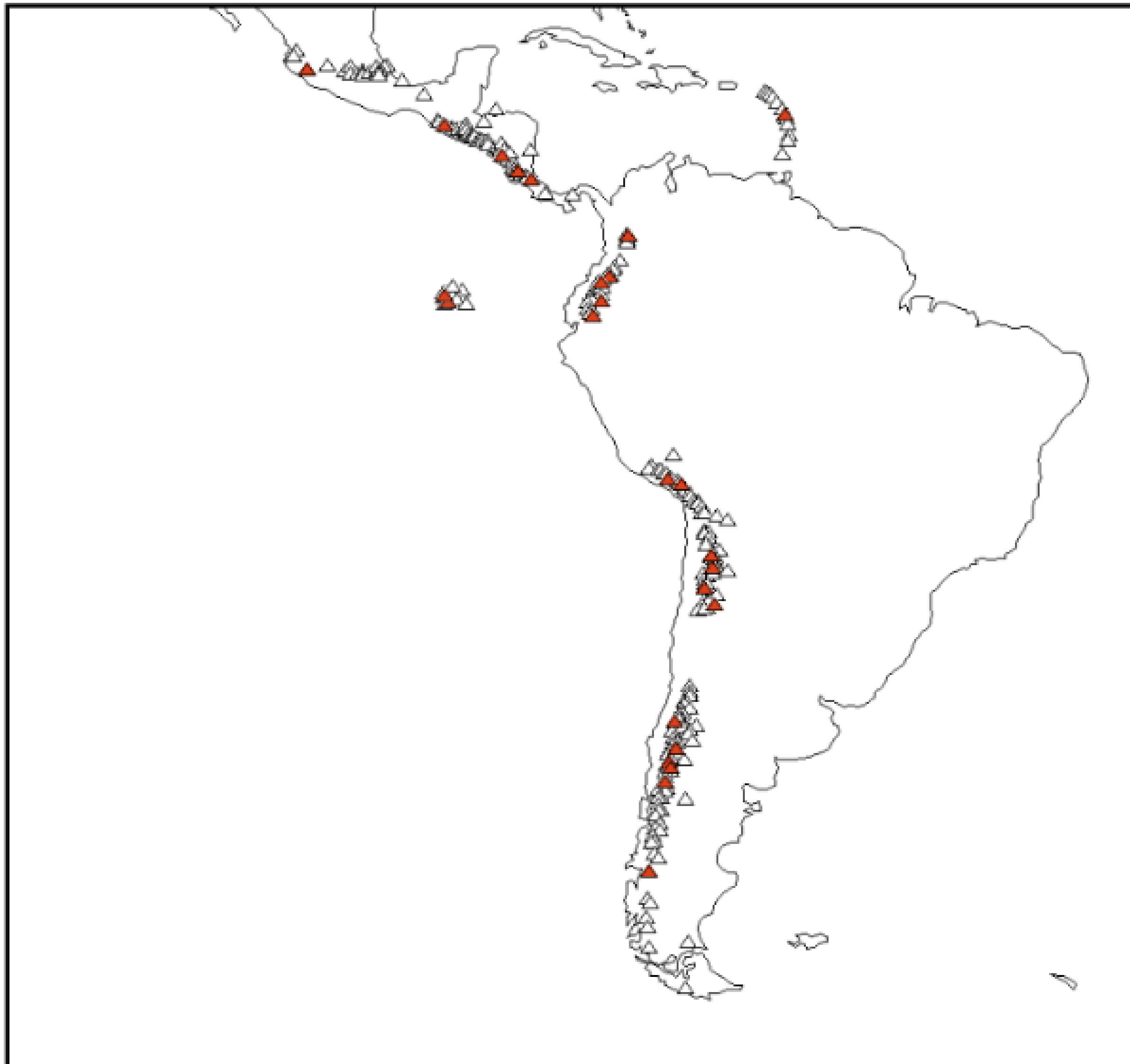
courtesy Fabrizzio Ferucci, Open University

Objective A: Regional demonstration

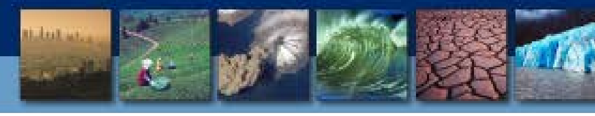
- Demonstrate how EO data can be used to cost-effectively monitor all 315 volcanoes in the region that erupted in the last 10,000 years
- Identify volcanoes that may became active in the near future
- Track new and ongoing eruptive activity

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	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	Ordered / Allocated	Noteworthy results
RADARSAT-2	**243 / 270**	Córdon Caulle, Pacaya
COSMO-SkyMed	**491 / 600**	Fernandina, Wolf
TSX	**164 / 400**	Chiles–Cerro Negro
ALOS-2	**98 / 200**	Arc-wide studies
TDX (CoSSC exp.)	**22/150**	Montserrat

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

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

Results: Santiaguito

Volcanic Cloud Monitoring — NOAA/CIMSS

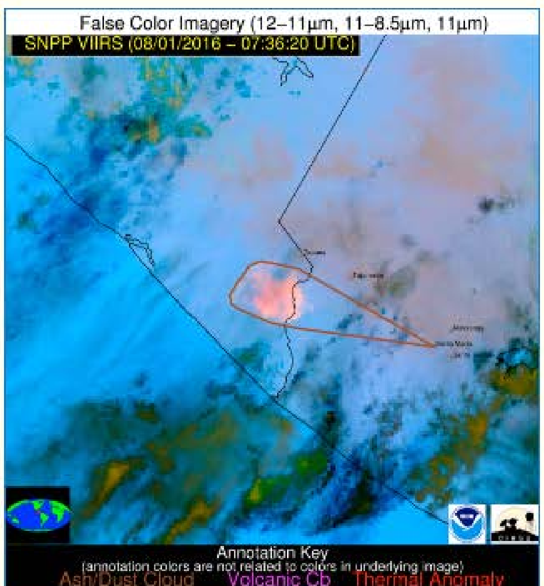
Home | Satellite Imagery | Alerts | Coverage Map | Tutorials | Admin | Logout (mpav@ssec.wisc.edu)

Volcanic Cloud Alert Report

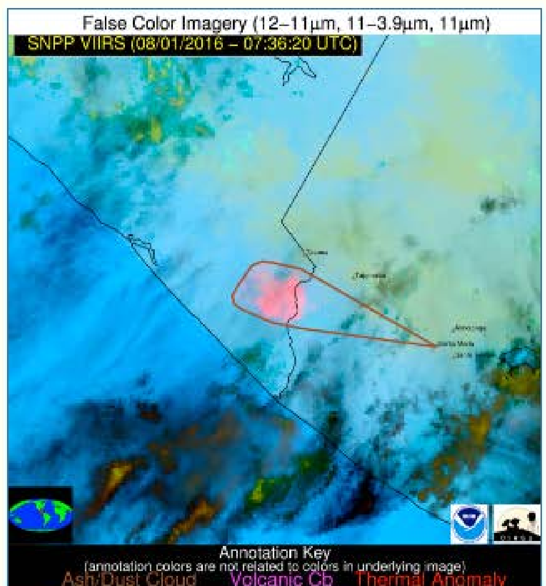
DATE:	2016-08-01
TIME:	07:36:20
Production Date and Time:	2016-08-01 14:34:22 UTC
PRIMARY INSTRUMENT:	NPP VIIRS

More details ▼

Possible Volcanic Ash Cloud



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



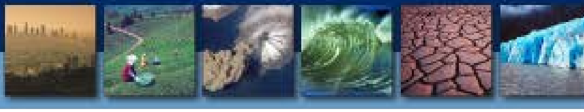
False Color Image (12-11, 11-3.9, 11) [zoomed-in]

