Committee on Earth Observation Satellites

WGDisasters Volcano Demonstrator

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Matt Pritchard, Juliet Biggs, Ian Hamling, Yosuke Aoki

WGDisasters-15 Meeting

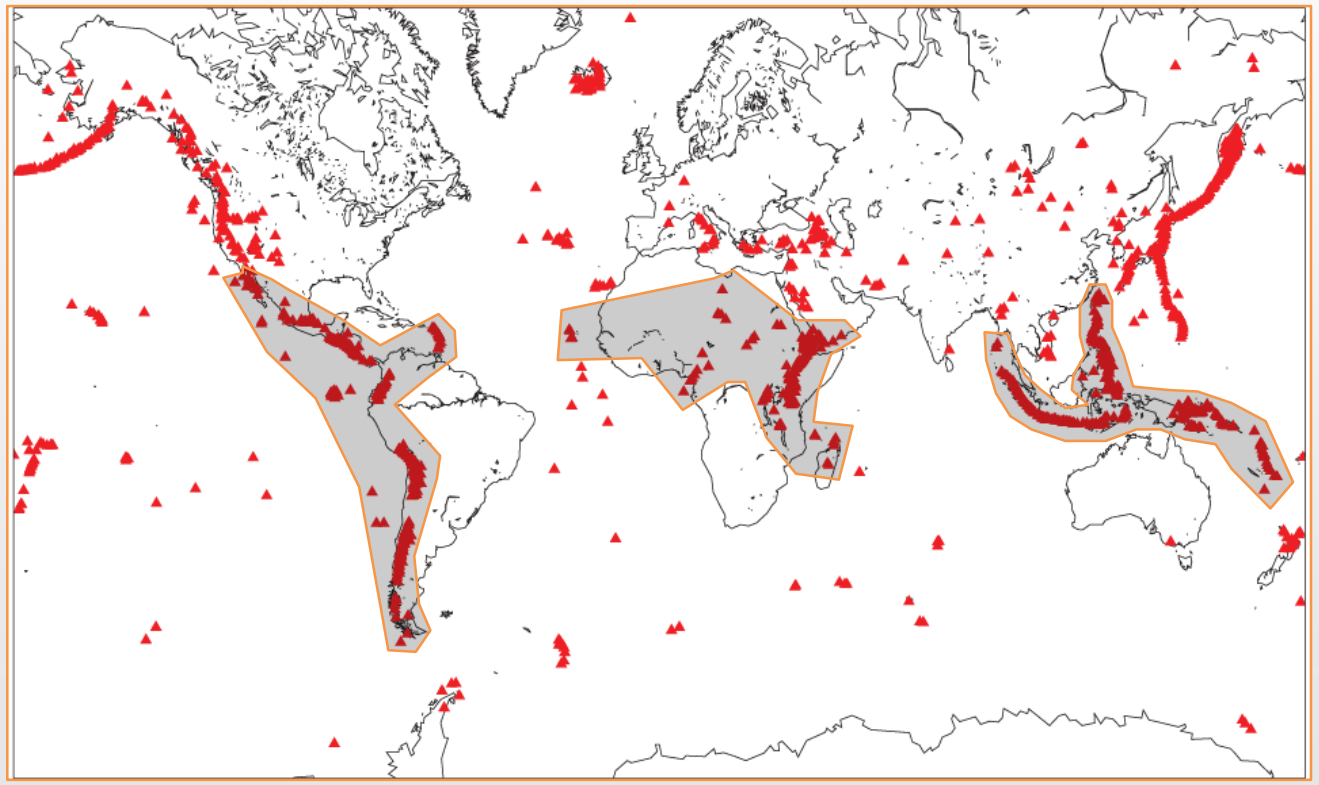
Virtual Meeting

9 – 11 March 2021

Volcano Demonstrator Aims - reminder

- Extension of Latin American Pilot project to African and SE Asian volcanoes
- Fill gaps in current monitoring

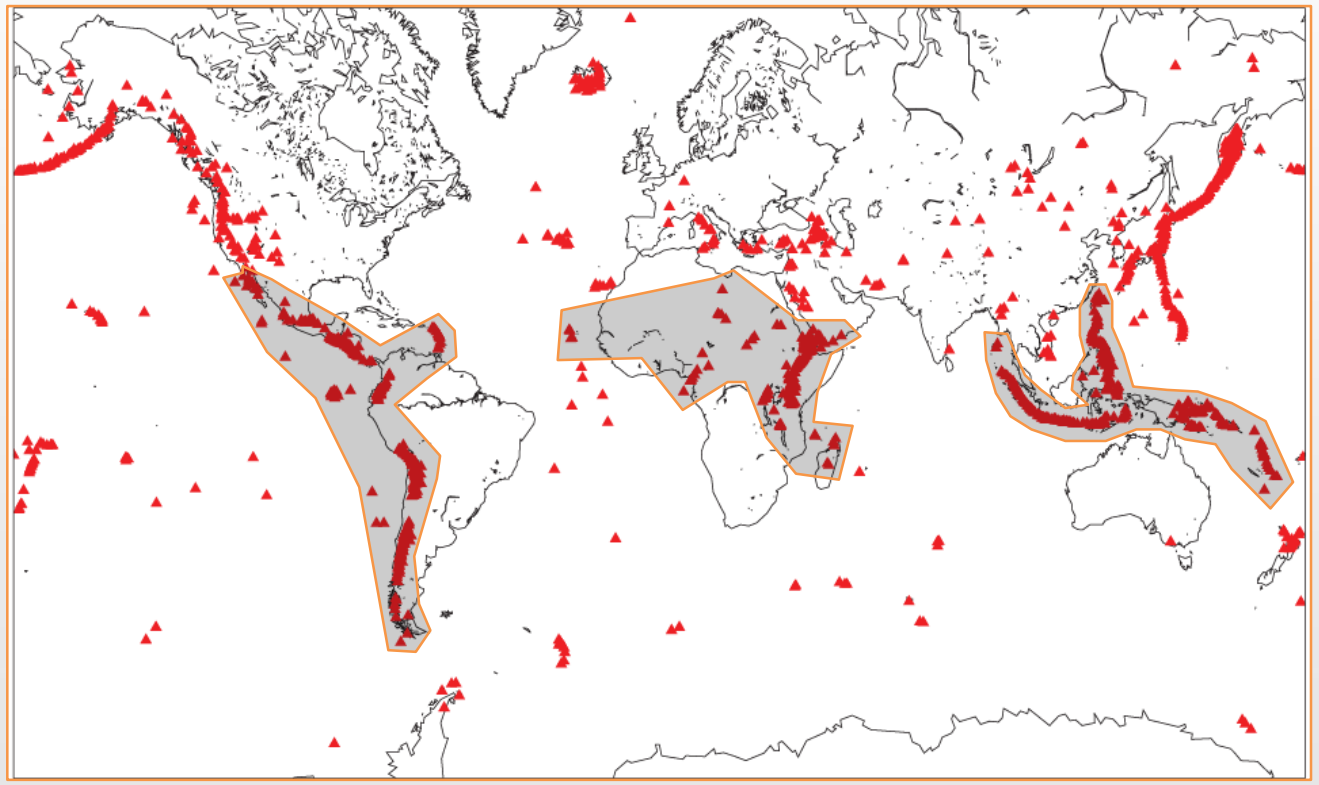
- **Long term goal**: to demonstrate the necessity and viability of international coordination of satellite tasking for volcano monitoring (after polar science community)



Volcano Demonstrator Aims - reminder

1. Expand use of satellite remote sensing for volcano monitoring
2. Research link between volcanic unrest and eruption from satellite observables
3. International coordination of satellite tasking to maximise its usefulness to volcano observatories
4. Supporting capacity building initiatives to increase the uptake of satellite imagery

Focus on use of diverse wavelengths - supplementing C-band with X and L.



Organisation - reminder

Latin America:

Matt Pritchard

Cornell University

Africa:

Juliet Biggs

University of Bristol

SE Asia:

Yosuke Aoki

University of Tokyo

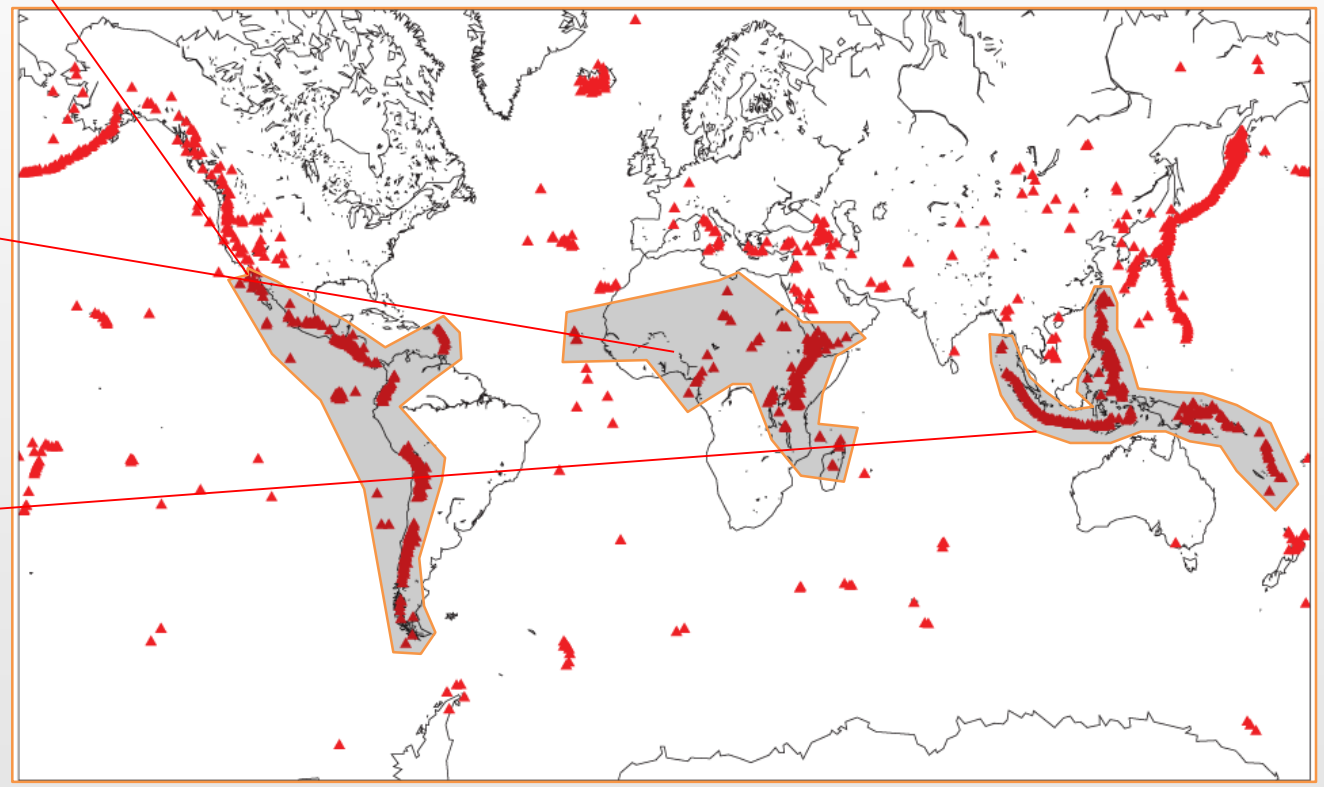
Ian Hamling

GNS New Zealand

Coordination:

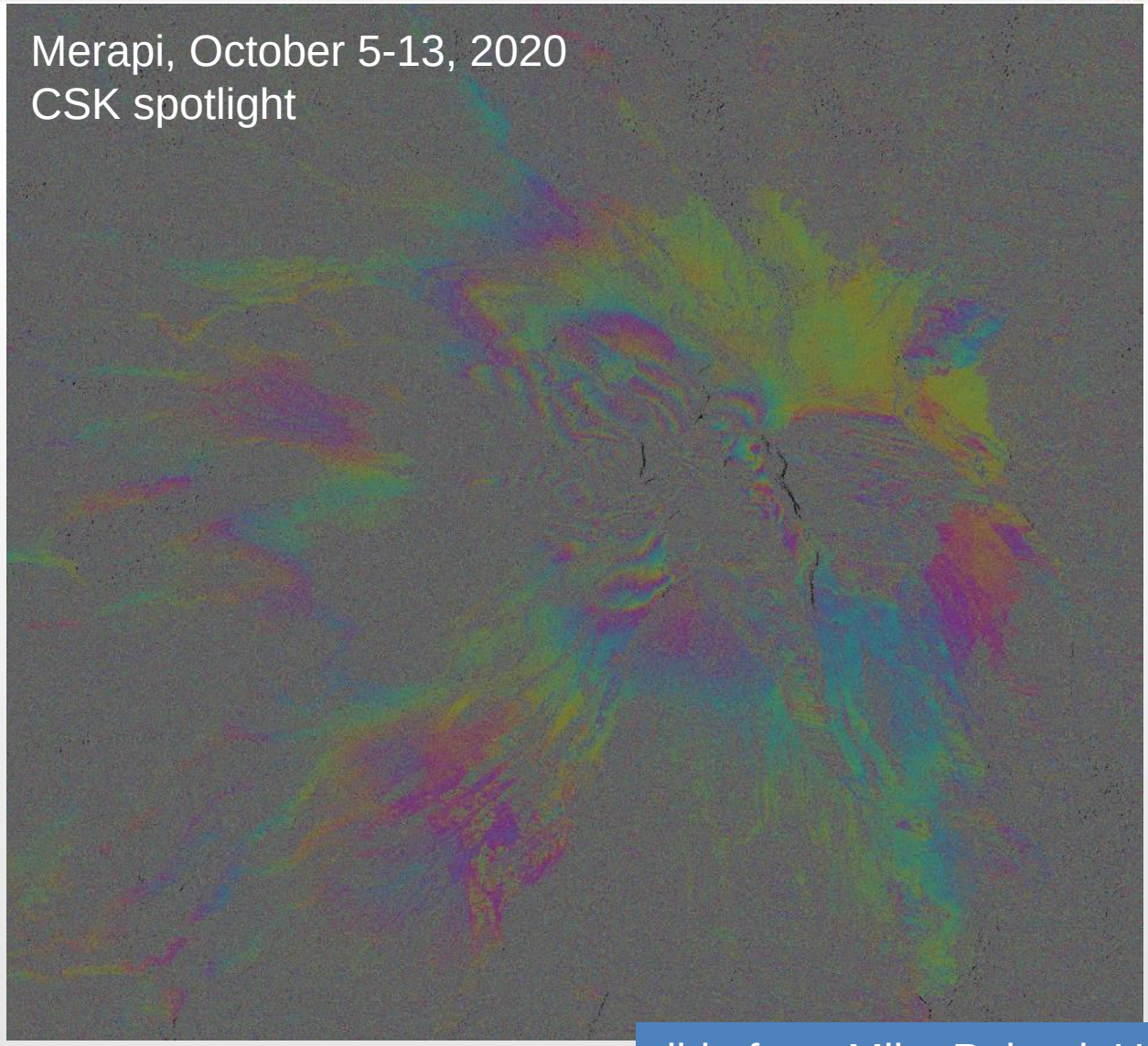
Mike Poland (USGS)

Susanna Ebmeier (University of Leeds)



Example: TSX and CSK from Merapi, Indonesia

- Merapi volcano, Indonesia, showed signs of unrest starting in late 2020
- Deformation monitoring consisted of one EDM line on the west flank of the volcano and several distal GNSS sites
- High-resolution X-band data proved vital to assessing complex deformation patterns that were first detected in early October

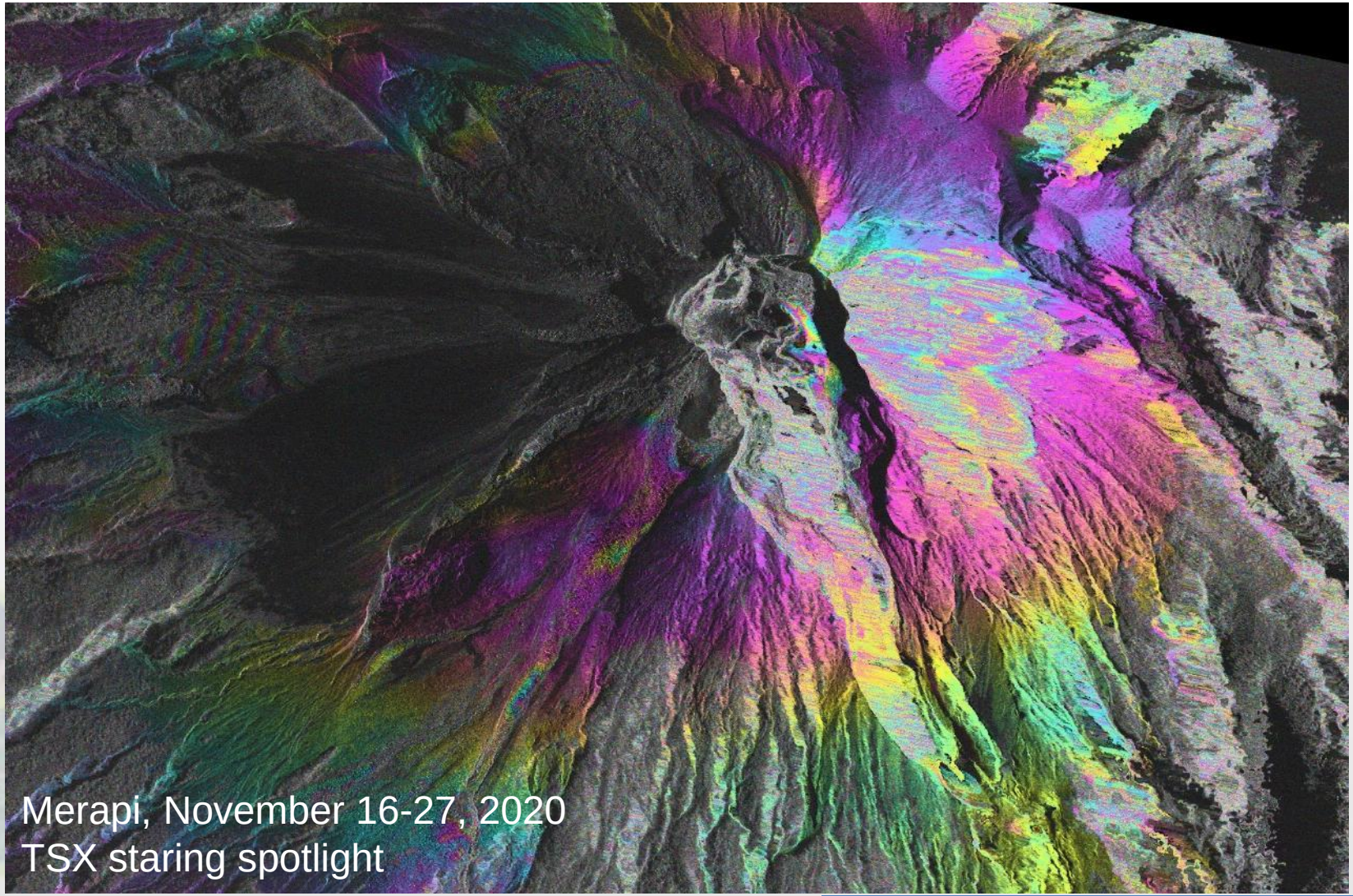


- Results shared with CVGHM

slide from Mike Poland, USGS

Example: TSX and CSK from Merapi, Indonesia

- Available data included “staring spotlight” TerraSAR-X data, with a pixel size of less than 1 meter
- Through November and December, small-scale, rapid displacements were detected on the west flank of the volcano

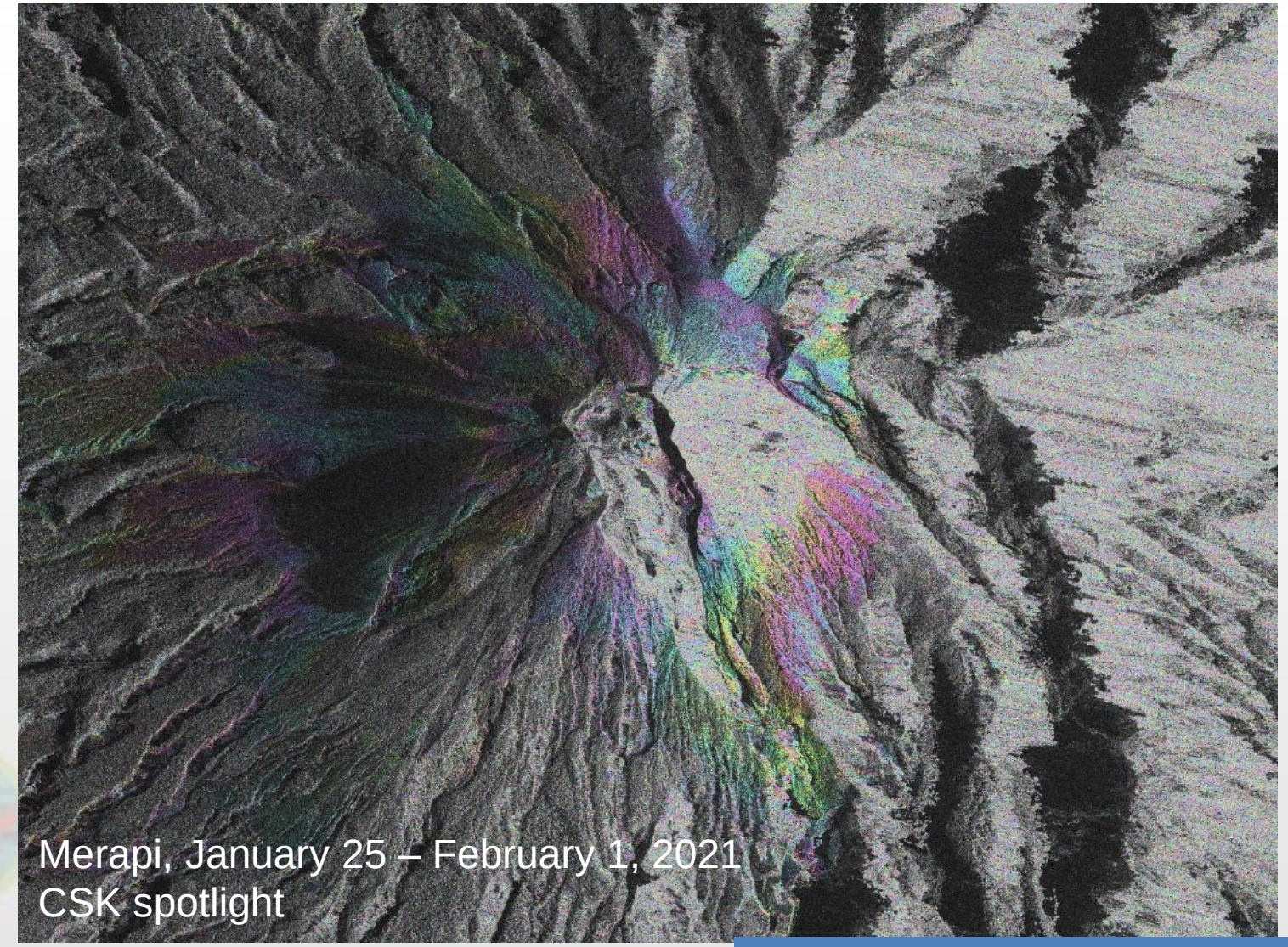


- Results shared with CVGHM

slide from Mike Poland, USGS

Example: TSX and CSK from Merapi, Indonesia

- The volcano finally began to erupt in early January, 2021
- High-resolution X-band satellite data confirmed that the rapid and localized displacements on the volcano's west flank had ceased
- SAOCOM and PAZ imagery also provided – combination of PAZ and TSX allowed 4 and 7 day spans (rather than 11)



