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The stability and collapse of lava domes: insight from UAS-derived 4D structure and slope stability models

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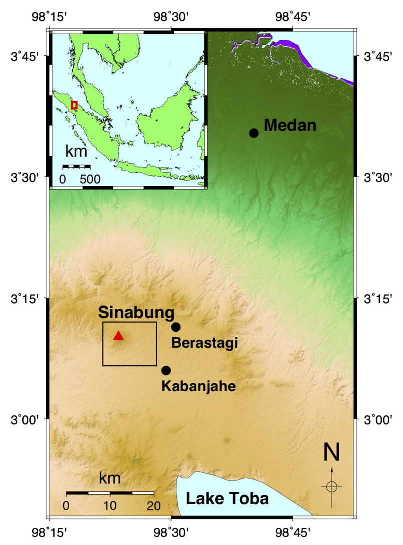
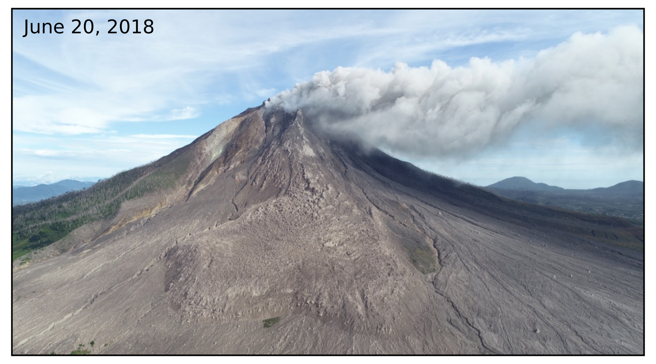
Motivation

- Dome collapse-generated pyroclastic flows are a primary hazard of lava dome eruptions
- Dome-forming eruptions can last for years to decades, creating a persistent hazard
- Improved understanding of collapse mechanisms and how to estimate the risk of collapse can improve hazard assessment for these eruptions

Dome Collapse at Sinabung



The eruption of Sinabung Volcano (2013 - present)[1,2] has included explosions, emplacement of a 3 km long lava flow[3,4], and frequent dome collapse[5]



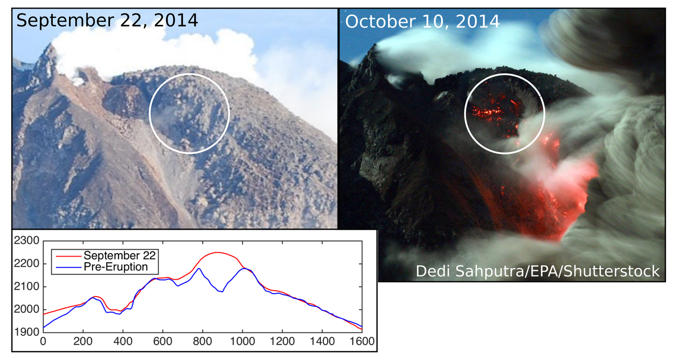
Dome Collapse during the eruption is caused by multiple processes:

Active Collapse[6]:
- Caused by effusion of lava and growth of domes and/or flows ("pushed")
- Size and/or frequency generally correlates with eruption rate, can be anticipated by monitoring eruption signals

Passive Collapse[6]:
- Caused by weakening of the internal structure of erupted lava ("pulled" by gravity)
- Not correlated to other activity, can occur unexpectedly

