

Measuring **ground deformation** and **topographic changes** from multi-angular and multi-sensor SAR amplitude imagery

Arthur Hauck, Raphaël Grandin, Fidel Costa

17 June 2026

in collaboration with

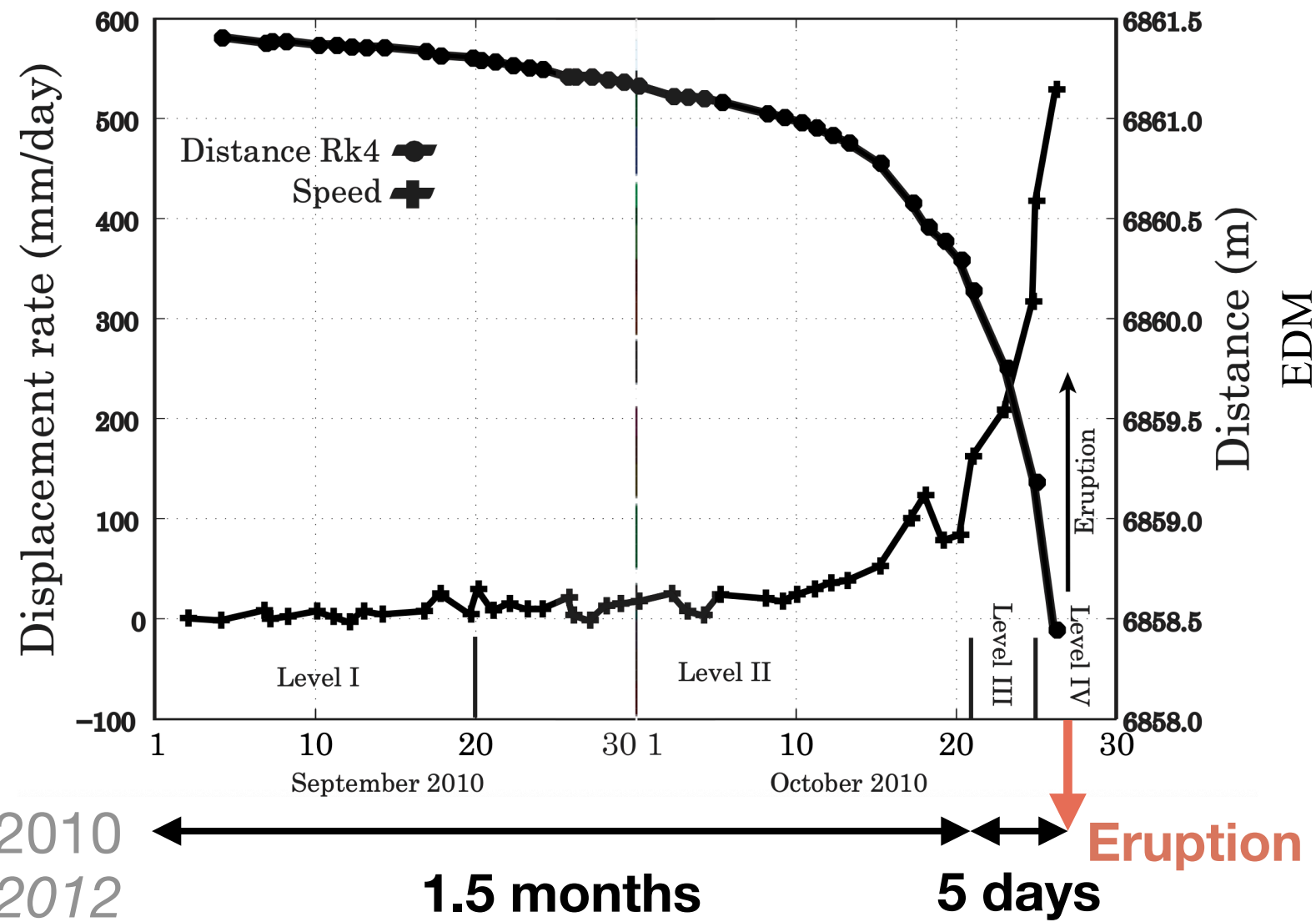
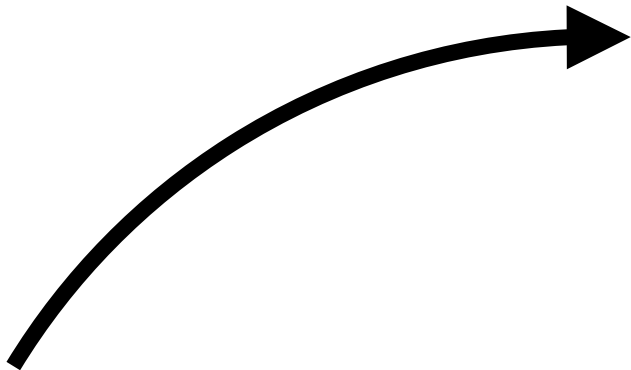
Thibaud Ehret, Gabriele Facciolo, Paul Lundgren, Mary Grace Bato, Aline Peltier, Nicolas Villeneuve, Jean-Luc Froger, Magdalena Oryaëlle Chevrel, Roland Akiki, Jérémy Anger, Carlo de Franchis



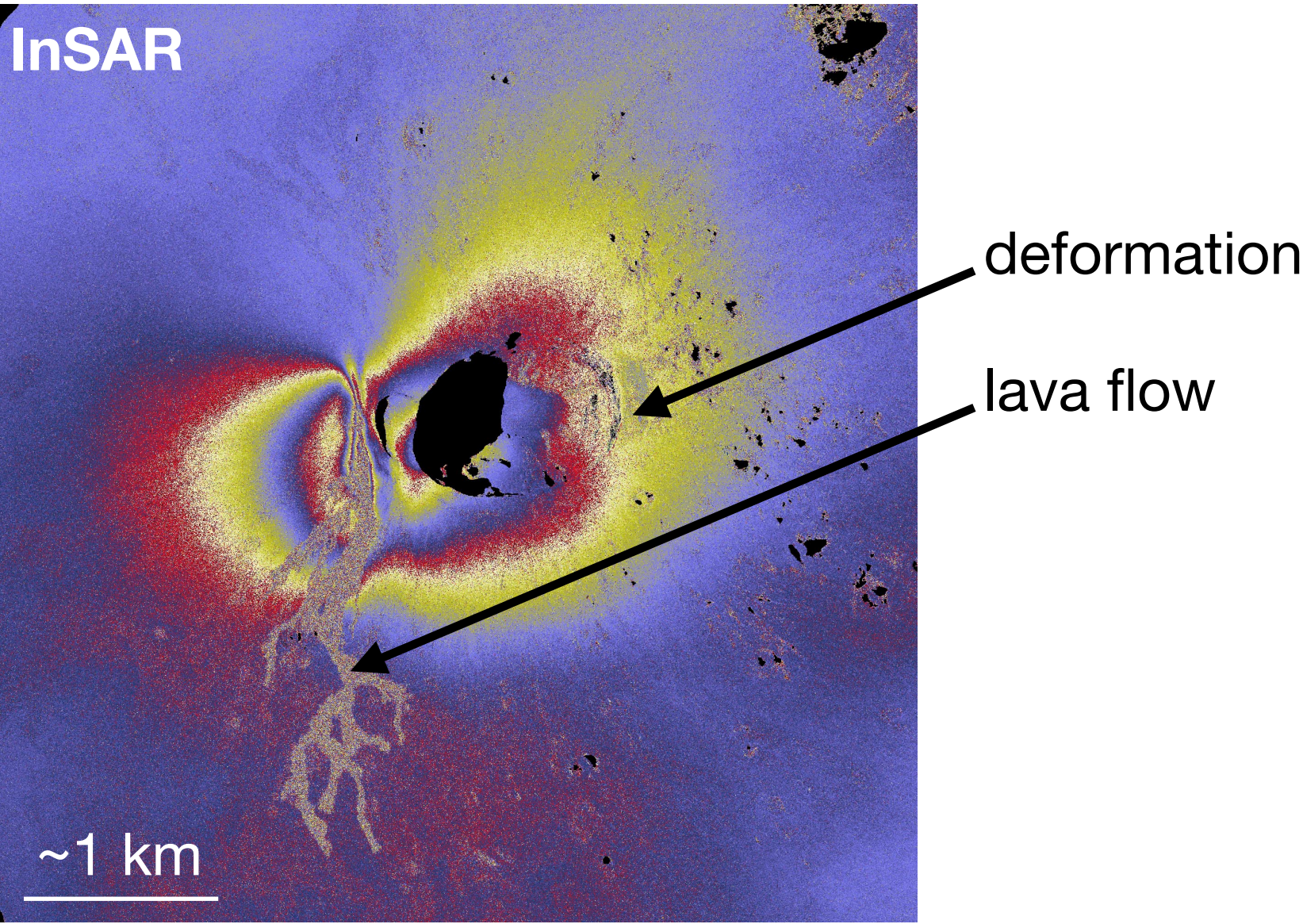
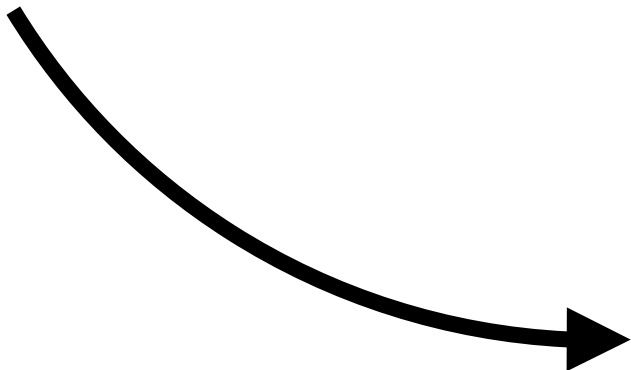
Context



Ground
Daily basis



Space
Weekly basis



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

Problem

How to decrease the revisit time?



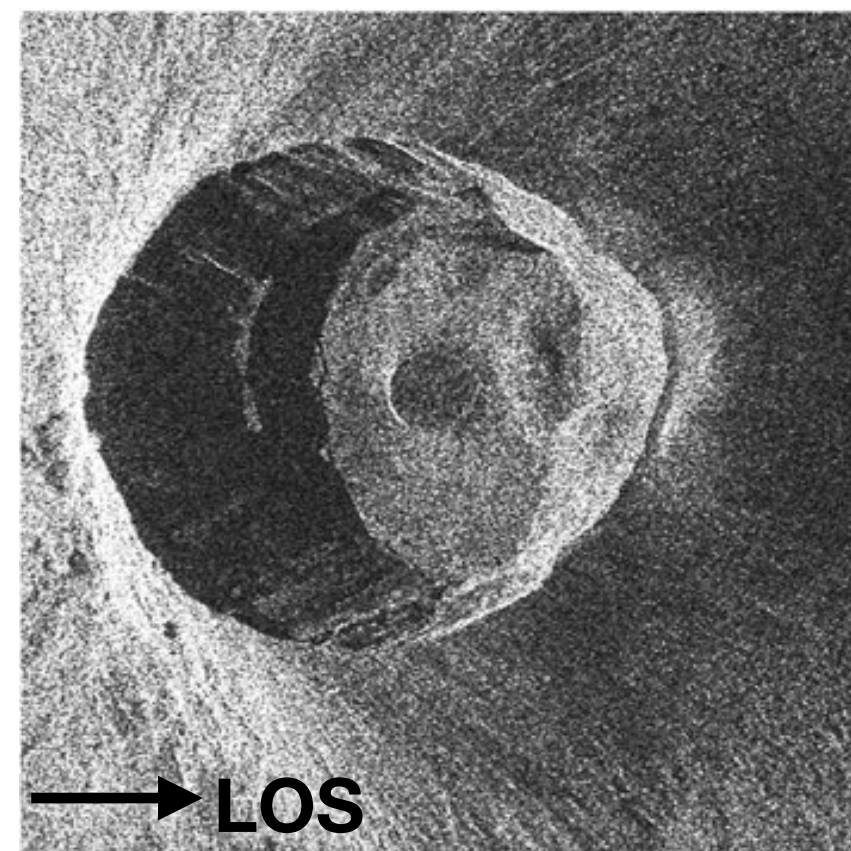
Multi-sensor approach



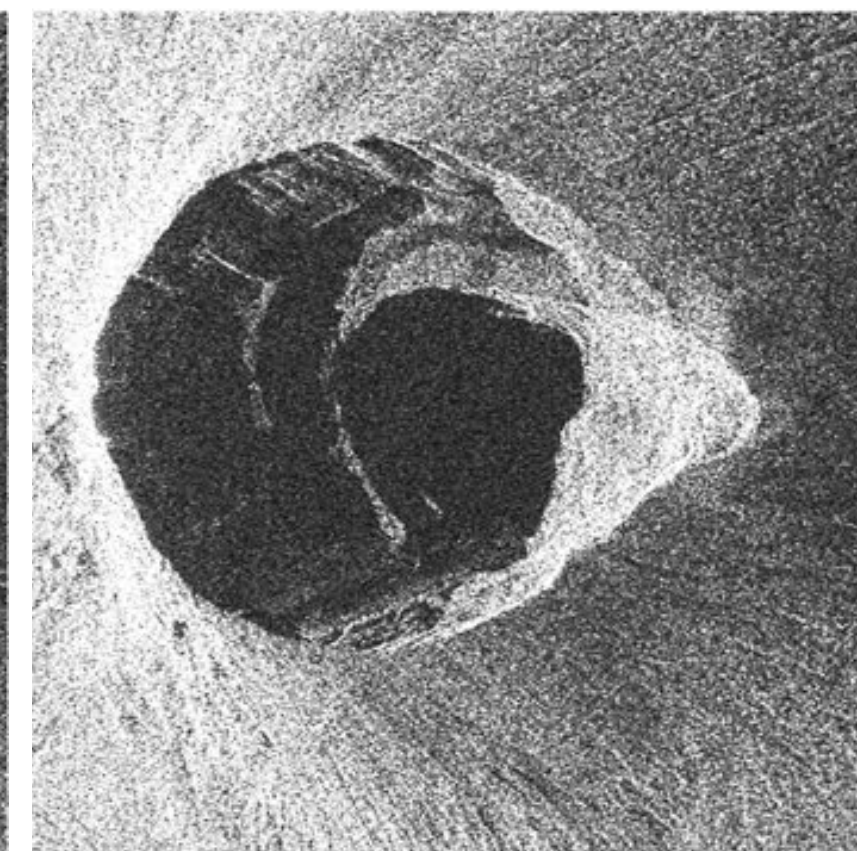
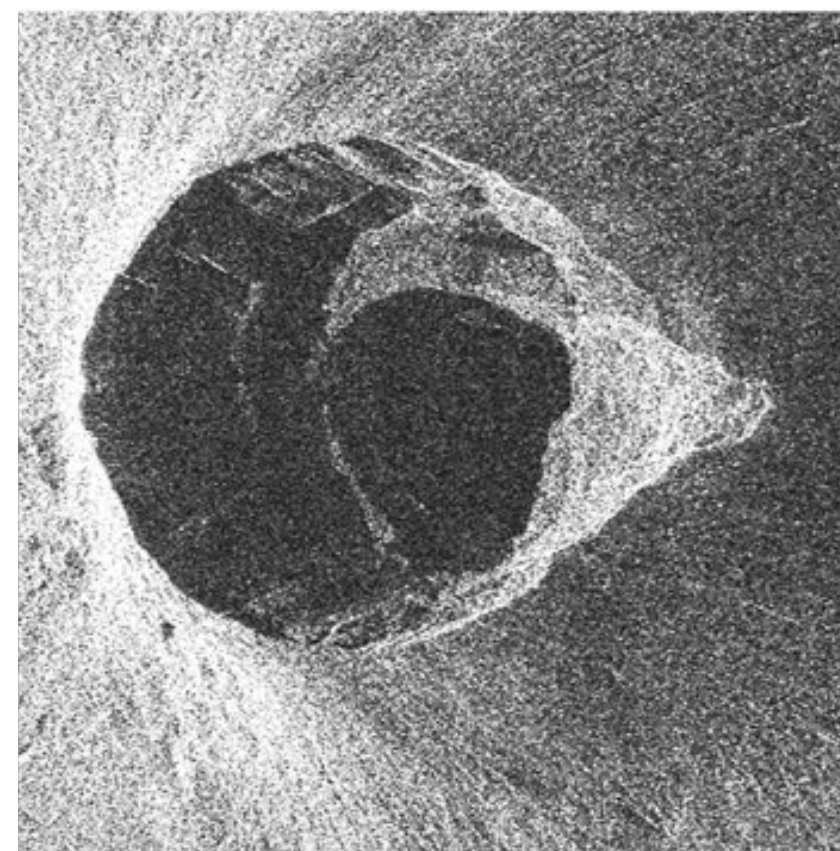
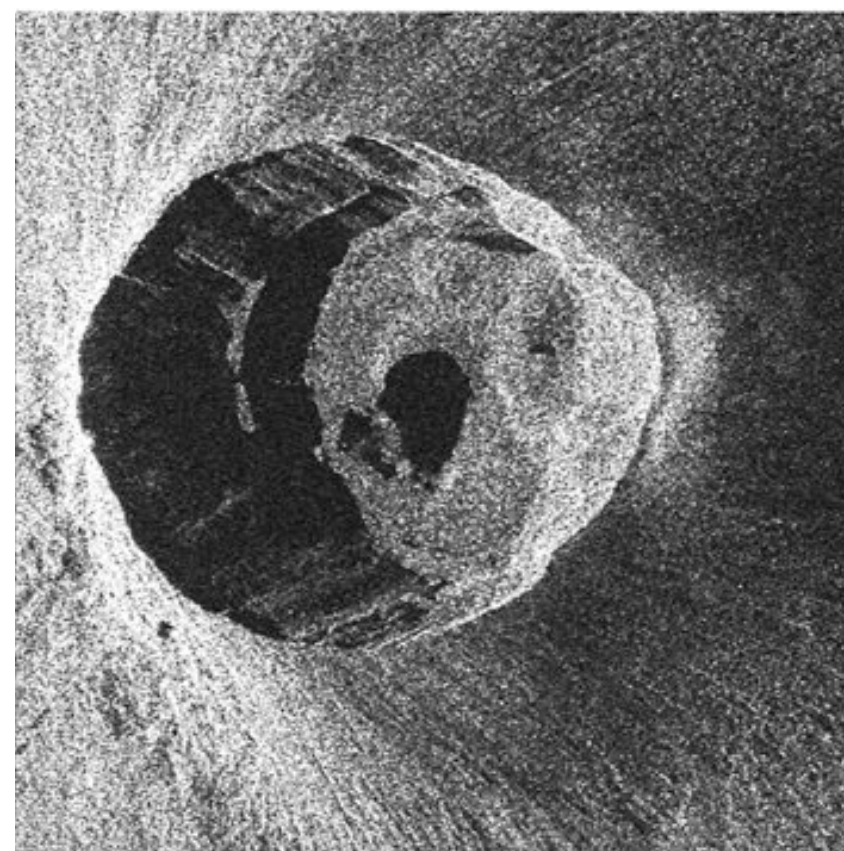
Changing geometry

No reference image

Single sensor / geometry: **weekly**



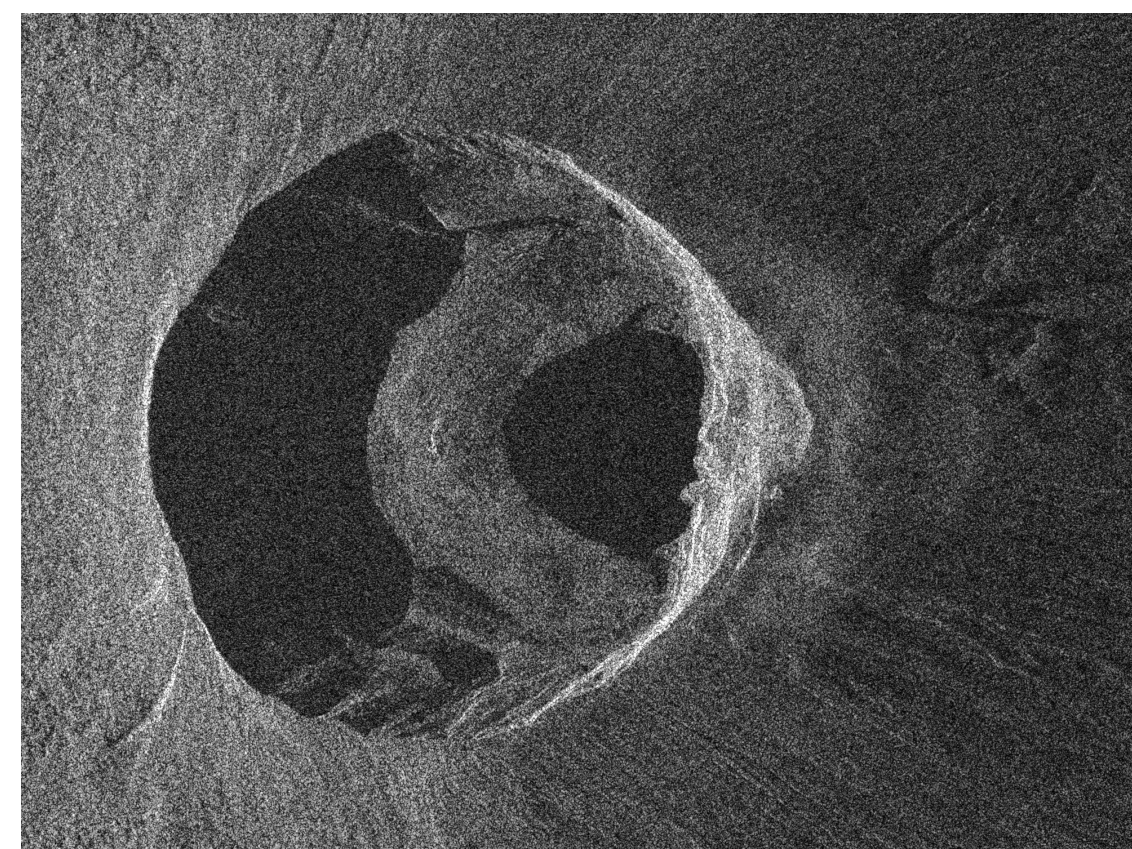
COSMO-SkyMed
 $i = 35^\circ$



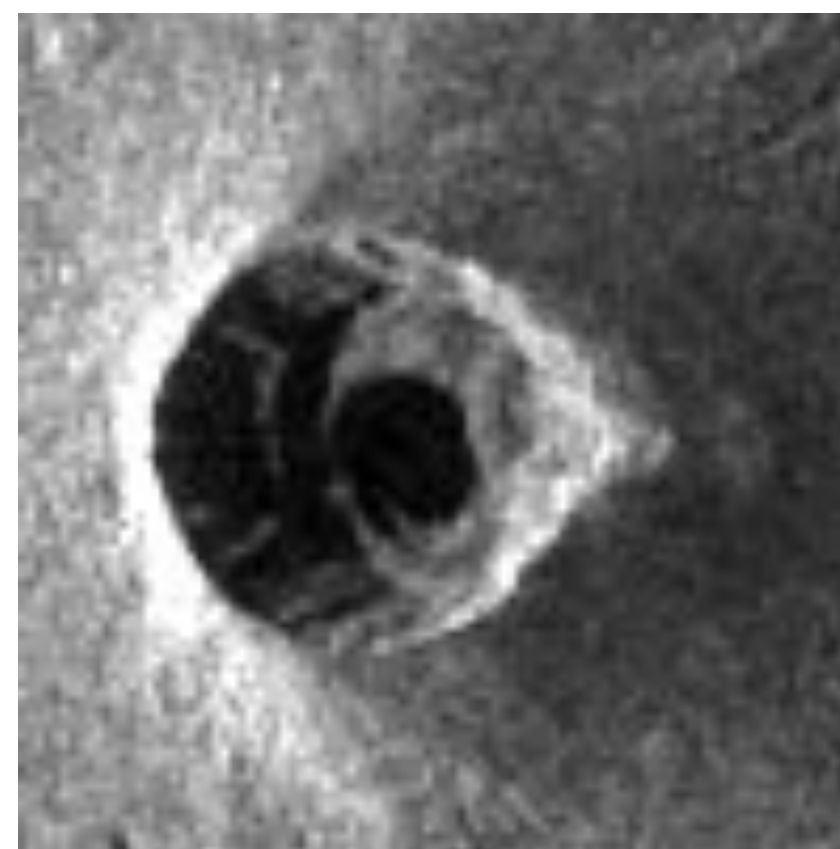
Multiple sensors / geometries: **daily**



