



A Cosmos in Motion: From the Primordial Explosion to the Present and Future Dynamics of the Universe and Planets

CDD 2025



Towards near-real time monitoring of volcanic deformation and lava flow using Capella SAR images

Arthur Hauck, Raphaël Grandin, Fidel Costa

2025-05-22

in collaboration with

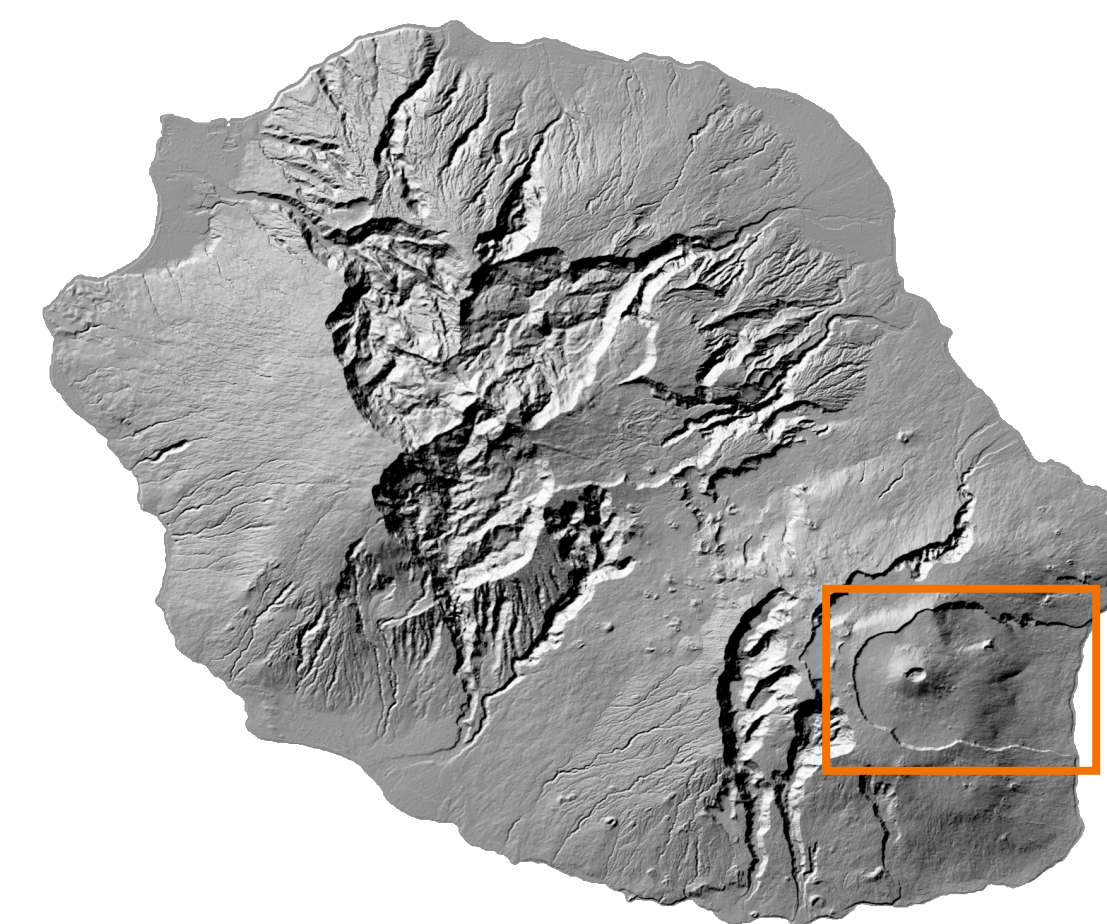
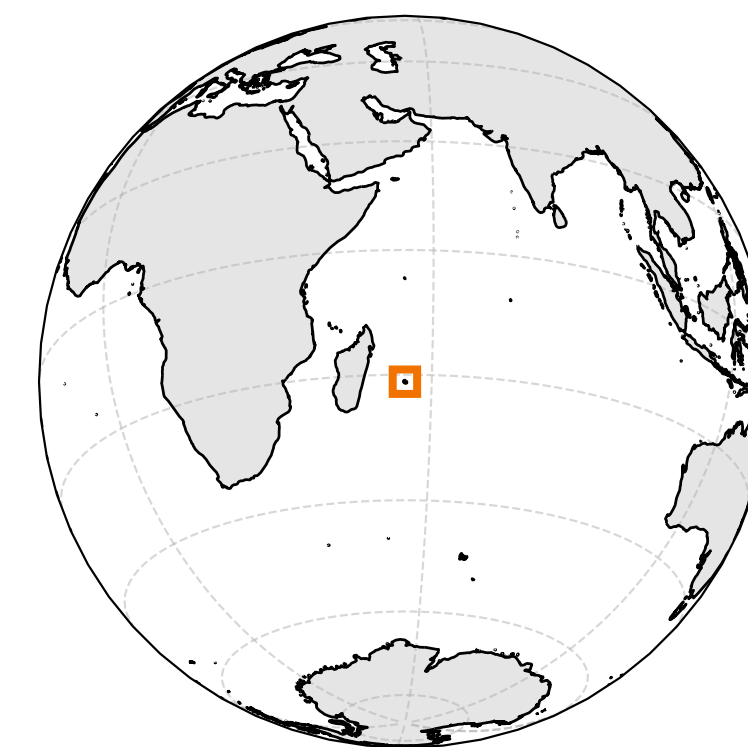
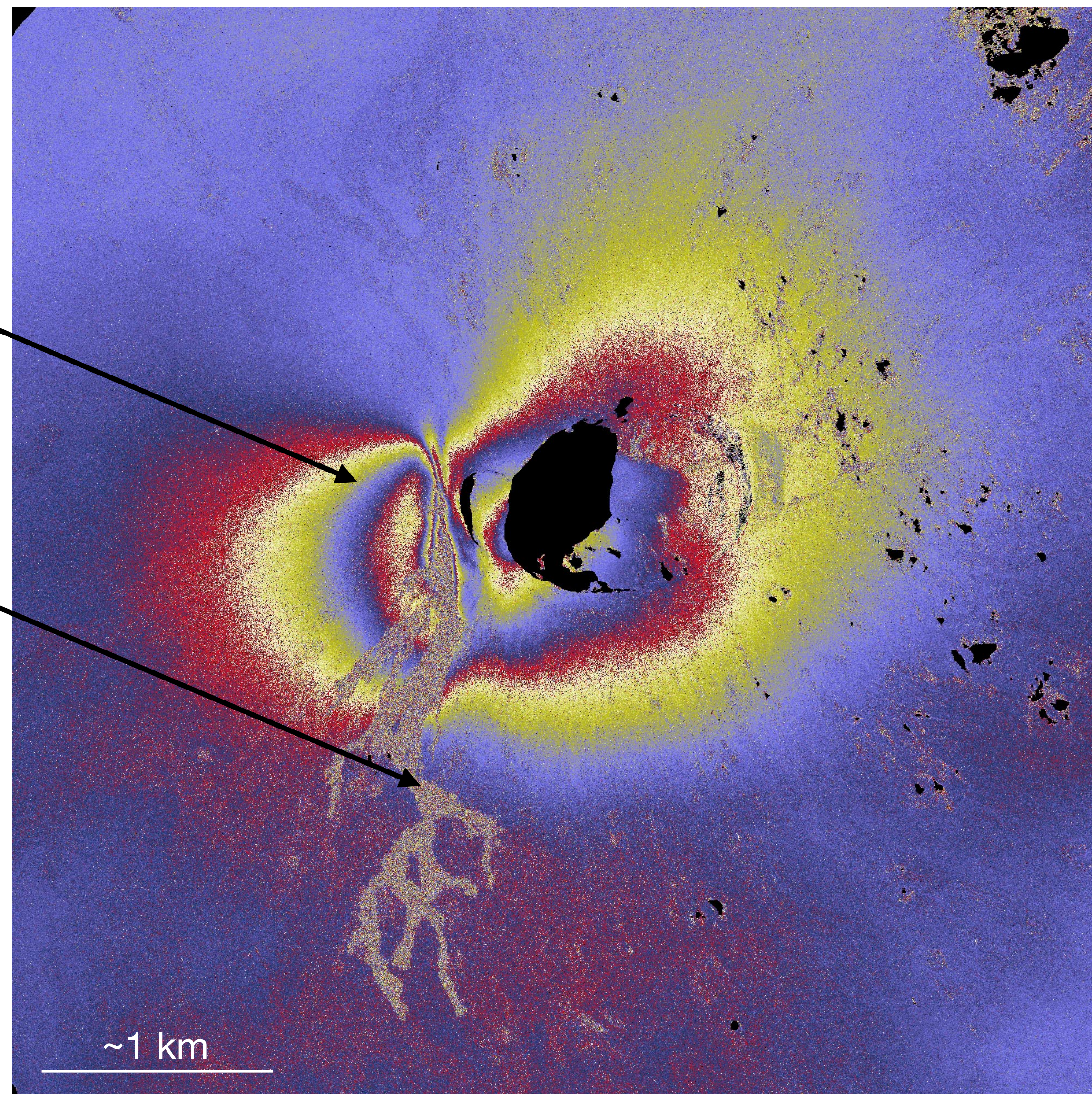
Aline Peltier, Magdalena Oryaëlle Chevrel, Nicolas Villeneuve, Jean-Luc Froger
Jérémy Anger, Roland Akiki, Carlo de Franchis, Thibaud Ehret, Gabriele Facciolo



Why not use InSAR?

deformation

lava flow

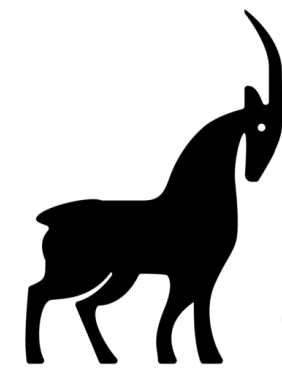
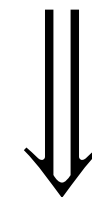


©Jean-Luc Froger
ALOS-2 Spotlight interferogram
Piton de la Fournaise, 2015

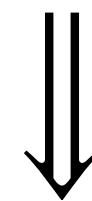
Problem

InSAR: revisit time of ~10 days

Near-real time ($\lesssim 1$ day) observations required to detect changes in the course of an eruption



Capella Space

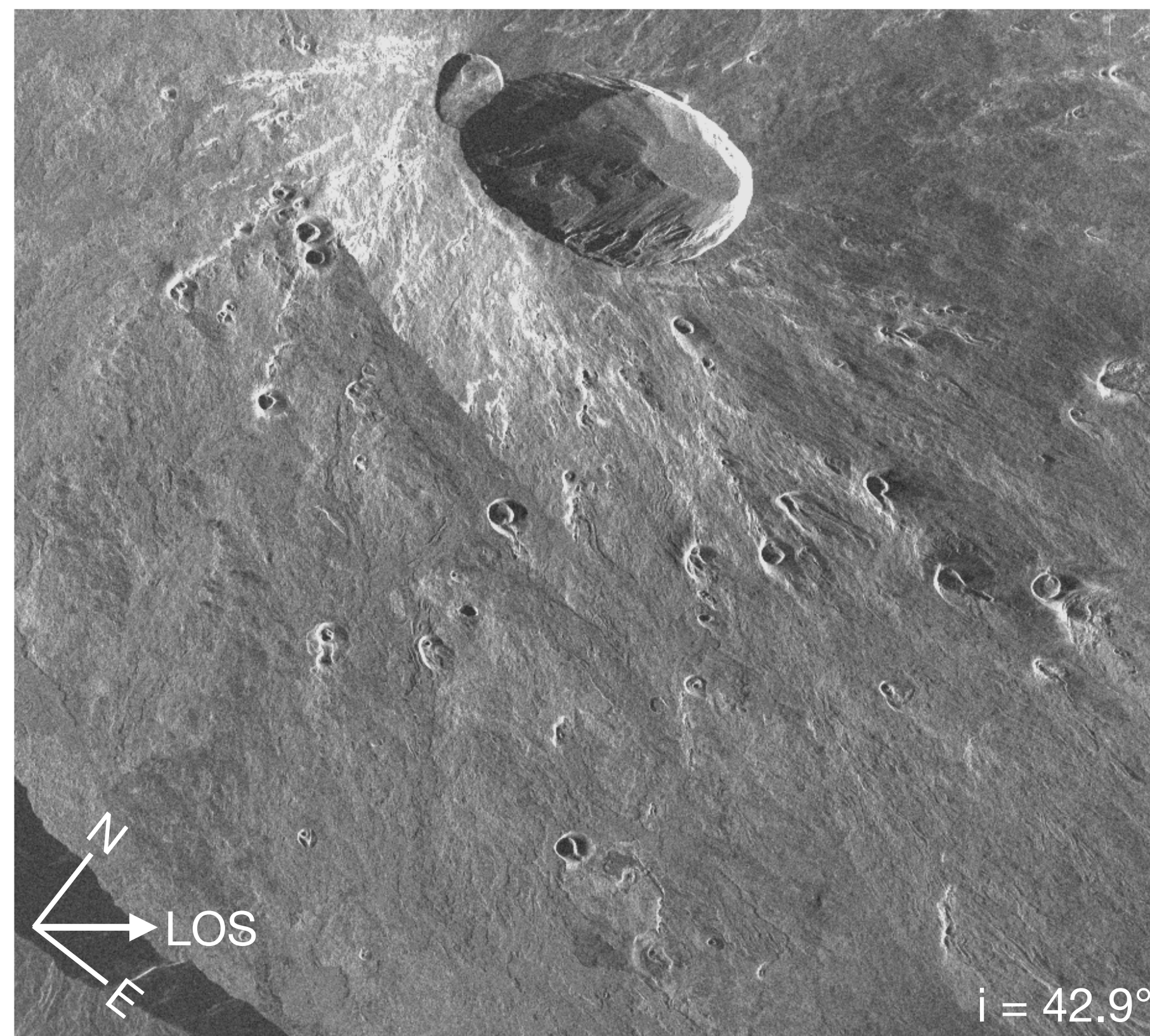


No stability of the acquisition geometry

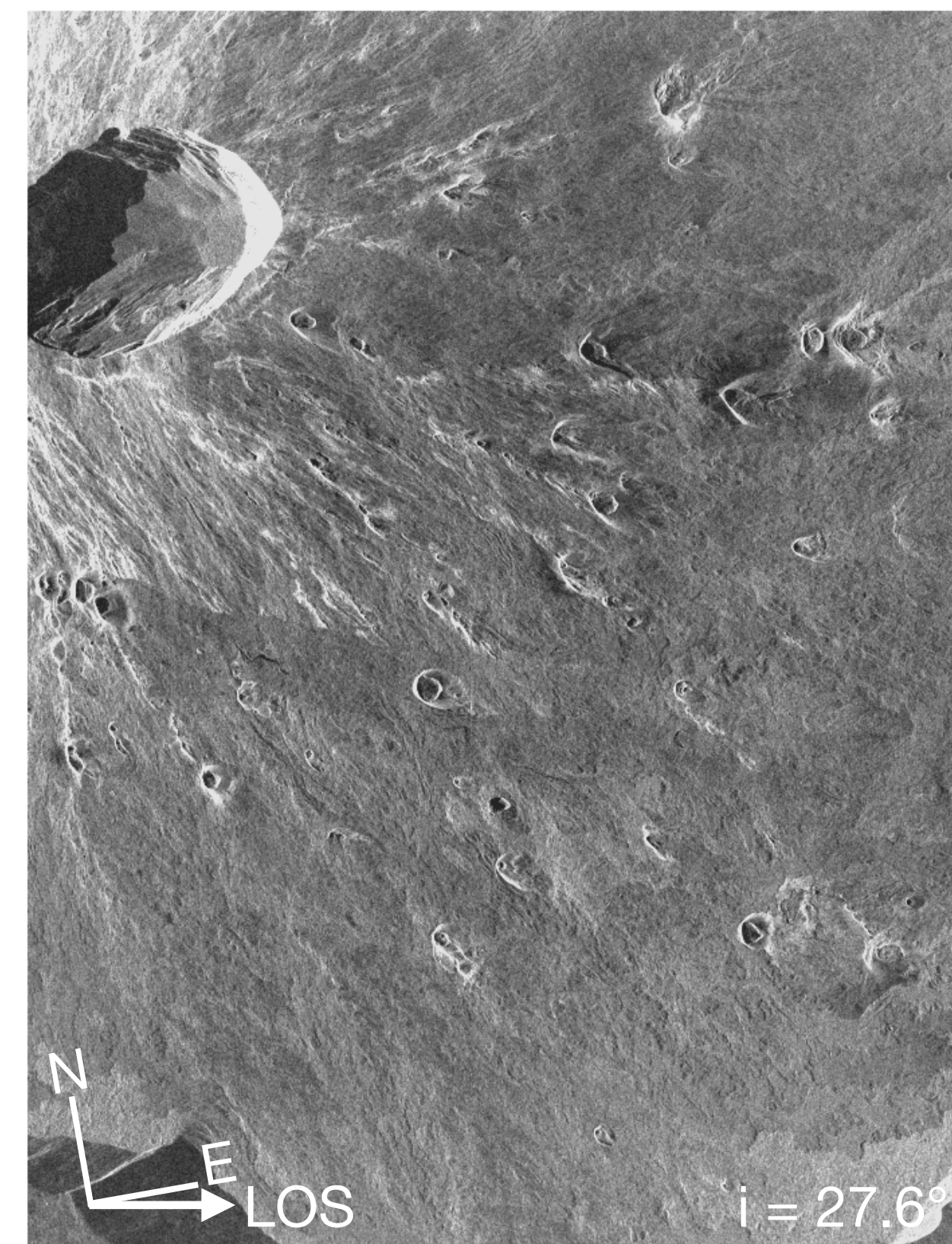
Changing geometry



1 October



2 October



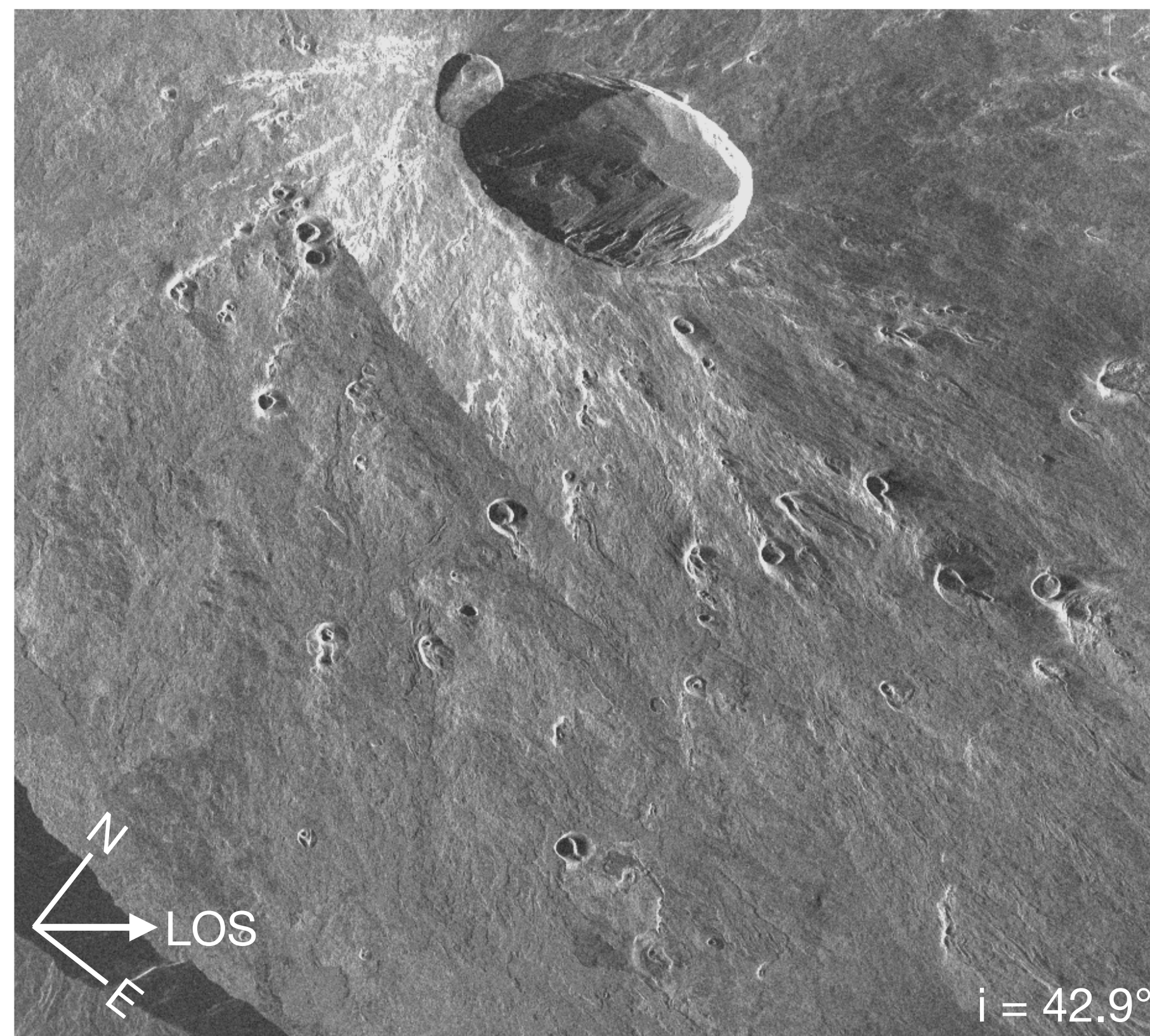
4 October 2022

Piton de la Fournaise
Sept.-Oct. 2022 eruption

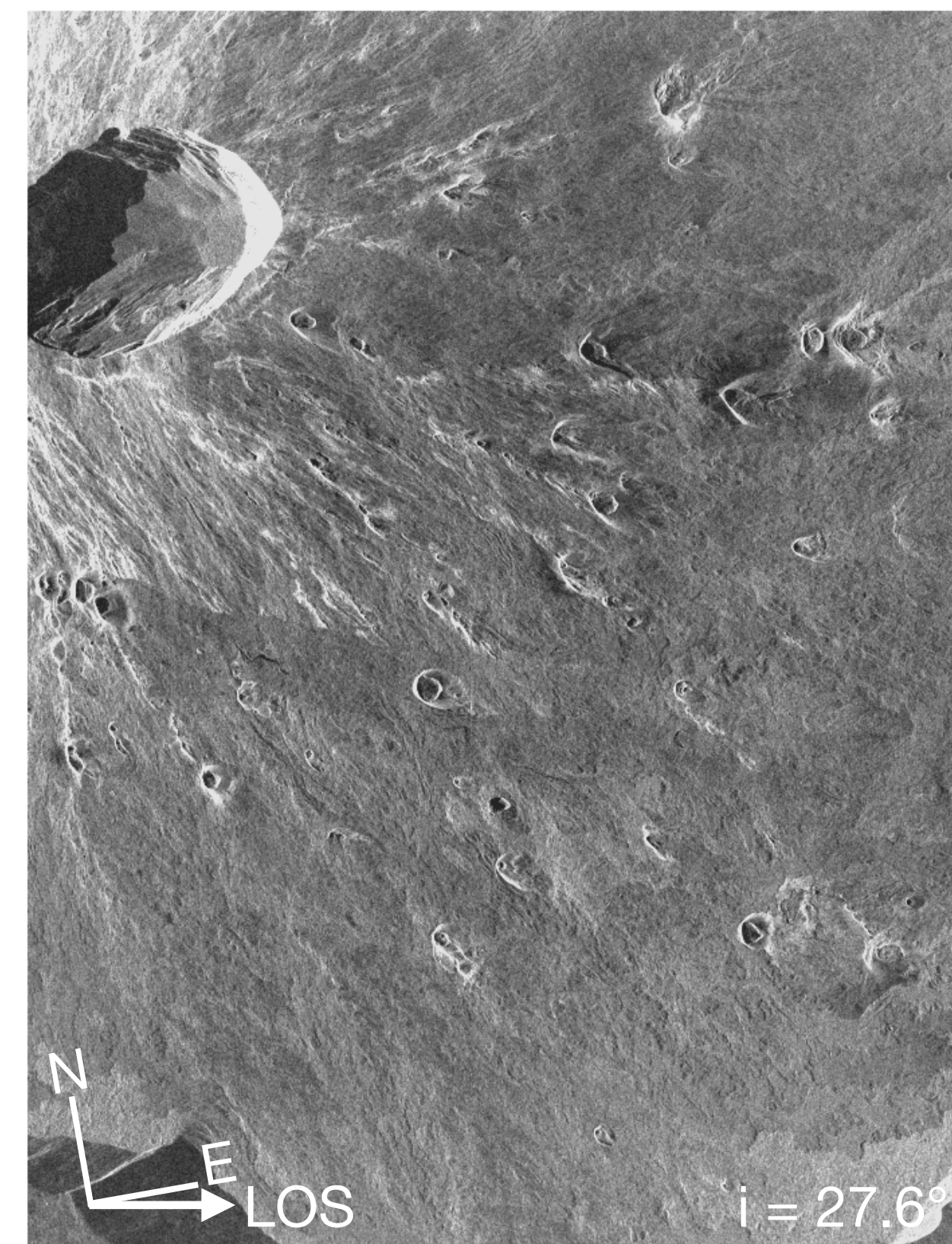
Changing geometry



1 October



2 October



4 October 2022

?

Δ_{1-2}

?

