Committee on Earth Observation Satellites

The CEOS Volcano Demonstrator

Rationale and Implementation

Why focus on volcanoes?

- Over 300,000 people have been killed by volcanoes since the 1600s
- Globally, ~30 million people live within 10 km of an active or potentially active volcano
- Volcanoes need not cause fatalities to be disruptive—losses due to the 2010 Eyjafjallajökull eruption were $200M/day, with ~100,000 cancelled flights

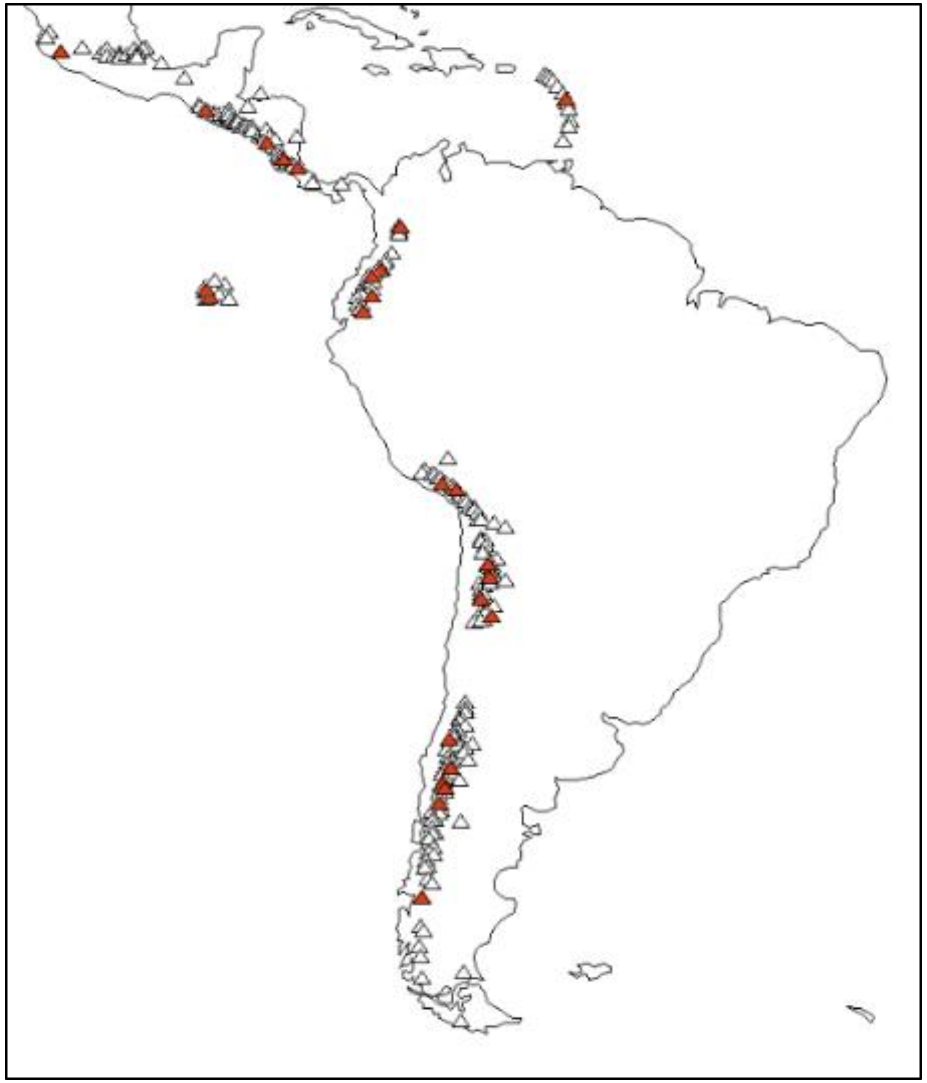
What is needed?

- 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

Holuhraun eruption, Iceland, 2014.
Photo credit: M Parks

The 2014–2017 CEOS Volcano Pilot: Goals

- Identify volcanoes in Latin America that are in a state of unrest
- Track unrest and eruptions using satellite data to support hazards mitigation
- Assess data needs in terms of volume, repeat times, spatio-temporal resolution, wavelength, etc., to improve satellite-based monitoring techniques
- Develop a strategy for capacity-building in countries that do not currently have access to abundant EO data and/or the ability to process and interpret such data.



Volcanoes in Latin America. Red indicates erupting or restless volcanoes targeted for focused study.

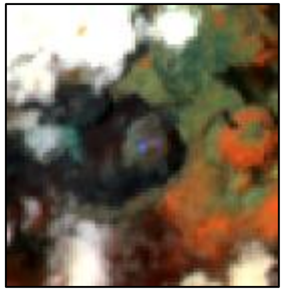
The 2014–2017 CEOS Volcano Pilot: Achievements

- Identified restless volcanoes that would not otherwise be known (for example, Cordón Caulle, Chile)

- Comprehensive tracking of unrest and eruptive activity

- Demonstrated need for a diverse approach (multiple satellites, multiple capabilities)