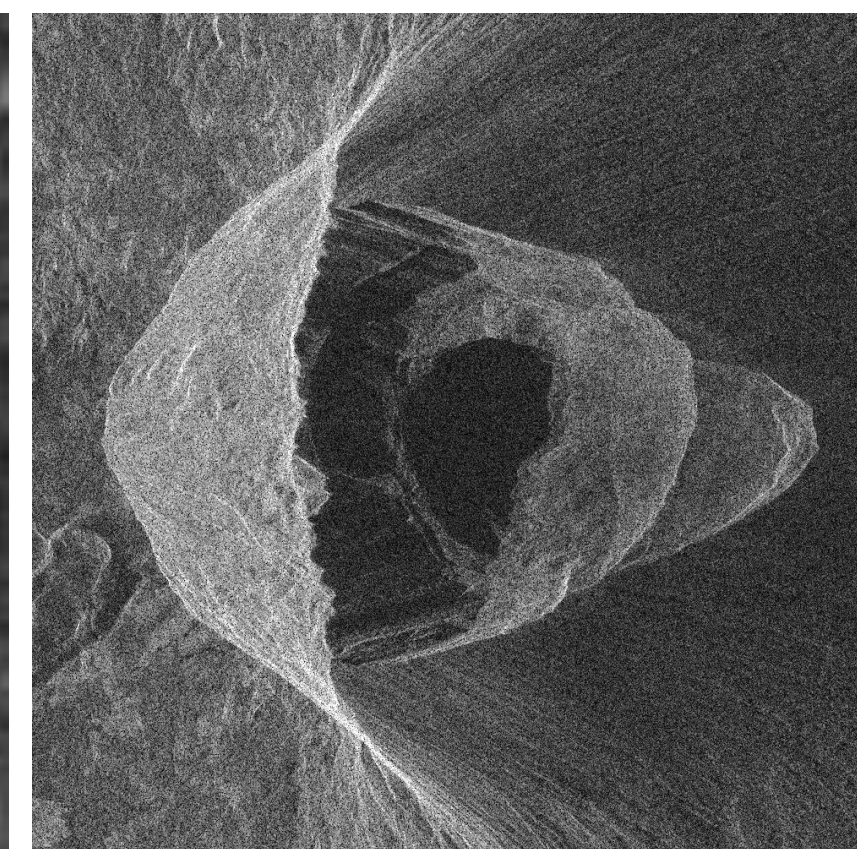
Capella Space
 $i = 30^\circ$



RADARSAT
 $i = 41^\circ$



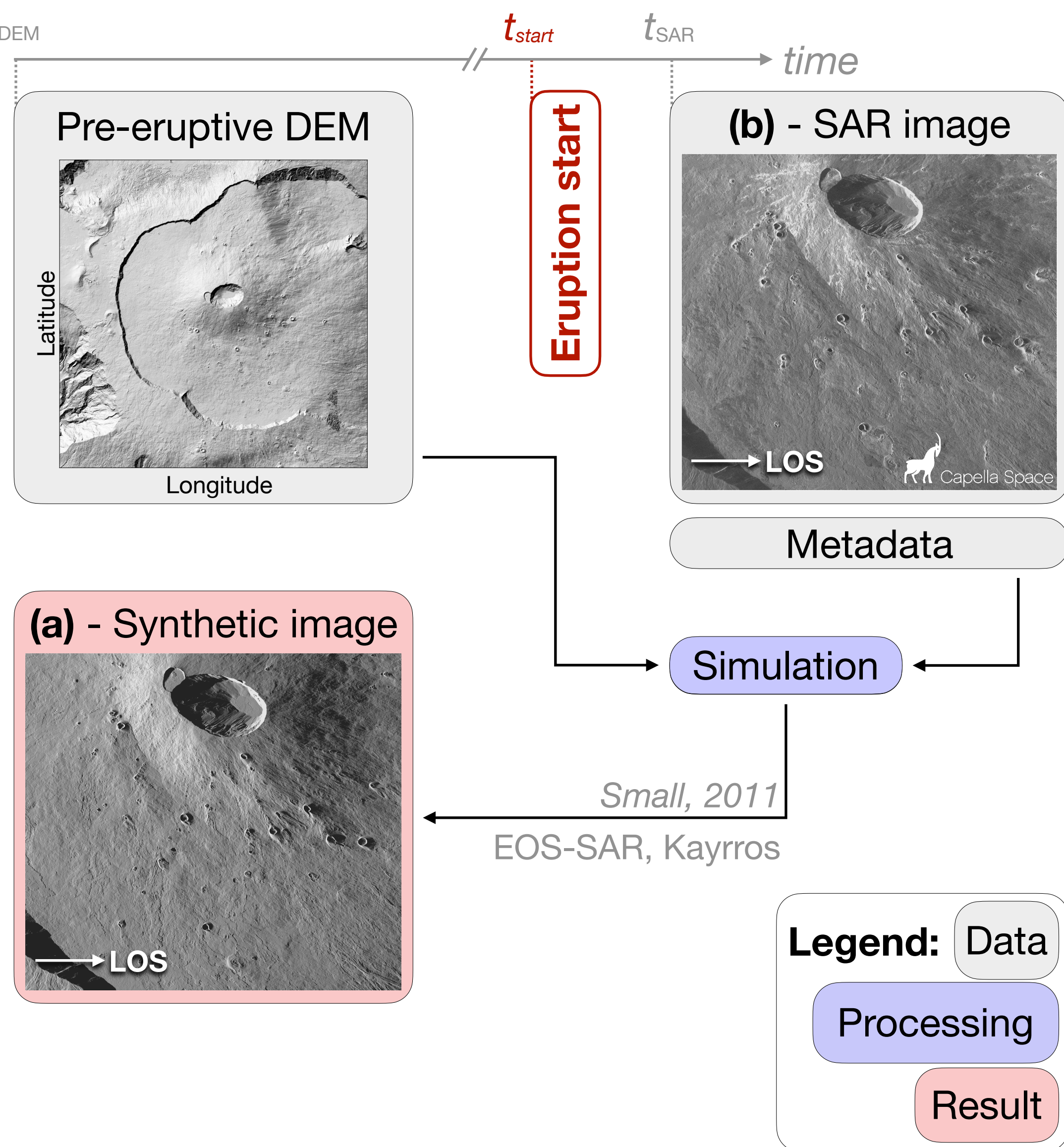
Sentinel-1
 $i = 38^\circ$



ICEYE
 $i = 24^\circ$

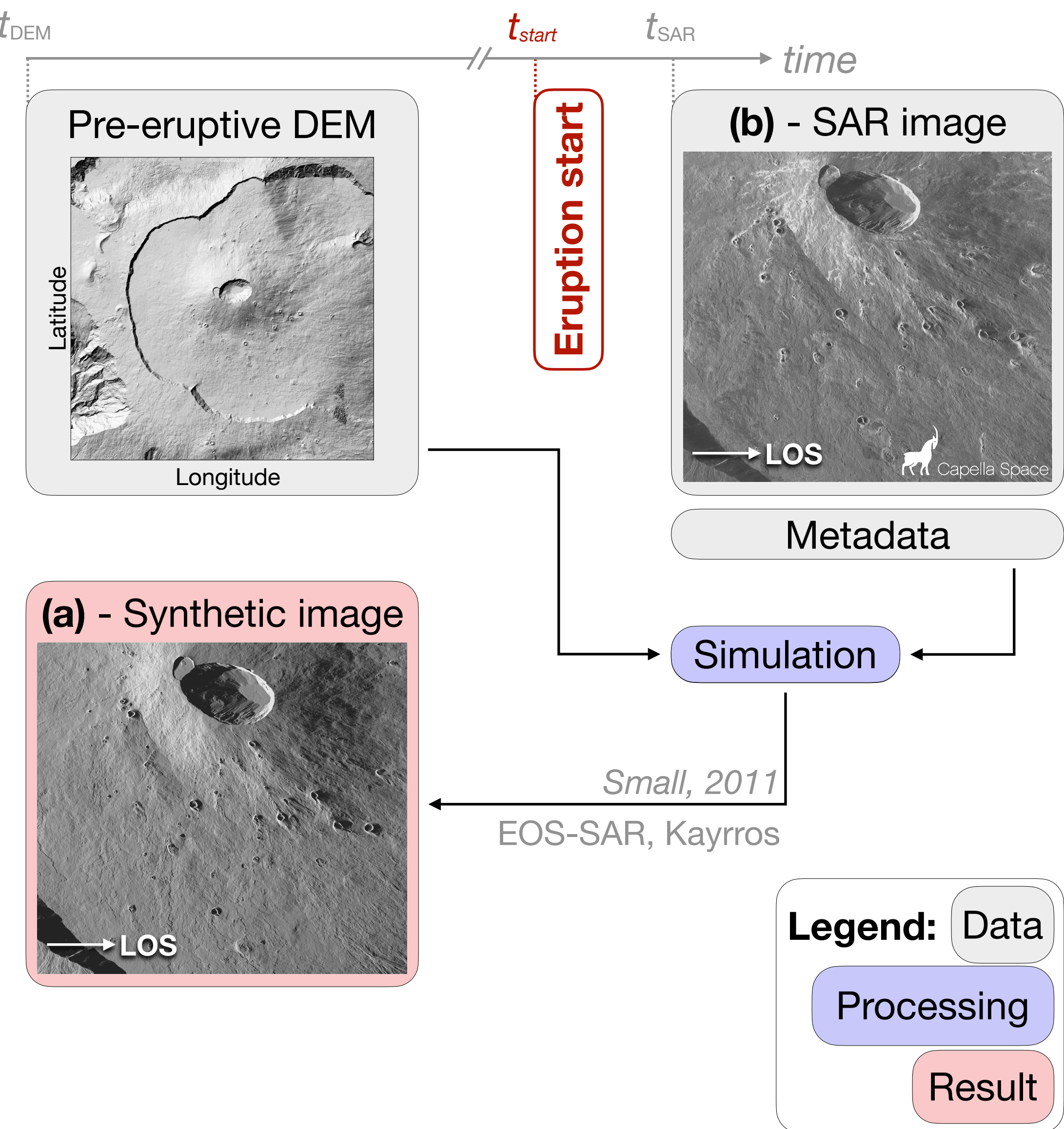
Method

SAR simulation

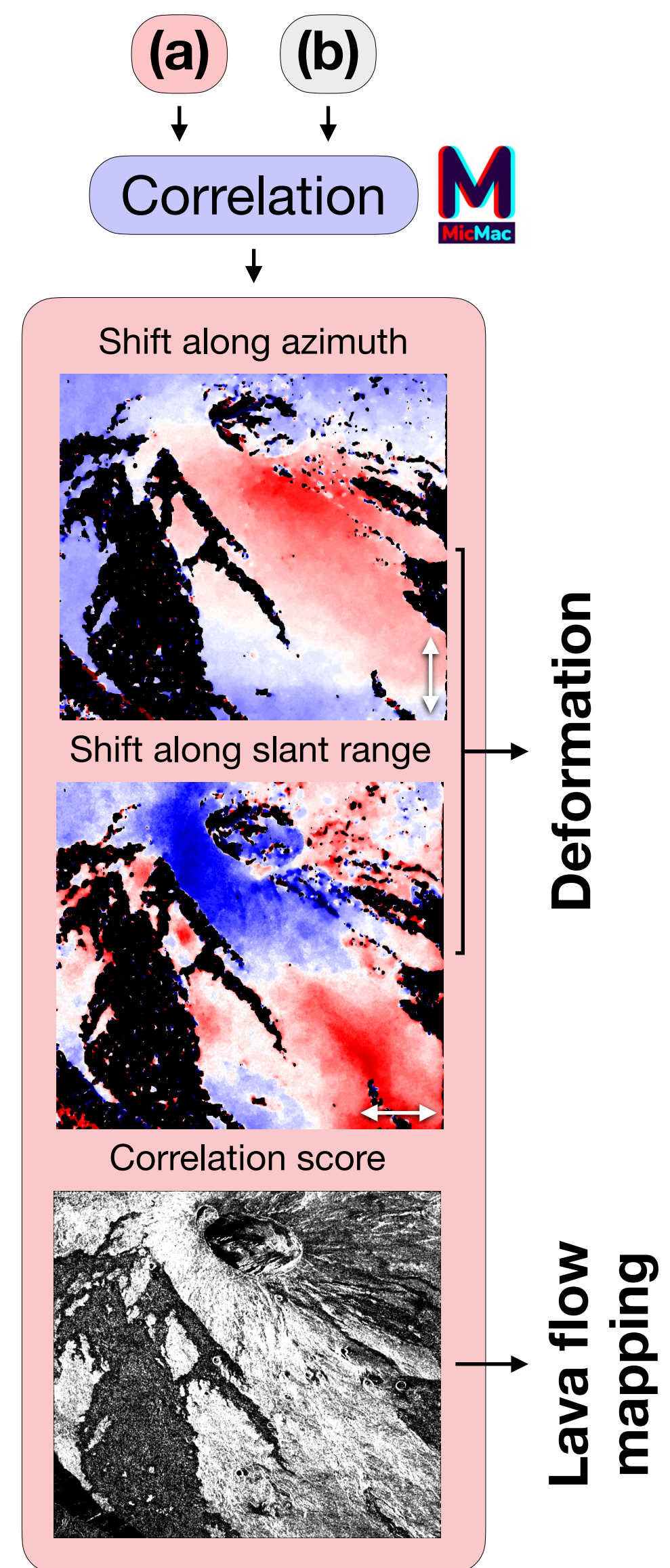


Method

SAR simulation

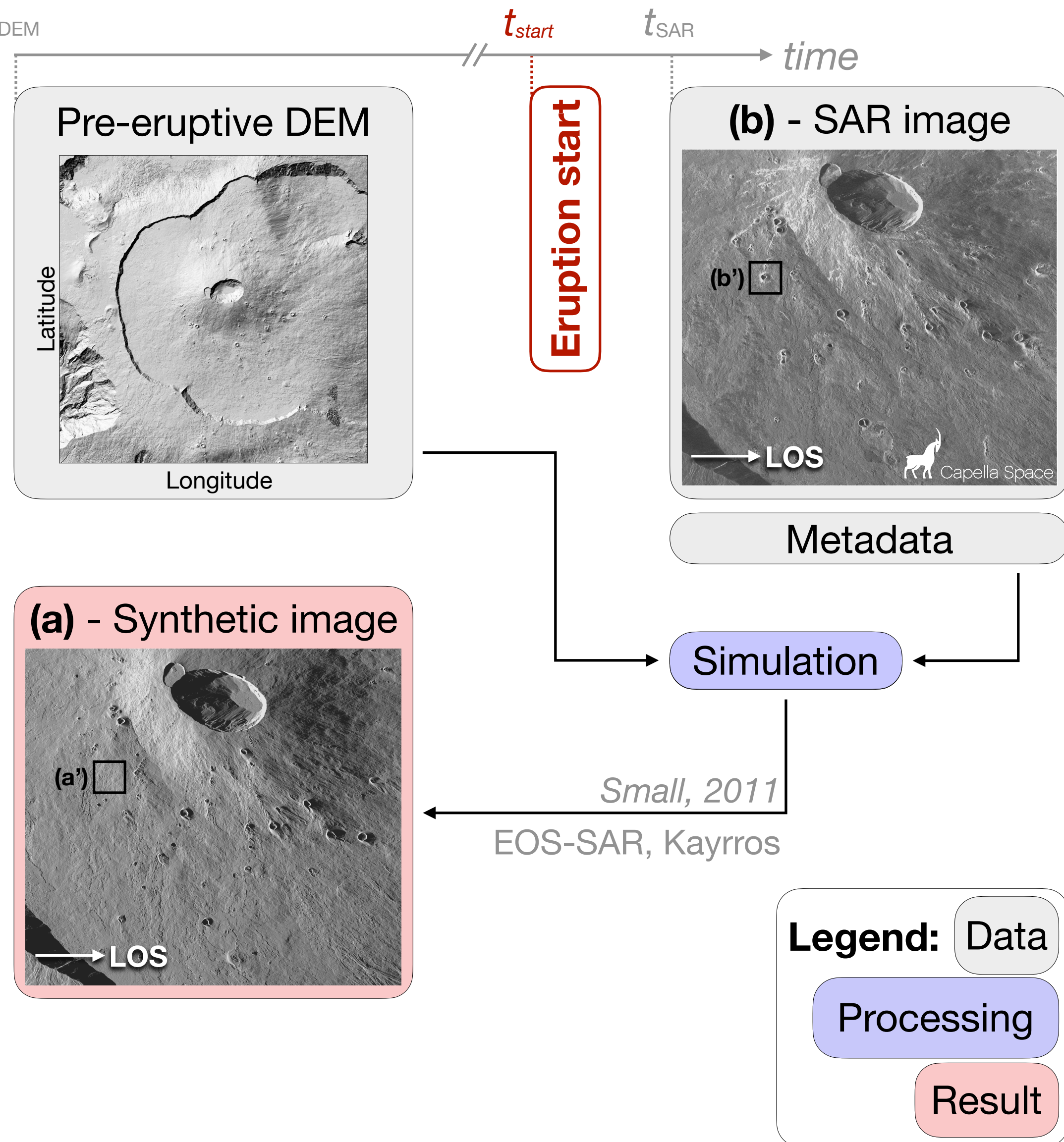


Change detection

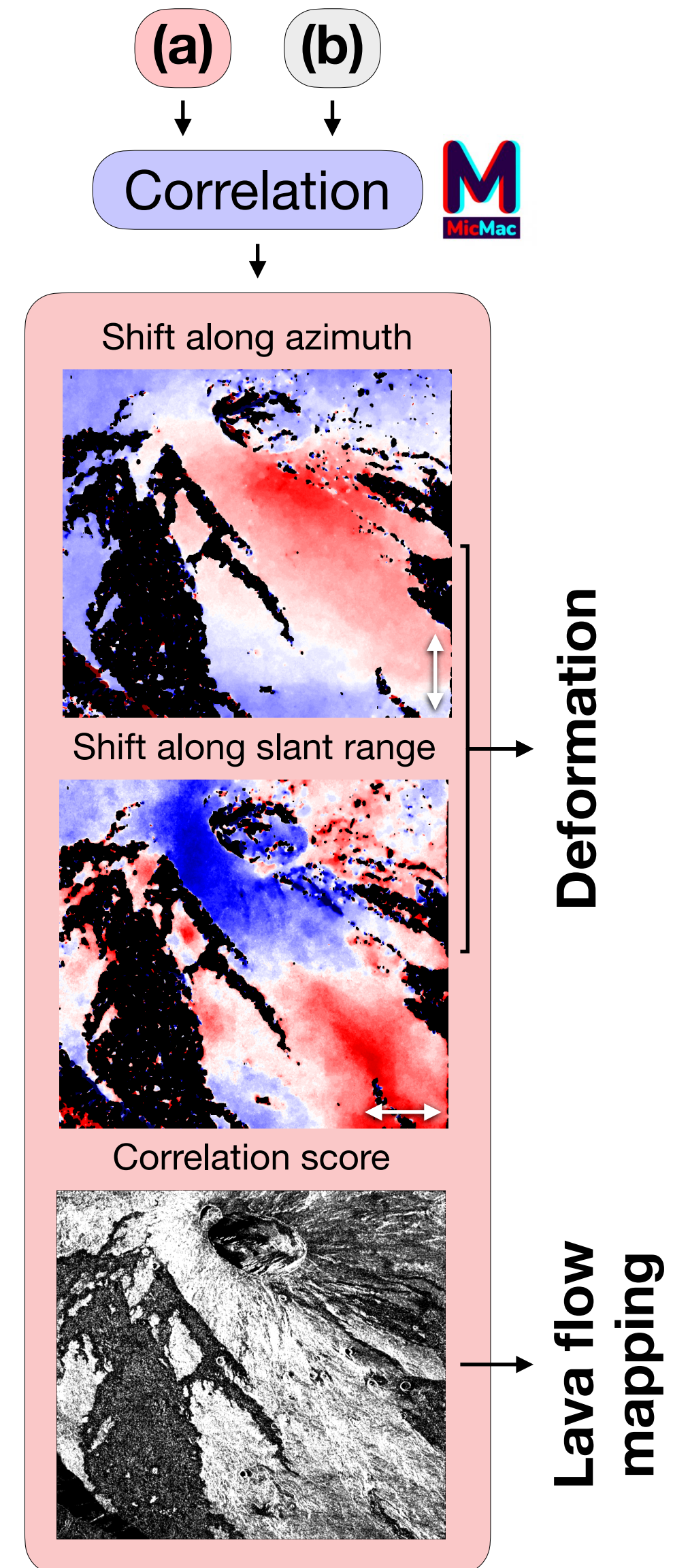


Method

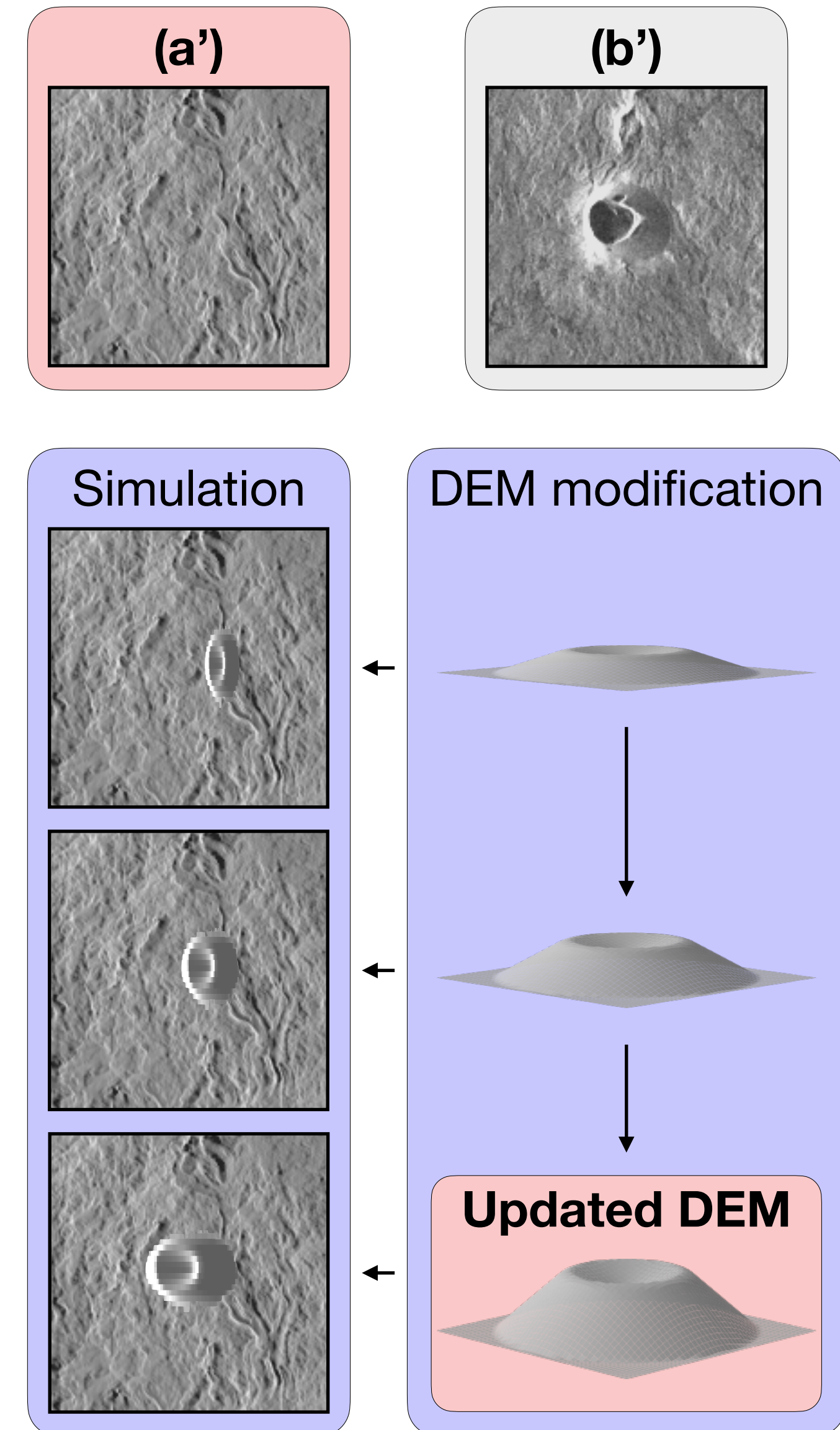
SAR simulation



Change detection

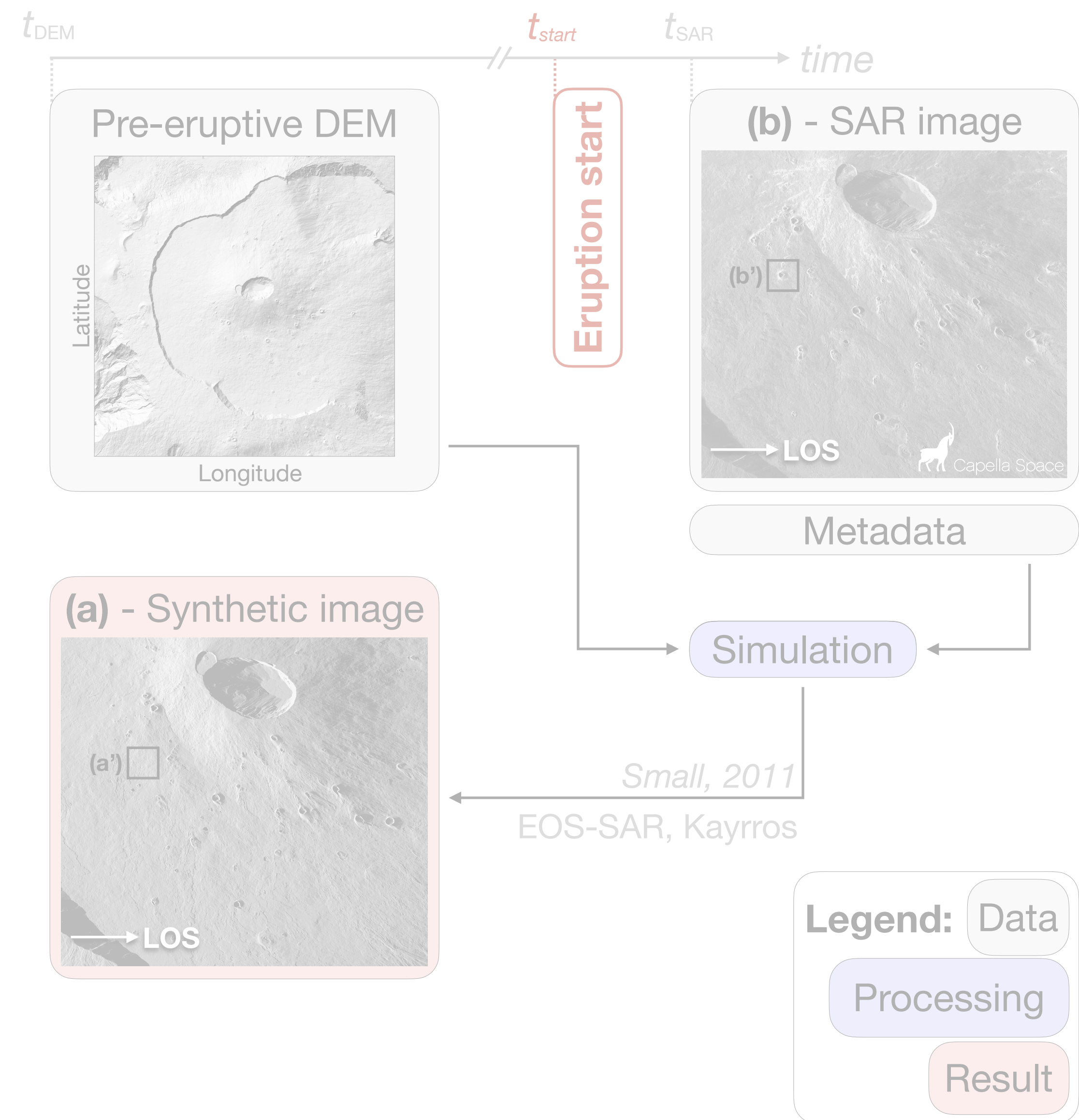