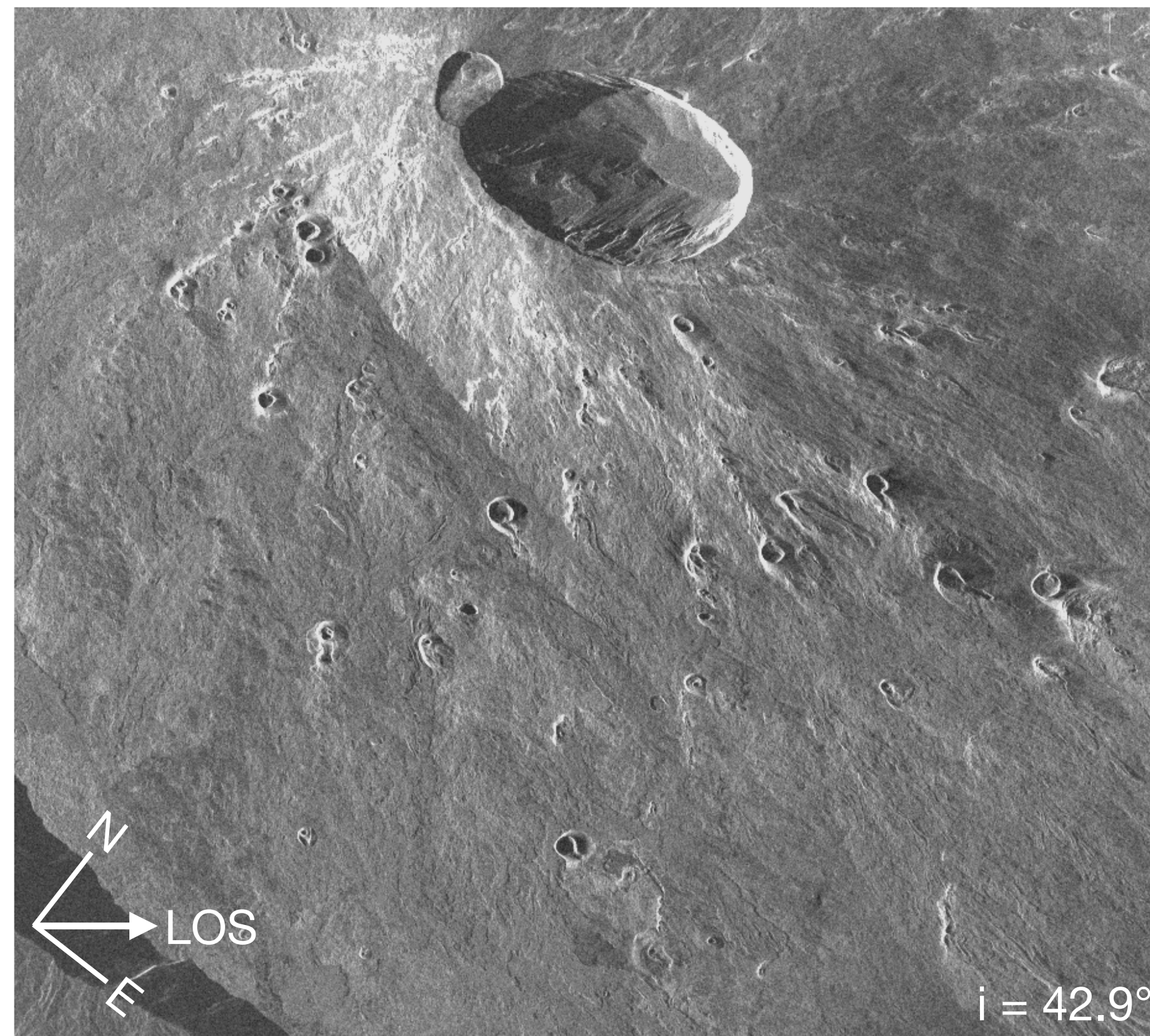
Δ_{2-4}

Piton de la Fournaise
Sept.-Oct. 2022 eruption

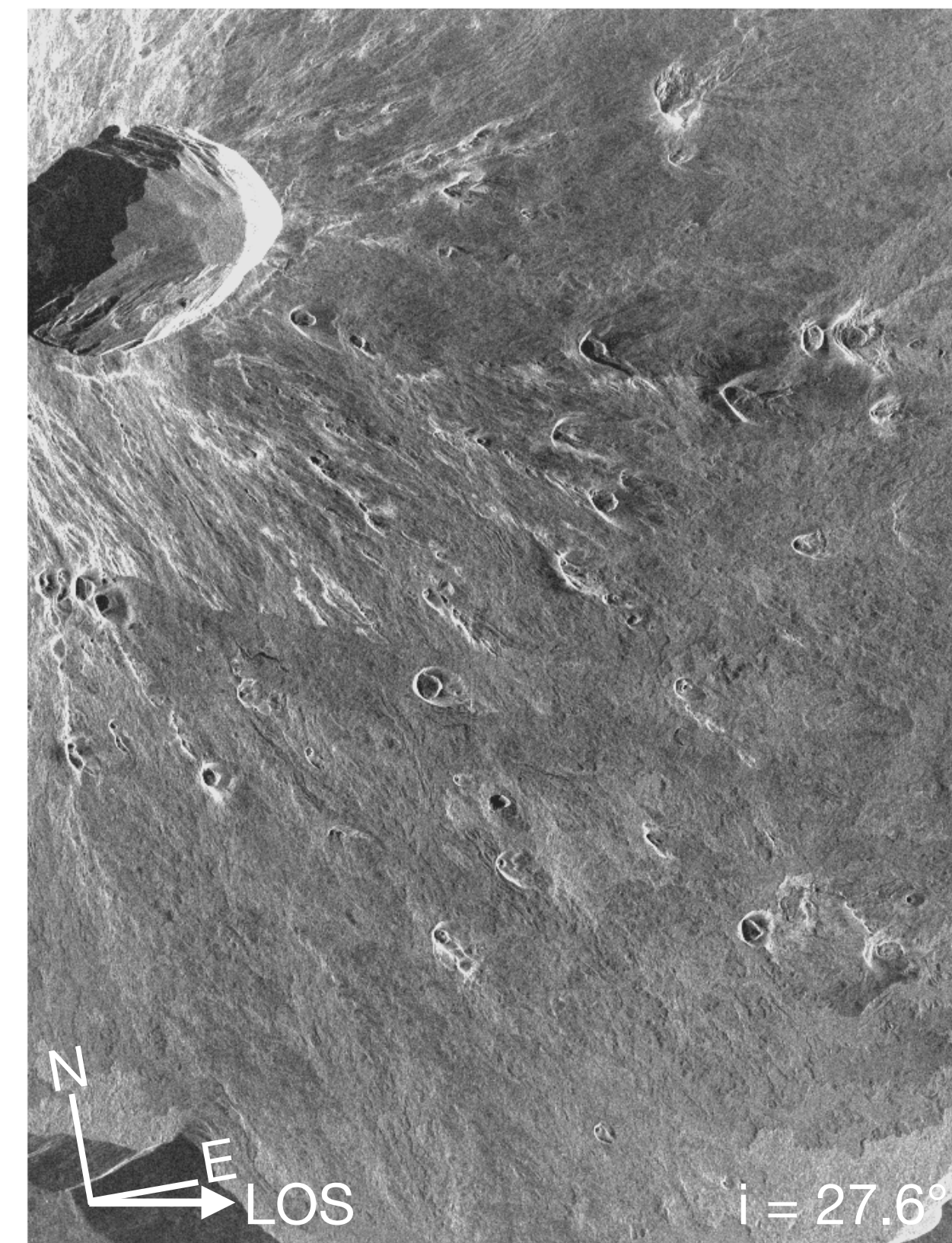
Changing geometry



1 October



2 October



4 October 2022

$\Delta_{1\text{-DEM}}$

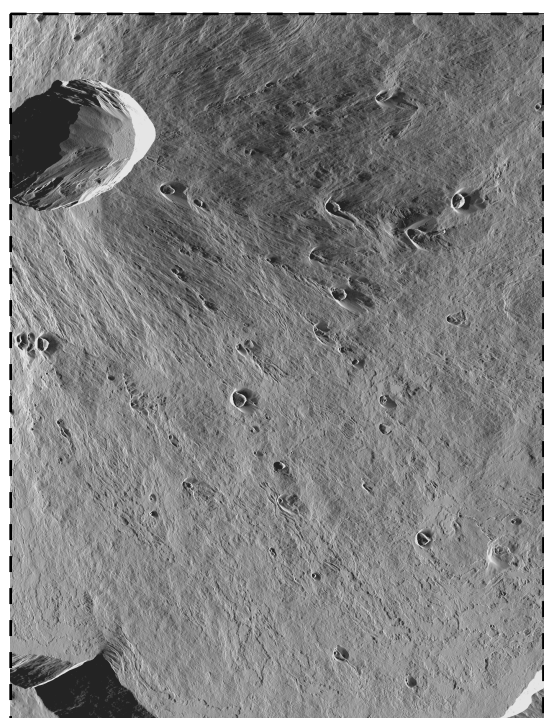
$\Delta_{2\text{-DEM}}$

$\Delta_{4\text{-DEM}}$

DEM

Piton de la Fournaise
Sept.-Oct. 2022 eruption

Pre-eruptive synthetics



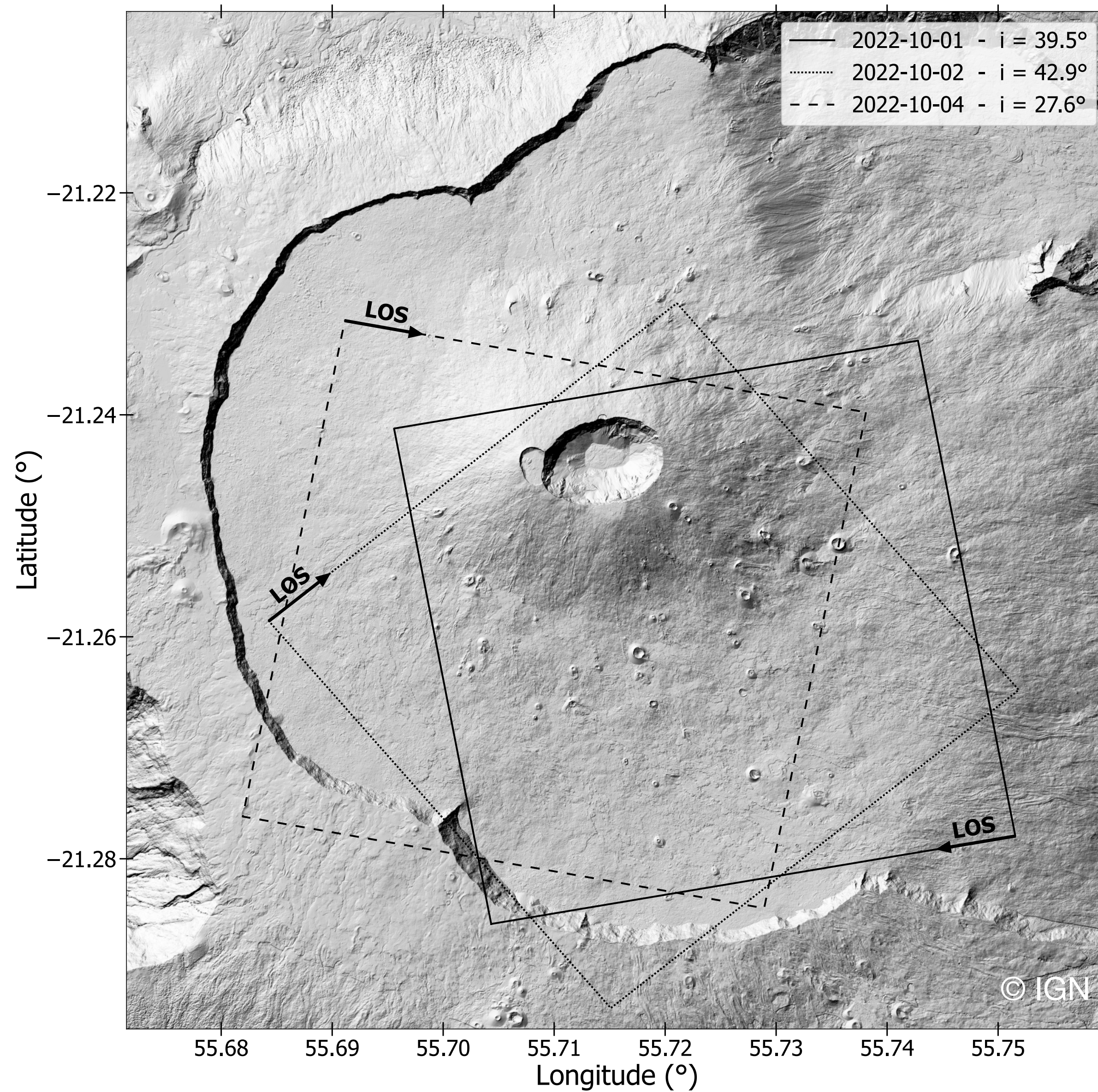
2018

Small, 2011



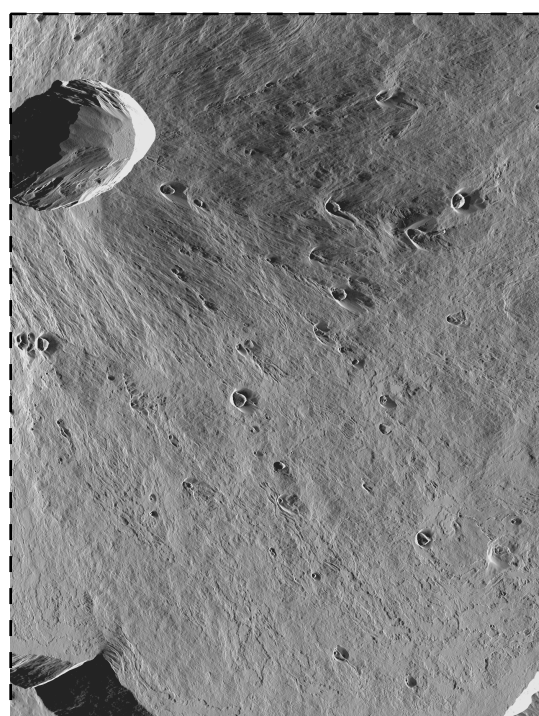
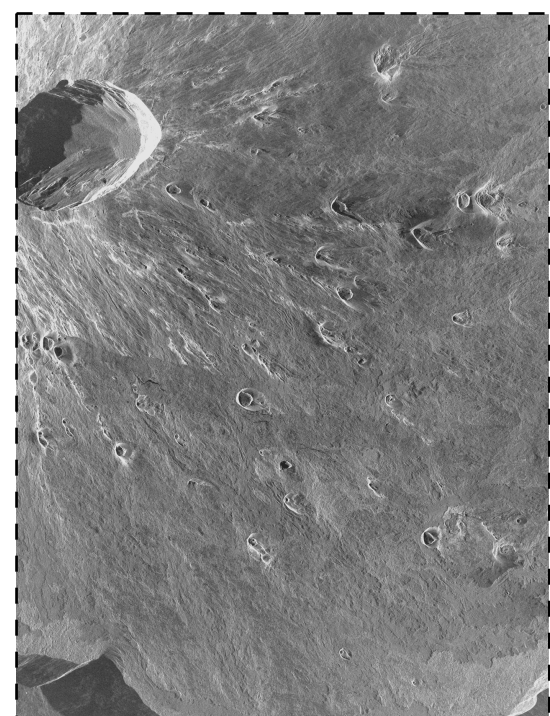
EOS-SAR
Kayros

Pre-eruptive DEM 2018



Co-eruptive images

Pre-eruptive synthetics



2022

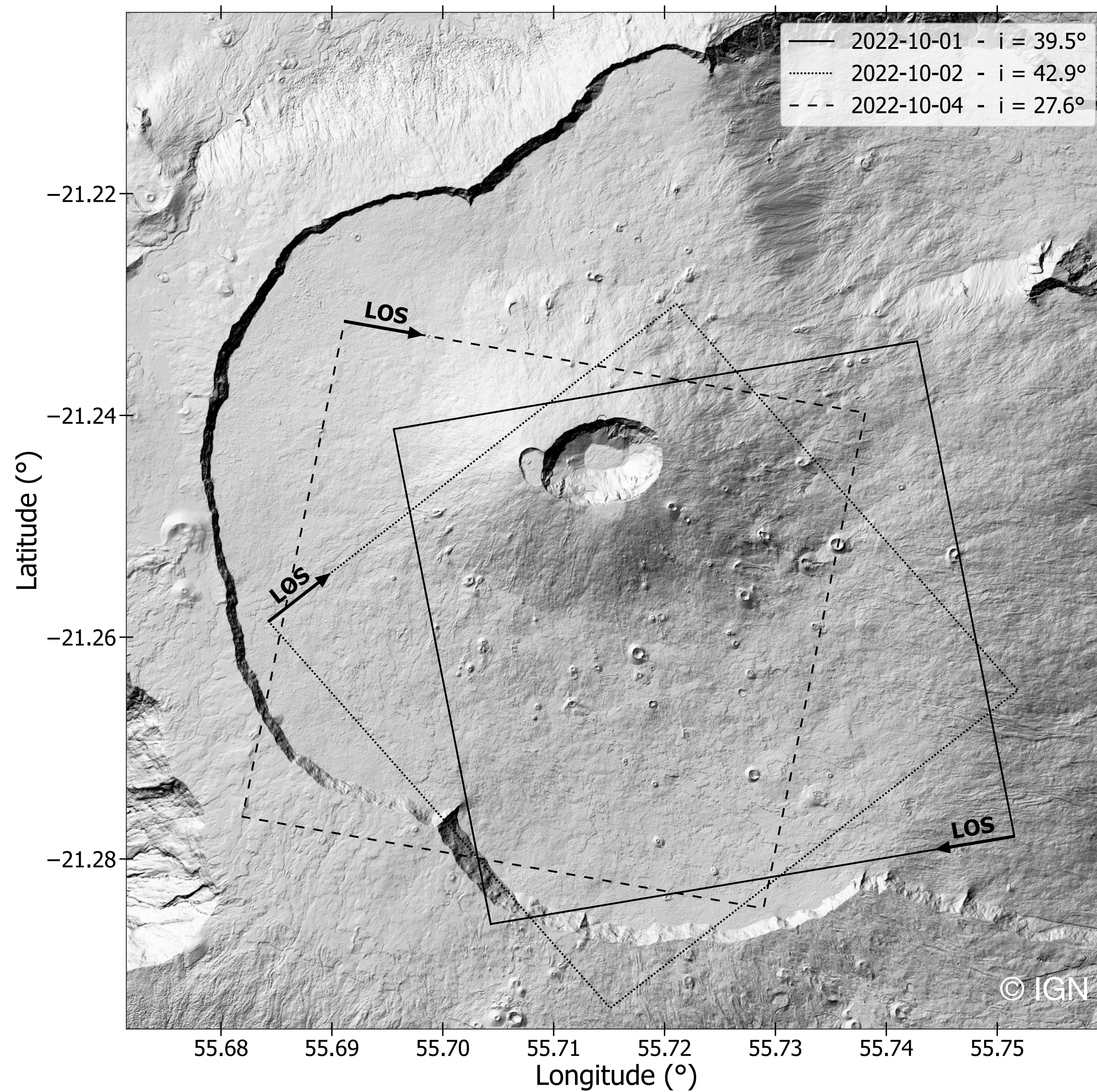
2018

Small, 2011



EOS-SAR
Kayros

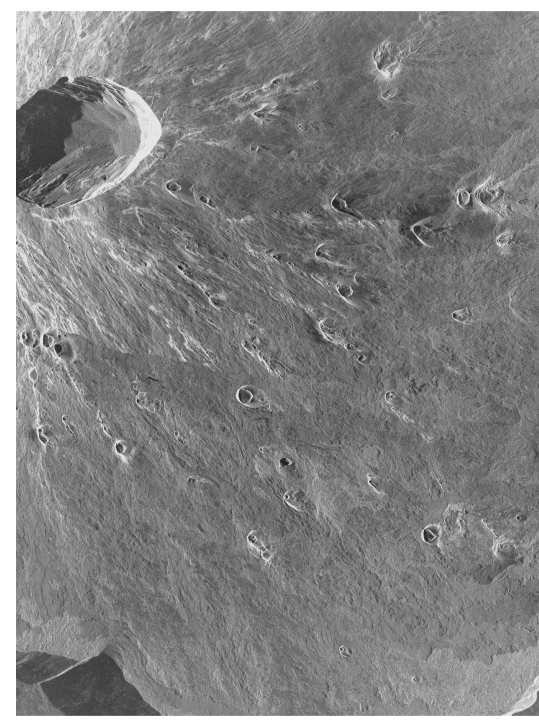
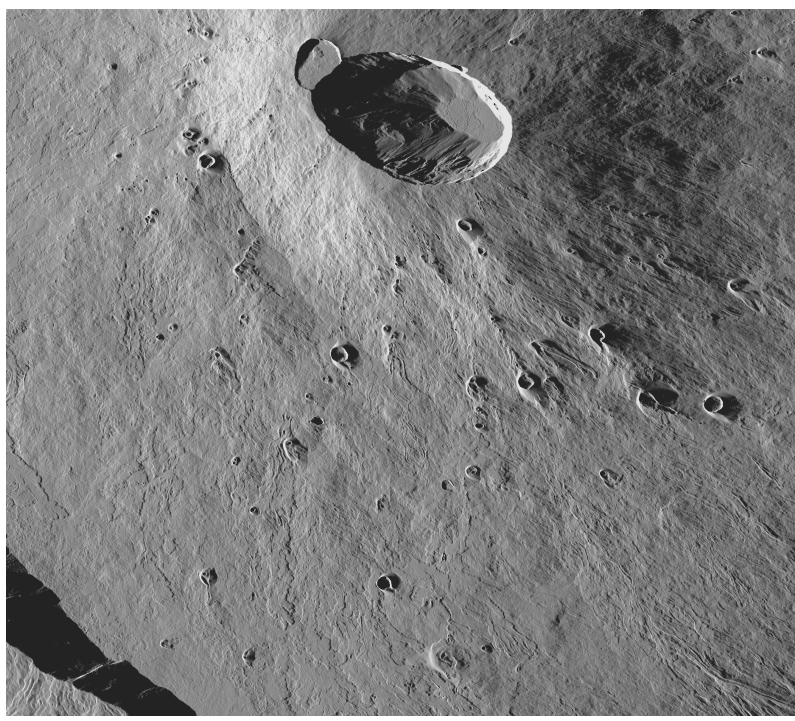
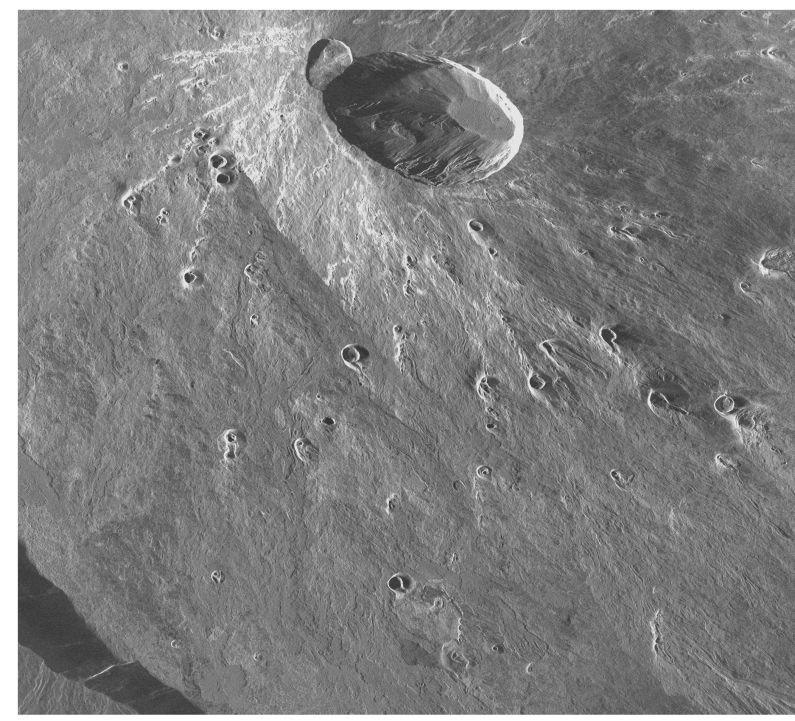
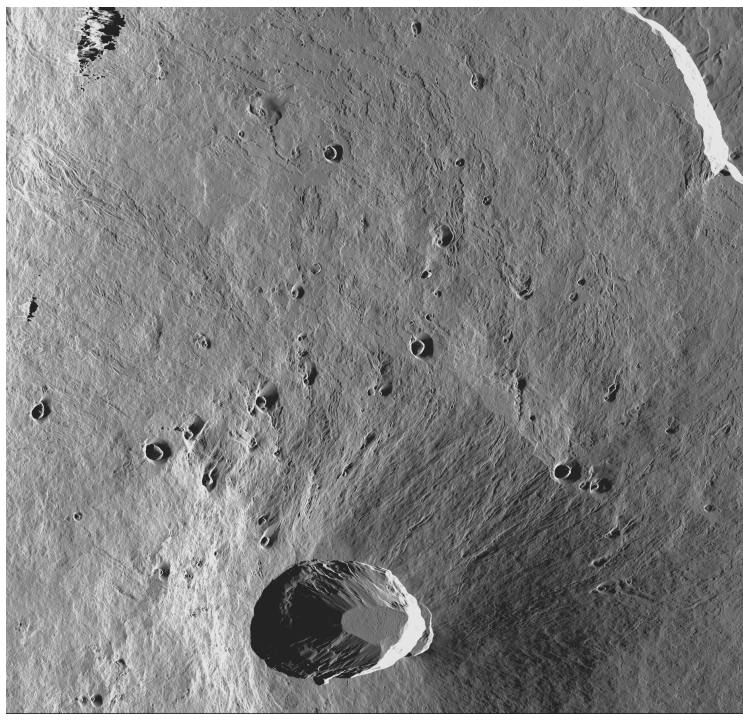
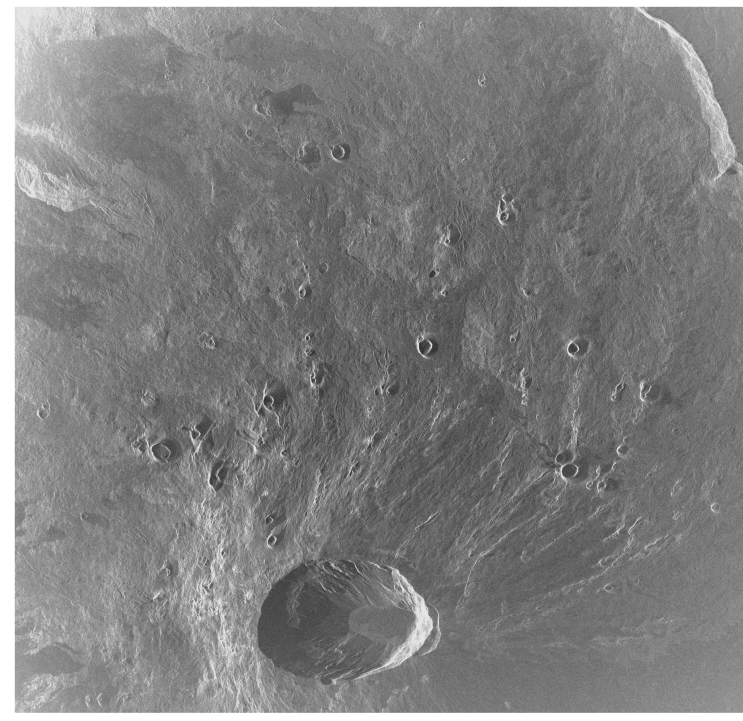
Pre-eruptive DEM 2018