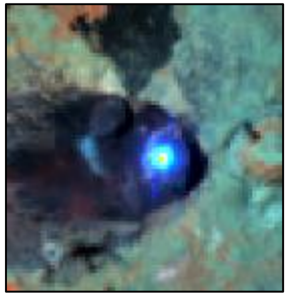
- Helped inform decisions about alert levels and response (for example, Chiles-Cerro Negro, Chile; Masaya, Nicaragua; Sabancaya, Peru)



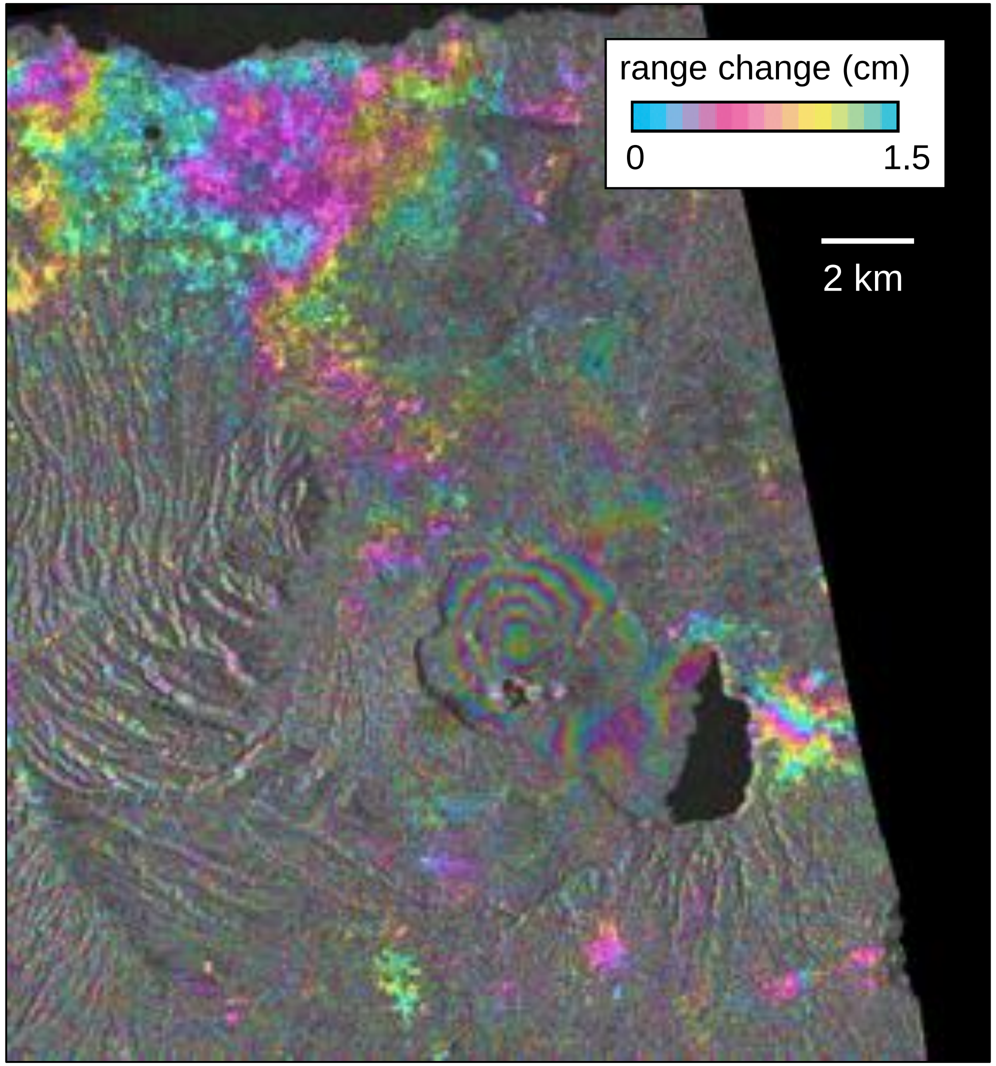
Sep. 16, 2015

Nov. 19, 2015

Feb. 7, 2016



Mar. 26, 2016



Unrest at Masaya volcano, Nicaragua, during 2015-2016. (left) Growth of a thermal anomaly as a lava lake rose within the volcano's crater. (right) Inflationary deformation in a Cosmo-SkyMed interferogram spanning October 17, 2015–March 9, 2016.

