CEOS Volcano Pilot Project: main results and lesson learned

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WHAT IS MISSING?

- up to 45% of the world's ~1400 Holocene age volcanoes are not monitored

- What EO data are most critical for detecting changes in unrest and eruptive activity vs. different volcanism and environment?

- Strategy for satellite observations depending on volcanoes level of activity
Demonstrate the potential impact of EO data for better understand volcano hazard and reduce impacts and risks from eruptions.

Enforce coordination between Space Agencies, value-added providers and end users to ensure that the agencies who are responsible for volcano monitoring have access to, and understanding of, those data sets that are most critical for making informed DRM decisions.

Propose a strategy for a global satellite monitoring system.
Regional demonstration over Latin America

- Demonstrate potential impact of EO data: regional focus on Latin America (319 volcanoes)
- Identify volcanoes that may became active in the near future
- Track new and ongoing eruptive activity

Why Latin America?
- Range of eruption type/ages and environments
- Abundant volcanic activity
- Impact on people/air traffic
- Well established observatories
- ~202 volcanoes in the region have no ground monitoring of any type
Participants in the Pilot

CEOS Agencies:
USGS, ASI, CNES, CSA, DLR, ESA, NASA, NOAA, JAXA

Value-added providers:
University of Bristol (UK), Cornell University (US), University of Miami (US), Pennsylvania State University (US), IREA/CNR (IT), Open University (UK), NOAA, USGS

End users:
Observatorio Volcanológico de Los Andes del Sur (OV-DAS) Chile; Instituto Geofísico del Perú; Instituto Geofísico de la Universidad Nacional de San Agustín, Peru; Instituto Geofísico, Escuela Politécnica Nacional, Ecuador; Servicio Geológico Colombiano, Colombia, Buenos Aires Volcanic Ash Advisory Center, Argentina, Instituto nacional de sismología, vulcanologia, meteorología e hidrologia, (NSIVUMEH), Guatemala, Instituto Nicaraguense de Estudios Territoriales (INETER), Nicaragua
• Optical and IR data for detecting thermal anomalies, gas emissions, and ash plumes
• Radar data for ground deformation, new volcanic deposits, and topographic changes

**FOCUS on Radar data** (ALOS, RADARSAT-2, COSMO-SkyMed, Terra SAR-X, Tandem-X, Sentinel 1) to understand how the entire international SAR constellation could be used for detecting and characterizing volcano behavior.
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)
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 (*Chiles-CN, Calbuco, Villarica, Manutombo*)

• Filled “gaps” at volcanoes that have some ground-based monitoring (*Tungarahuaba, Pacaya, Santiaguito*)

• Provide otherwise inaccessible data (*Reventador, SHV*)

• Research (*Ubinas*)
Inflation of Cordón Caulle, Chile, after the 2011-2012, has been a significant result of the pilot. This deformation would not otherwise be known without EO data.

The inflation seemed to have stopped in mid-2015.

Post-eruptive uplift of up to 0.8 m between March 2012 and May 2015. The line-of-sight uplift rates reached 45 cm/yr, but the deformation was not accompanied by earthquakes.
New results indicate that inflation at Cordón Caulle resumed in mid-2016!

In response to these observations, OVDAS is installing a continuous GNSS station to establish ground-based monitoring of the volcano.
The project frequently responded to requests from local observatories to provide satellite data to complement ground based measurements of unrest.

Satellite observations were requested often to assess whether there is evidence of large magma accumulation during a seismic crisis or to confirm observation of deformation from a single sensor.

EO observations have showed a lack of magma driven deformation during crises at Chiles and Cerro Negro de Mayasquer, Monotombo, Sabanacaya and Nevados de Chillan and have consequently been instrumental in the decision not to raise the alert level.
Chiles – Cerro Negro, Ecuador-Colombia border

Volcán Chiles

Very limited monitoring
Potentially Active
Inaccessible
Chiles – Cerro Negro

The graph shows seismic activity from September to December. The vertical axis represents the number of seismic counts, while the horizontal axis represents the months from September to July. The largest event is marked with $M_w 5.6$.

The graph indicates a significant increase in seismic activity starting in November, with a peak in December. The data suggests a possible correlation with the CHLS event around 1st November.
CEOS data indicated about 30 cm of ground movement associated with the earthquake, but no deformation indicative of magma accumulation or transport. The lack of deformation in INSAR images played a key role in the decision to reduce rather than elevate the alert level of volcano.
Calbuco, Chile

Observed (left), modeled (center), and residual (right) deformation (from Sentinel-1a, spanning April 14–26, 2015) due to an eruption at Calbuco, Chile, on April 22, 2015. A model of the deflation indicates that the source is located about 5 km SW of the volcano’s summit at a depth of 9.3 km beneath the surface. Confirmed single ground base sensor co-eruptive and showed post eruptive sensor unreliable.

OVDAS used this source model to validate their tilt meter records
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.
IG monitors lava effusion rate using field measurements and photos from overflights (irregular sampling and dependent on clear weather)

- 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

Thickness of new lava flows between 2011 and 2014 from TDX CoSSCs
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• **Christina Neal**, Scientist-in-Charge, Hawaiian Volcano Observatory, U.S. Geological Survey (USA)
6 principles for SAR component of a global satellite monitoring system:

• A volcano monitoring system must involve **multiple space agencies and satellite platforms** to make the most of each satellite system, to get nearly daily coverage when needed and to have updated high resolution topographic maps.

• **Data quotas** should be assigned for a) systematic background observations using the needed observing mode (spatial resolution, polarization, etc.), b) case studies requiring dense datasets and c) flexible response to unrest and eruption.

• A **systematic background mission** using ascending and descending passes should take into account both the level of activity at each volcano and the temporal and spatial baselines required to form coherent interferograms and observe deformation transients.
Lessons learned

- **Acquisition plans need to be flexible** to accommodate changes in activity, evolving methods and improved understanding of data types.
- **Near real-time data access** is vital for decision making, requiring frequent overpasses, rapid tasking and short data latency.
- **Coordination between space agencies, scientists and volcano observatories is crucial** in order to provide an operational response and avoid conflicting requests for satellite tasking or interpretations of satellite observations to observatories.
A summary publication describes the Latin America aspect of the pilot project, lessons learned, and potential future applications (submitted to Journal of Applied Volcanology).
Thank you