GEOS639 Lecture 10:

Quantifying morphology changes using SAR amplitude images

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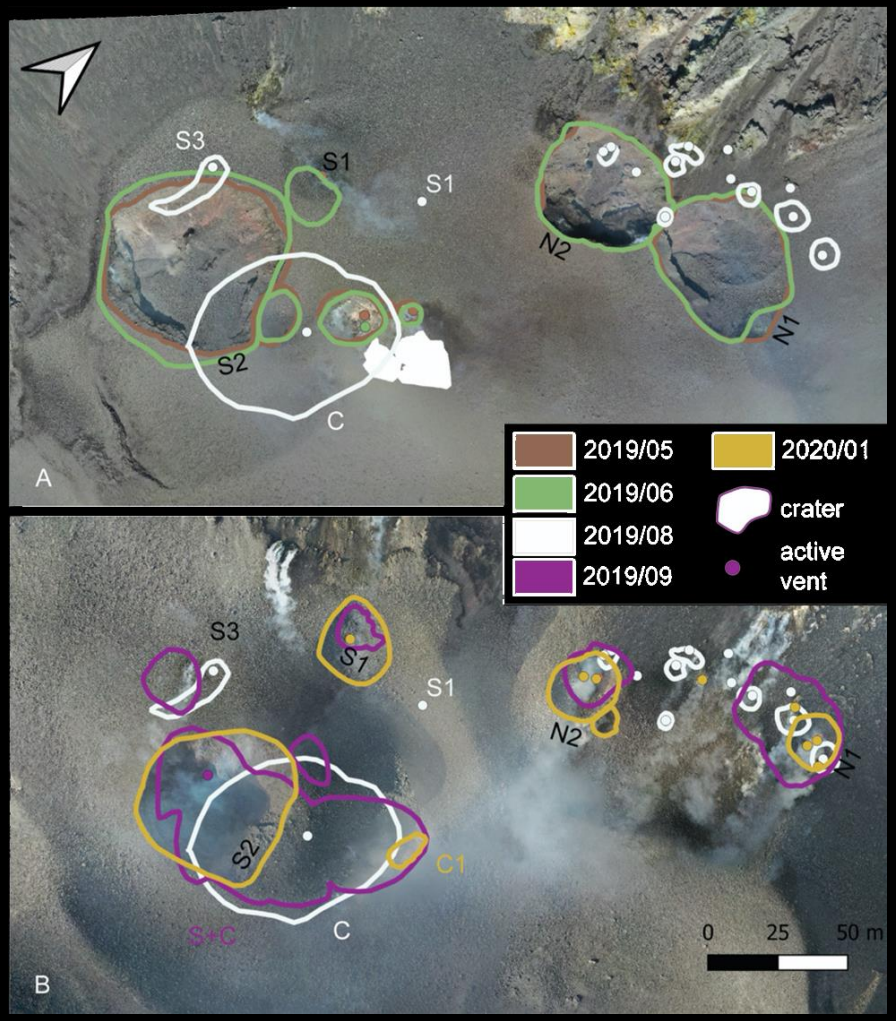
Motivation

Global Volcanism Program

- We want to quantify morphology changes to infer hazards associated with volcanic eruptions.
- For instance, the direction that a pyroclastic flow might take.

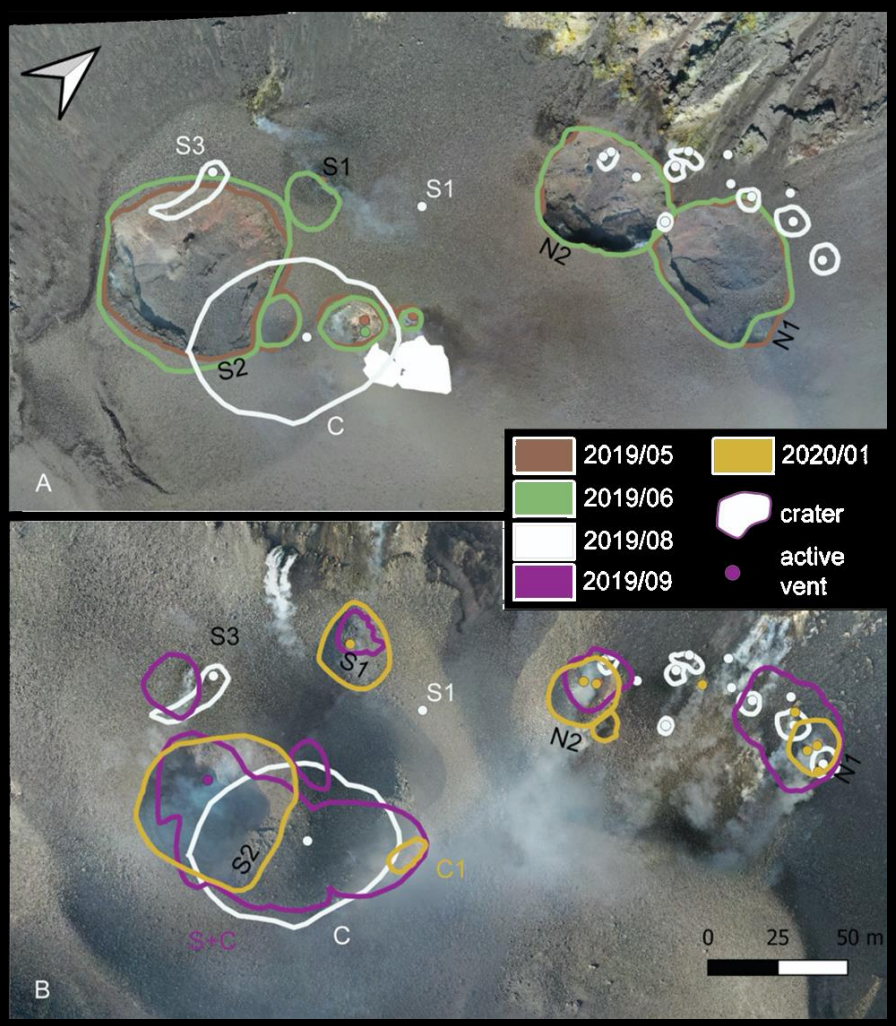
Motivation

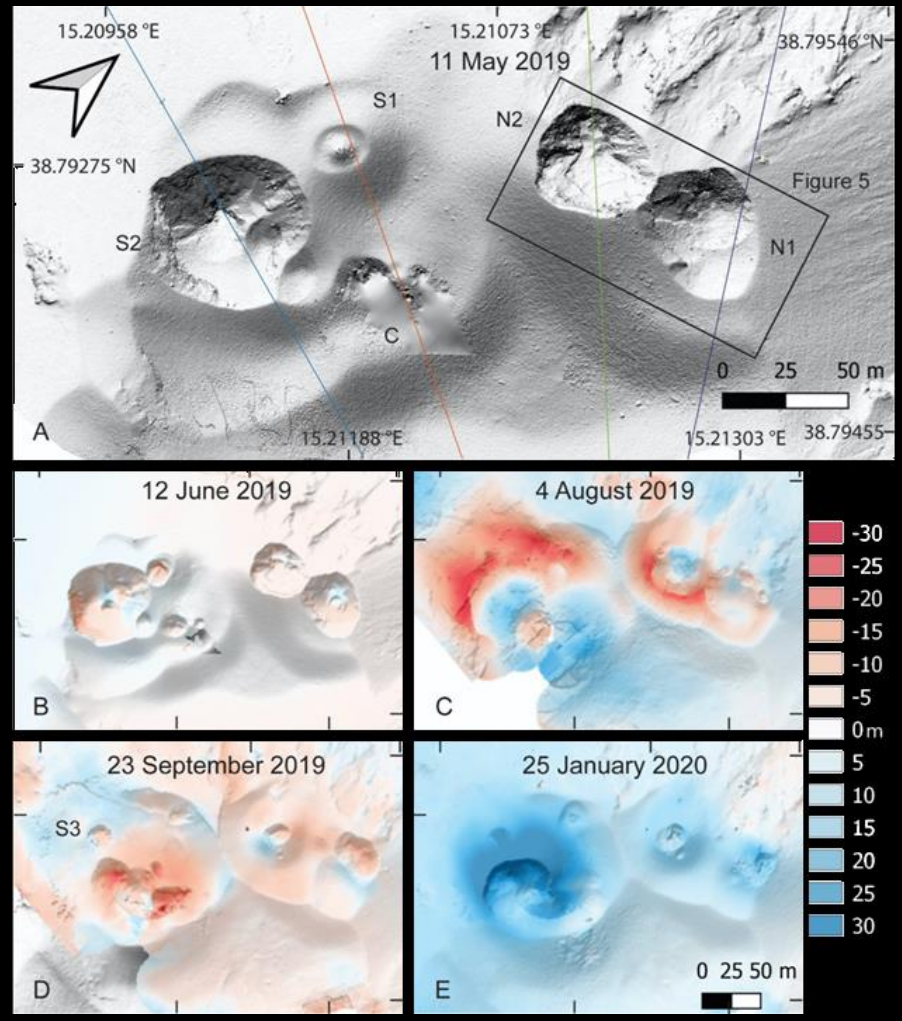


Schmid et al. (2021)

- Usually, this quantification has been made with optical images and photogrammetry techniques
- However, they are susceptible to cloud obstruction and night time.

Motivation





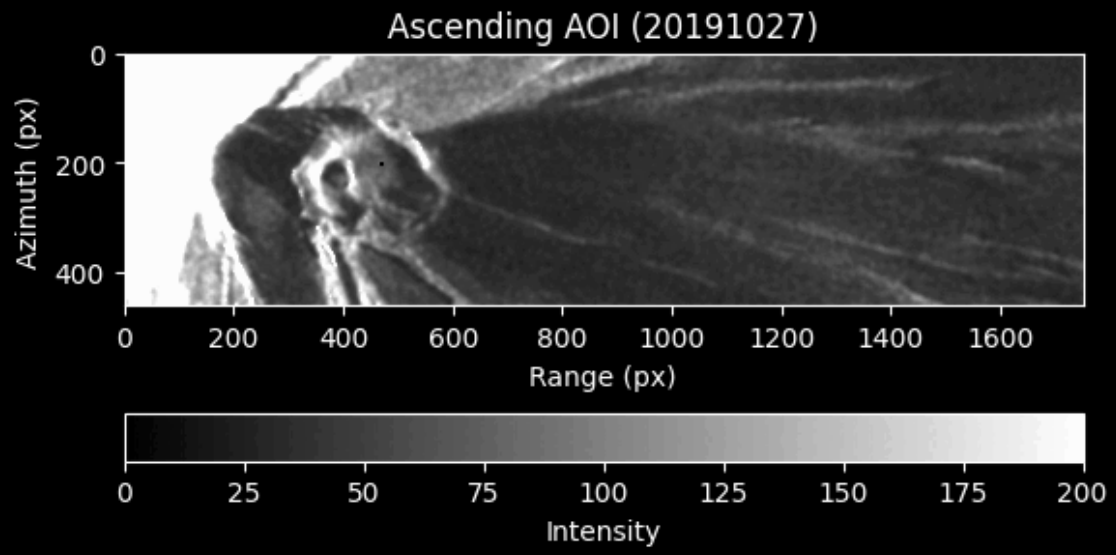
Schmid et., al. (2021)

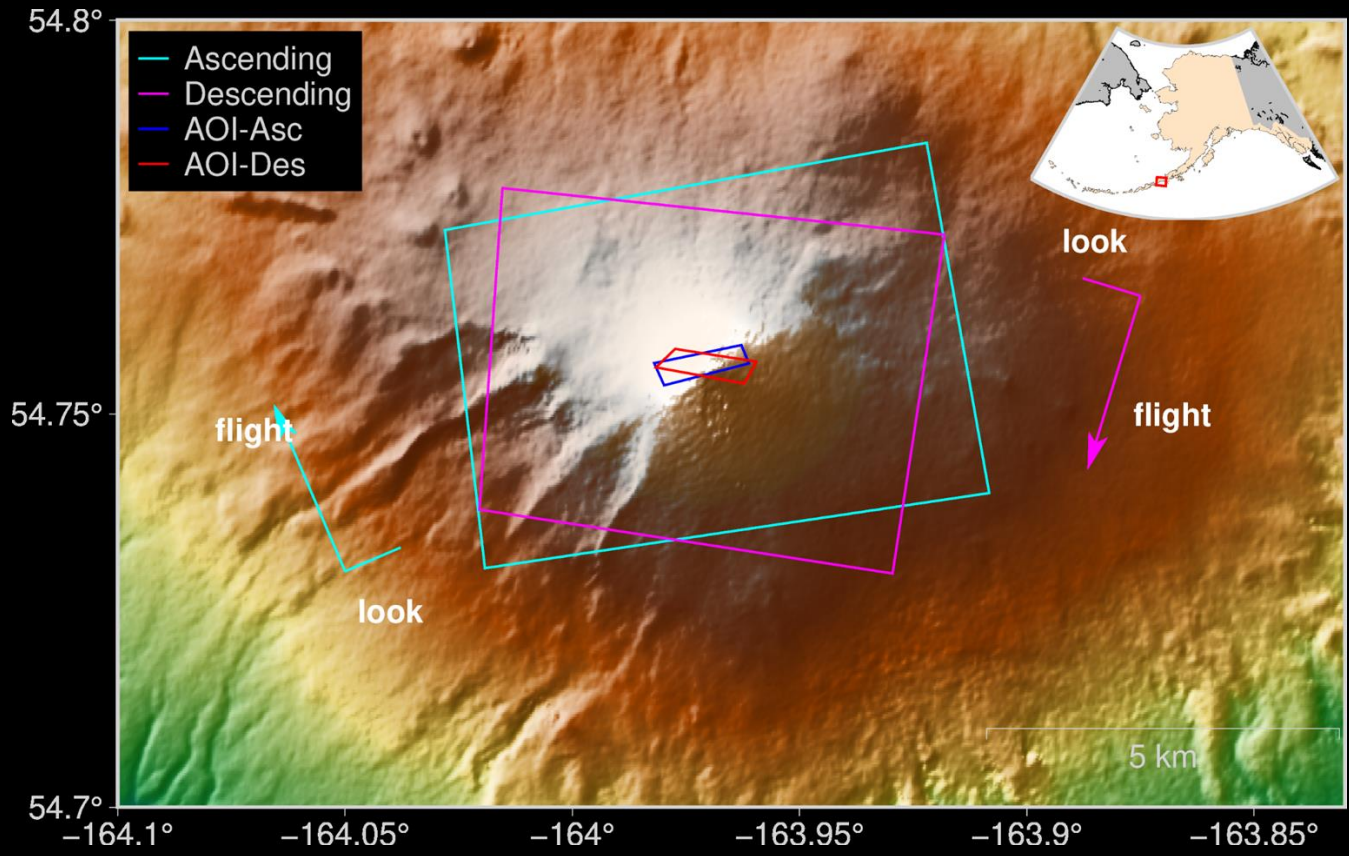
Motivation

We wanted to apply use a similar method for eruptions in Alaska.

