

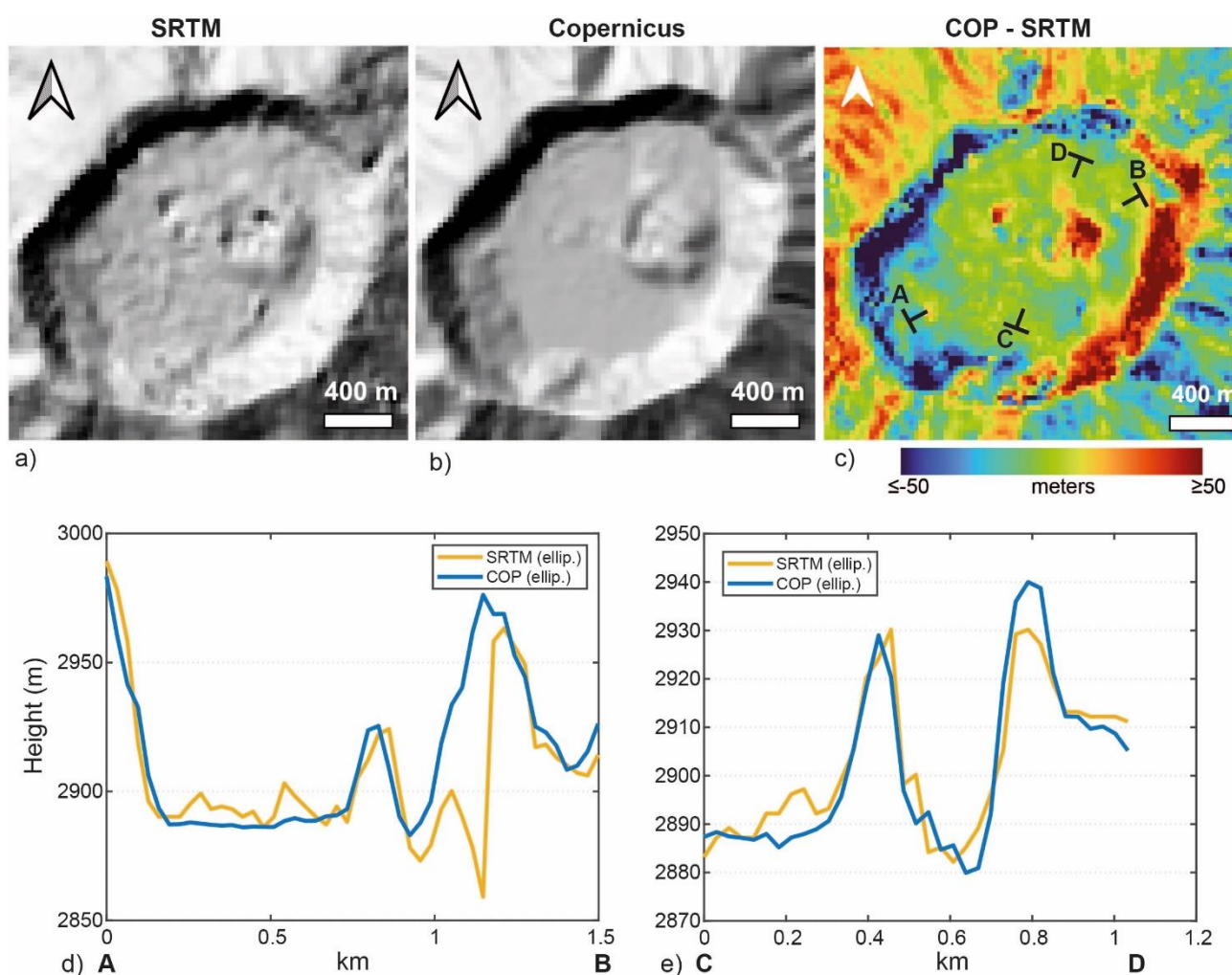
Supplementary Figures for the article (submitted to *Bulletin of Volcanology*) entitled:

The use of high-resolution satellite topographic data to quantify volcanic activity at Raung volcano (Indonesia) from 2011 to 2021

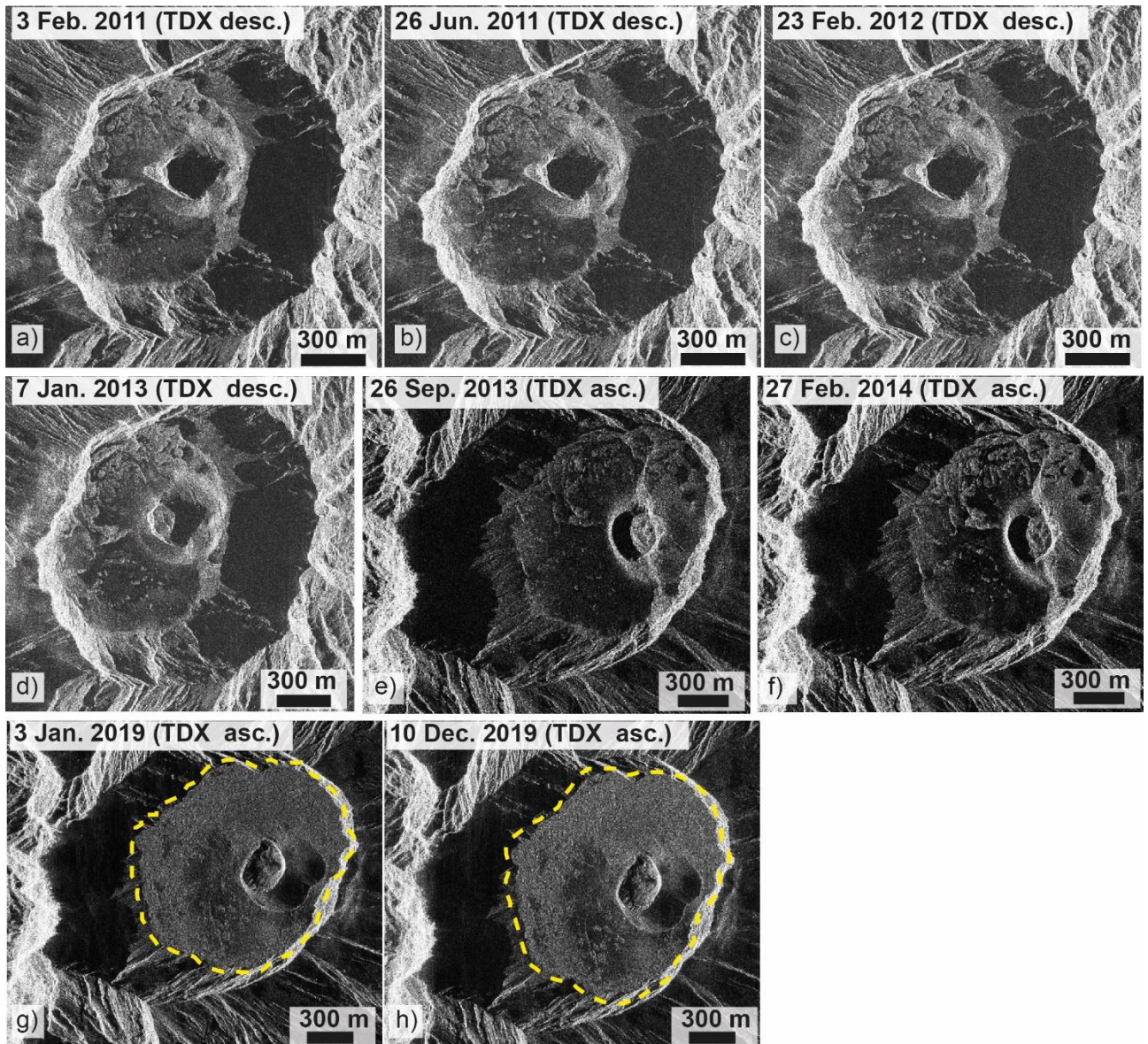
Federico Galetto^{1*}, Diego Lobos Lillo¹, Matthew E. Pritchard¹

¹ Cornell University, Department of Earth and Atmospheric Sciences; Ithaca, NY, USA

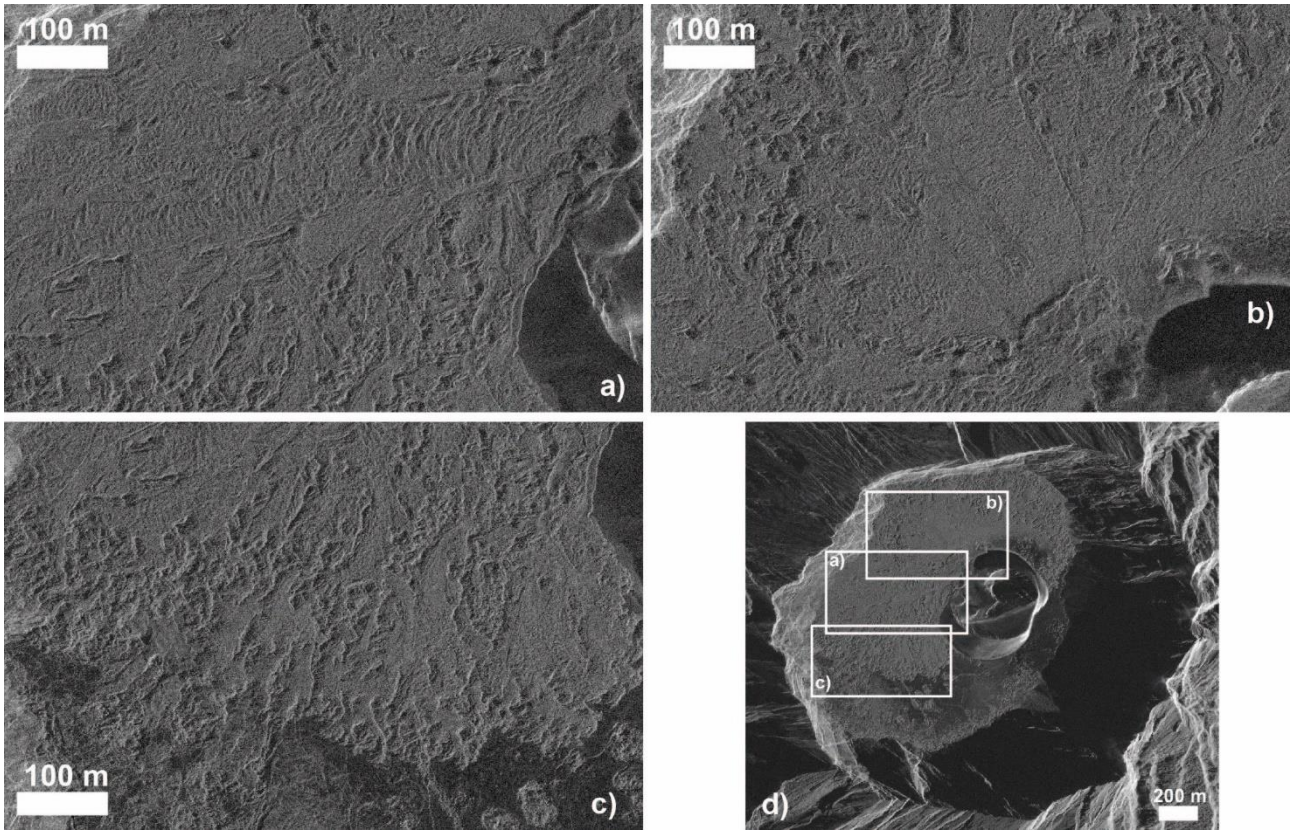
* Corresponding author: fg253@cornell.edu