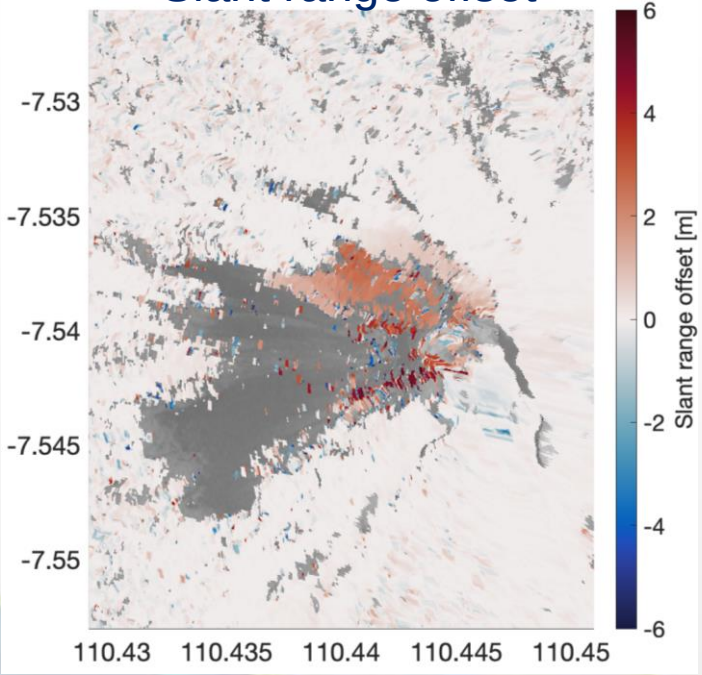
Merapi, January 25 – February 1, 2021
CSK spotlight

- Results shared with CVGHM

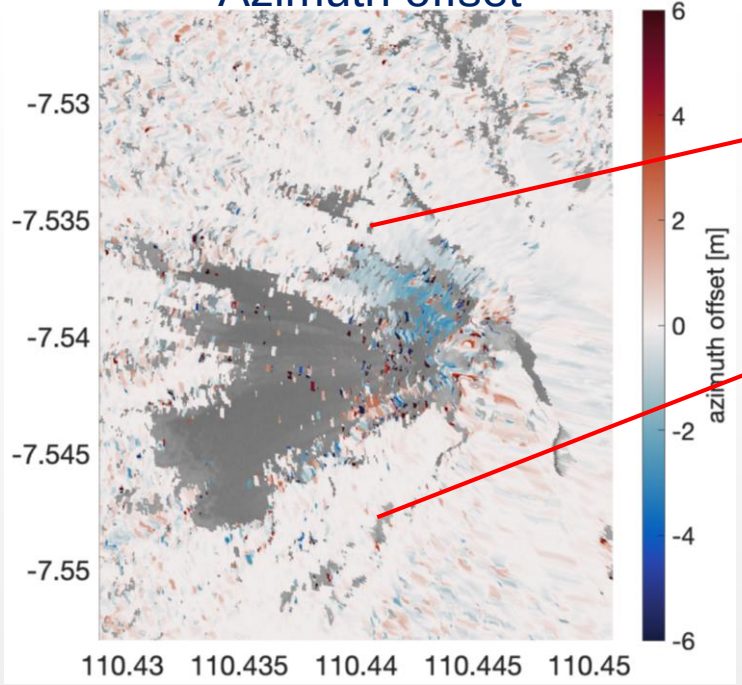
slide from Mike Poland, USGS

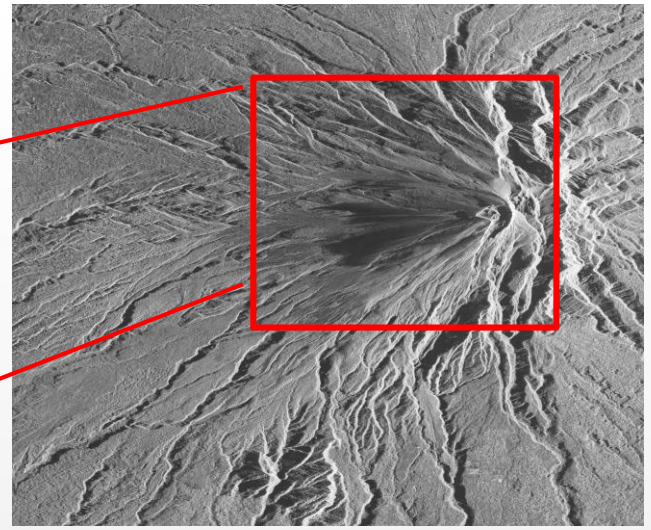
Example: TSX and CSK from Merapi, Indonesia

Slant range offset



Azimuth offset





Cosmo-SkyMed spotlight (desc) 2020-10-05 → 2020-11-22

Range: reds = range extension/subsidence and/or westward

Azimuth: red = displacement in flight direction.

Deformation detection threshold ~0.1*pixel size

- **10 cm CSK spotlight, bit ~2 m Sentinel-1 -> we need high resolution SAR data**

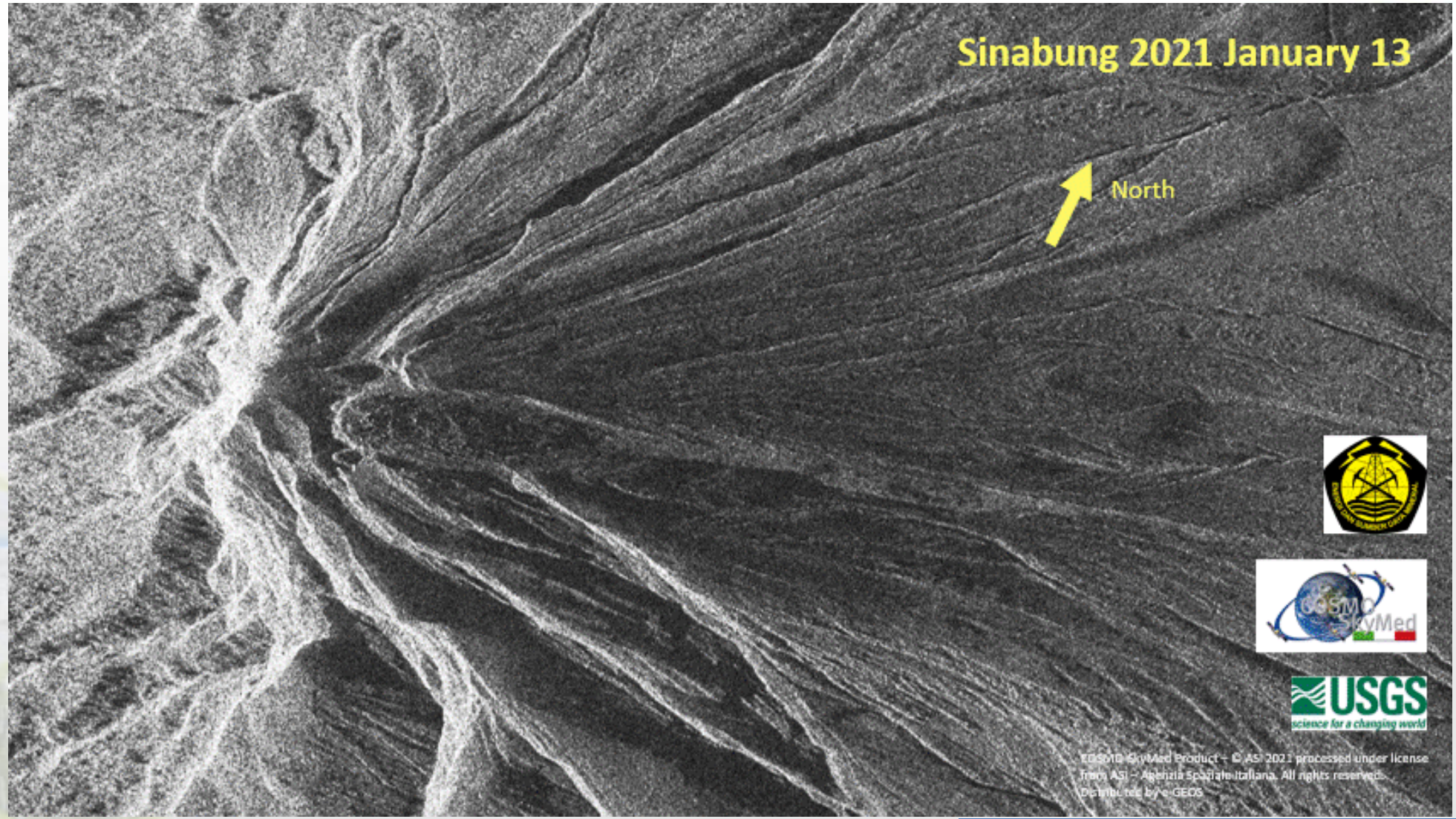
Less affected by: large baselines, dense vegetation and/or steep slopes at tropical stratovolcanoes

Slide from Mark Bemelmans, Bristol

Example: CSK from Sinabung, Indonesia

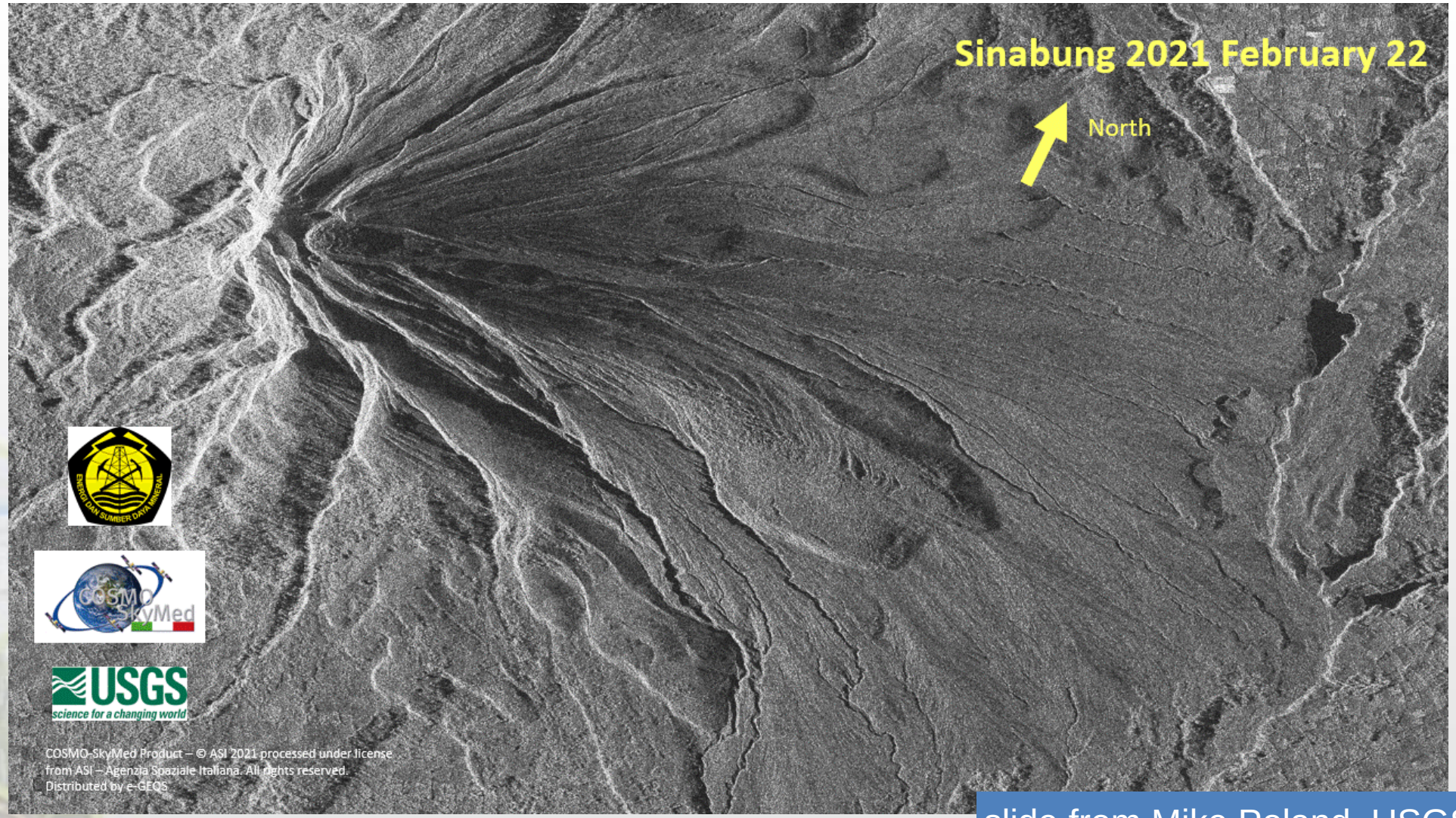
COSMO-SkyMed amplitude data from Sinabung volcano, Indonesia, have been used to map changes in lava dome and flow activity over time