3D reconstruction

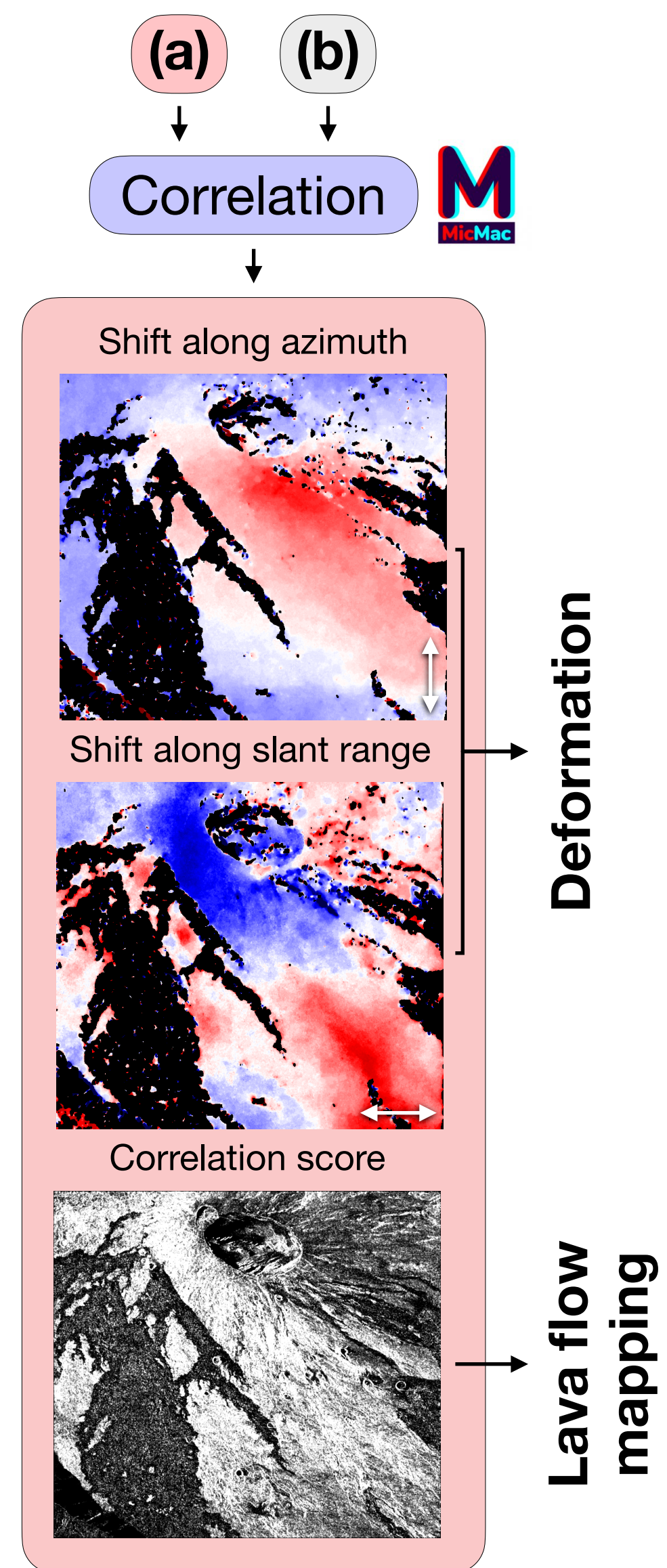


Method

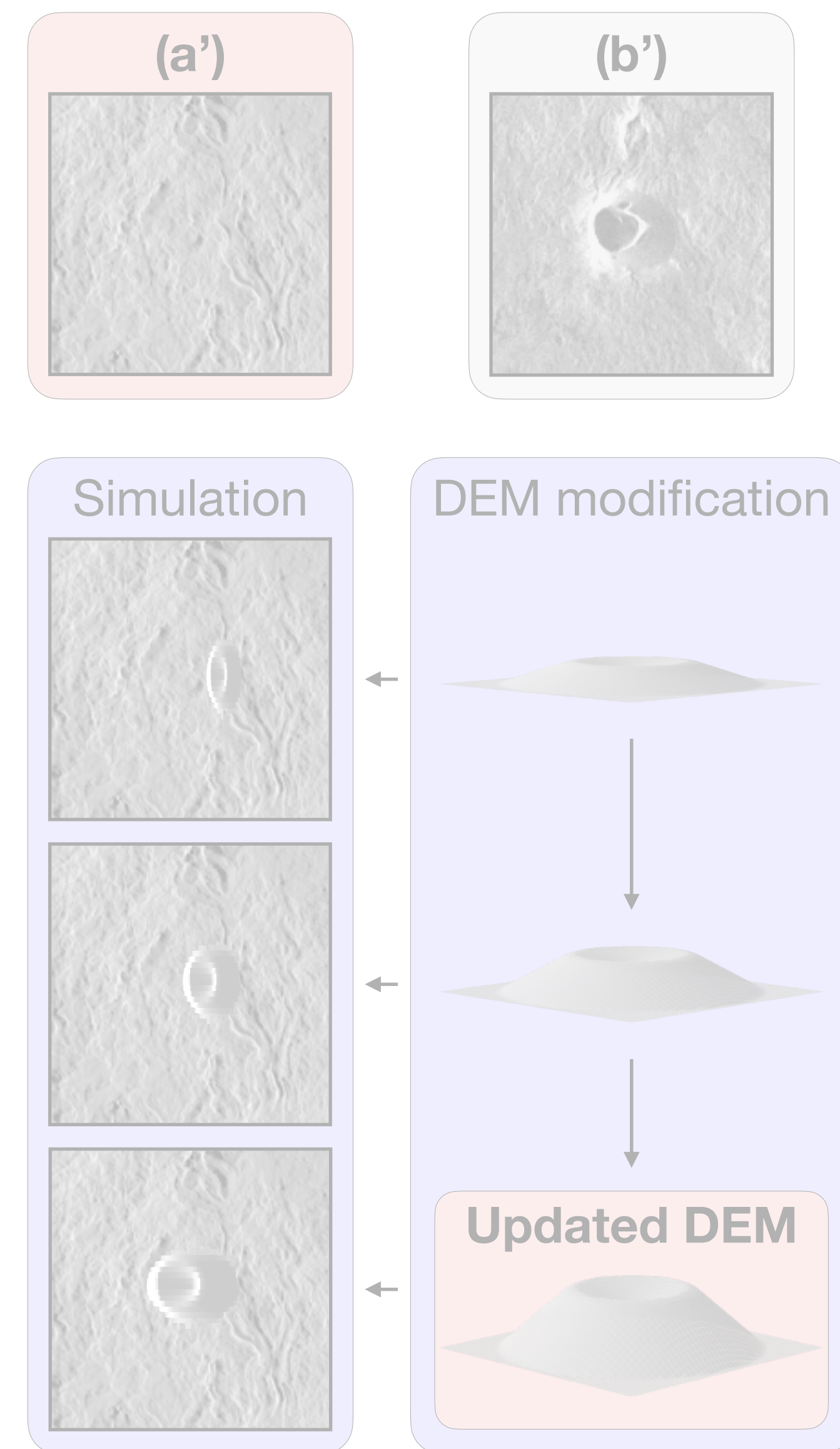
SAR simulation



Change detection

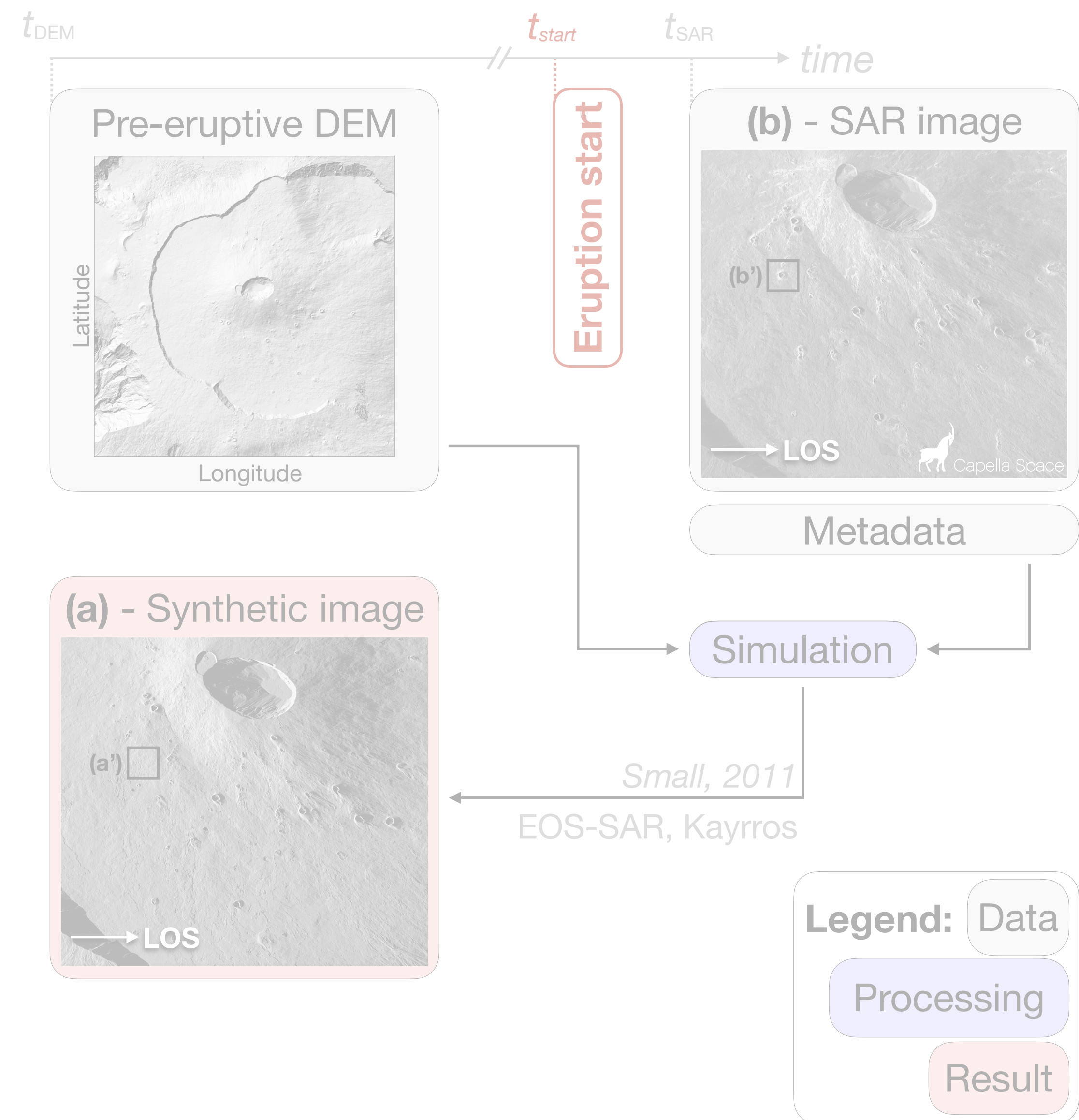


3D reconstruction

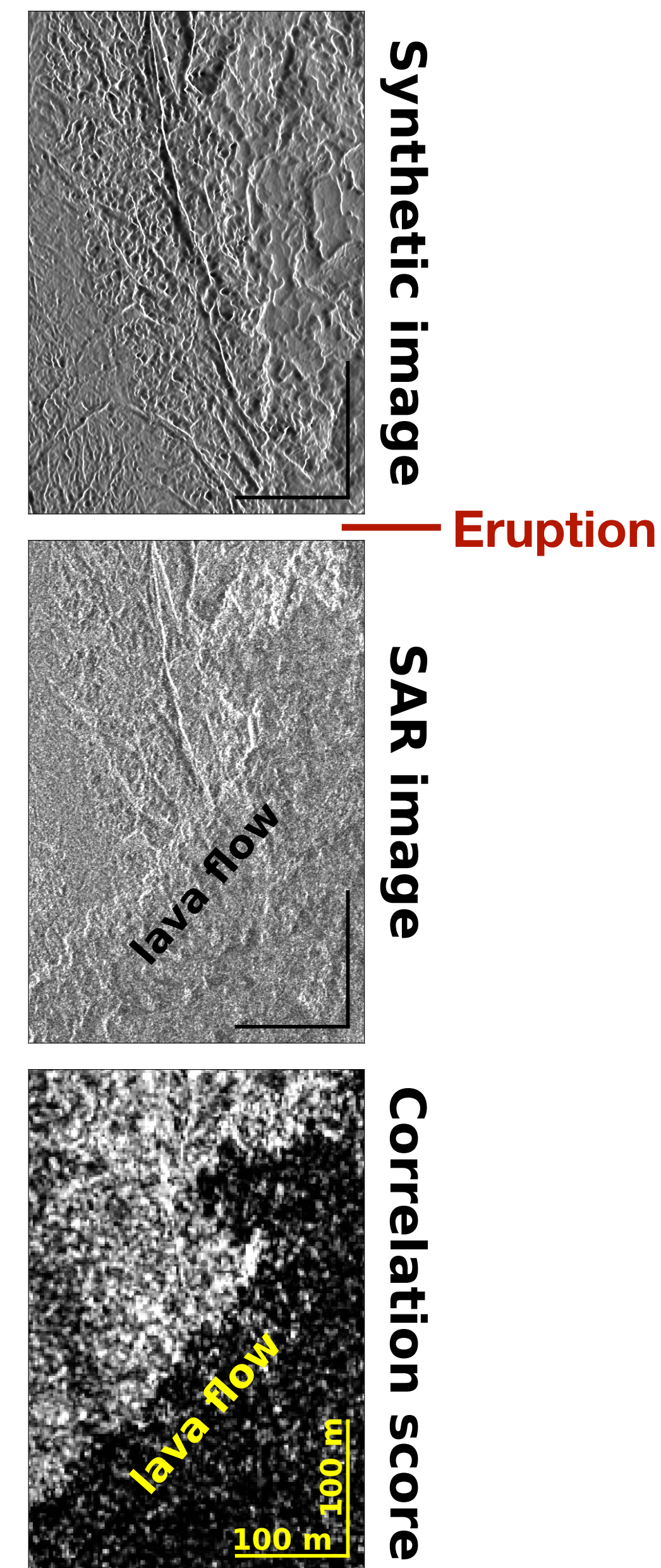
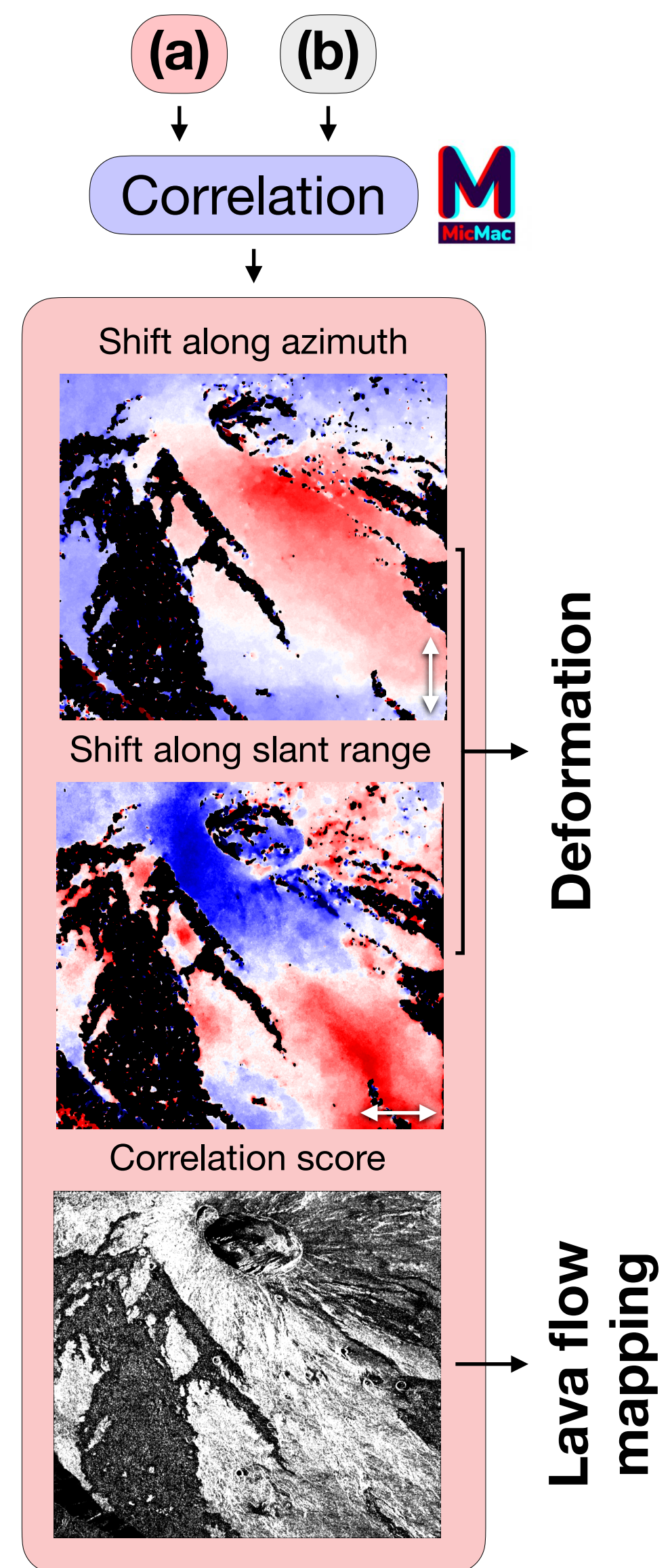


Method

SAR simulation



Change detection

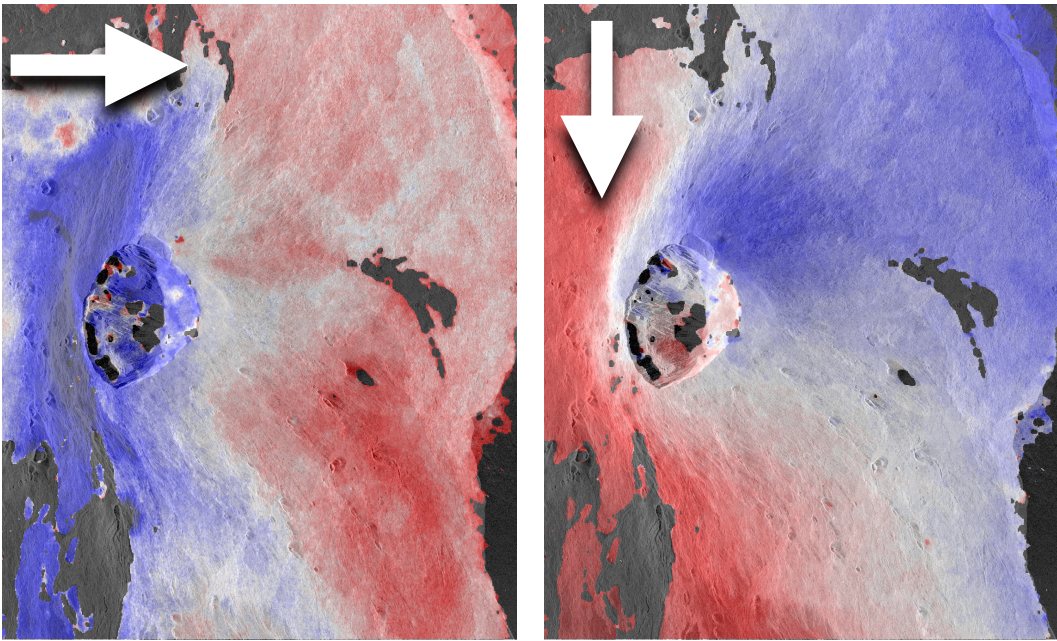


1 Deformation

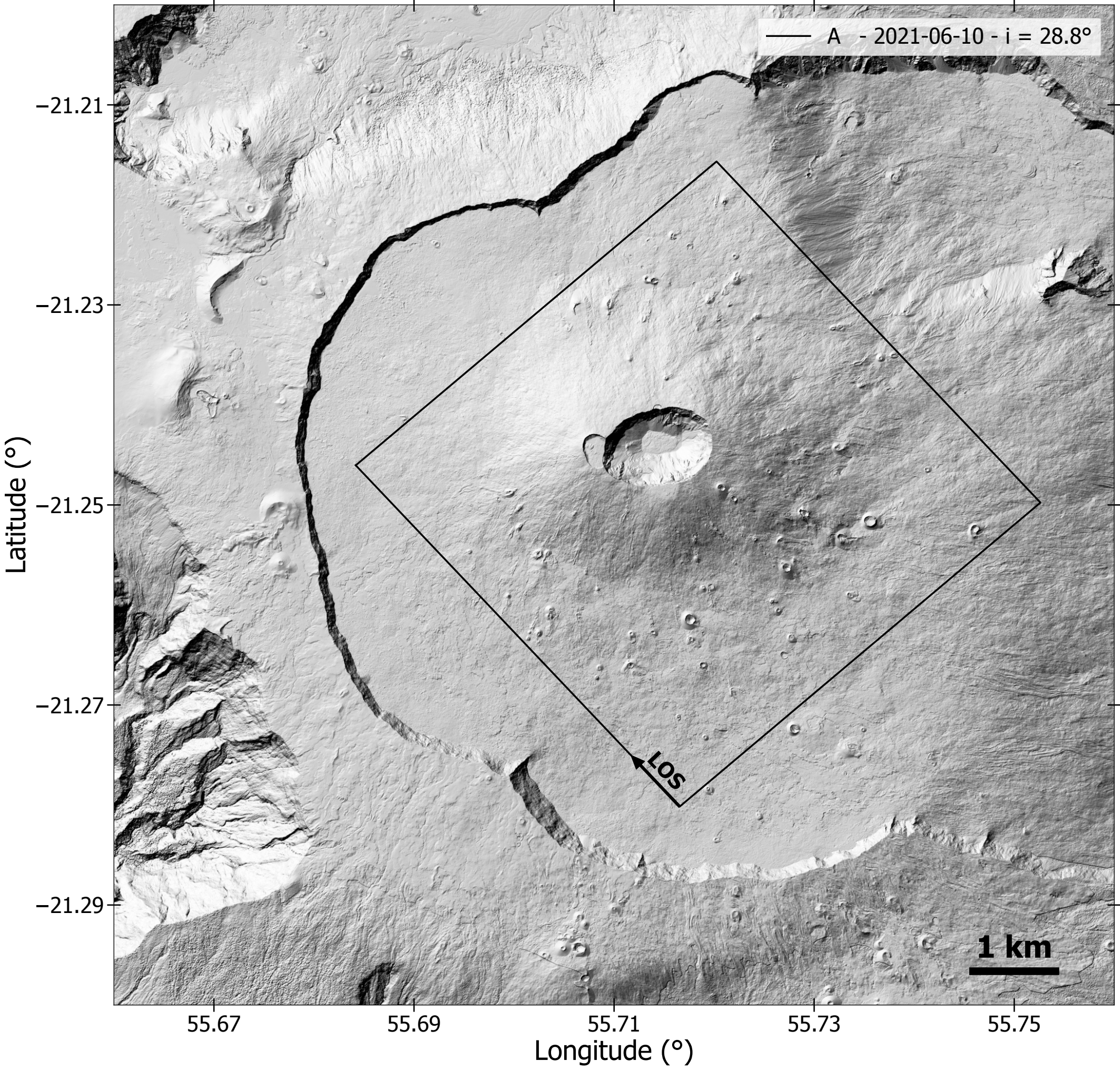


LOS

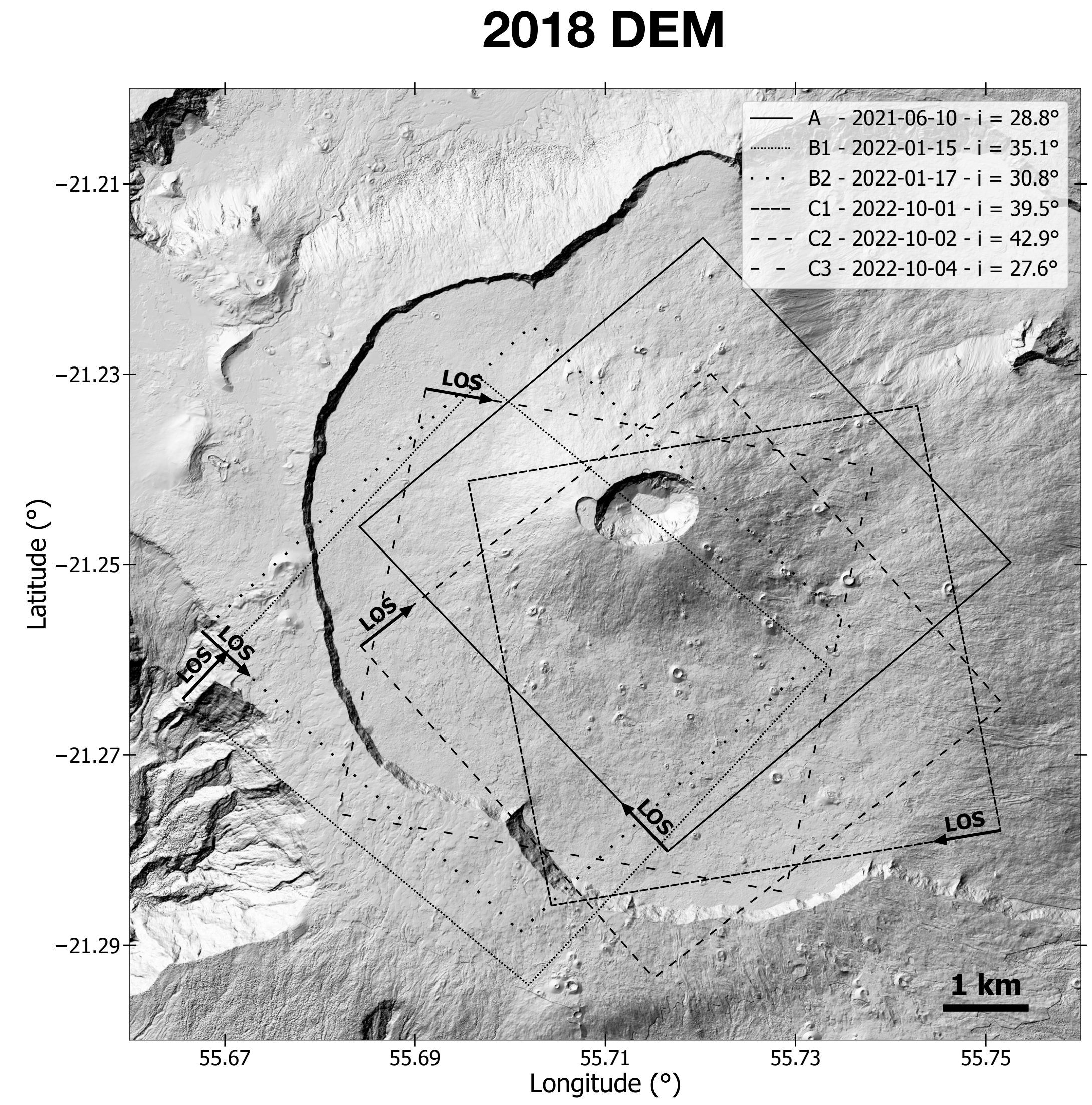
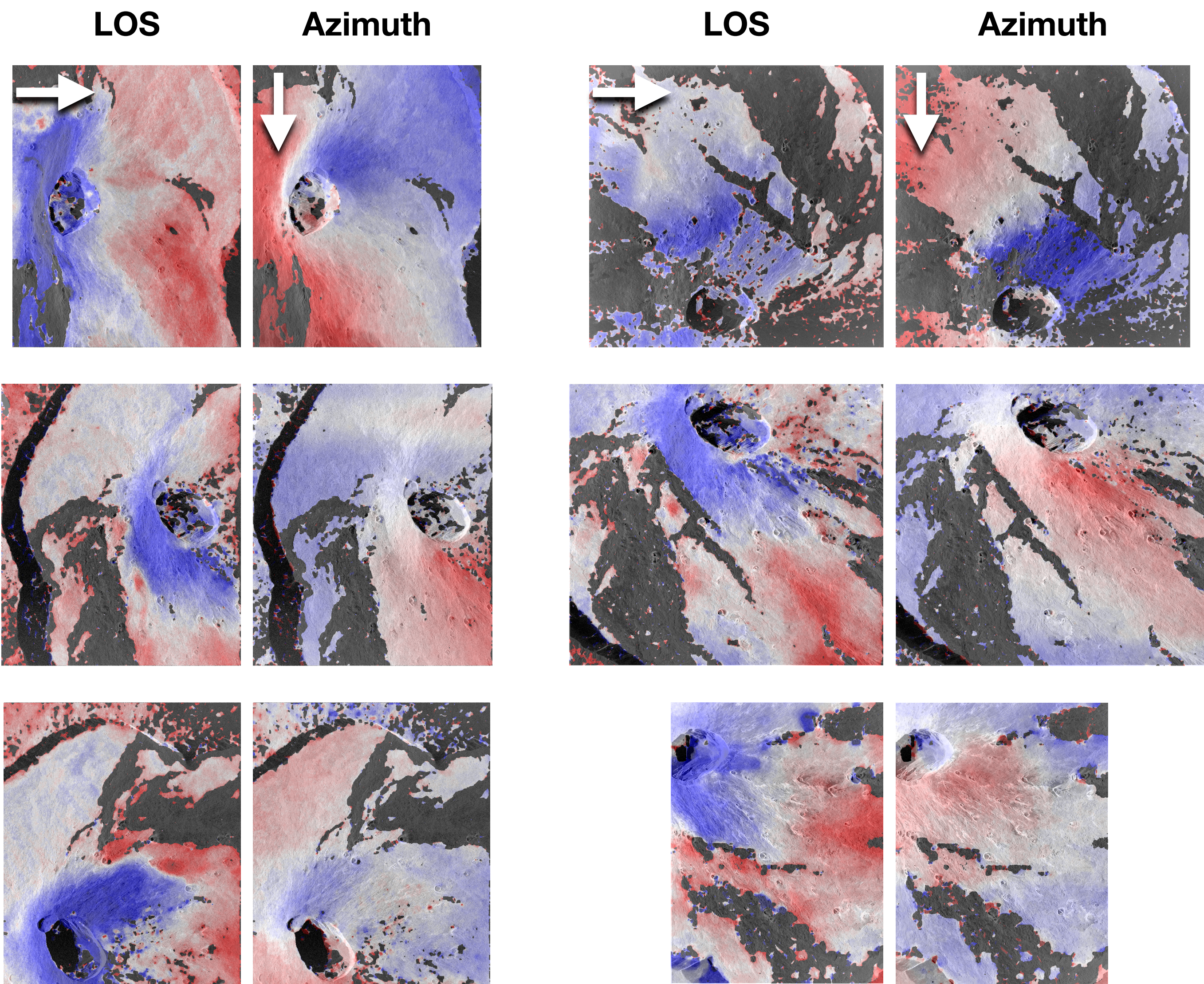
Azimuth