The CEOS 2014–2017 Volcano Pilot: Lessons

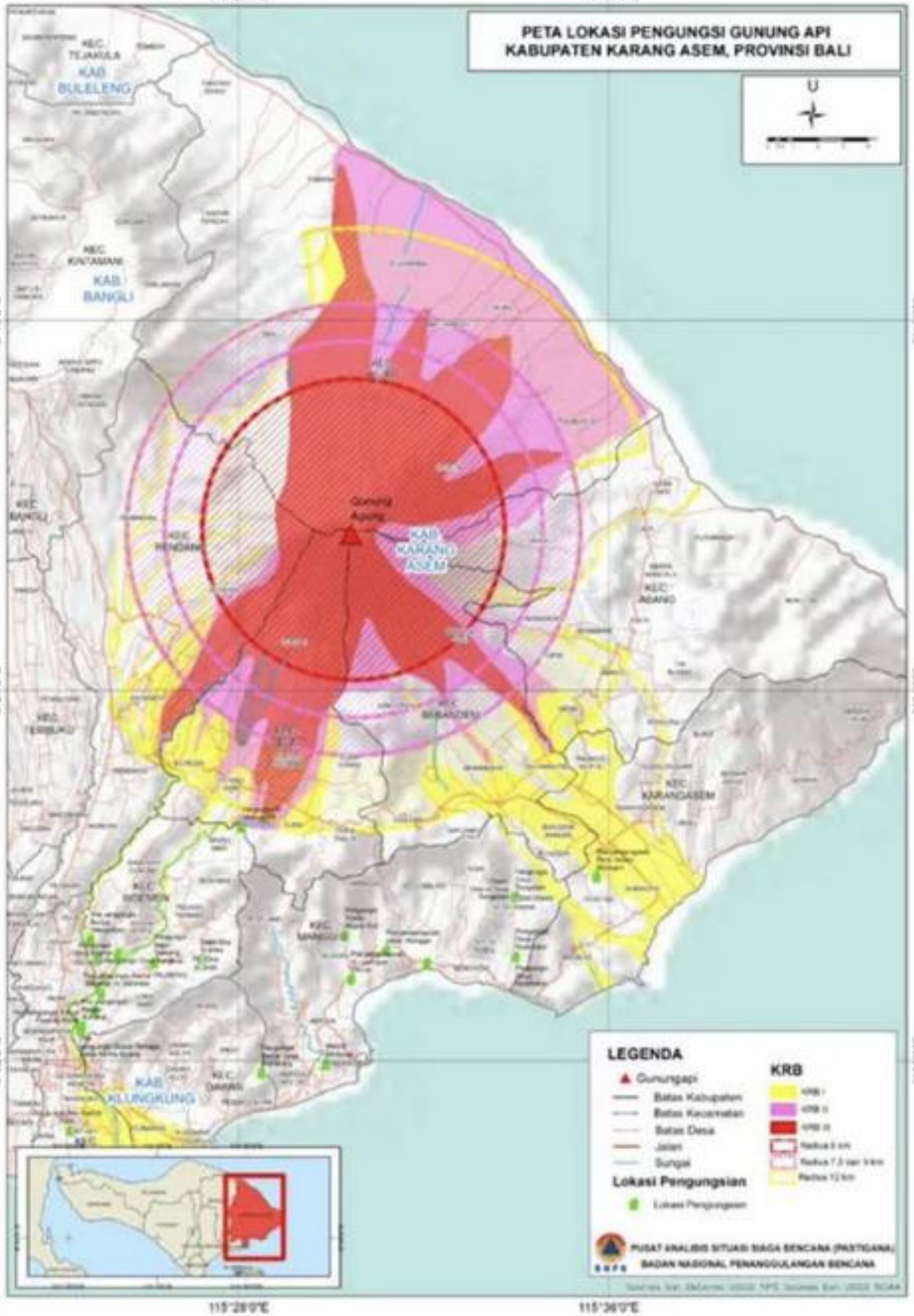
- Coordination between multiple space agencies yields near-daily coverage during volcanic crises
- Systematic background observations are critical
- Acquisition plans should be flexible
- Low latency is critical
- No one-size-fits-all solution for volcano observatories
    - raw data vs. interpreted data
    - no active observatories in some volcanically active areas
    - Need to include uncertainty in interpretation
    - Short courses are appreciated, but extended visits and MS/PhD training are better

Masaya volcano, Nicaragua

Villarica volcano, Chile

Why continue? What is the need for a global demonstrator?