Real

Synthetic



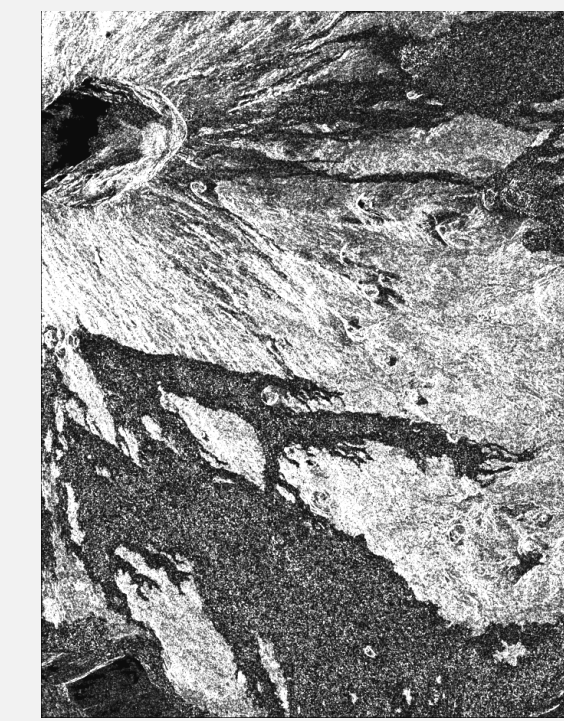
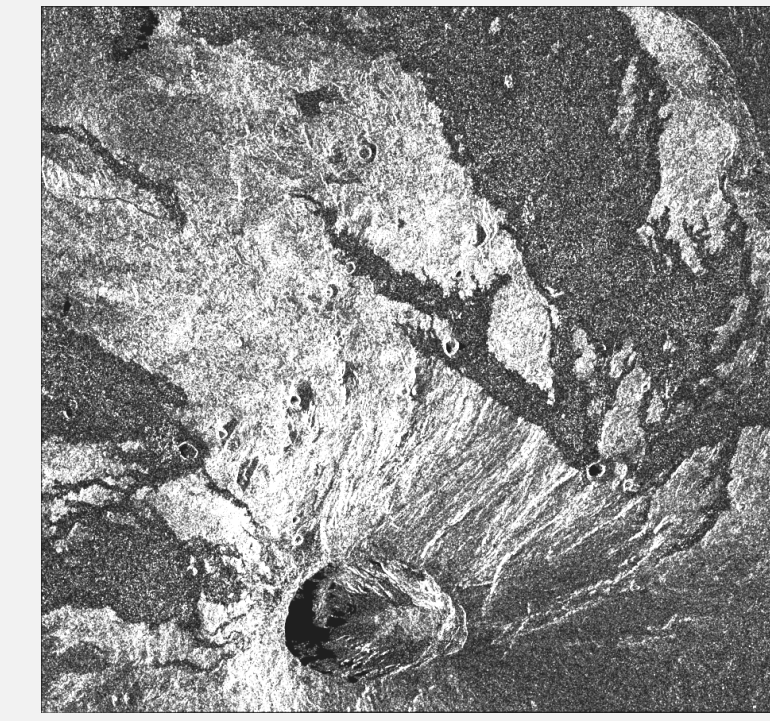
2022

2018

Output 1

Lava flows

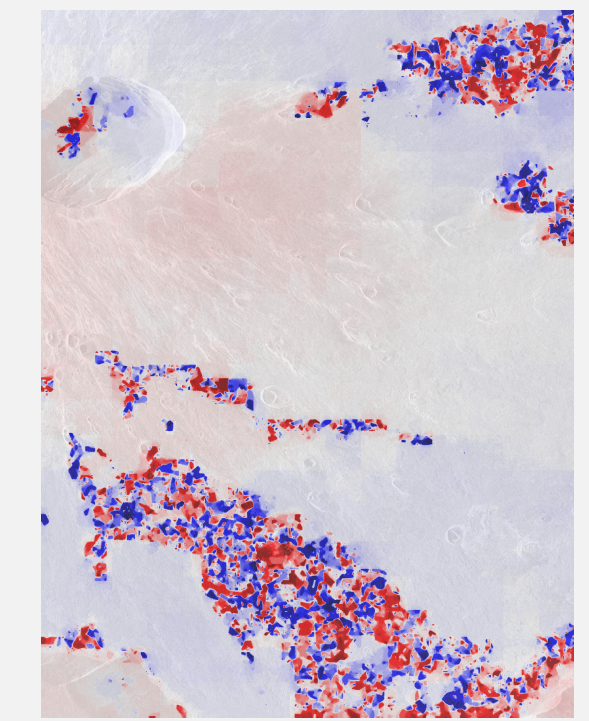
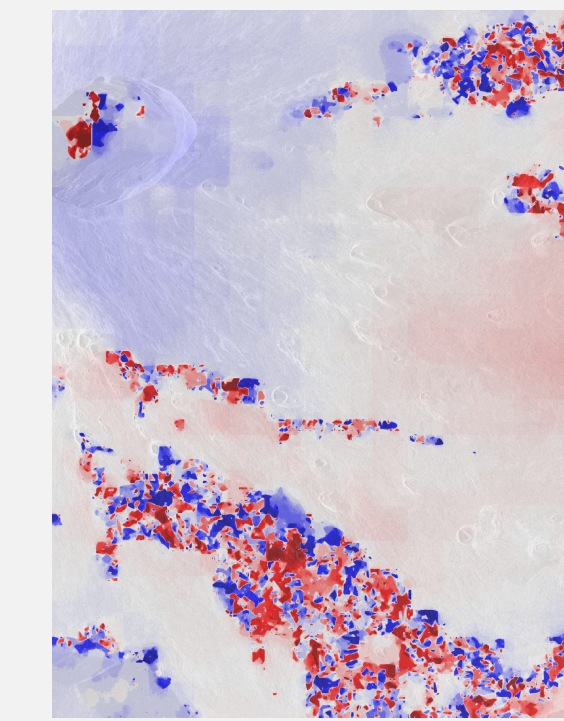
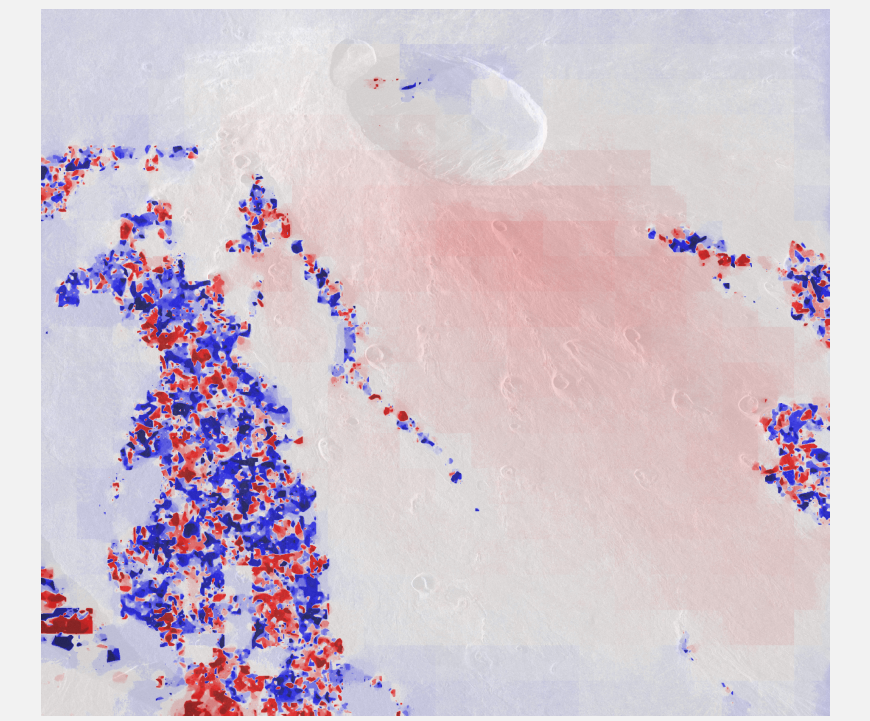
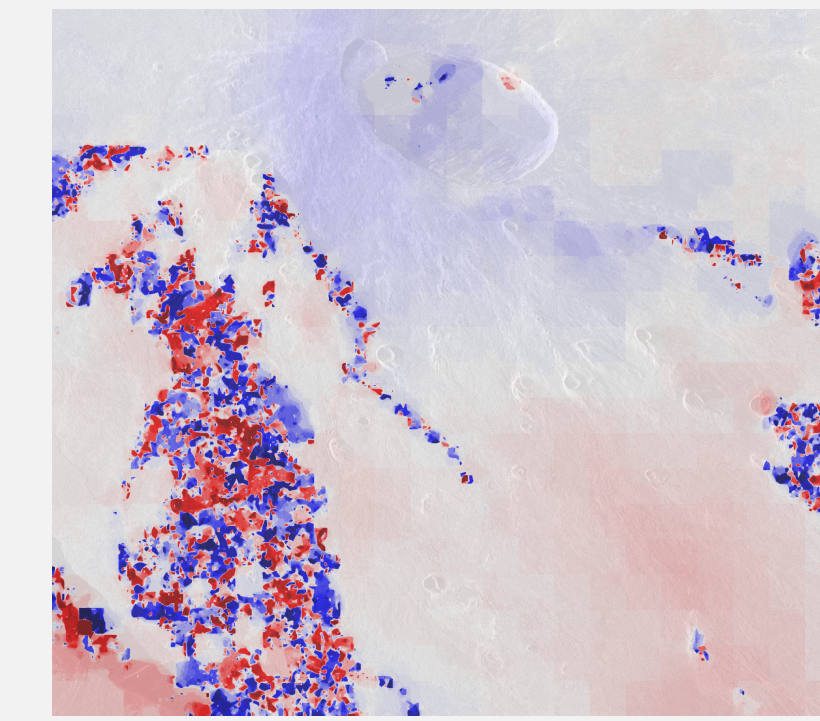
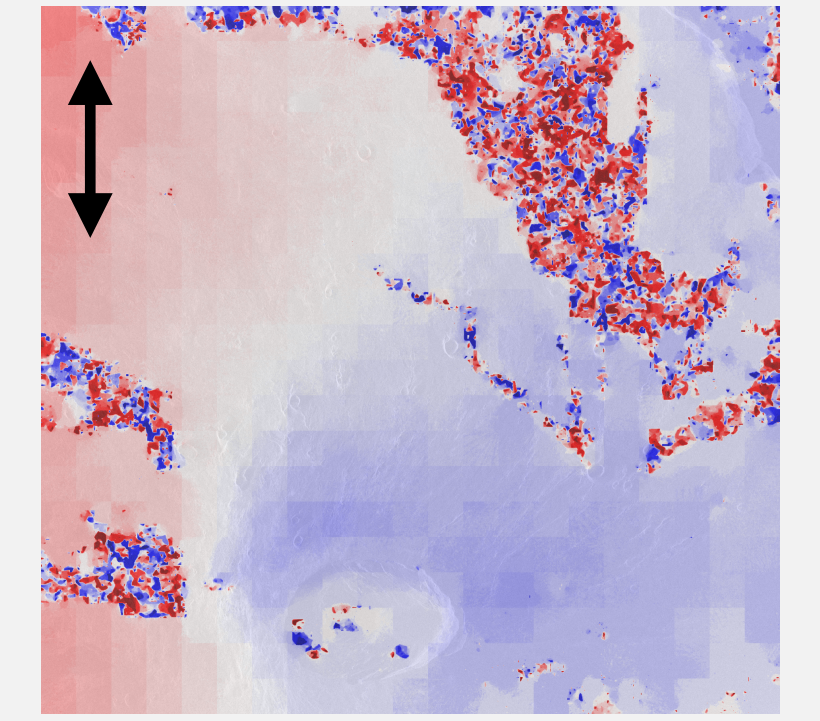
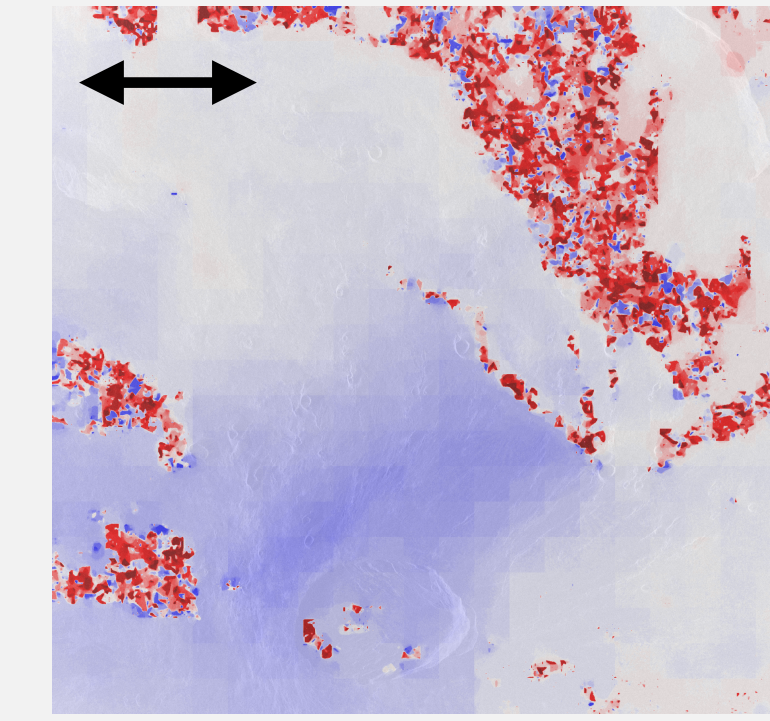
Correlation score



Output 2

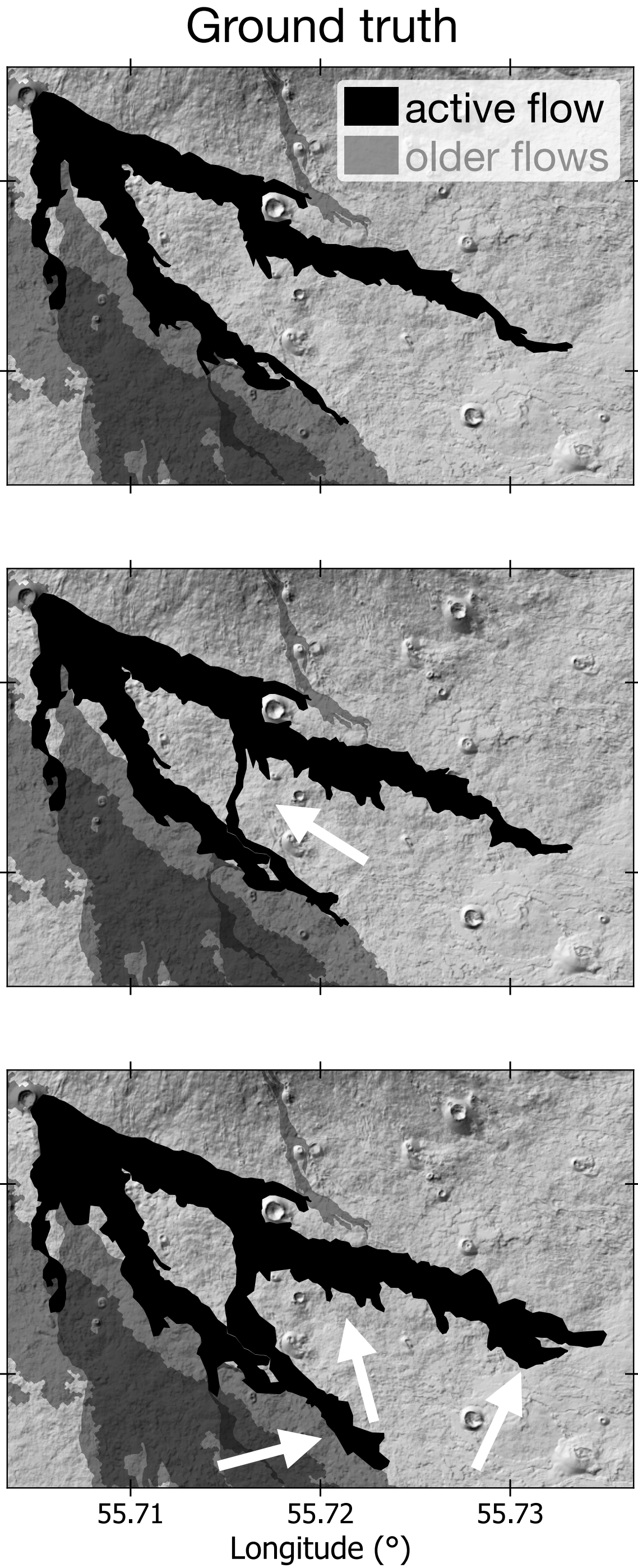
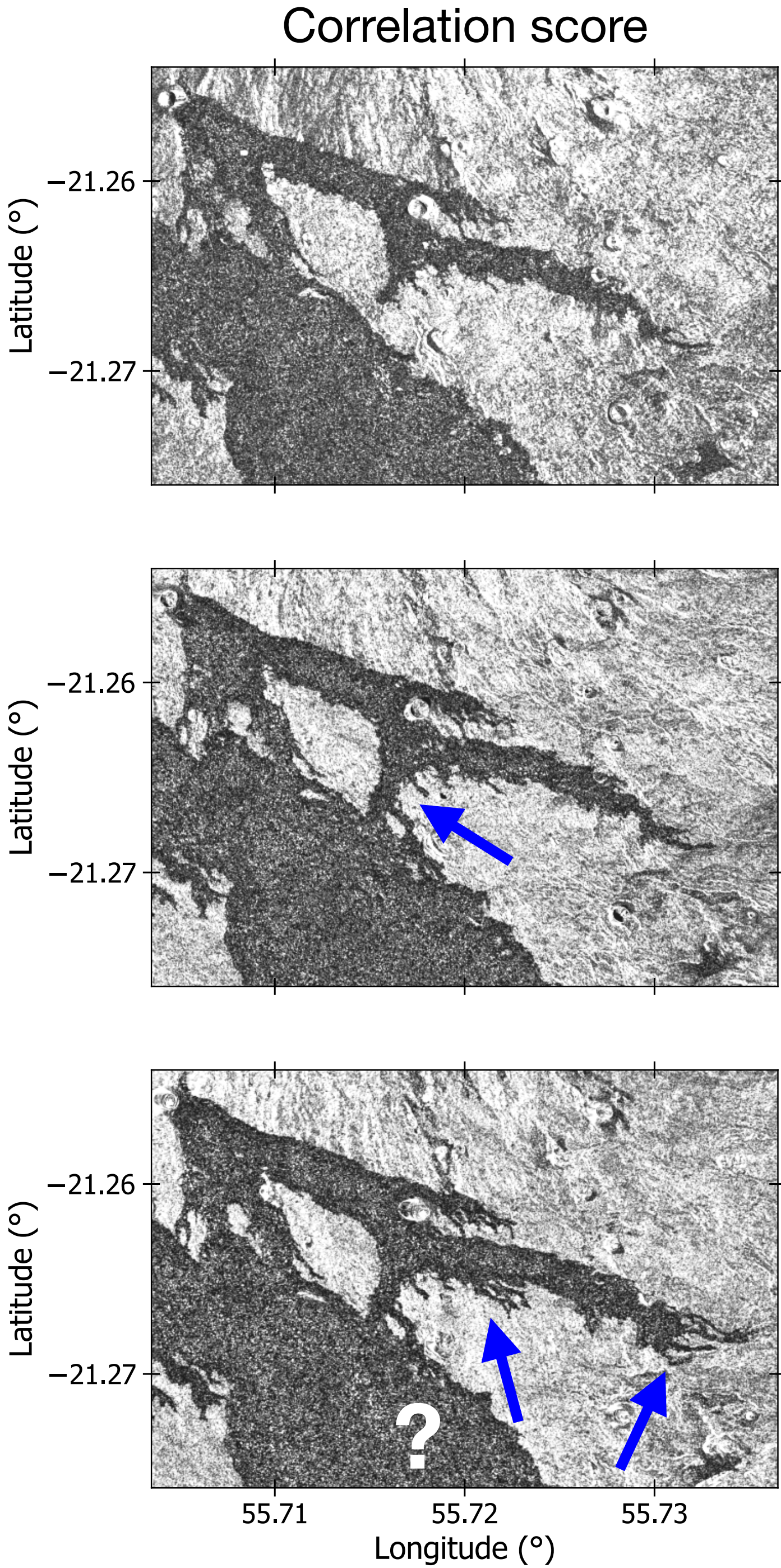
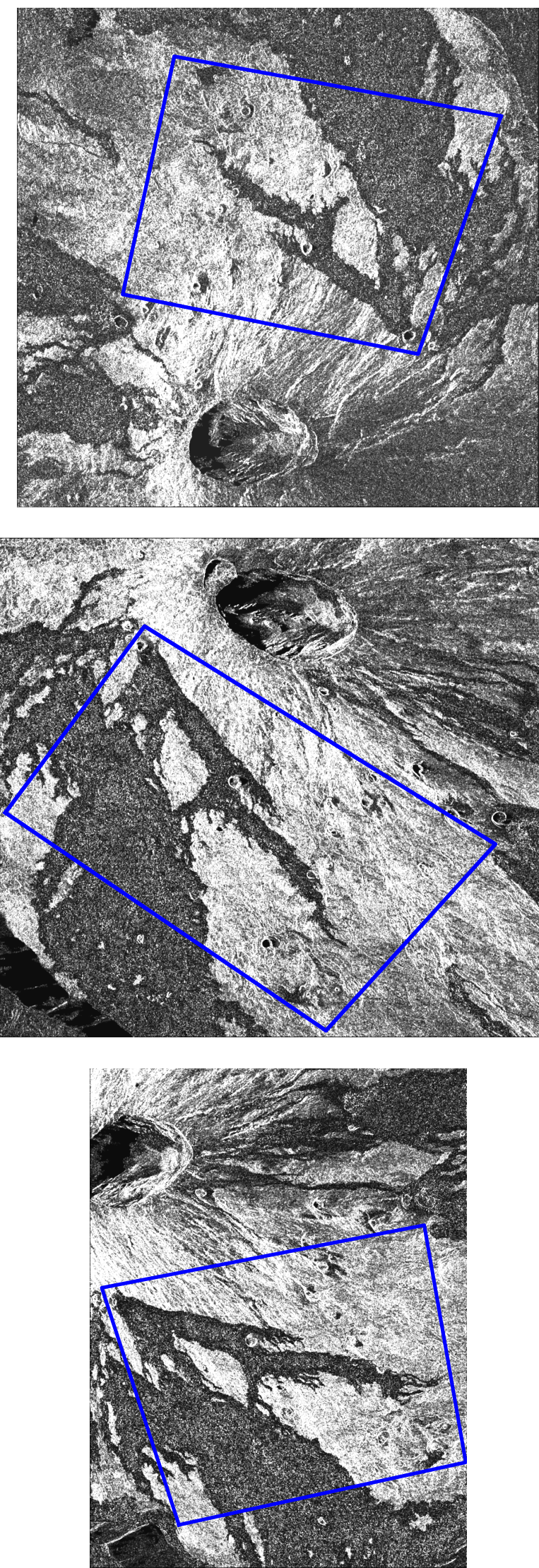
Deformation