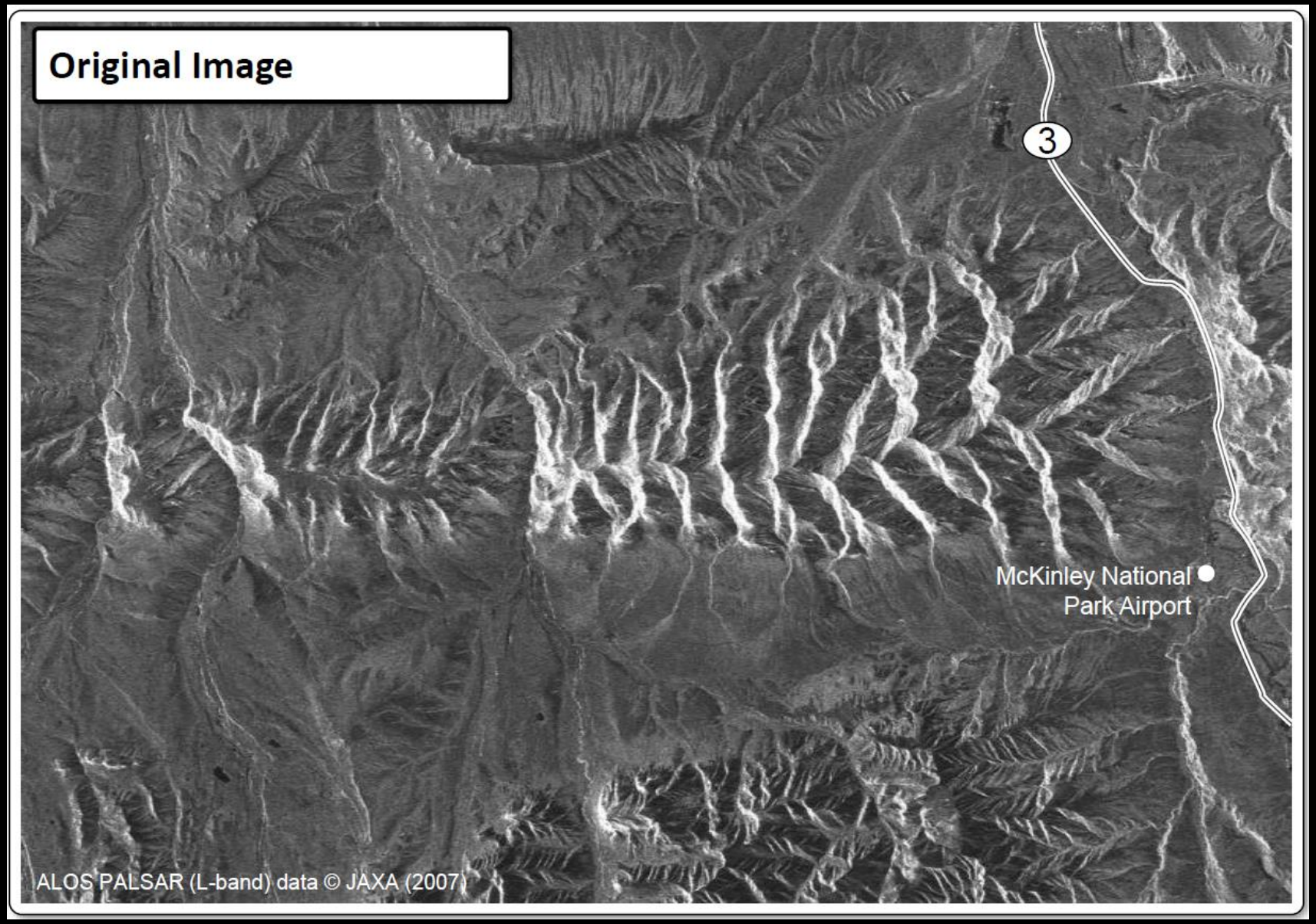
Motivation

- Radar images are less susceptible to these issues.
- For example, these TerraSAR-X images span the 2019-2020 Shishaldin eruption.





How are the amplitudes often used?



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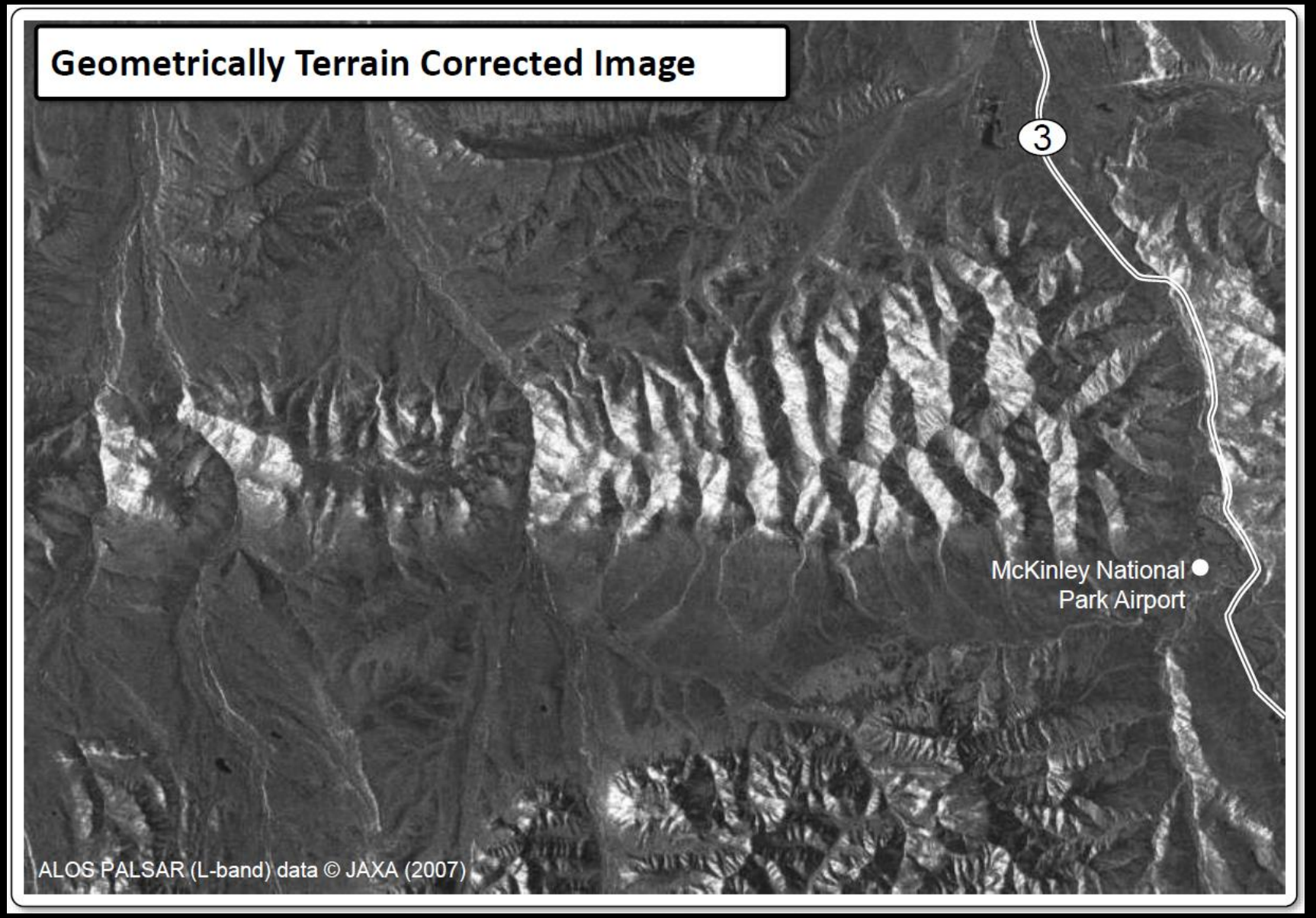
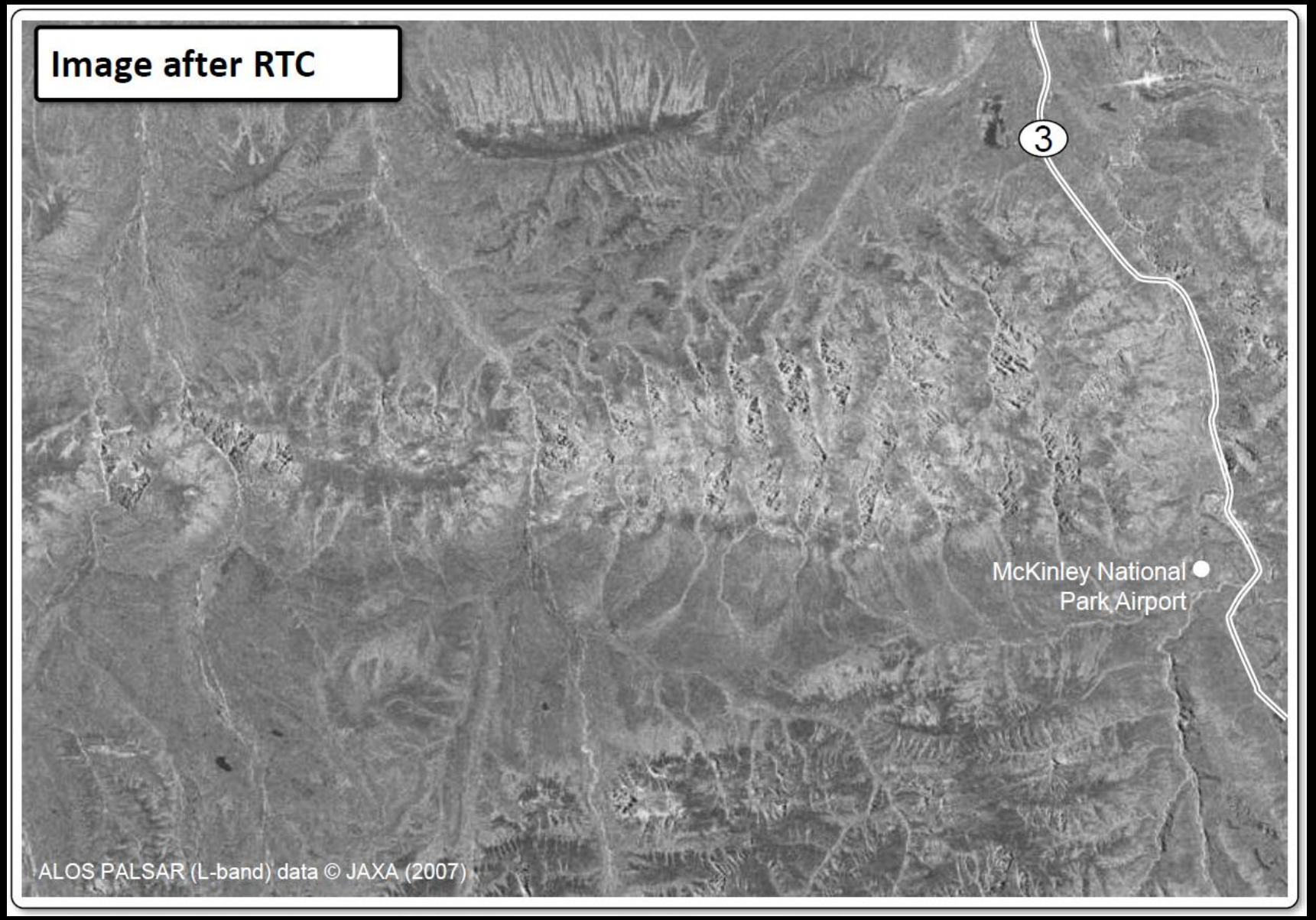
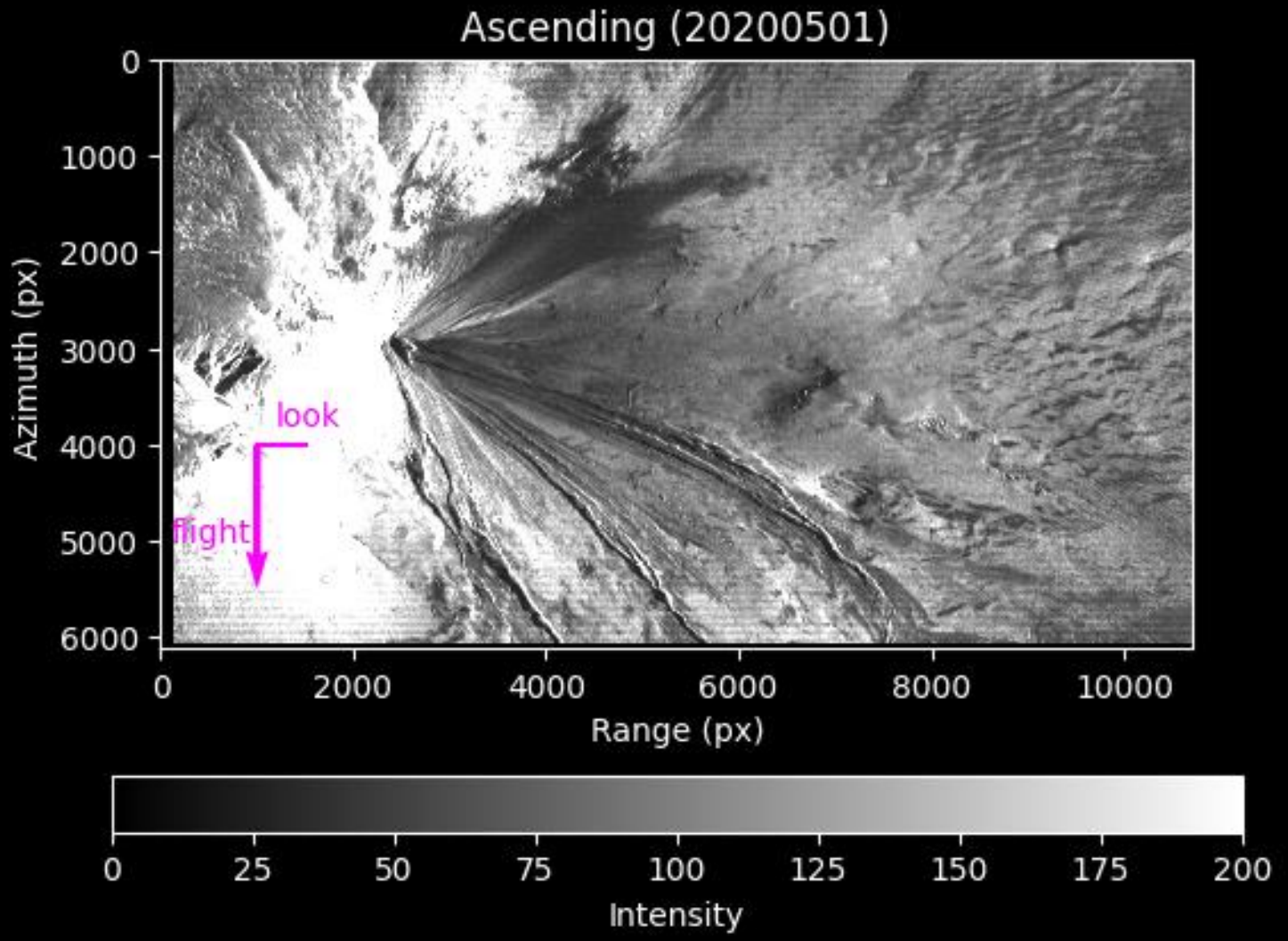


How are the amplitudes often used?