Agung, Bali, Indonesia 2017–2018



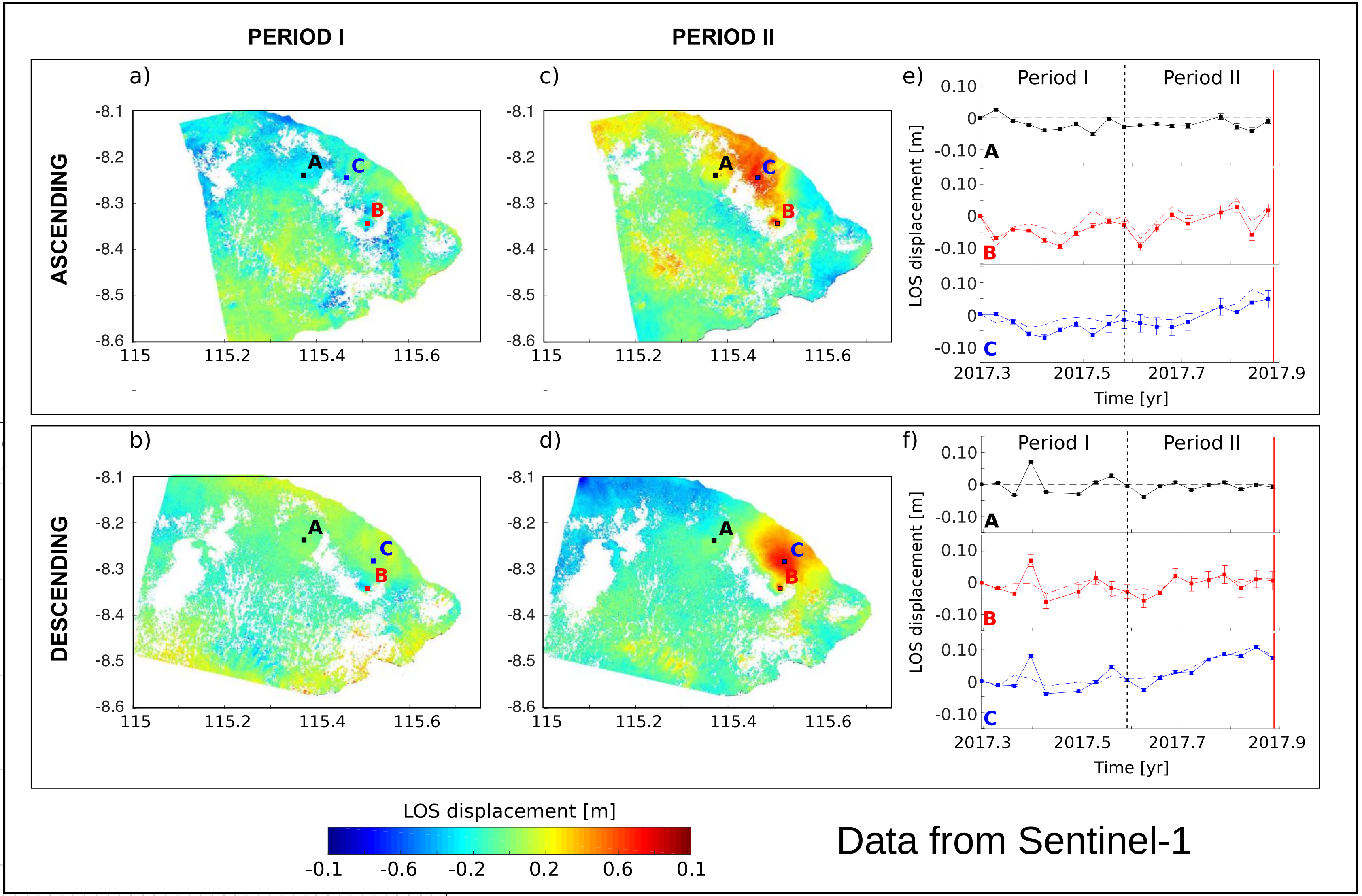
Volcanic hazards map, Agung volcano, Bali, Indonesia