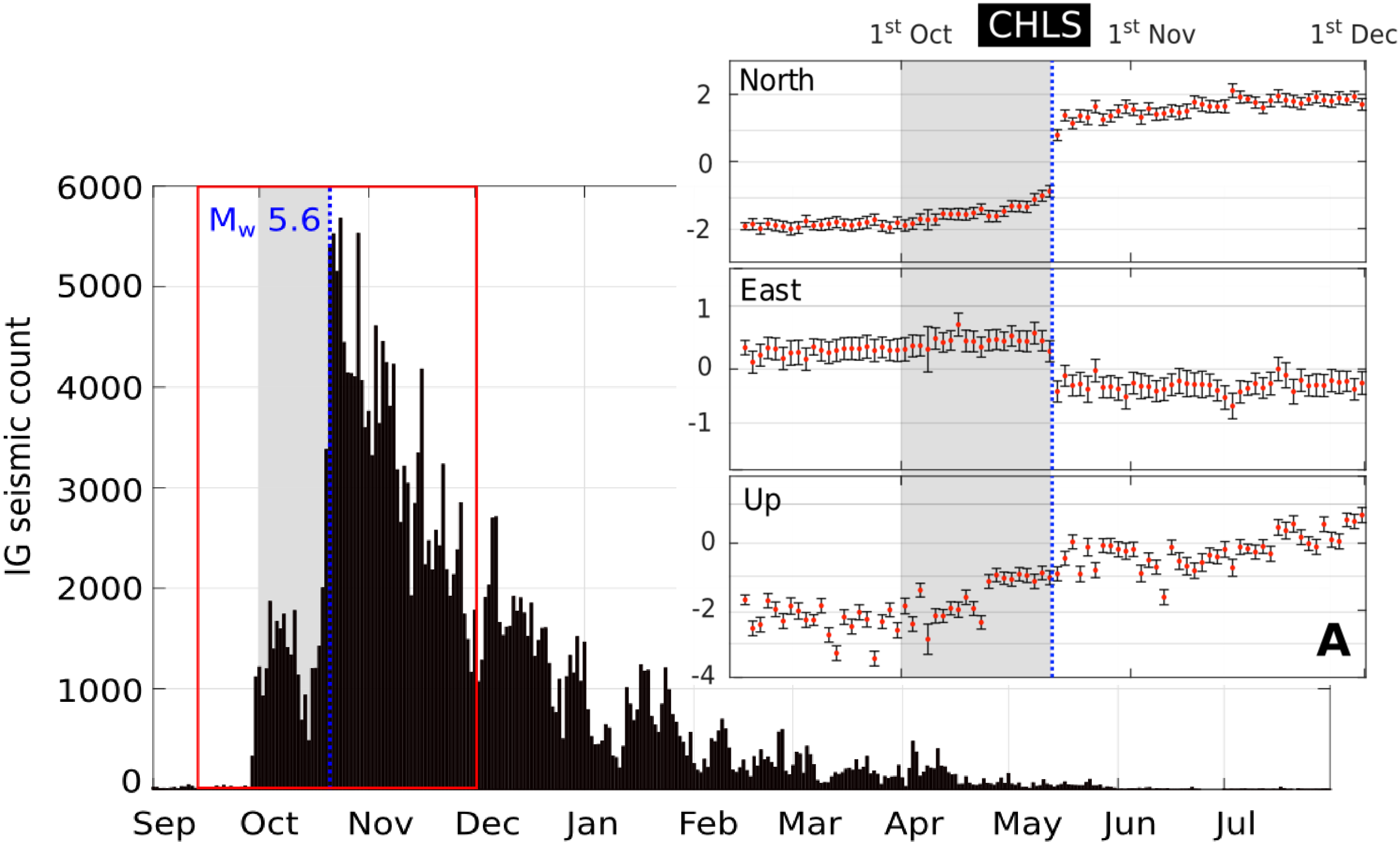
Basic Information

Volcanic Region(s)	Mexico and Central America
Country/Countries	Guatemala
Volcanic Subregion(s)	Guatemala
VAAC Region(s) of Nearby Volcanoes	Washington
Mean Object Date/Time	2016-08-01 07:36:20UTC
Radiative Center (Lat, Lon):	14.760 °, -91.550 °
Nearby Volcanoes (meeting alert criteria):	Santa Maria (0.00 km) Santo Tomas (9.40 km) Almolonga (10.50 km) Toliman (42.20 km) Atitlan (43.90 km)
Maximum Height [AMSL]	7.60 km; 24934 ft
90th Percentile Height [AMSL]	6.20 km; 20341 ft
Mean Tropopause Height [AMSL]	16.50 km; 54134 ft

Show More ▲ | View all event imagery »

Results: Chiles – Cerro Negro





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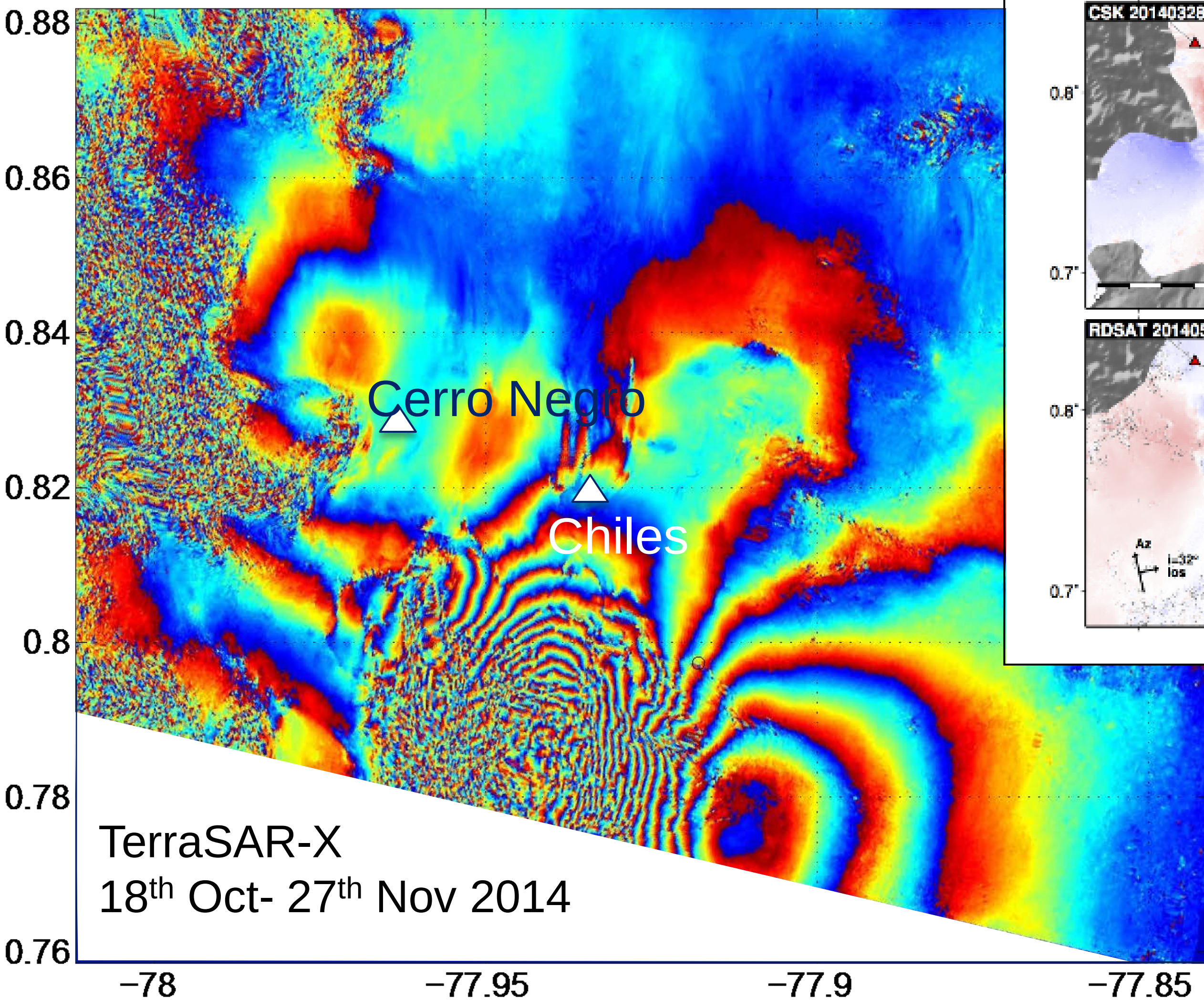
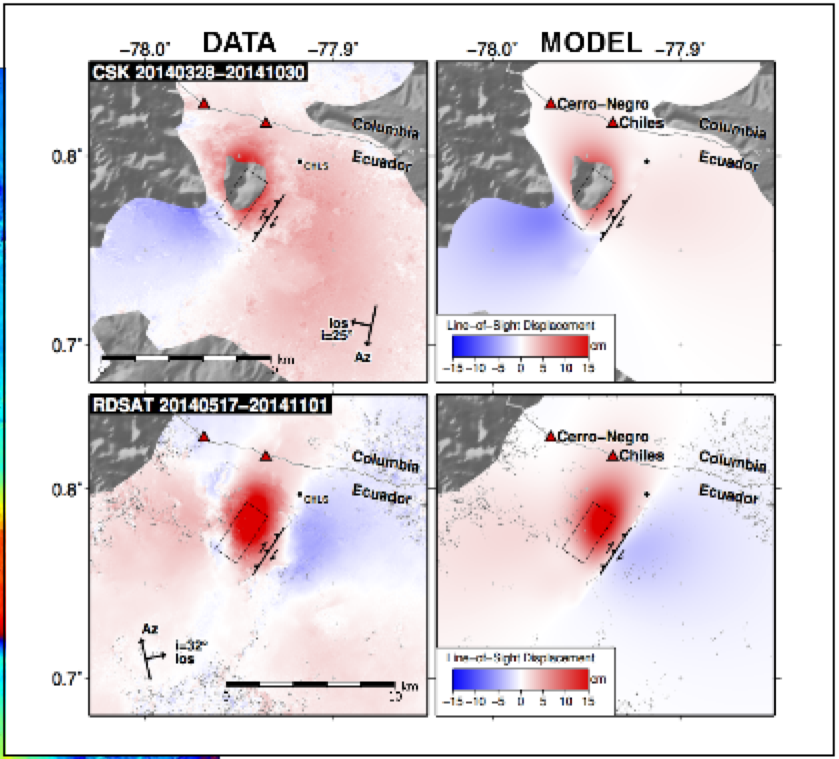
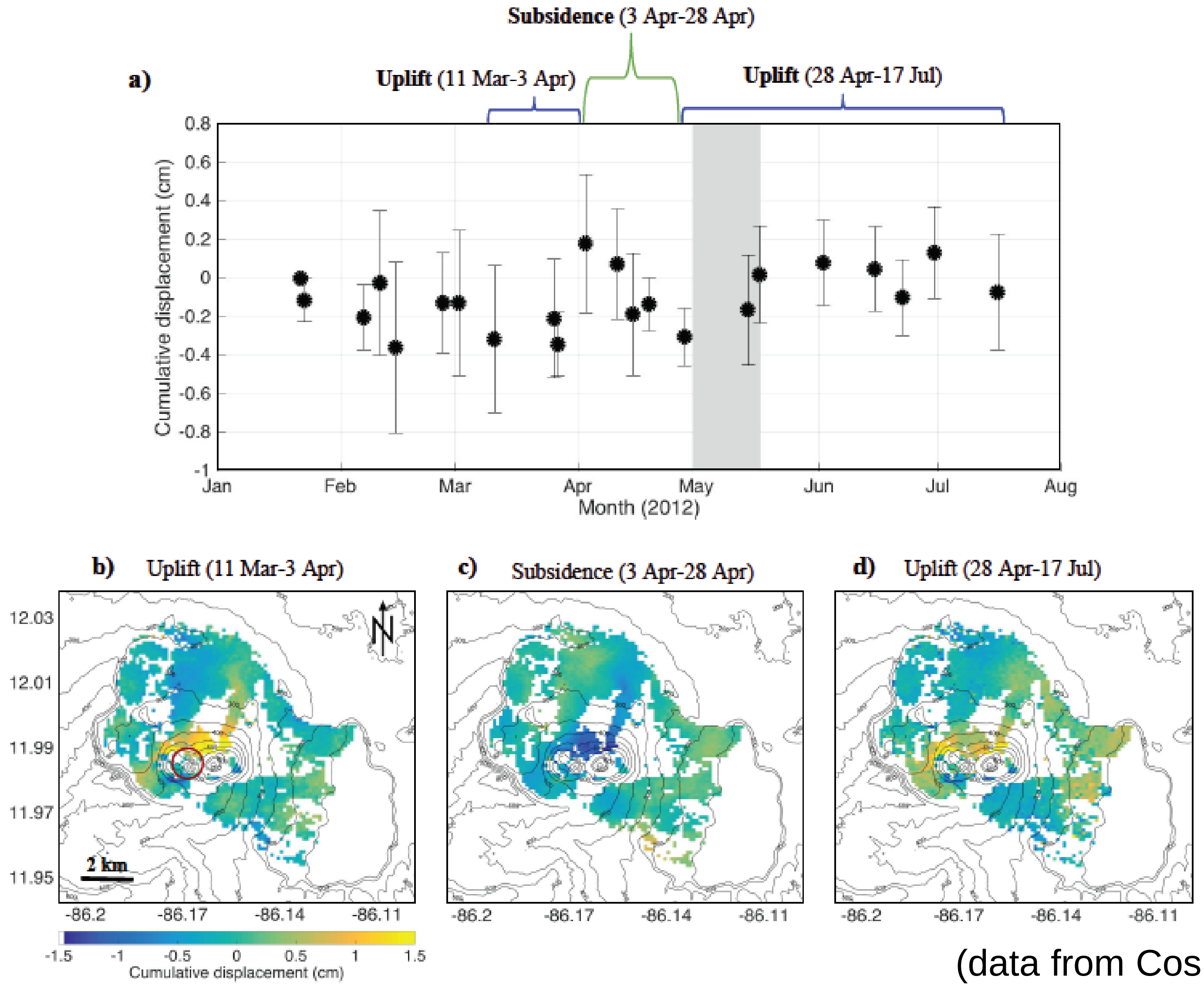




