Pilot Name: Volcano		
February 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; data from Hawaii were used to investigate the formation of a new pit crater on Mauna Kea
- Attended science workshop at Santiaguito, Guatemala, where we interfaced with local users from Latin America
- Assessed deformation during recent eruptions of Momotombo volcano Nicaragua, and communicated results to INETER
- Processed CoSSC TDX data to map topographic changes associated with lava domes at Soufrière Hills Volcano (Montserrat) and Reventador (Ecuador)

Activities:

- We began ordering ALOS2 data from Latin America to implement synoptic coverage of volcanoes in Mexico, Central America, the Lesser Antilles, the Northern Andes, and the Southern Andes
- We ordered and processed CoSSC data from TanDEM-X to map topographic change and effusion rates at volcanoes in the Lesser Antilles and Ecuador
- We responded to eruptive activity in Latin America, including at Momotombo (Nicaragua), Nevado del Ruiz (Colombia), and Cotopaxi (Ecuador). Products have been distributed to local end users (volcano observatories and ash advisory centers), where they have aided in constraining such variables as erupted volumes, ash emissions, and the volume of likely magma accumulation at depth.
- We continue to support the volcano Supersites. In Hawaiʻi, RADARSAT-2 Supersite data helped to constrain the formation time of a small pit crater on Mauna Kea—an event that appears to have been preceded by localized subsidence and may point to a means of identifying sites of potential future crater formation (important, given the crater's location near the main access road to Mauna Kea's summit).
- Integration between visible/thermal and SAR is beginning. For example, based on InSAR results showing inflation of Cordon Caulle (Chile), NOAA has increased the detection sensitivity of thermal and ash advisories in this area. InSAR specialists within the pilot also now have access to NOAA alerts.
- Began conducting systematic SAR studies of volcanoes in Central America, including the very active Pacaya and Santiaguito volcanoes, Guatemala.
- We will visit Colombia in March 2016 and will conduct interviews of Colombian scientists about pilot data while on site.

Data accessed this Q (#images /satellite) ALOS2: 79 COSMO-SkyMed: 68 TerraSAR-X: 109 RADARSAT-2: 96 TanDEM-X: 14 Numbers of images are only reported for Objective A, since C has not started and B has a different system for tracking orders.	Total data accessed to date (#images /satellite) ALOS2: 84 COSMO-SkyMed: 381 TerraSAR-X:135 RADARSAT-2: 235 TanDEM-X: 14 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., Cotopaxi), as well as those currently experiencing low-level eruptions (e.g., Momotombo, Nevado del Ruiz, Tungarahua). 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 Hawai'i, 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

<u>Abstracts</u>

Arnold, D., et al., 2015, Satellite Measurements of Lava Extrusion Rate at Volcán Reventador, Ecuador: Fall Meeting, AGU, San Francisco, Calif., December 14–18, Abstract G32A-07.

Delgado, F., et al., 2015, The dynamics of a tectonically-controlled active silicic intrusion at Cordón Caulle volcano (Southern Andes) imaged by InSAR; building to the next eruption?: Fall Meeting, AGU, San Francisco, Calif., December 14–18, Abstract G41A-1018.

Ebmeier, S., et al., 2015, Stress controlled magma-earthquake interaction during unrest at Chiles-Cerro Negro Volcanoes (Ecuador-Colombian border): Fall Meeting, AGU, San Francisco, Calif., December 14–18, Abstract G31C-06.

Pritchard, M., et al., 2015, Linking space observations to volcano observatories in Latin America: Results from the CEOS DRM Volcano Pilot: Fall Meeting, AGU, San Francisco, Calif., December 14–18, Abstract PA41B-2169.

<u>Manuscripts</u>

Ebmeier, S., et al., in review, Bidirectional feedback observed between a magmatic intrusion and shallow earthquake: Earth and Planetary Science Letters.

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

Two manuscripts are currently in preparation by Francisco Delgado (Cornell University) and colleagues, describing InSAR results from Cordon Caulle and from Llaima/Villarrica/Calbuco.

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 have ordered large swaths of ALOS2 data and are working with

Sentinel-1a data to conduct routine monitoring, but these efforts are not yet mature. 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. (80% complete)

- We are ordering ALOS2 data but have not yet started processing the data in an operational sense yet, although preliminary work is promising and demonstrates the utility of the data. (50% 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. (60% 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 2016. (10% 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. (60% complete)

Objective B (support volcano supersites)
- We continue to support exploitation of Supersite data in Hawai'i, Iceland, Italy, Ecuador, and New Zealand. (60% complete)

Objective C (response to major eruption)
- 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

- Most products delivered continue to be derived from InSAR, and we continue to struggle to integrate InSAR and thermal/visible datasets. Communication between the thermal and SAR components of the pilot is improving, but more complex interactions, such as automated triggering of one dataset due to detections in another, will probably not be possible and instead become part of our recommendations at the conclusion of the project.
- There have been some tasking conflicts with TSX data, in part because that satellite does not have a background program for volcano observation. This problem can be solved by better communication between those users who are tasking the satellite.

- RADARSAT-2 acquisitions are somewhat random—the mode or resolution of acquisitions over a given area changes frequently, leading to a lack of consistency in results and a lack of understanding of what acquisitions might be scheduled next. To alleviate this, we hope to develop an acquisition strategy for different satellite types that might be used by the space agencies for tasking to provide the most useful data for volcano disaster risk reduction. That said, the randomness in acquisitions was what allowed the Mauna Kea pit crater to be imaged—that volcano was not on anyone's "watch" list for SAR.
- We are sensitive to limited data quotas. Although the space agencies have been quite generous in providing SAR data especially, dozens of images are needed to glean a useful deformation result for some volcanoes (especially those in vegetated areas) because time series methods are required to mitigate against atmospheric artifacts and poor coherence. It is therefore quite easy to consume hundreds of images studying just a few volcanoes, especially when acquisitions are frequent (as with X-band sensors).
- It has become clear that dedicated FTE will be needed to sustain the efforts of the pilot. Indeed, just to compile a list of global volcano unrest has required 2 full time employees. Systematic monitoring of volcanoes in Latin America, to say nothing of global monitoring, will require a dedicated effort by a team of scientists—student case studies are not a viable means of continuing the work (especially since PhD students have significant demands on their time and cannot devote all of their time towards operational monitoring). This also assumes continued access to datasets at no cost. It is continues to be our view that the primary hurdles for continuing the volcano disaster risk reduction work of the pilot are the definition of dedicated teams to accomplish the work and the commitment from space agencies (and their partners) to provide relevant data. Capacity building will be an important part of the team approach, and should include the training of students from the countries that need the capability to process and interpret remote sensing data, instead of solely short courses and isolated outreach efforts.