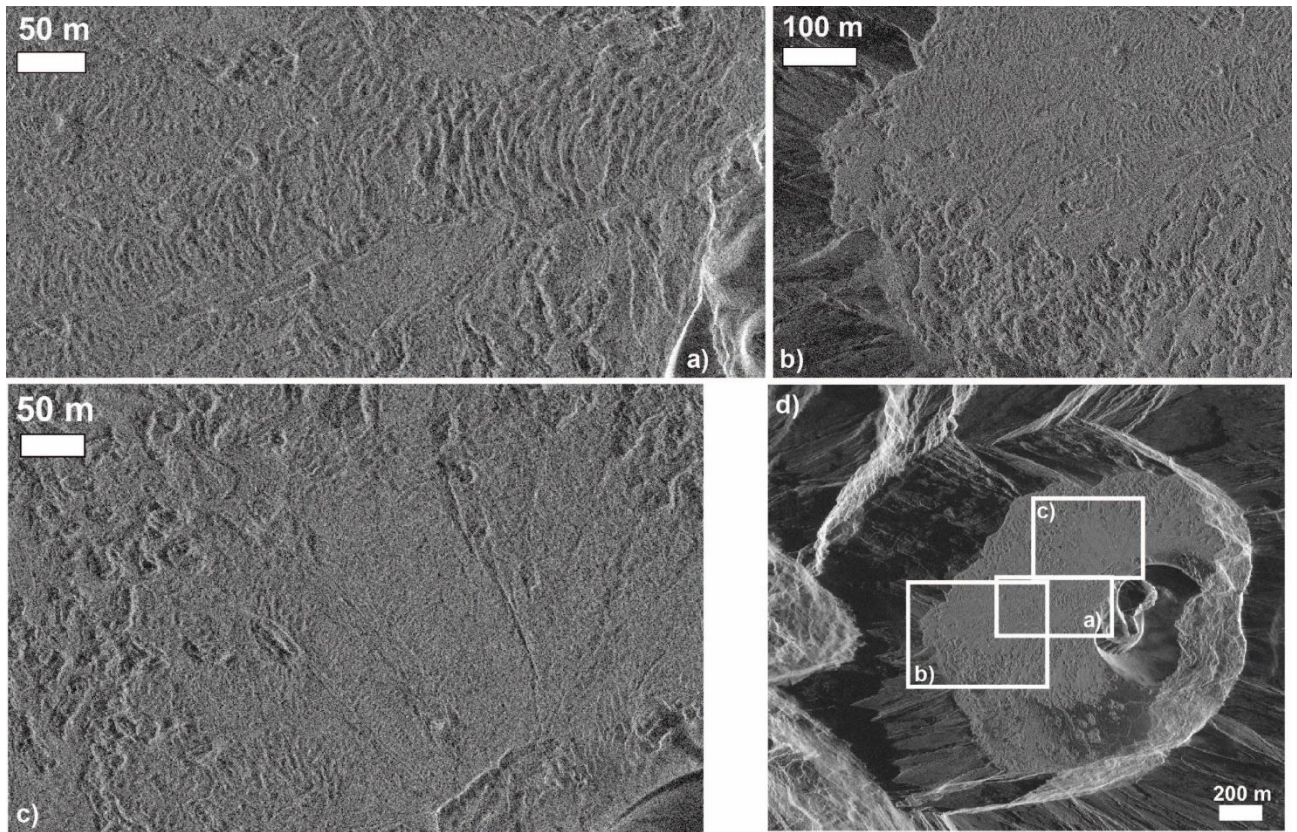
Supplementary Figure S1. a-b) Hillshade from Shuttle Radar Topography Mission (SRTM) DEM (a) and from Copernicus DEM (COP; panel b). c) Height change between the Copernicus DEM and the SRTM DEM. The heights of both DEMs have been referred to the ellipsoidal vertical datum WGS84 before the subtraction. The hachured lines delimit the trace of the elevation profiles in panel (d) (track A-B) and in panel (e) (track C-D). d-e) Elevation profiles of SRTM and Copernicus DEMs. Heights are referred to the ellipsoidal vertical datum WGS84.



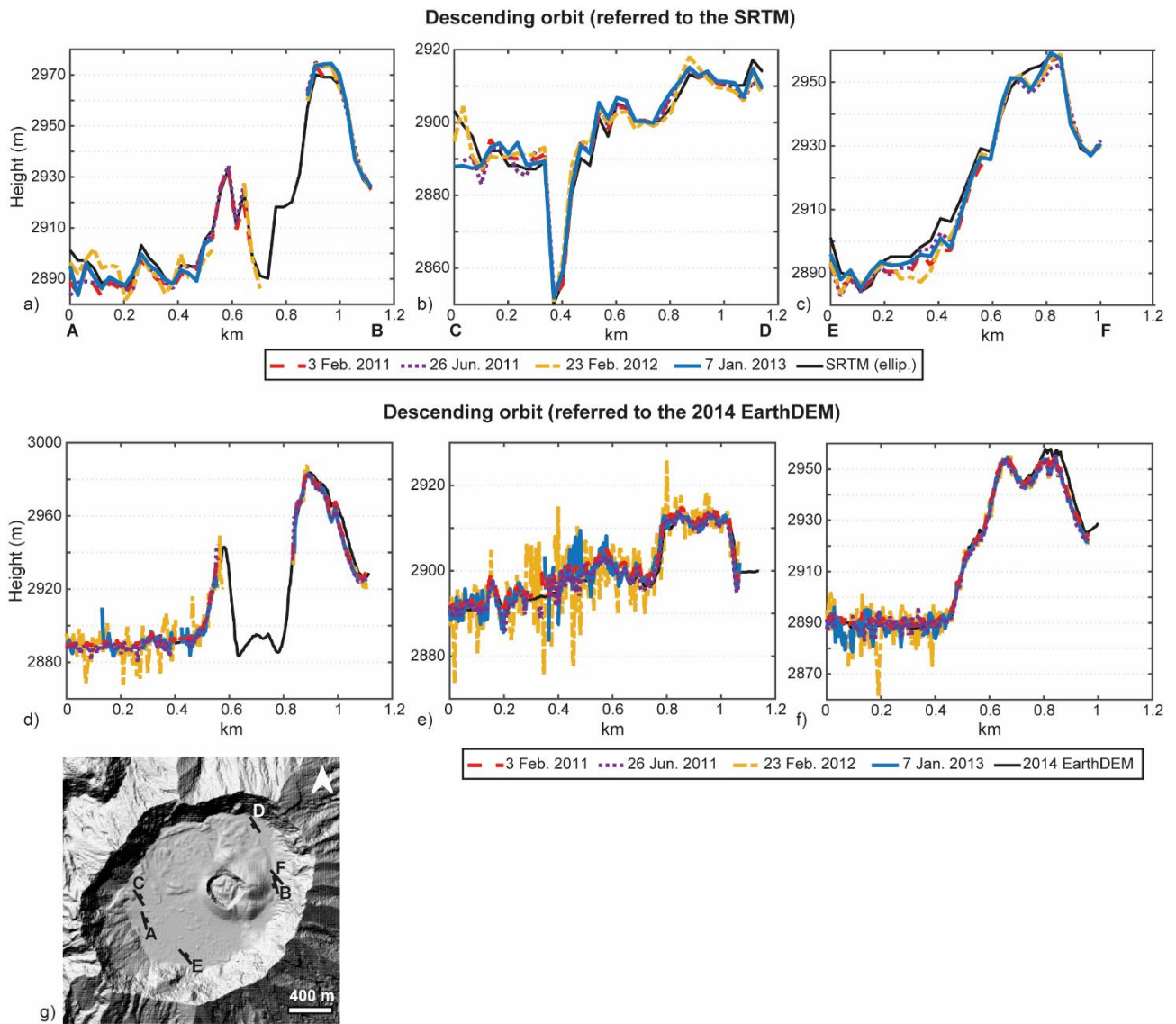
Supplementary Figure S2. TanDEM-X SAR amplitude data of Raung from descending (a-d) and ascending (e-h) orbits. Data are in radar coordinates (descending data have been reflected vertically, while ascending data have been reflected horizontally to be consistent each other). Yellow dashed lines in panels g-h show the extent of the lava flow erupted of the 2014-2015 eruption. Panels c,d,f,g are the same shown in Figure 4 (panels a,b,c,f) of the main text.



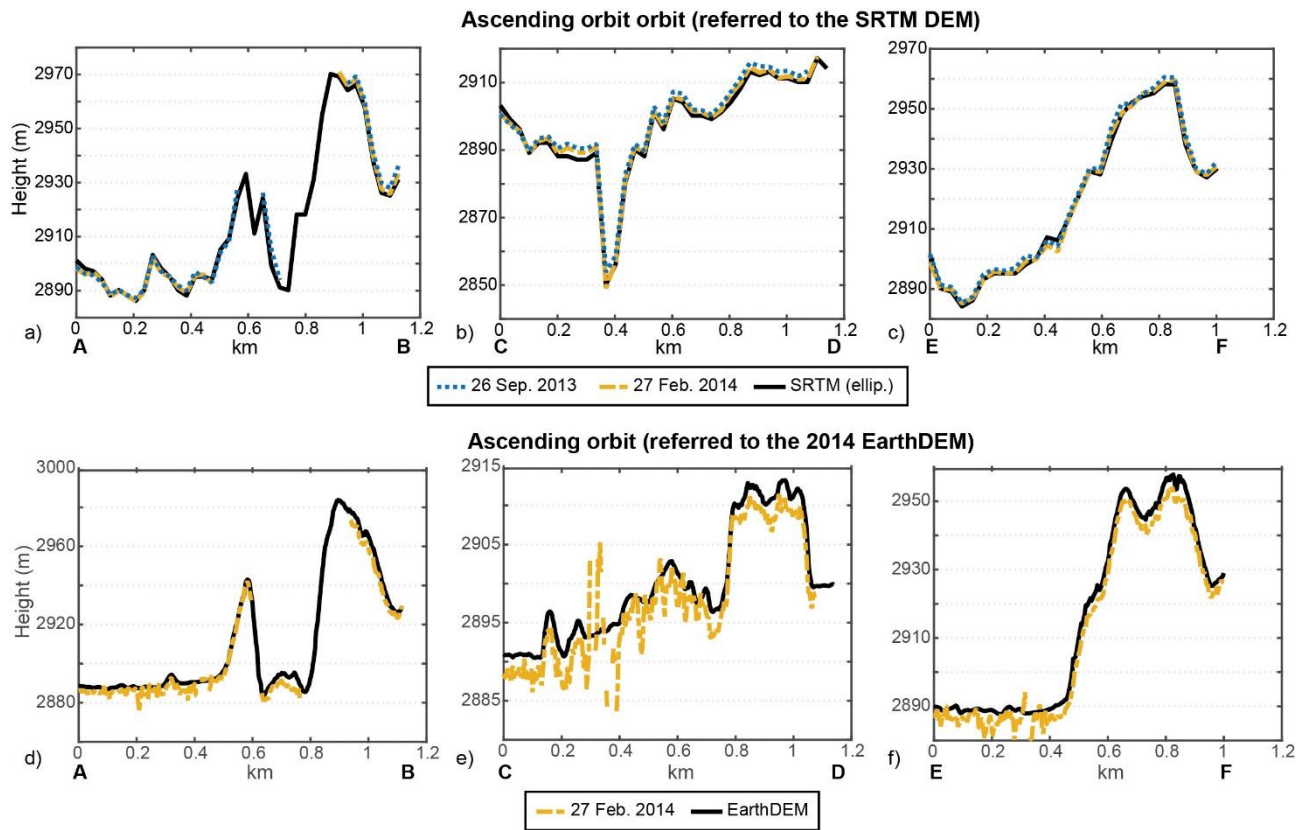
Supplementary Figure S3. Umbra Geocoded Ellipsoid Corrected (GEC) product (descending orbit with observation direction to the right) acquired on 7 October 2023. a-c) Details of the January-April 2021 lava flow. Panel (a) shows the billowy surface of the central lava lobe. Panel (b) also show some channels. c) Morphology of the lava in its south termination. d) Location of panels a-c.