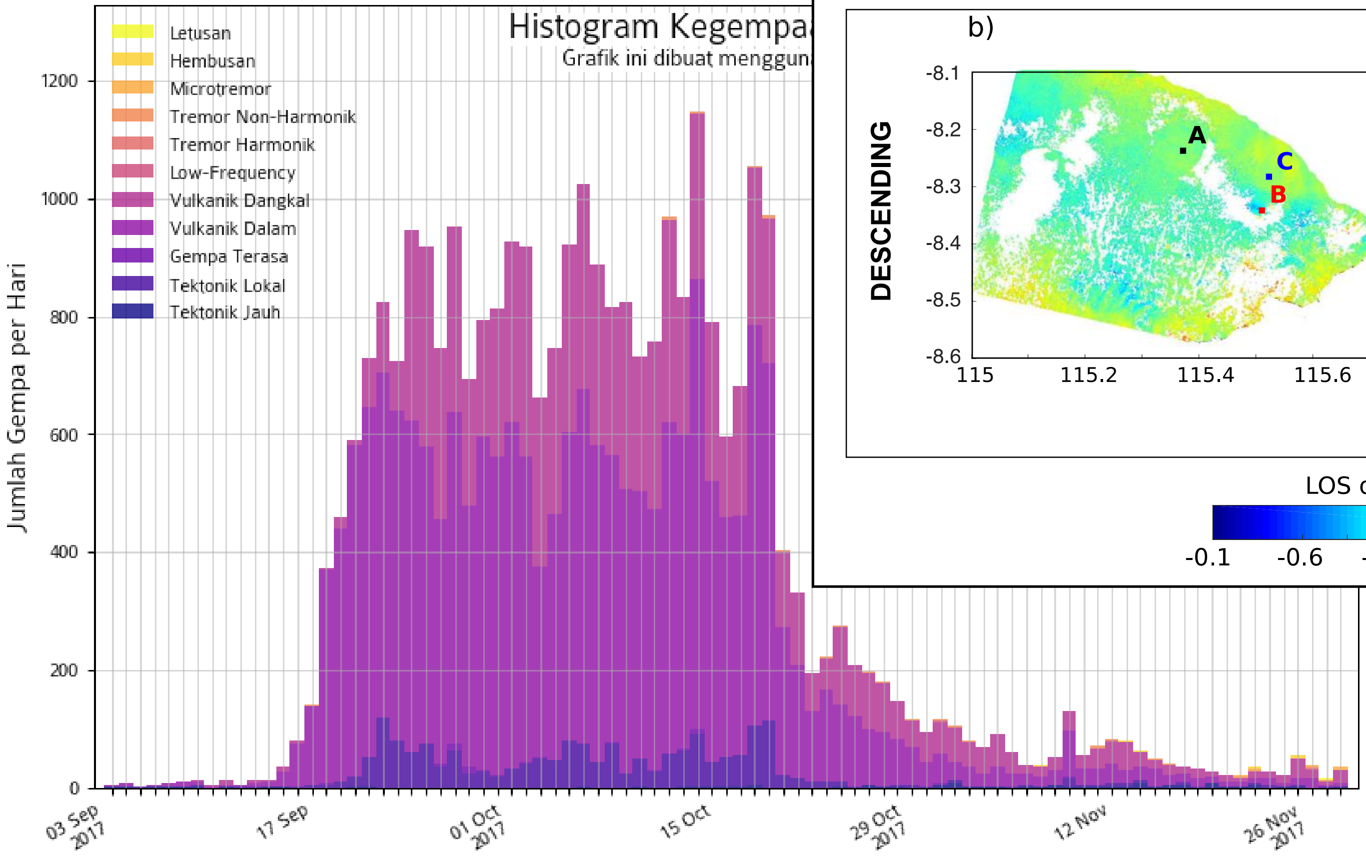
Agung Volcano, Bali, Indonesia

- Erupted in 1963–64, caused over 1000 deaths and had a major impact on global climate
- Seismic swarm starting in September 2017 resulted in the evacuation of ~100,000 people
- Seismicity waned in October 2017, but elevated levels of earthquake activity persisted
- Explosive eruptions began in mid-November 2017, lava in the crater a few days later
- Intense socio-political pressure on CVGHM
- No direct access to satellite data
- Conflicting messages on Twitter

Coordinated satellite response by global volcanological community aided CVGHM with interpretation and decision making.

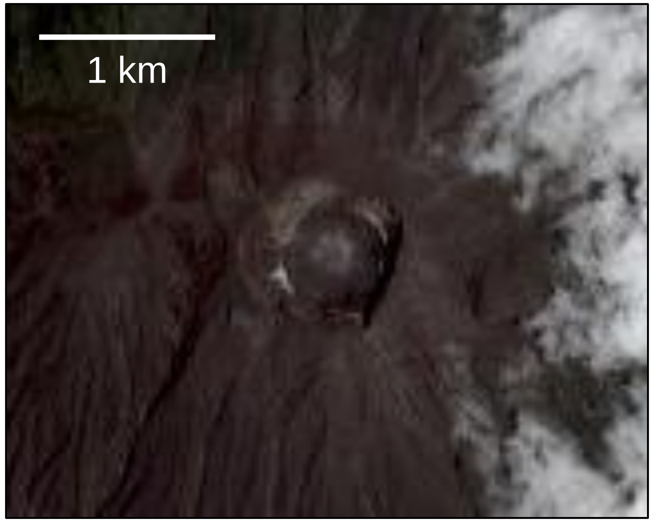
September-October seismicity was a result of a dike intrusion (this was not clear from ground-based data alone

