Pilot Name: Volcano		
August 2016	**PI or PoC:** Mike Poland and Simona Zoffoli	**Collaborating organisations:** USGS, ASI, CNR/IREA, University of Bristol, Cornell University, University of Miami, Pennsylvania State University, NOAA, Open University, University of Iceland, INGV
Achievements: • Processed numerous interferograms for the volcano Supersites; TanDEM-X data from Hawai'i were used to create a new DEM for lava flow path forecasting • Published (or submitted) results related to datasets made available over Chiles-Cerro Negro (Colombia / Ecuador), Montserrat, Cordón Caulle (Chile / Argentina), Masaya (Nicaragua), Villarrica, Llaima, and Calbuco (Chile), and Pacaya (Guatemala) • Assessed recent deformation at Masaya volcano, Nicaragua, associated with heightened eruptive activity, and communicated results to INETER. • Examined deformation associated with the 2015 eruption of Wolf, Galápagos		
Activities: • We completed work on the assessment of deformation associated with unrest at Chiles – Cerro Negro volcanoes (on the Colombia / Ecuador border) • We completed work on the assessment of post-eruptive inflation at Cordón Caulle volcano (on the Chile / Argentina border) • We completed work on the assessment of deformation associated with unrest and eruptions at Villarrica, Llaima, and Calbuco volcanoes—the highest threat volcanoes in Chile • We responded to eruptive activity in Latin America, including at Masaya (Nicaragua) and Santiaguito (Guatemala). Products have been distributed to local end users (volcano observatories and ash advisory centers), where they have aided in constraining such variables as the likely depth of magma storage. • We continue to support the volcano Supersites. In Hawai'i, TanDEM-X data were critical for developing new lava flow path forecasts for Kīlauea Volcano, since other DEMs (like SRTM) do not include topographic change due to recent lava flows and therefore do not provide accurate flow path forecasts. The updated flow path forecasts were provided to Hawai'i County Civil Defense officials and made available to the public via the Hawaiian Volcano Observatory website. • Systematic SAR studies of volcanoes from Central America to the southern Andes are ongoing • Integration of thermal, visible, and SAR data remains in a nascent stage, but dialog between data processing experts is ongoing • Biennial reports were submitted for the Mount Etna supersite and the Vesuvius / Campi Flegrei supersite		

Data accessed this Q (#images /satellite)	Total data accessed to date (#images /satellite)	
ALOS2: 14 COSMO-SkyMed: 110 TerraSAR-X: 29 RADARSAT-2: 8 TanDEM-X: 7 Numbers of images are only reported for Objective A, since C has not started and B has a different system for tracking orders.	ALOS2: 98 COSMO-SkyMed: 491 TerraSAR-X: 164 RADARSAT-2: 243 TanDEM-X: 22 Pleiades: 3 We do not include Sentinel-1a data in these tallies, even though we make use of them as part of the pilot, because those data are distributed at no cost and with no restrictions.	
Products: (delivered this quarter)	**User** (by product)	**User or practitioner endorsement/opinion/outcomes**
Interferograms, amplitude imagery, and other products derived from SAR data	SERNAGEOMIN, Chile; Observatorio San Calixto, Bolivia; Instituto Geofísico del Perú; Instituto Geofísico de la Universidad Nacional de San Agustín, Peru; Instituto Geofísico, Escuela Politécnica Nacional, Ecuador; Servicio Geológico Colmbiano, INETER, Nicaragua	Data are being used by volcano scientists in many countries to assess volcanic unrest and the likelihood of future hazardous volcanic activity at restless volcanoes (e.g., Momotombo), as well as those currently experiencing low-level eruptions (e.g., Pacaya, Santiaguito, Masaya). Feedback from these users has uniformly been positive, emphasizing use of the data to bridge monitoring gaps, assess results from single ground-based sensors, and inform decisions about volcanic alert levels. There is a desire for more frequent data (both in terms of volume and lower latency) and additional formats (e.g., Google Earth and ArcGIS imagery), but the most critical need is for in-depth training of graduate students who can become experts in processing and interpretation of remote sensing data for their home countries. Regarding the Supersites, major initiatives (MED-
Ash and thermal anomaly maps	Buenos Aires Volcanic Ash Advisory Center	

		SUV and FUTUREVOLC) depend upon the data for scientific purposes. In Hawaiʻi, Supersite data have been specifically identified as a critical resource by the Hawaiian Volcano Observatory for hazards monitoring and mitigation.