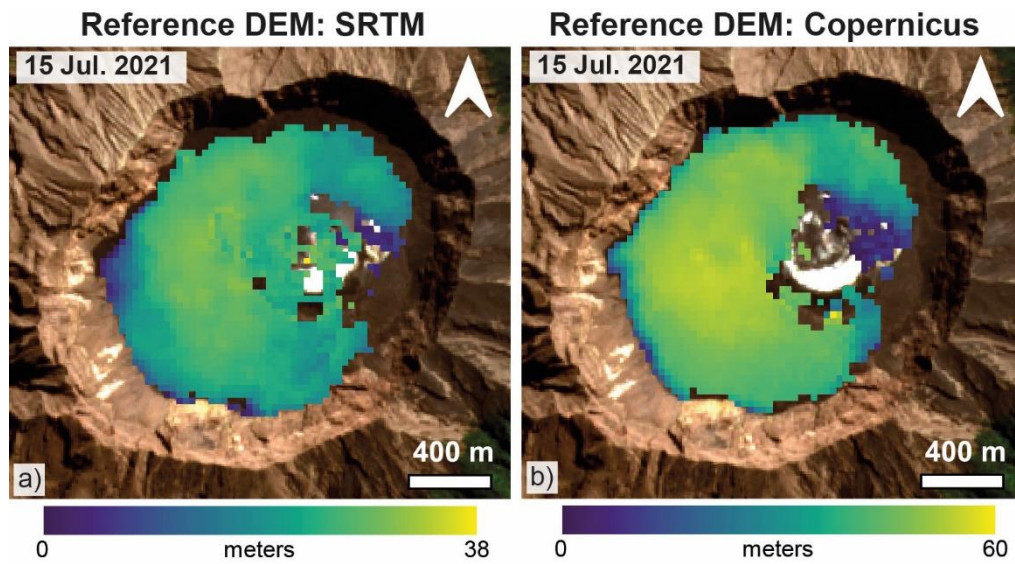
Supplementary Figure S4. Umbra Geocoded Ellipsoid Corrected (GEC) product (descending orbit with observation direction to the left) acquired on 11 November 2023. a-c) Details of the January-April 2021 lava flow. Panel (a) shows the billowy surface of the central lava lobe. b) Morphology of the lava in its south and west termination, with some channels and billowy surface in the upper part. c) North part of the lava flows with some channels d) Location of panels a-c.



Supplementary Figure S5. a-c) Profiles of elevation referred to the descending orbit data in Figure 5a-d. d-f) Profiles of elevation referred to the descending orbit data in Figure 5e-h. g) Tracks of the profiles in panels a-f plotted over the EarthDEM acquired in 2014. The heights of the DEMs are referred to the ellipsoidal vertical datum WGS84.



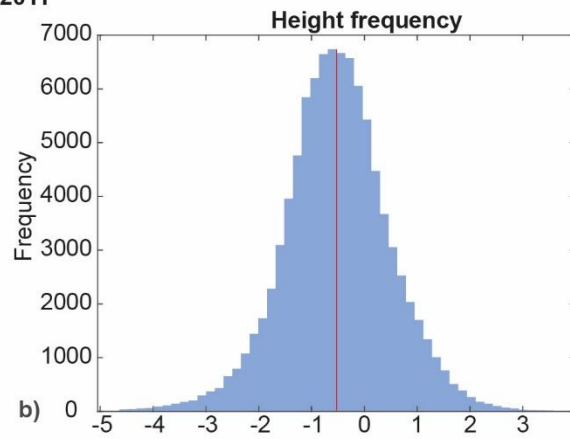
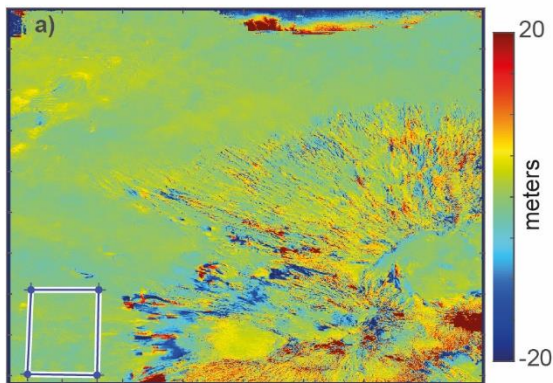
Supplementary Figure S6. a-c) Profiles of elevation referred to the ascending orbit data in Figure 5i-j. d-f) Profiles of elevation referred to the ascending orbit data in Figure 5k. The tracks position of the profiles is reported in Supplementary Figure S5g. The heights of the DEMs are referred to the ellipsoidal vertical datum WGS84.



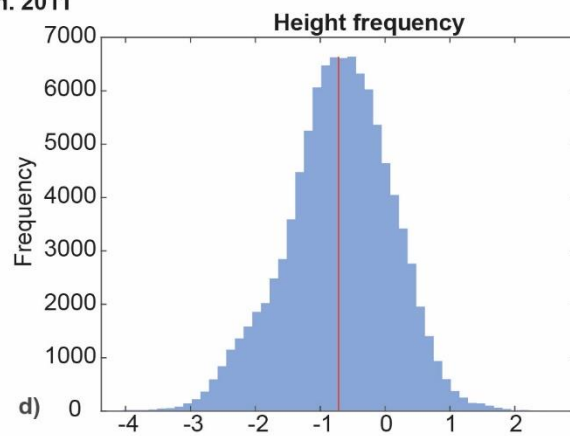
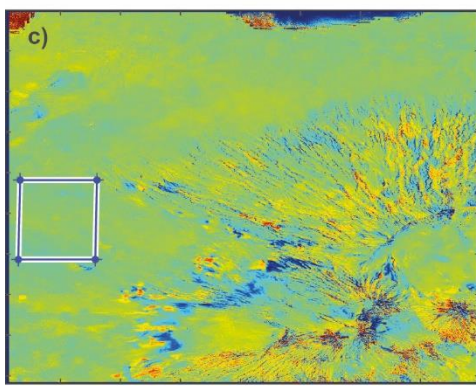
Supplementary Figure S7. Height change at Raung from bistatic data acquired in July 2021. Data have been processed with the SRTM DEM (a) and the Copernicus DEM (b), respectively.

Flat reference area (data processed with the SRTM DEM)

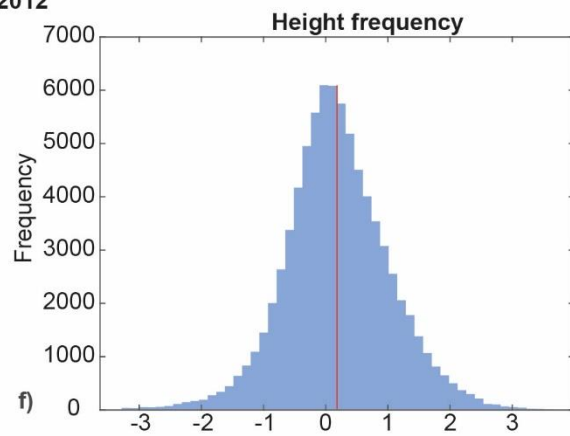
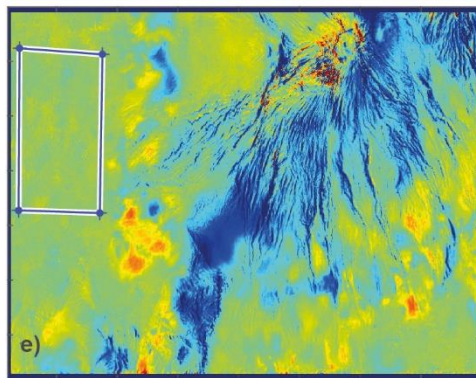
3 Feb. 2011



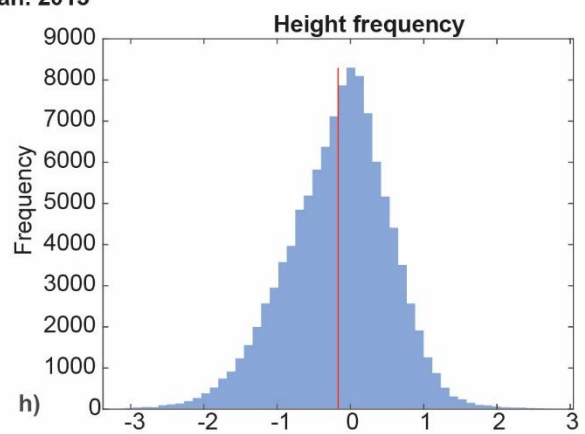
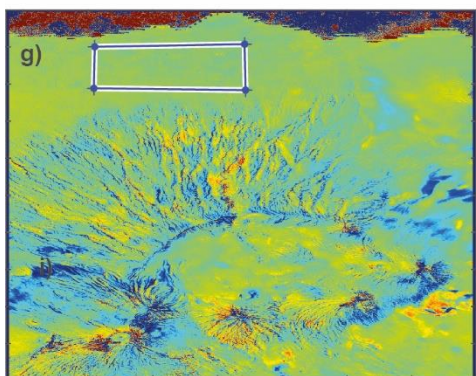
26 Jun. 2011



23 Feb. 2012



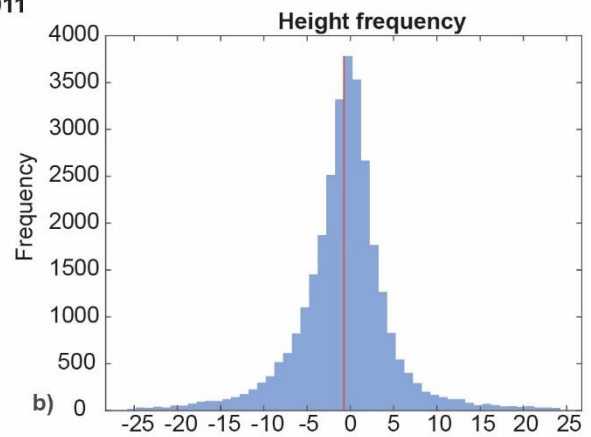
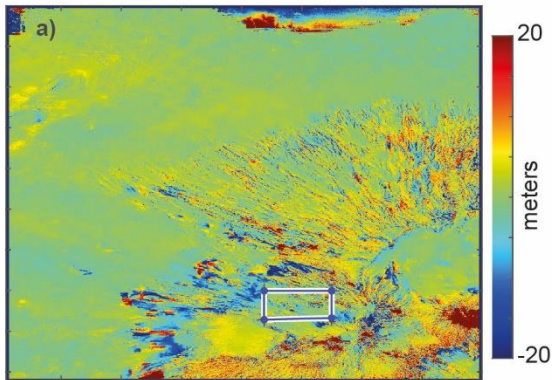
7 Jan. 2013