- Animations shared with CVGHM



slide from Mike Poland, USGS

Example: CSK from Sinabung, Indonesia

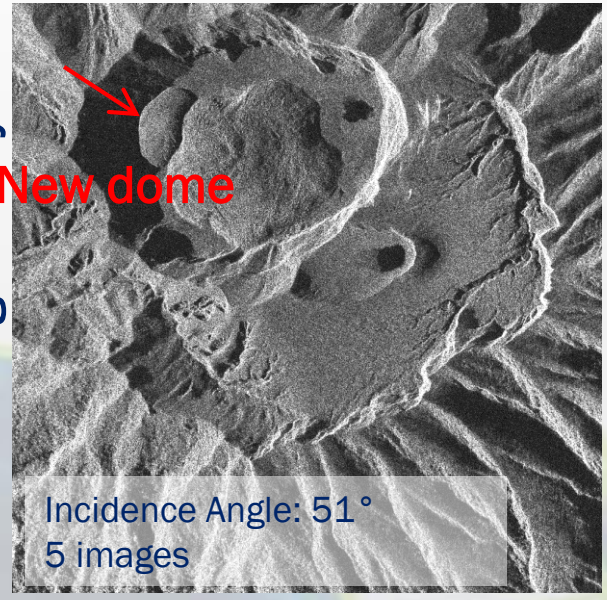


slide from Mike Poland, USGS

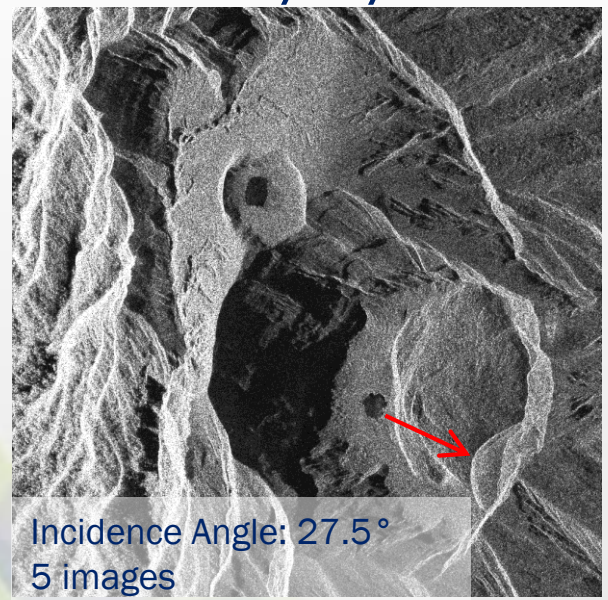
Example: dome growth at St Vincent

Radar geometry

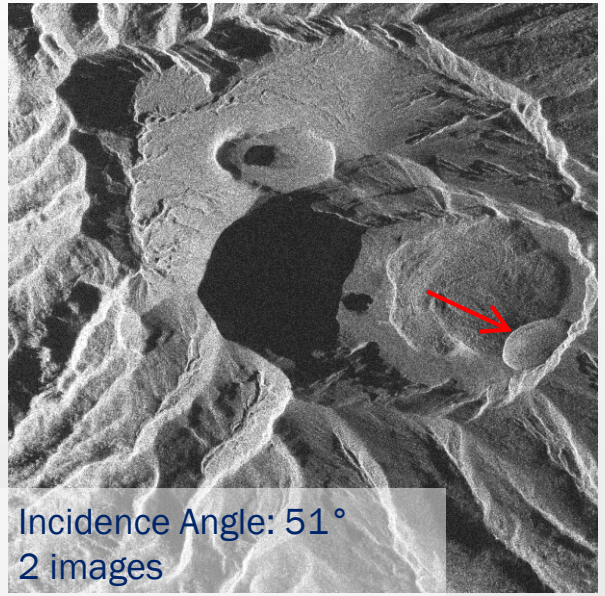
TSX Ascending – 2021/01/24



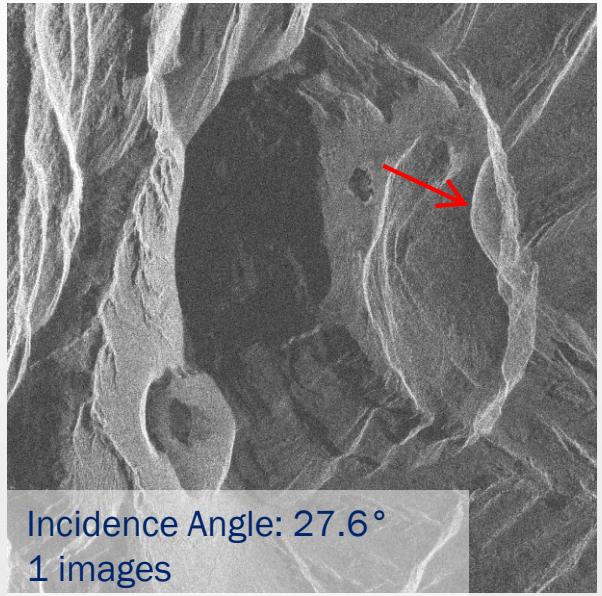
TSX Descending - 2021/01/25



CSK - 2021/01/17

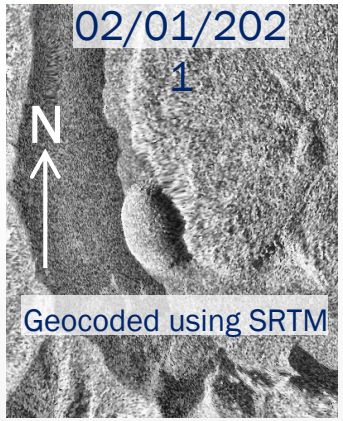


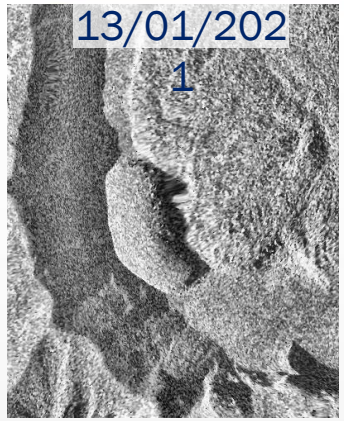
ICEYE (2021/01/27)

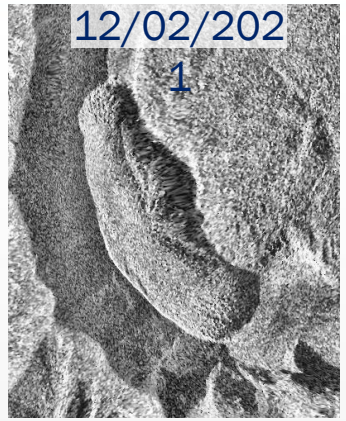


Imagery and results being shared with University of the West Indies and the Seismic Research Centre (Trinidad & Tobago)

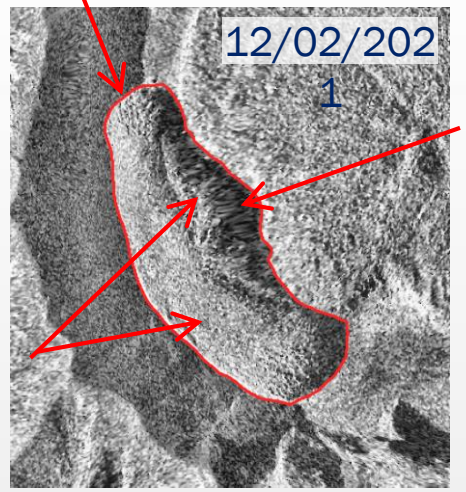
Example: dome growth at St Vincent







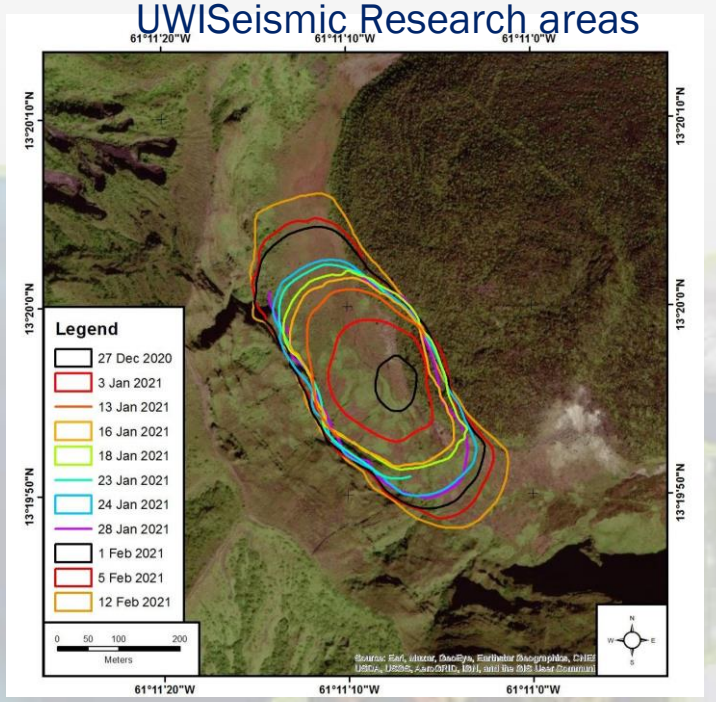
Extracted area



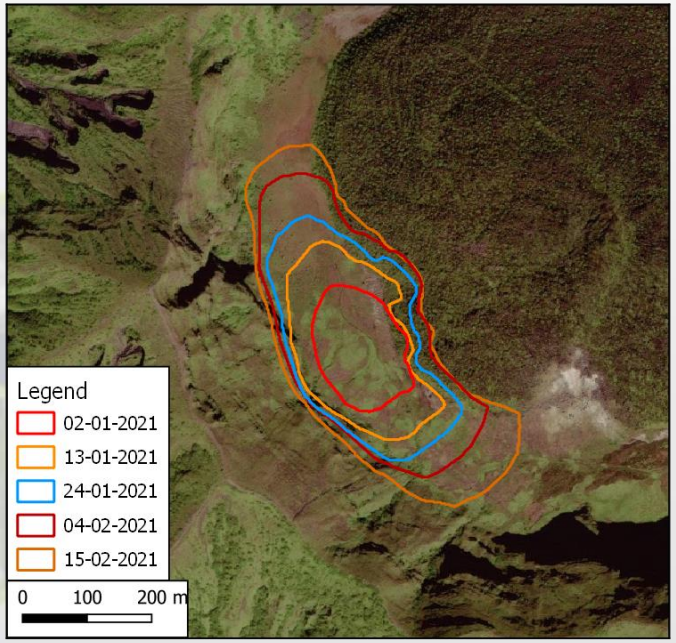
Dome shadow

Structures on dome?