List any publications directly stemming from pilot work

Manuscripts

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*.

A manuscript for the *Journal of Applied Volcanology* is in preparation (submission planned for late 2016).

List objective milestones and state progress to date (%)

<u>Objective A (regional monitoring of Latin American volcanic arcs)</u>
- Our primary goal is systematic arc-wide monitoring of volcanoes in Latin America. We continue to generate ash and thermal alerts for various volcanoes in Latin America. In the near future, the NOAA alerting system will allow users set their own refresh time on thermal anomaly alerts, which will make them easier to use to identify new activity (as opposed to sustained activity) that can be potentially targeted by InSAR and SAR. We have ordered large swaths of ALOS2 data and are working with Sentinel-1a data to conduct routine monitoring. ALOS2 processing has proven problematic, but we expect to solve these challenges soon. Study of individual volcanic systems is proceeding well, with results from numerous locations that have been communicated to local scientists. We anticipate that we are on pace to achieving overall monitoring of all volcanoes in Latin America and focused analysis of restless/erupting sites by the end of 2016. (85% complete)
- We continue to examine individual volcanoes and volcanic regions for signs of deformation, thermal anomalies, and ash, reporting results as they become available to users at volcano observatories and ash advisory centers, and have covered roughly half of all volcanoes in the arc in one way or another. (75% complete)
- We will write a Journal of Applied Volcanology article describing the results of our work, and especially the value to end users, to be submitted in late 2016. (30% complete)
- We have collected feedback on our efforts from Costa Rica, Guatemala, Colombia, Peru, Ecuador, and Chile. We will reach out to other countries in Latin America as results become available and are provided to local users, and we will reconnect with colleagues who had already provided feedback to assess any changes in their perception. (90% complete)

<u>Objective B (support volcano supersites)</u>
- We continue to support exploitation of Supersite data in Hawai'i, Iceland, Italy, Ecuador, and New Zealand. (80% complete)

<u>Objective C (response to major eruption)</u>
- Completed and submitted proposal for data in advance of a major eruption, preferably in SE Asia. (100% complete)
- Have not yet identified a volcano that is likely to have a significant impact in local population or infrastructure and that would be well suited for study as the Objective C target. (0% complete)

Issues identified and risk management approach

- We continue to be challenged by poor interactions between SAR scientists and those working on thermal/visible datasets. It is probably too late to make this a

thrust of the pilot, but it will be a theme of the USGS Powell Center project on volcano remote sensing, the start of which will coincide with the end of the pilot.

- We note that there are very large archives of CSK data (hundreds of scenes) over some volcanoes—Tungurahua, for example. To our knowledge, no one has looked at ALL of these data to see what might be done with such a unique collection and to help better understand the spatial and temporal range of deformation behavior (which would help us address the question of how frequently measurements are needed to characterize volcanic unrest at some volcanoes). Can access to such datasets over, for example, Tungurahua, Masaya, Villarrica, or Santiaguito be granted so that we can exploit the richness of the CSK archive and learn what intensive observations might teach us?

- We have developed a model for pilot sustainability based on the availability of funds. Ideally, a full-time employee would be available to coordinate research and monitoring efforts between space agencies and the academic and operational communities, but it is unclear if any organization would sponsor such an effort. We therefore imagine several potential sustainability tiers:

  Tier 0: no global or regional coordinated effort, limited ad hoc data availability

  Tier 1: continued regional or global activities, quotas of data available from satellite operators, teams of academics work with volcano observatories, best-effort approach to volcanic crisis response

  Tier 2: some new funding available for a partial FTE to support project management, quotas of data available from satellite operators, coordinated approach with teams of academics working with volcano observatories, best-effort approach to volcanic crisis response

  Tier 3: funding available for full FTE to support project management (should be a scientifically trained person who will serve as an interface between space agencies, academic institutions, operational organizations, and volcano observatories), routine near-real-time data processing, coordinated approach with teams of academics working with volcano observatories, routine response to all volcanic crises *[This is similar to the effort currently being put forth by NOAA to detect ash plumes—an effort that will continue beyond the pilot]*