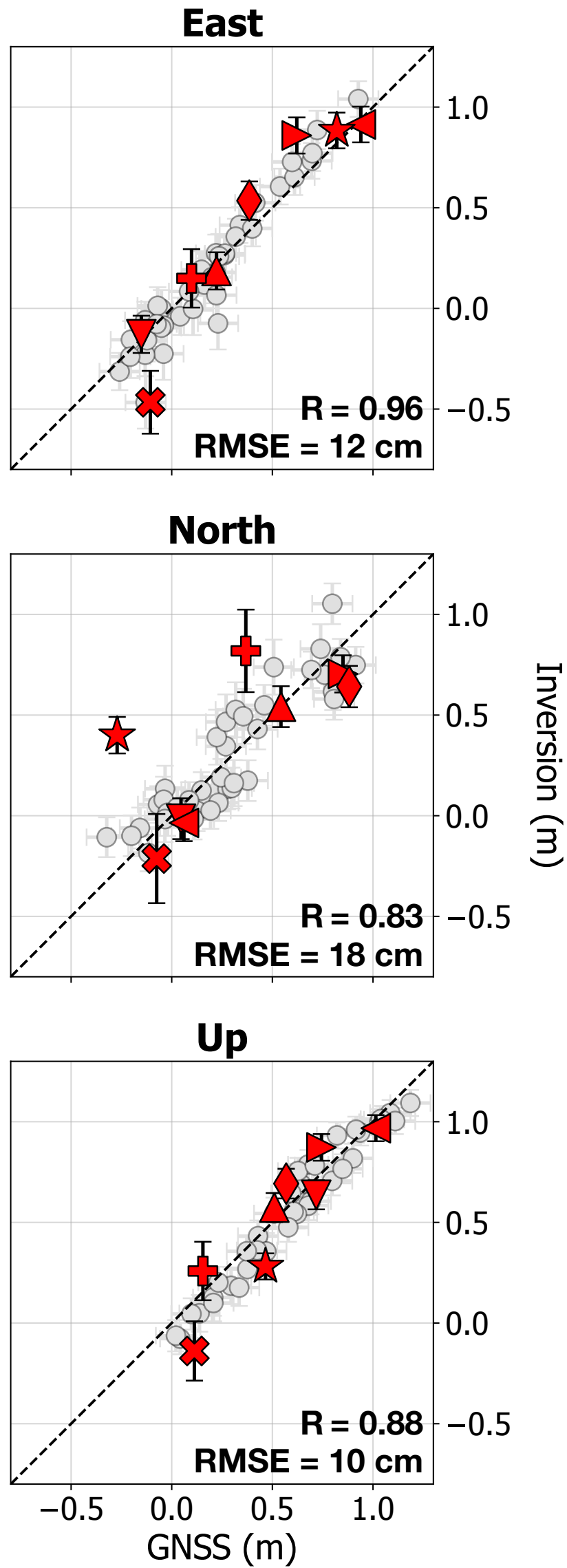
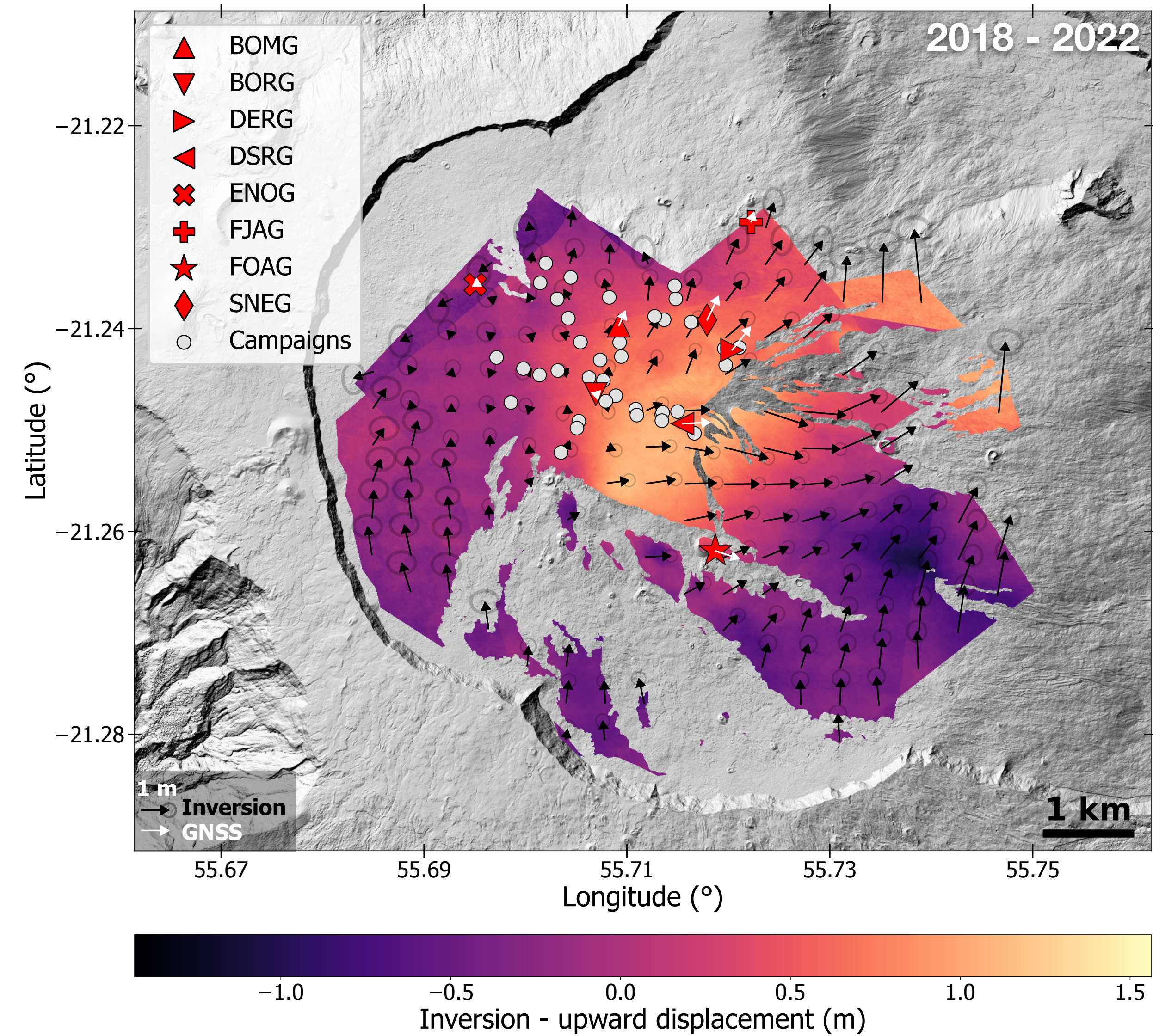
2018 DEM



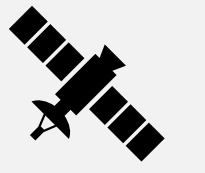
1 Deformation



1 Deformation



Comparison with other methods

	GNSS	InSAR	Our method
Δt	1 s	10 days	1 day
ΔX	1 mm	1 cm	10 cm
$\Delta X_{\max}$	No	$\lambda/2$ / px	No
	Yes	No	No
	No	Yes	Yes

2D mapping

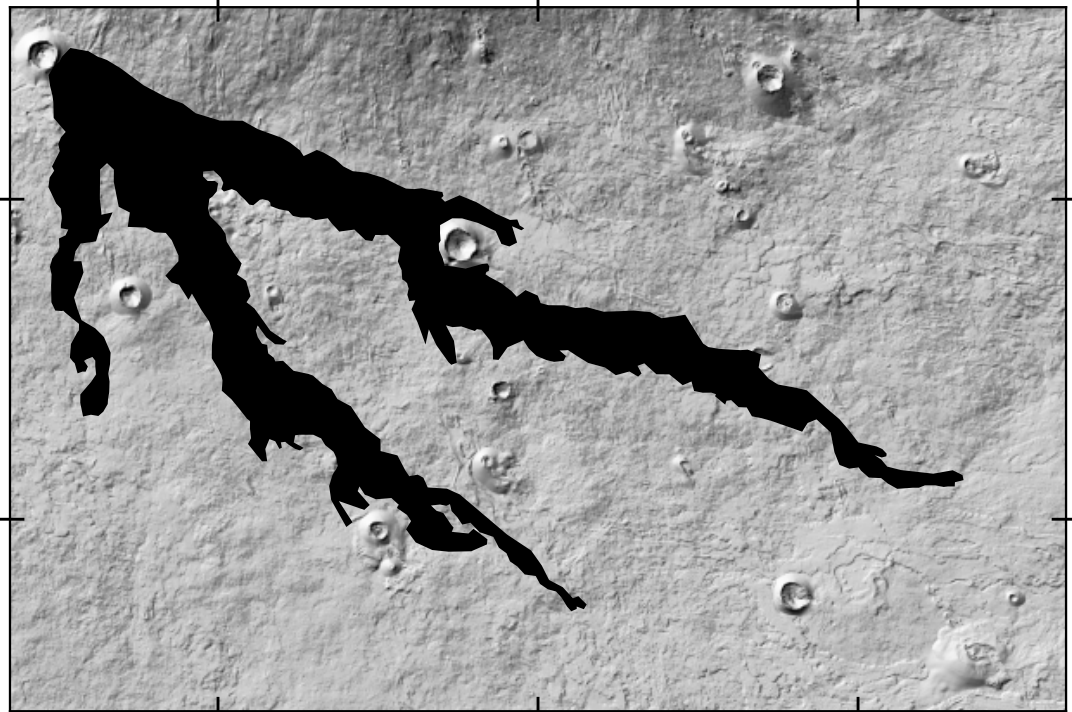
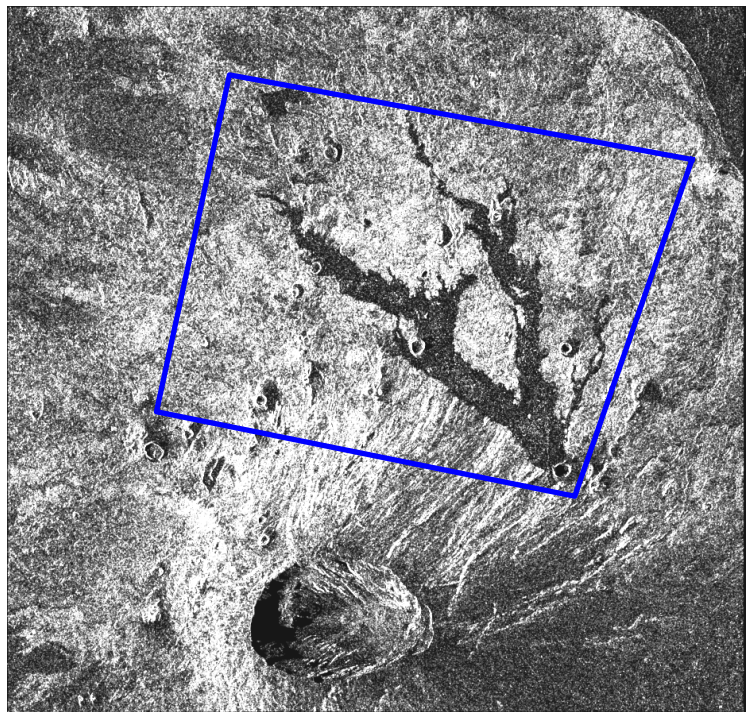
Correlation score

Chevrel et al., 2023

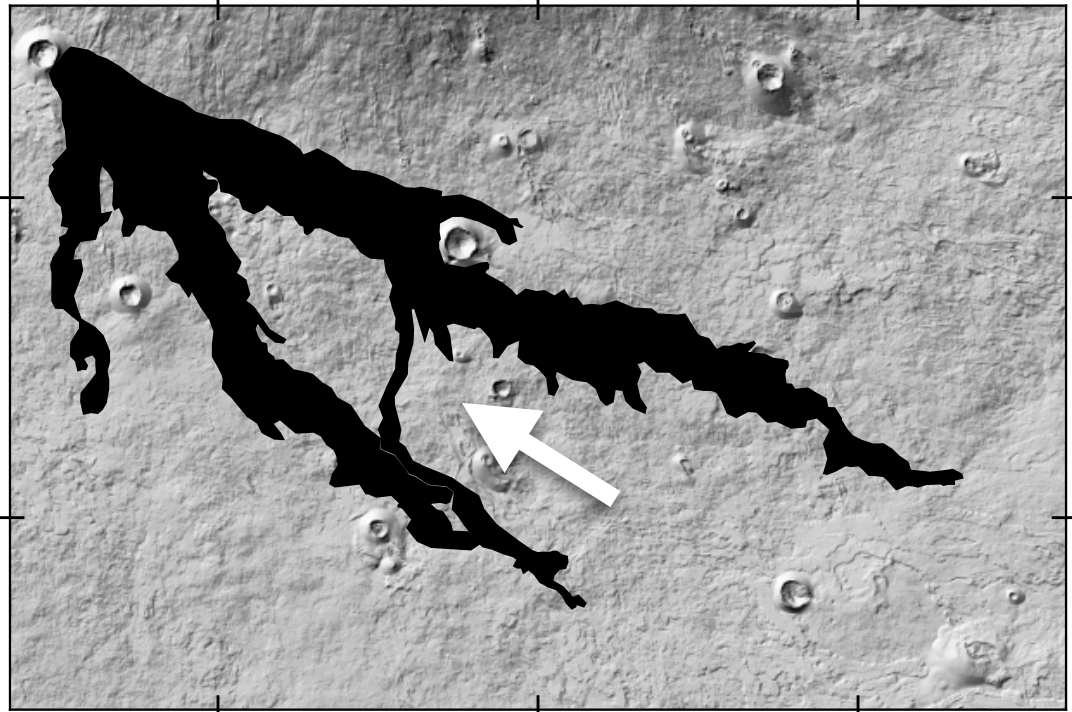
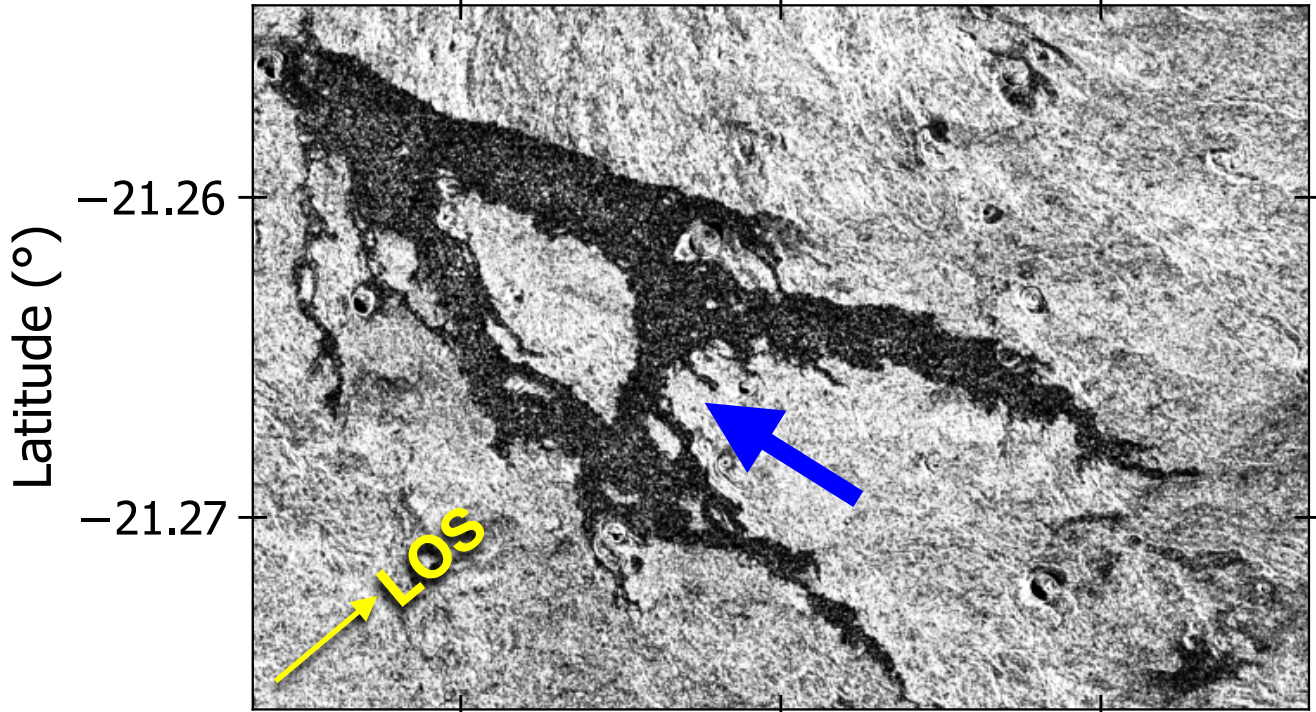
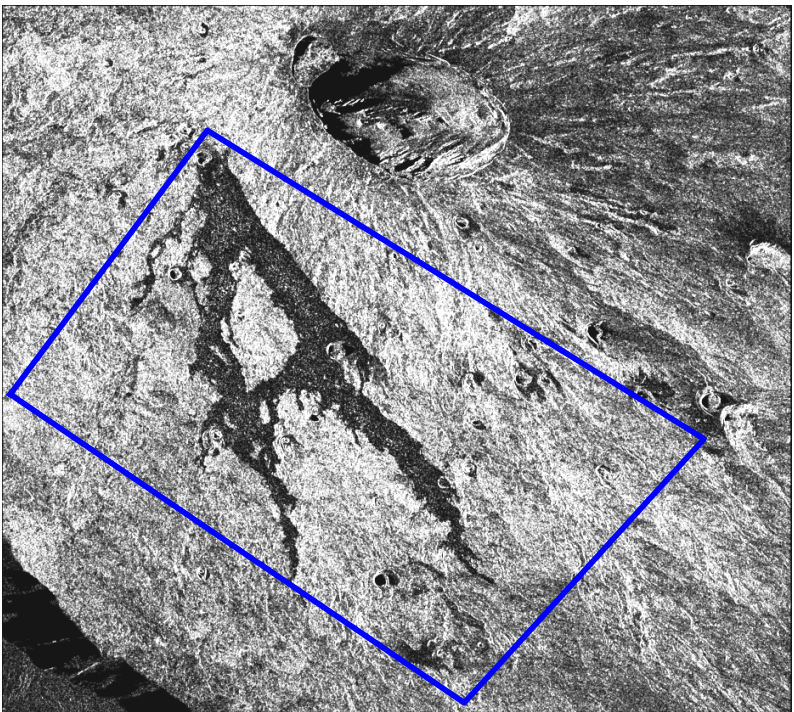
Ground truth



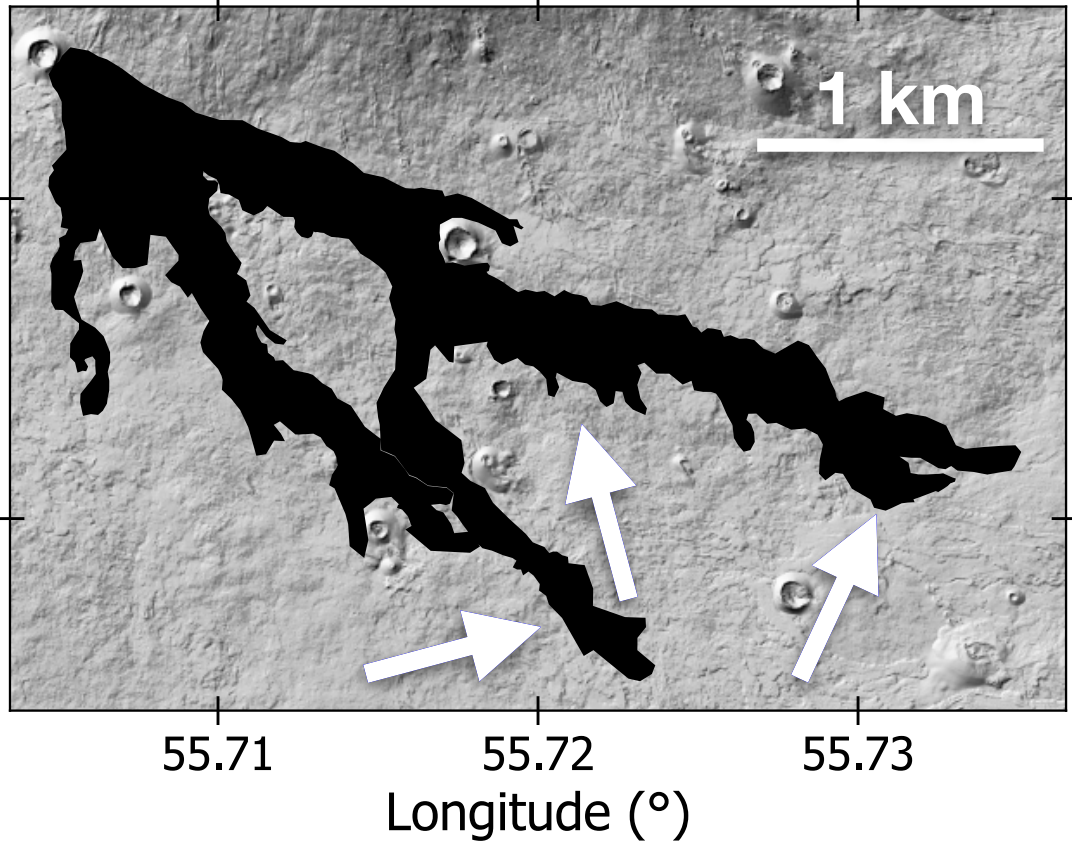
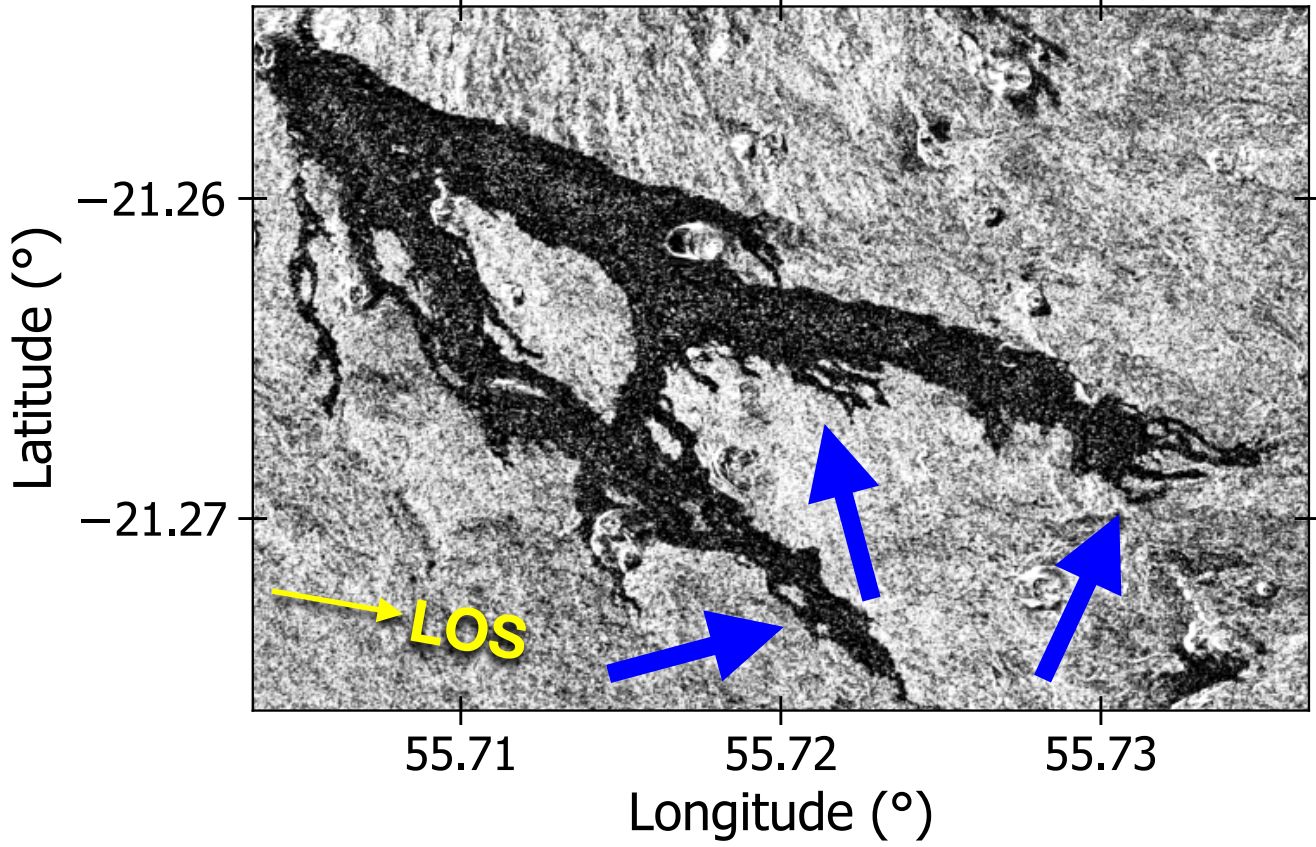
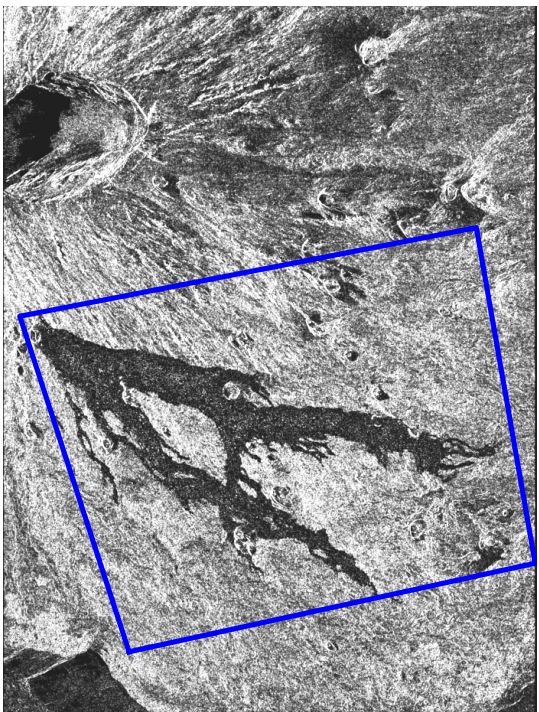
Day 1