Active
Advance of lava flow

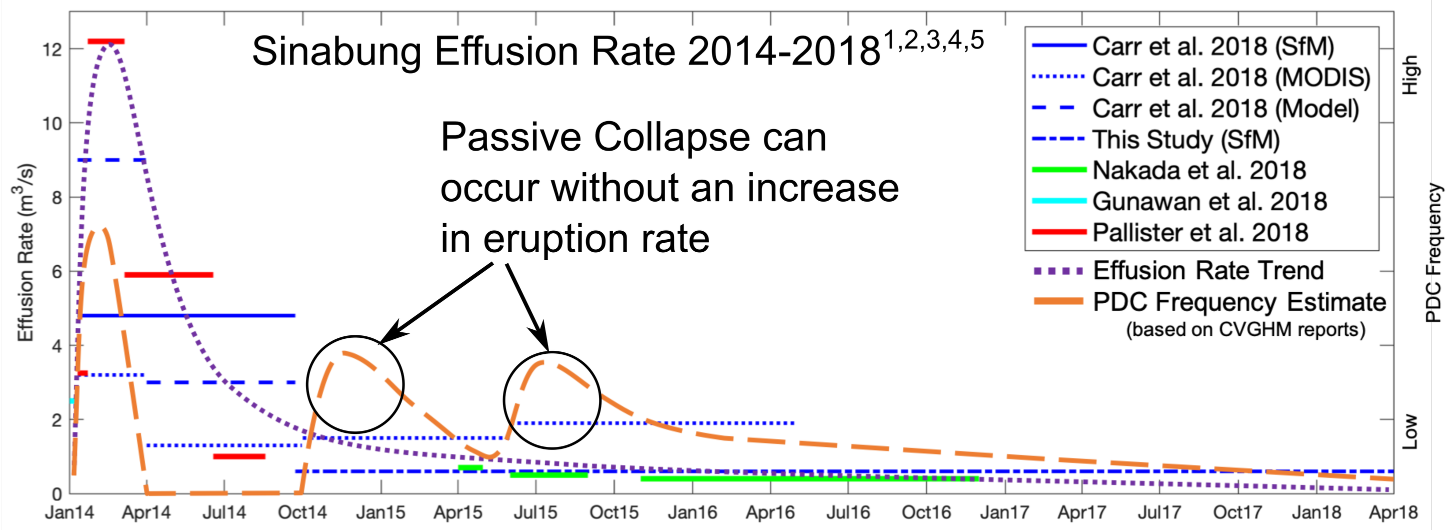
Passive
Overtopping Topography



Dome Growth

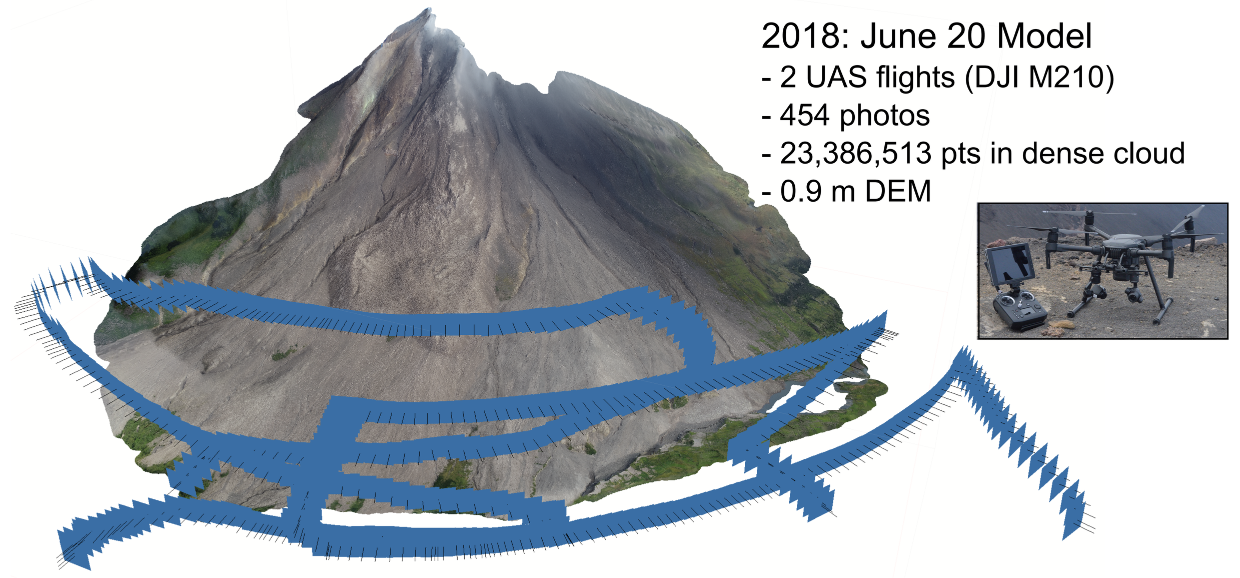
Gas Pressurization

Weakening of material??