Shifts



1. Lava flows

Apr. 2018 DEM



1 October

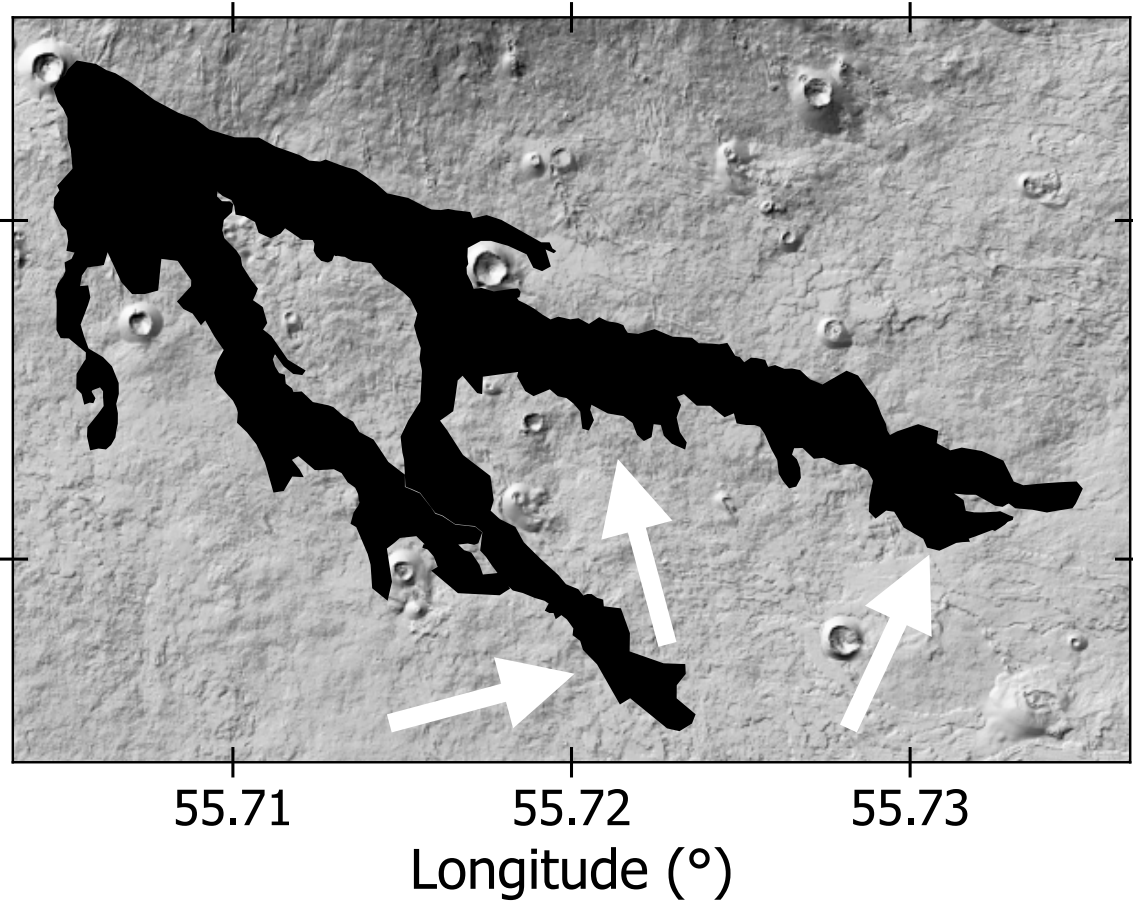
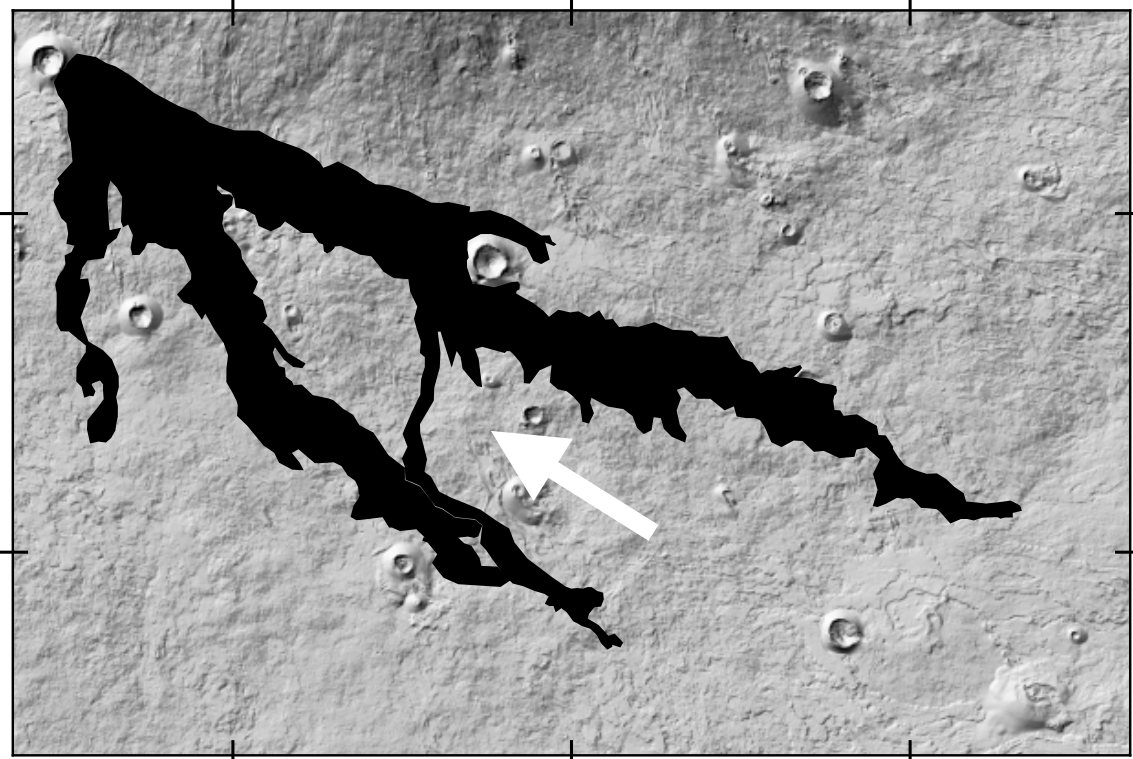
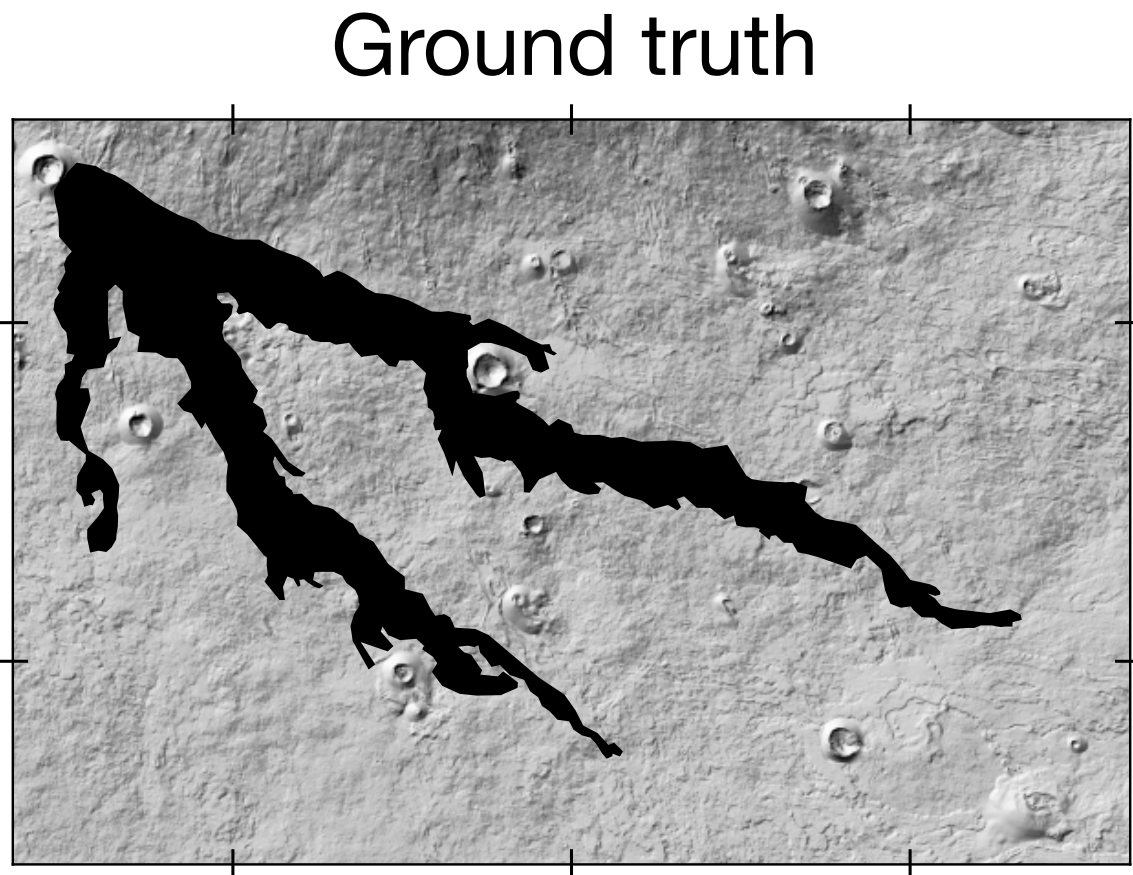
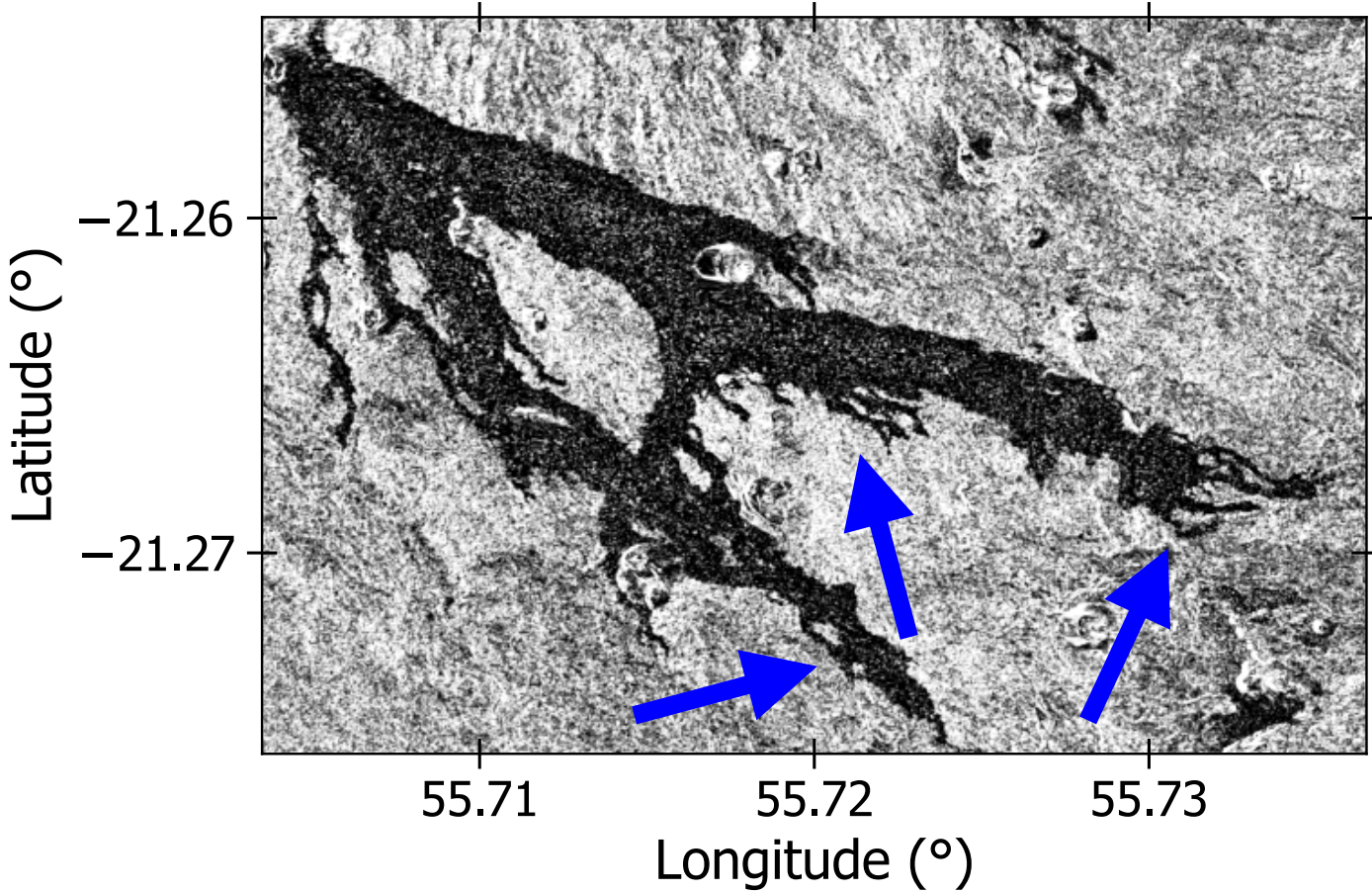
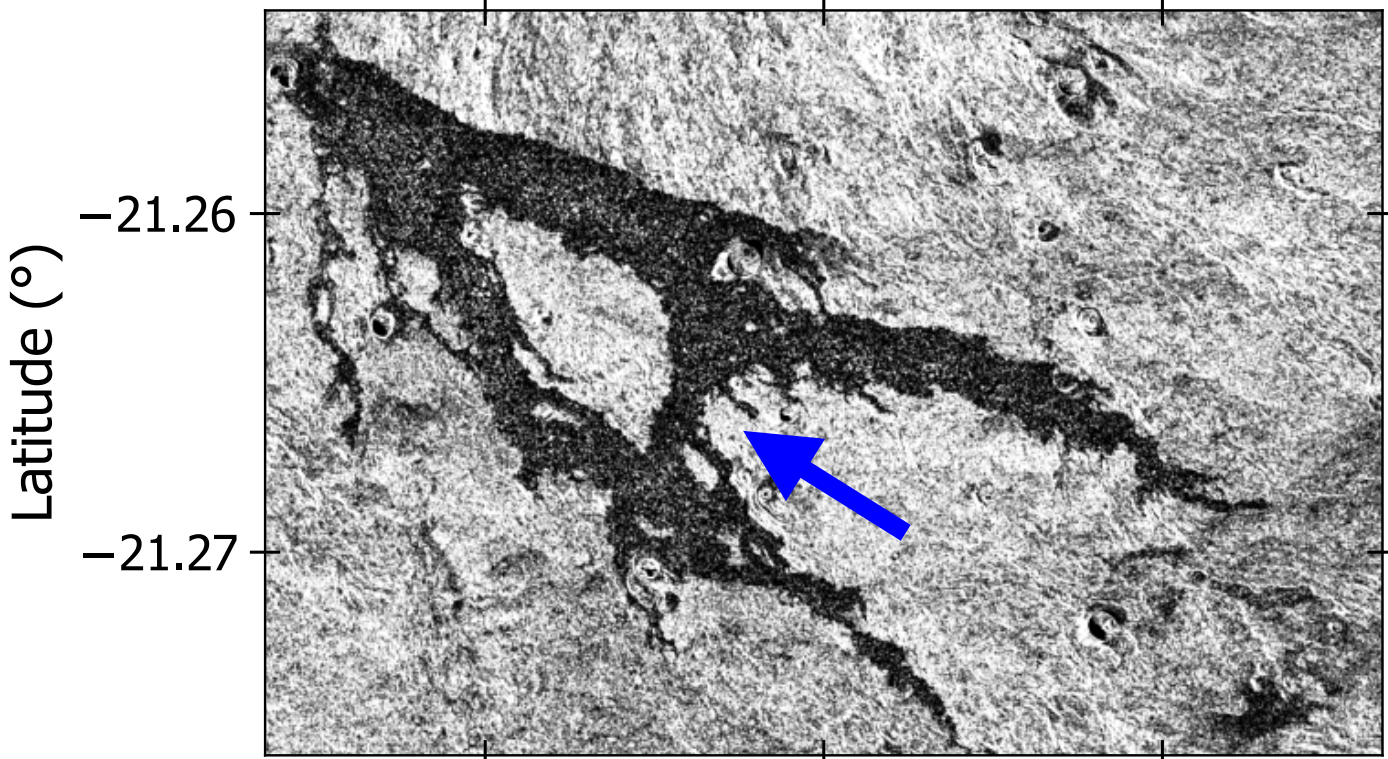
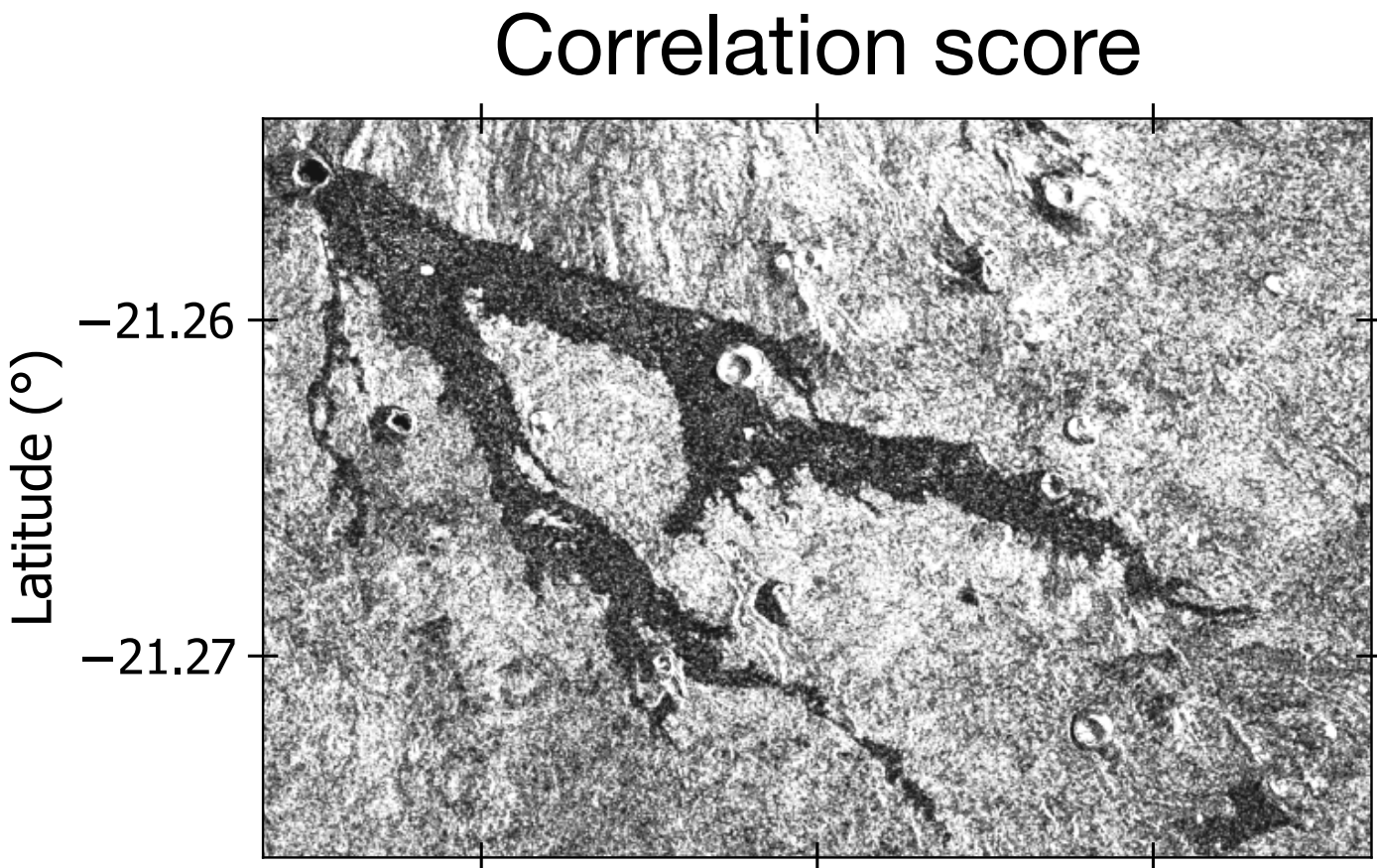
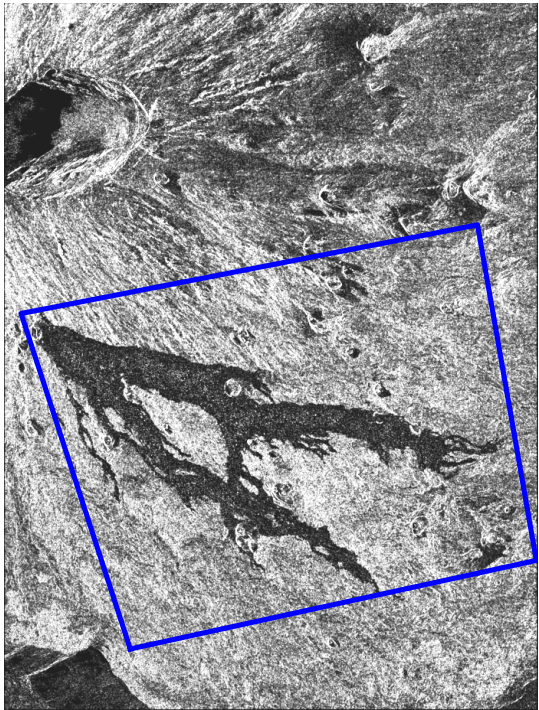
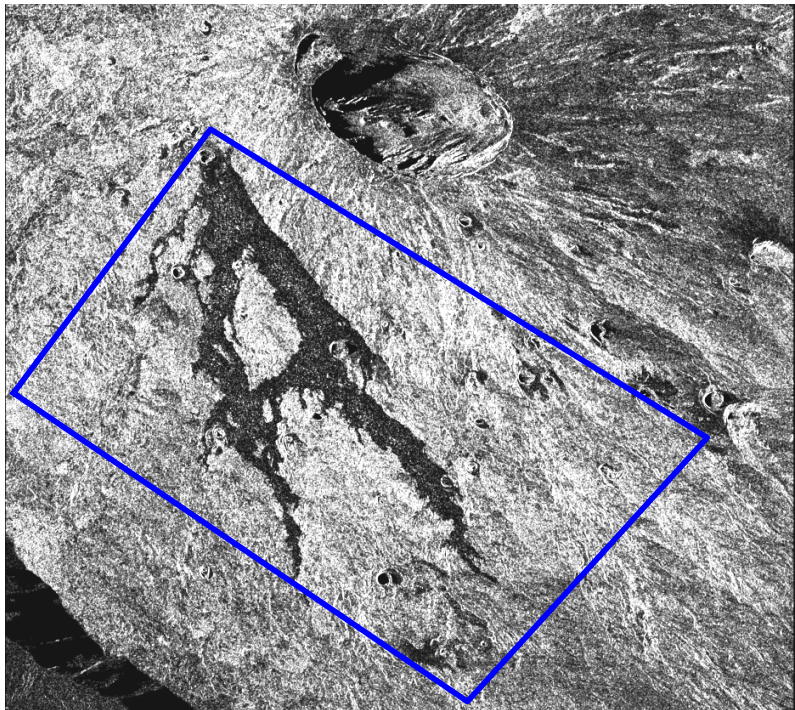
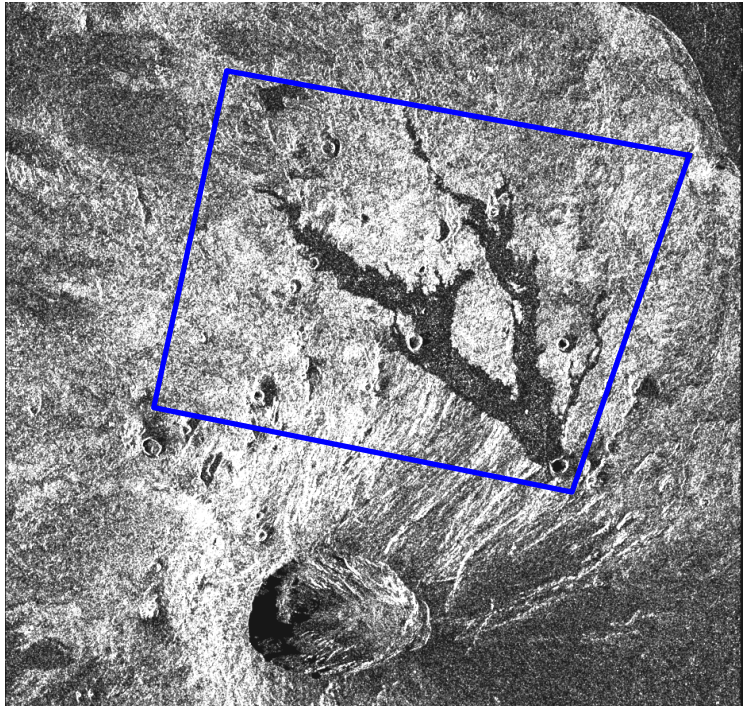
2 October

4 October 2022

Chevrel et al., 2023
from PlanetScope images

1. Lava flows

Feb. 2022 DEM



1 October

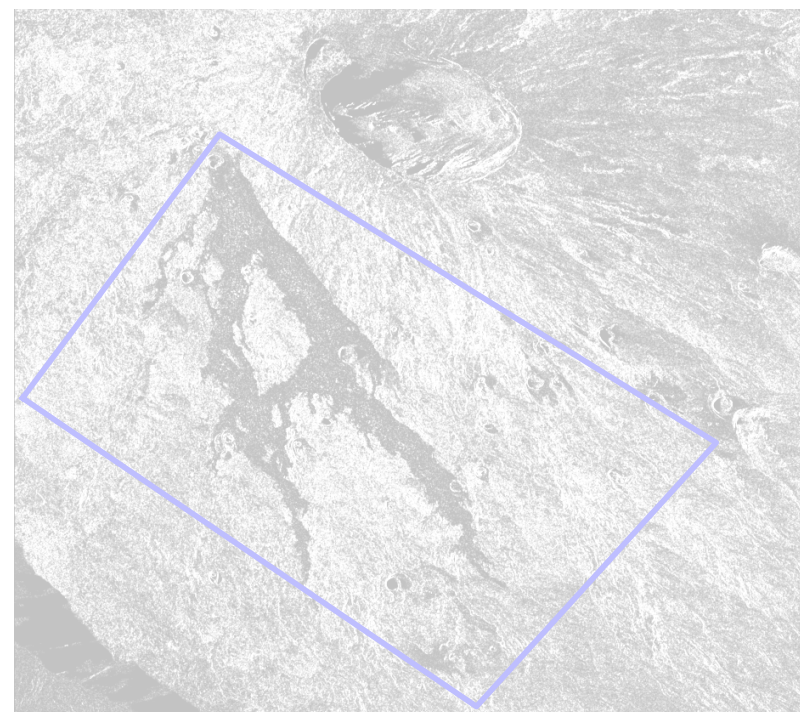
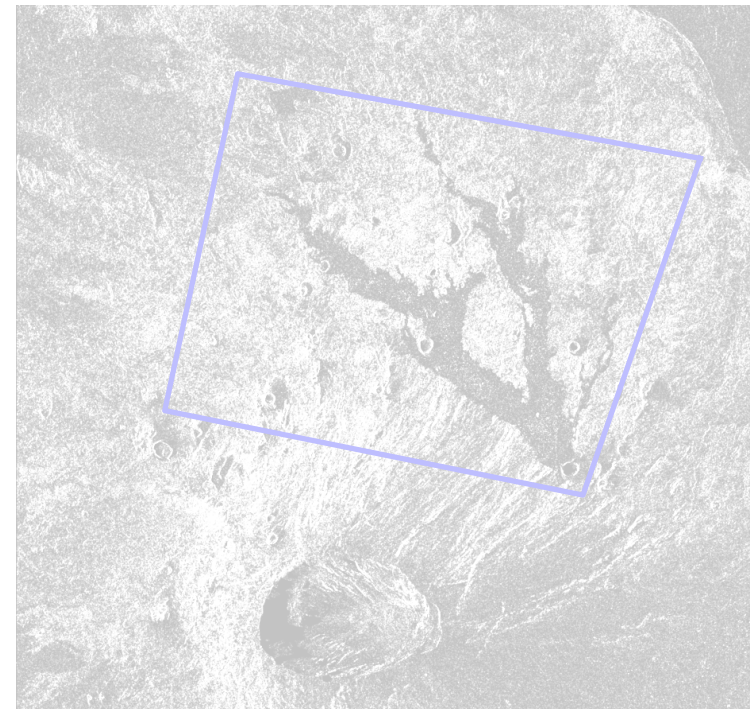
2 October