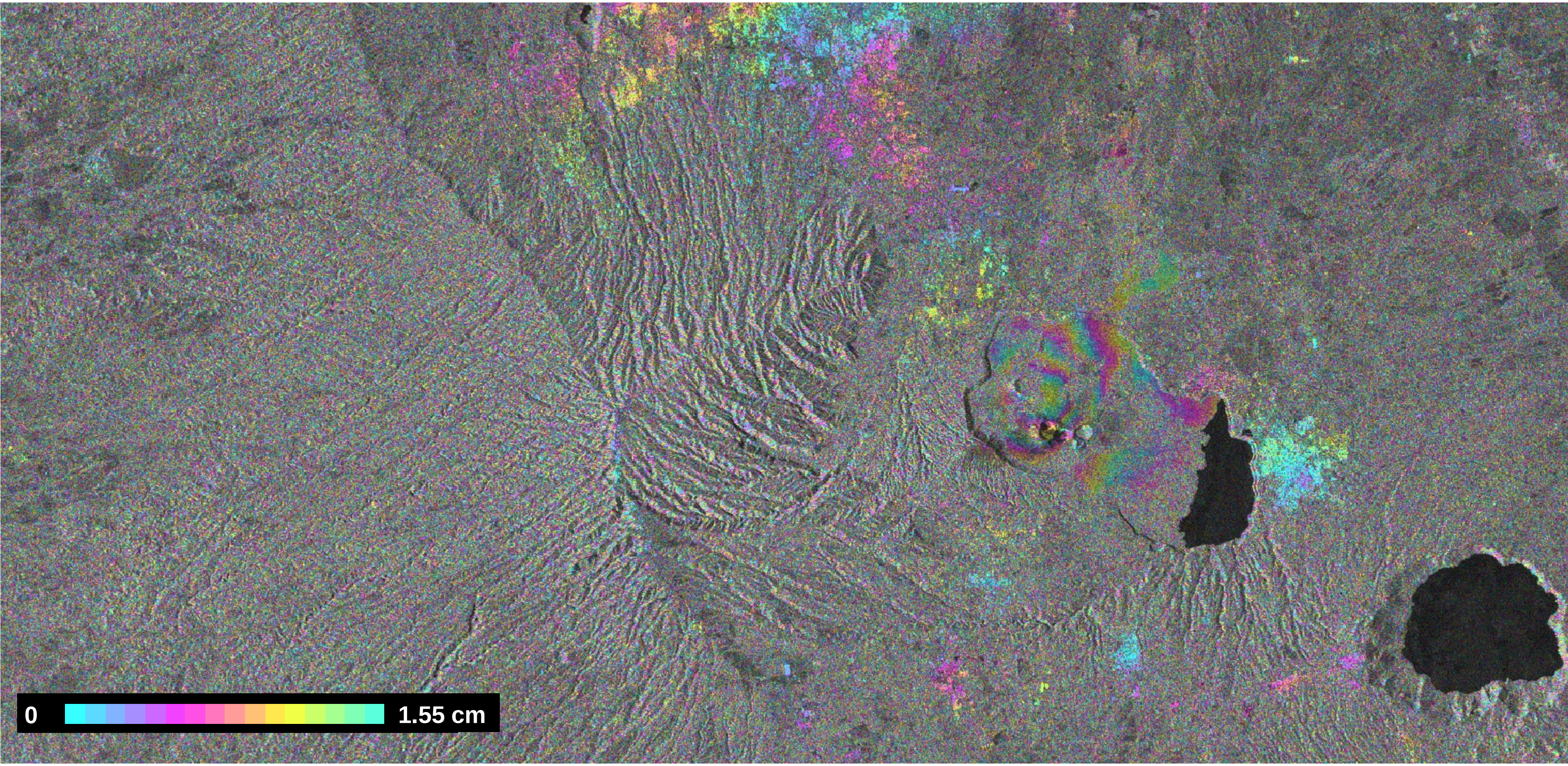
Ground deformation – is it magma or “just” the earthquake?

Results: Masaya (2012 explosions)



(data from Cosmo-SkyMed)

Results: Masaya (2015–2016)