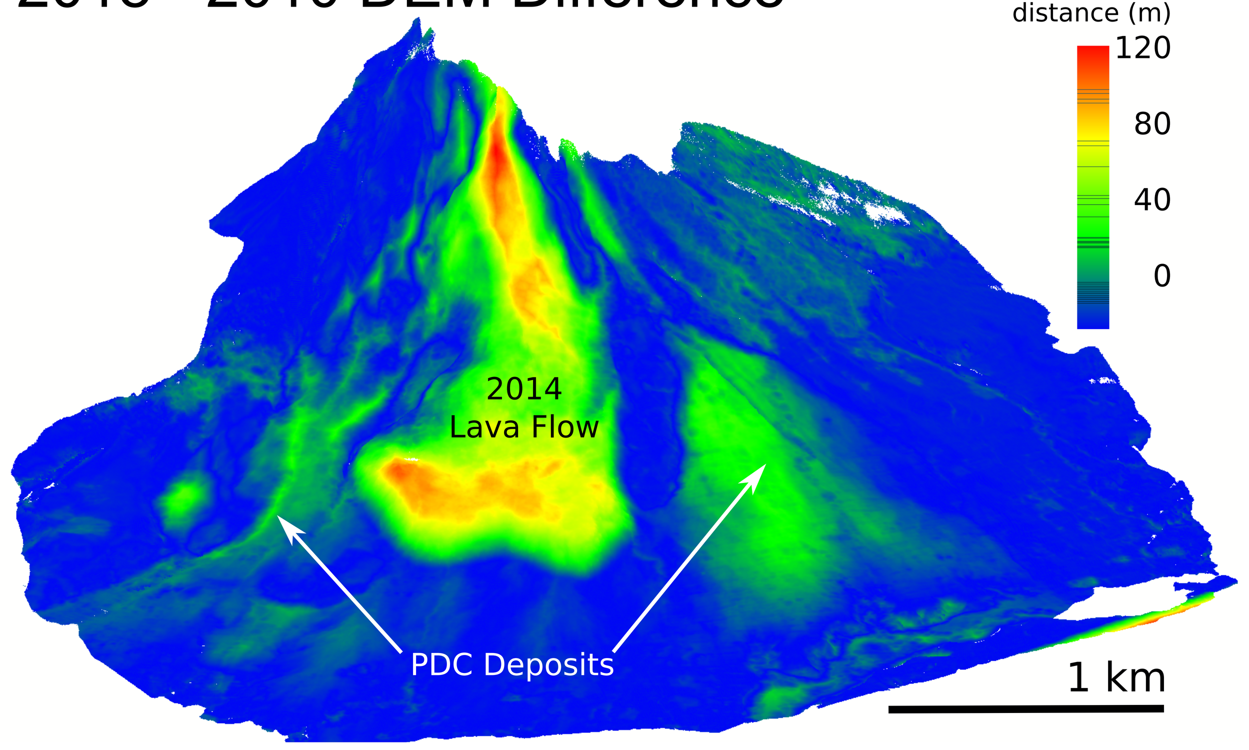


Topographic Change

We create digital elevation models (DEMs) of Sinabung by applying Structure-from-Motion photogrammetry[7] to image sets collected during field surveys in 2014[3] and 2018