4 October 2022

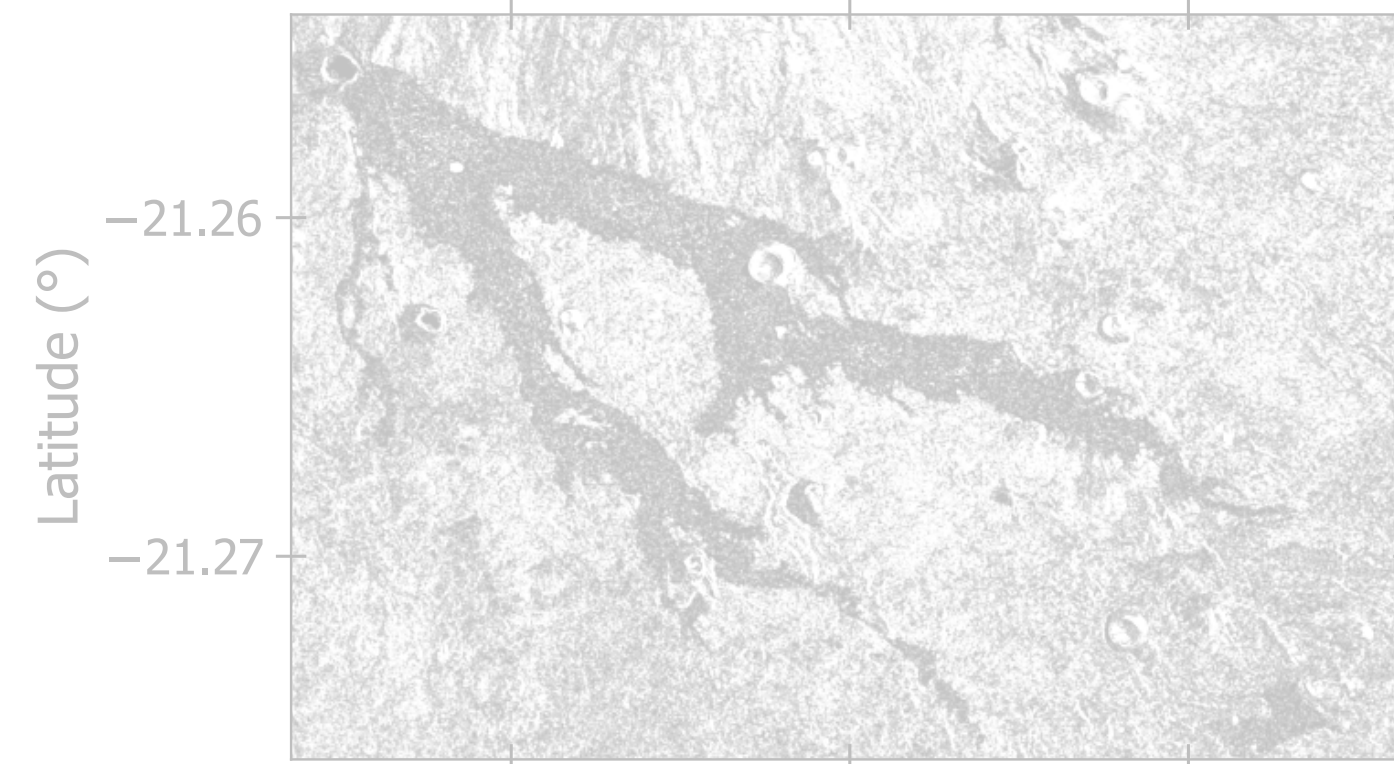
Chevrel et al., 2023
from PlanetScope images

1. Lava flows

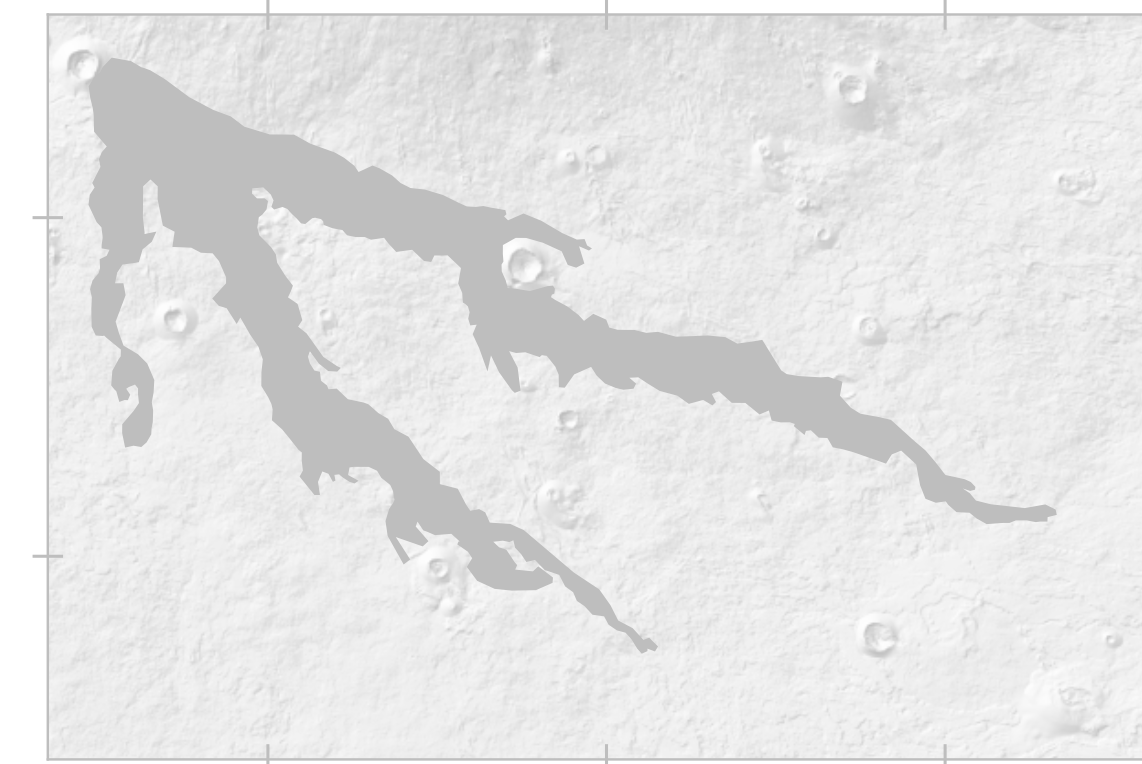
Feb. 2022 DEM



Correlation score



Ground truth

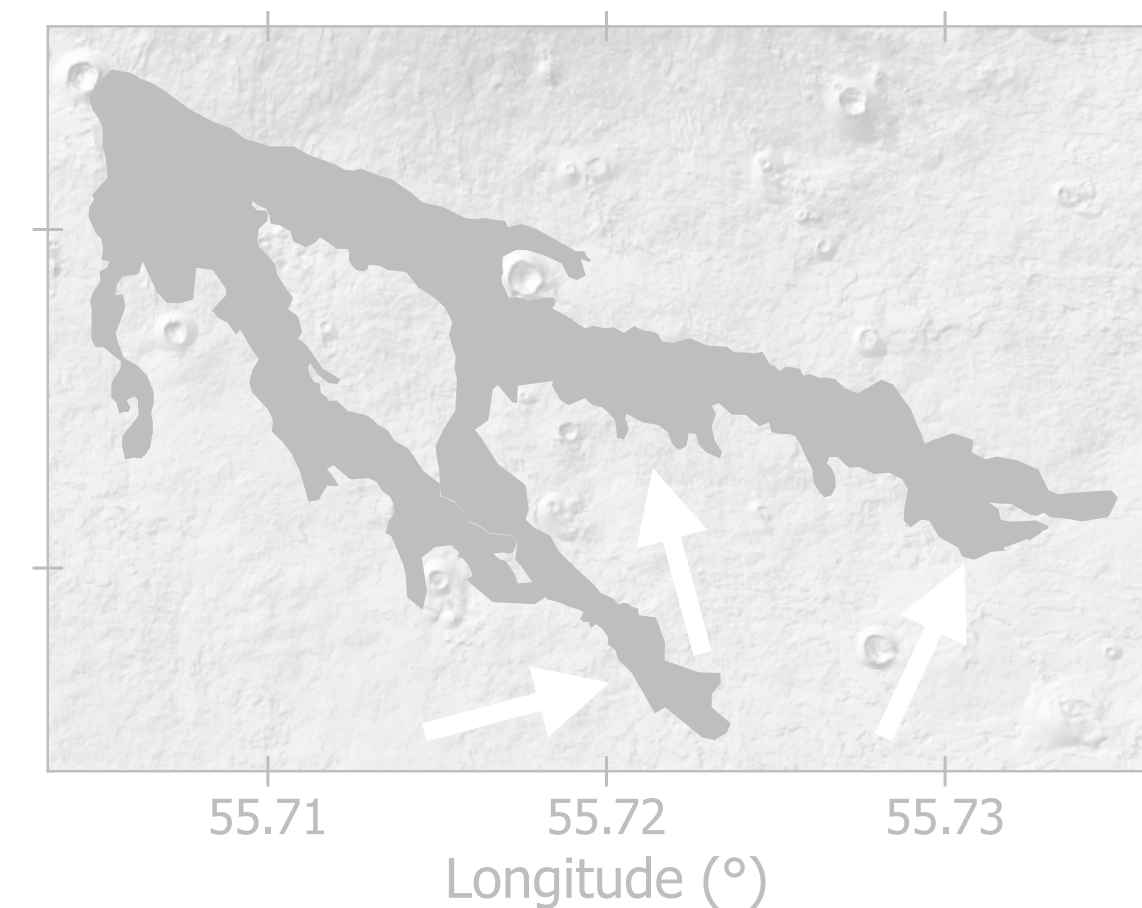
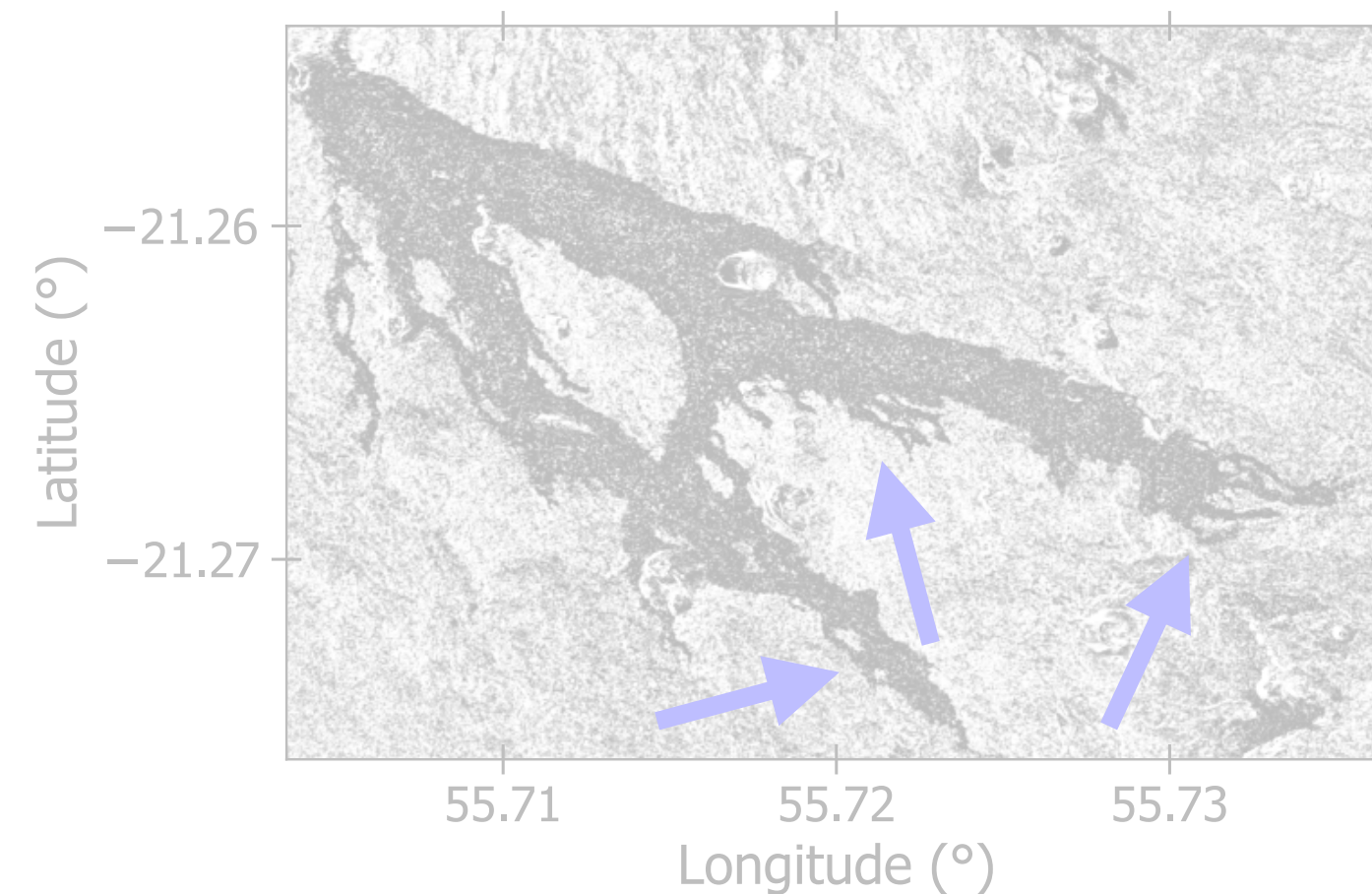


1 October



2 October

We need up-to-date DEMs



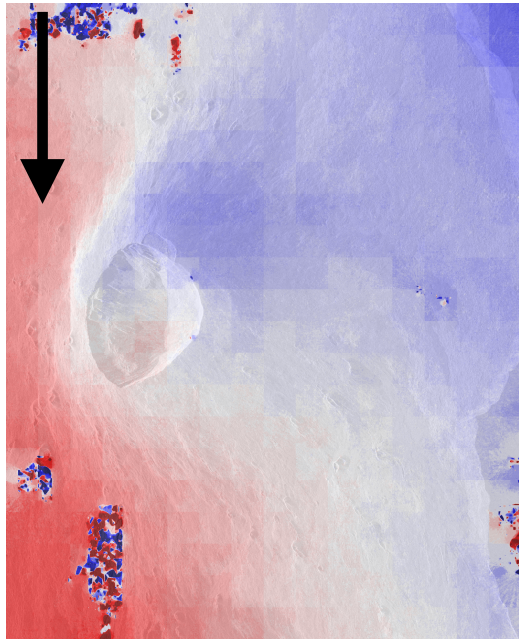
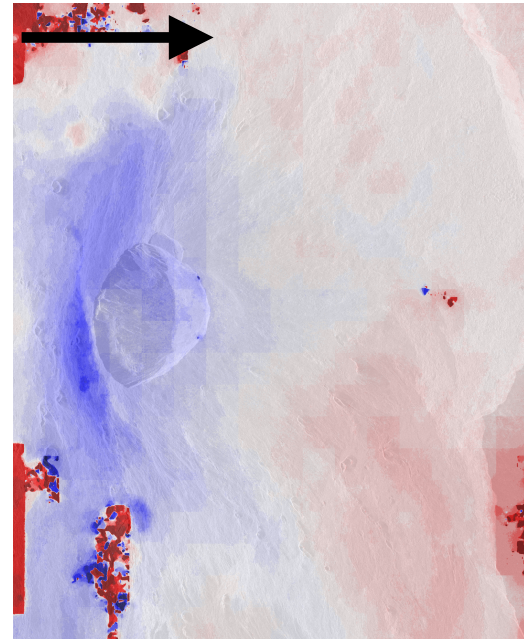
4 October 2022

Chevrel et al., 2023
from PlanetScope images

2. Volcanic deformation

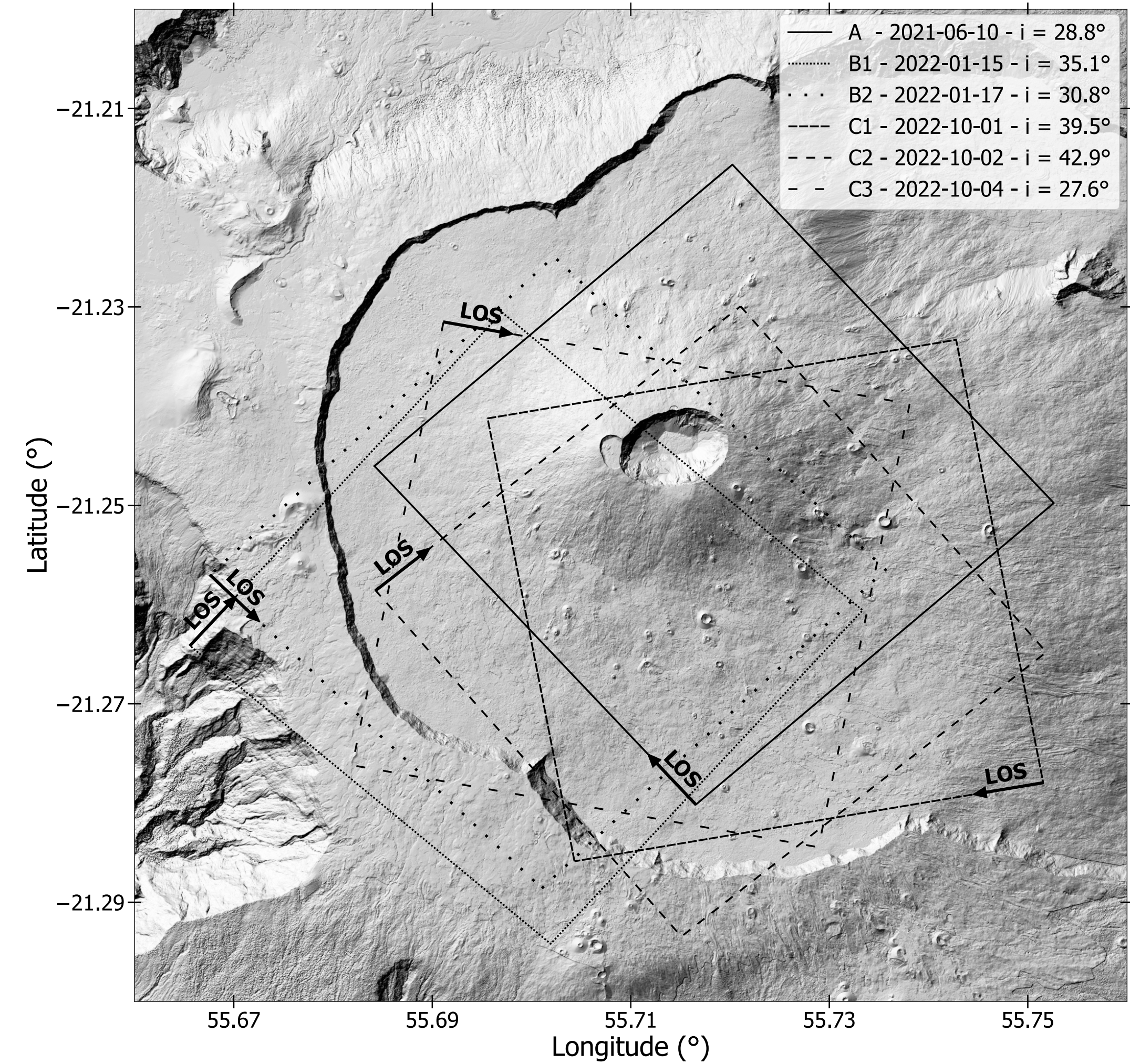
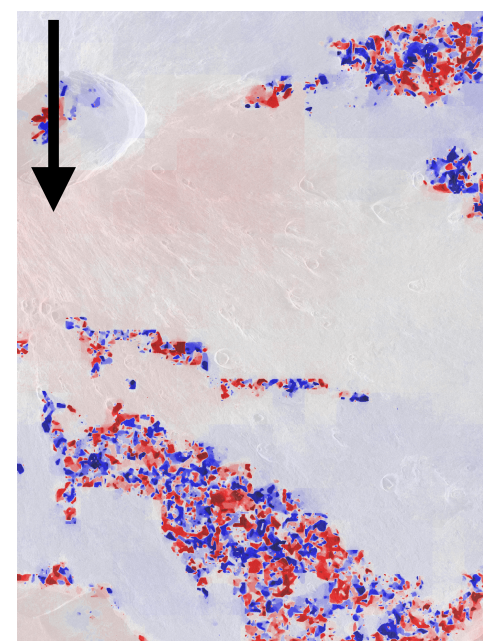
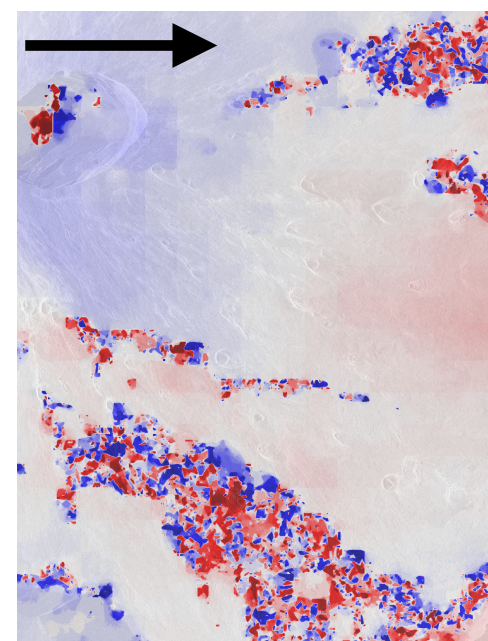
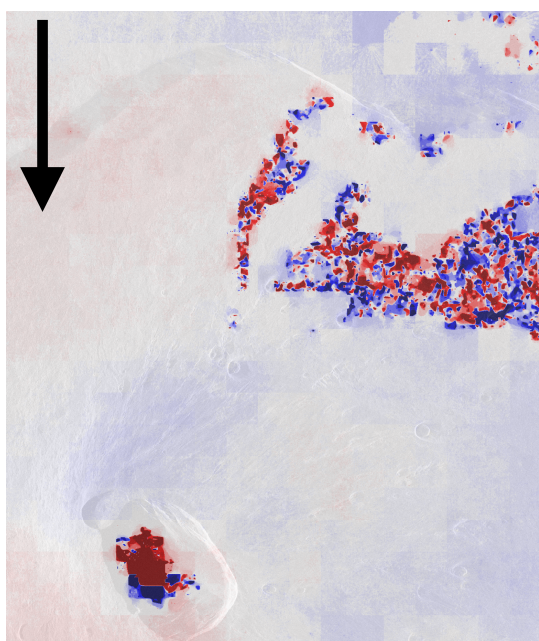
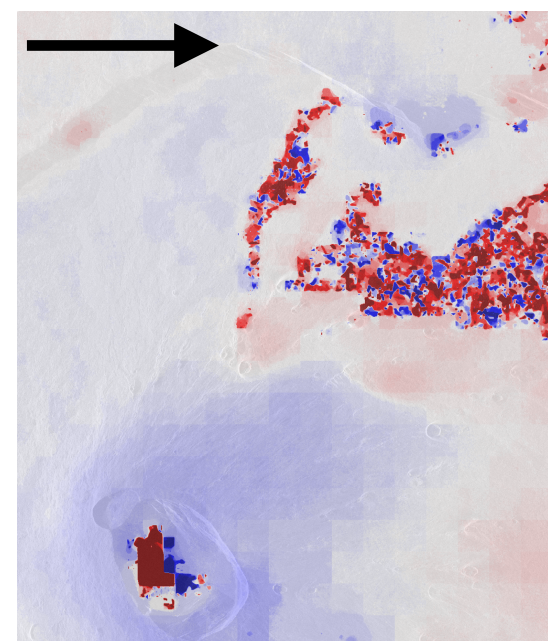
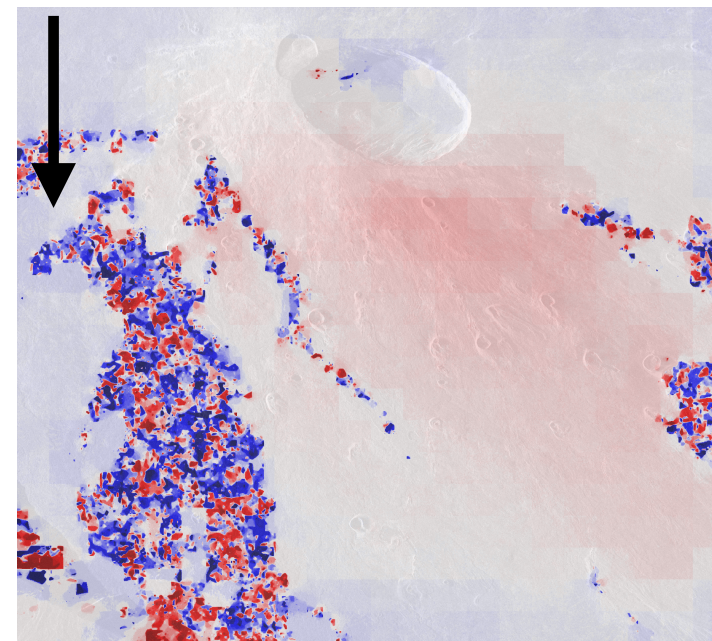
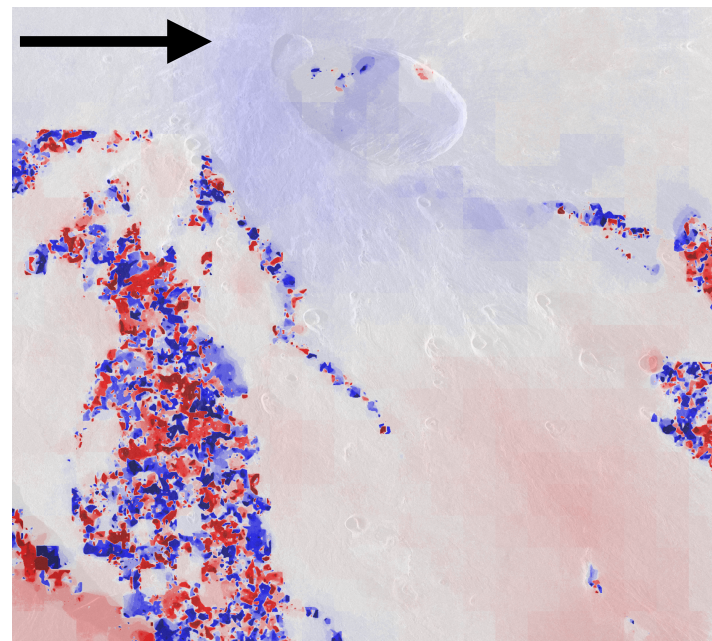
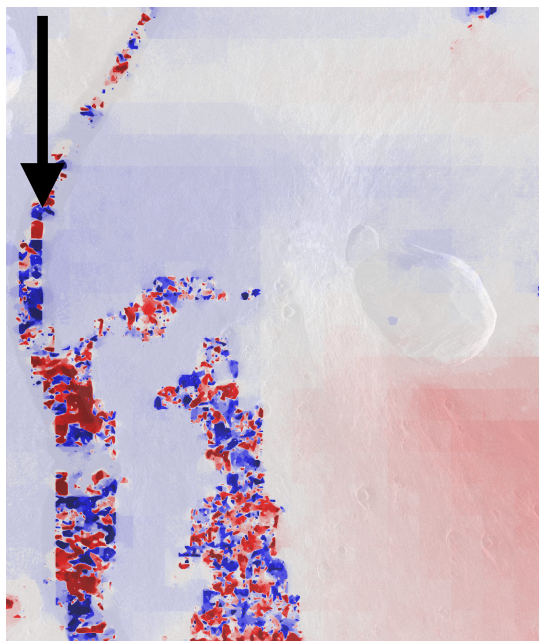
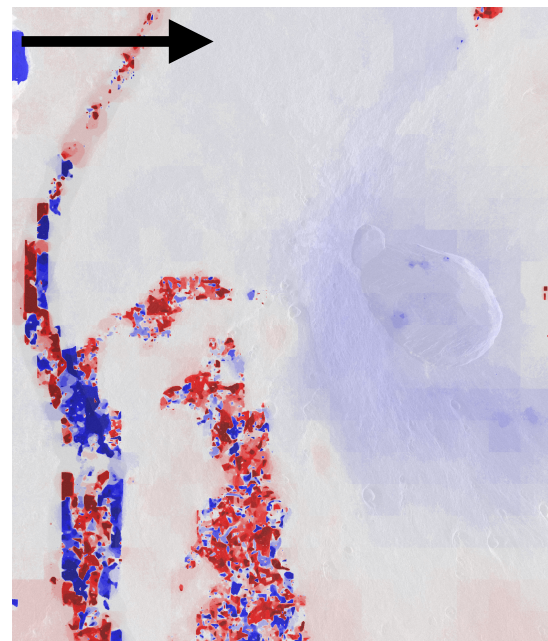
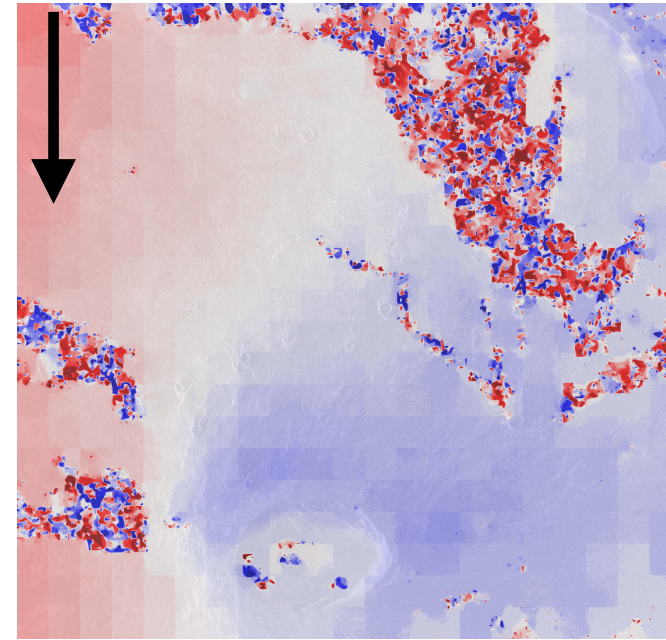
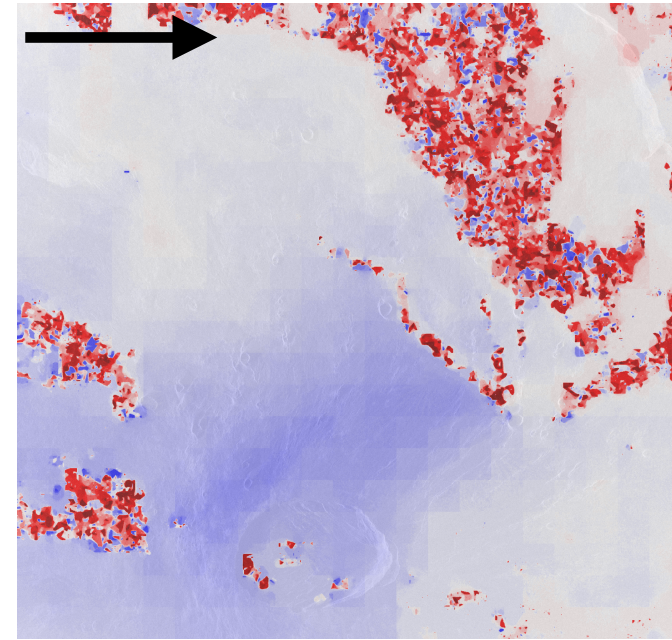
Slant range
(LOS)