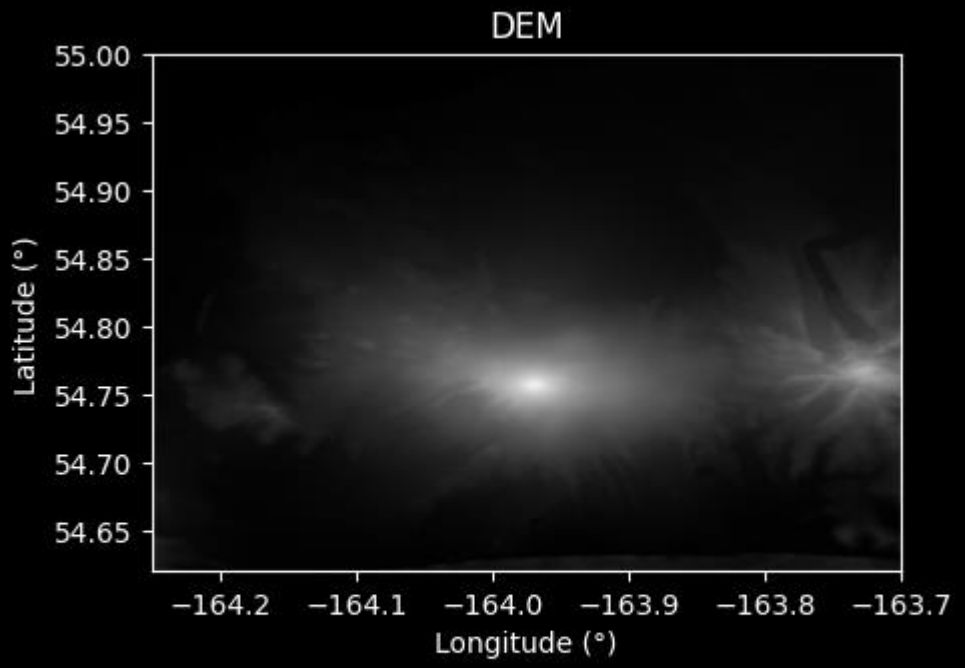
How to quantify morphology changes?

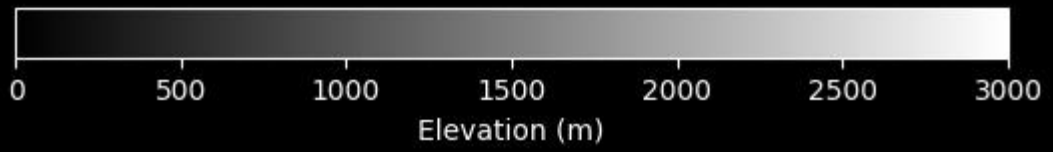
- At first glance the amplitude seems to capture topographic features.
- Therefore, we look to relate the amplitude image with a good resolution DEM.



How to quantify morphology changes?

However, the first step was to translate the DEM to radar coordinates.





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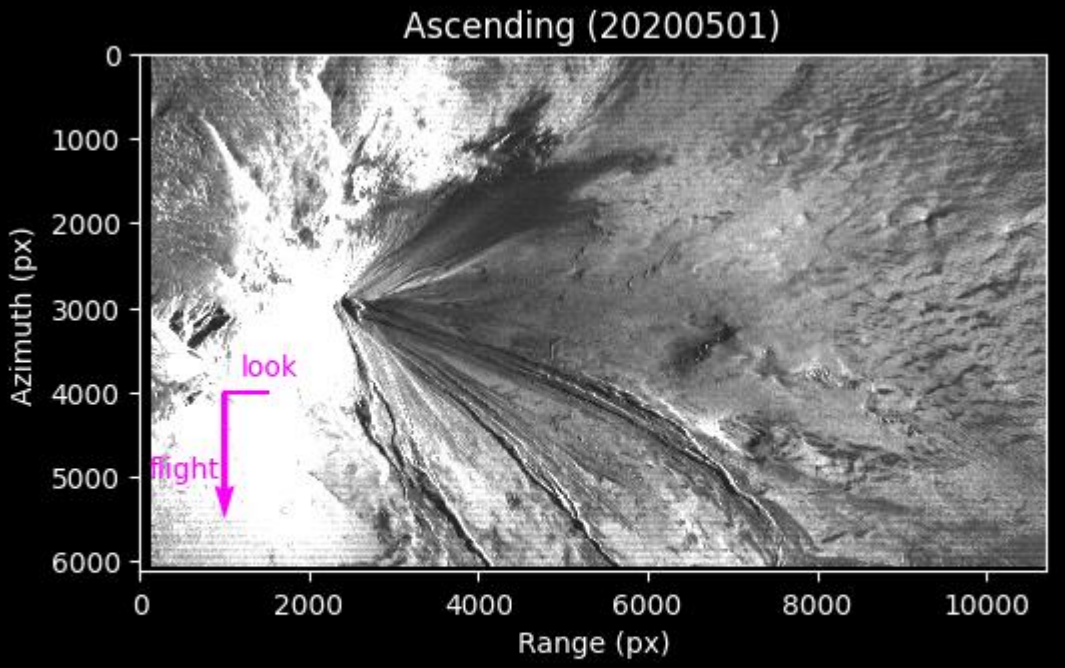
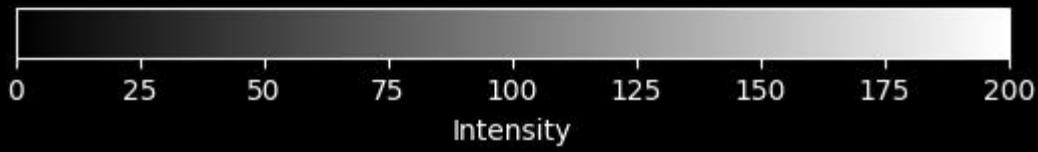
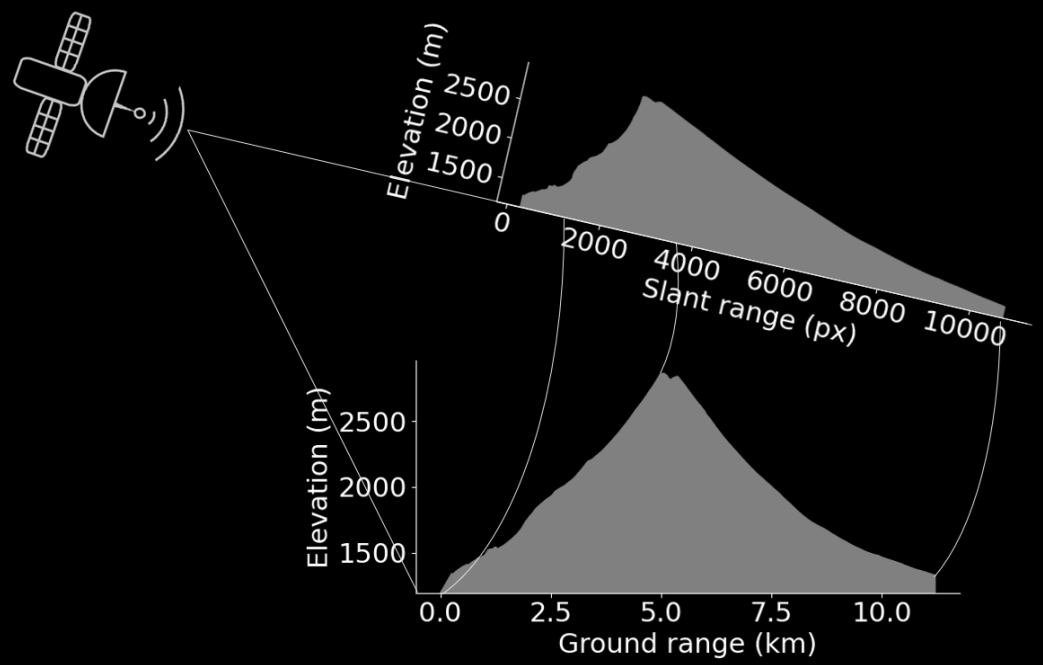
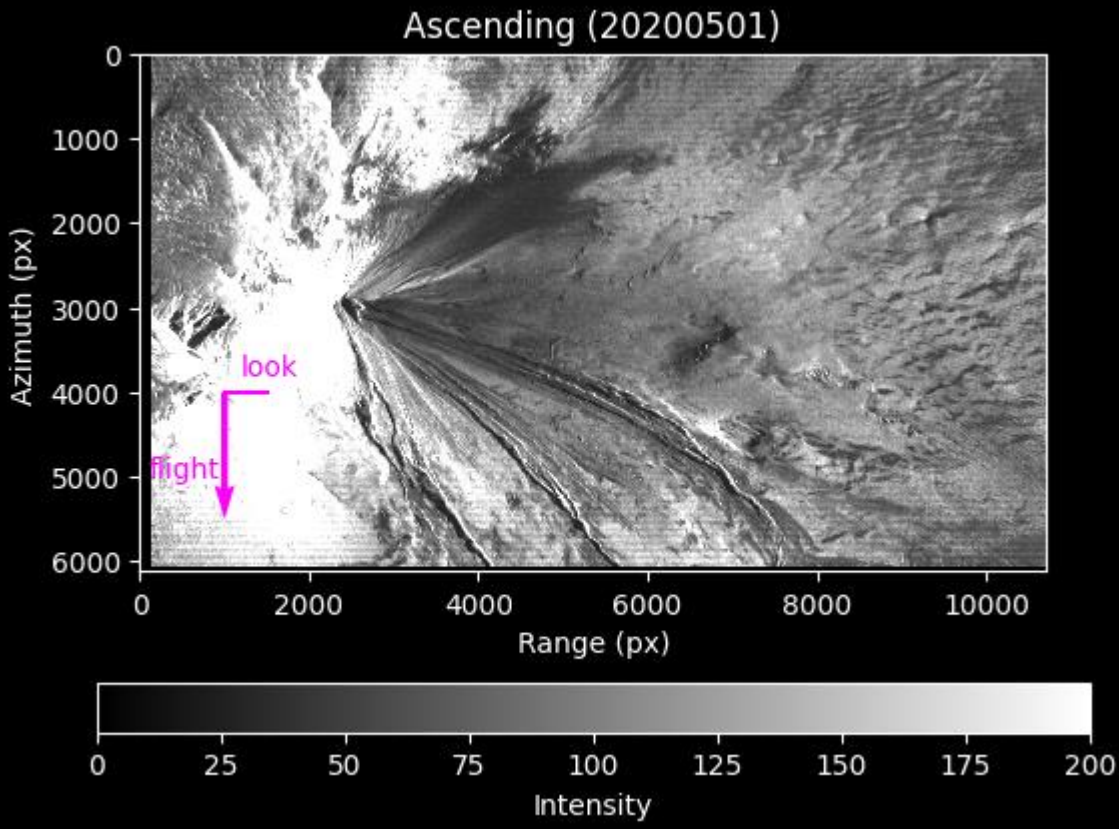




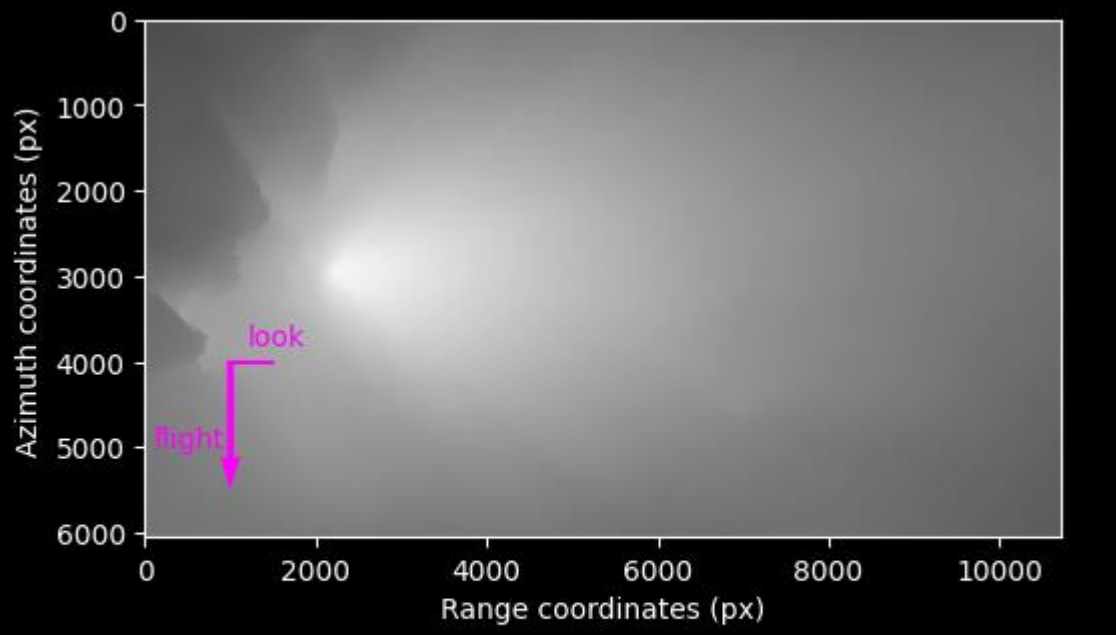
How to quantify morphology changes?