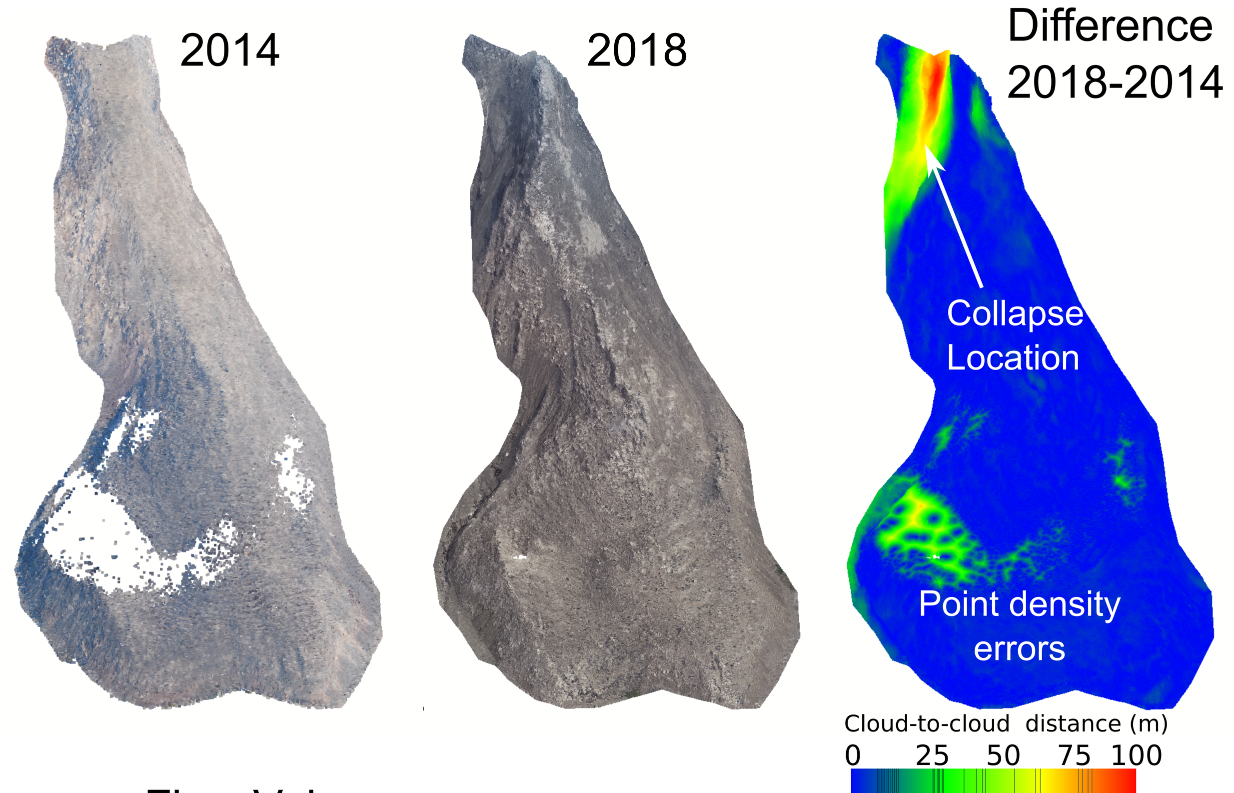


2018 - 2010 DEM Difference



Total Erupted Volume (2013-2018): 173 x 10^6 m^3
Volume of PDC (Collapse) Deposits: 76 x 10^6 m^3

Lava Flow Collapse 2014 - 2018



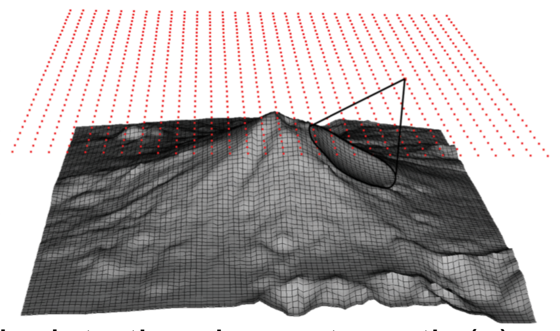
Flow Volume:
Sept 2014[3] (Before Collapse): 103 x 10^6 m^3
June 2018 (After Collapses): 97 x 10^6 m^3
Initial Collapse Volume: 0.2 x 10^6 m^3
Total Collapse Volume: 9.4 x 10^6 m^3

Slope Stability

Scoops3D

We apply the Scoops3D slope stability model[8] to evaluate collapse hazard at Sinabung. For given input parameters:

DEM:	SfM Photogrammetry
Cohesion (c) (kPa):	100 - 500 [8,9,10,11] erupted lava
	1000 [8,9] edifice
Angle of Internal Friction (φ):	25 - 40 [8,9,10,11] erupted lava
	40 [8,9] edifice
Unit Weight (kN m-3):	24.5 [5]