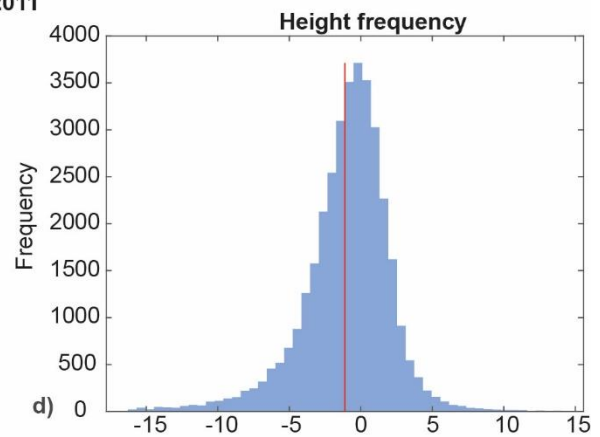
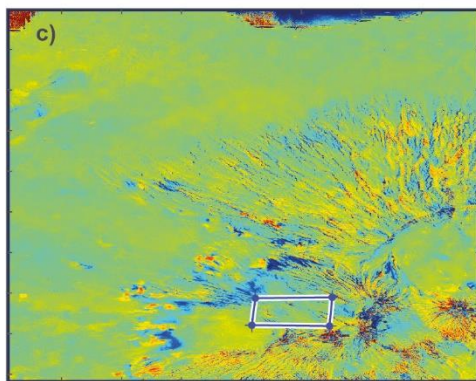
Supplementary Figure S8. a,c,e,g) Height change from bistatic descending orbit data (in radar coordinates) processed with the SRTM DEM. Data have been reflected vertically to be better oriented with the geographic east-west. Footprints showing the location of the area covered by data in panels a,c,e,g are in Supplementary Figure S14. Boxes in panels a,c,e,g show the location of the reference area that should not have been affected by height changes and that has been used to calculate the height change errors. The reference area is a relatively flat area with low vegetation. b,d,f,h) Histogram of frequency of the height changes of the pixels within the boxes in panels (a,c,e,g). Red line points the mean value.

Steep and vegetated reference area (data processed with the SRTM DEM)

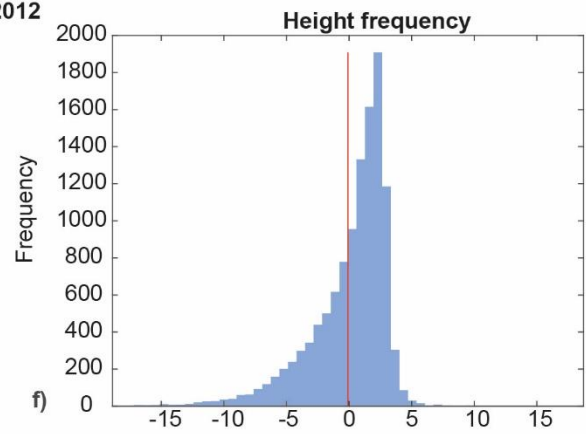
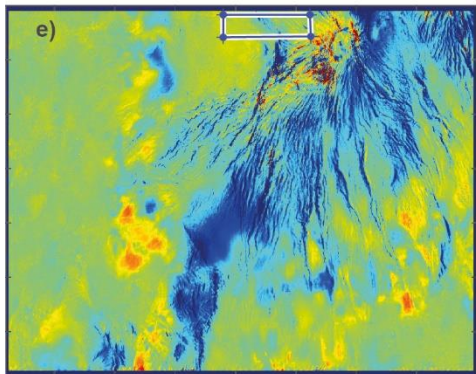
3 Feb. 2011



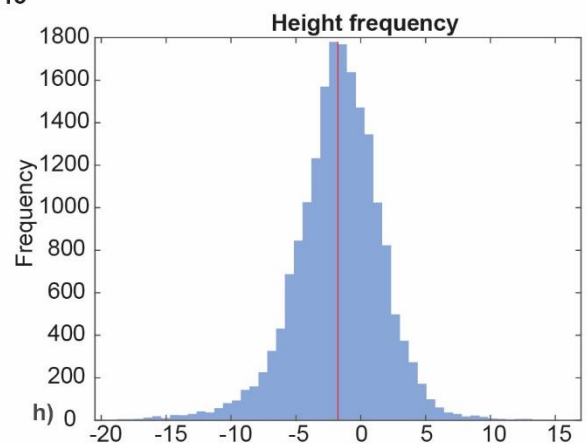
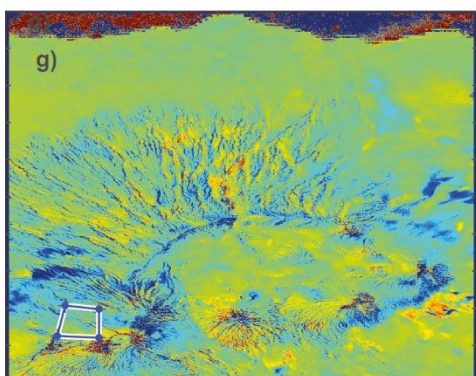
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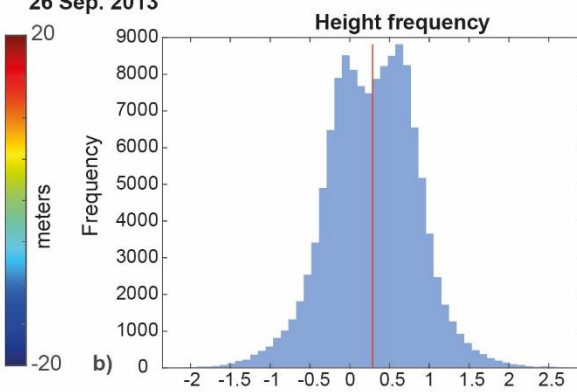
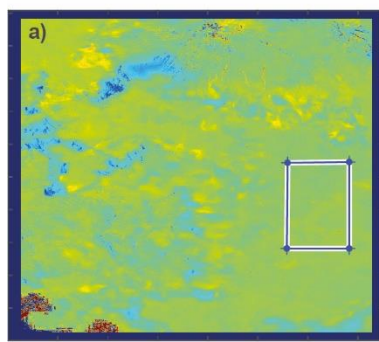
7 Jan. 2013



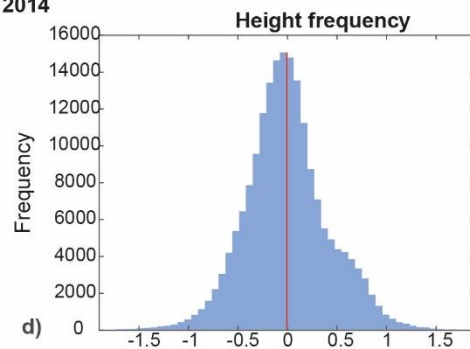
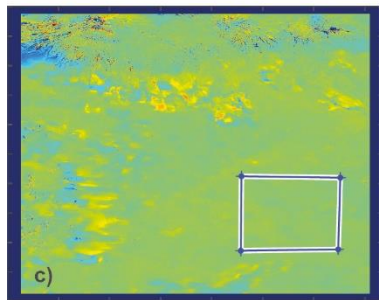
Supplementary Figure S9. a,c,e,g) Height change from bistatic descending orbit data (in radar coordinates) processed with the SRTM DEM. Data have been reflected vertically to be better oriented with the geographic east-west. Footprints showing the location of the area covered by data in panels a,c,e,g are in Supplementary Figure S14. Boxes in panels (a,c,e,g) show the location of the reference area that should not have been affected by height changes and that has been used to calculate the height change errors. The reference area is a steep and vegetated area. b,d,f,h) Histogram of frequency of the height changes of the pixels within the boxes in panels (a,c,e,g). Red line points the mean value.

Flat reference area (data processed with the SRTM DEM)

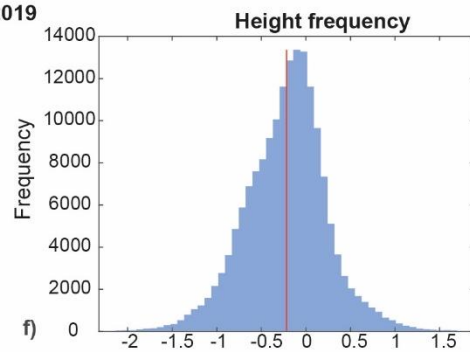
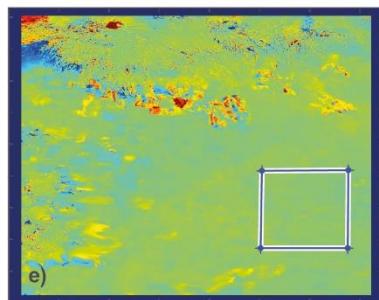
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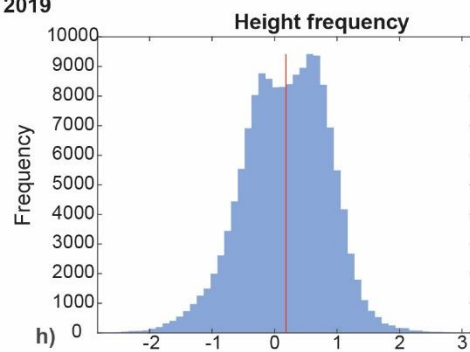
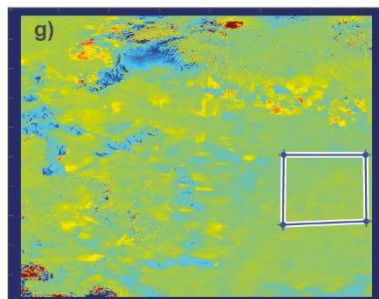
27 Feb. 2014



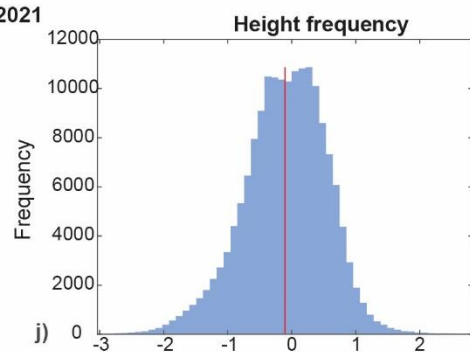
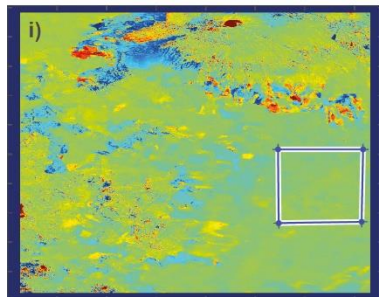
3 Jan. 2019