Azimuth
(along track)



Slant range
(LOS)

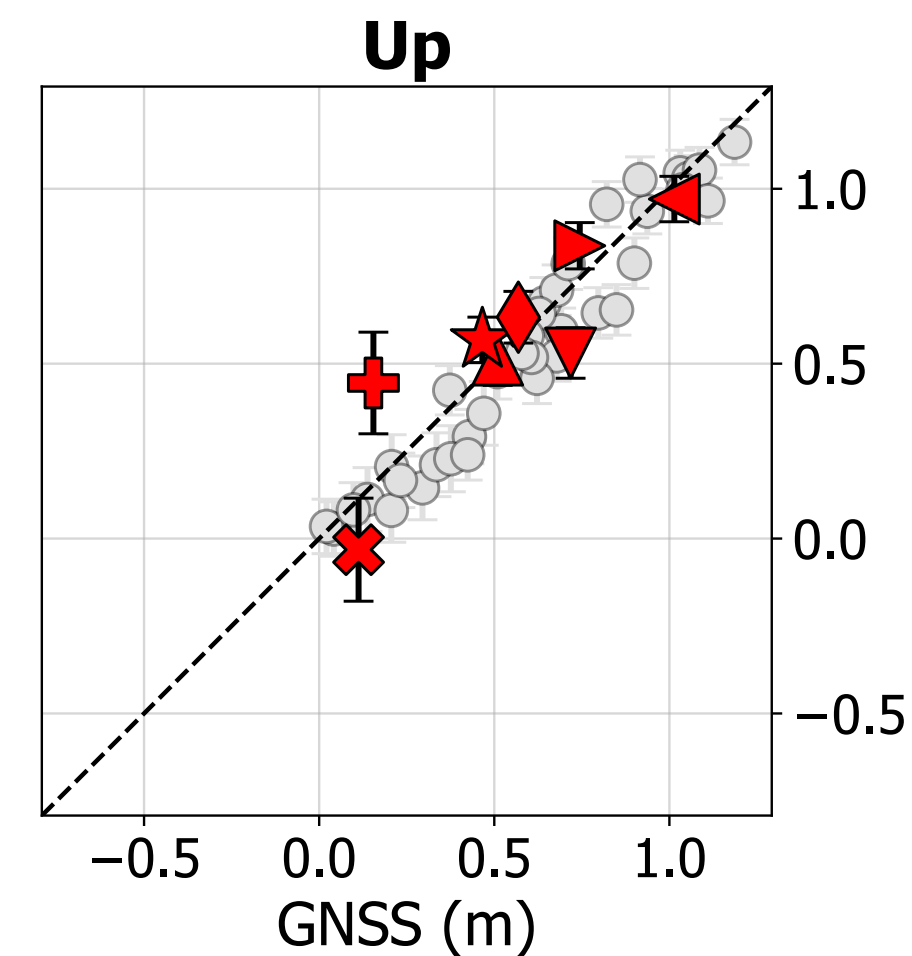
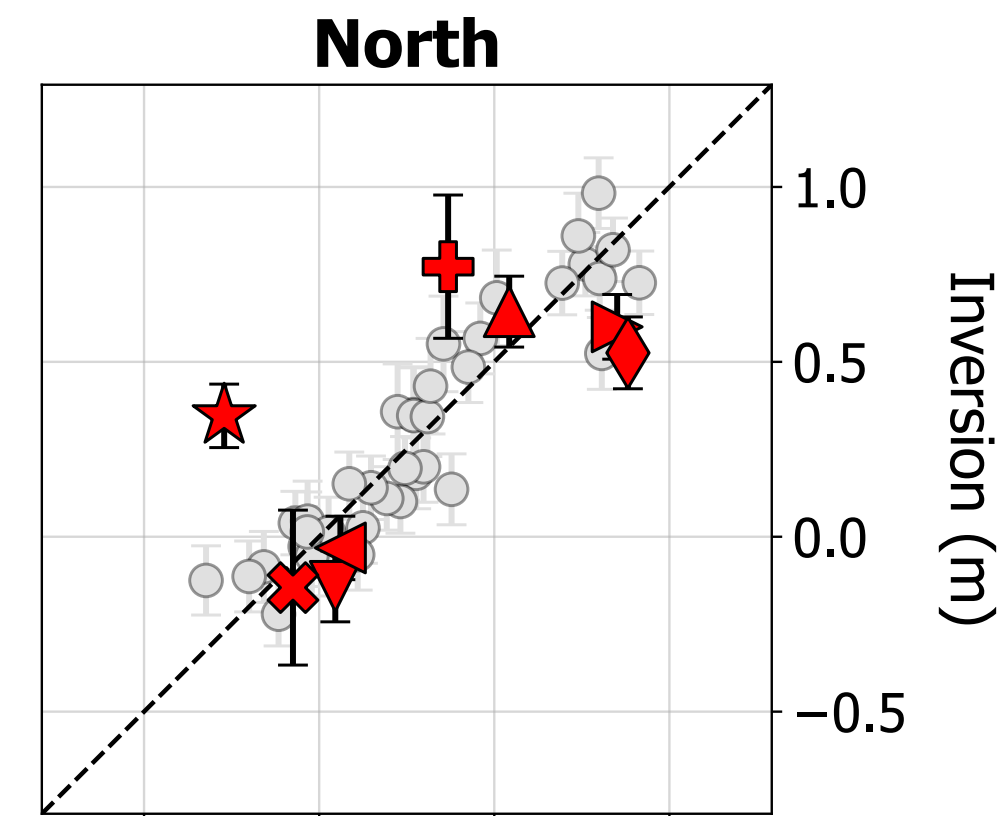
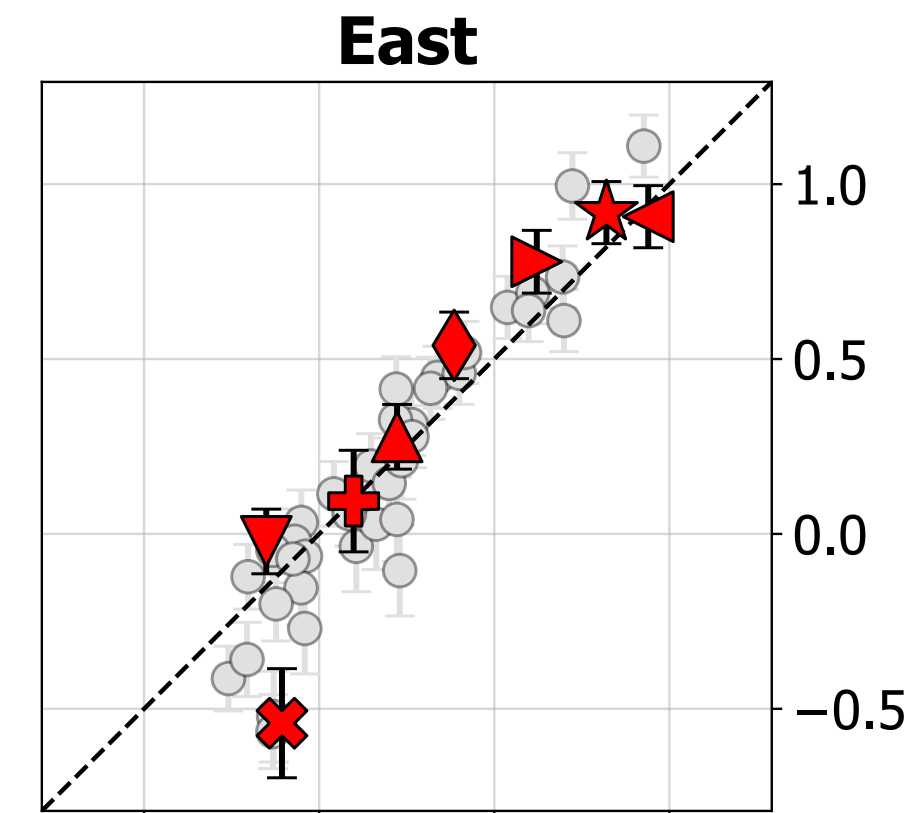
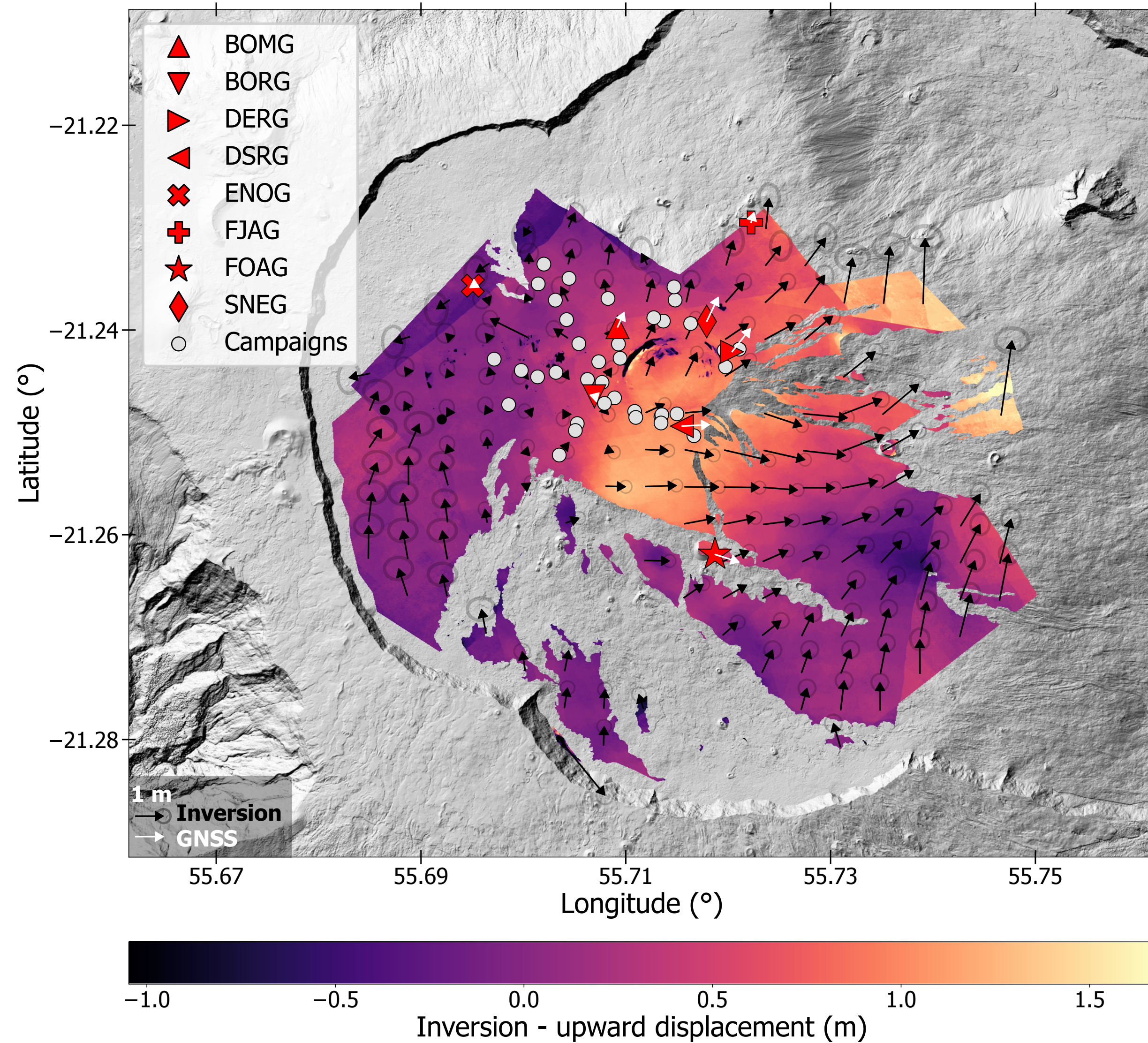
Azimuth
(along track)



2. Volcanic deformation

2018 - 2022

Absolute displacement



Permanent
Campaigns
All

R^2
0.88 - 0.86 - 0.86

RMSE
18 cm - 16 cm - 16 cm

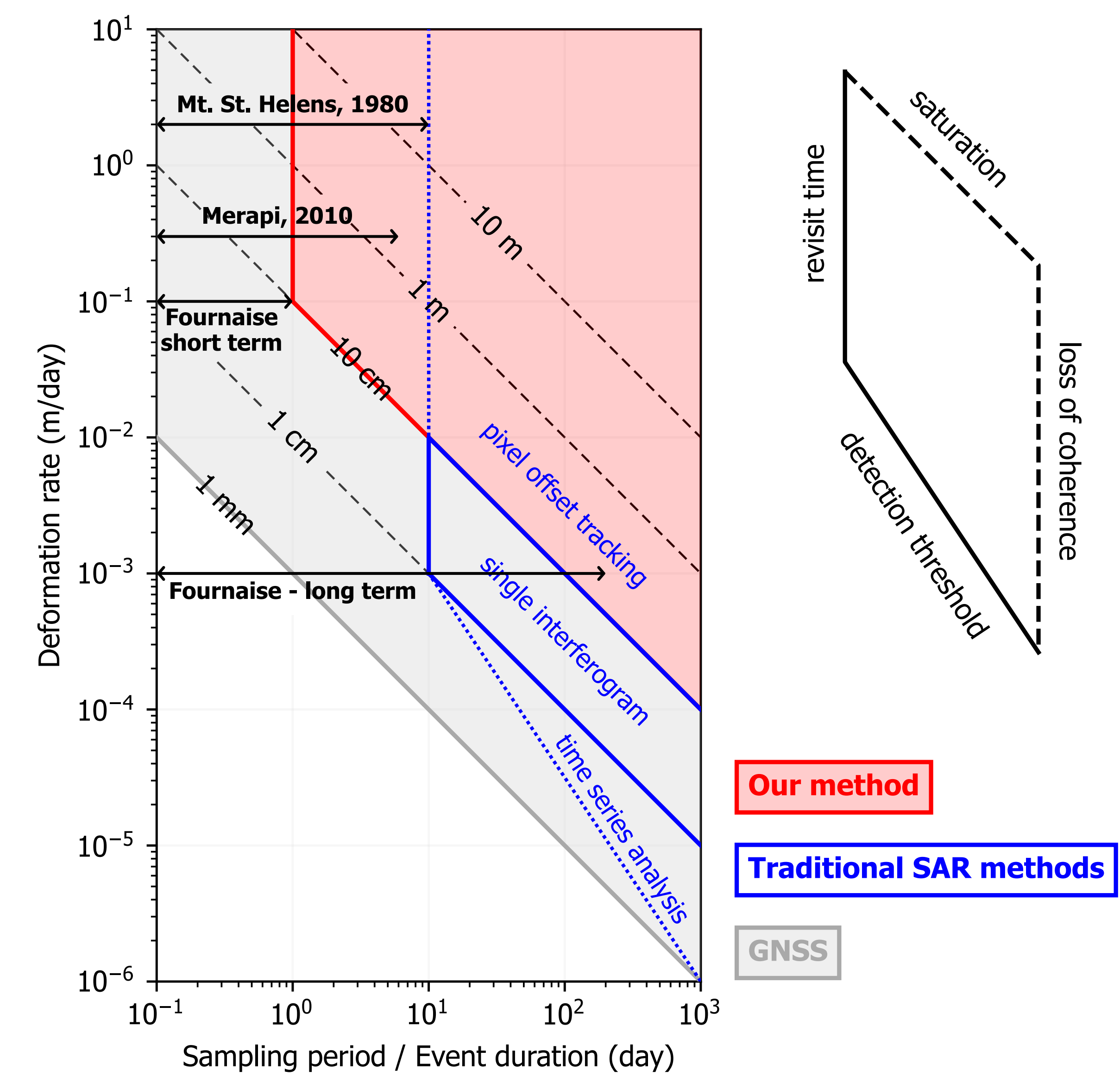
R^2
0.44 - 0.81 - 0.72

RMSE
31 cm - 12 cm - 17 cm

R^2
0.76 - 0.76 - 0.76

RMSE
14 cm - 9 cm - 11 cm

	GNSS	InSAR	Our method
Sampling interval	~ 1 s	~ 10 days	~ 1 day
Detection threshold	~ 1 mm	~ 1 cm	~ 10 cm
Saturation	No	$\sim \lambda/2$ / pixel	No
Spatial continuity	No	Yes	Yes
Damaged during eruptions	Potentially	No	No