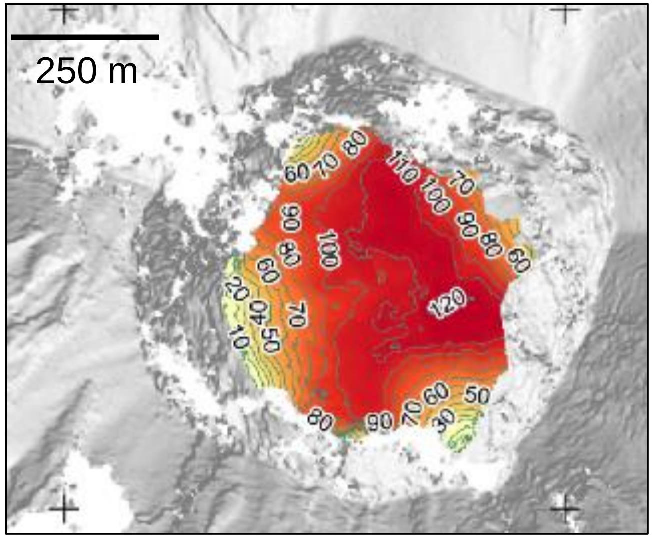


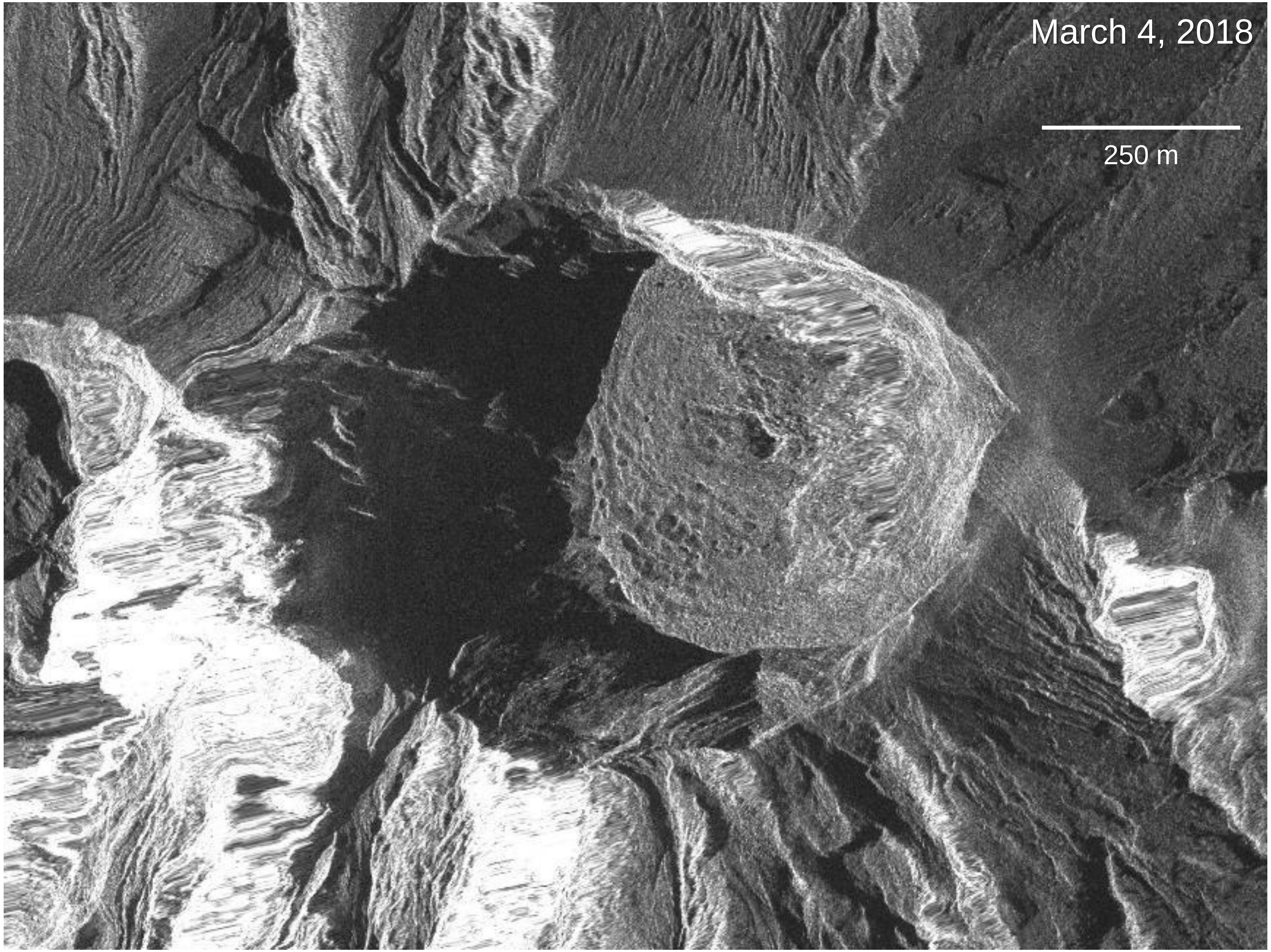


Left: seismicity at Agung during September – November, 2017. Above: InSAR stacks and time series showing deformation on the volcano's north flank indicating magmatic intrusion. Results from Fabien Albino and Juliet Biggs, University of Bristol

High-res views of lava accumulation and degradation from SAR







Pléiades imagery (top left) can be used to construct Digital Elevation Models (bottom left) that give the volume of lava effusion, while Cosmo-SkyMed spotlight data (right) provide details of lava flow emplacement and degradation that would not otherwise be accessible due to cloud cover.

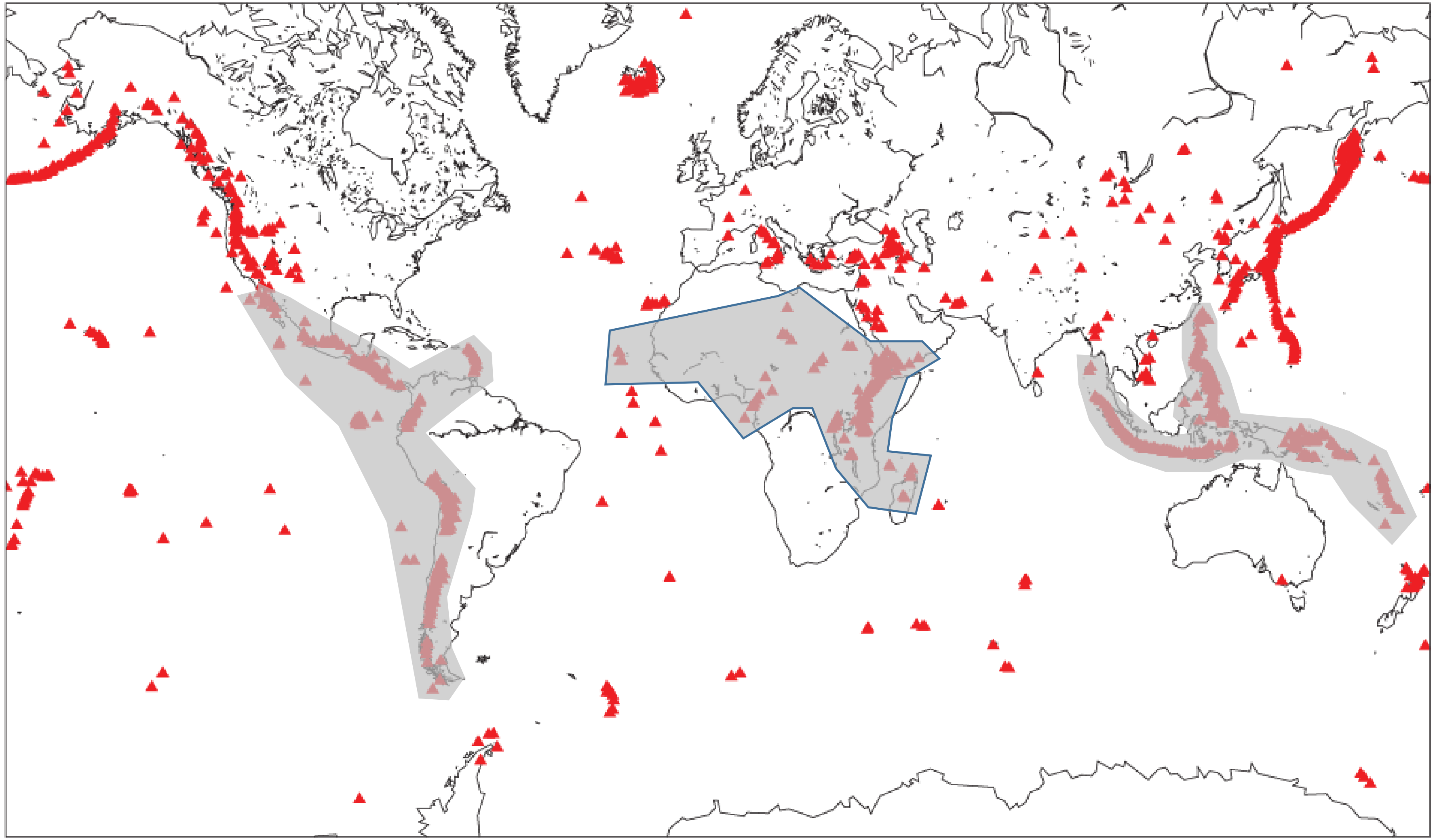
Volcano Demonstrator: An Evolution from the Volcano Pilot