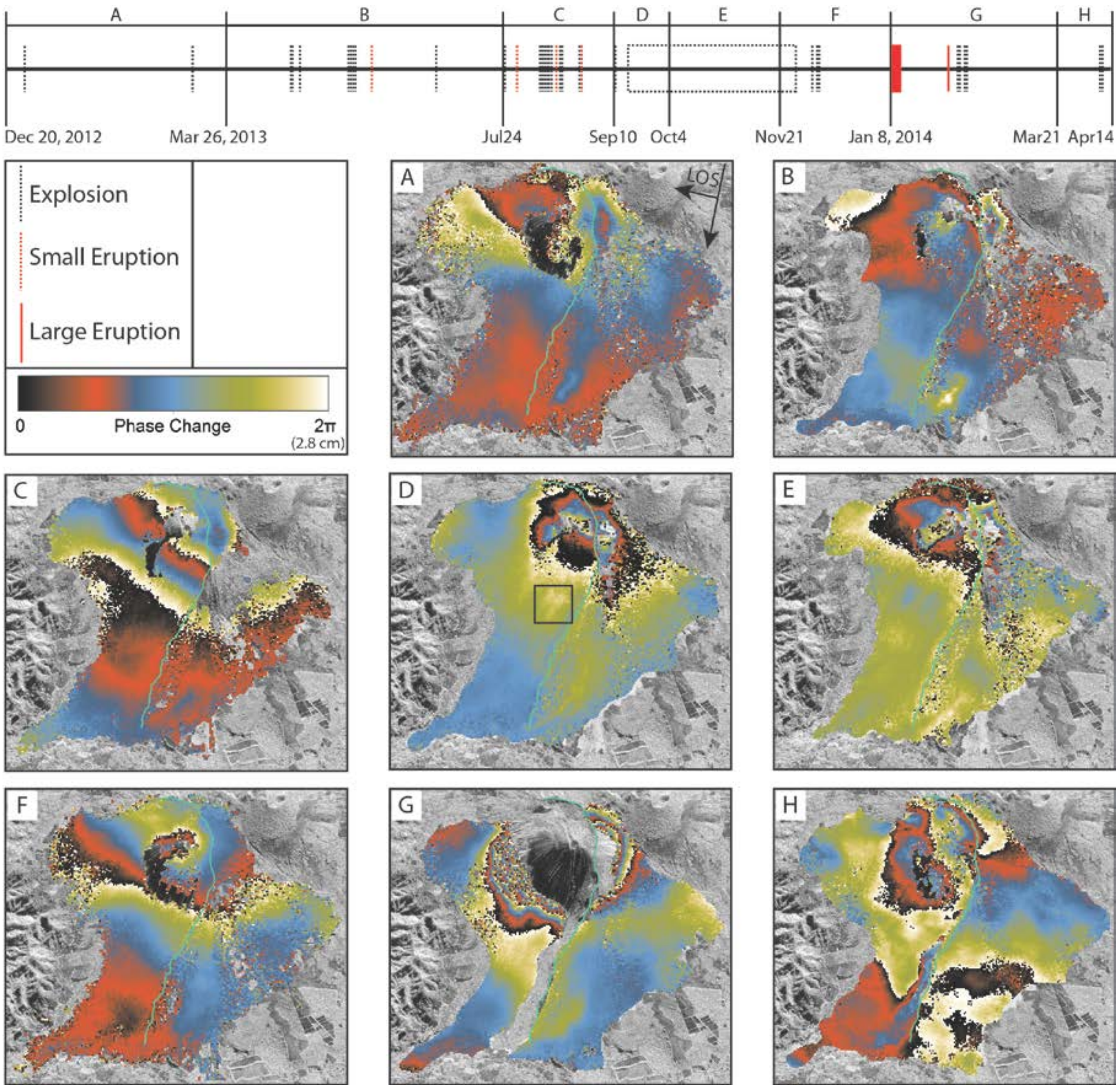


November 4, 2015 – May 14, 2016
Sentinel-1a, ascending track

Modeled source depth: 1.5 km

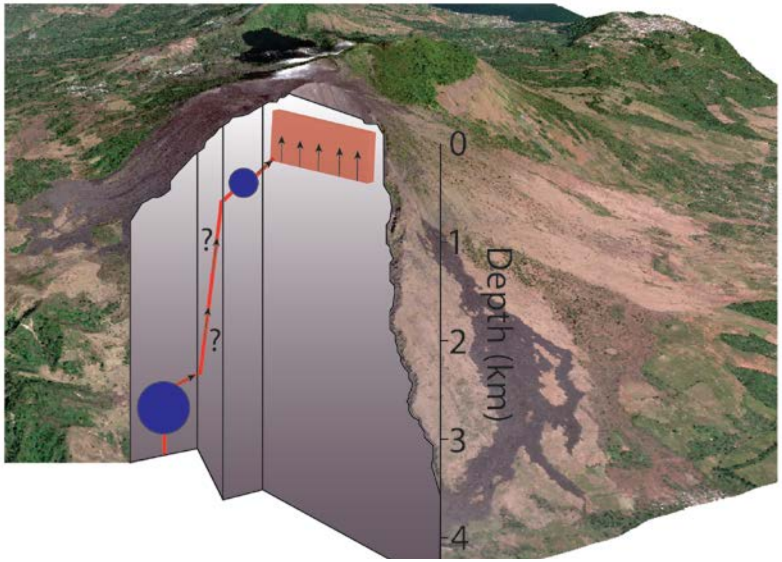
Results: Pacaya

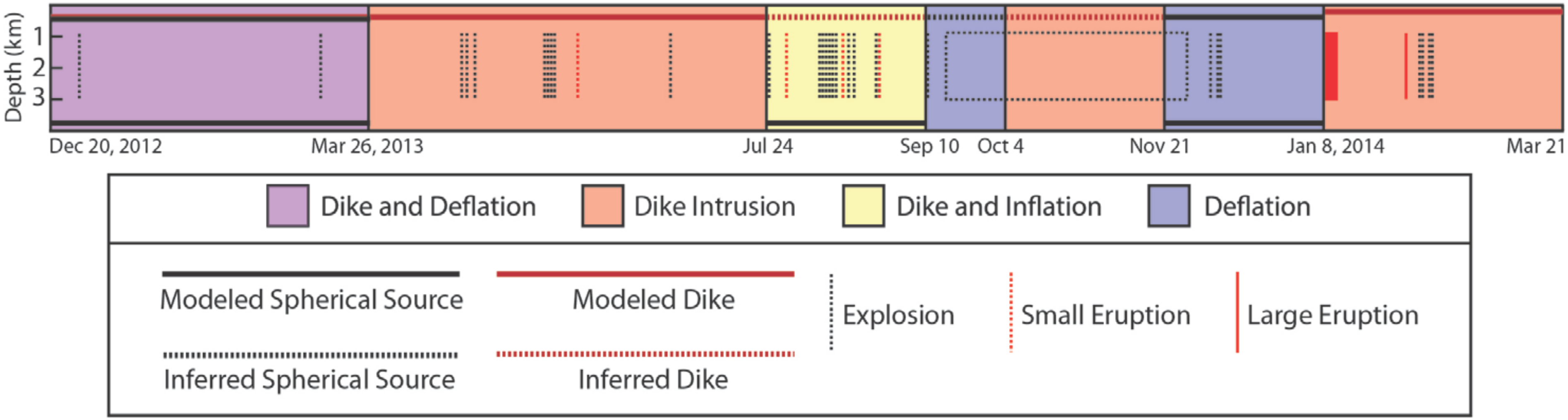
Complex deformation of Pacaya, Guatelama, revealed by RADARSAT-2



Results: Pacaya

Modeling of InSAR reveals the magmatic plumbing system at Pacaya



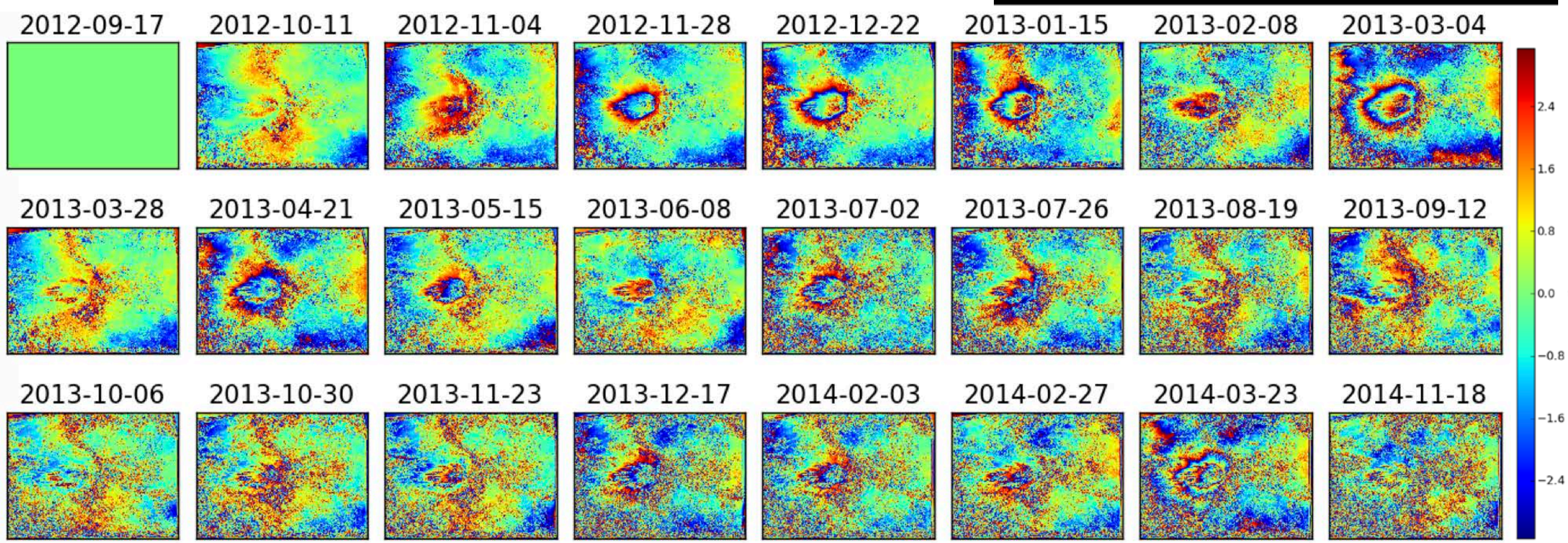


Results: Popocatepetl

Radarsat-2 displacement time-series

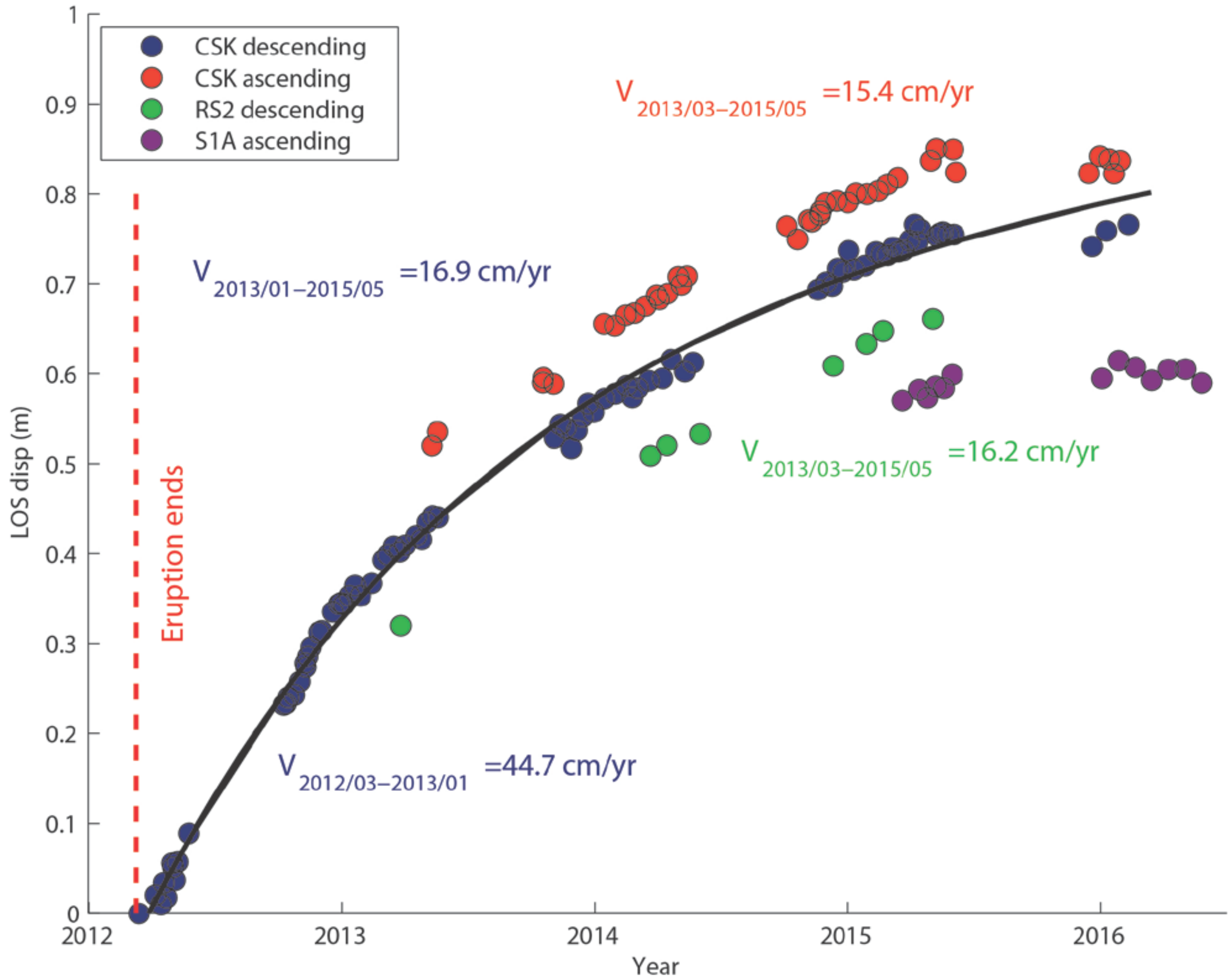
Next steps:

- combine with TSX in collaboration with Thomas Walter, GFZ
- use GPS zenith delays to assess troposphere
- explore TSX over Colima



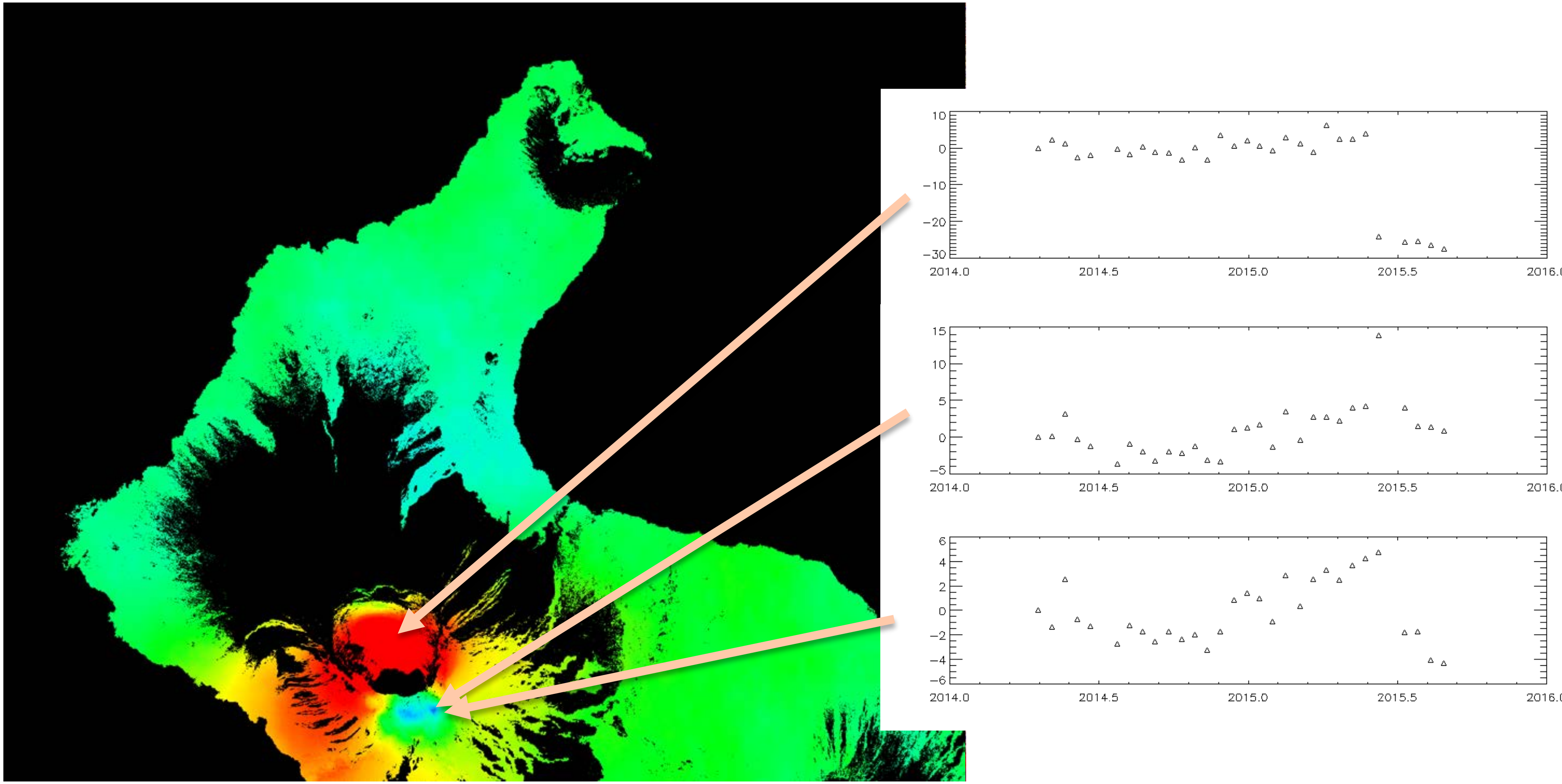
Results: Cordón Caulle

OVDAS installed 3 continuous GPS stations in response to interferograms showing inflation of Cordón Caulle