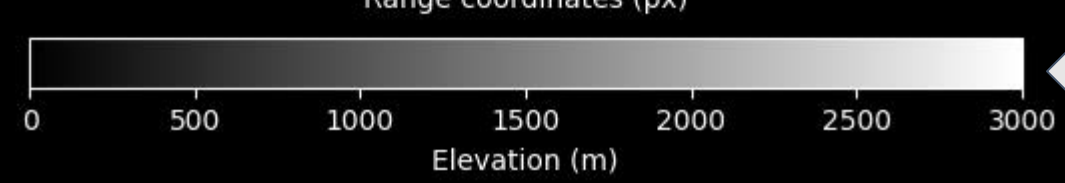


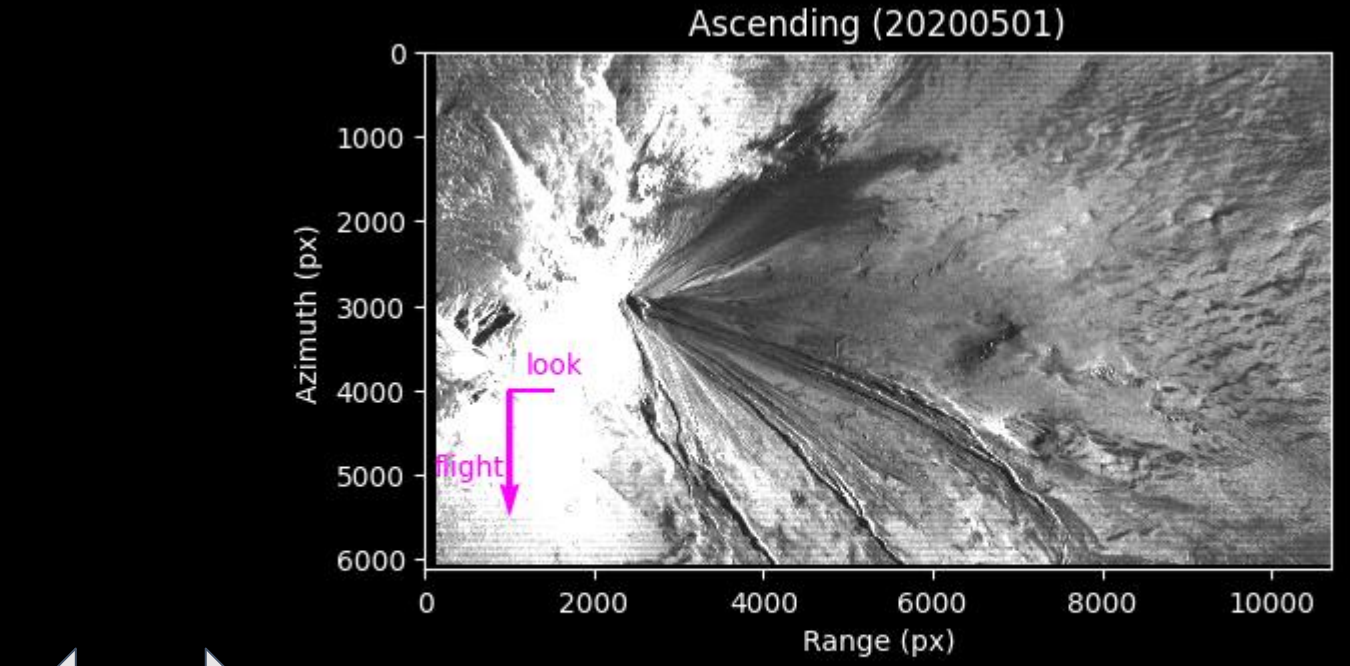
?

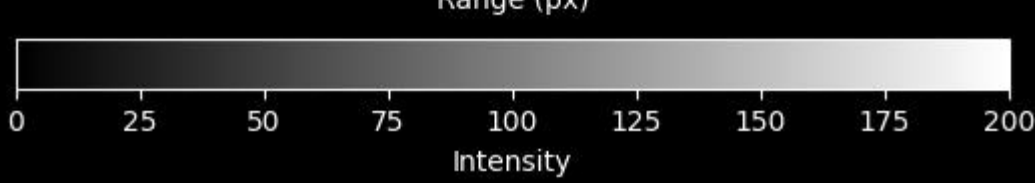


How to quantify morphology changes?



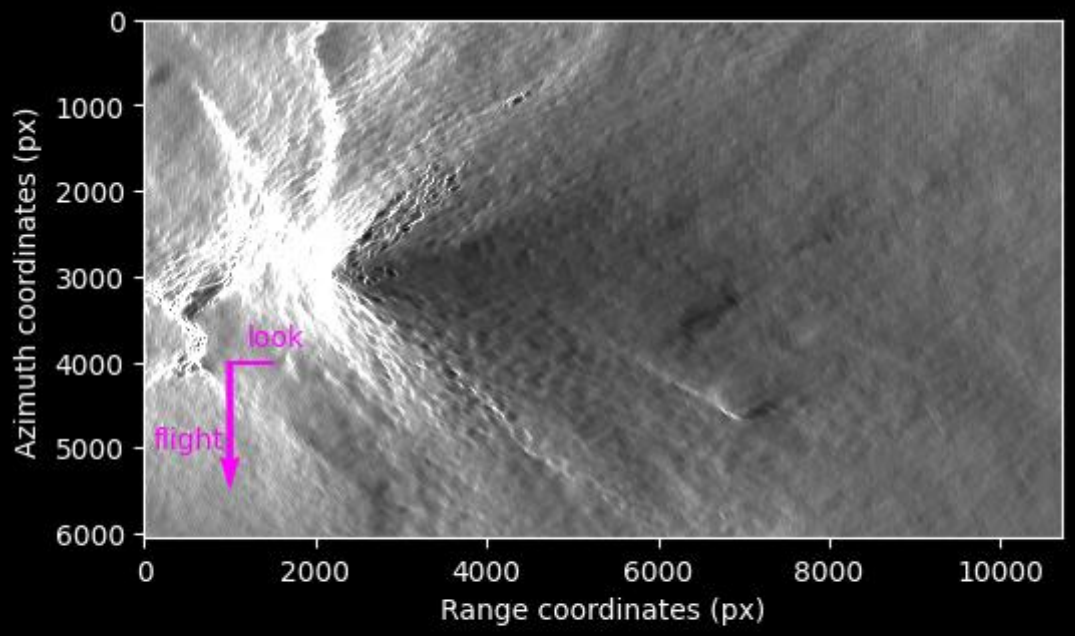


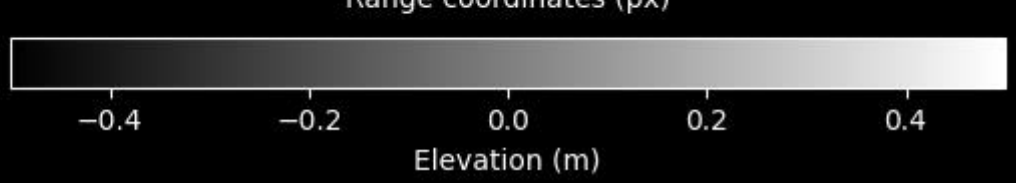


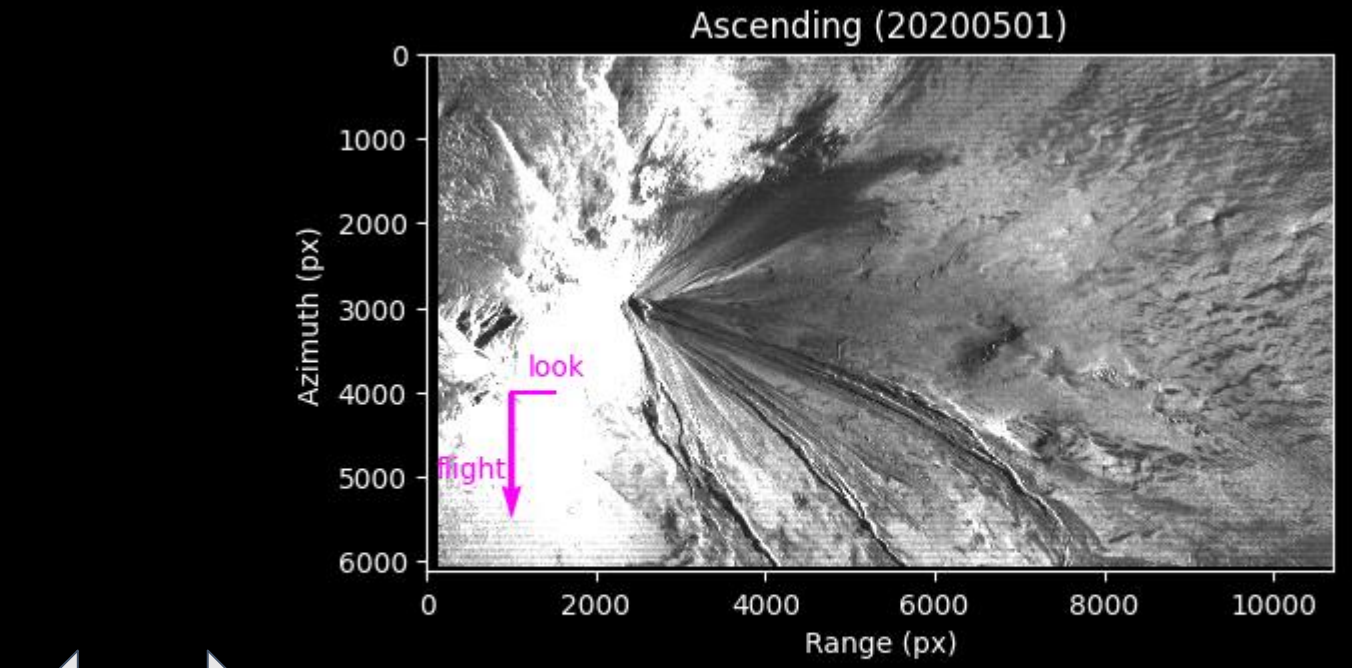


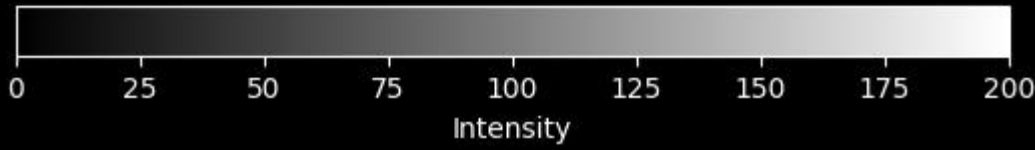
How to quantify morphology changes?

When we calculate the gradient. The similarities are more noticeable.

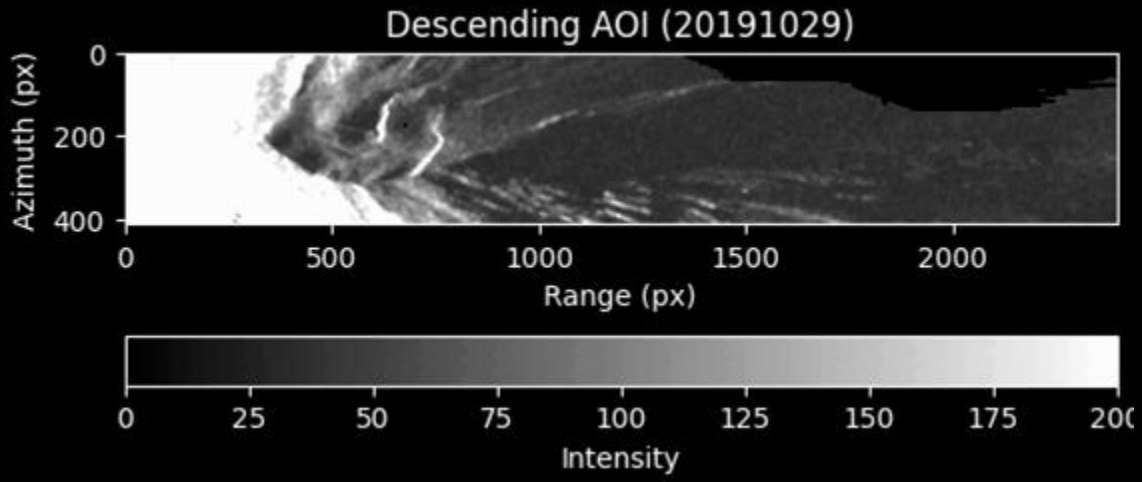




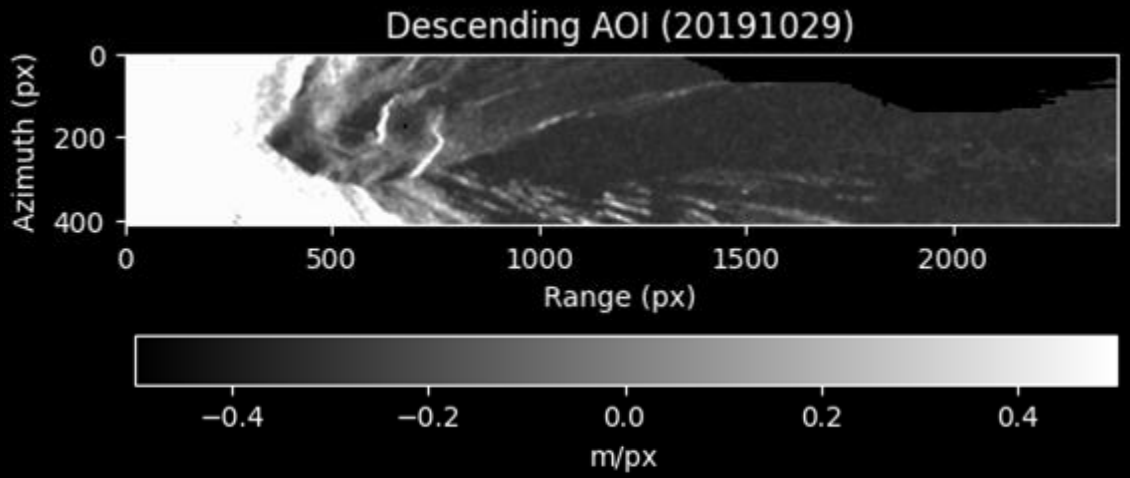


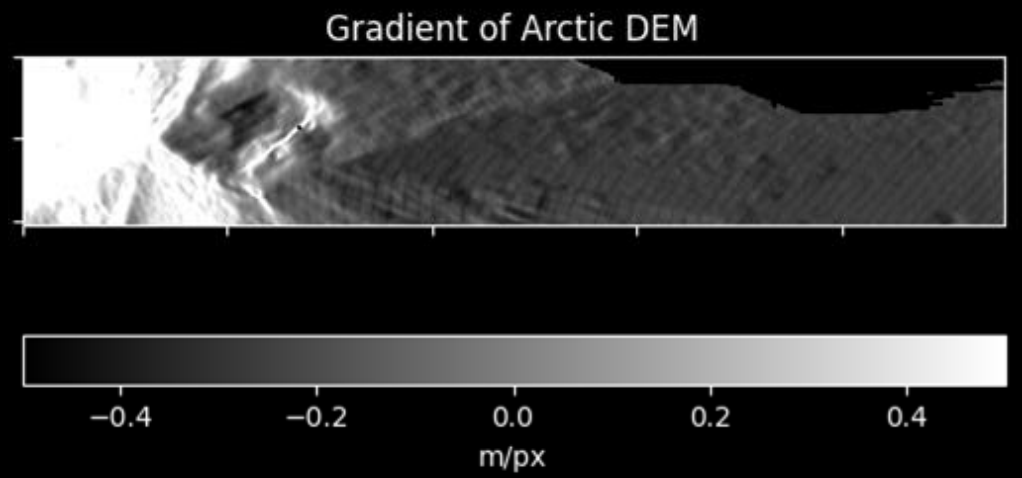


Method


Descending AOI (20191029)
Azimuth (px)
0
200
400
0
500
1000
1500
2000
Range (px)
0
25
50
75
100
125
150
175
Intensity