Day 2



Day 3

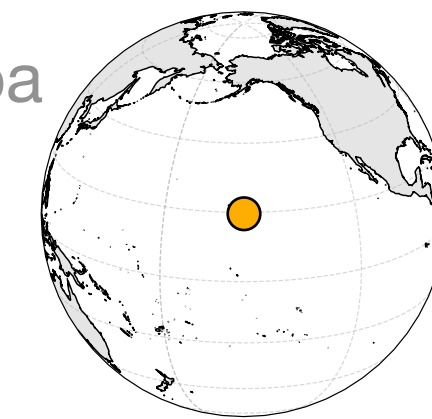


1

Lava flows

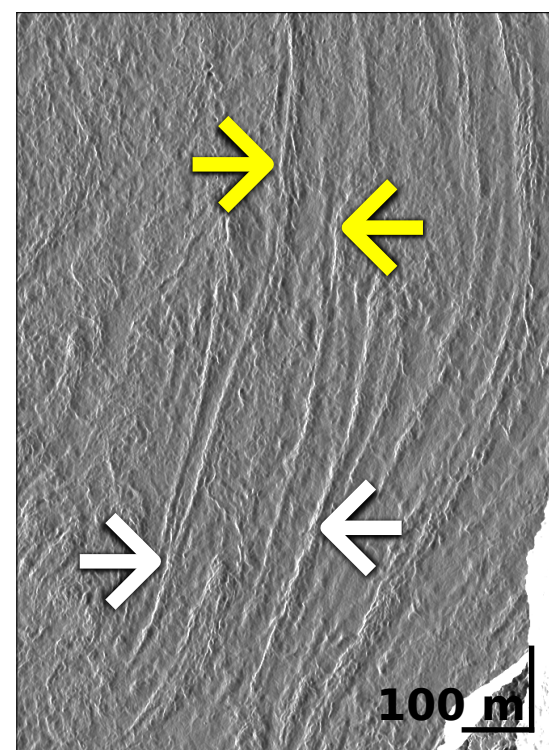
3D mapping

Mauna Loa

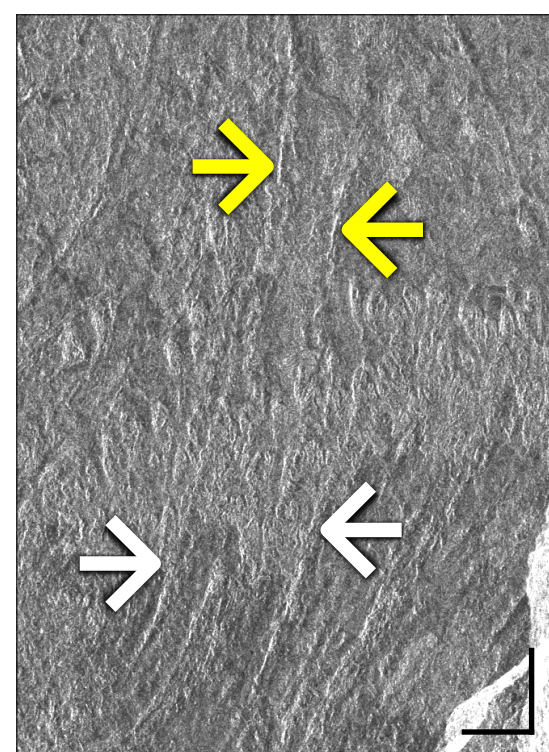


Eruption

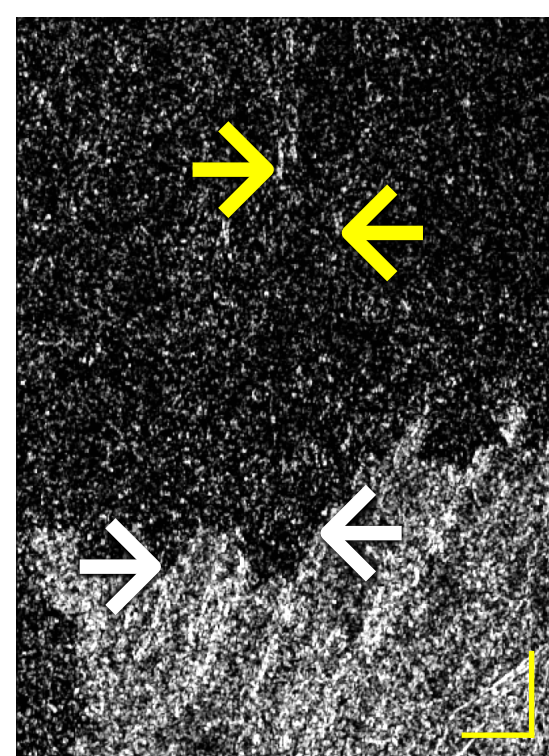
Synthetic image



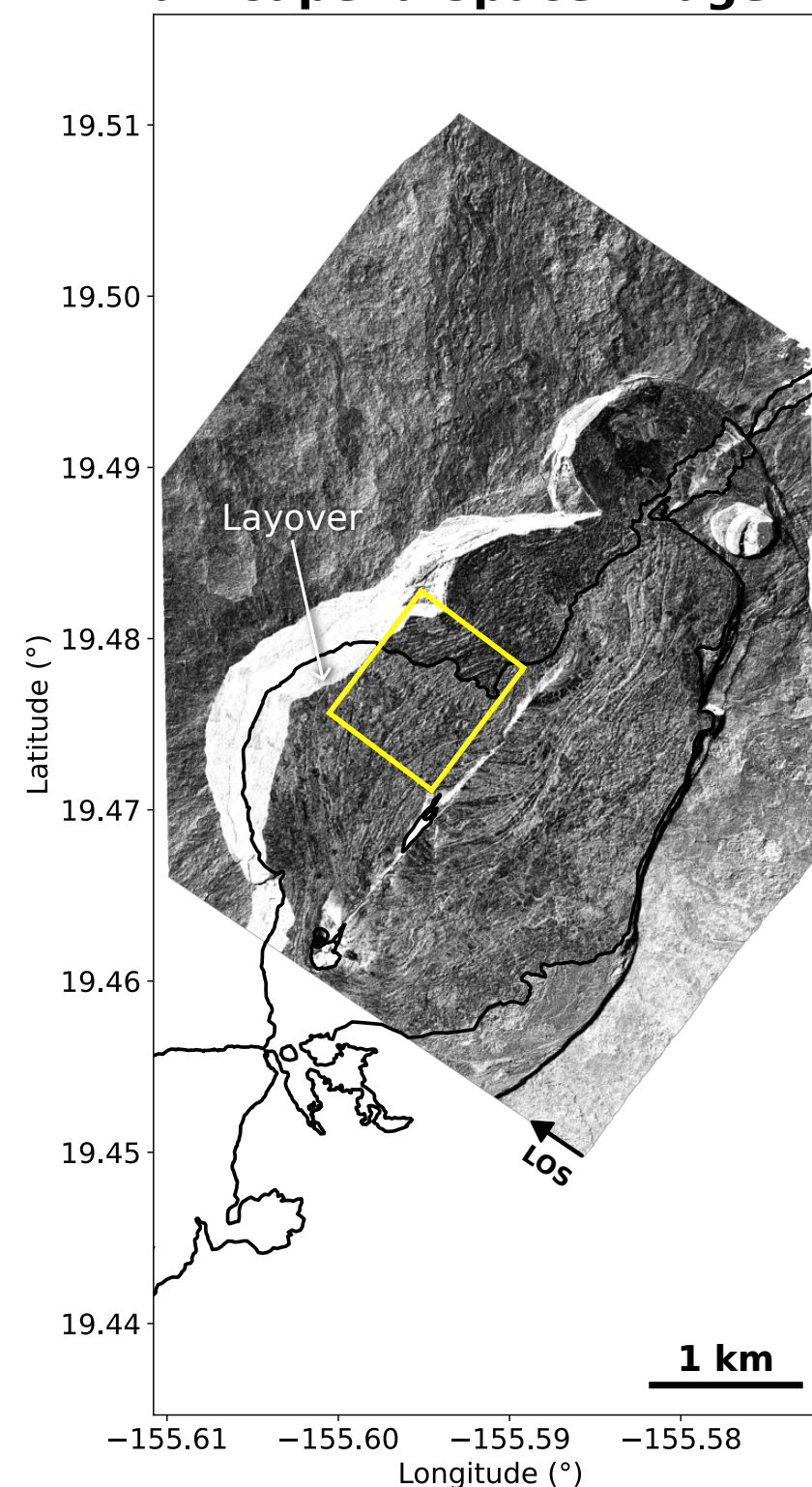
SAR image



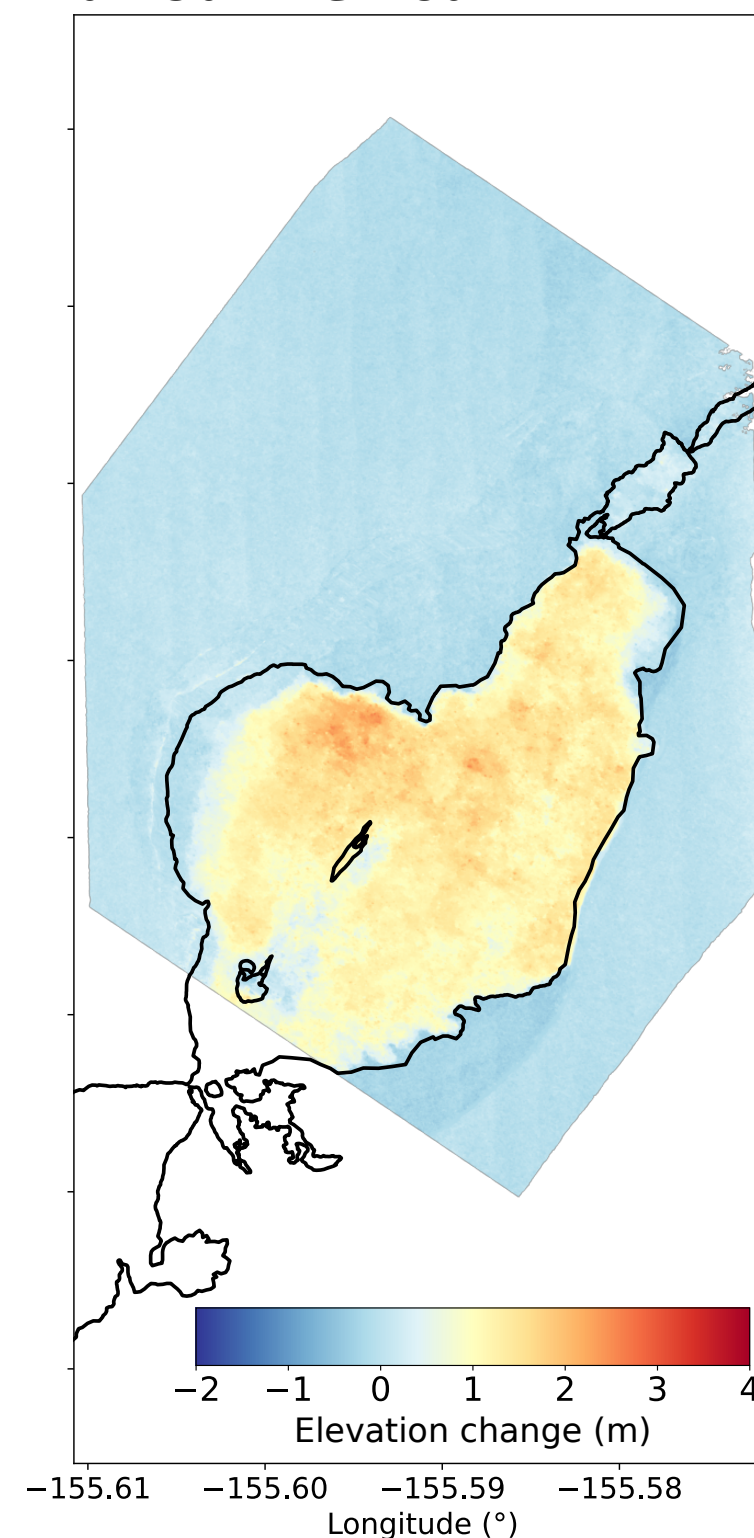
Correlation score



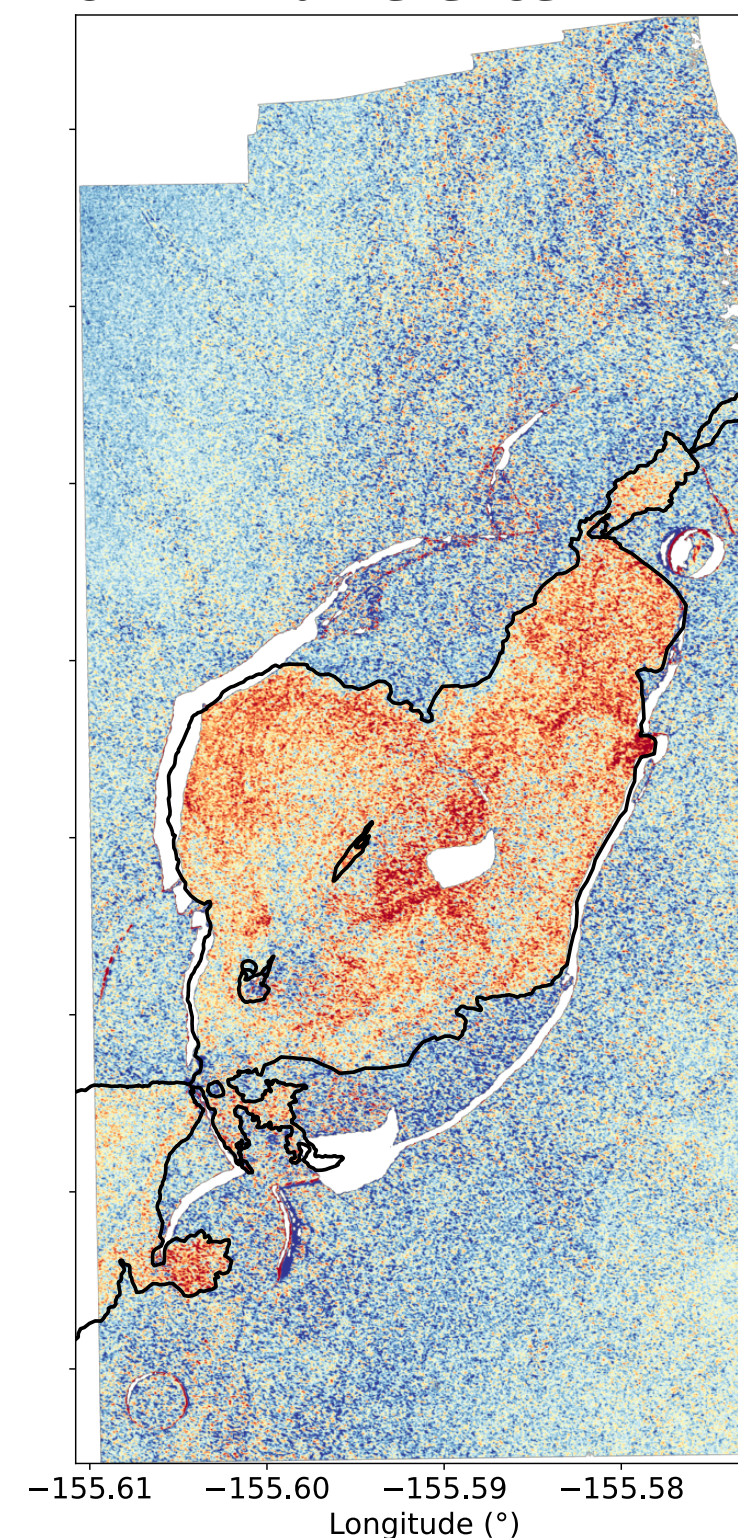
a - Capella Space image



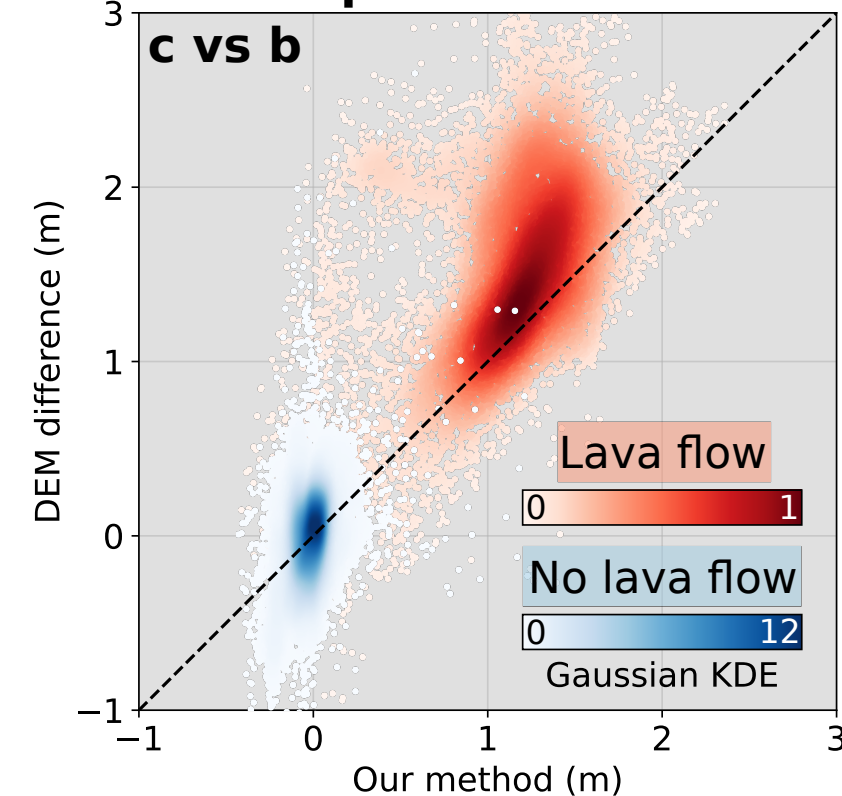
b - Our method



c - DEM difference



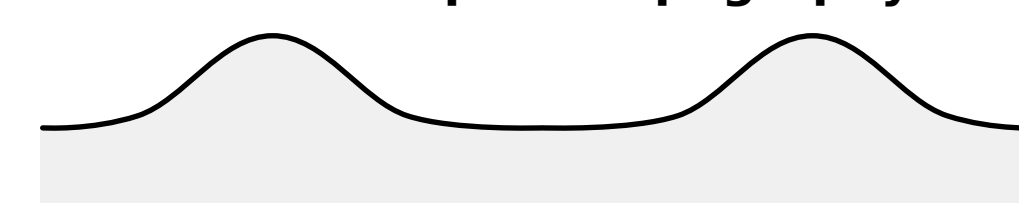
d - Comparison



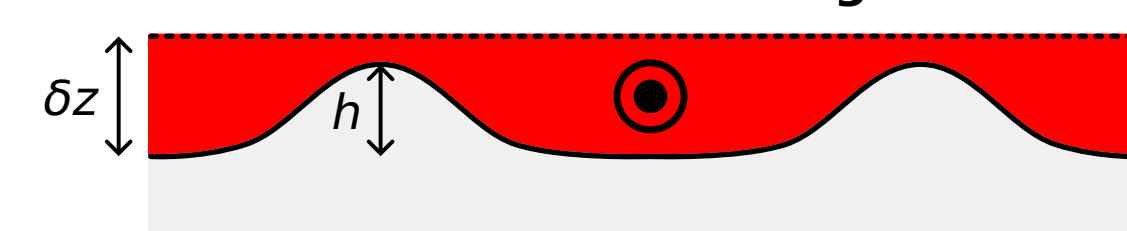
- Specific to the **2022 Mauna Loa eruption**
- Peculiar lava emplacement conditions
- Coating of the pre-eruptive topography