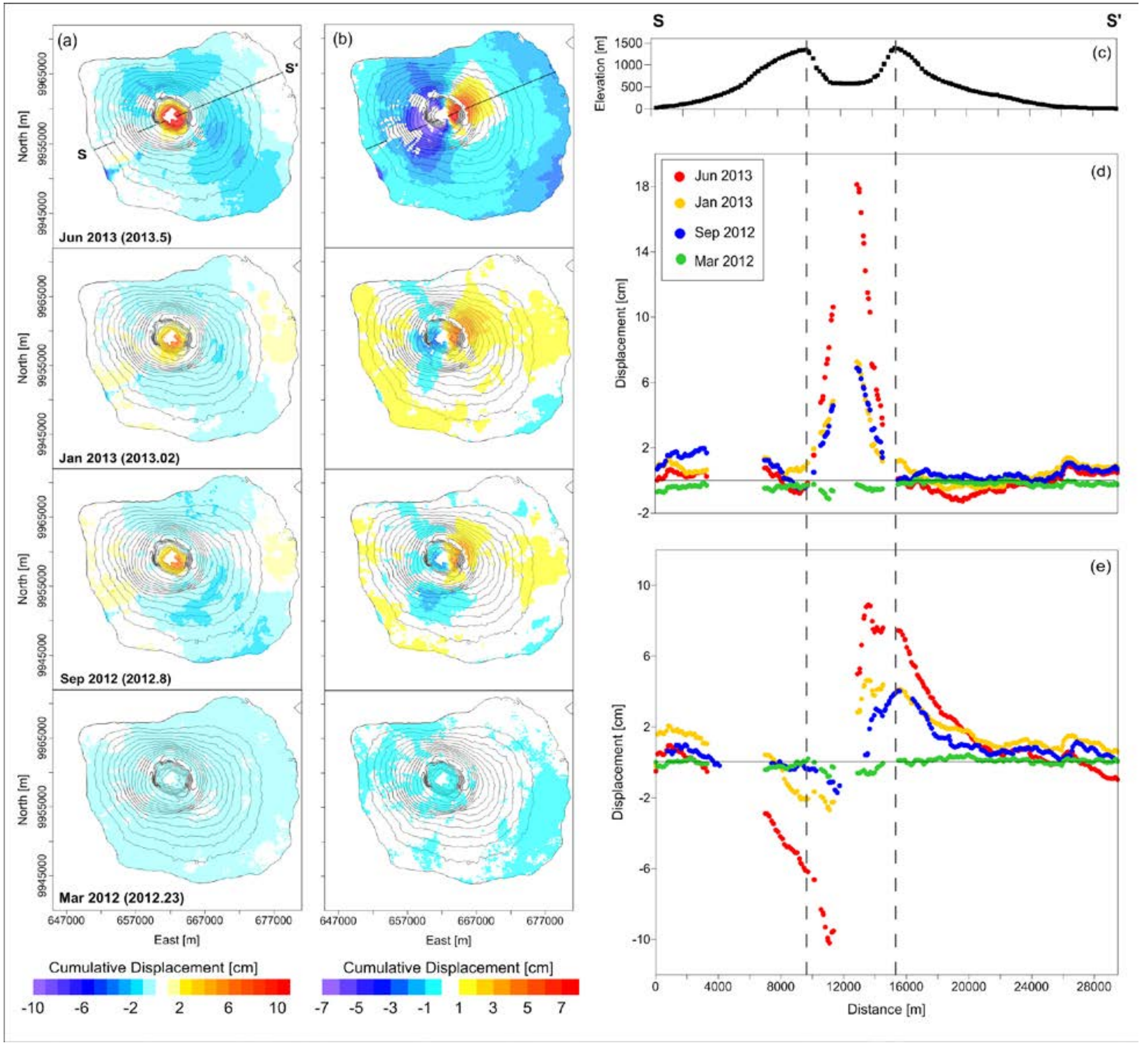
Results: Wolf

Eruption of Wolf volcano, Galápagos, May 25 – July 11, 2015



Results: Fernandina

Deformation of Fernandina volcano, Galápagos, in space and time



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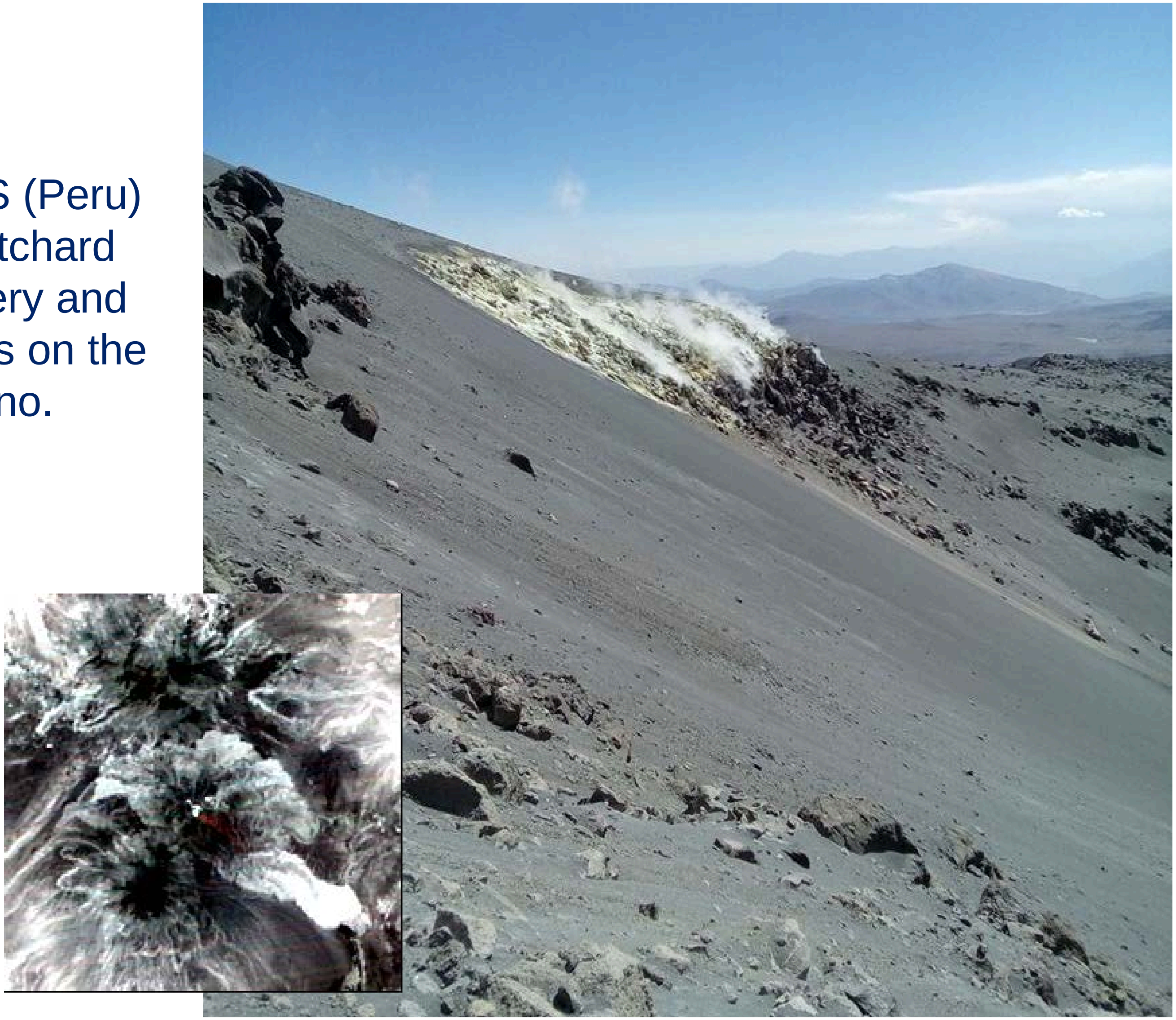
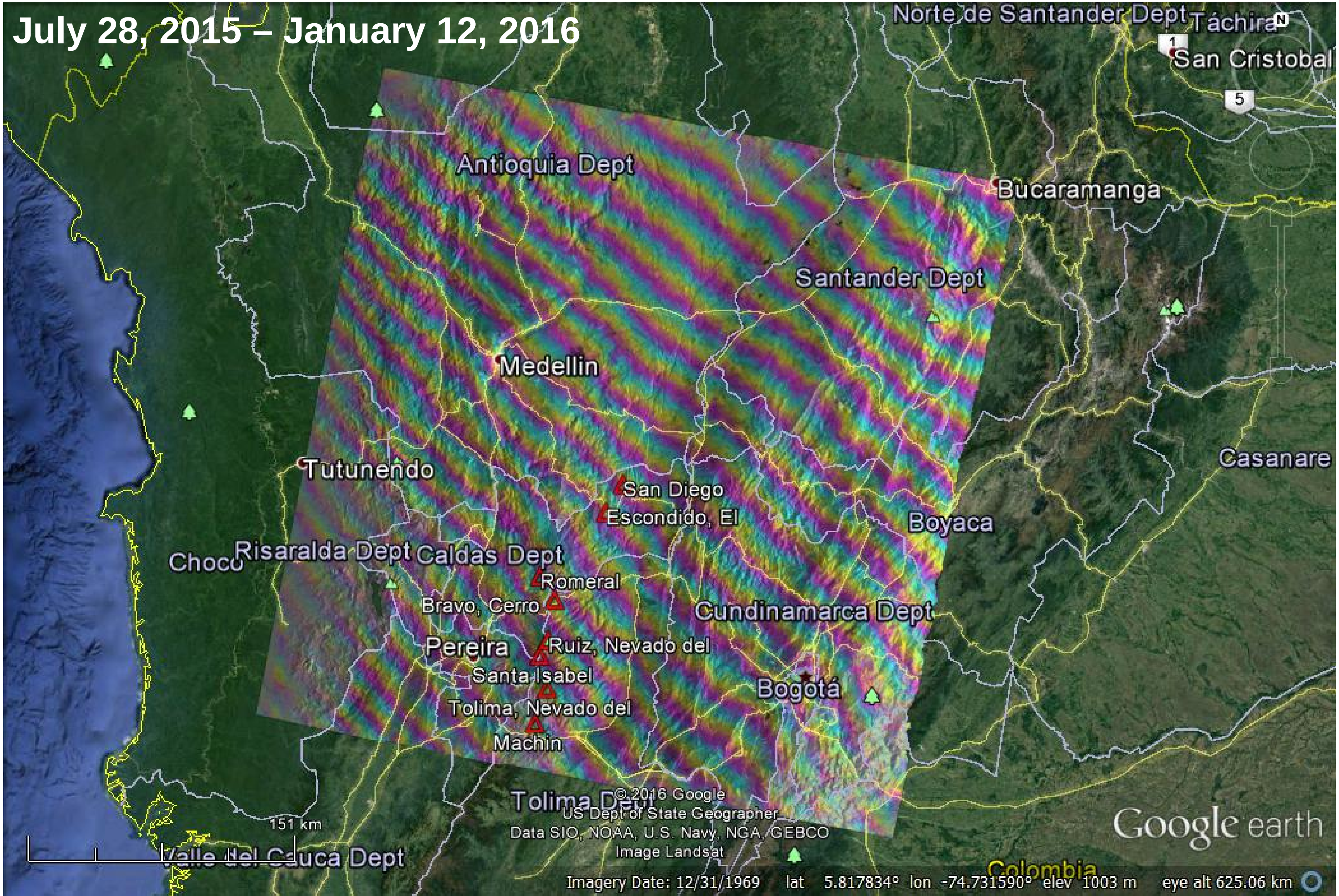
Results: Request from Peru

On August 31, 2016, OVS (Peru) sent a request to Matt Pritchard for thermal satellite imagery and InSAR covering fumaroles on the flank of Sabancaya volcano.