UWISeismic Research areas



SAR calculated areas



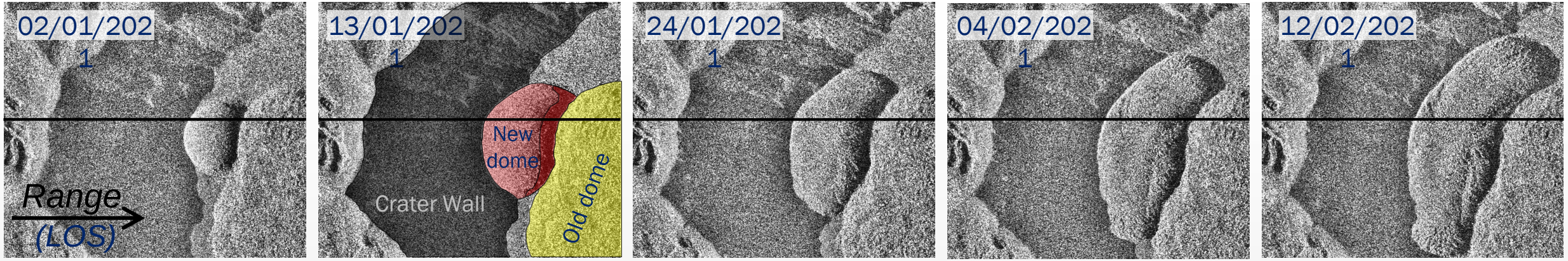
Dome area estimates from TSX asc

1. 02/01/2021 22 368.5 m²
2. 13/01/2021 46 858.8 m²
3. 24/01/2021 67 431.6 m²
4. 04/02/2021 92 742.6 m²
5. 15/02/2021 119 737.0 m²

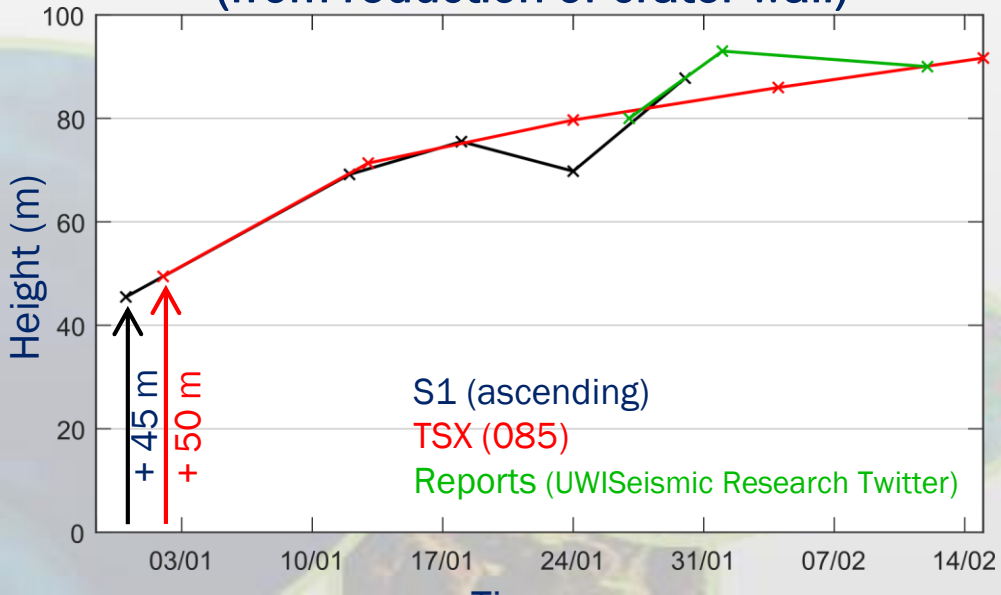
slide from Edna Dualeh, Leeds

Example: dome growth at St Vincent

TSX ascending track

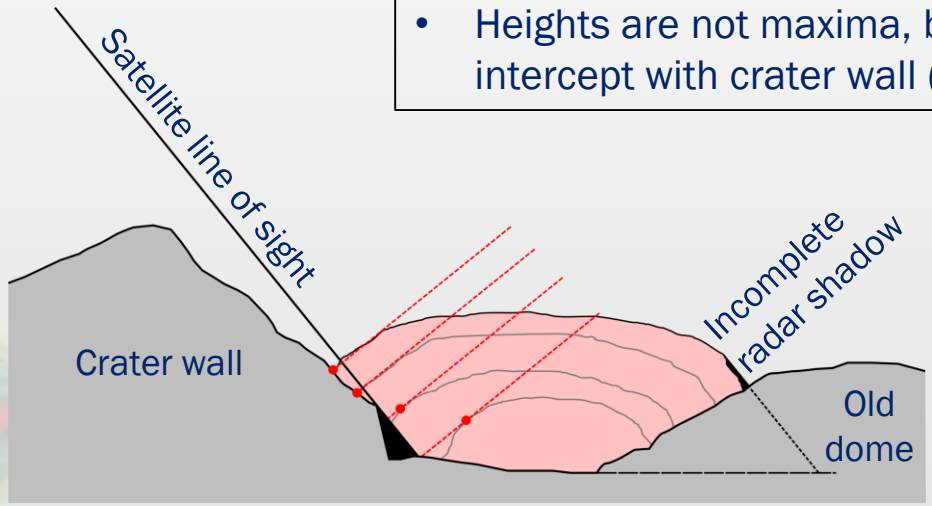


Rough dome height (from reduction of crater wall)



Assumptions in rough height estimations:

- Heights are not maxima, but estimations of point of intercept with crater wall (shown in diagram)



Schematic of dome interaction and satellite line of sight (LOS) with example points (red) of dome and wall intersect used to estimate dome growth

slide from Edna Dualeh, Leeds

Example: Pleiades in Latin America

Crisis Response

Nevados de Chillan Volcano Complex : 2016- ?

Captura Colada desde el 01 a 15 FEB 2021

Se mantiene la desgasificación continua y anómala desde frente de L5, se destaca el mayor desarrollo del canal central en cuanto a su ancho y extensión. Se observa un avance del frente de forma "compacta" y además, en bloques. Esta evolución es coherente con el aumento de tasa de emisión y cambio reológico reportado la quincena anterior.

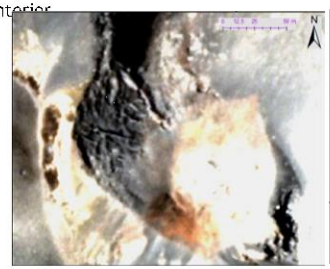


Imagen Skysat 09.12.2020

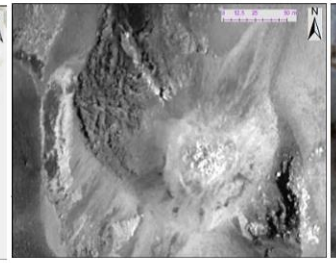


Imagen Pleiades 01.01.2021

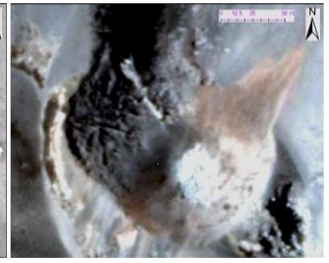
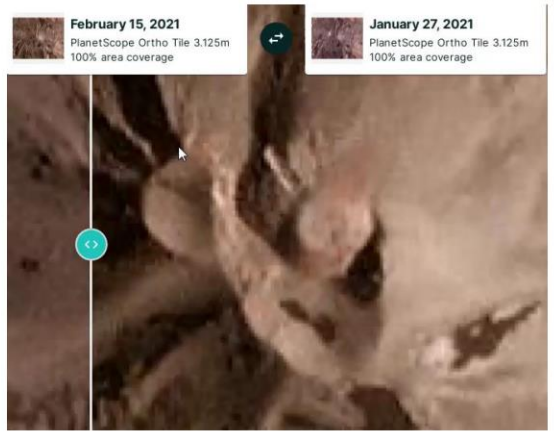


Imagen Skysat 10.01.2021



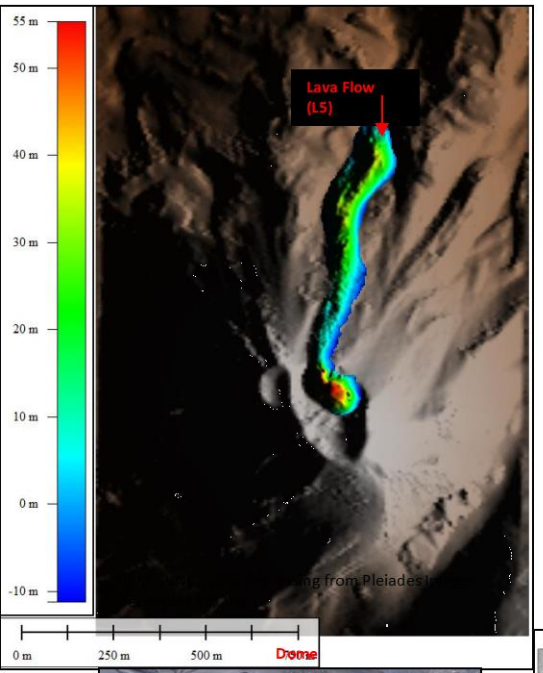
- Pleiades imagery provided through Volcano Demonstrator used to assess lava flow volumes at Nevados de Chillan, Chile
- Comparison to other optical instruments critical to measure change
- Pleiades imagery is being used to look at processes at Sabancaya, Peru
- Tasking also at Nevado del Ruiz, Colombia

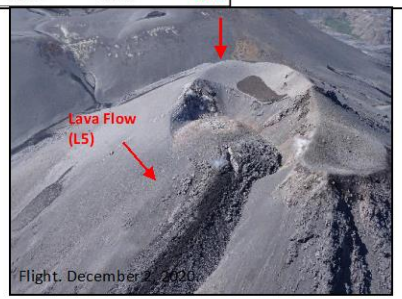
slide from Loreto Cordova, OVDAS, Chile

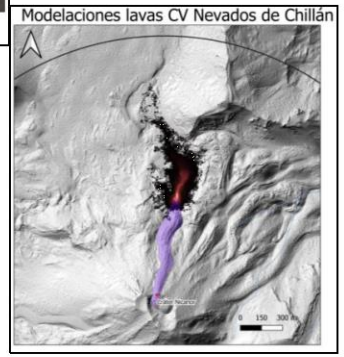
Example: Pleiades in Latin America

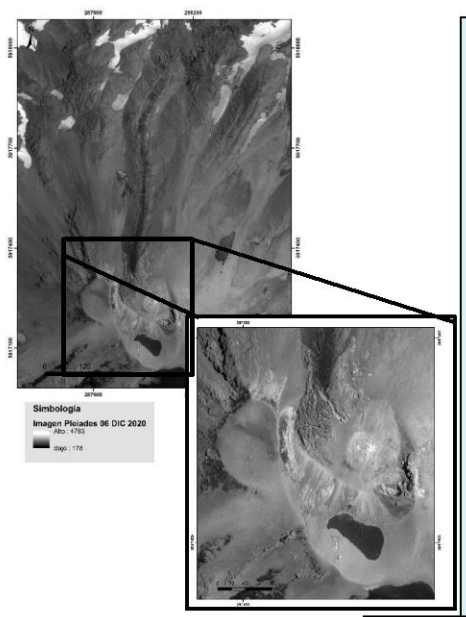
Crisis Response

Nevados de Chillan Volcano Complex: 2016– ?