10 Dec. 2019

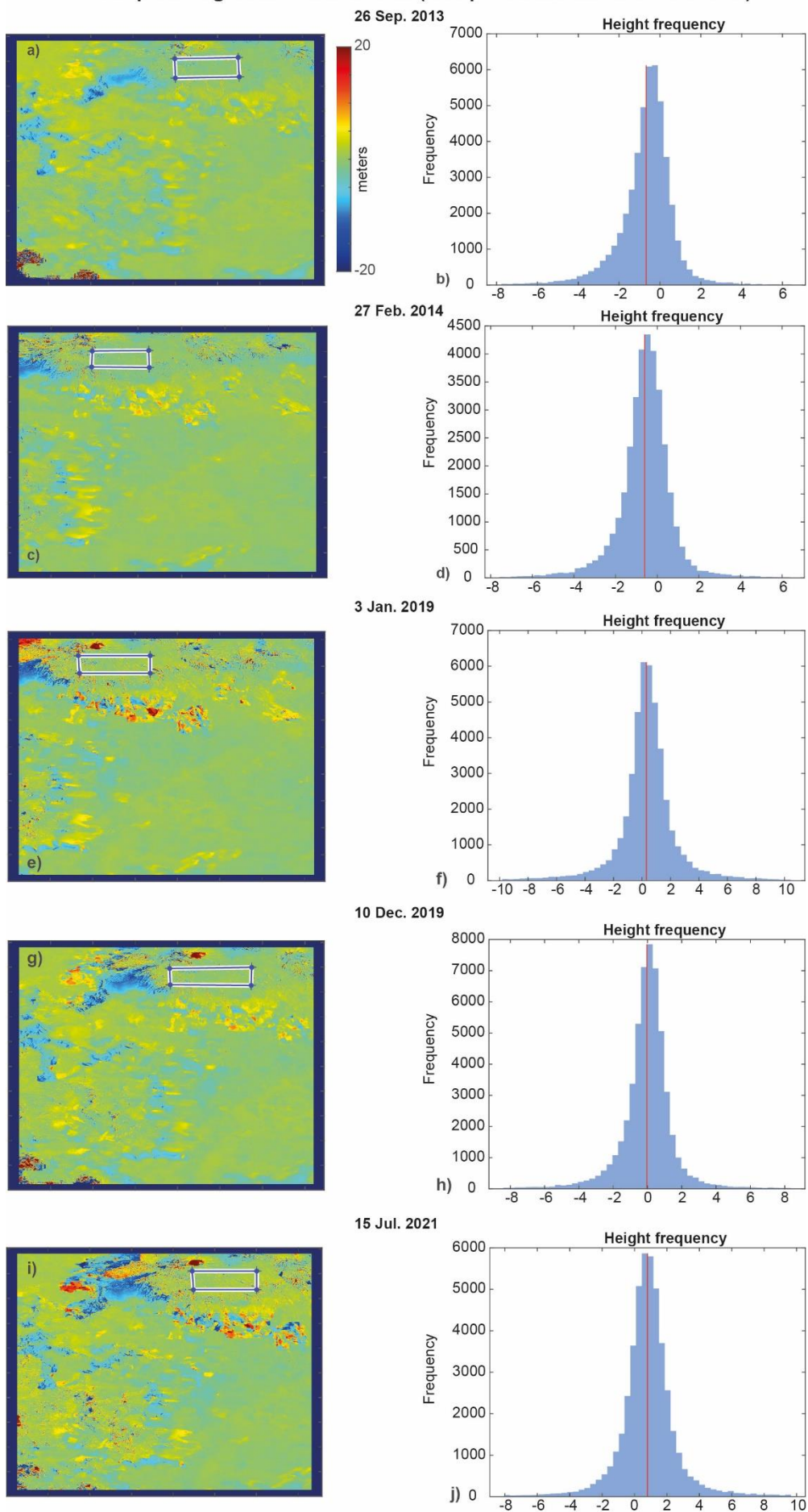


15 Jul. 2021

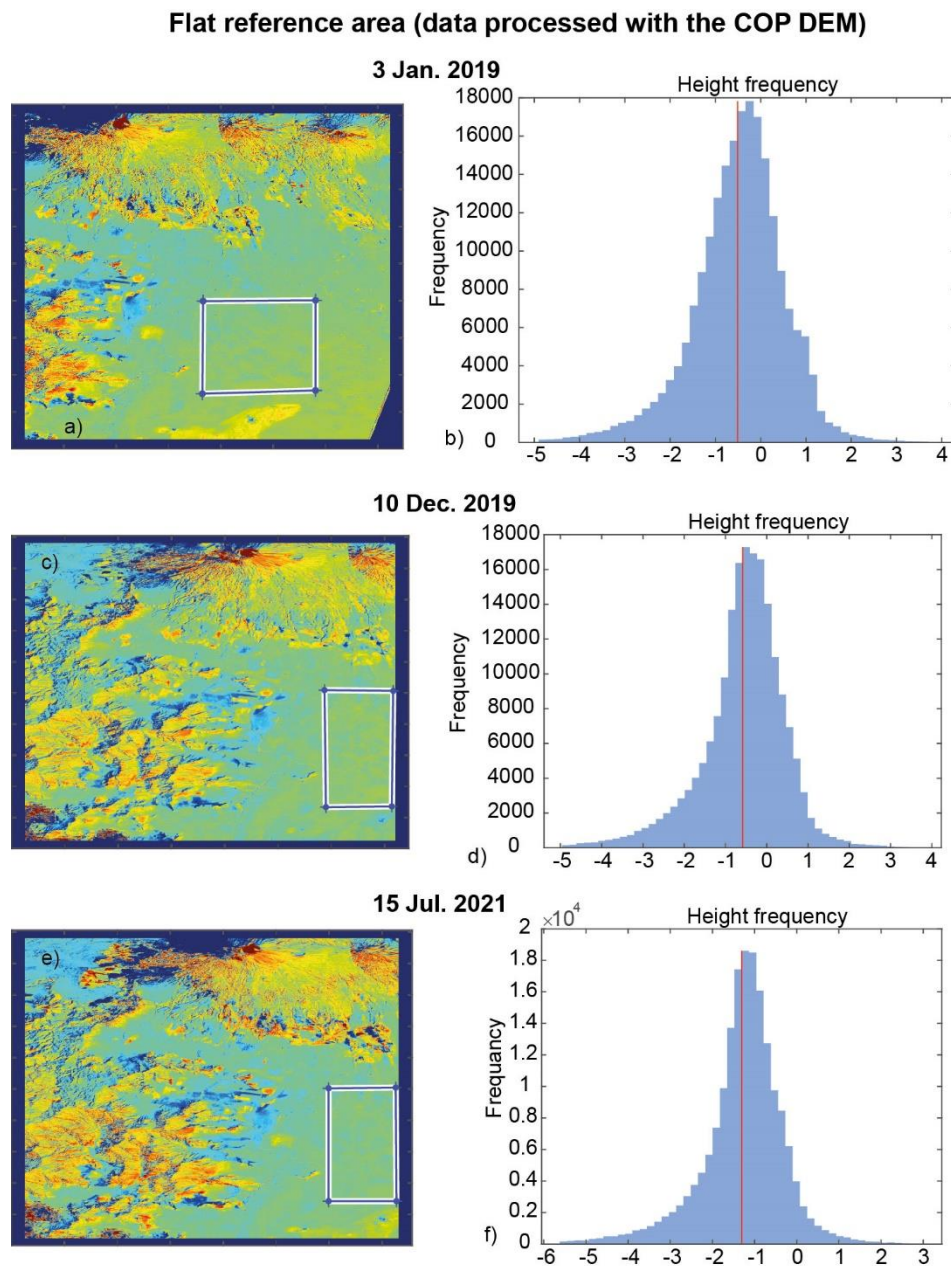


Supplementary Figure S10. a,c,e,g,i) Height change from bistatic ascending orbit data (in radar coordinates) processed with the SRTM DEM. Data have been reflected horizontally to be better oriented with the geographic north. Footprints showing the location of the area covered by data in panels a,c,e,g,i are in Supplementary Figure S15. Boxes in panels (a,c,e,g,i) show the location of the reference area that should not have been affected by height changes and that has been used to calculate the height change errors. The reference area is in a relatively flat area with low vegetation. b,d,f,h,j) Histogram of frequency of the height changes of the pixels within the boxes in panels (a,c,e,g,i). Red line points the mean value.

Steep and vegetated reference area (data processed with the SRTM DEM)

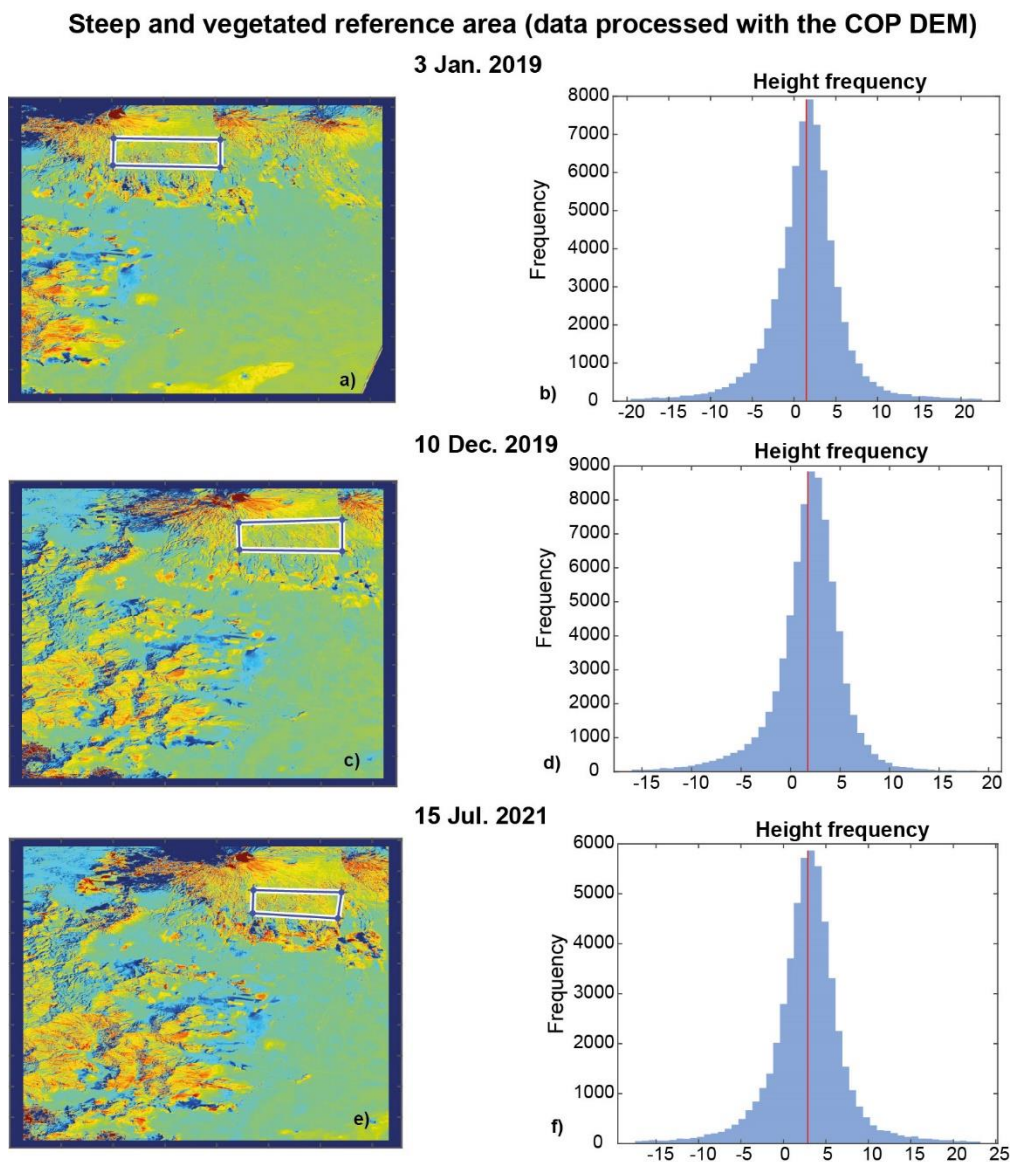


Supplementary Figure S11. Height change from bistatic ascending orbit data (in radar coordinates) processed with the SRTM DEM. Data have been reflected horizontally to be better oriented with the geographic north. Footprints showing the location of the area covered by data in panels a,c,e,g,i are in Supplementary Figure S15. Boxes in panels (a,c,e,g,i) show the location of the reference area that should not have been affected by height changes and that has been used to calculate the height change errors. The reference area is in a steep and vegetated area. b,d,f,h,j) Histogram of frequency of the height changes of the pixels within the boxes in panels (a,c,e,g,i). Red line points the mean value.