Results: ALOS2 broad-scale InSAR



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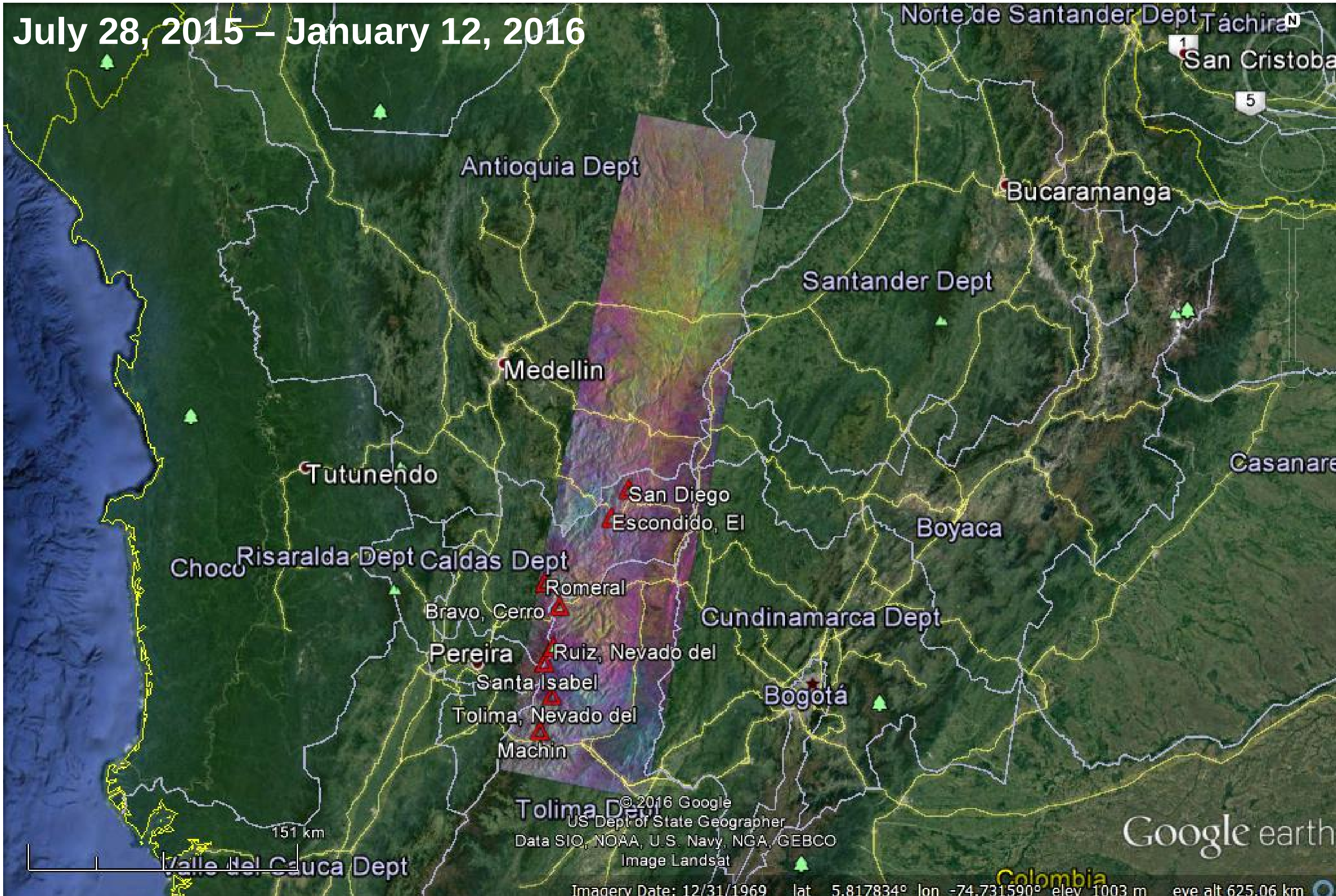
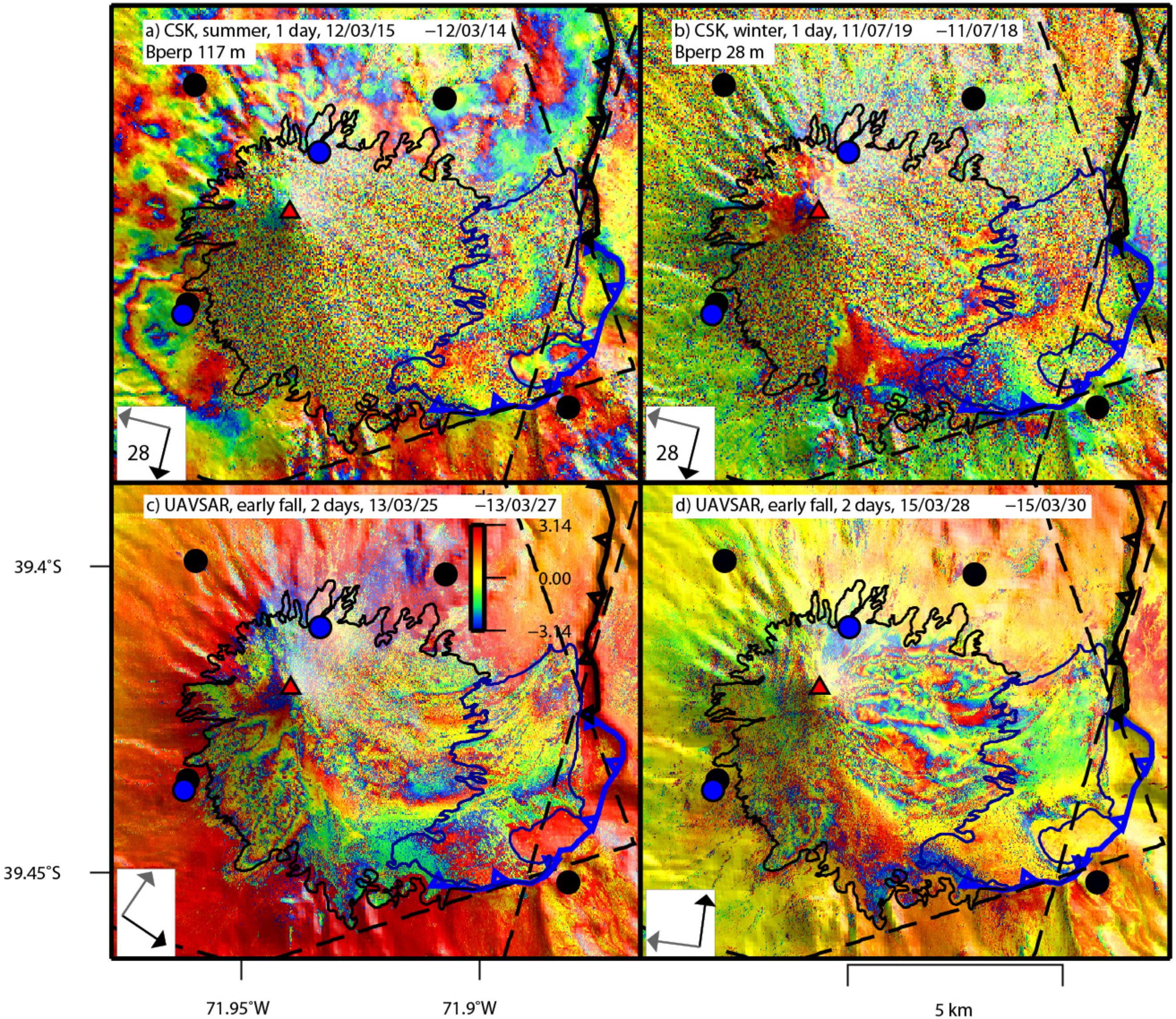
Results: ALOS2 broad-scale InSAR



Results: Lessons learned



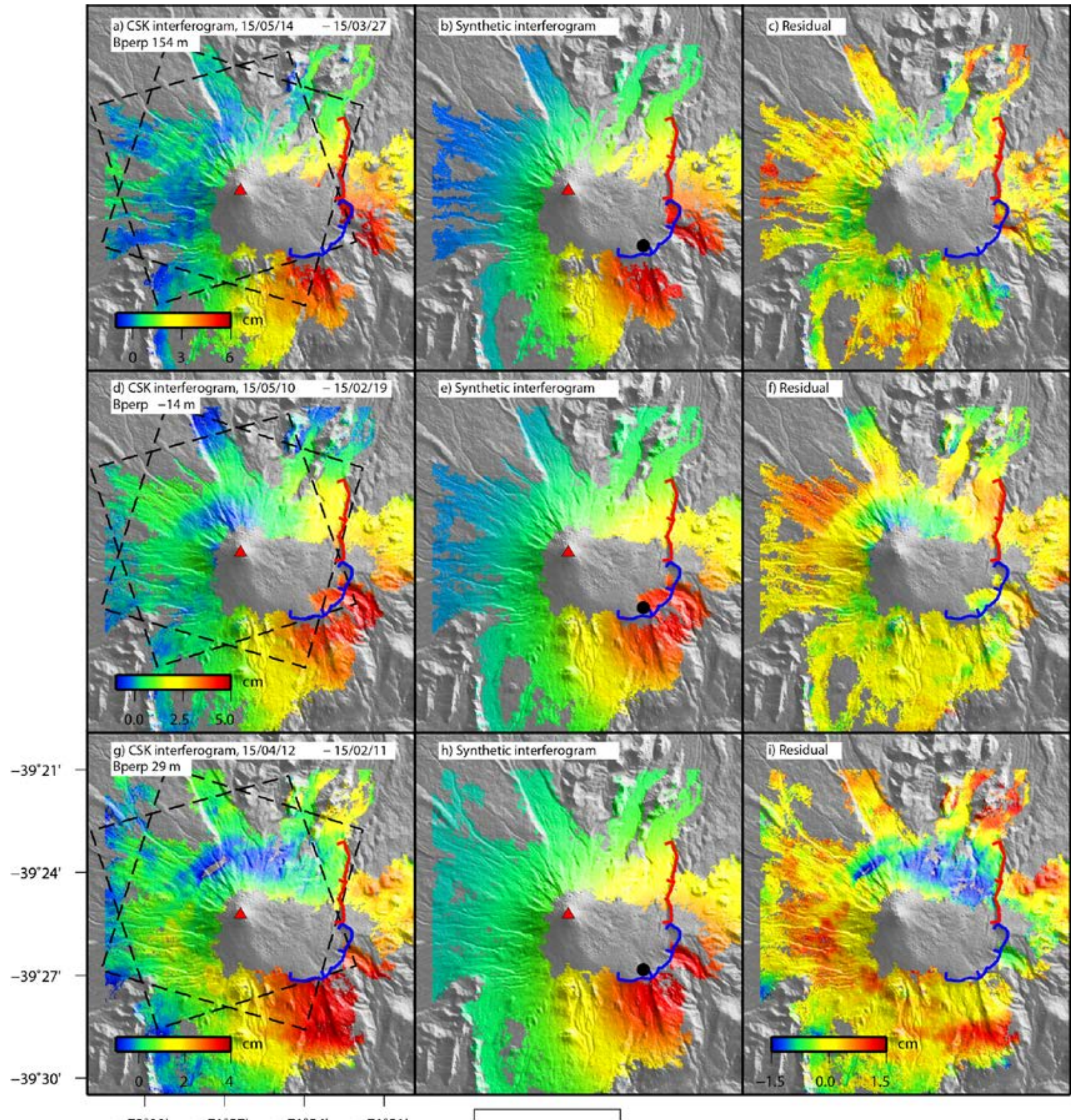
Villarica, Chile

The volcano is capped by a glacier. Even 1-2-day interferograms (X- and L-band) are not very coherent, implying that InSAR will not be useful for studying shallow magma dynamics.