- There are ~100 volcano observatories around the world with a range of capabilities. How can we meet their heterogeneous needs?
- More observations are needed at a diversity of volcanoes to understand the nature of precursors and manifestations of eruptive activity
- Focus on integrating SAR with IR, UV, and visible observations to develop a comprehensive approach to satellite monitoring of active volcanism.

<u>Goals</u>:

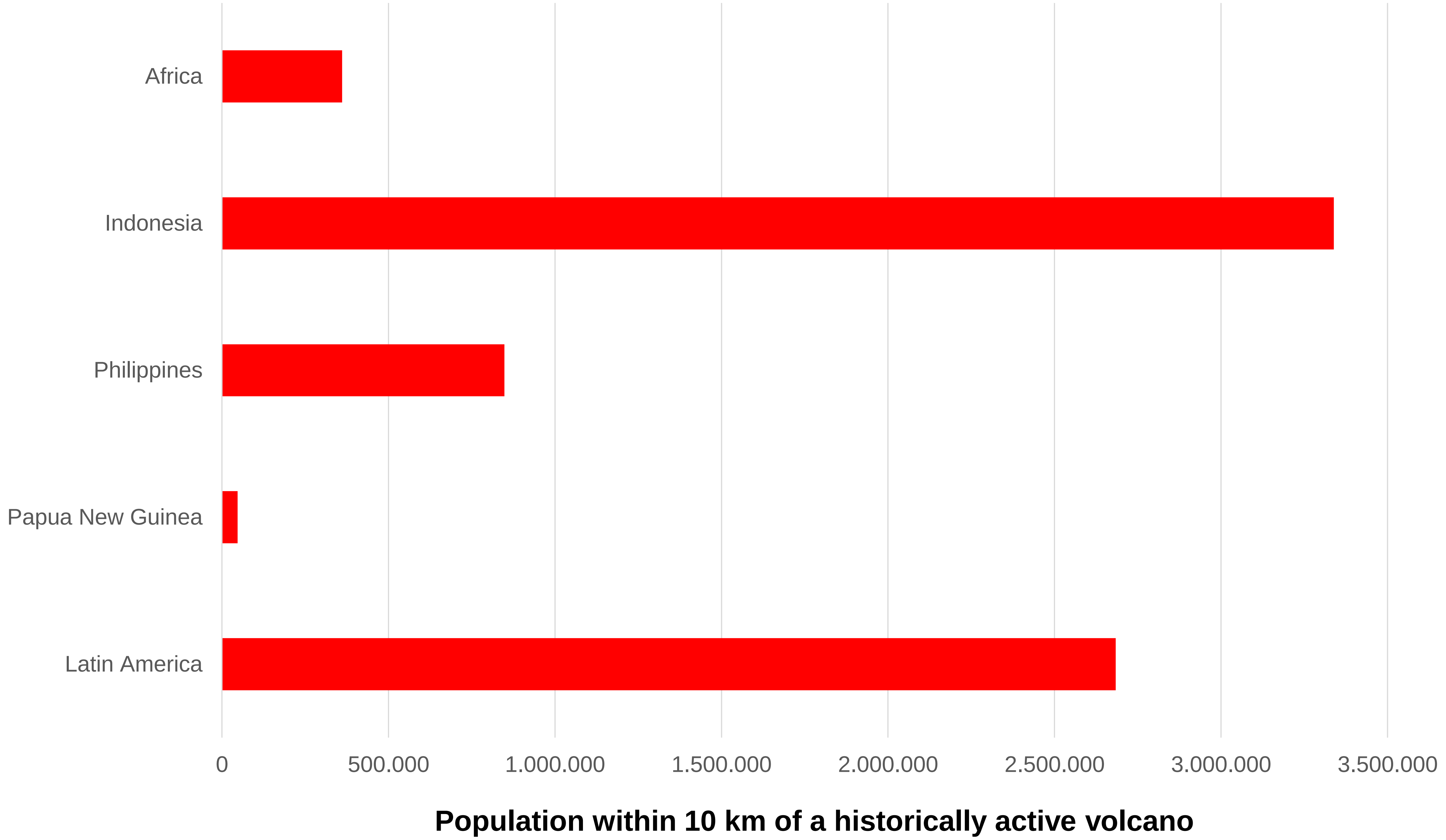
1) Fill gaps where satellite observations are not being fully exploited
2) Learn more about volcanoes to aid forecasting and risk reduction
3) Aid with crisis responses
4) Build capacity in developing nations
5) Demonstrate a sustainable volcano monitoring system