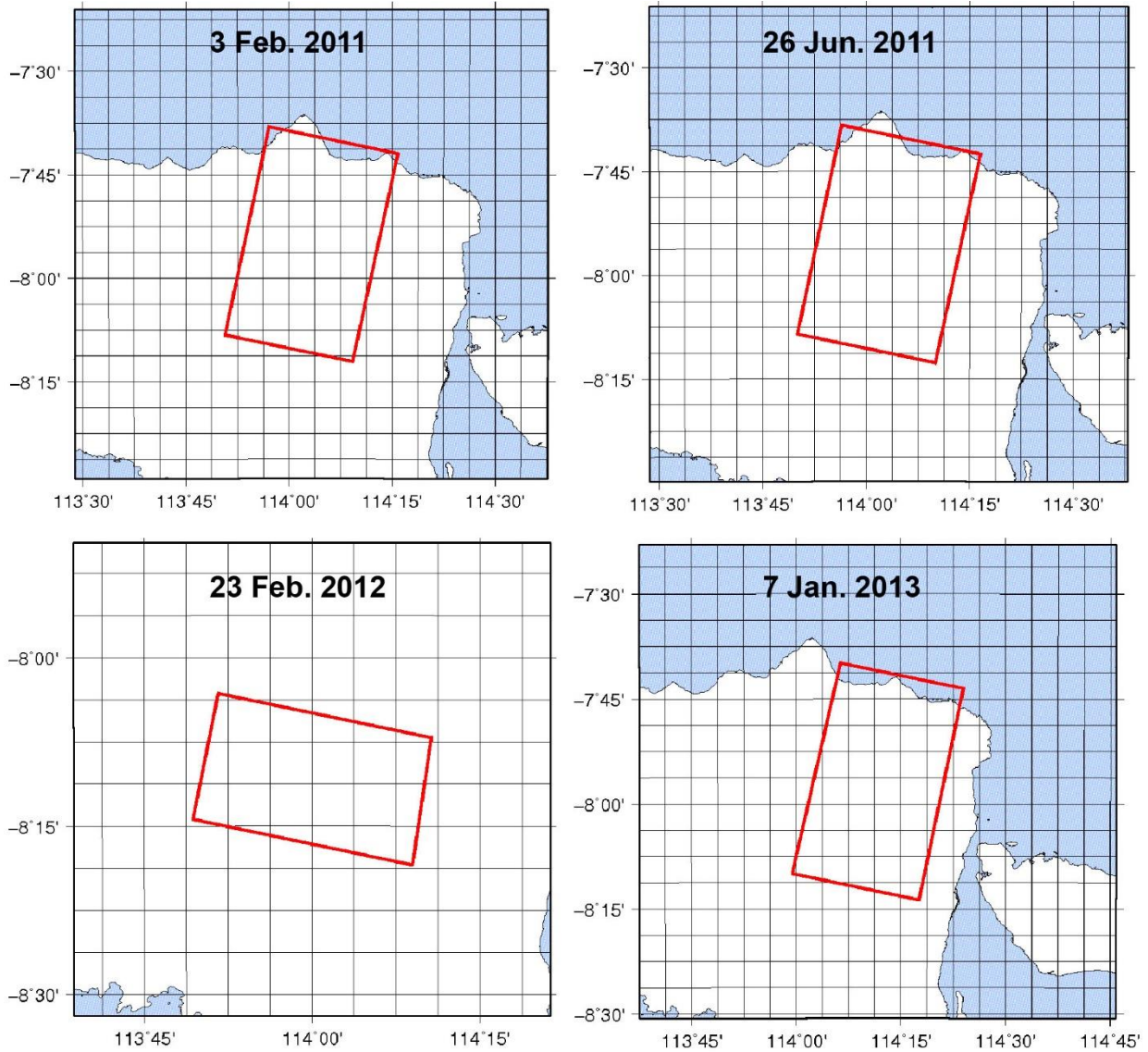
Supplementary Figure S12. a,c,e) Height change from bistatic ascending orbit data (in radar coordinates) processed with the Copernicus DEM. Data have been reflected horizontally to be better

oriented with the geographic north. Footprints showing the location of the area covered by data in panels a,c,e are in Supplementary Figure S15. Boxes in panels (a,c,e) show the location of the reference area that should not have been affected by height changes and that has been used to calculate the height change errors. The reference area is in a relatively flat area with low vegetation. b,d,f) Histogram of frequency of the height changes of the pixels within the boxes in panels (a,c,e). Red line points the mean value.

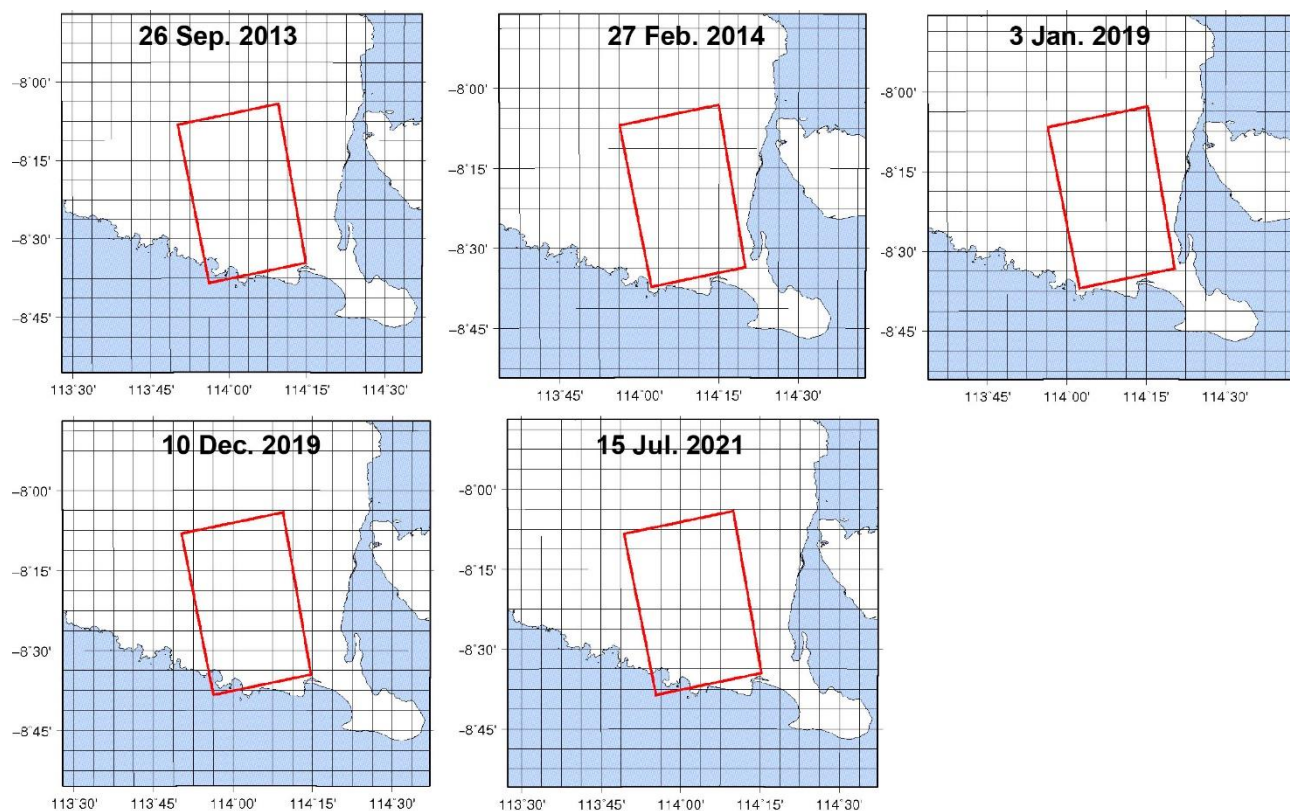


Supplementary Figure S13. a,c,e) Height change from bistatic ascending orbit data (in radar coordinates) processed with the Copernicus DEM. Data have been reflected horizontally to be better oriented with the geographic north. Footprints showing the location of the area covered by data in panels a,c,e are in Supplementary Figure S15. Boxes in panels (a,c,e) show the location of the reference area that should not have been affected by height changes and that has been used to calculate