Results: Lessons learned

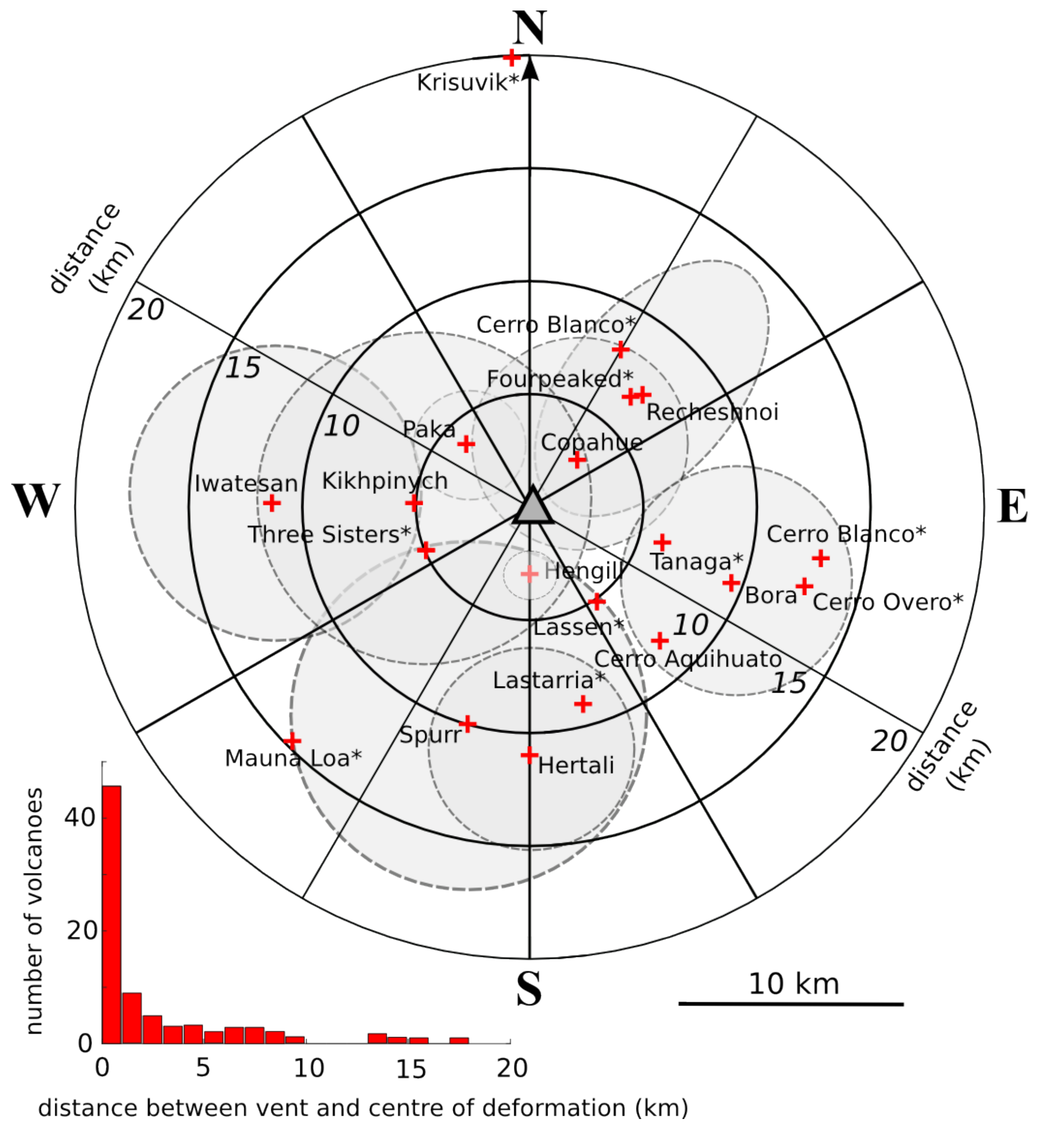
Villarica, Chile

Deformation may not be centered on the volcano. This means that extremely high resolution SAR scenes (like TSX Spotlight) of a volcano's summit might "miss" volcano-wide deformation.



Results: Lessons learned

- 43 examples of deformation > 5 km from volcano associated with unrest
- Eight observations of distal deformation associated with volcanic eruptions
- Ten distal deformation signals associated with major earthquakes, ~25 have an unclear relationship with eruptive centres



Results: Lessons learned

- **Is there an ability to exploit the massive archive of CSK data (hundreds of scenes, in some cases) available over some volcanoes?**
  - **Villarica**
  - **Santiaguito**
  - **Masaya**
  - **Tungarahua**

- **What are the spatial-temporal characteristics of deformation?**
- **How frequently are acquisitions needed?**

Results: Publications

- Arnold, D. W. D., J. Biggs, G. Wadge, S. K. Ebmeier, H. M. Odbert, and M. P. Poland (2016), Dome growth, collapse, and valley fill at Soufrière Hills Volcano, Montserrat, from 1995 to 2013: Contributions from satellite radar measurements of topographic change, *Geosphere*, doi:10.1130/GES01291.1.
- Delgado F., M. E. Pritchard, S. Ebmeier, P. Gonzalez, L. Lara (submitted), Recent unrest (2002-2015) imaged by space geodesy at the highest risk Chilean volcanoes: Villarrica, Llaima, and Calbuco (southern Andes), *Journal of Volcanology and Geothermal Research*.
- Delgado, F., M. E. Pritchard, D. Basualto, J. Lazo, L. Córdova, and L. Lara (in press), Rapid re-inflation following the 2011-2012 rhyodacite eruption at Cordón Caulle volcano (Southern Andes) imaged by InSAR: evidence for magma chamber refill, *Geophysical Research Letters*.
- Ebmeier, S. K., J. R. Elliott, J. M. Nocquet, J. Biggs, P. Mothes, P. Jarrín, M. Yépez, S. Aguaiza, P. Lundgren, and S. V. Samsonov (2016), Shallow earthquake inhibits unrest near Chiles–Cerro Negro volcanoes, Ecuador–Colombian border, *Earth and Planetary Science Letters*, v. 450, 283–291.
- Stephens, K.J., S.K. Ebmeier, N.L. Young, and J. Biggs (submitted), Transient deformation associated with explosive eruption measured at Masaya volcano (Nicaragua) using Interferometric Synthetic Aperture Radar, *Journal of Volcanology and Geothermal Research*.
- Wnuk, K. C., and C. Wauthier (submitted), Temporal evolution of magma sources and surface deformation at Pacaya Volcano, Guatemala revealed by InSAR, *Journal of Volcanology and Geothermal Research*.

Capacity Building

- **STREVA workshop in Pasto, Colombia: "Interpreting and modelling volcano InSAR" (will involve scientists from Colombia and Ecuador) – September, 2016**
- **Cities on Volcanoes 9 workshop in Puerto Varas, Chile: "Interferometric Synthetic Aperture Radar (InSAR) Processing" – November 2016**
- **IAVCEI workshop in Portland, OR, USA: "Volcano remote sensing" – August 2017**

Sustainability: Questions

What elements of the pilot have proven to be successful, especially with regard to user interest and involvement? Are there specific elements that will be "missed" if stopped now? Which ones and why?

- **InSAR results, both crisis and non-crisis**
- **Information about ash plumes**
- **On-site training (Colombia, Ecuador, Peru, Chile, etc.)**
- **All these elements would be “missed” because they provide both indications of potentially active volcanoes and situational awareness during eruptions**

Sustainability: Questions

Are there elements of the pilot that are likely to be supported (possibly financially) from outside CEOS and the pilot going forward beyond 2017? If yes, what organizations might be willing to contribute to a sustainability plan?

- A number of database projects (including the Powell Center) will continue beyond 2017
- Outreach will continue via efforts like STREVA
- USGS (Volcano Disaster Assistance Program) is a logical partner in sustainability

Sustainability: Questions

In considering successes that should go forward, do these involve a transition from research to operations? Are there data issues involved?

- Operational effort MUST involve dedicated scientific personnel to coordinate work (FTE)
- Data availability (mostly SAR, but also some thermal/optical) must be assured

Sustainability: Questions

Do you consider that data for the sustainable elements should come from CEOS, or from commercial providers, or some mix?

- **Data must come from a mix, but can be coordinated and supported by CEOS**

Sustainability: Questions

Who are the key partners for achieving sustainability?

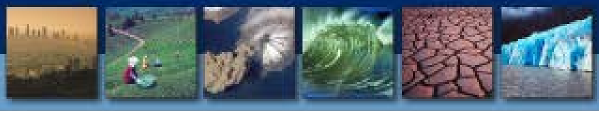
- Academic institutions (can provide training as well as data processing/interpretation)
- Operational institutions (e.g., USGS, NOAA)
- Space Agencies
- CEOS

Sustainability: Questions

Who are the main clients and users of the sustainable services?

- Volcano Observatories
- VAACs
- Academic Institutions
- Operational Institutions (e.g., USGS, NOAA)

Sustainability: Questions



What if any is the role for CEOS in the sustainable service?

- **Facilitating access to satellite data for use in hazards assessment/mitigation and disaster response (beyond the International Charter)**

Sustainability: Questions

What are the largest threats to sustainability, and what are the consequences of not achieving a sustainable service as proposed?

Threats

- Data availability
- Need trained scientists to work on data, communicate with VOs, interface with space agencies

Consequences

- Business as usual (VOs don’t get needed insights)

Sustainability: Questions

Does sustainability imply a simple continuation, or does it involve scaling something developed in the pilot to a global level, or other larger level? What is involved? Can you provide a description/vision of this larger system and what it entails from a cost perspective (using elements from the pilot as a the starting point for costing)?

- **Many possibilities, from regional to global, depending on the level of support**

Sustainability: Paths forward

Tier 0 [Pre-pilot]

- **No coordinated global volcano observing strategy**
- **Limited, ad hoc data availability from commercial satellites (ALOS2, CSK, DLR, RSAT2)**

Sustainability: Paths forward

Tier 1a [no cost, just data]: continued regional activities

- Quotas of satellite data from commercial satellites (write proposals, manage quotas, write reports)
- Coordinated approach—teams of academics work with VOs
- Best effort response to crises

Tier 1b [no cost, just data]: continued global activities

- Larger quotas from commercial satellites (write proposals, manage quotas, write reports)
- Coordinated approach—teams of academics for each region work directly with VOs
- *Best effort response to crises

Sustainability: Paths forward

Tier 2a [some new funds]: expanded regional activities

- Quotas of satellite data available from commercial satellites
- Partial FTE to support project management: proposals, quotas, reports, telecons, communicate with space agencies and VOs
- Coordinated approach—teams of academics work with VOs
- Best effort response to crises

Tier 2b [no cost, just data]: expanded global activities

- Larger quotas from commercial satellites
- Partial FTE (larger fraction than with option a) to support project management: proposals, quotas, reports, telecons, communicate with space agencies and VOs
- Coordinated approach—teams of academics for each region work directly with VOs
- Best effort response to crises

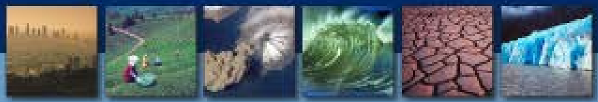
Sustainability: Paths forward

Tier 3 [new funds]: scalable to regional or global

- Large quotas of satellite data available from commercial satellites
- One or more FTE's:
  - Project management by a scientifically trained person: write proposals, manage quotas, write reports, communicate with space agencies and VOs, participate in telecons
  - Routine, near real time data processing—interpretation and processing strategy needs continuous scientific input (not just an advisory board); who will do the work, who has the oversight, and how this will be funded needs to be worked out
- Coordinated approach—teams of academics work directly with supported FTES and with VOs
- Routine response to all crises (but how to decide what constitutes a crisis?)

Coming Up…

- **Prepare a Journal of Applied Volcanology article describing the results of our work, focusing on the value to end users**
- **Develop broader space-based EO strategy using insights from pilot**
- **Powell Center (2017–2019)**
  - **15–20 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**



Thank you