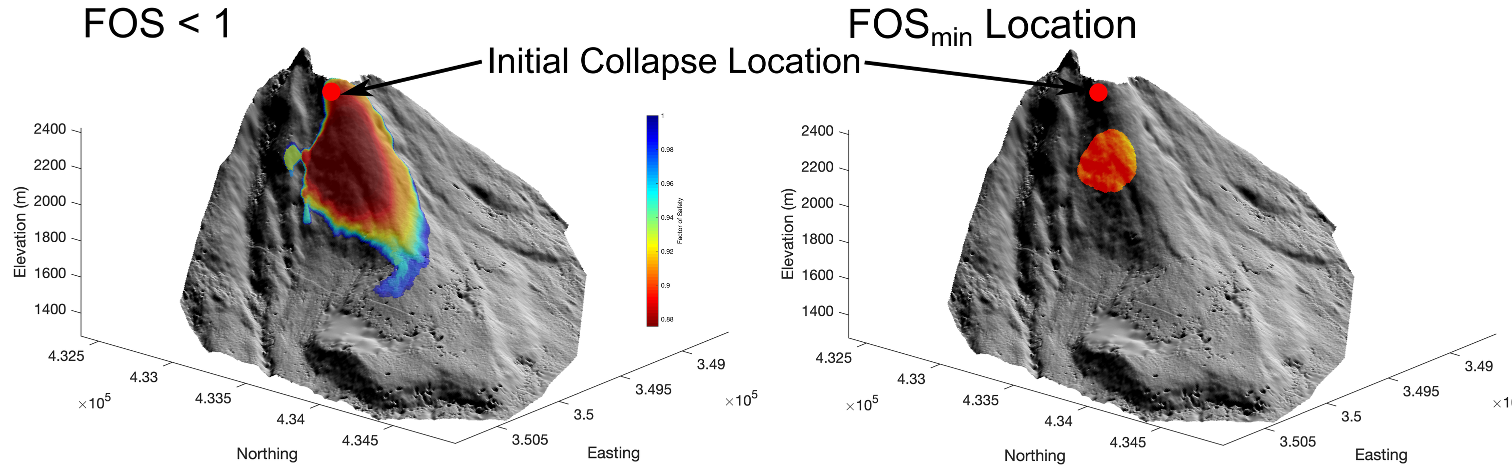


Scoops3D applies the Coulomb failure criteria to calculate the shear strength (s)

$s = c + \sigma_n \tan(\varphi)$ (normal stress) and then the Factor of Safety (FOS) $FOS = \frac{s}{\tau}$ (shear strength / shear stress)

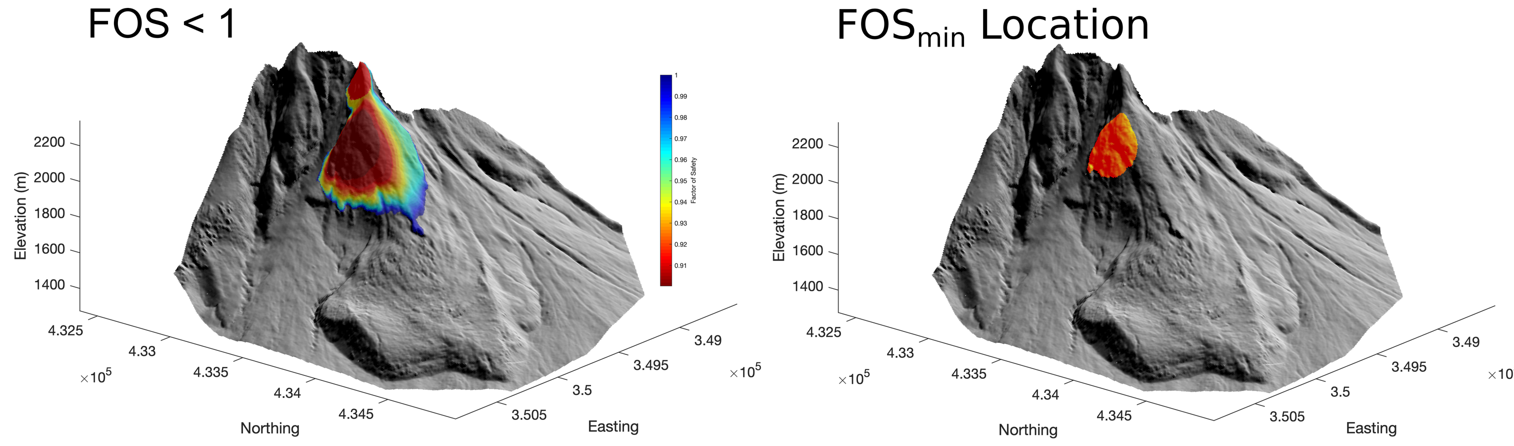
for thousands of potential rotational, spherical slip surfaces.
A FOS < 1 indicates instability. FOS_{min} is the lowest FOS found for the DEM

Can Scoops3D Identify 2014 Collapse?