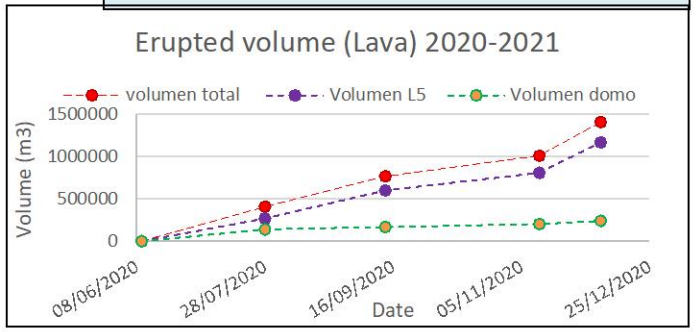


Remotes Sensing contribution to track CVNCh activity

Sources:
- Skysat y Planet Scope
- **Pleiades Images-World View**
- **DEMs from post procesing Pleiades and World View images**

(Support from Volcano Demostrator Program and VDAP)

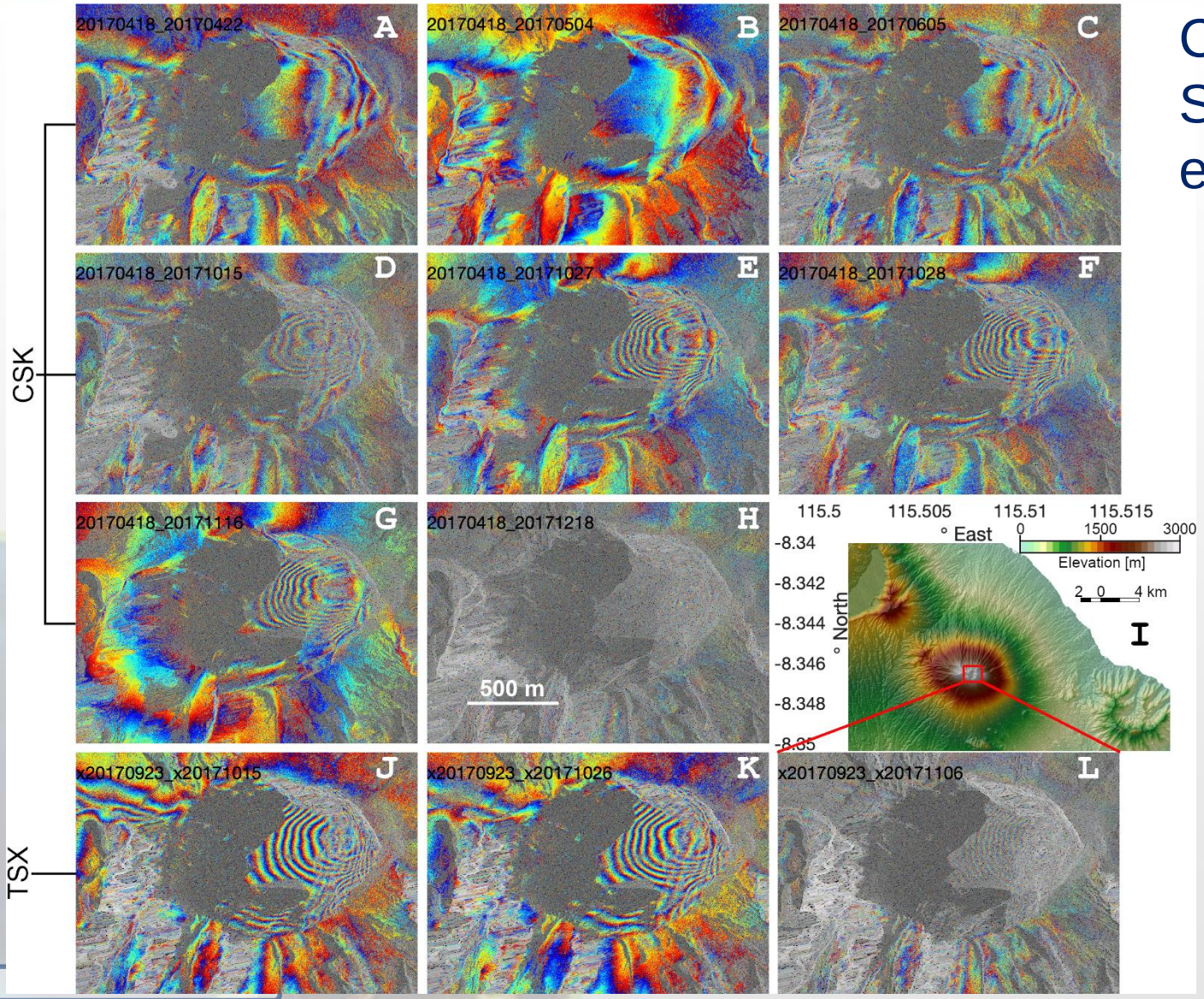
Results:
- ✓ Morphological evolution
- ✓ Mapping lava flows
- ✓ Volume estimations
- ✓ Eruptive rate tracking and changes on regime.
- ✓ Volcanic hazards modelling.



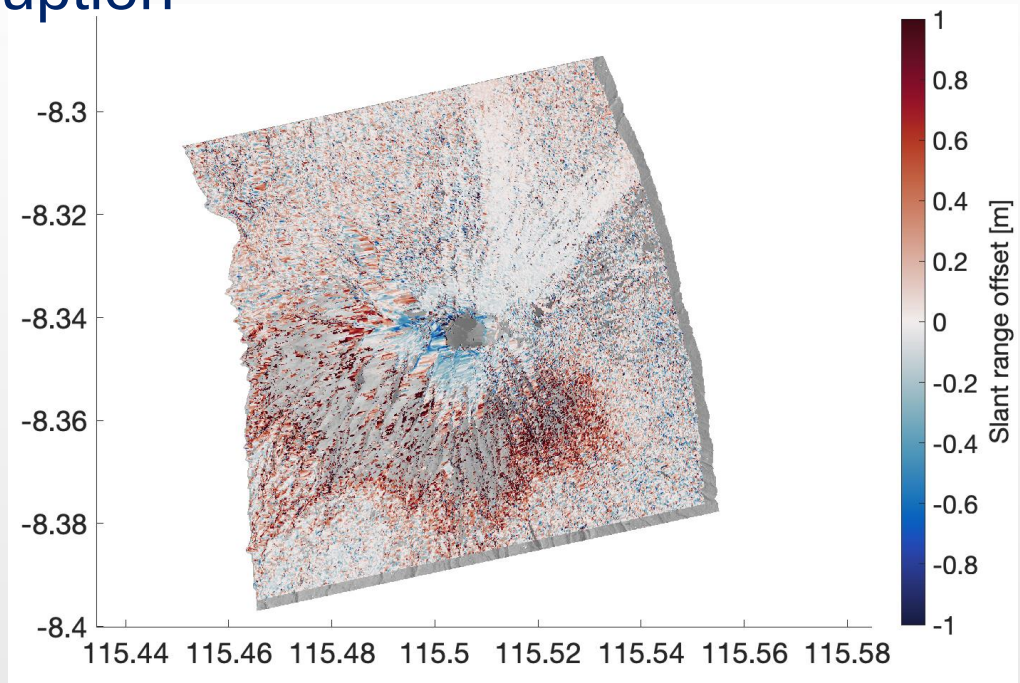
- Contribution to estimations of volumes and therefore effusion rate
- Enthusiastic feedback about CEOS datasets during March workshop on satellite and ground-based volcano monitoring

slide from Loreto Cordova, OVDAS, Chile

Example: further analysis of Agung 2017 event



CSK and TSX analysis adding to earlier Sentinel work focused on an important eruption



CSK 2017-11-20 → 2017-11-28 asc
Reds: range extension/ subsidence and/or eastward, Blues: range shortening/ uplift and/or westward

Figures from Mark Bemelmans, Bristol

Other ongoing work

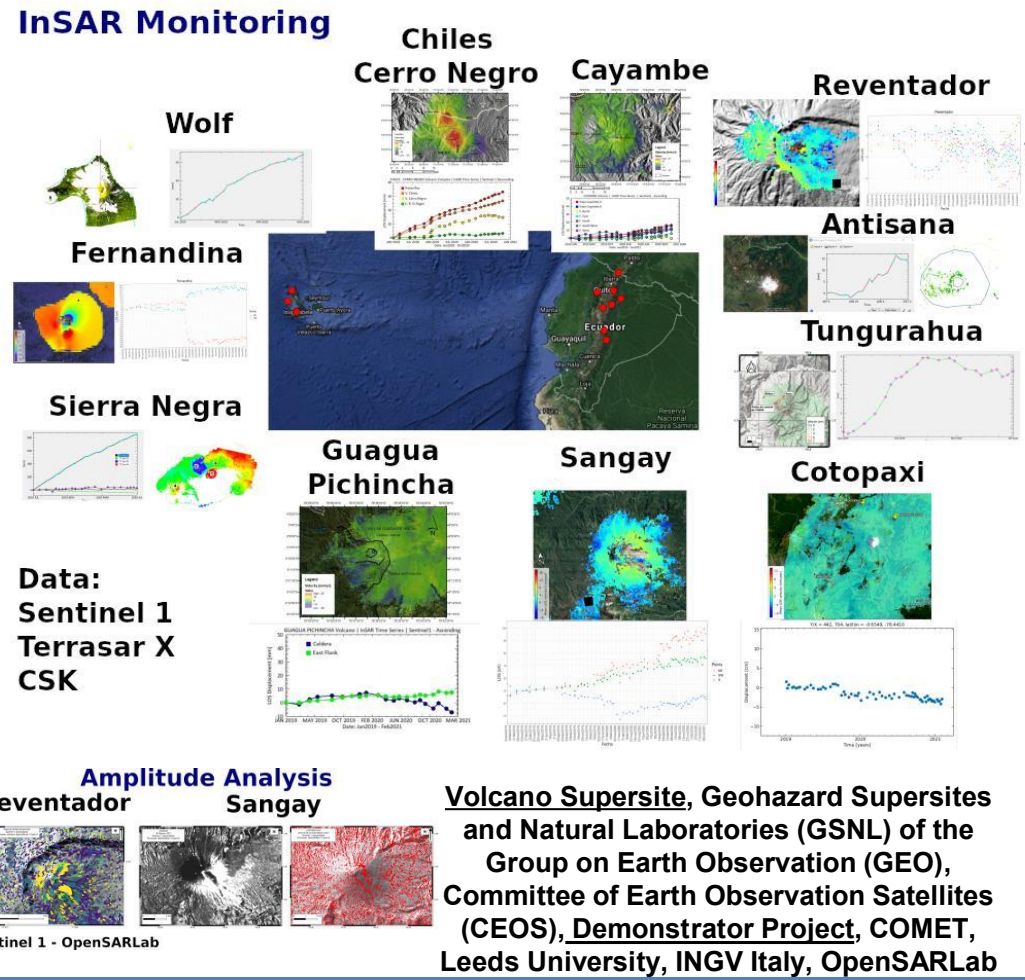
- Sangay (CSK), Chiles-Cerro Negro, Cotopaxi (TSX) – IG-EPN Ecuador
- Pleiades imagery requested for Cayambe (Ecuador) ,Nevado del Ruiz (Colombia), Sabancaya (Peru) and Nevados

- Regular ‘Baseline’ TSX tasking by Mike:

Chile (7), Ecuador (3), Peru (1), Indonesia (5), Philippines (4), PNG (5), Vanuatu (3), Caribbean (2).

Satellite based monitoring

- Deformation



Volcano Supersite, Geohazard Supersites and Natural Laboratories (GSNL) of the Group on Earth Observation (GEO), Committee of Earth Observation Satellites (CEOS), Demonstrator Project, COMET, Leeds University, INGV Italy, OpenSARLab

figure from Silvana Hidalgo, IG-EPN, Ecuador

2021 Workshop on volcano monitoring infrastructure on the ground and in space

Hosted by Matt Pritchard online

(original intention was to be part of IAVCEI Cities on Volcanoes May 2020)

- **254** registrants from 29 countries
- **>20 volcano observatories** represented, as well as researchers from national agencies and universities.