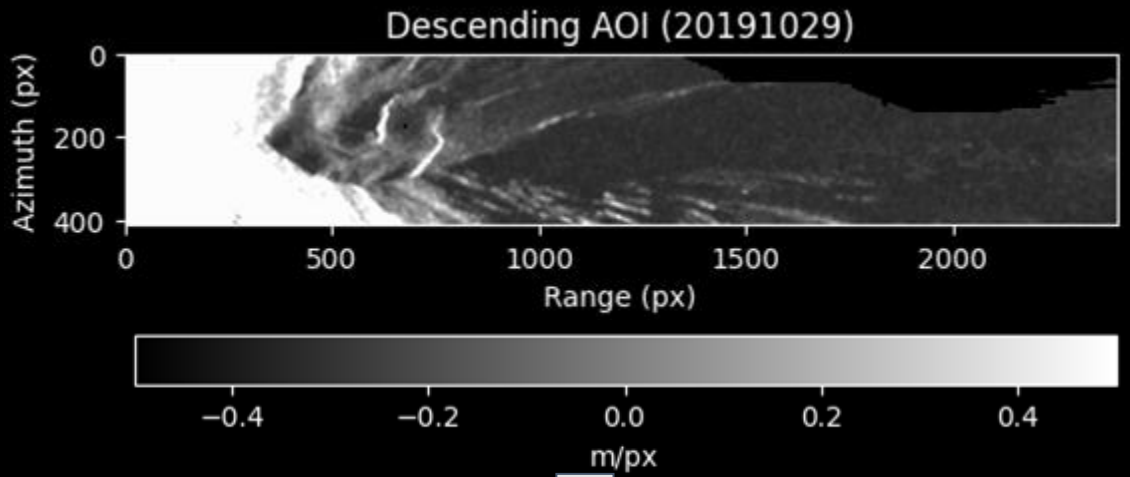
Method

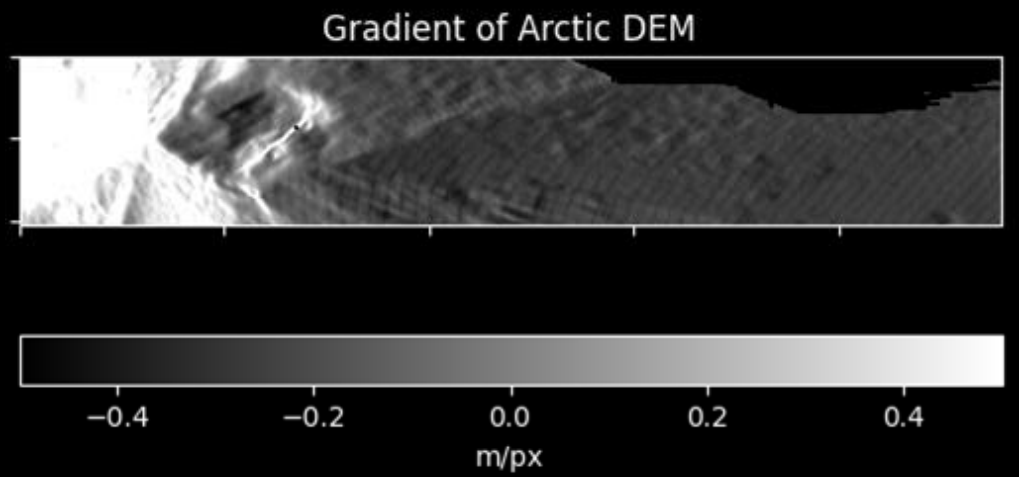




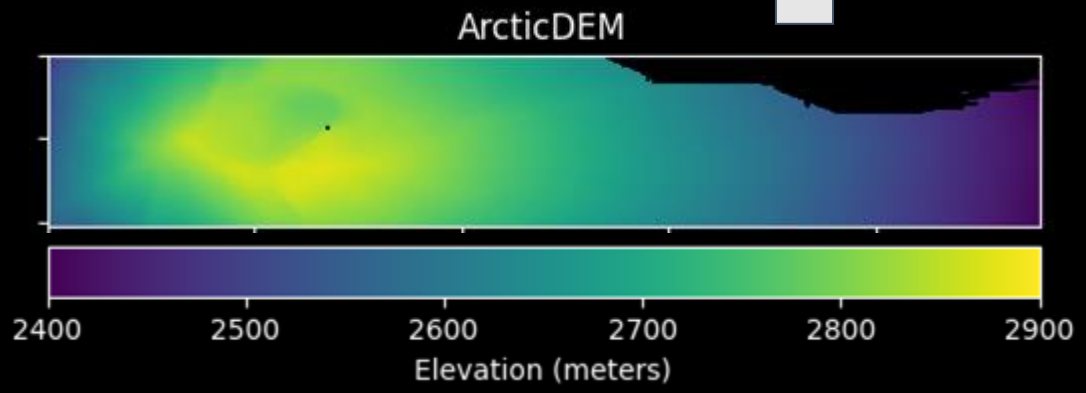
$$\frac{\partial u}{\partial r} = a * I + b$$

Method

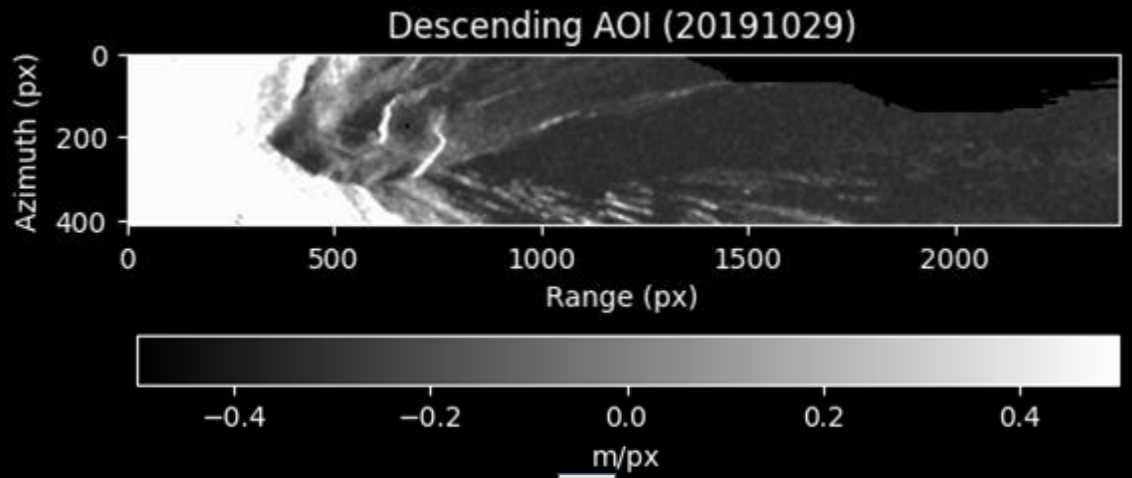


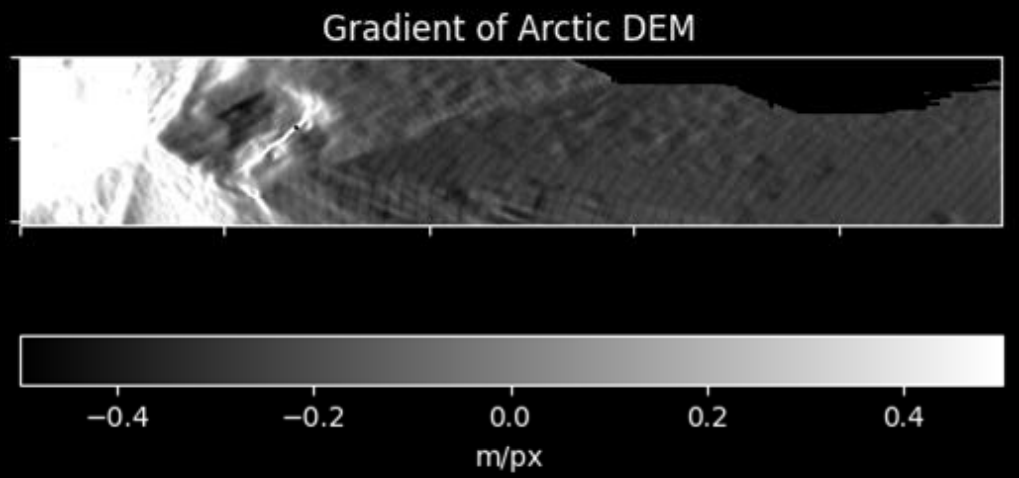


$$u = \int \boxed{\frac{\partial u}{\partial r}} \partial r + \boxed{c}$$



Method





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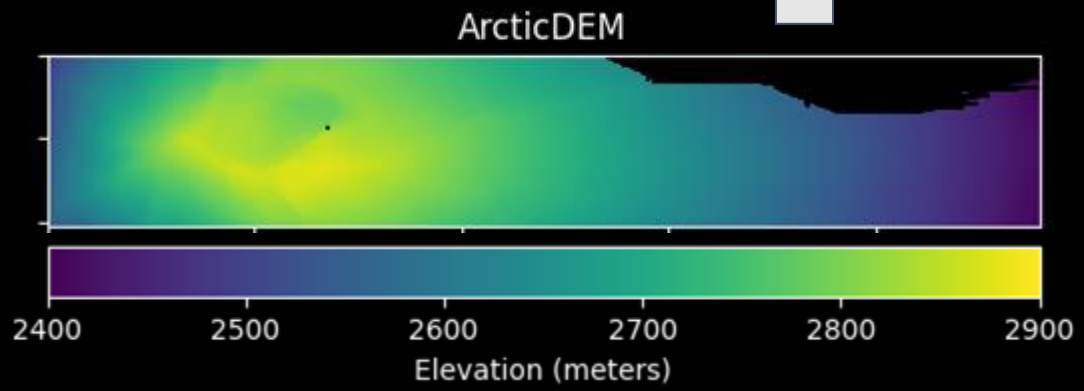

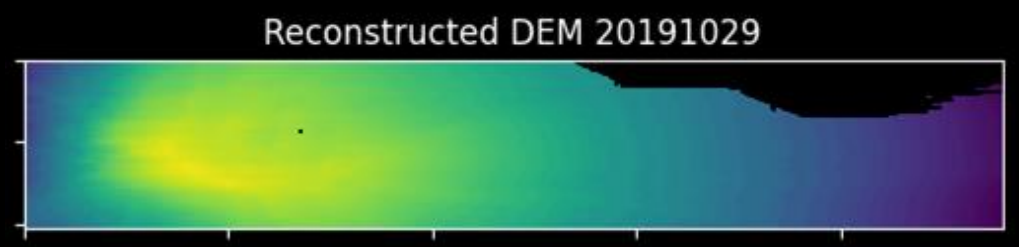

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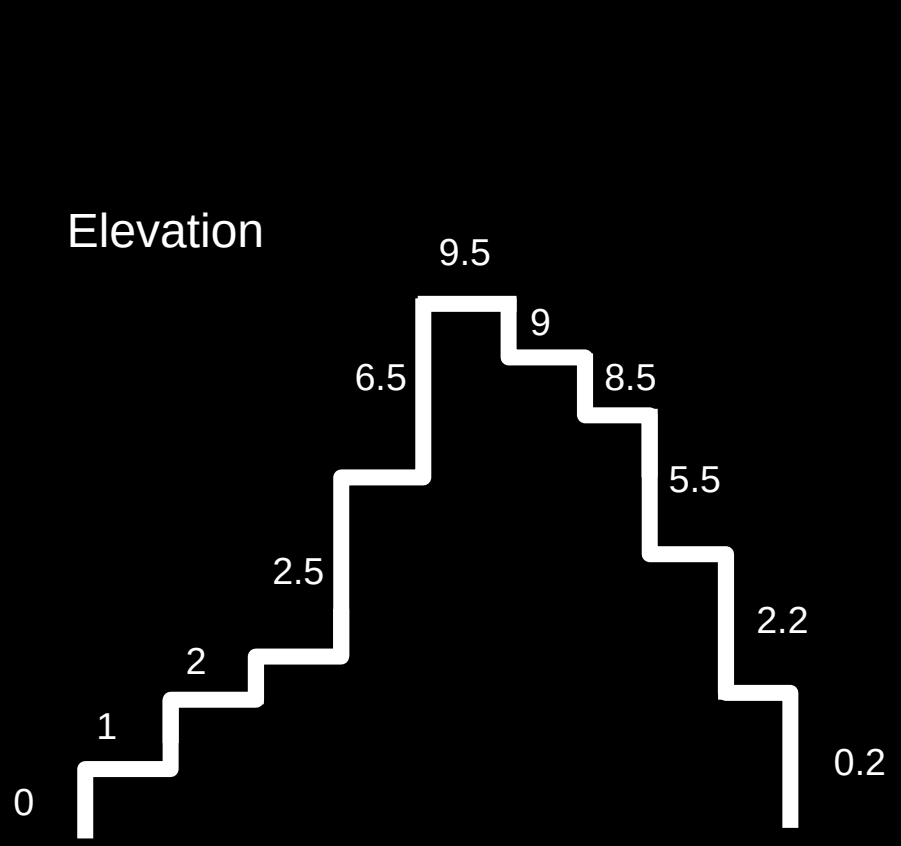