Model of lava emplacement

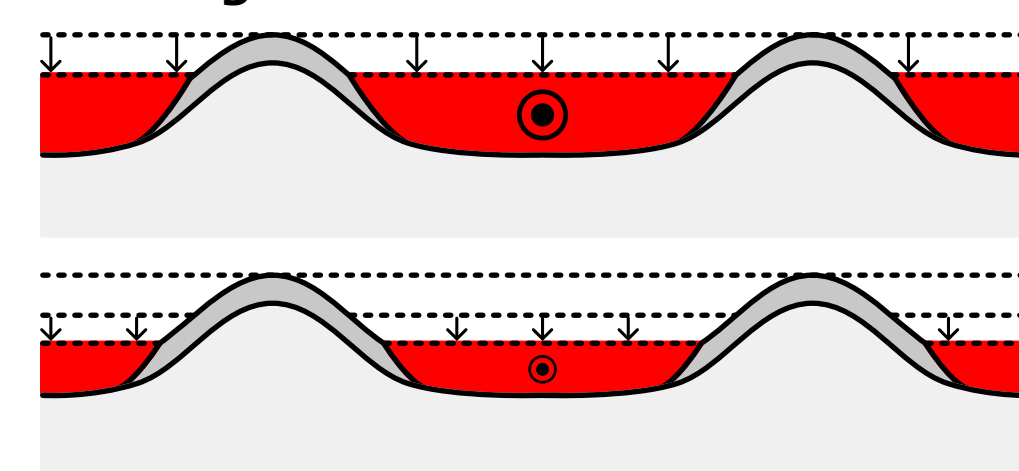
a - Pre-eruptive topography



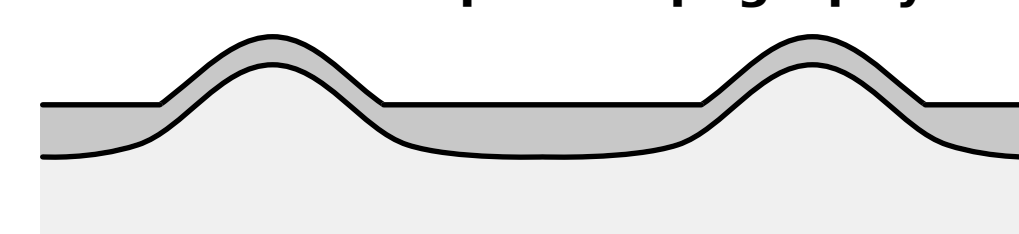
b - Lava flooding



c - Progressive decrease in lava flux



d - Post-eruptive topography



flux →

time ↓

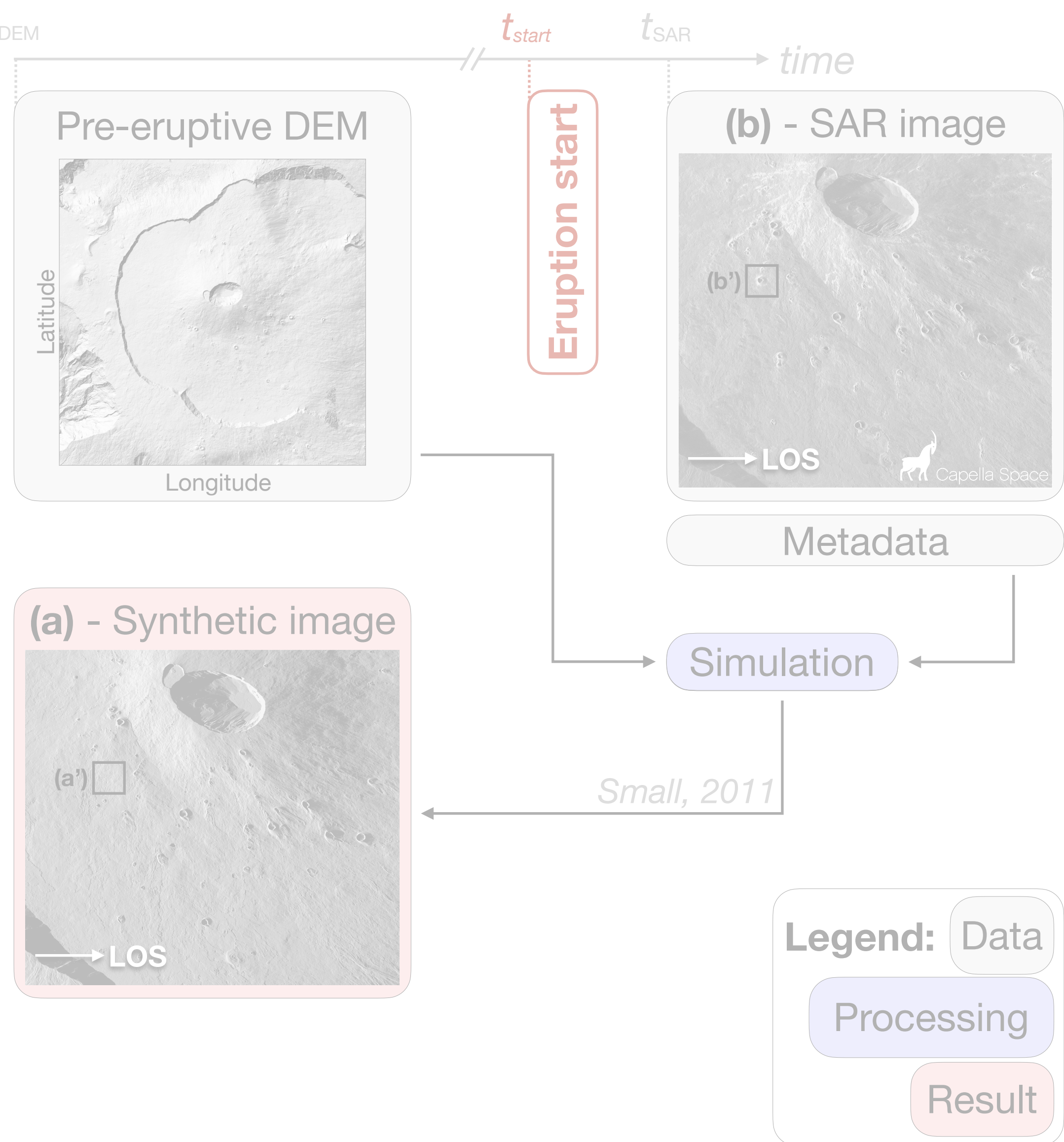


Jet Propulsion Laboratory
California Institute of Technology

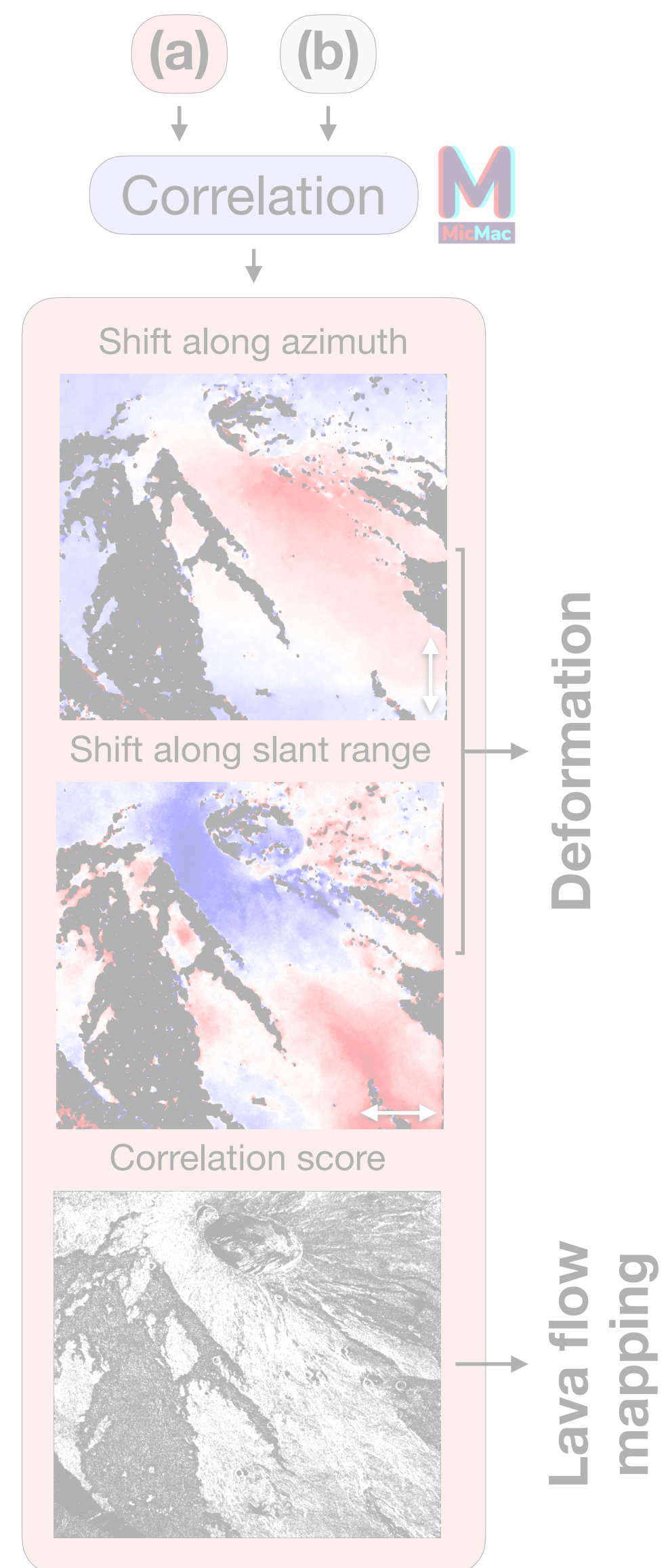
Hauck, Lundgren et al., in prep.

Method

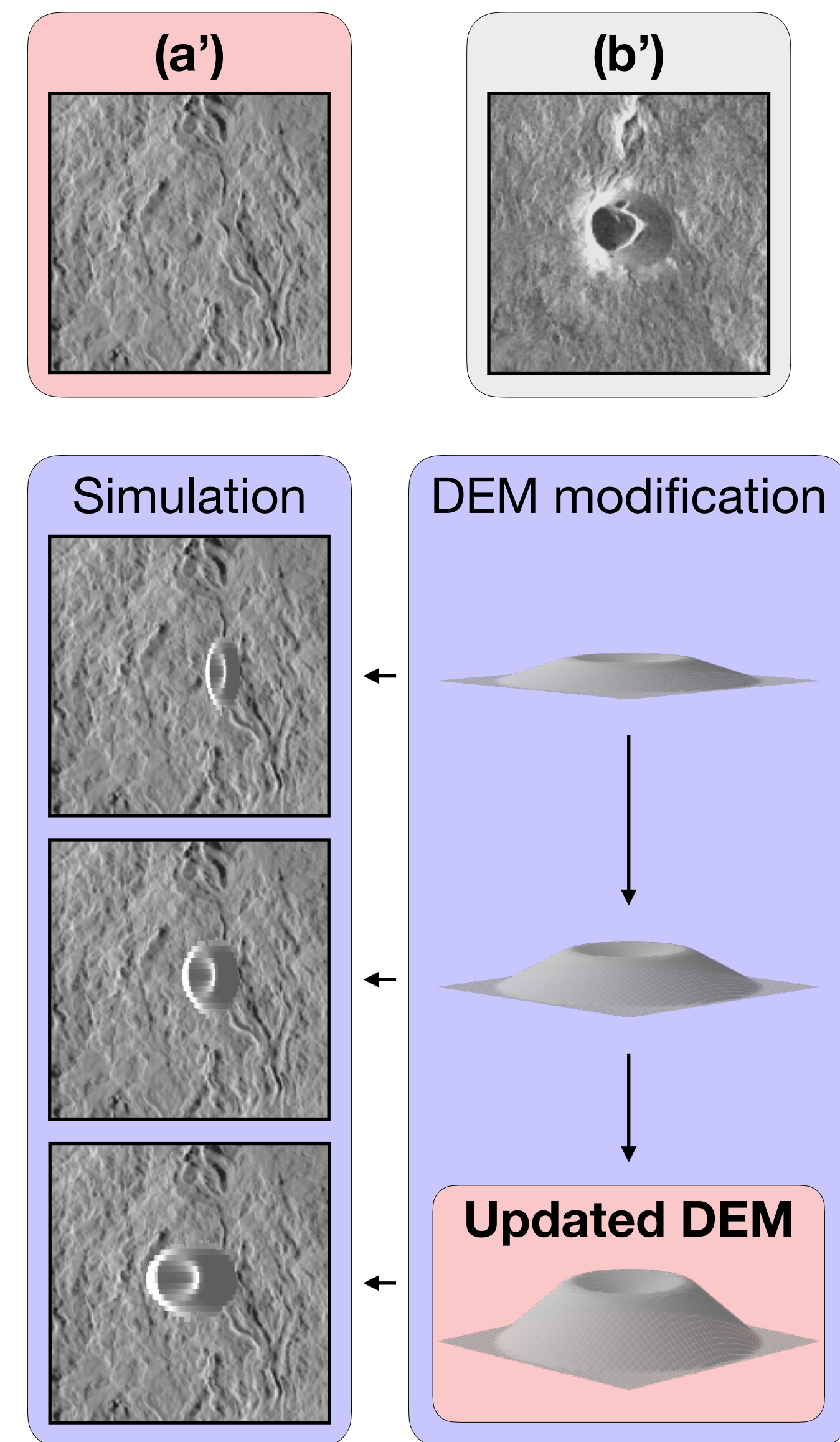
SAR simulation



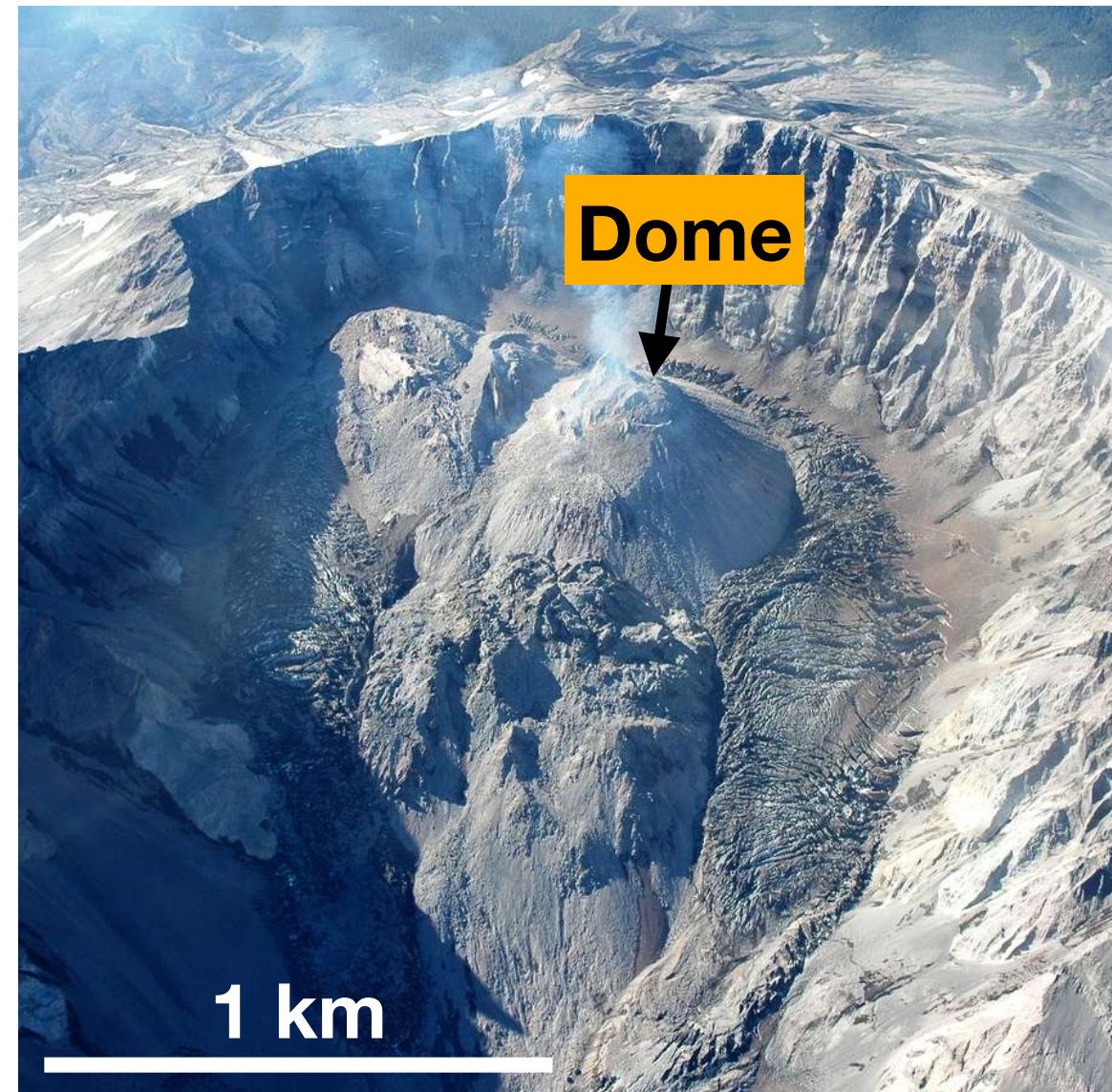
Change detection



3D reconstruction

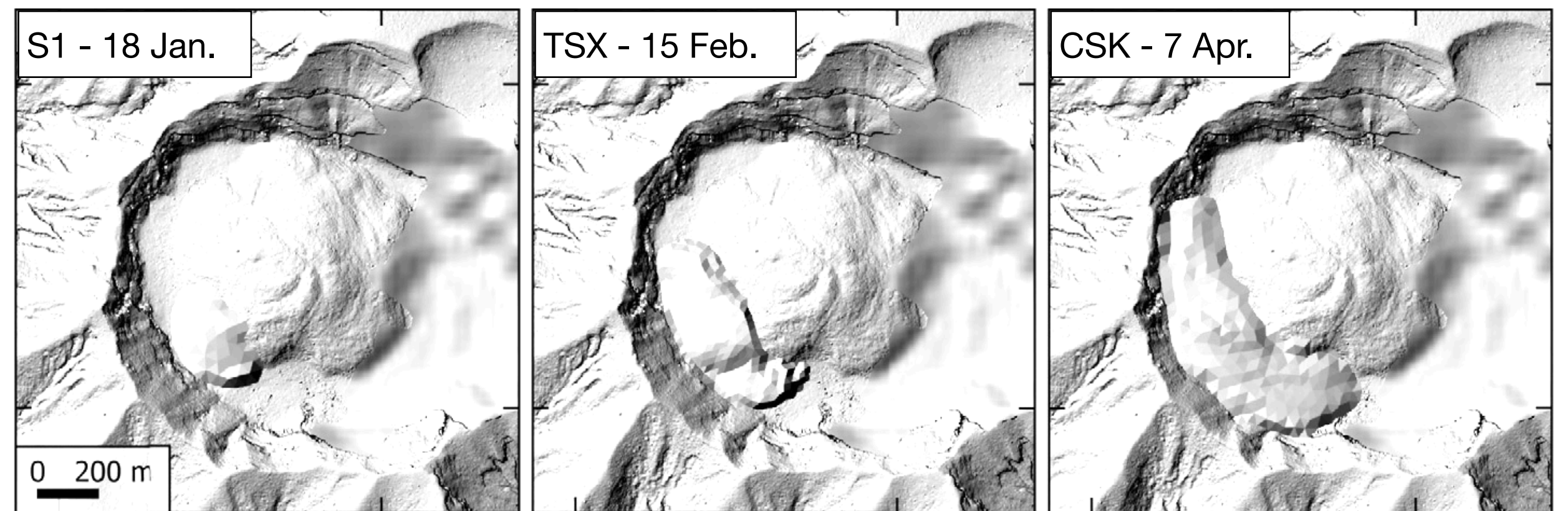
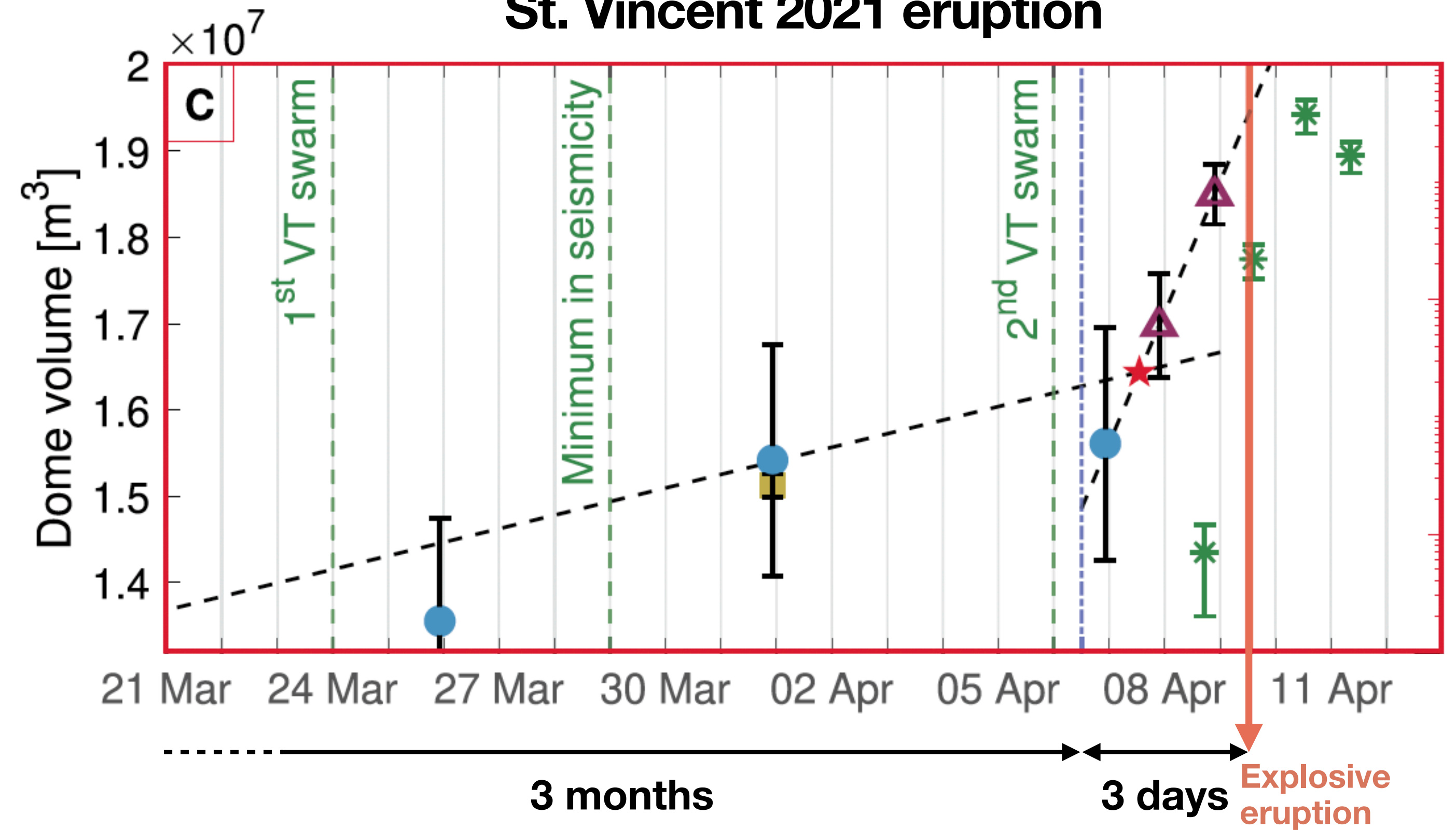


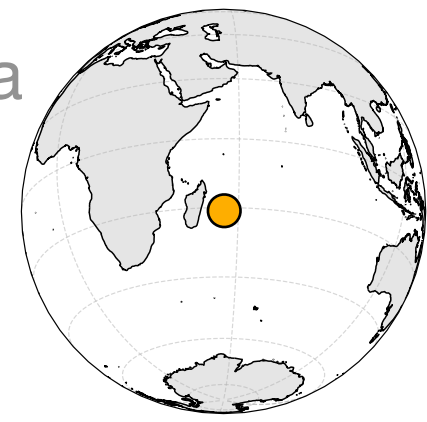
2 Topographic changes



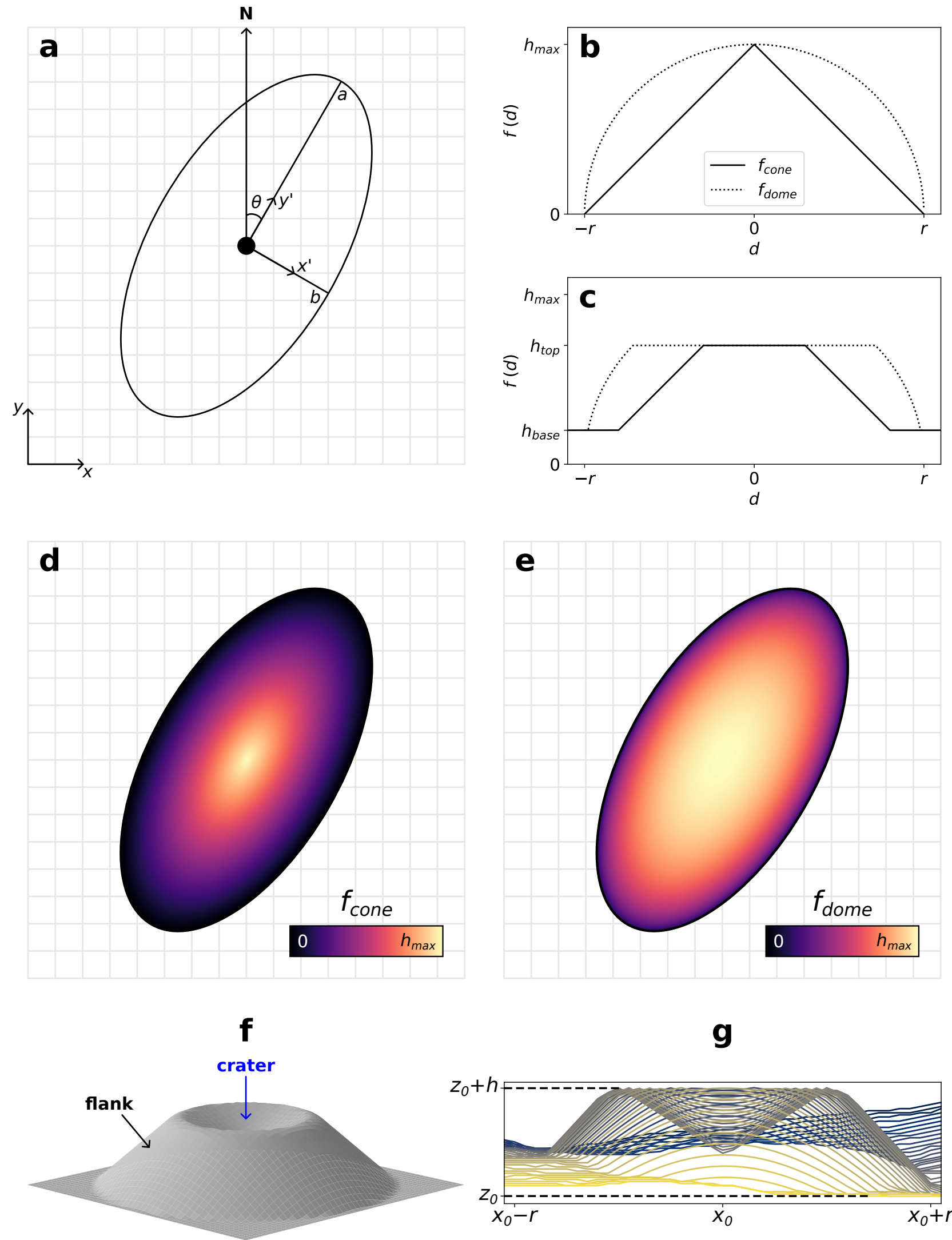
?