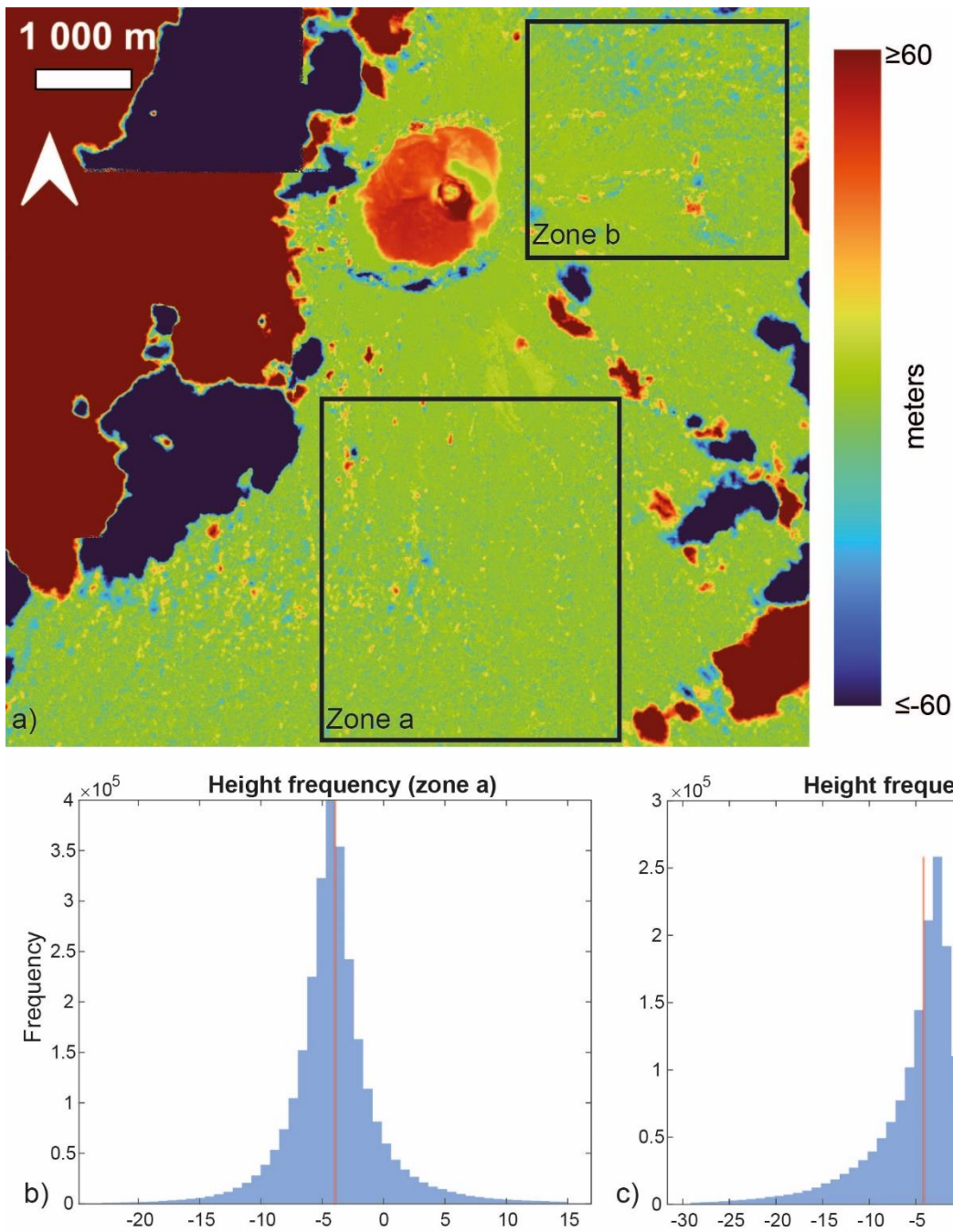
the height change errors. The reference area is placed in a steep and vegetated area. b,d,f) Histogram of frequency of the height changes of the pixels within the boxes in panels (a,c,e). Red line points the mean value.



Supplementary Figure S14. Footprints showing the location of descending orbit data in Supplementary Figures S8-9.

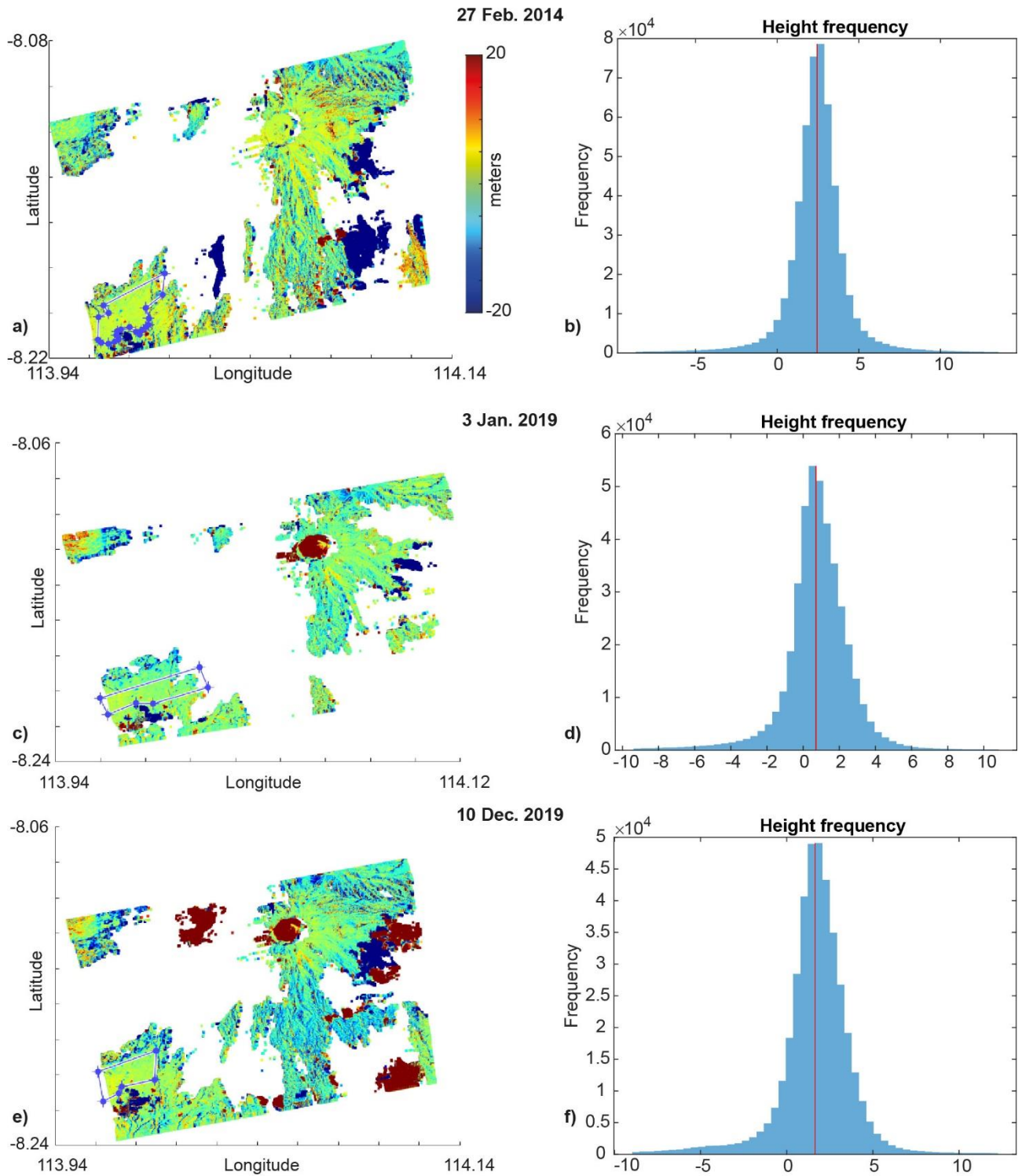


Supplementary Figure S15. Footprints showing the location of ascending orbit data in Supplementary Figures S10-13.



Supplementary Figure S16. a) Height change obtained by differentiating the 2018 and the 2014 EarthDEMs. Dark red and dark blue areas outside the caldera of Raung are zone covered by clouds. Boxes represent the two reference areas, placed in relatively steep and vegetated areas, that should not have been affected by height changes and that have been used to calculate the height change errors. b-c) Histogram of frequency of the height changes of the pixels within the boxes in panel (a). Red line points the mean value.

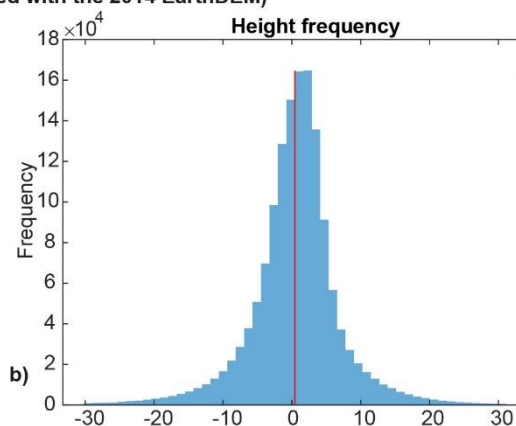
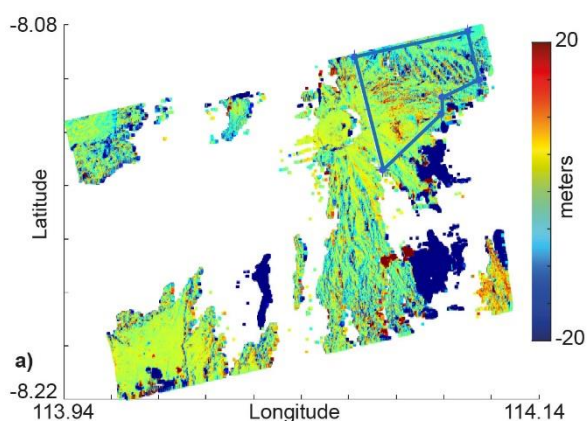
Nearly flat reference area (data processed with the 2014 EarthDEM)



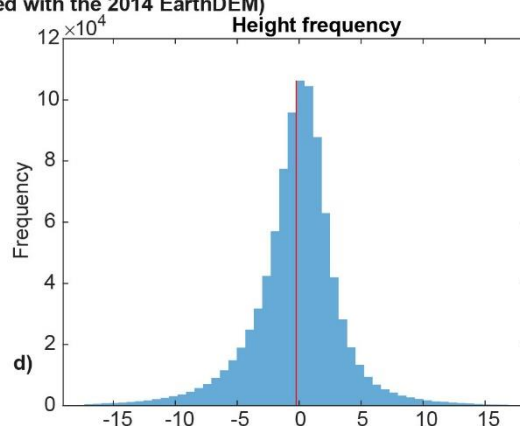
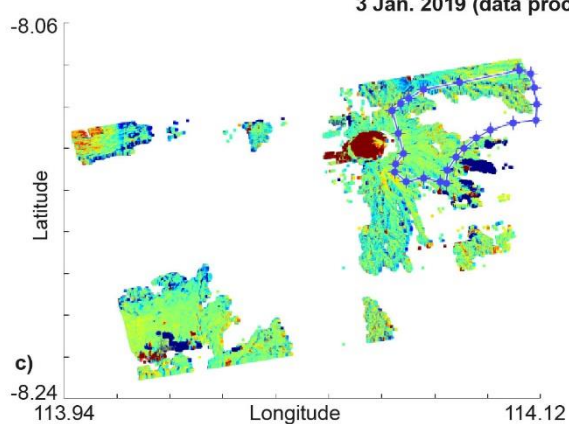
Supplementary Figure S17. Height change from bistatic ascending orbit data (geocoded) processed with the entire 2014 EarthDEM. Polygons in panels a,c,e show the location of the reference area that should not have been affected by height changes and that has been used to calculate the height change errors. The reference area is placed in a relatively flat, but vegetated, area. b,d,f) Histogram of frequency of the height changes of pixels within the boxes in panels (a,c,e). Red line points the mean value.