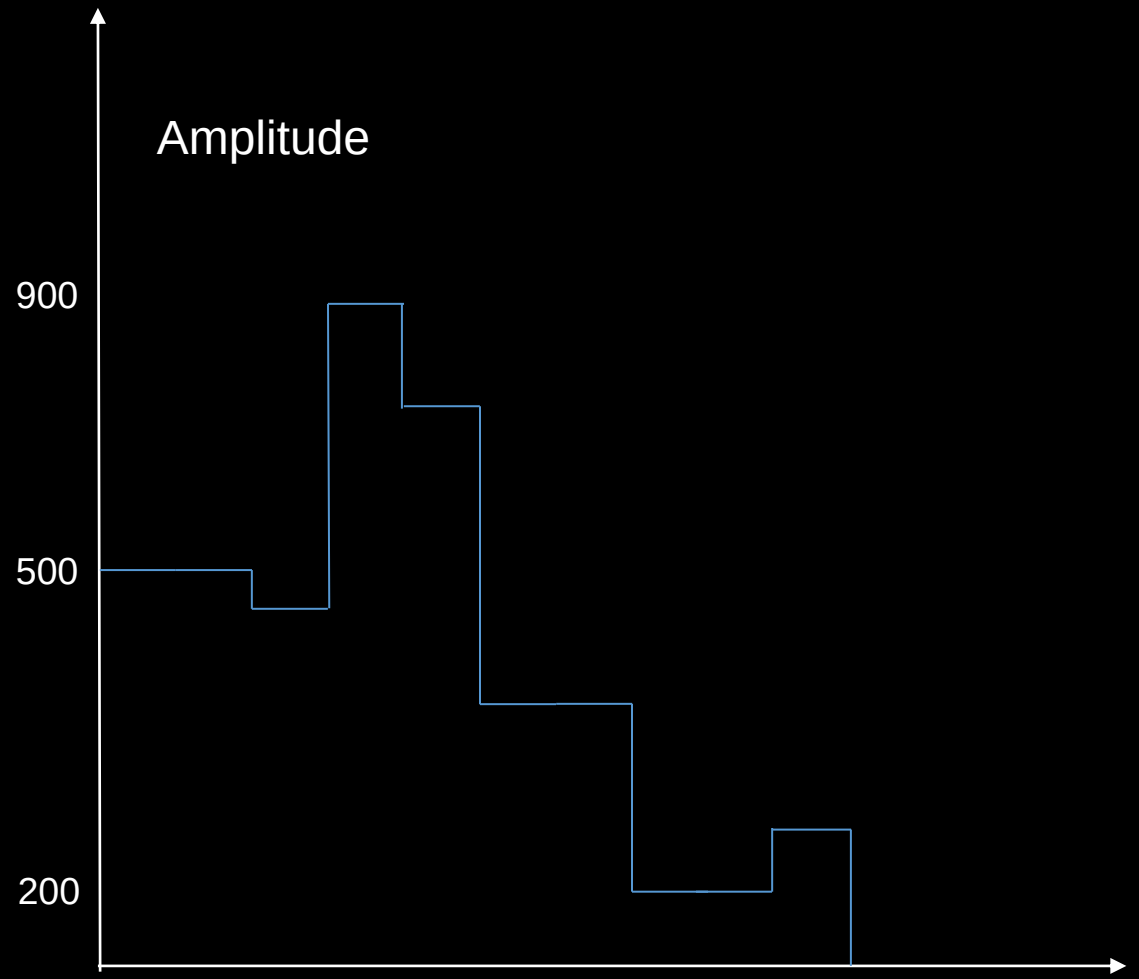

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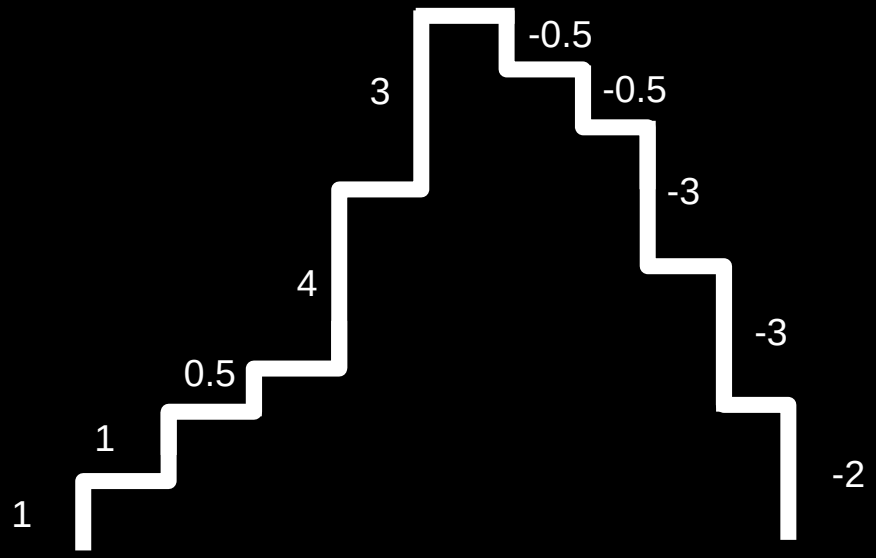

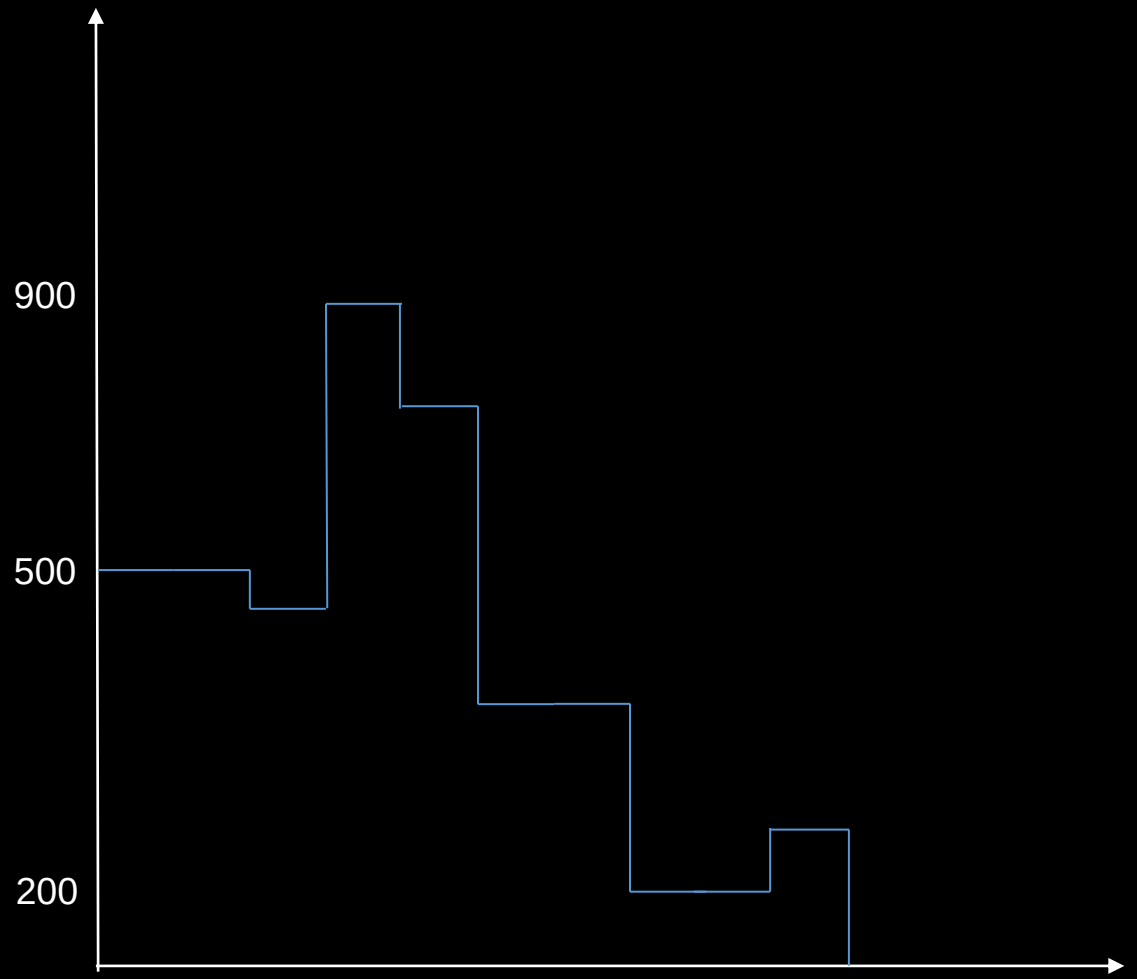

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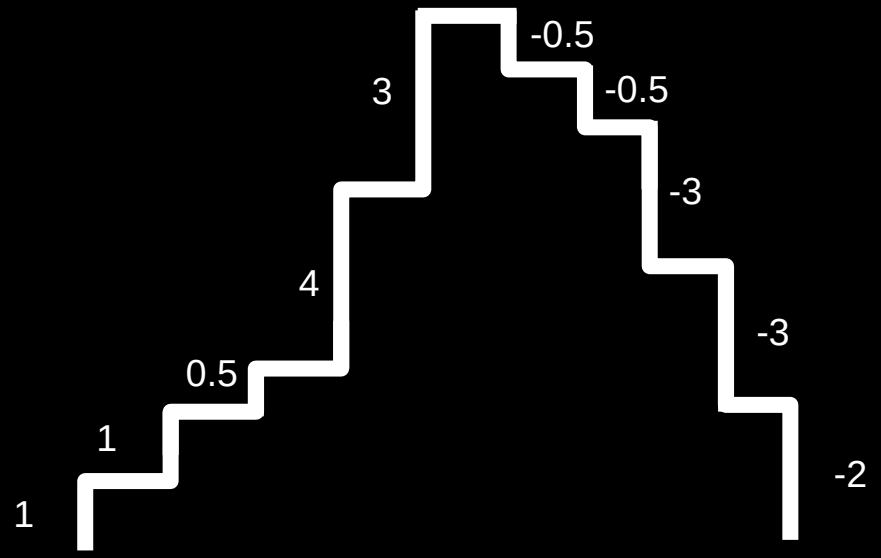
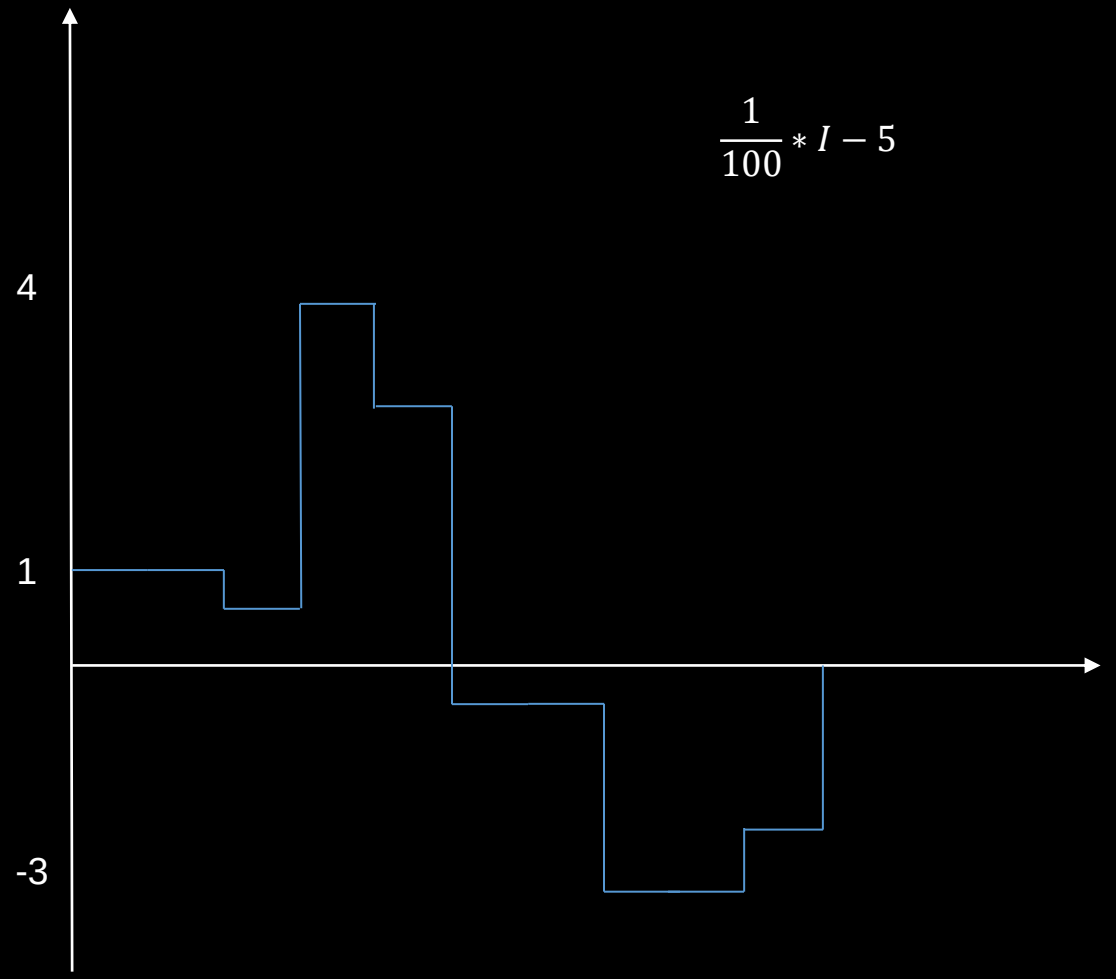
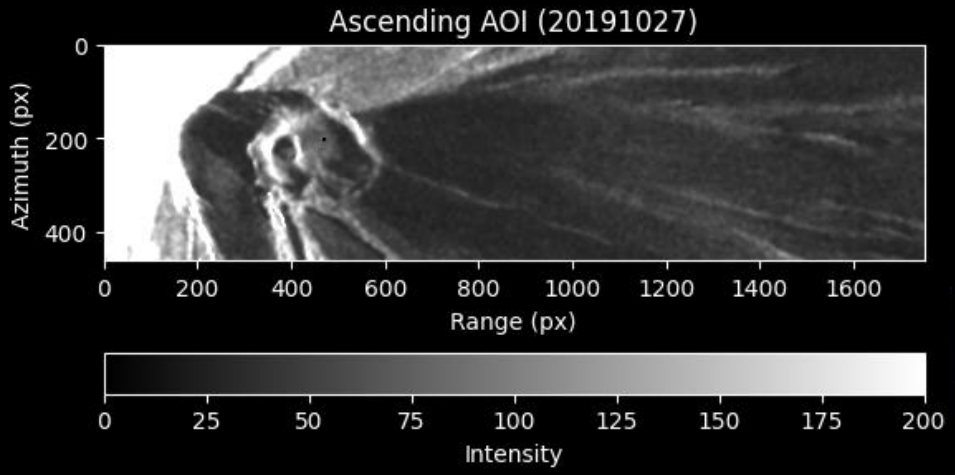
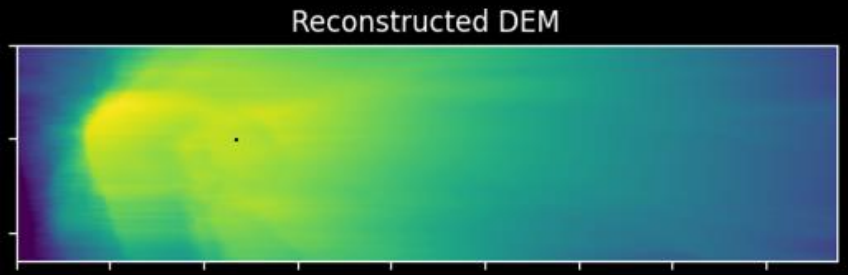