St. Vincent 2021 eruption





Model parameterization



Exploration of the model space

Interactive

1. Name the structure

Name of the next structure

Structure 3

Add structure

Order of creation

[1, 2]

2. Select the structure to edit

Current structure to edit

Structure 2

3. Edit the selected structure

Choose the shape of the structure

Cone

Dig the shape

x position (m): -7

y position (m): -17

Minimum z position (m)

0

Maximum z position (m)

90

z position (m): 82

Azimuth of the major axis (°): 36

Maximum major axis (m)

180

Major axis (m): 45

Minor axis (m): 37

Maximum height (m)

180

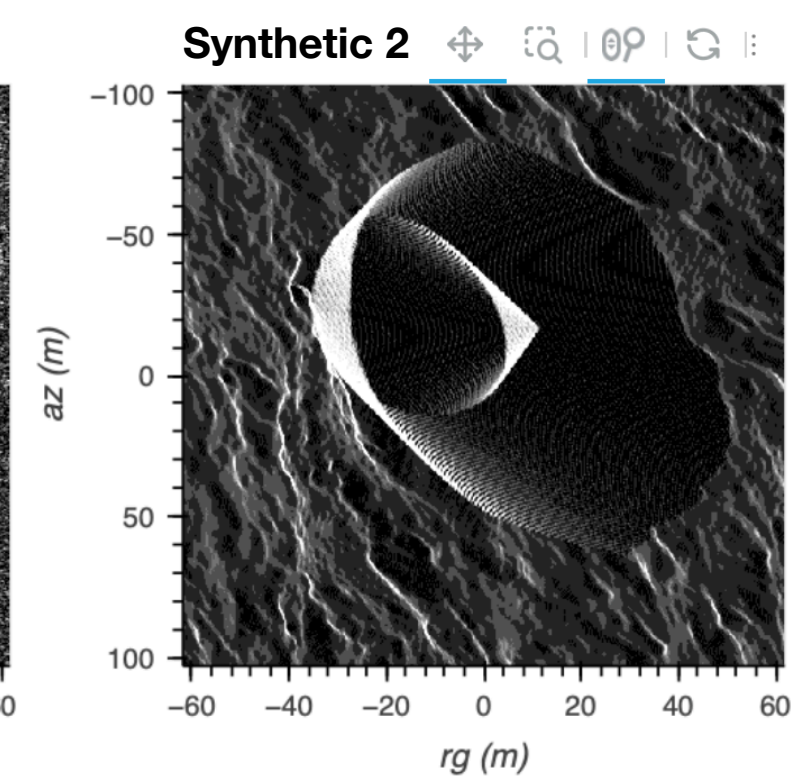
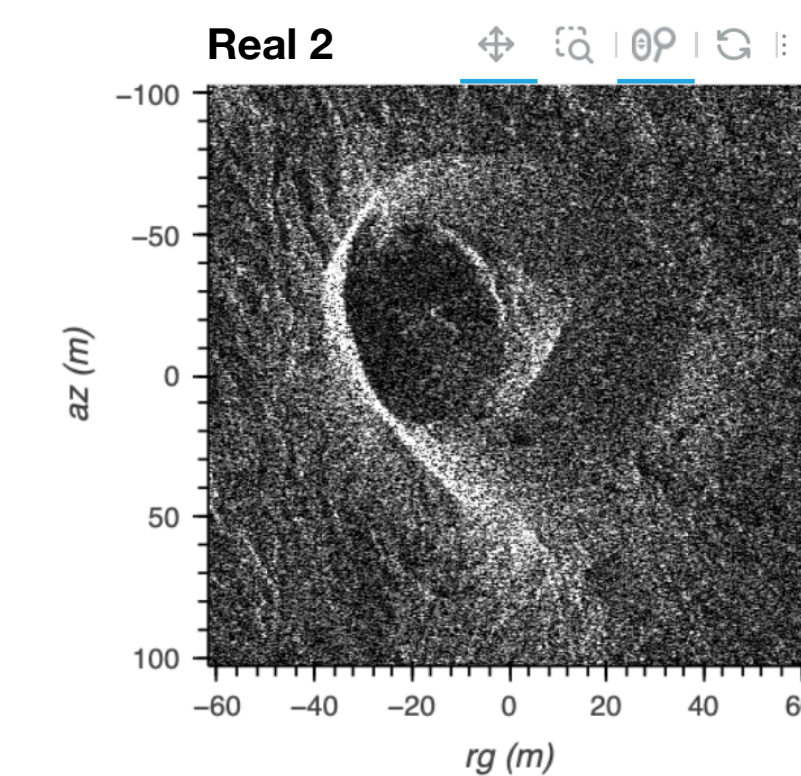
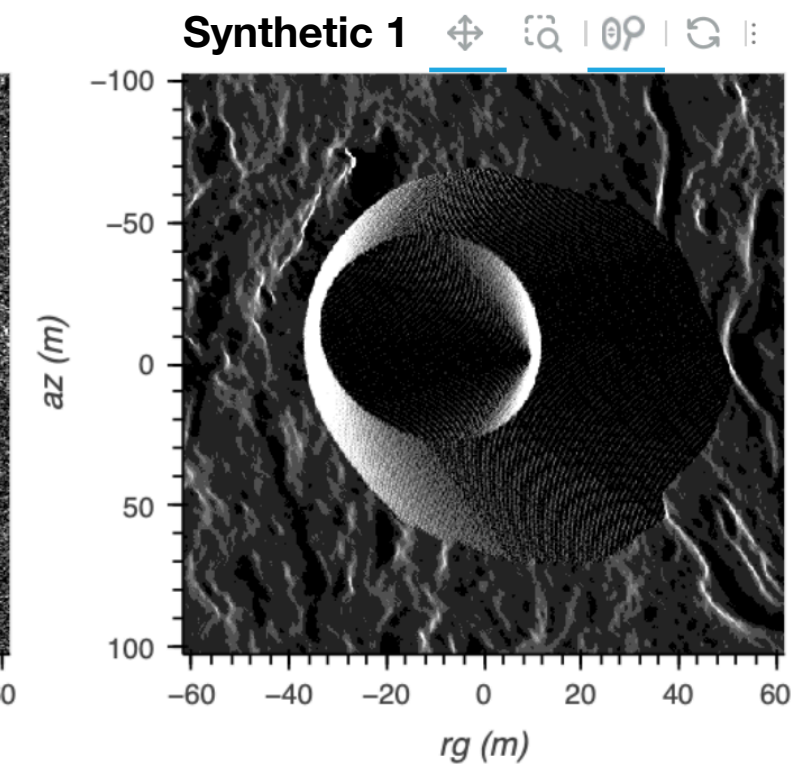
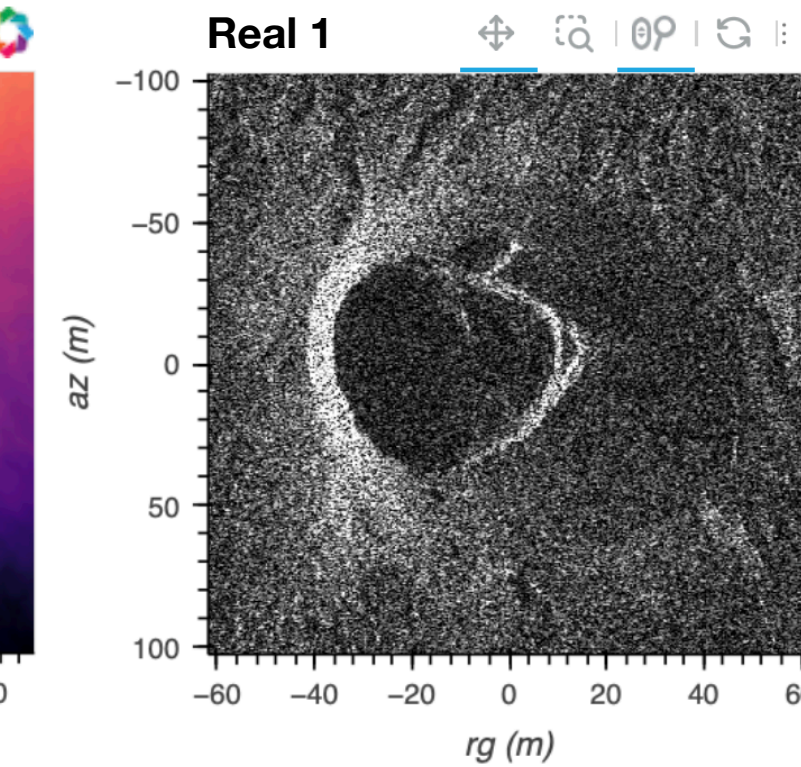
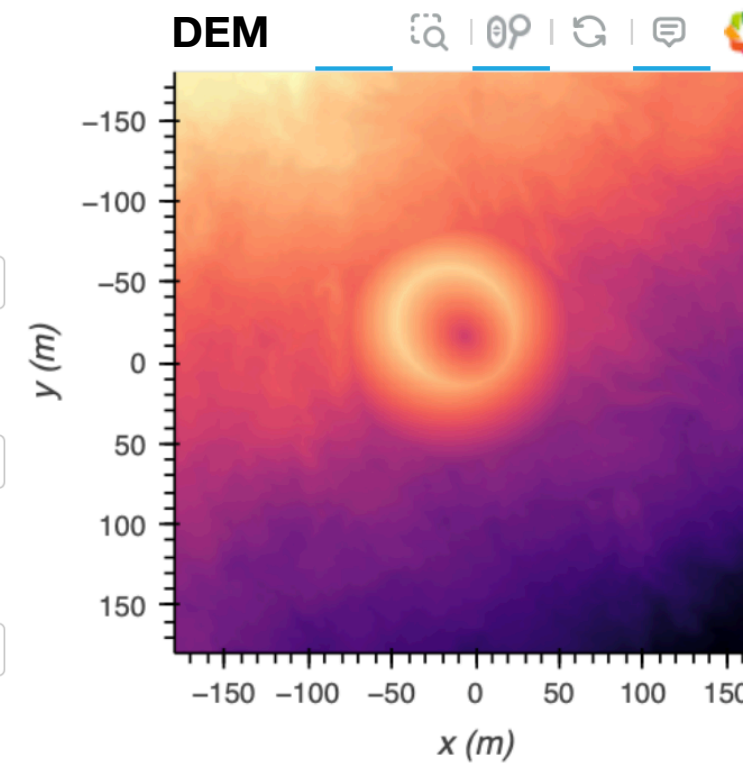
Maximum height (m): 31

Activate truncation

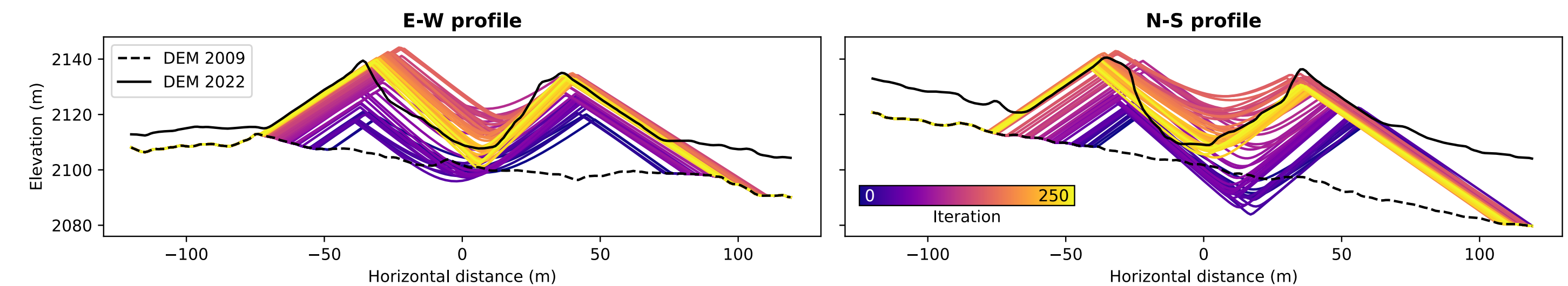
Truncation height (m): 0

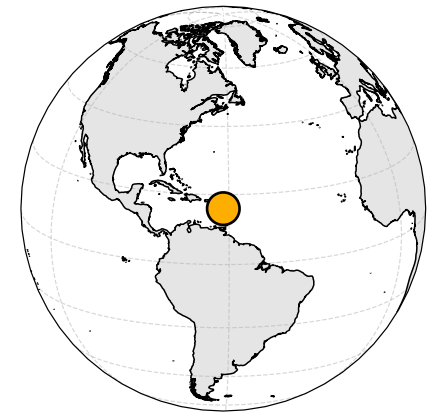
4. Store the structure:

Store structure



Automatic (Metropolis)





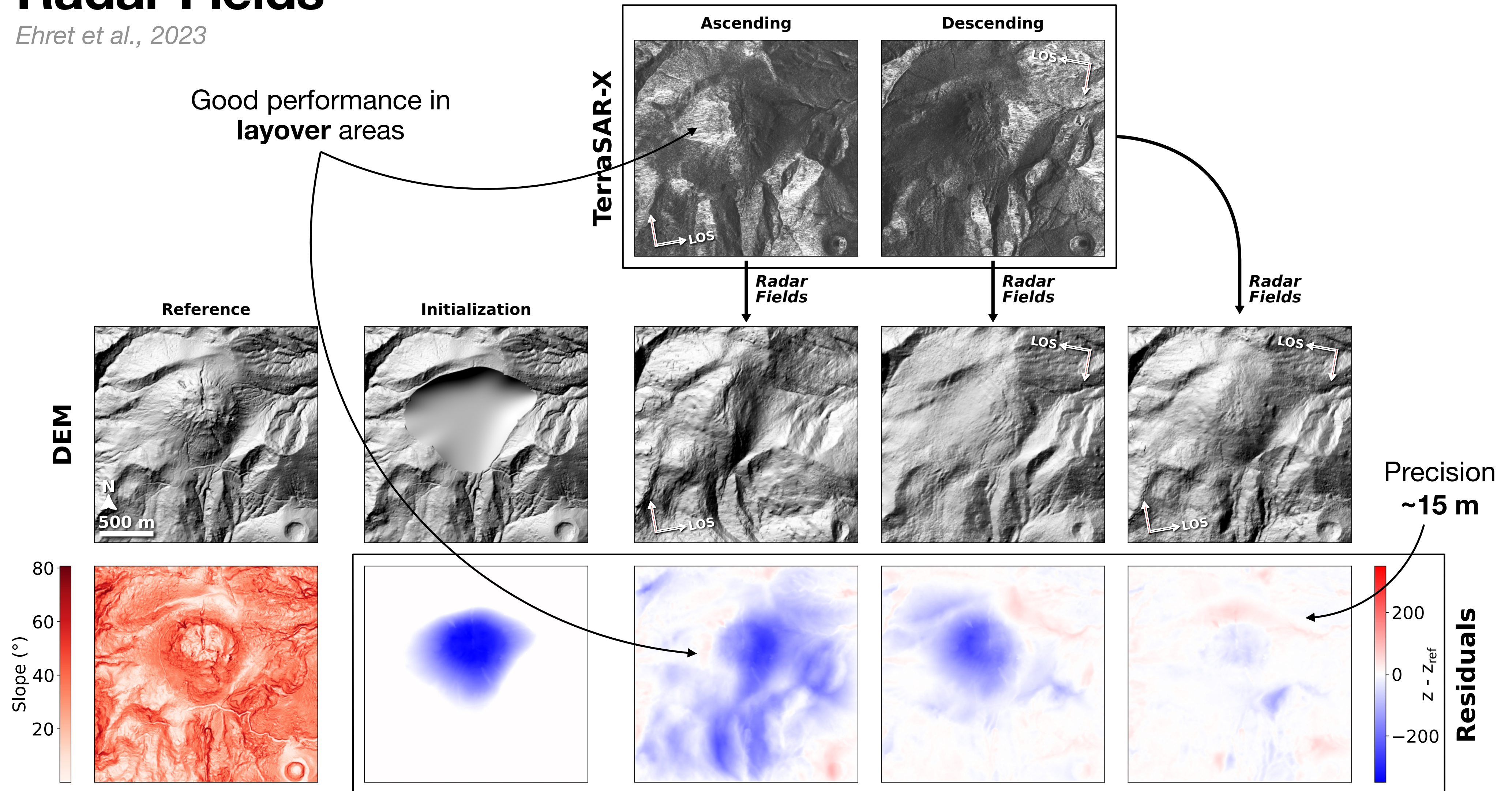
NeRF



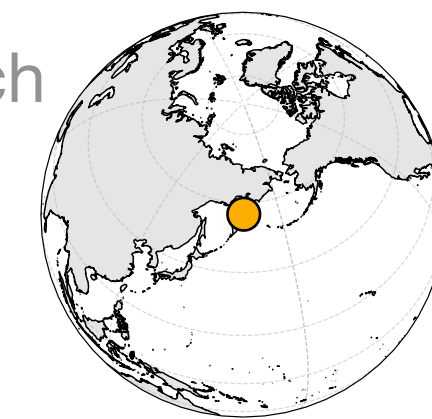
Mildenhall et al., 2022

Radar Fields

Ehret et al., 2023



Shiveluch



Shiveluch



2023 eruption



© Yu. Demyanchuk, IVS FEB RAS, KVERT

Explosion
2023-04-10

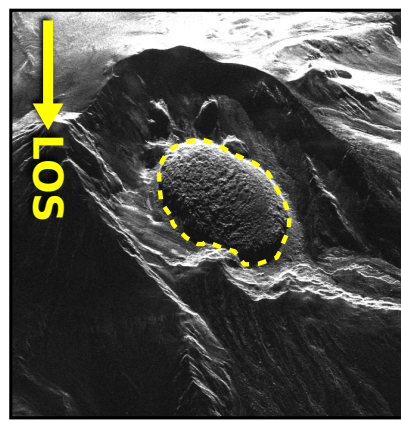
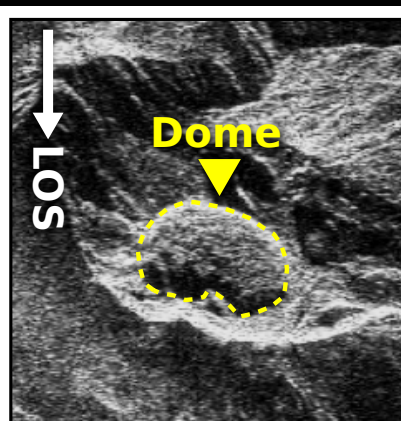
Lava dome growth

time

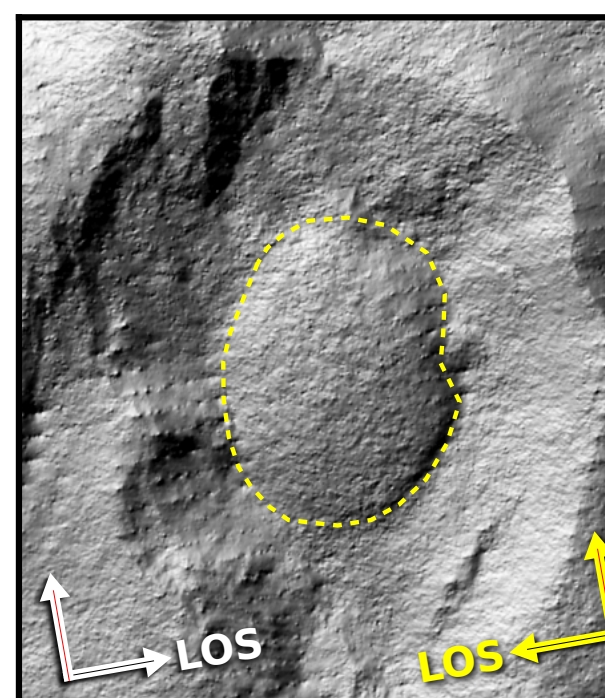
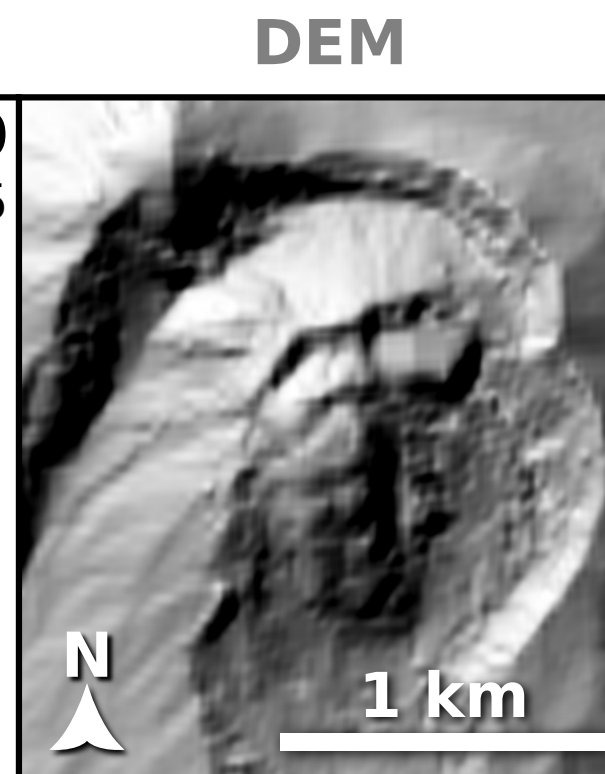
SAR images

Sentinel-1
2023-04-19

Capella
2023-04-20

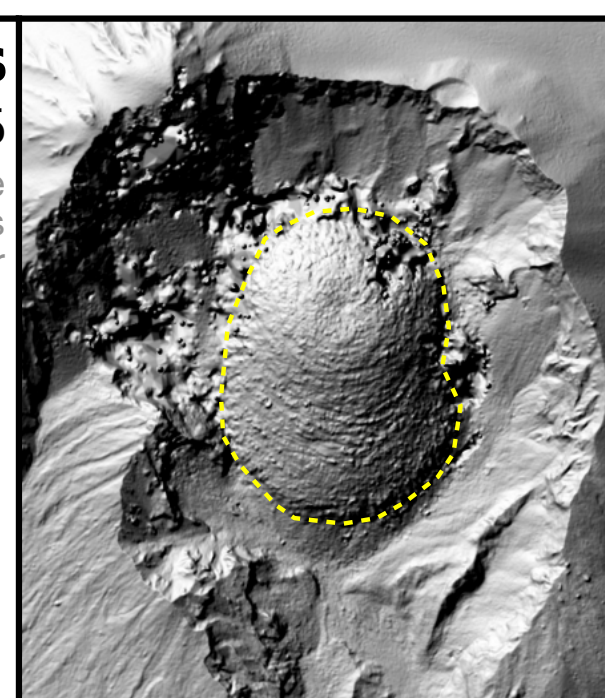


Radar Fields

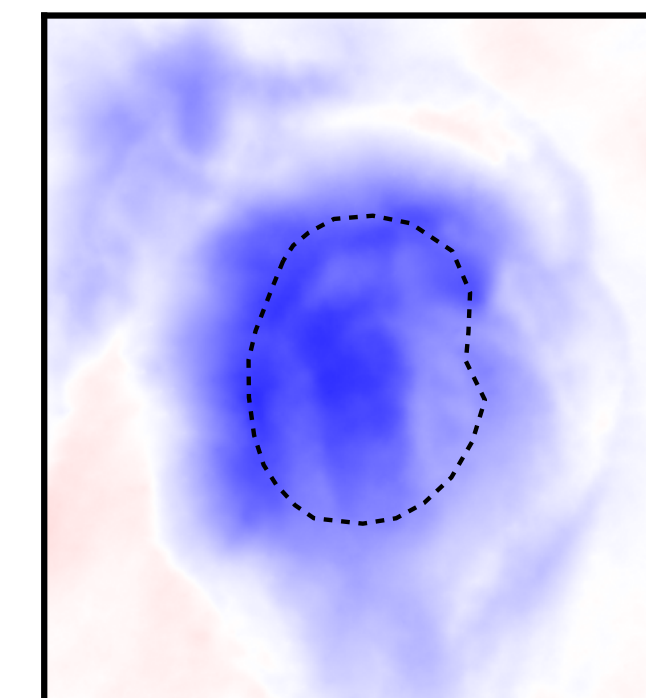


Pléiades
2023-05-15

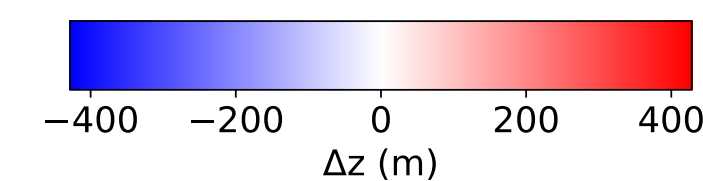
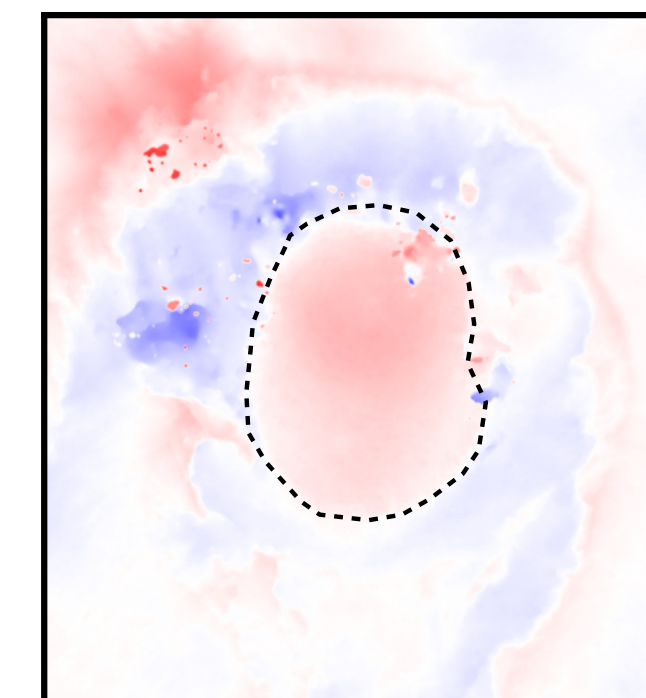
Kamchatka-Kuriles Supersite
Geohazard Supersites and Natural Laboratories
A. V. Shevchenko, T. R. Walter



Radar Fields — GLO-30



Pléiades — Radar Fields



Conclusion

How to decrease the
revisit time?