Sessions on InSAR, degassing, thermal

- Mike Poland introduced CEOS Volcano Demonstrator during the InSAR session.
- Demonstrations of various online tools for analysis of satellite imagery

Workshop on volcano monitoring infrastructure on the ground and in space

online meeting hosted by Matt Pritchard at Cornell University

online on Feb. 18-22 2021

The goal of this 3-day workshop is to improve the understanding of the current capabilities and limits of volcano monitoring from the ground and space. By the end of the workshop, participants will contribute to the development of a Global Volcano Monitoring Infrastructure Database (GVMID) to be hosted at WOVOdat, learn about satellite tools for volcano monitoring, and contribute to improving the utility of satellite data for volcanoes. **Please register by Feb 15th**

Day 1 (Feb. 18): Introduction and rationale of the Global Volcano Monitoring Infrastructure Database: Focus on ground-based observations.Speakers include: Fidel Costa, Christina Widiwijayanti, Diana Roman, Eisuke Fujita, Giuseppe Puglisi, and others
8am-12pm (EST)

Day 2 (Feb. 19): Remote sensing: InSAR and degassing
Speakers include: Juliet Biggs, Susanna Ebmeier, Simon Carn, Vince Realmuto, and others
8am-12pm (EST)

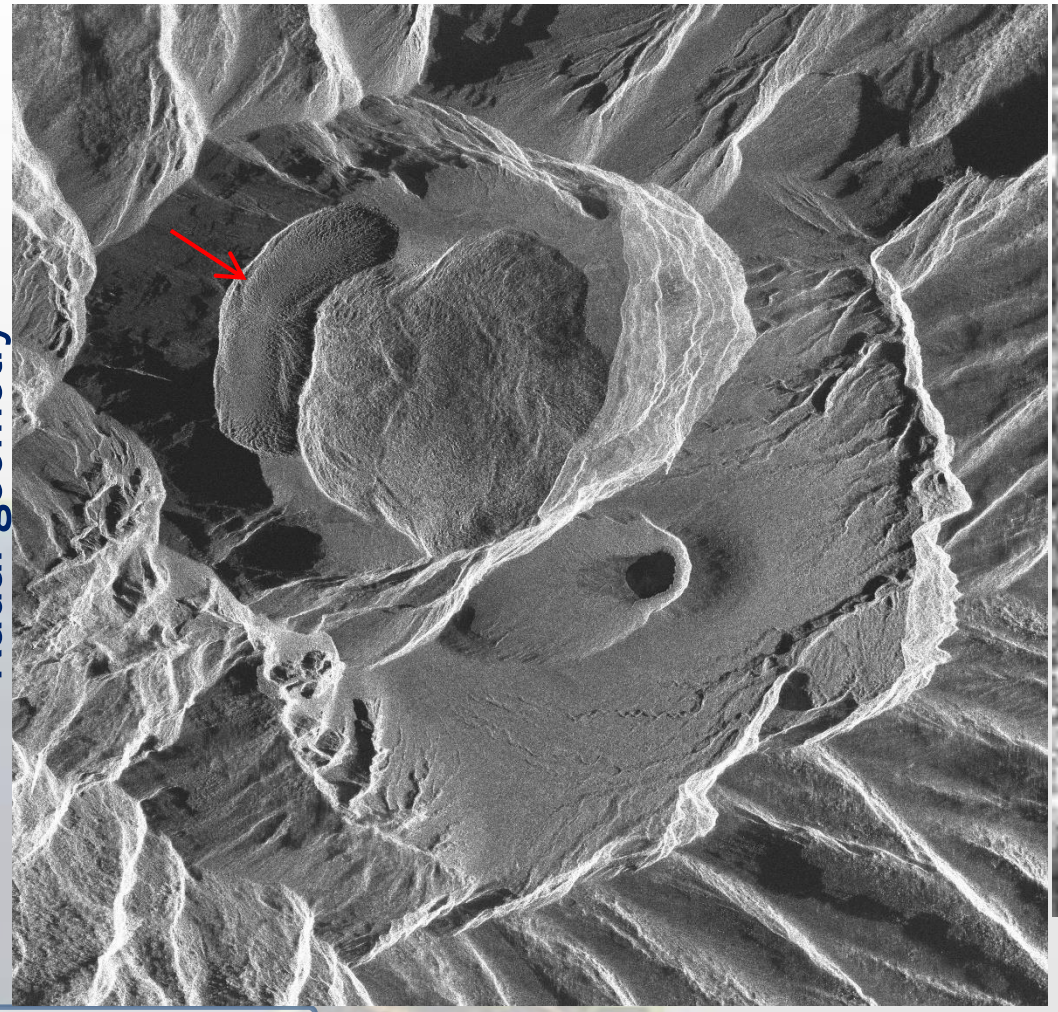
Day 3 (Feb. 22): Remote sensing: Thermal, surface and topographic change
Speakers include: Greg Vaughan, Elise Rumpf, Diego Coppola, Rick Wessels, Angie Diefenbach, and others
8am-12pm (EST)

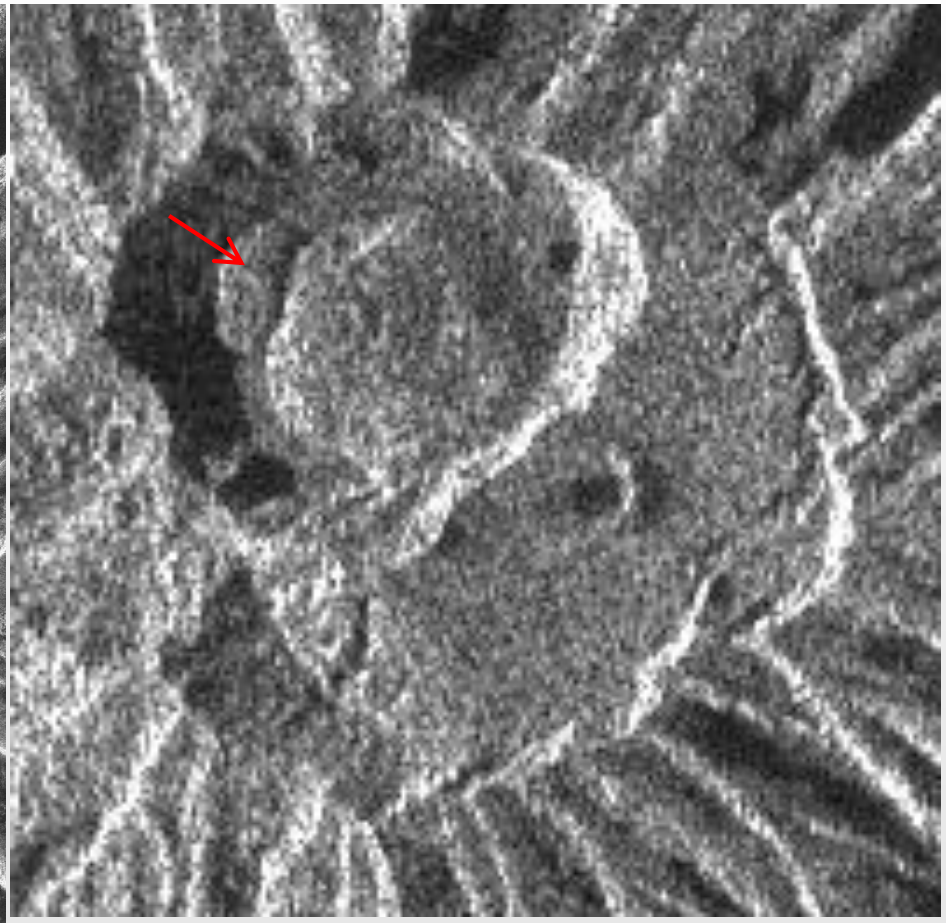
Discussion point: High resolution backscatter

TSX Asc staring spotlight – 2021/02/21

S1 (2021/01/24)

Radar geometry



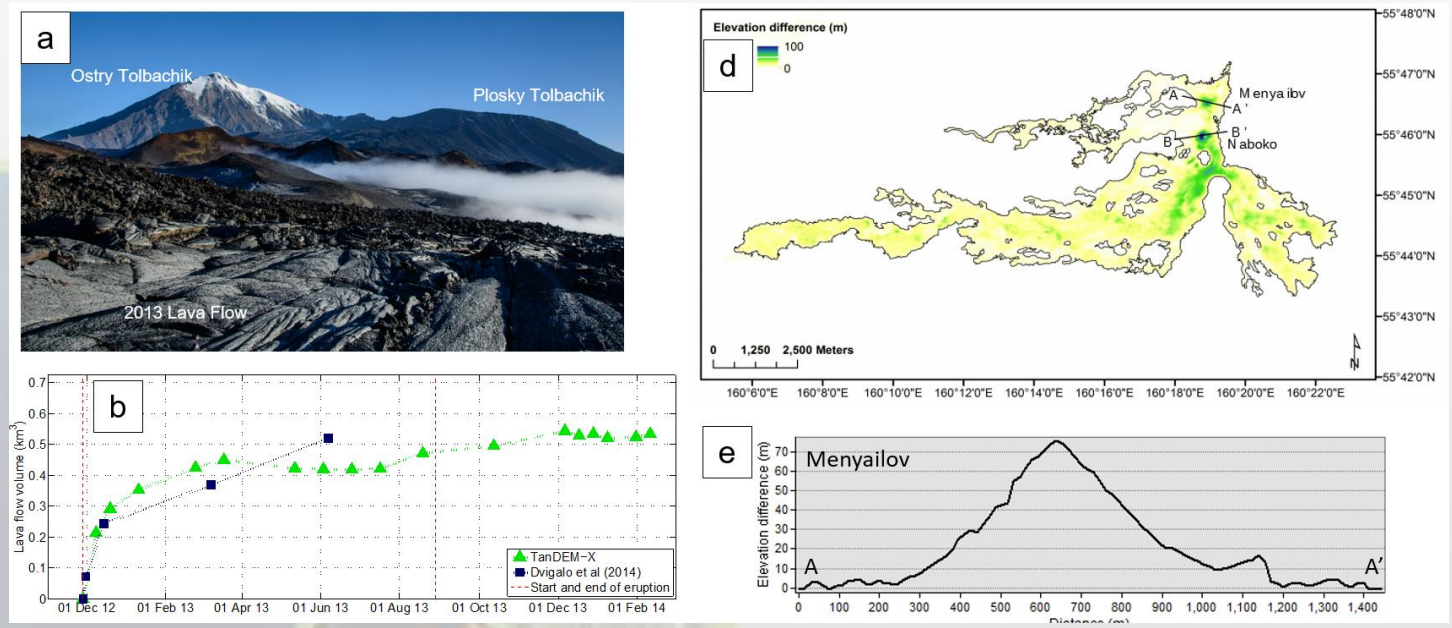


CSK and TSX spotlight/staring modes provide unique data for eruption response – only instruments with high enough resolution to detect local changes important for hazard

slide from Edna Dualeh, Leeds

Discussion point: topographic data

- Accurate, recent DEMs are critical for hazard assessment during an eruption:
  - **Estimation of effusion rate, flow modelling and hazard assessment**
  - Critical for interpretation of high resolution SAR imagery (e.g., CSK, TSX especially spotlight modes)



- TanDEM-X is an immensely powerful tool for volcanology

- Precise, high resolution measurements of topographic change, allowing detection of new lava flows, dome growth and explosive deposits

Kubanek, Poland & Biggs, 2021

Discussion point: topographic data

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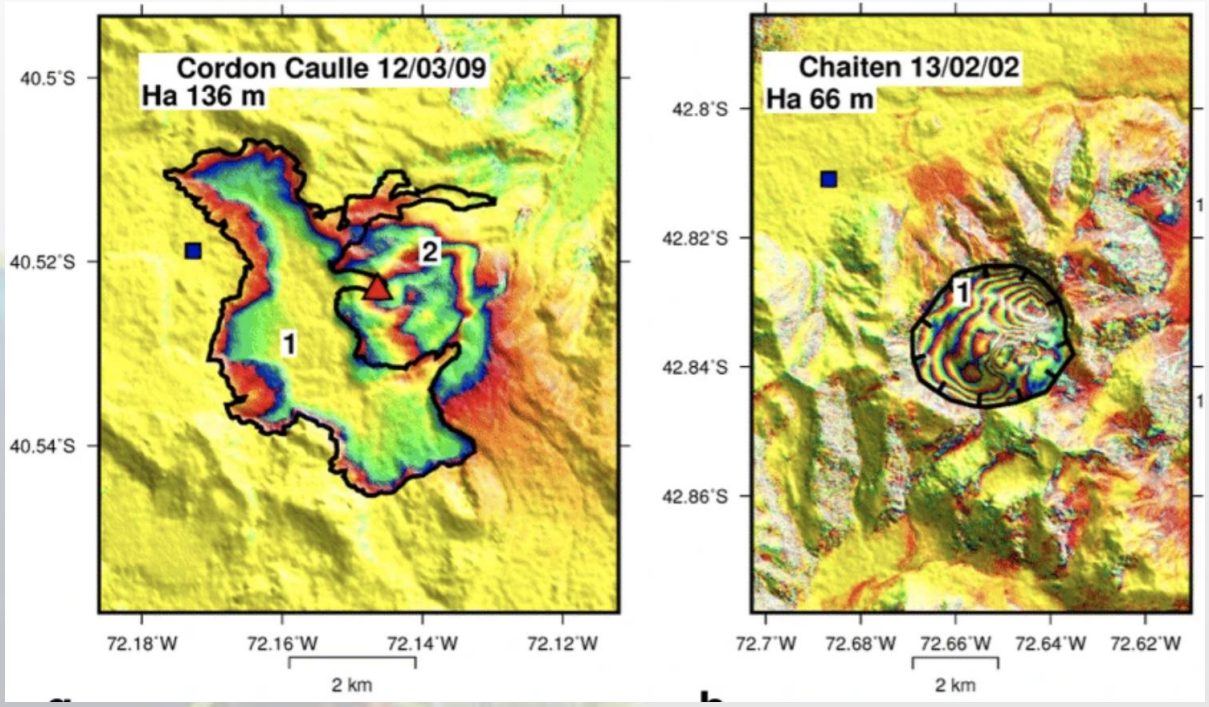