Steep and vegetated reference area

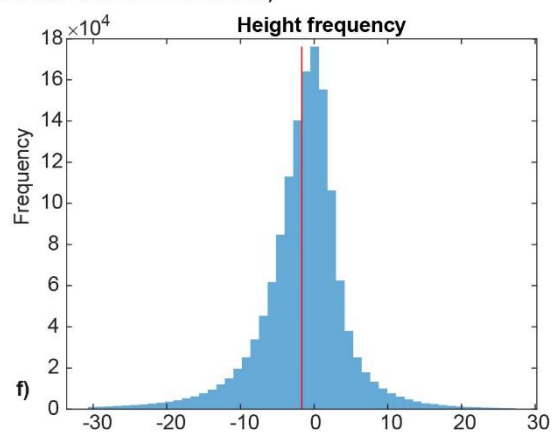
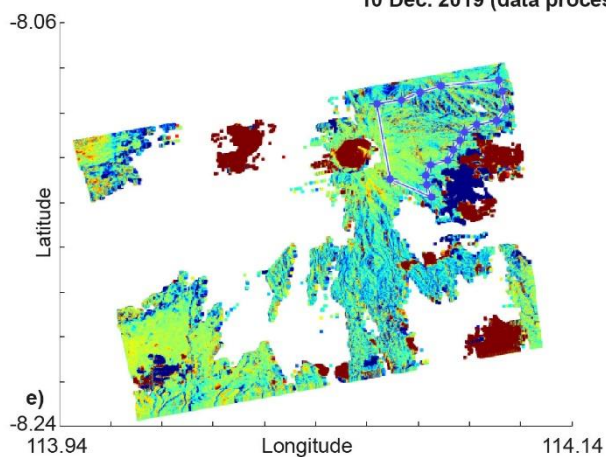
27 Feb. 2014 (data processed with the 2014 EarthDEM)



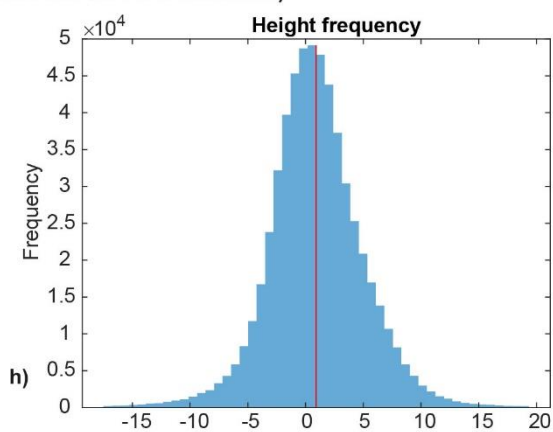
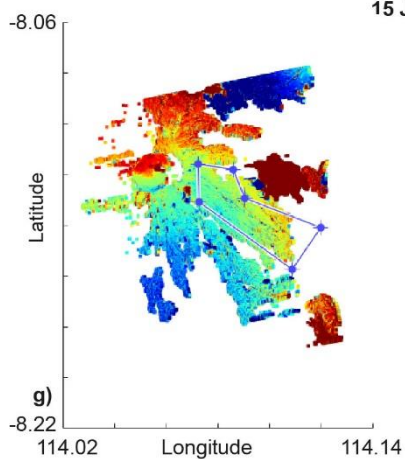
3 Jan. 2019 (data processed with the 2014 EarthDEM)



10 Dec. 2019 (data processed with the 2014 EarthDEM)

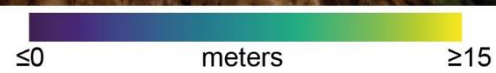
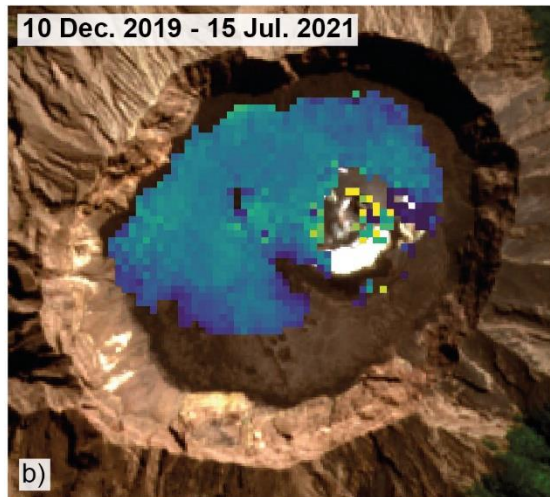
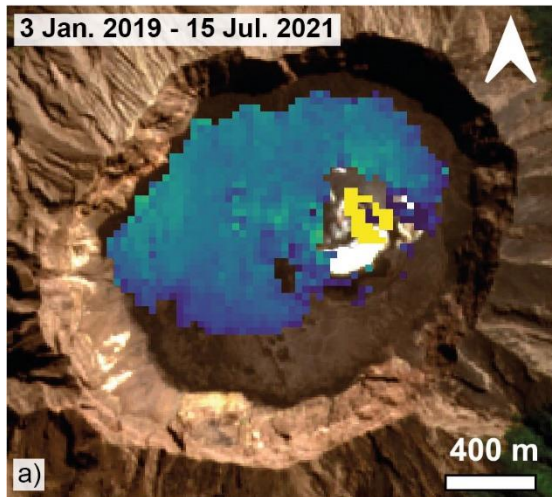


15 Jul. 2021 (data processed with the 2018 EarthDEM)

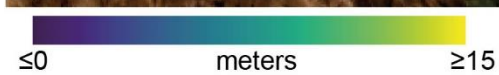
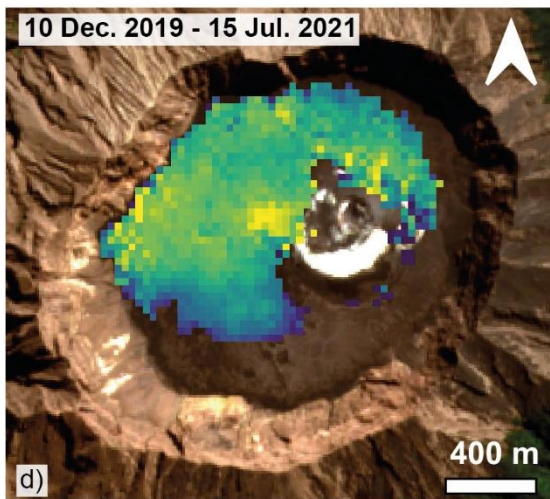
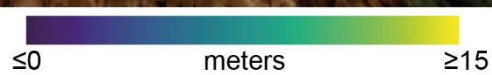
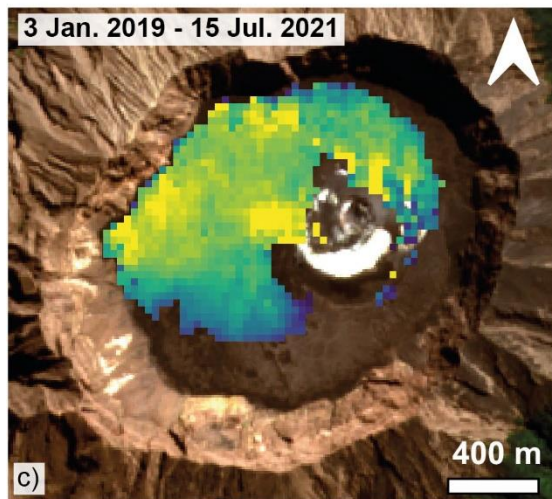


Supplementary Figure S18 Height change from bistatic ascending orbit data (geocoded) processed with the entire EarthDEMs. Polygons in panels a,c,e,g show the location of the reference area that should not have been affected by height changes and that has been used to calculate the height change errors. The reference area is placed in relatively steep and vegetated areas. b,d,f,h) Histogram of frequency of the height changes of pixels within the boxes in panels (a,c,e,g). Red line points the mean value.

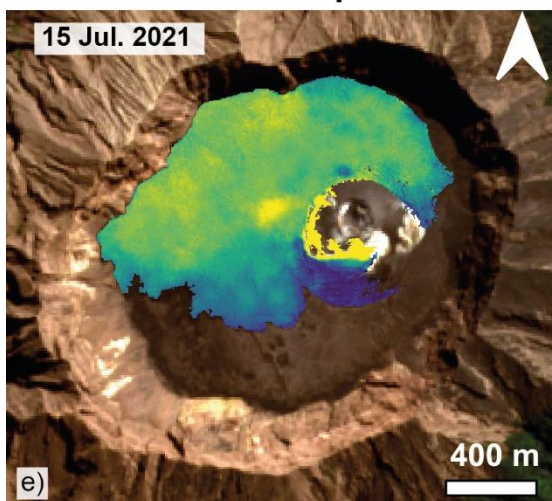
Reference DEM: SRTM



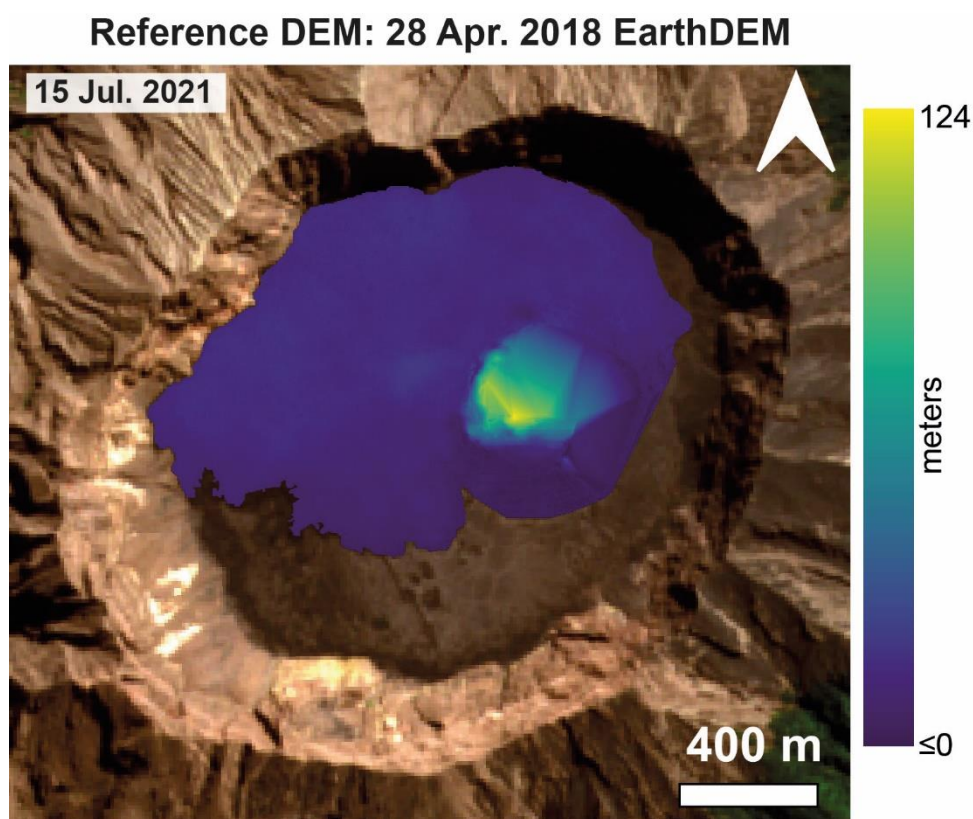
Reference DEM: Copernicus



Reference DEM: 28 Apr. 2018 EarthDEM



Supplementary Figure S19. Height change associated to the January – April 2021 eruption at Raung from bistatic data acquired in July 2021. Here we show only the height change in the area covered by volcanic deposits associated with the 2021 eruption. These data have been used to calculate volumes in Table 3. Data have been processed with the SRTM DEM (a-b), the Copernicus DEM (c-d) and with the EarthDEM acquired in April 2018 (e), respectively. Data in panels a-b and c-d have been obtained from the difference between the height changes obtained from the 2021 bistatic data and the height changes from bistatic data acquired in 2019, processed with the same DEM to remove the common background (unchanging) topography.



Supplementary Figure S20. Same of Supplementary Figure S19e, with voids that have been filled with the interpolation of the data.