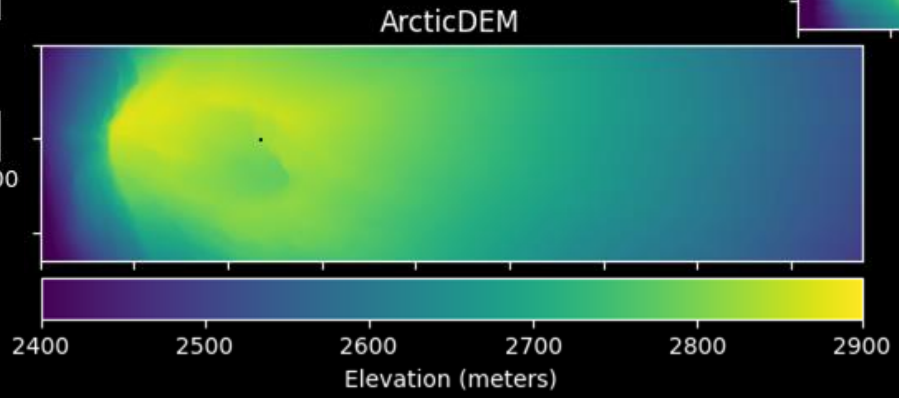


Method

$$\begin{bmatrix} u_{y1} \\ u_{y2} \\ \vdots \\ u_{yn} \end{bmatrix} = \begin{bmatrix} I_{y1} & 1 & 1 \\ I_{y1} + I_{y2} & 2 & 1 \\ \vdots & \vdots & \vdots \\ \sum_{k=1}^{n} I_{yk} & n & 1 \end{bmatrix} \begin{bmatrix} a_y \\ b_y \\ c_y \end{bmatrix}$$



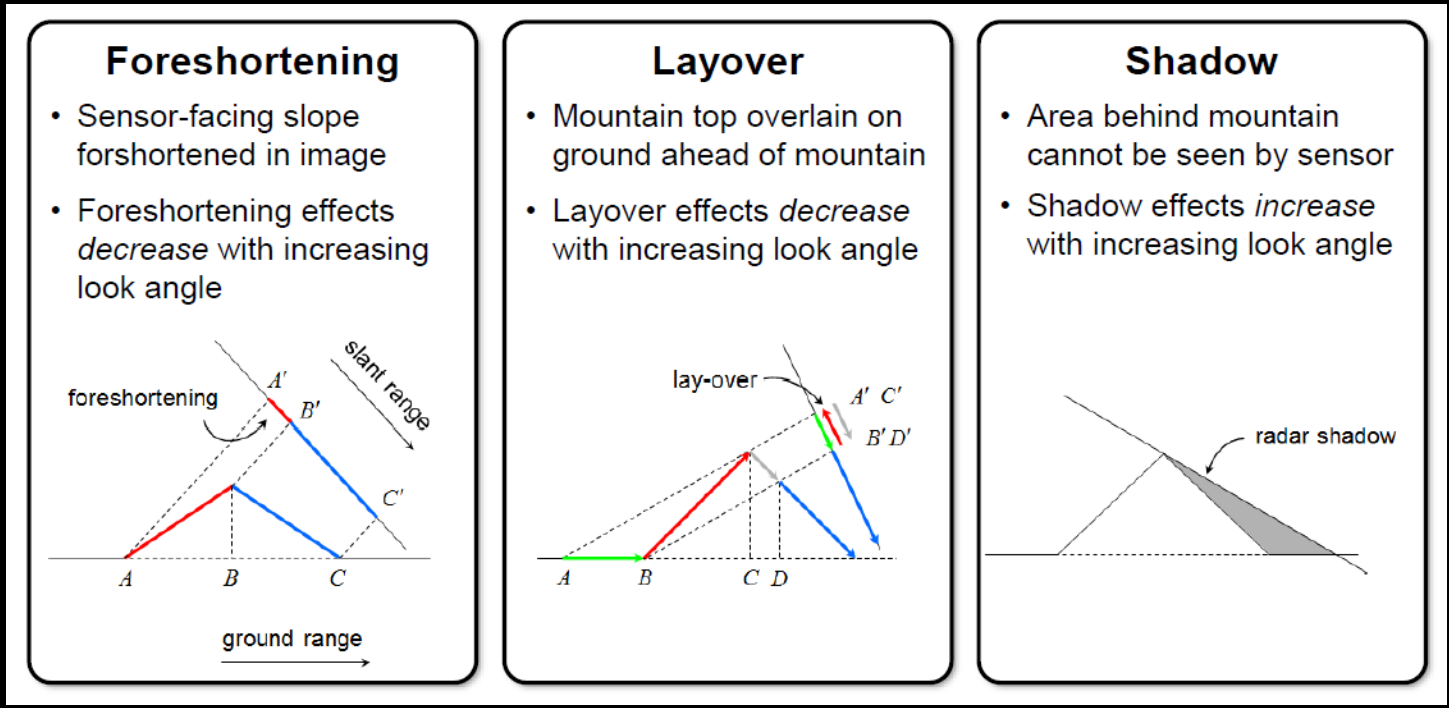




Limitations

The method assumes all changes in intensity are related with the topography.

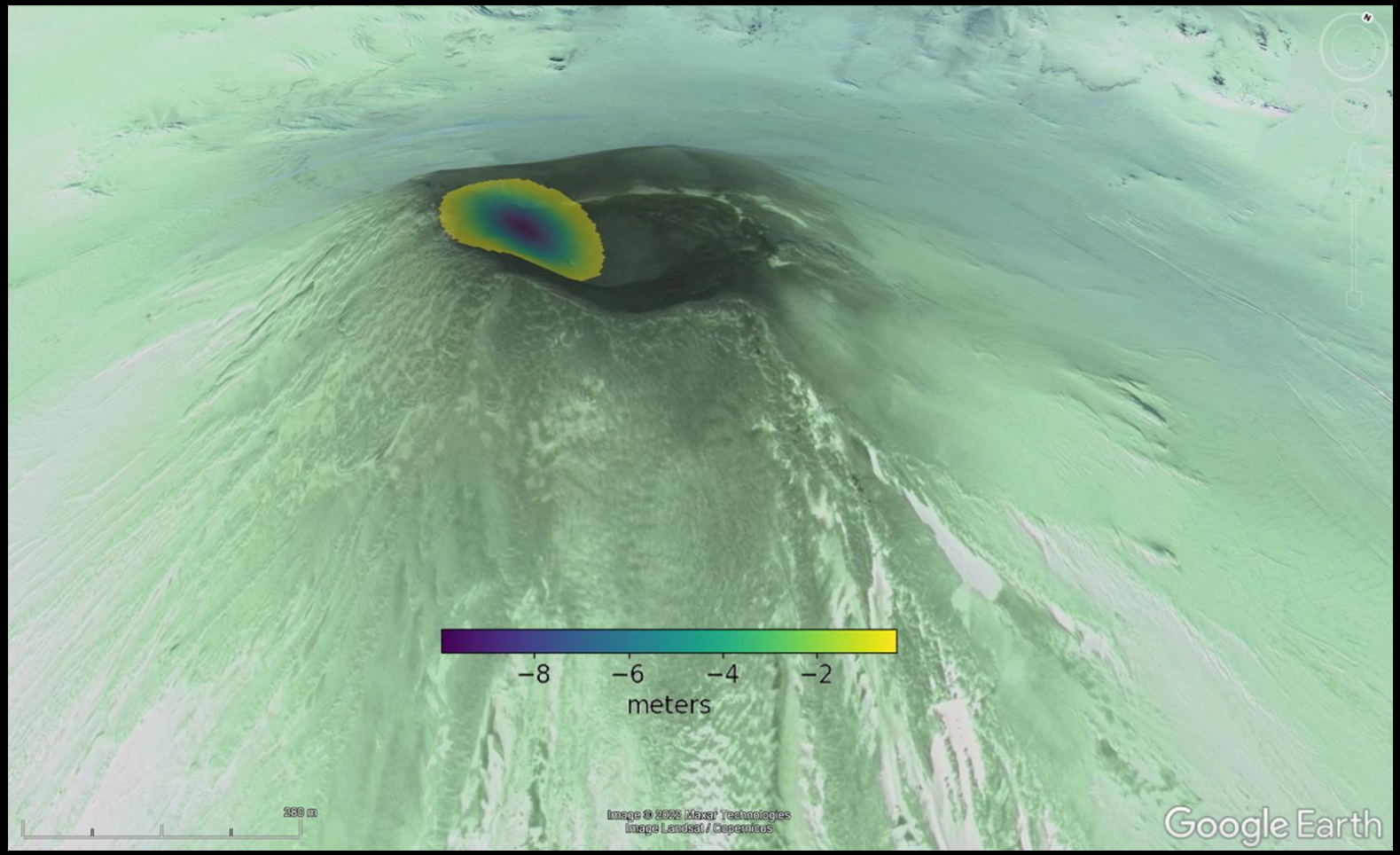
Limitations



- The radar shadow obscures the topography.

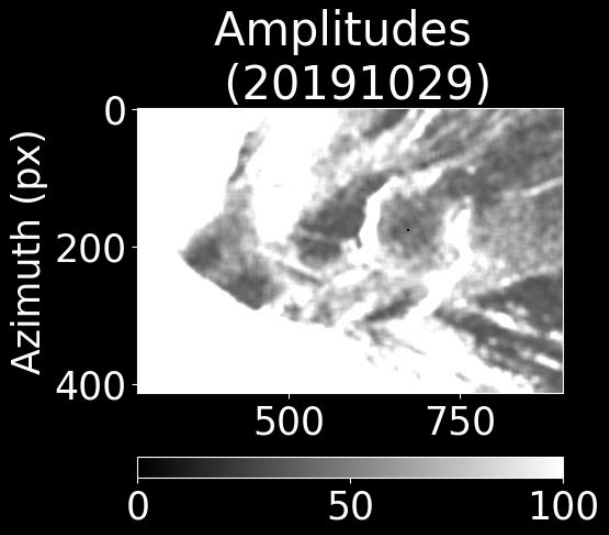
- Pixels with foreshortening and layover have bigger uncertainty.

Verification

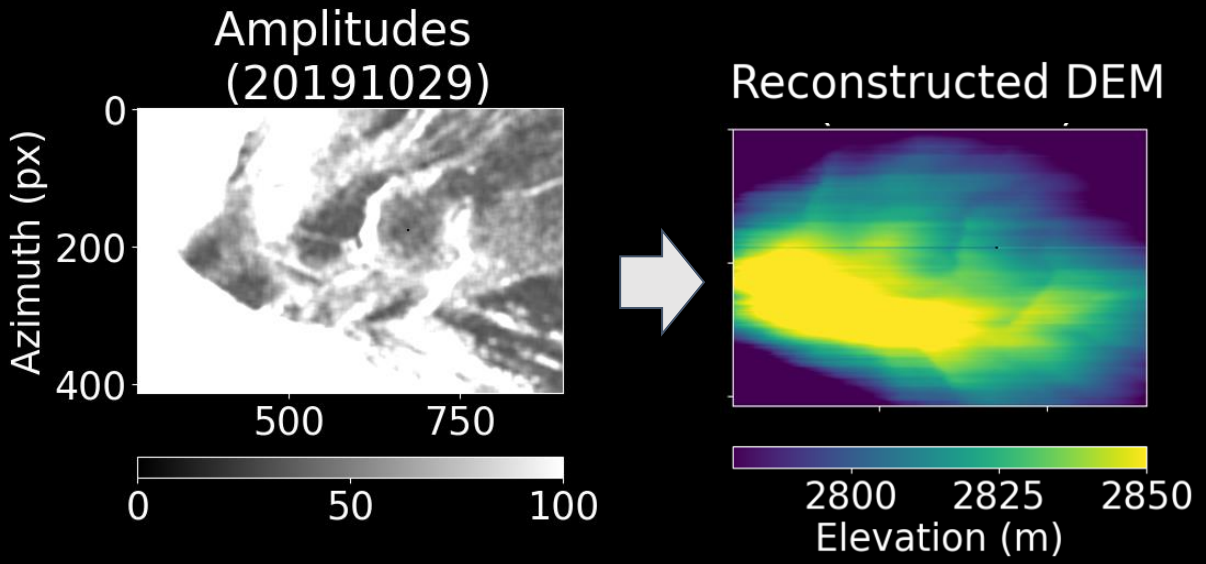


- To verify our method we create a synthetic test.
- In this test we simulated a collapse in Shishaldin crater.