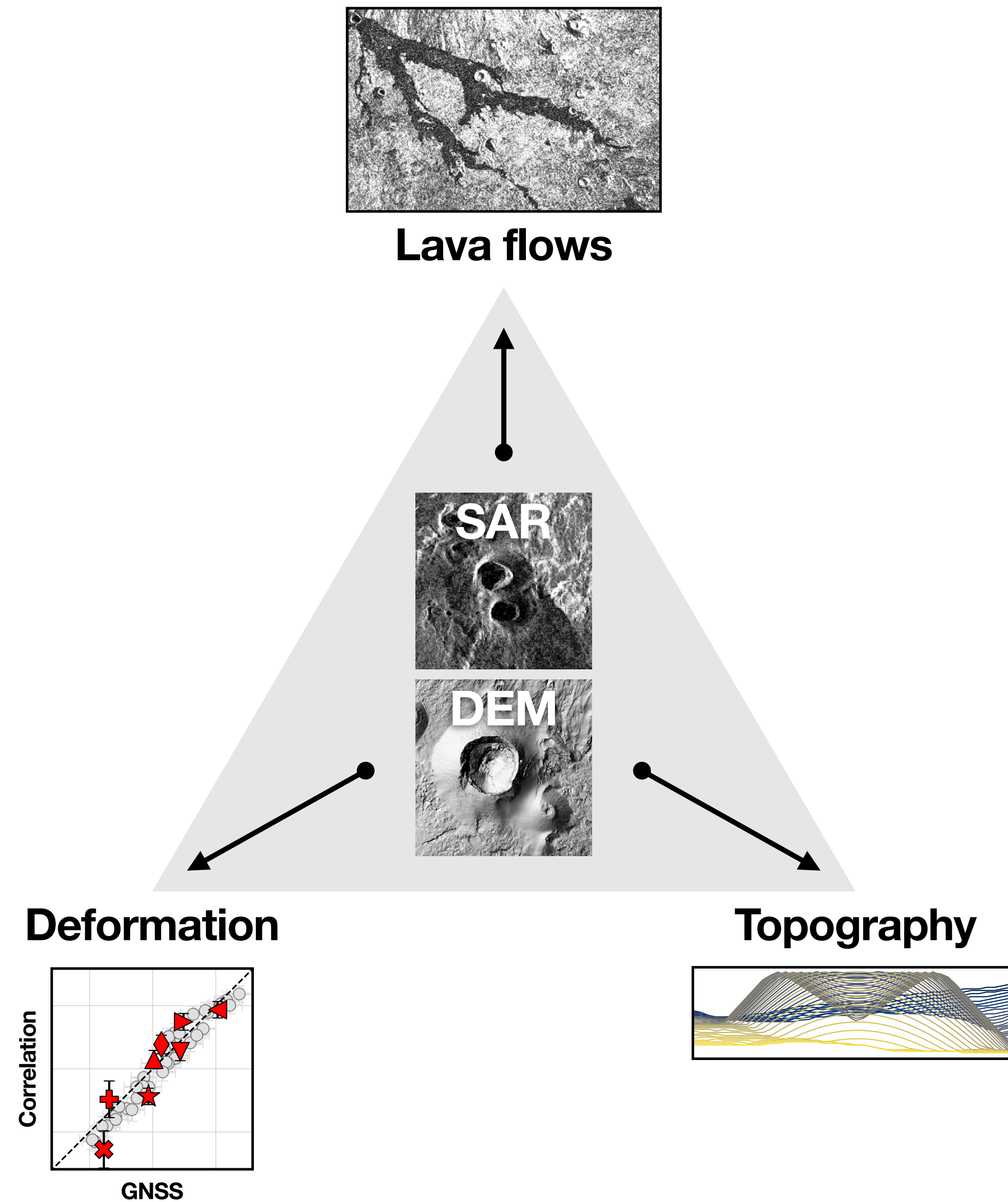


Multi-sensor approach



Changing geometry

No reference image



References

Hauck, A., Grandin, R., Costa, F. et al. (2026). Near real-time monitoring of volcanic deformation and lava flows from multi-angular Capella Space SAR imagery. *Bulletin of Volcanology*, 88(35). <https://doi.org/10.1007/s00445-025-01928-8>

Chevrel, M. O., Villeneuve, N., Grandin, R. et al. (2023). Lava flow daily monitoring: the case of the 19 September–5 October 2022 eruption at Piton de la Fournaise. *Volcanica*, 6(2), 391–404. <https://doi.org/10.30909/vol.06.02.391404>

Dualeh, E. W., Ebmeier, S. K., Wright, T. J. et al. (2023). Rapid pre-explosion increase in dome extrusion rate at La Soufrière, St. Vincent quantified from synthetic aperture radar backscatter. *Earth and Planetary Science Letters*, 603, 117980. <https://doi.org/10.1016/j.epsl.2022.117980>

Ehret, T., Marí, R., Derksen, D. et al. (2024). Radar Fields: An Extension of Radiance Fields to SAR. *2024 IEEE/CVF Conference on Computer Vision and Pattern Recognition Workshops (CVPRW)*, Seattle, WA, USA, 564–574. <https://doi.org/10.1109/CVPRW63382.2024.00061>

Institut De Physique Du Globe De Paris (2021). Data collection of the volcanological observatory of Piton de la Fournaise. <https://doi.org/10.18715/REUNION.OVPF>

Mildenhall, B., Srinivasan, P. P., Tancik, M. Et al. (2021). NeRF: representing scenes as neural radiance fields for view synthesis. *Communications of the ACM*, 65(1), 99–106. <https://doi.org/10.1145/3503250>

Rupnik, E., Daakir, M. & Pierrot Deseilligny, M. (2017). MicMac – a free, open-source solution for photogrammetry. *Open geospatial data, software and standards*, 2, 1–9. <https://doi.org/10.1186/s40965-017-0027-2>

Small, D. (2011). Flattening gamma: Radiometric terrain correction for SAR imagery. *IEEE Transactions on Geoscience and Remote Sensing*, 49(8), 3081–3093. <https://doi.org/10.1109/TGRS.2011.2120616>

Smittarello, D., Grandin, R., Jaspard, M. et al. (2023). Nyiragongo crater collapses measured by multi-sensor SAR amplitude time series. *ESS Open Archive*. <https://doi.org/10.22541/essoar.167979224.40405342/v1>

Surono, Jousset, P., Pallister, J. et al. (2012). The 2010 explosive eruption of Java’s Merapi volcano — a ‘100-year’ event. *Journal of volcanology and geothermal research*, 241, 121–135. <https://doi.org/10.1016/j.jvolgeores.2012.06.018>

SAR image processing: EOS-SAR Python package (KAYRROS)

Thank you

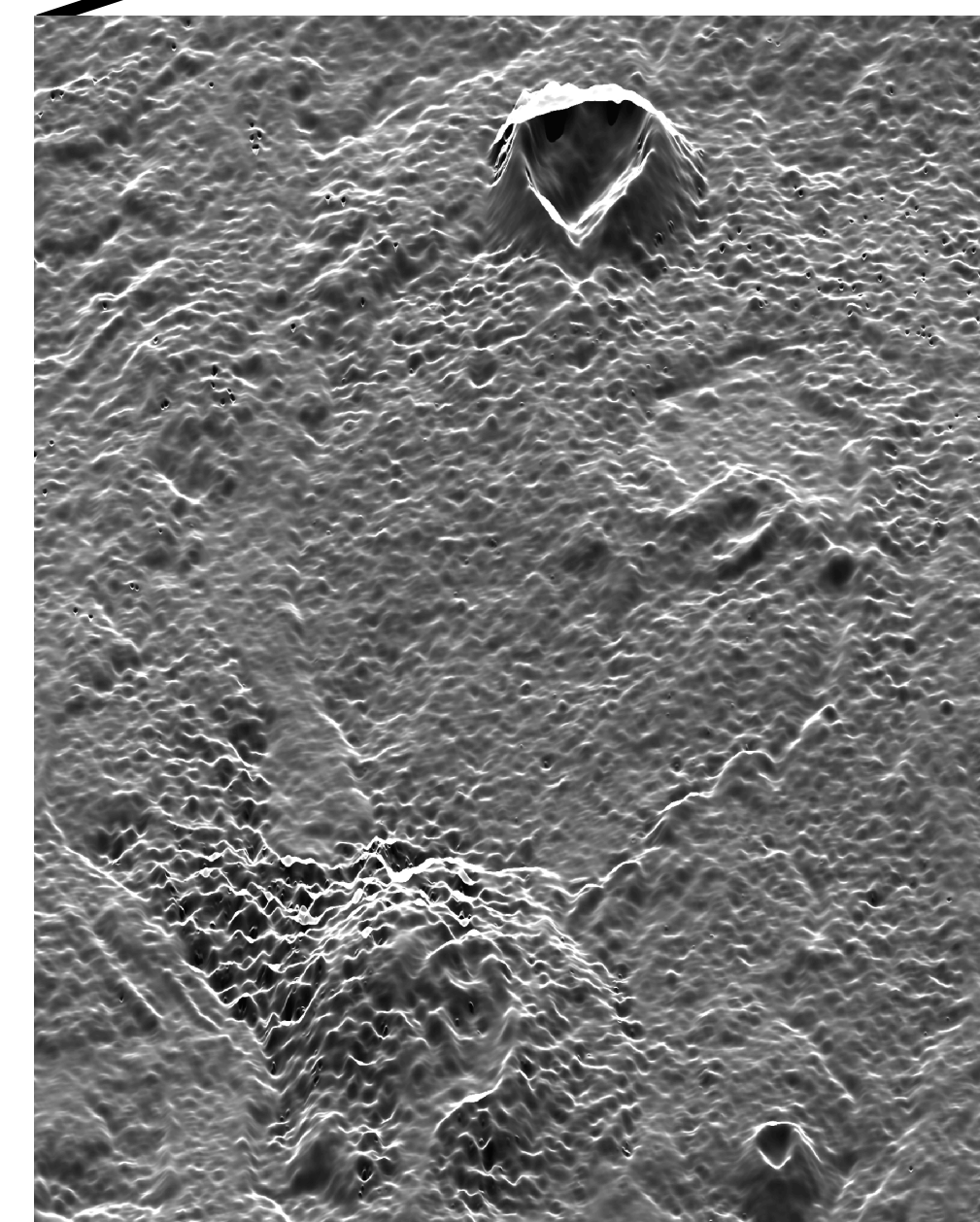
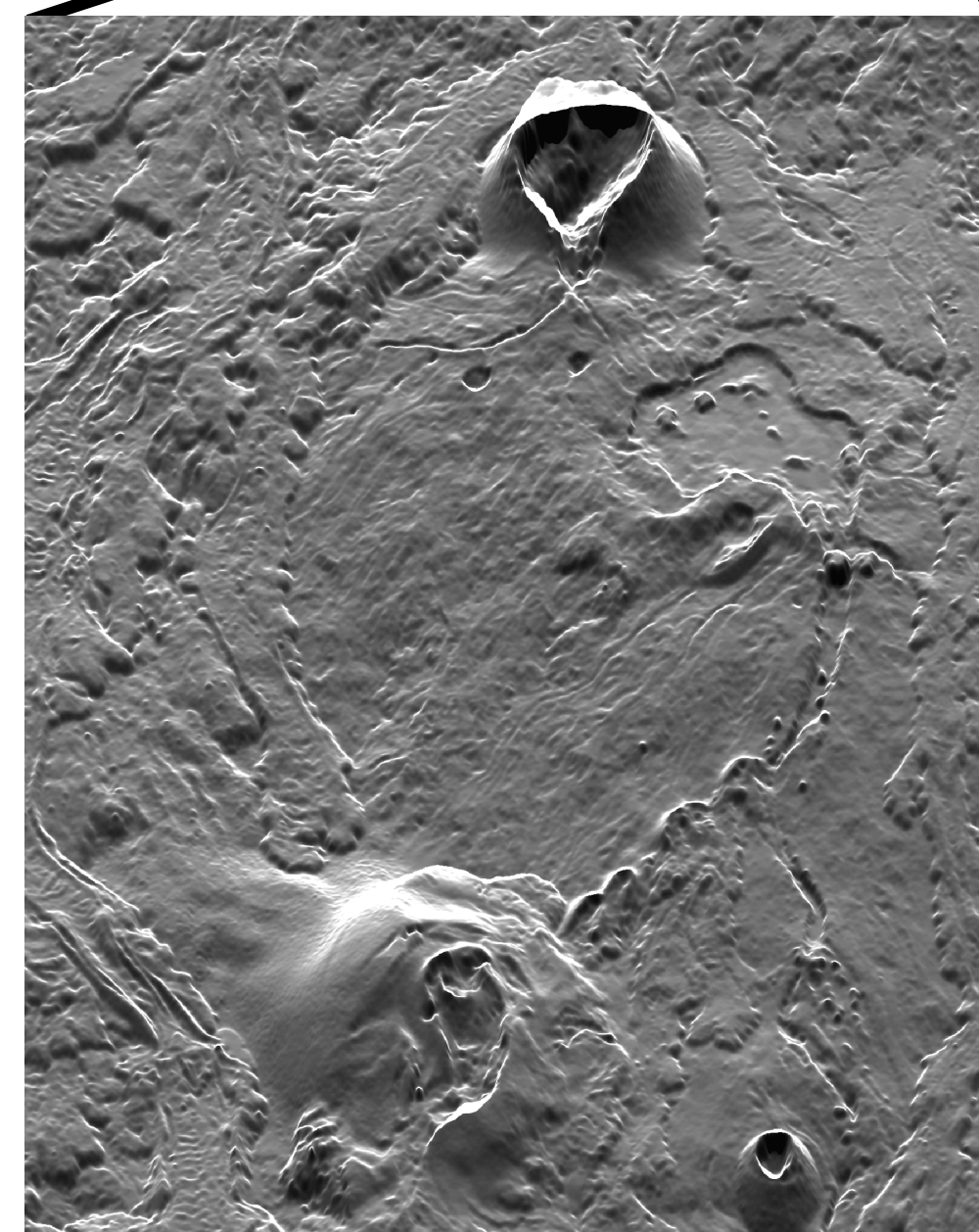
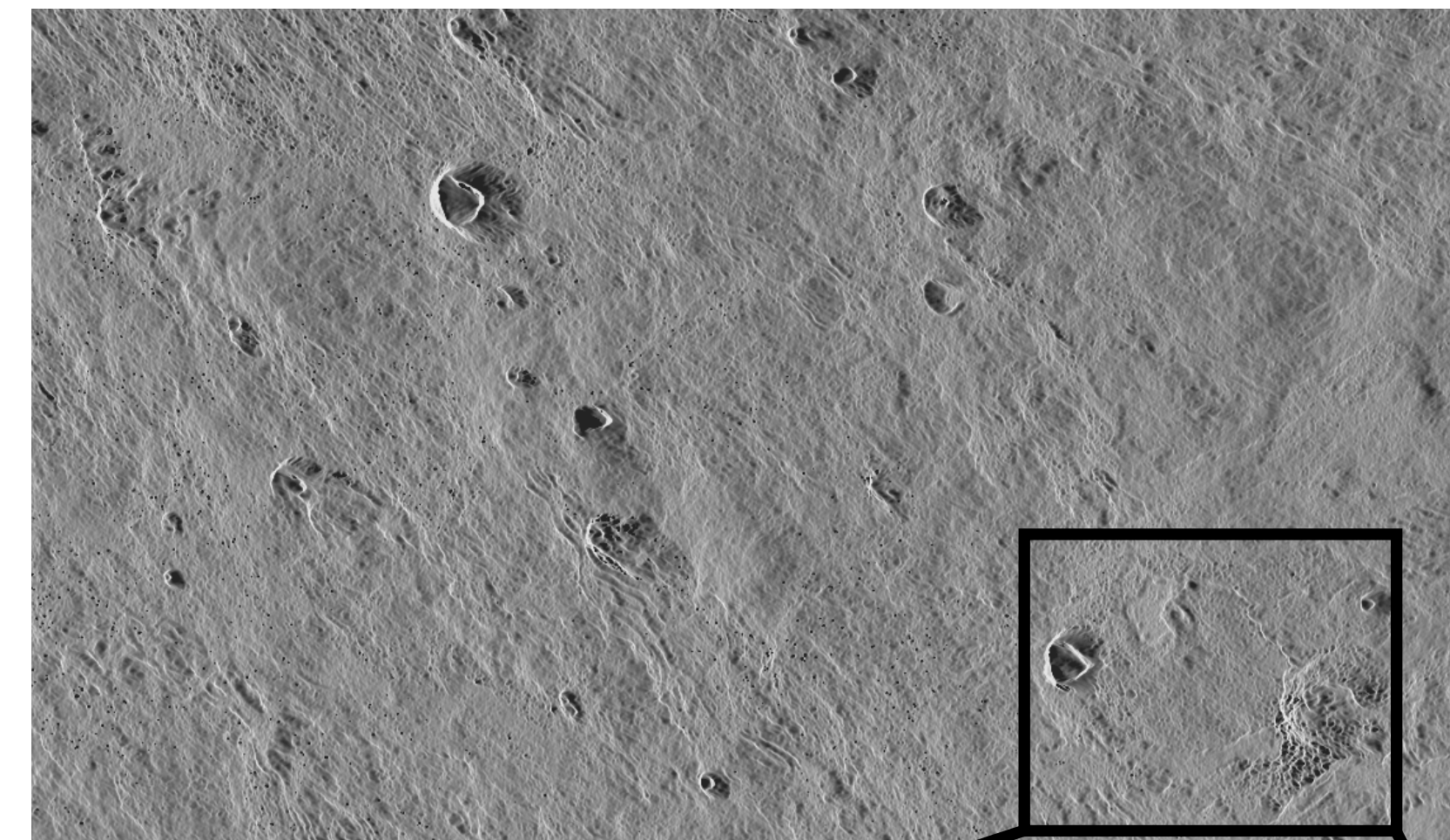
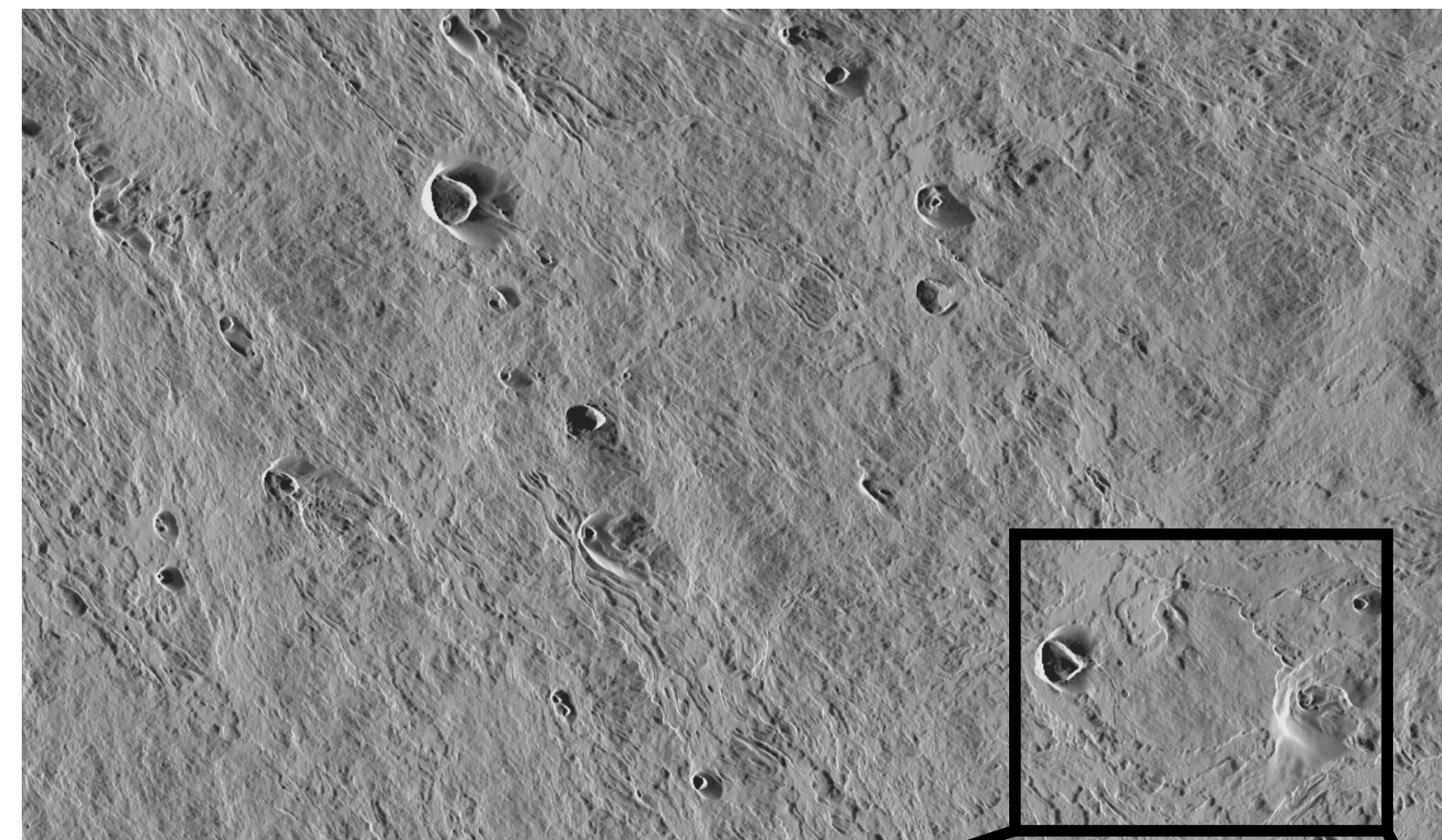
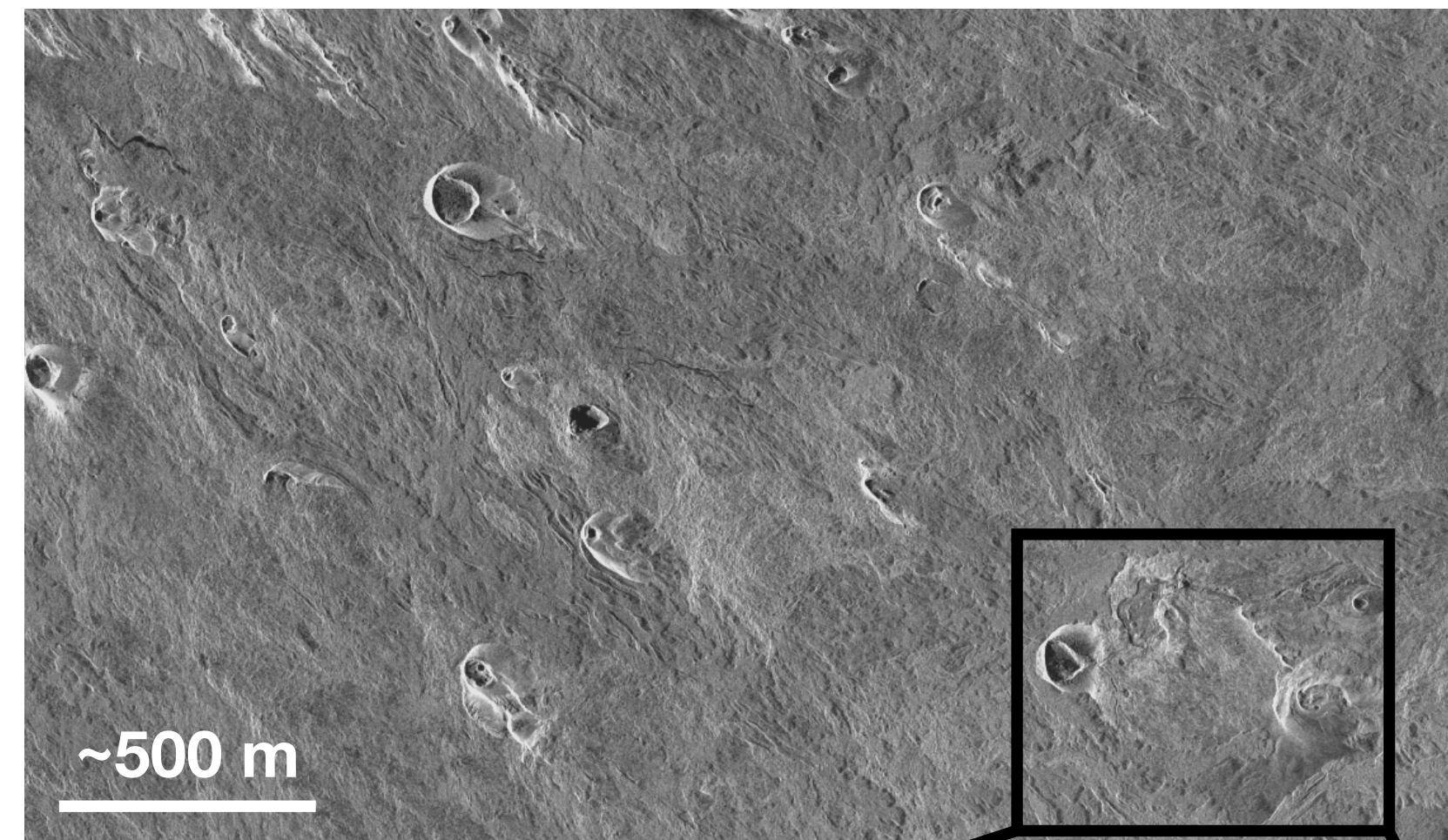
hauck@ipgp.fr

Capella Space image

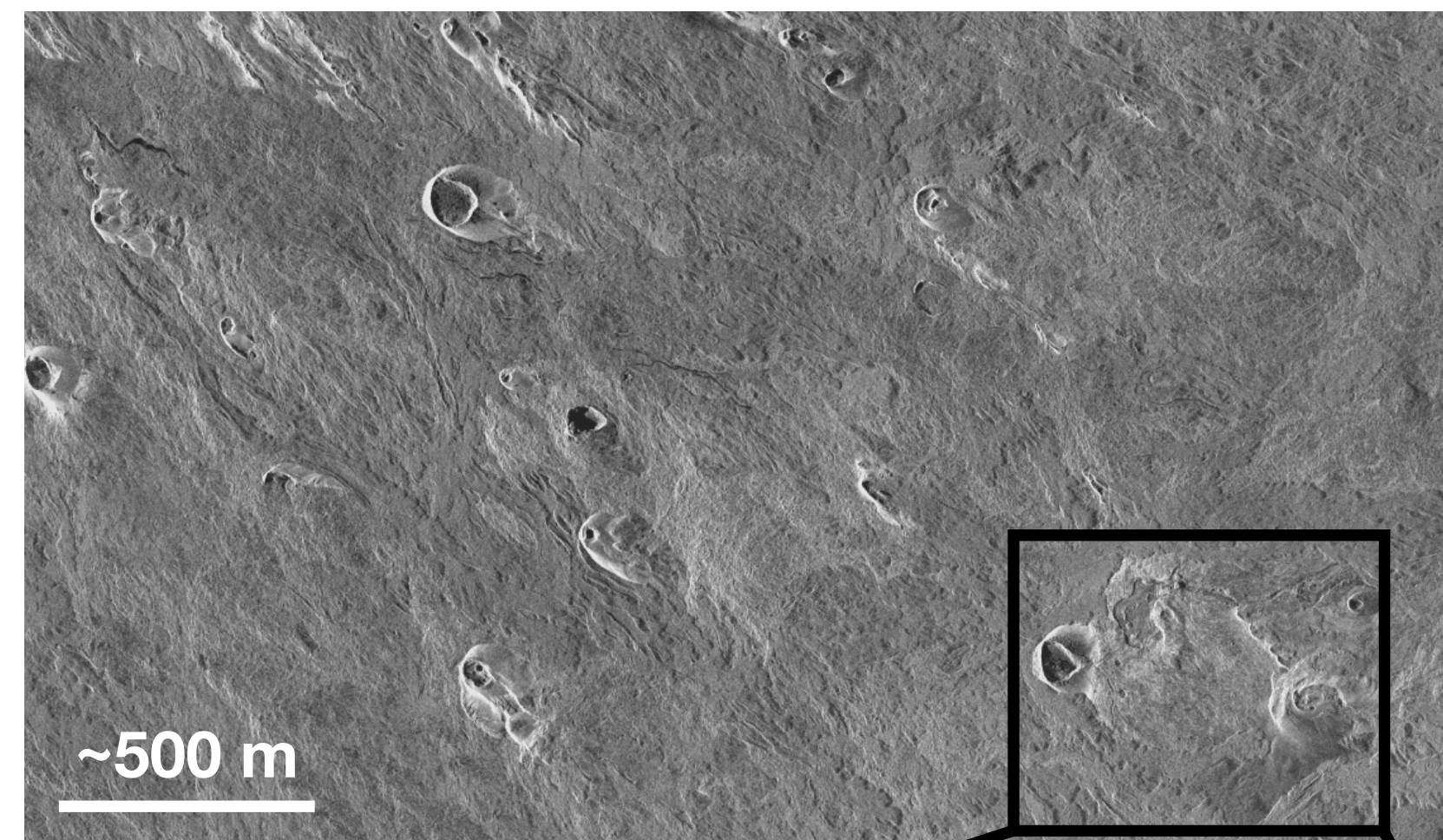
LiDAR DEM

Synthetic images

Pléiades DEM



Capella Space image



LiDAR DEM



Correlation score

Pléiades DEM