Conclusion

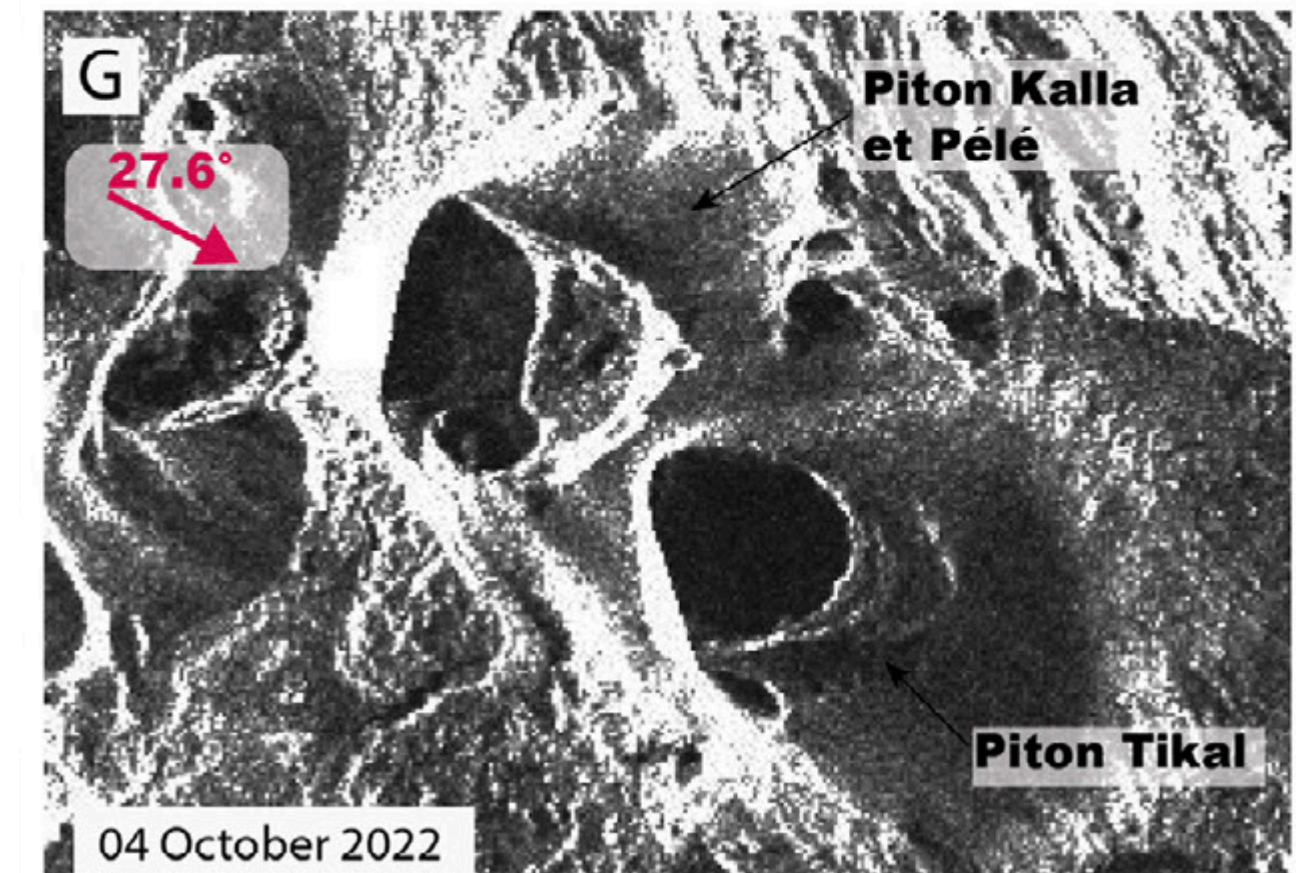
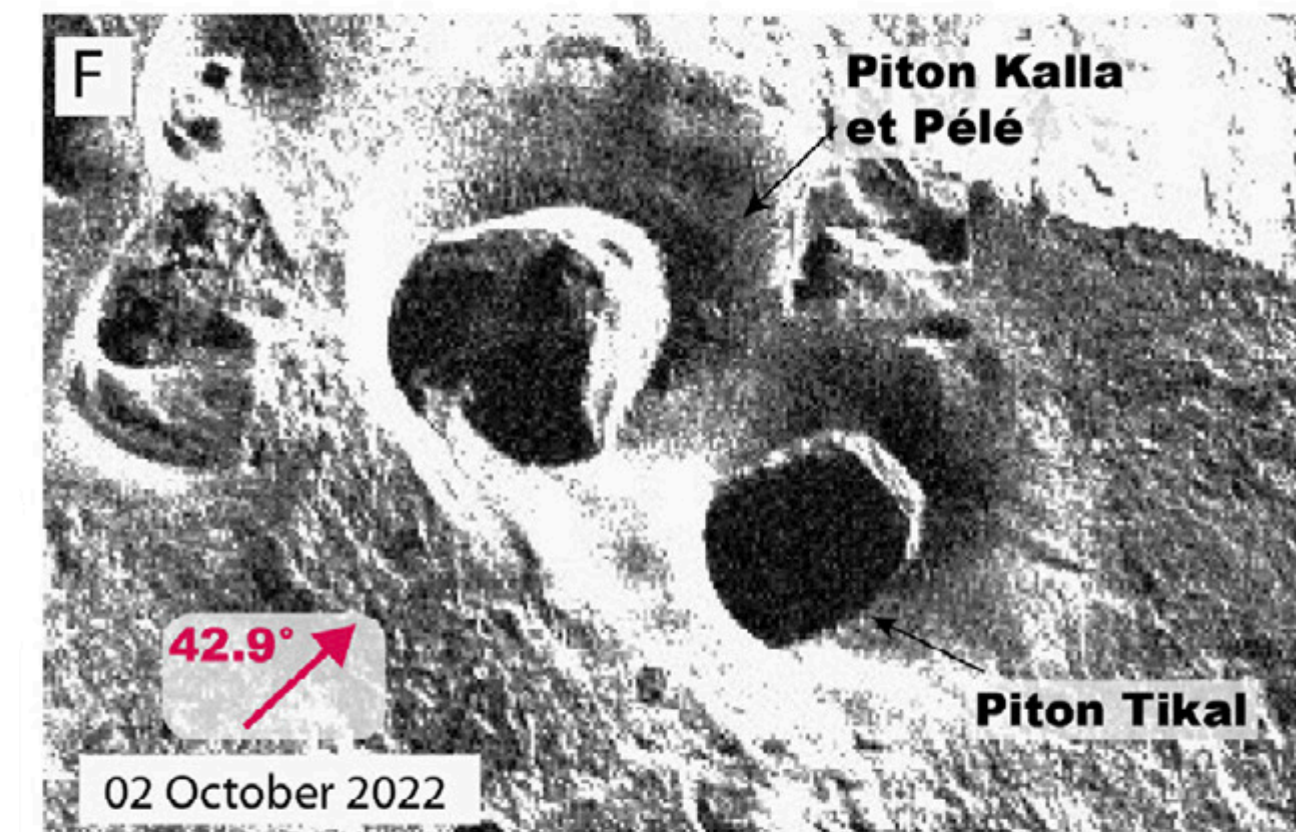
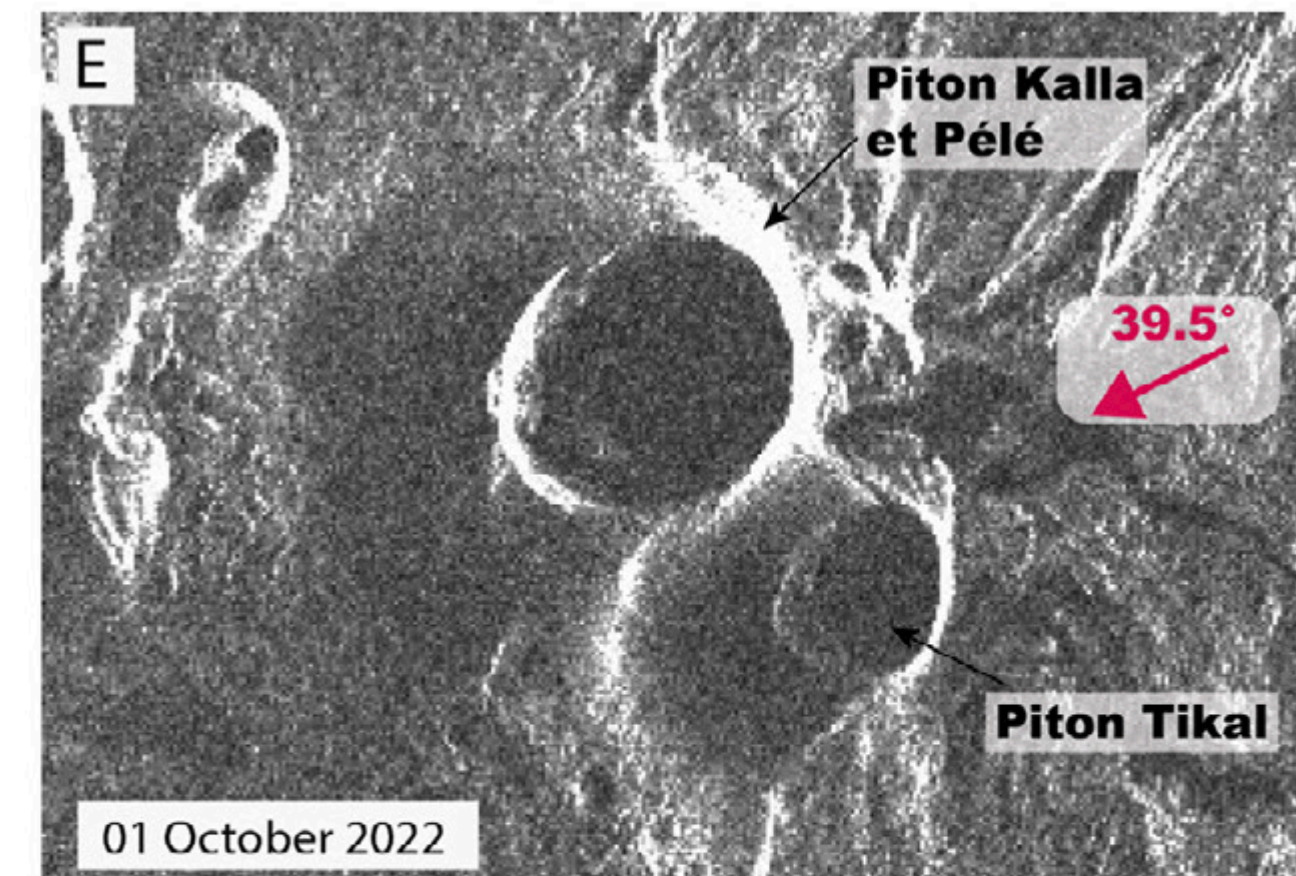
To assist volcanic eruptions monitoring from space we need:

- a very high spatial resolution $\lesssim 1$ m
- a very high temporal resolution $\lesssim 1$ day

To that end, we have to use every available image, **no matter its acquisition geometry**.

Using **Capella Space SAR images** and a **high resolution DEM** we are able to:

- map **lava flows** on a daily basis
- measure **volcanic deformation**



References

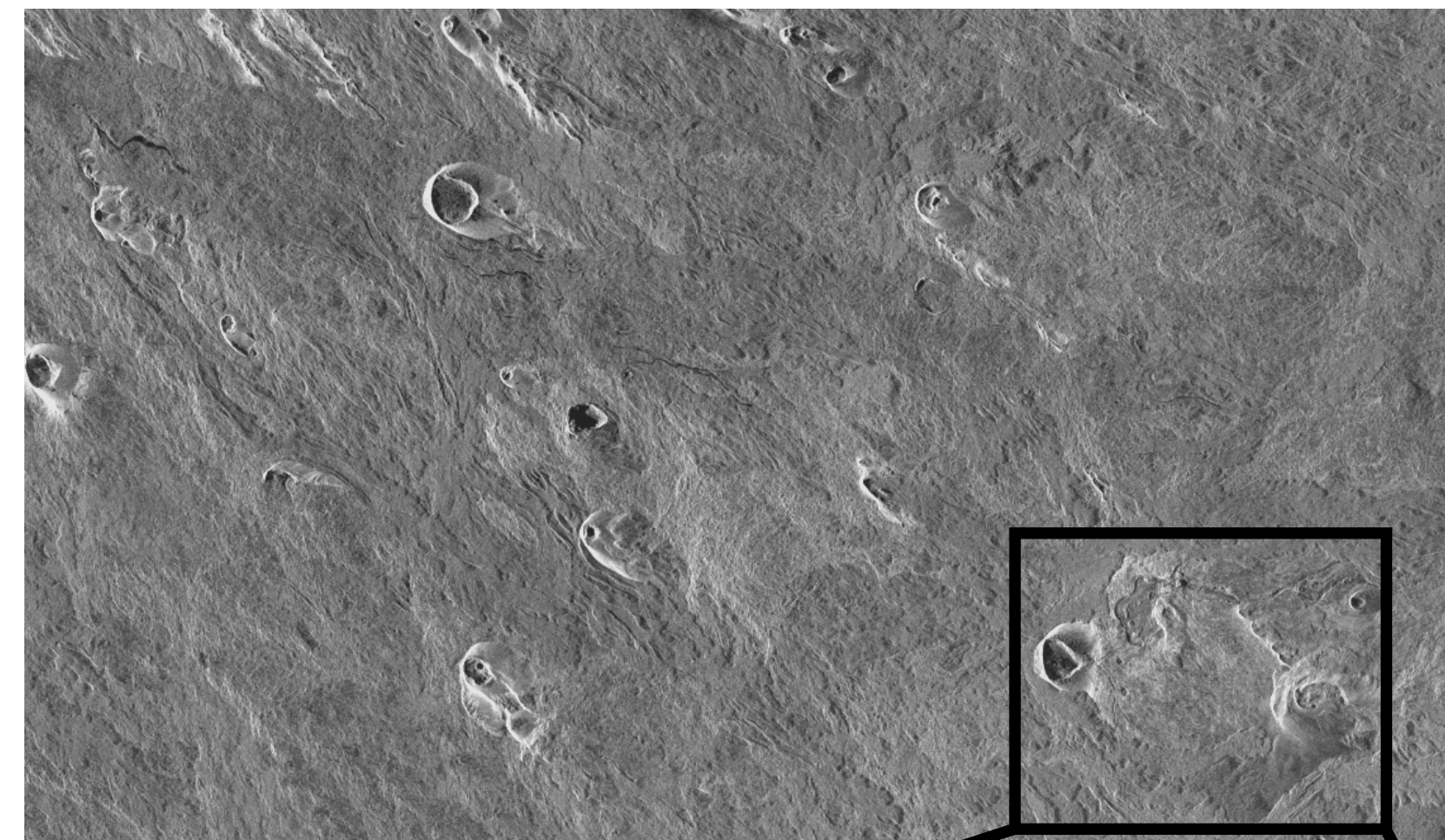
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- Richter, N., & Froger, J. L. (2020). The role of Interferometric Synthetic Aperture Radar in detecting, mapping, monitoring, and modelling the volcanic activity of Piton de la Fournaise, La Réunion: A review. *Remote Sensing*, 12(6), 1019. <https://doi.org/10.3390/rs12061019>
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Thank you

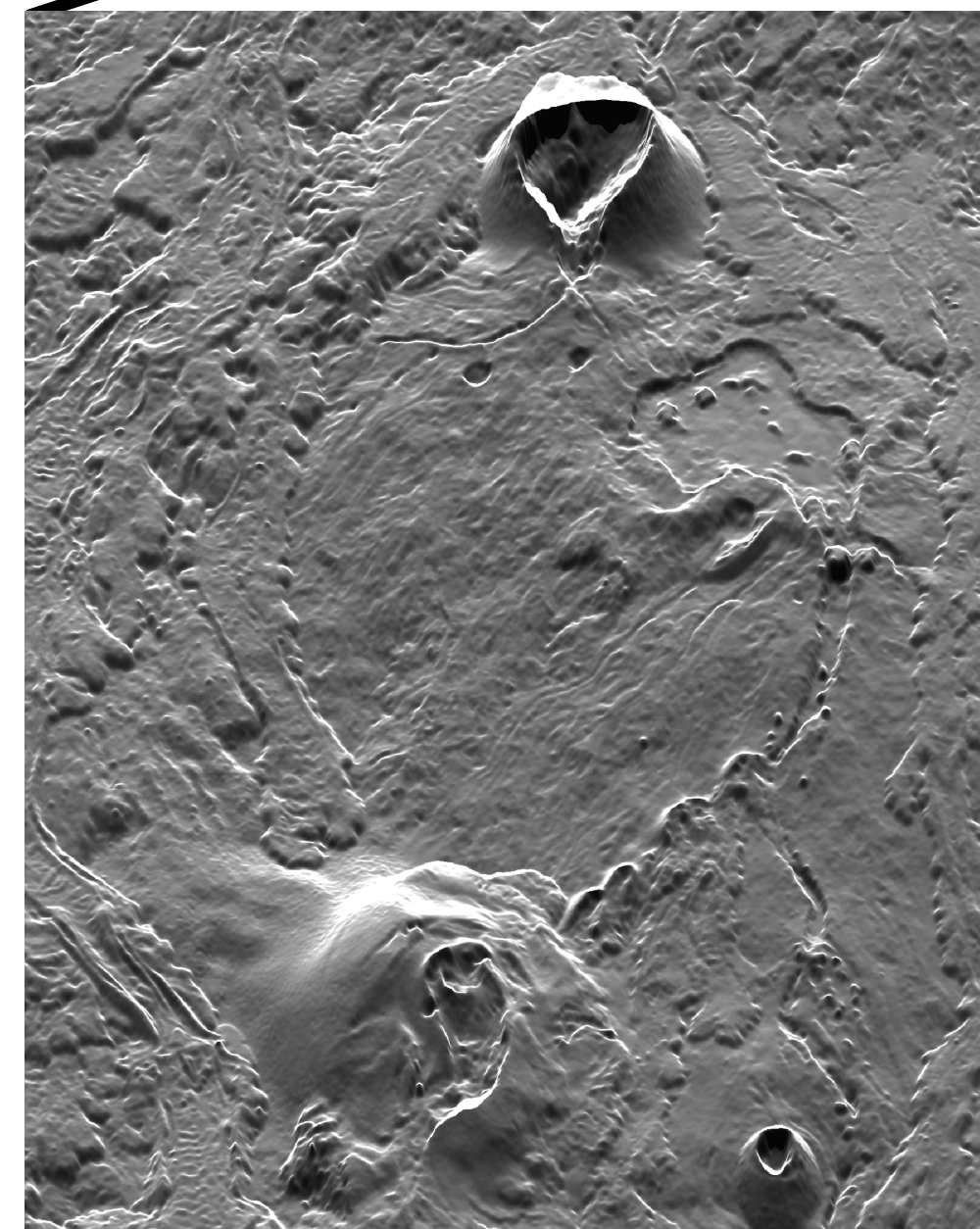
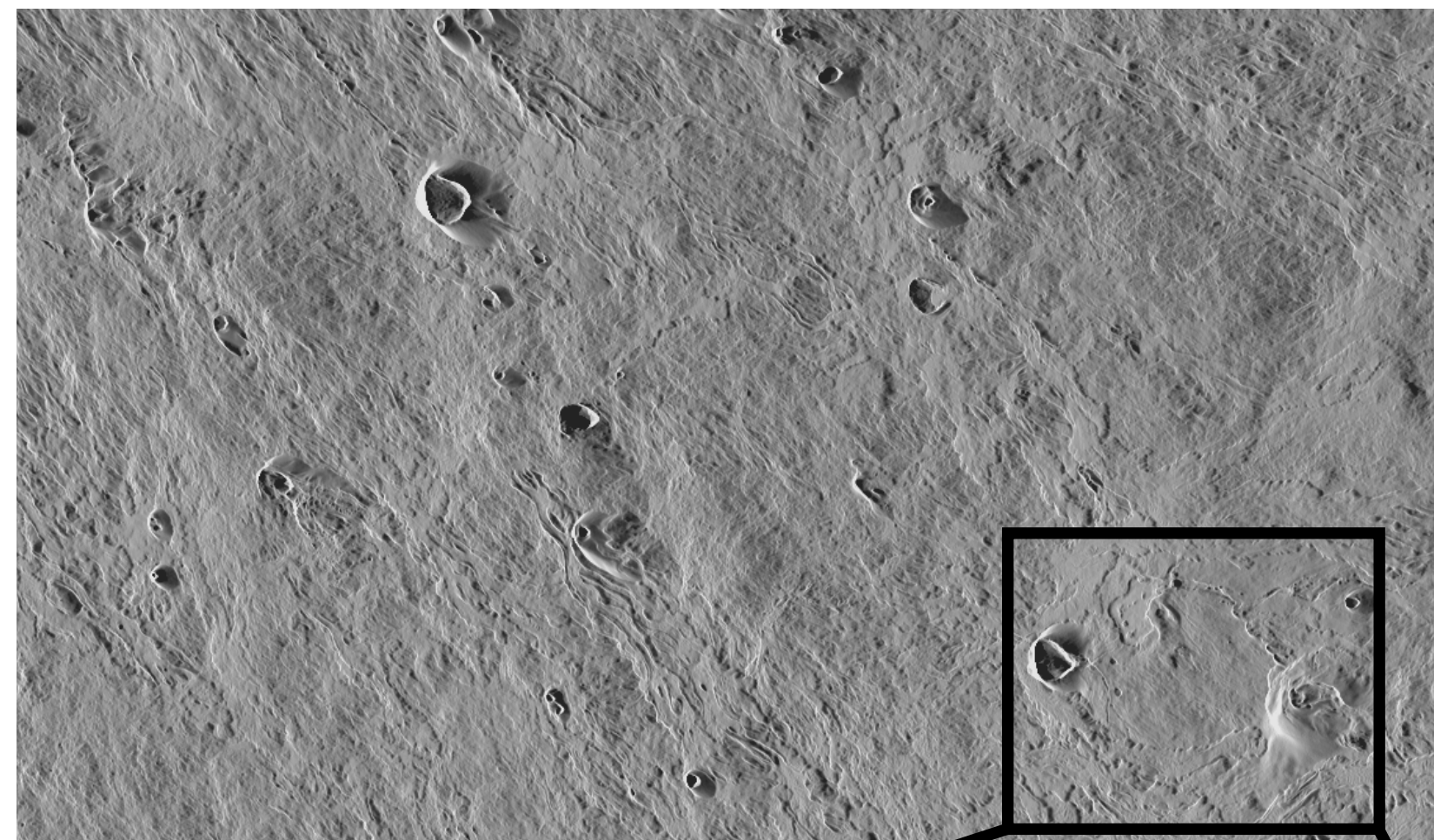
hauck@ipgp.fr

1. Lava flows

Capella Space image

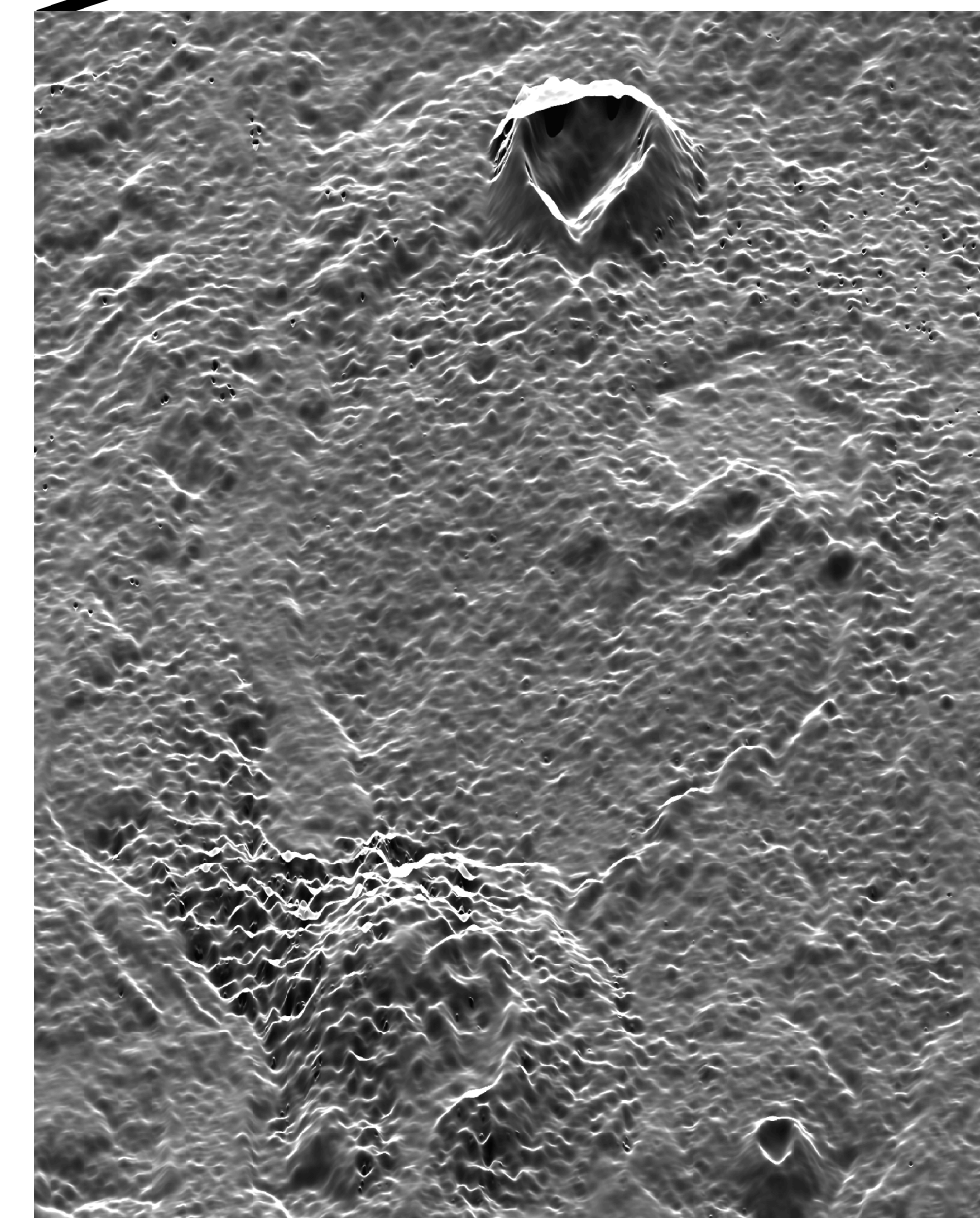
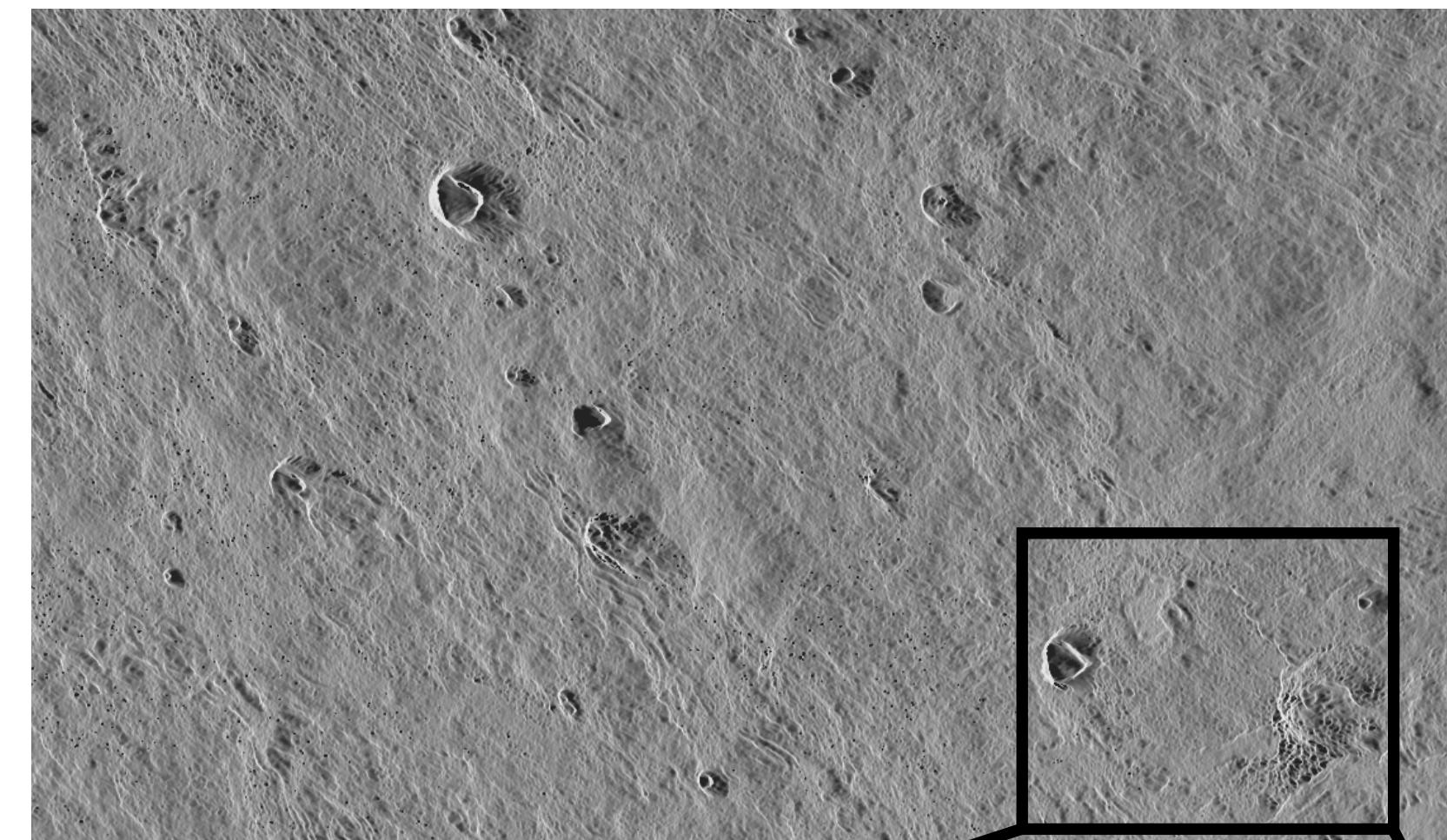