Volcano Demonstrator: Areas of focus



Map of volcanoes with Holocene eruptions

The CEOS Volcano Demonstrator will focus on areas highlighted in gray, where volcanic risk is highest and there is the most need for remote sensing resources to better understand volcanoes and monitor their behavior. These areas contain ~50% of all volcanoes that are considered potentially active.



Africa
Indonesia
Philippines
Papua New Guinea
Latin America
0
500.000
1.000.000
1.500.000
2.000.000
2.500.000
3.000.000
3.500.000
Population within 10 km of a historically active volcano

Volcano Demonstrator: Implementation strategy

- Follow the example of the Volcano Pilot
- Partner with established international agencies and universities, including global consortiums (like the IAVCEI Commission on Volcano Geodesy), to cultivate a community of contributors, facilitate capacity building, and broaden demonstrator reach/impact
- Use established archives and data distribution systems to ensure data accessibility (Volcano HDDS, GEP, WInSAR, etc.), with access governed by space agency license agreements
- Make use of the comprehensive suite of remote sensing wavelengths and capabilities: SAR, visible, thermal, and UV
- Leverage existing efforts, like COMET (U.K.) and ARIA (NASA JPL) to process data and assess results

Volcano Demonstrator: Proposed data request

- Request is based on Volcano Pilot experience from Latin America
- Volcanic activity in the target areas and proposed satellite monitoring:
  - About 120 volcanoes have erupted since 1990 [**WEEKLY MONITORING**]
  - About 135 volcanoes have experienced unrest since 1990 but have not erupted [**MONTHLY MONITORING**]
  - About 475 volcanoes have no detected unrest or eruptions since 1990 [**QUARTERLY MONITORING**]
- Volcanoes will be prioritized based on their current activity and the presence of a population at risk
- Data requests should include both archive data (to understand the development of unrest at volcanoes that become active) and new acquisitions
- Most UV, visible, and IR data are freely available, so we focus our data request on SAR and high-resolution optical

An important note about SAR data…

While Sentinel-1a/b data provide an excellent broad perspective of surface change and volcano deformation that is especially useful for regional assessments of volcanic activity, we cannot rely on those data alone

- Repeat time of 6–24 days is too long at some volcanoes, especially during a crisis
- Near-daily SAR acquisitions are needed at erupting volcanoes in populated areas (like Agung)—achievable using the whole constellation of SAR satellites!
- VV polarization is not optimal for vegetated volcanoes
- Relatively coarse spatial resolution (30 m) misses localized deformation
- C-band wavelength is not optimal for heavily vegetated volcanoes

Volcano Demonstrator: Proposed data request

- X-band SAR
  - COSMO-SkyMed: 1000 images/year (take advantage of frequent repeat intervals and large archive from background mission)
  - TerraSAR-X: 300 images/year (tight orbital controls ensure interferometric capability, focus on new acquisitions due to lack of background mission)
  - TanDEM-X: 100 images/year (for DEMs at actively erupting systems where topographic change over time is needed to update hazards assessments and calculate erupted volumes)
- C-band SAR
  - Sentinel-1: N/A (open data policy, will be used for broad tracking of unrest)
  - RSAT-2: 200 images/year (quad-pol capability; higher bandwidth gives better InSAR coherence)
- L-band SAR
  - ALOS-2: N/A (will be fulfilled by Japanese collaborators)
- Optical
  - Pleiades: 200 images/year (focus on restless and erupting volcanoes, update DEMs to aid with SAR processing and hazards assessment)

Volcano Demonstrator: Implementation timeline

Year 1

- Recruit partners for data analysis
- Establish strategy for capacity building operations (schedule site visits and recruit students for in-depth training)
- Begin studies of restless and erupting volcanoes in Indonesia, Africa, Philippines, Papua New Guinea, Latin America

Year 2

- Implement comprehensive studies of restless and erupting volcanoes in Indonesia, Africa, Philippines, Papua New Guinea, Latin America
- Begin studying quiescent volcanoes in those countries
- Initiate capacity building in via site visits and support student training

Year 3

- Demonstrate capability for monitoring of all Holocene volcanoes in Indonesia, Africa, Philippines, Papua New Guinea, and Latin America
- Complete student training and site visits to participating volcano observatories