Pritchard et al., 2018

- 12m WorldDEM greatly enhances analysis of high resolution SAR imagery
- Requested by some volcano observatories

Discussion point: L-band imagery

- L-band is critical for InSAR measurements at densely vegetated volcanoes, and where deformation is high magnitude

Sentinel-1 – ALOS-2 comparison of earthquakes at Sabancaya, Peru

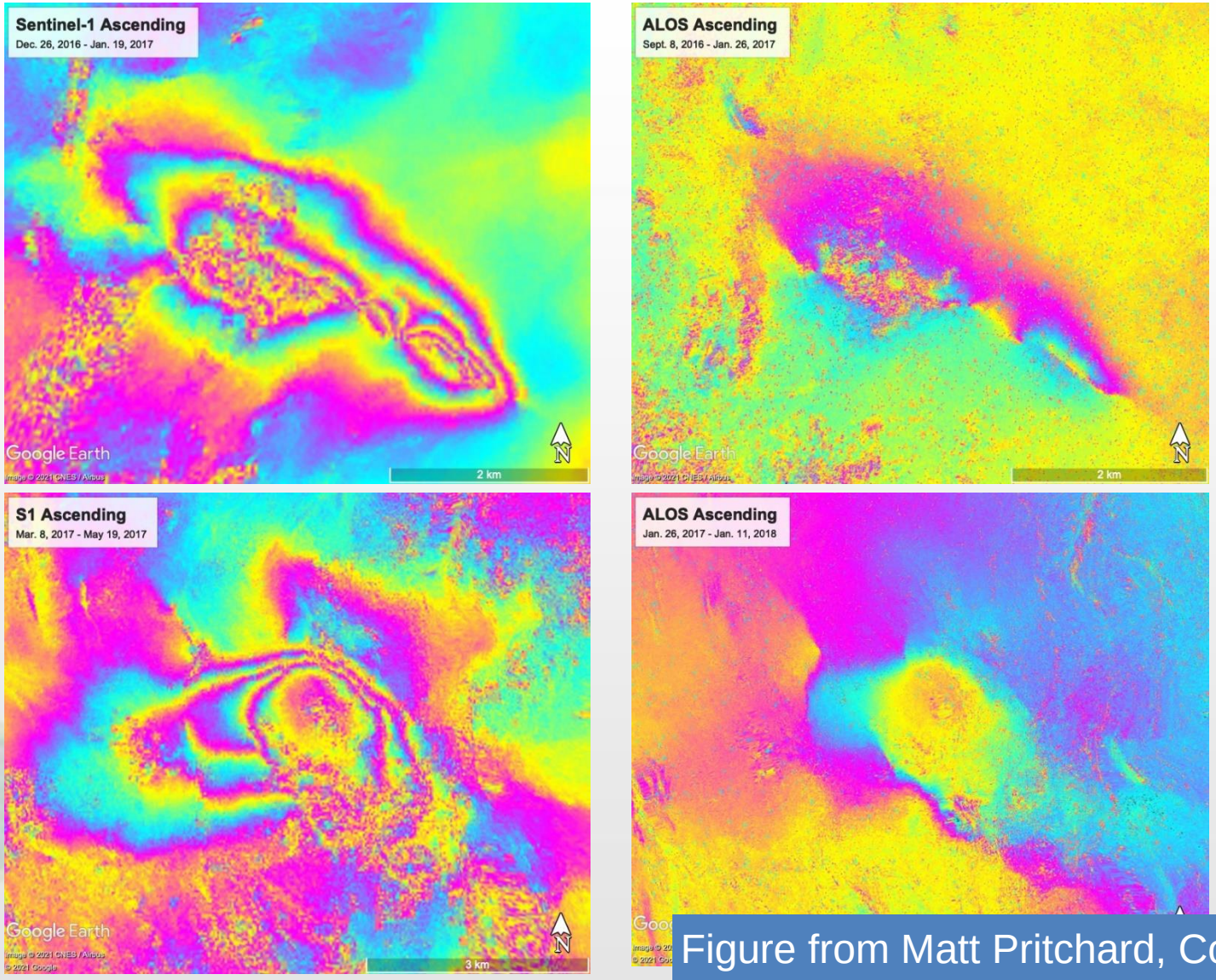


Figure from Matt Pritchard, Cornell

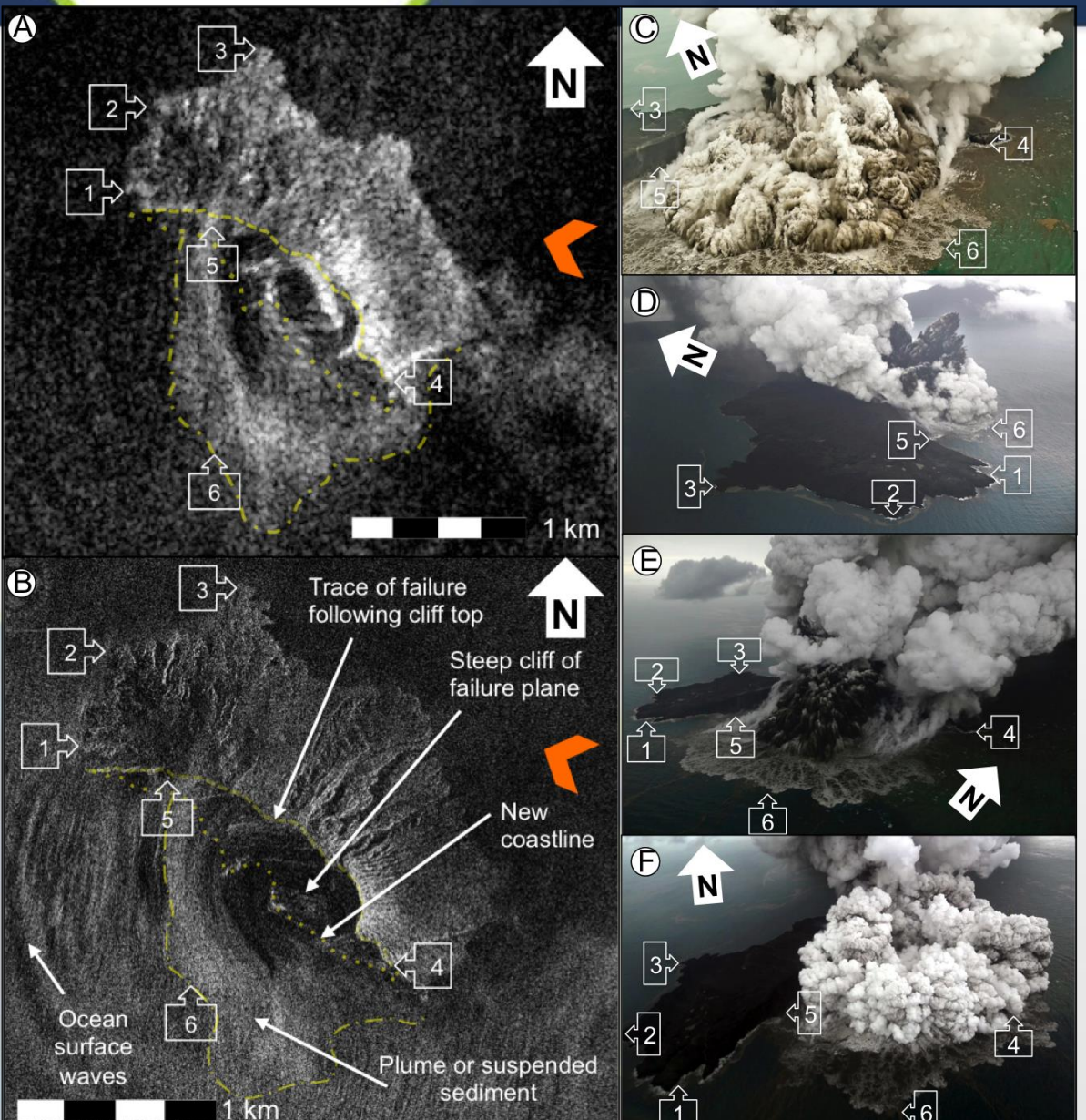
Discussion point: constellation imagery

• Volcanic unrest and eruption can progress very quickly – within hours or days – the sooner images can be acquired the better

• Access to imagery from multiple platforms greatly increases the likelihood to capturing rapid deformation during unrest or rapid topographic change during

• Denser time series also provide information about processes that might otherwise have been missed during retrospective analysis

Discussion point: constellation imagery



- Collapse of Anak Krakatoa on Dec 22nd 2018, S1 image acquired the same day

- Higher resolution CSK image (23rd Dec) allowed improved estimation of subaerial landslide and facilitated comparison (Hunt et al., 2021)

=> Use of multiple instruments allowed retrospective densification of SAR backscatter time series and more complete picture of failure event

RSat -2 imagery

• Anticipated requests:

Priority 1:
• Cordon Caulle, Chile (-40.59,-72.12)
Wide Ultra Fine 16 (descending) and Wide Ultra Fine 12 (ascending) with images every 24 days between November 15 and May 30 (late austral spring to late austral fall).
• Ambae, Vanuatu
Extra Fine W2 (descending), and the date range is 2017-07-14 to 2018-12-24

Volcanoes previously approved by CSA:
• Turrialba, Costa Rica (10.02 -83.76)
• Pacaya, Guatemala (14.38 -90.60)
• Santiaguito, Guatemala
• Popocatapetl, Mexico (19.02 -98.62)
• Reventaor, Ecuador (-0.078 -77.66)
• Llaima, Chile (-38.69 -71.73)

• Is there a quota?

• Any advice on how much we need to prioritise from CSA would be very welcome

Take home points

• Volcano demonstrator is active in tasking TSX, as well providing CSK and Pleiades to volcano observatory scientists and researchers.

• High resolution SAR (especially CSK and TSX) has been critical in recent response - volcano observatories are very appreciative of the data

• Access to Tandem-X co-SSCs and WorldDEM is incredibly useful for hazard response for many volcanoes – if we could find a way to do this, it would have a big impact

• L-band imagery remains the best tool for densely vegetation volcanoes and high magnitude deformation events

Related publications (last year)

- Albino, F., Biggs, J., Escobar-Wolf, R., Naismith, A., Watson, M., Phillips, J. C., & Marroquin, G. C. (2020). Using TanDEM-X to measure pyroclastic flow source location, thickness and volume: Application to the 3rd June 2018 eruption of Fuego volcano, Guatemala. *Journal of Volcanology and Geothermal Research*, *406*, 107063. (**TanDEM-X, Co-SSCs**)
- Araya, M. C., & Biggs, J. (2020). Episodic ground deformation associated with geothermal energy production at the Guayabo Caldera, Costa Rica. *Journal of Volcanology and Geothermal Research*, *407*, 107110. (**S1**, **ALOS-2**)
- Hickey, J., Lloyd, R., Biggs, J., Arnold, D., Mothes, P. and Muller, C., 2020. Rapid localized flank inflation and implications for potential slope instability at Tungurahua volcano, Ecuador. *Earth and Planetary Science Letters*, *534*, p.116104. (**S1, CSK**)
- Hunt J, Tappin D, Watt S, Susilohadi S, Novellino A, Ebmeier S, Cassidy M, Engwell S, Grilli S, Hanif M et al (accepted Feb 2021) Submarine landslide megablocks show half of Anak Krakatau island failed on December 22nd, 2018. *Nat. Comm*. (**CSK, TSX, S1**)
- Temtime, T., Biggs, J., Lewi, E., & Ayele, A. (2020). Evidence for Active Rhyolitic dike Intrusion in the Northern Main Ethiopian Rift from the 2015 Fentale Seismic Swarm. *Geochemistry, Geophysics, Geosystems*, *21*(6), e2019GC008550. (**CSK, S1**)