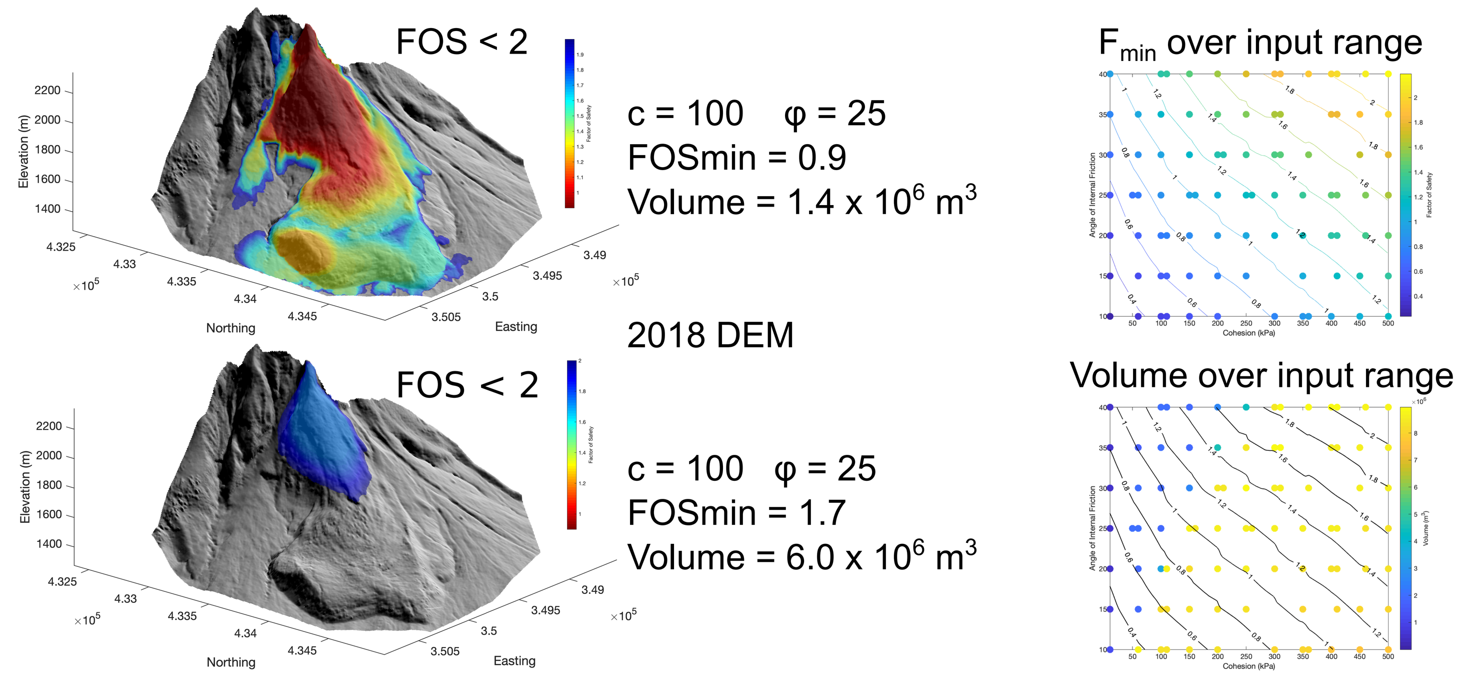
FOS_{min} = 0.87 Volume = 2 x 10^6 m^3

What is the current hazard?



FOS_{min} = 0.90 Volume = 1.4 x 10^6 m^3

What is the effect of Material Parameters?



Accurate constraint of material properties is essential for assessing the FOS of a failure surface. However, the location and volume of the surface where FOS_{min} occurs is not strongly affected by the material properties.

Conclusions

- For the 2014 DEM:
  - The initial 2014 collapse location has FOS < 1
  - The FOS_{min} is located in material that collapsed
  - The FOS_{min} volume is similar to observed collapse volumes
- For the 2018 DEM:
  - A large region of potential instability still exists
  - The potential collapse size is similar to that from earlier periods of active lava effusion
  - The FOS_{min} is located in the same region as in 2014
- Accurate constraint of material properties is needed to determine if FOS < 1 for potential failure surfaces
- The location and volume of the FOS_{min} can still be reasonably assessed without well-constrained material properties
- Application of Scoops3D with SfM-generated DEMs presents a means to assess passive collapse hazards in near-real-time during an eruption

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