LiDAR DEM



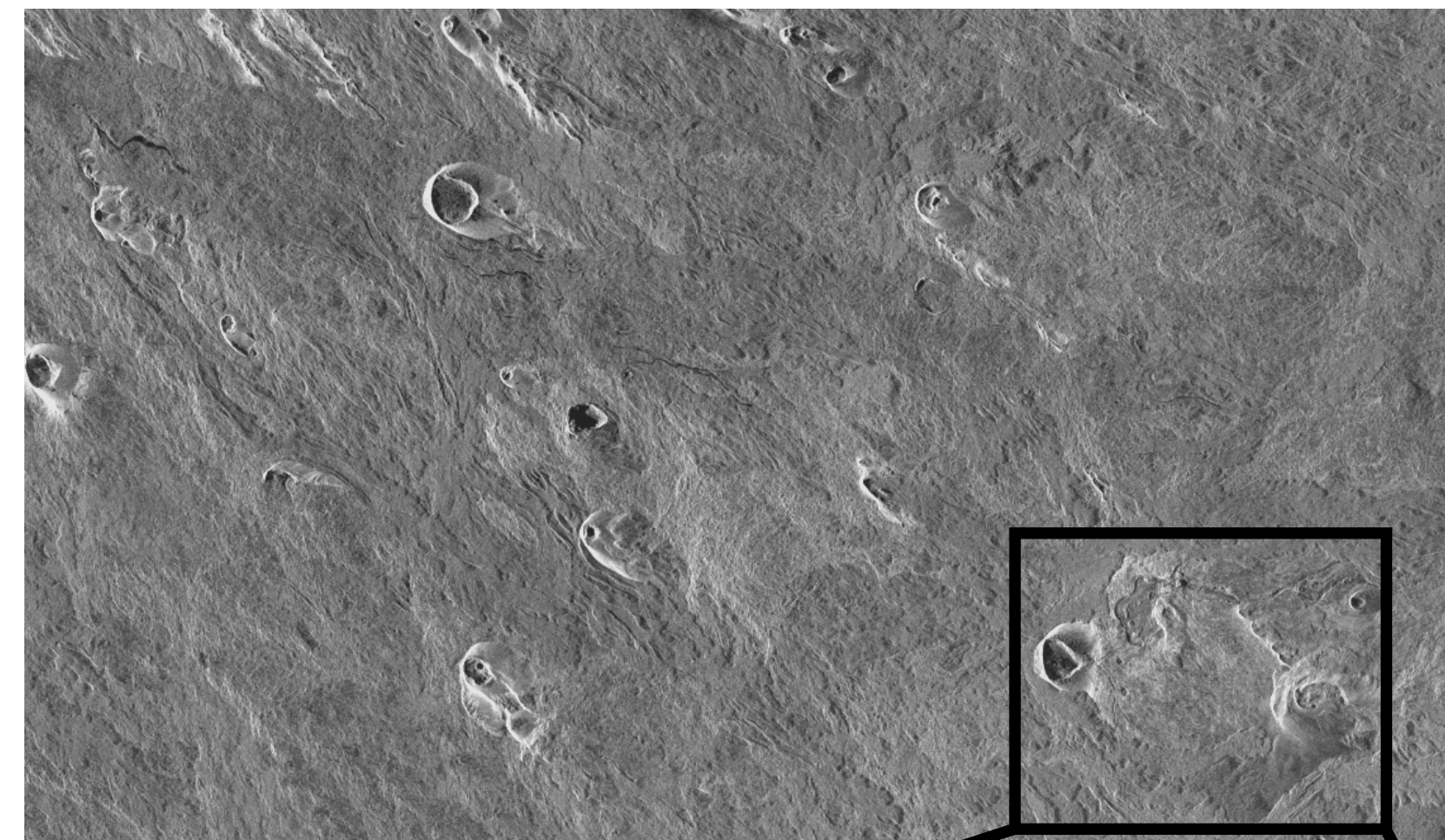
Synthetic images

Pléiades DEM

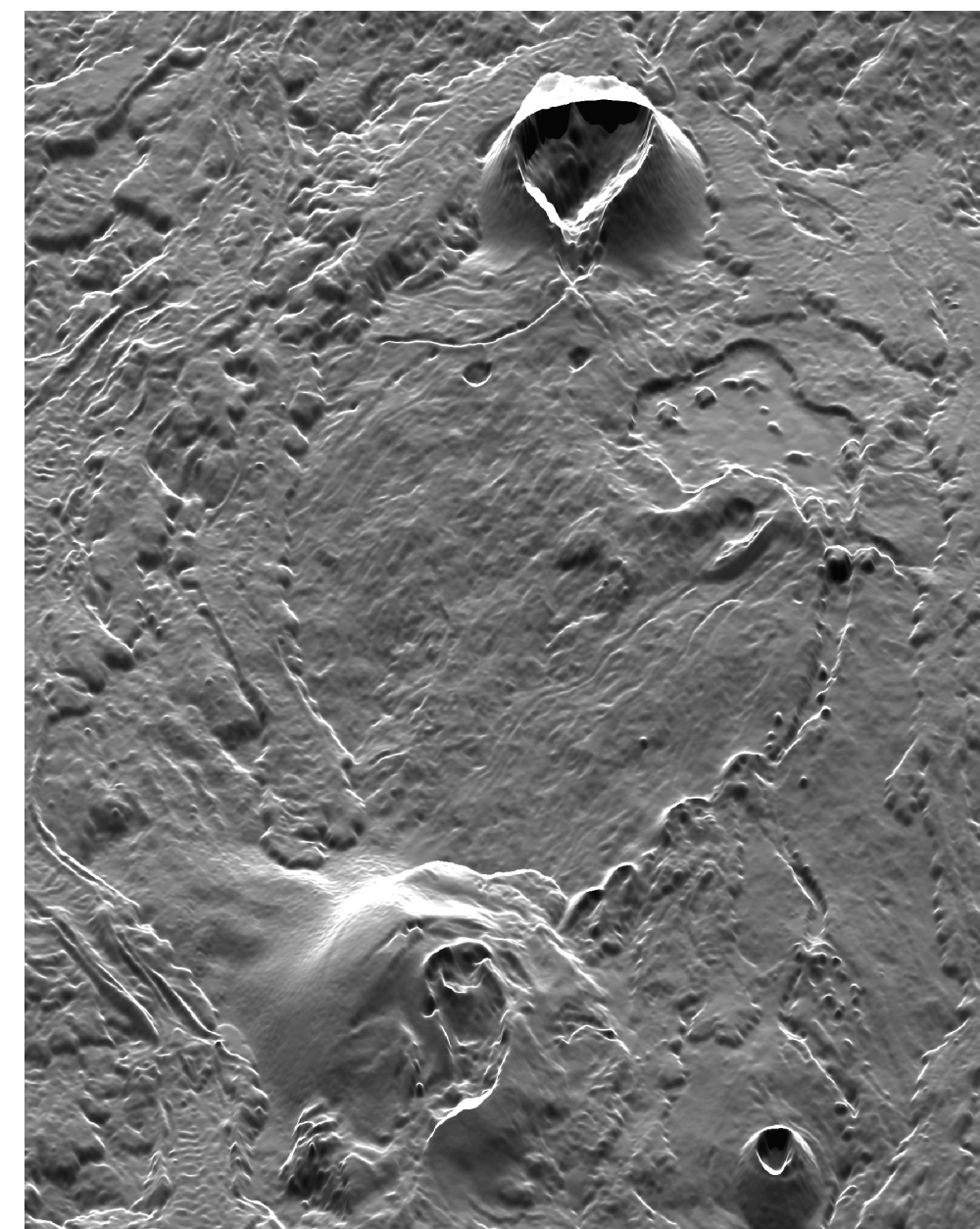


1. Lava flows

Capella Space image

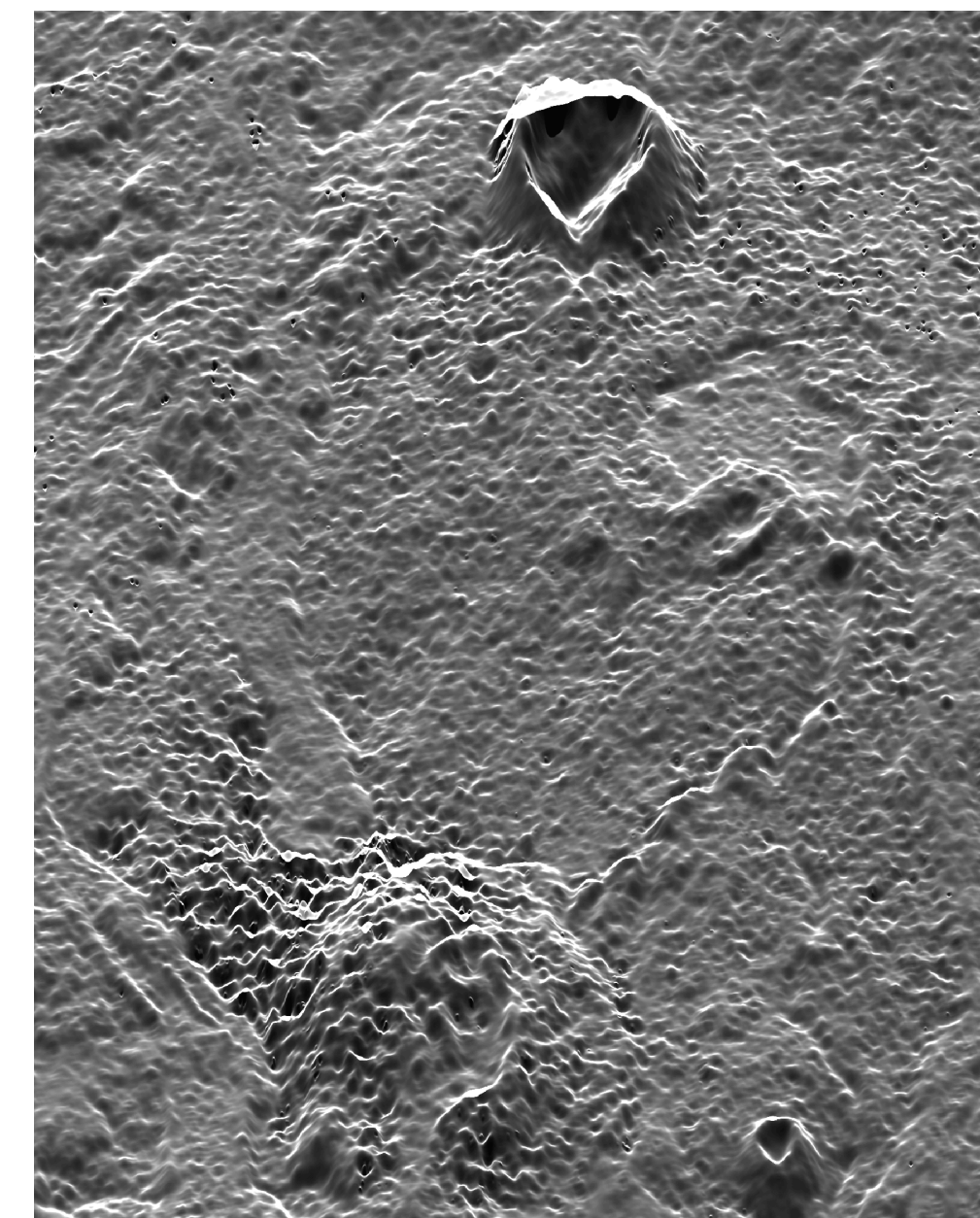
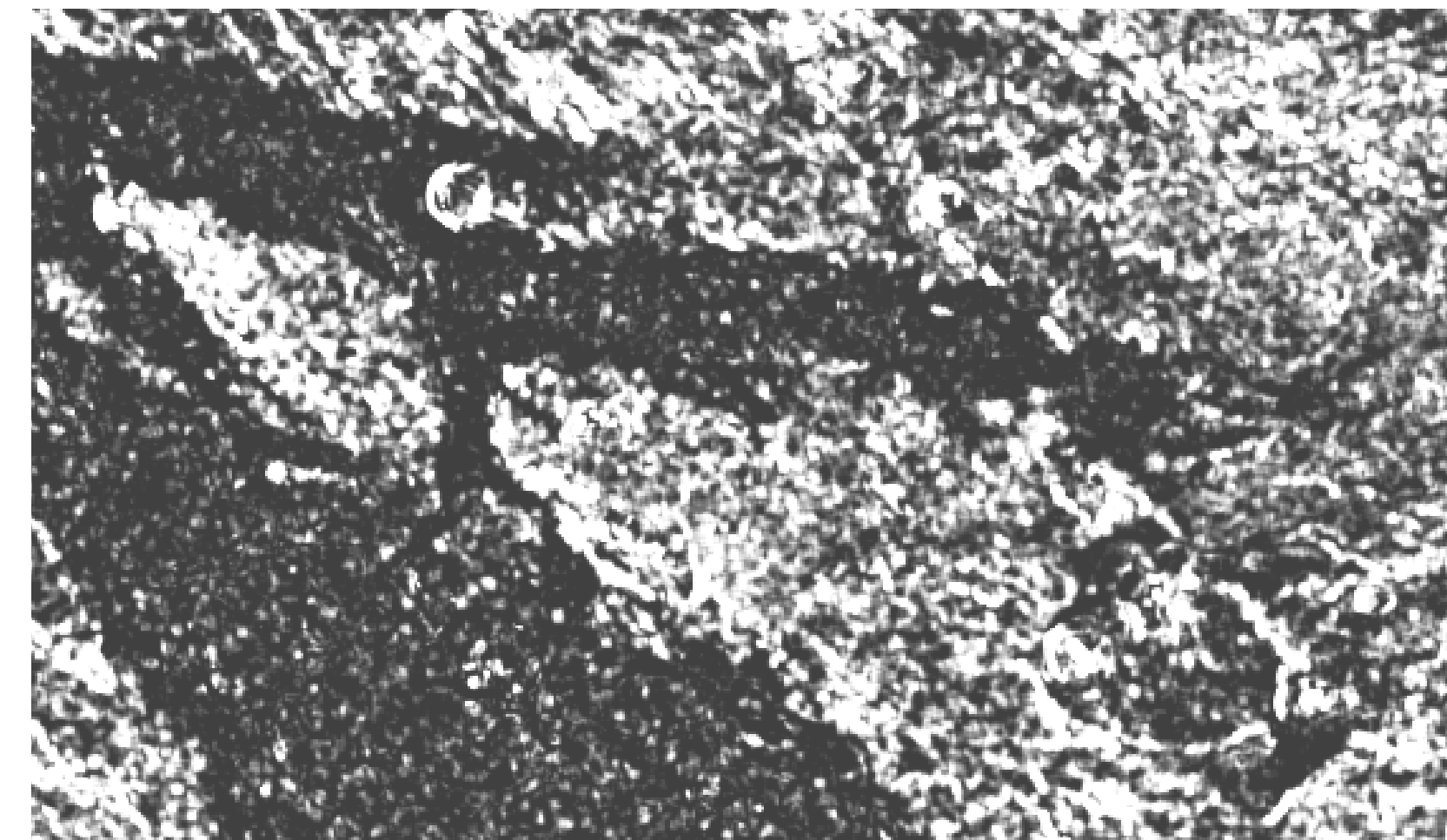


LiDAR DEM



Correlation score

Pléiades DEM



1. Lava flows

Capella Space image

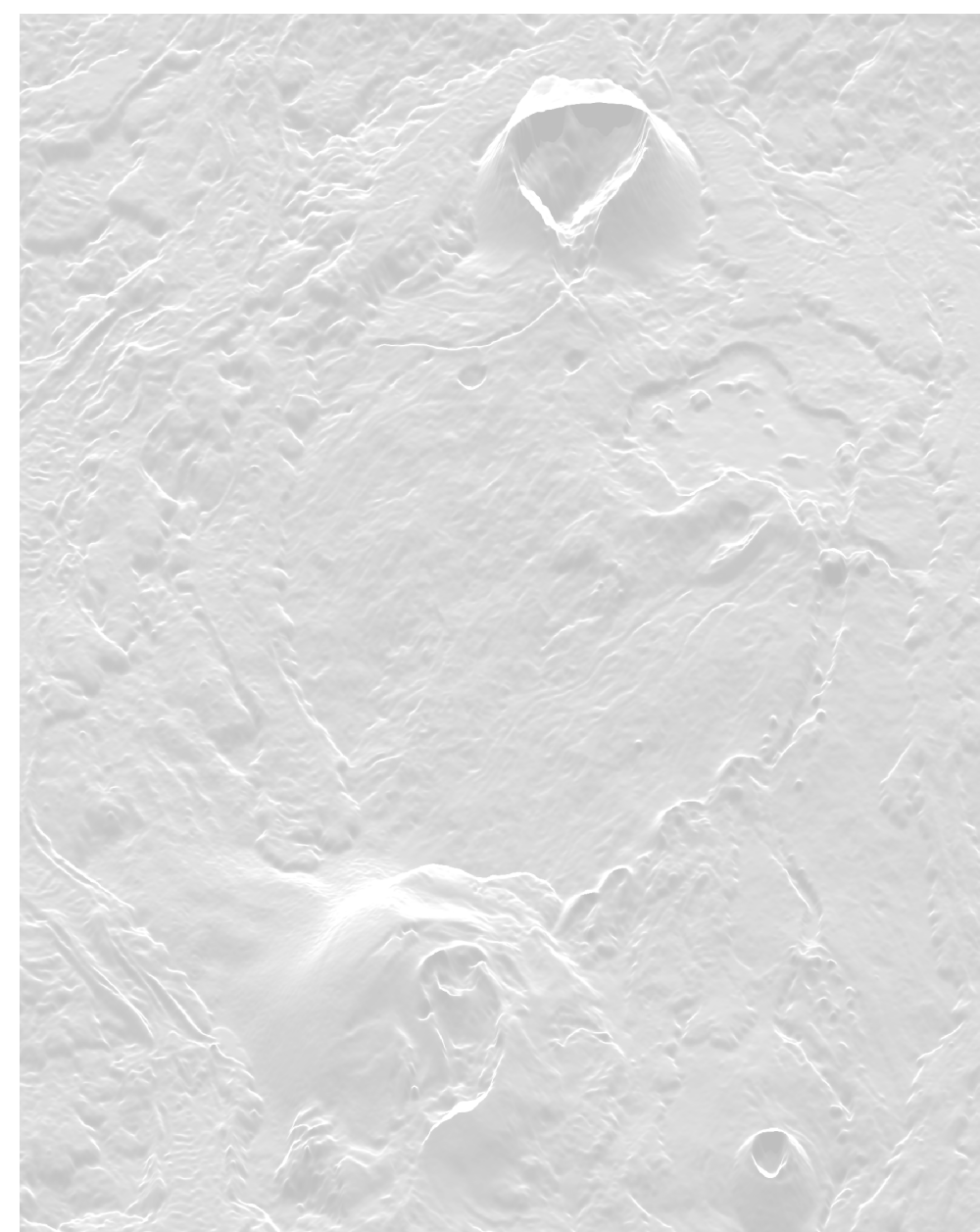
LiDAR DEM

Correlation score

Pléiades DEM

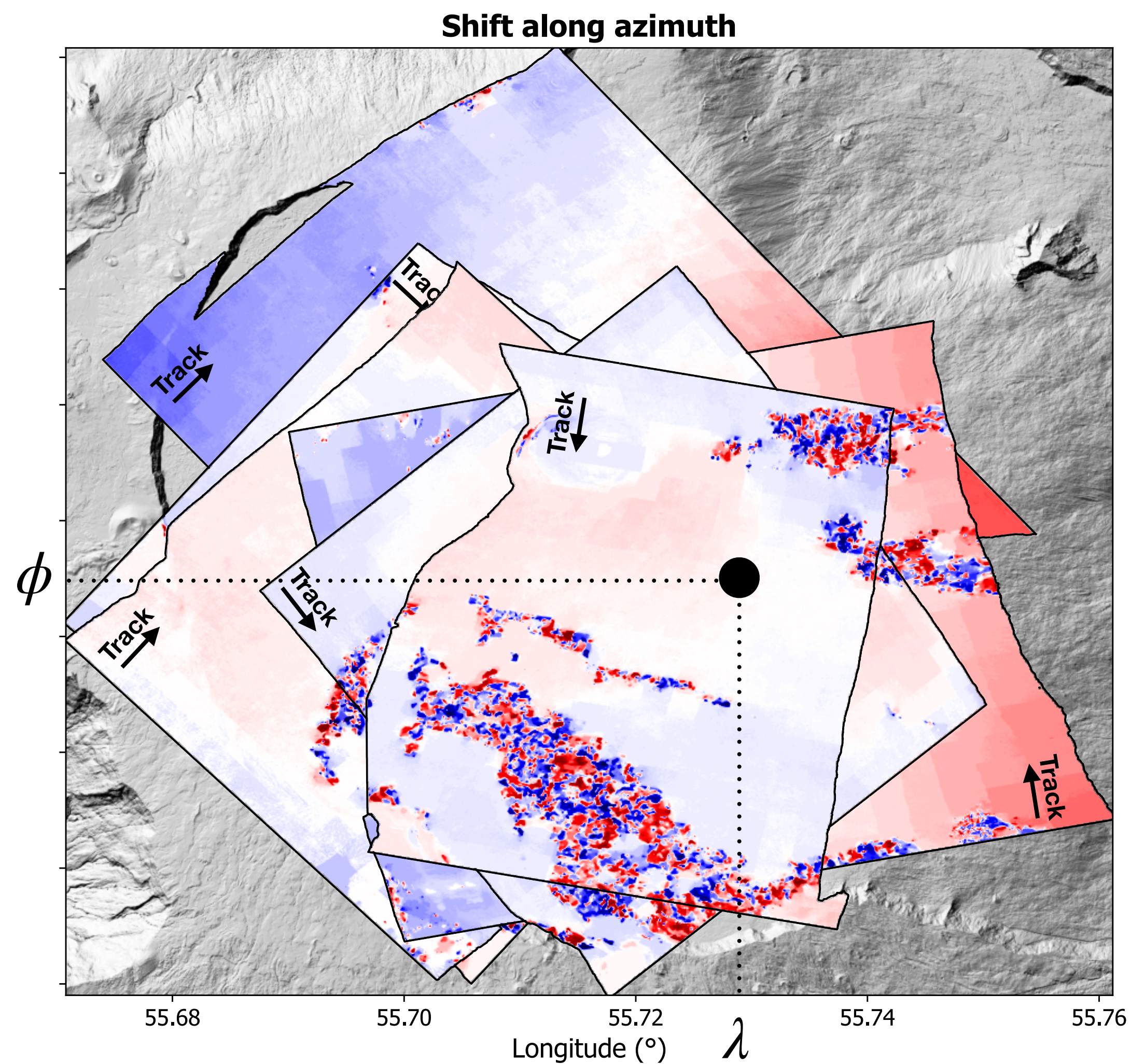
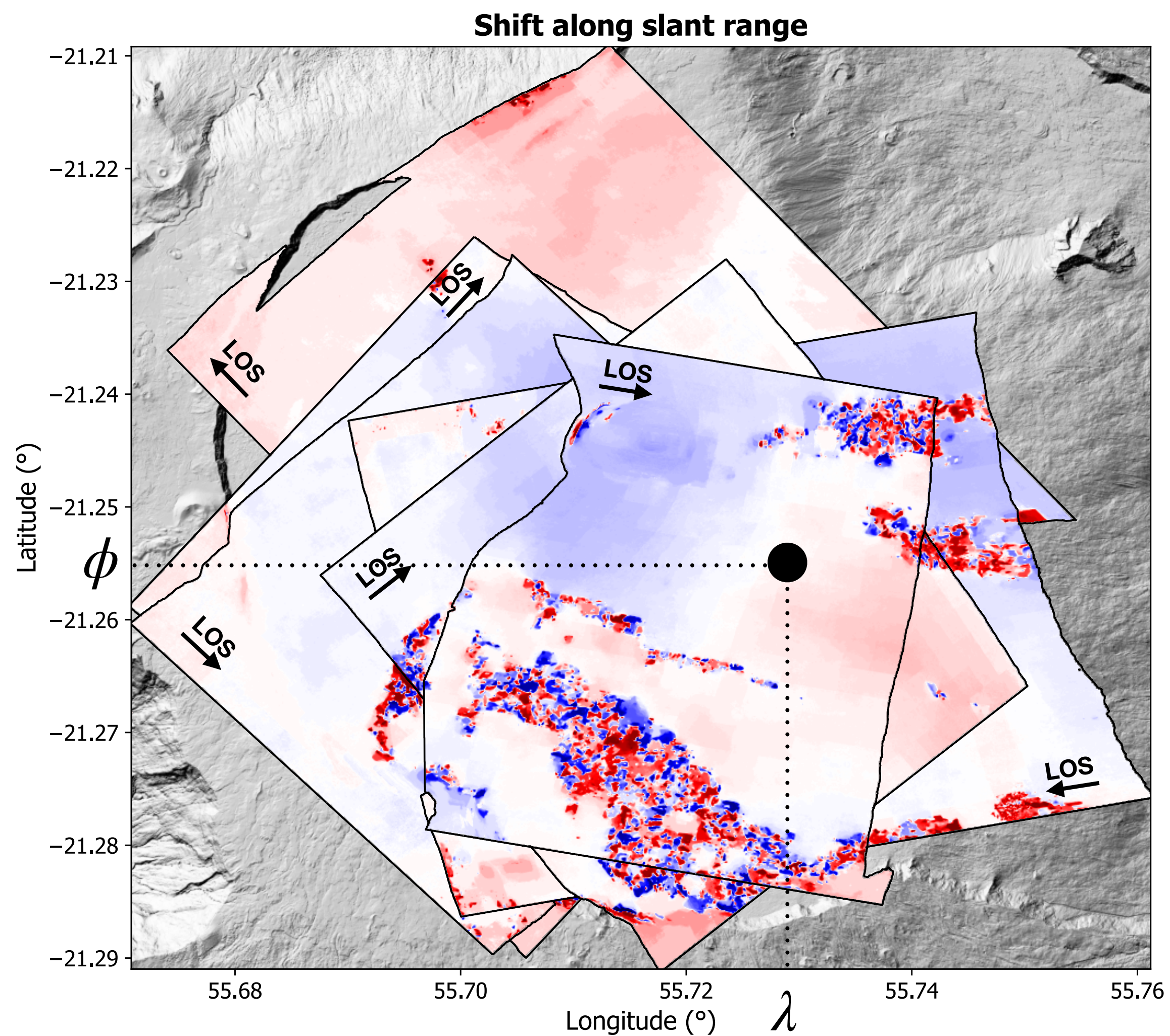


We need high resolution DEMs



2. Volcanic deformation

$$n_{obs}(\lambda, \phi) = 2 \times n_{images}(\lambda, \phi)$$



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We can only get the 3D displacement
of points where

$$n_{images}(\lambda, \phi) \geq 2$$

$$\begin{pmatrix} \left(\delta_{\mathbf{LOS}_\omega} \right)_{\omega \in \Omega} \\ \left(\delta_{\mathbf{Track}_\omega} \right)_{\omega \in \Omega} \end{pmatrix} = \begin{pmatrix} \left(\mathbf{LOS}_\omega \right)_{\omega \in \Omega} \\ \left(\mathbf{Track}_\omega \right)_{\omega \in \Omega} \end{pmatrix} \cdot \begin{pmatrix} \Delta x \\ \Delta y \\ \Delta z \end{pmatrix}, \quad \Omega = \{images(\lambda, \phi)\}$$

$2n_{images}(\lambda, \phi) \times 1$

$2n_{images}(\lambda, \phi) \times 3$

3×1

$n_{images}(\lambda, \phi)$