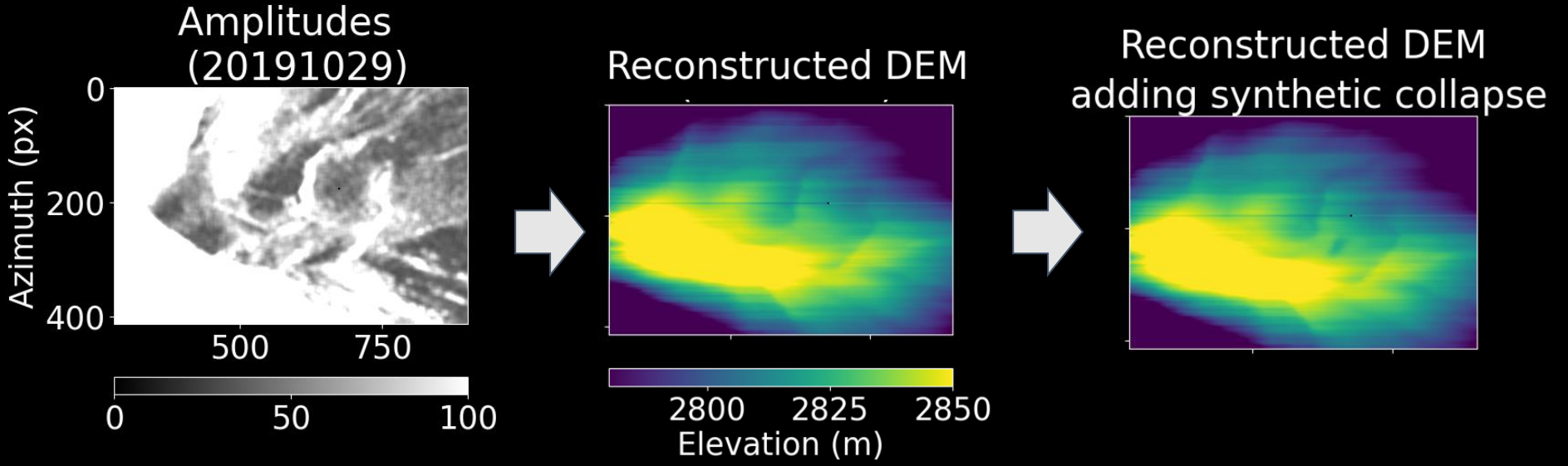
Verification



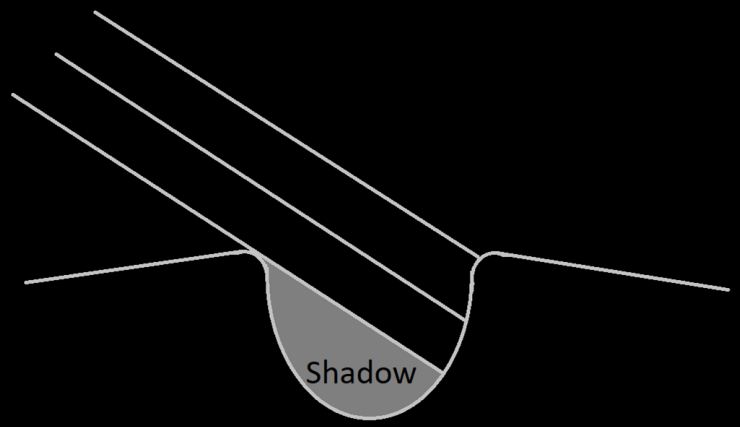
Verification

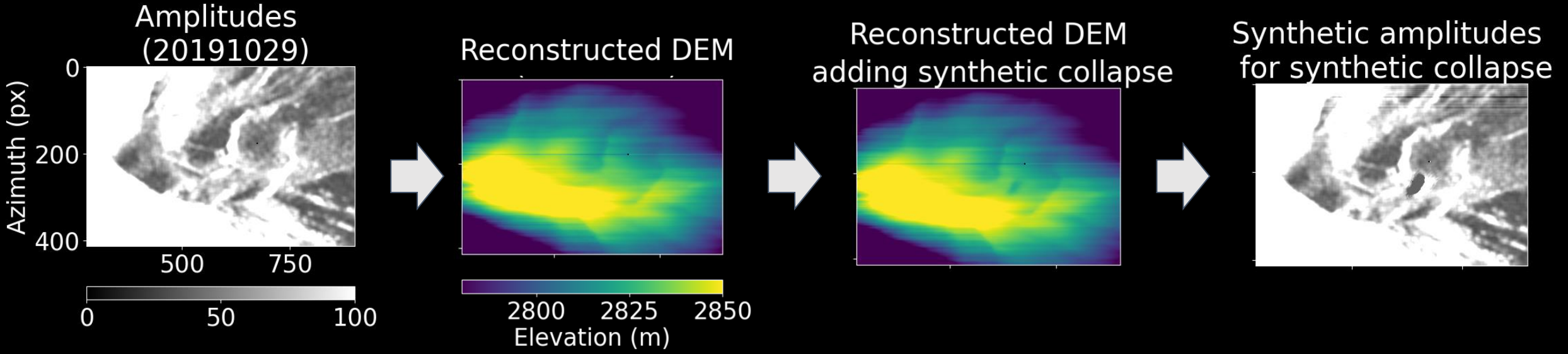


Verification

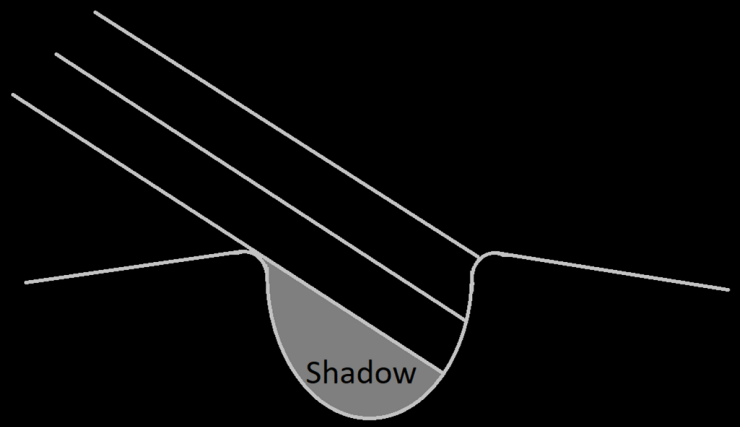


Verification

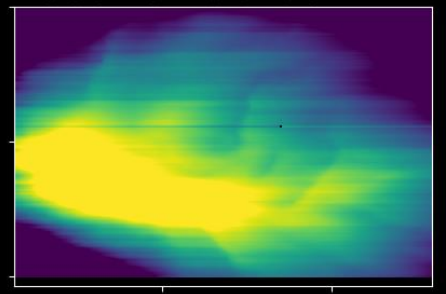




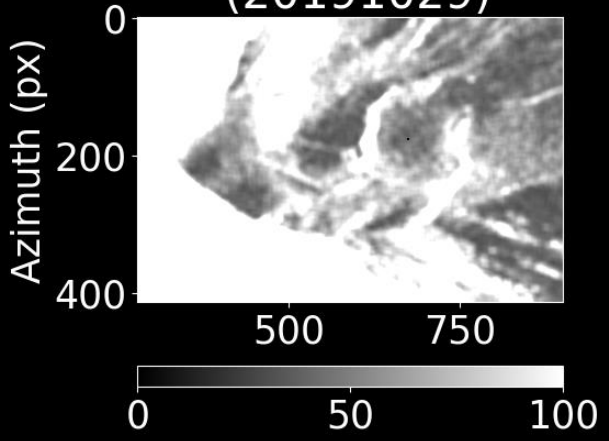
Verification



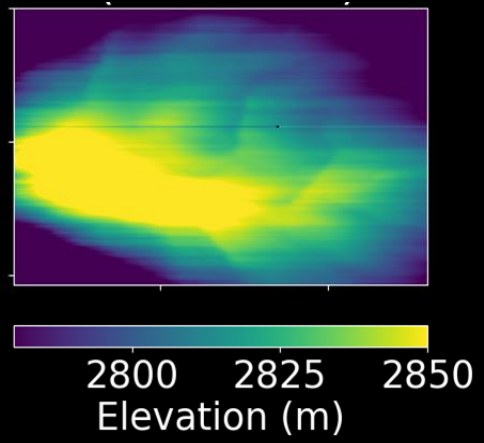
Reconstructed DEM



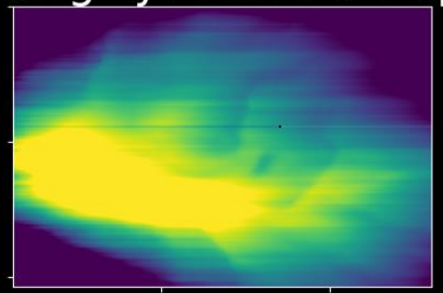
Amplitudes (20191029)



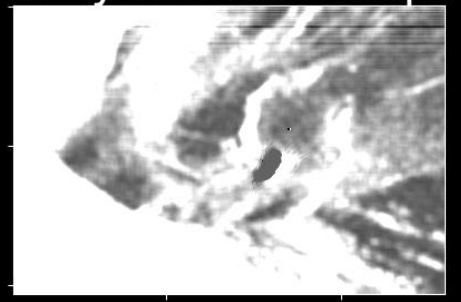
Reconstructed DEM



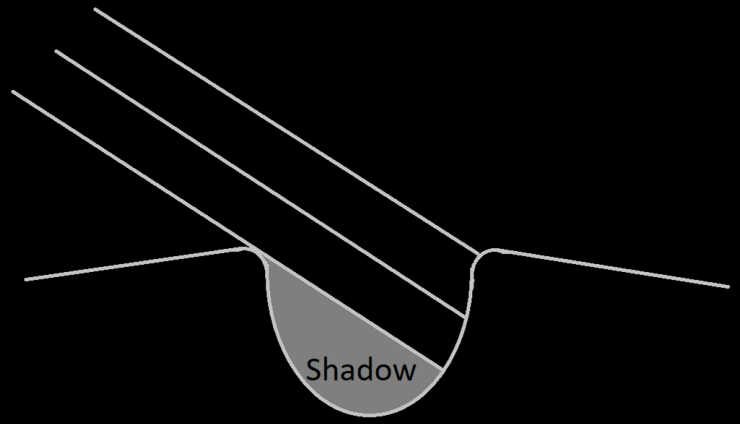
Reconstructed DEM adding synthetic collapse

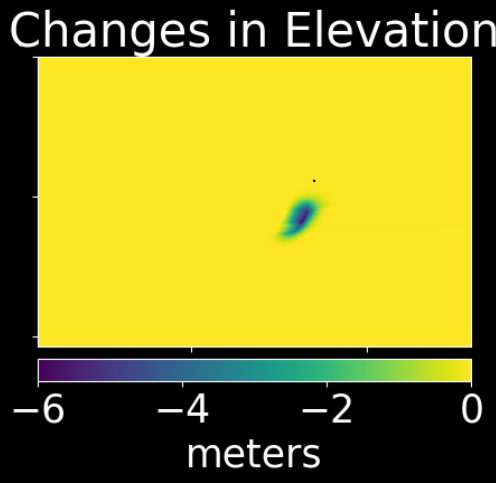


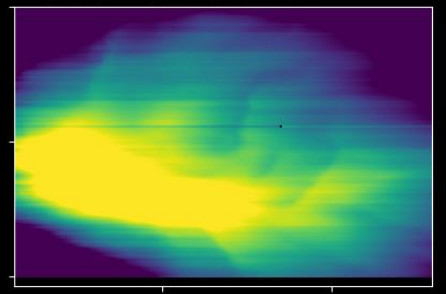
Synthetic amplitudes for synthetic collapse

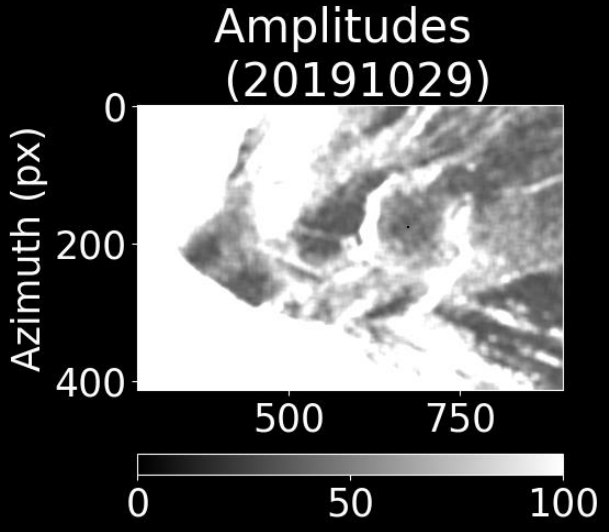


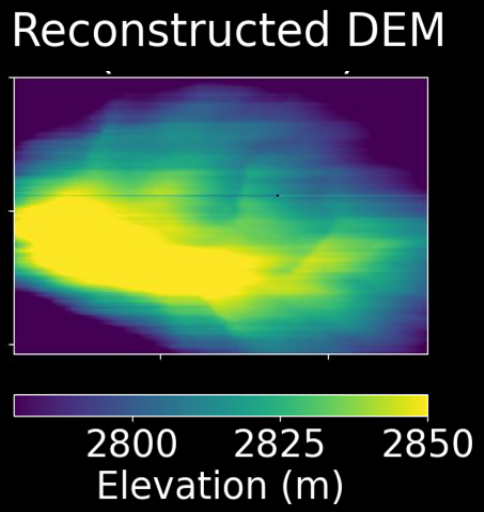
Verification

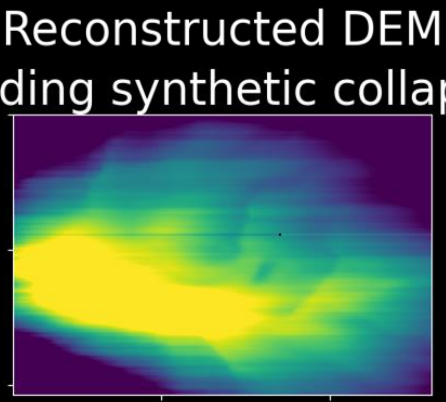


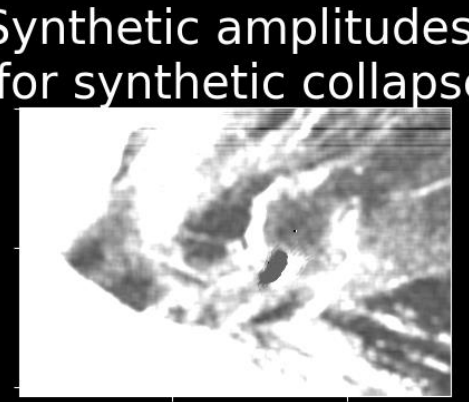






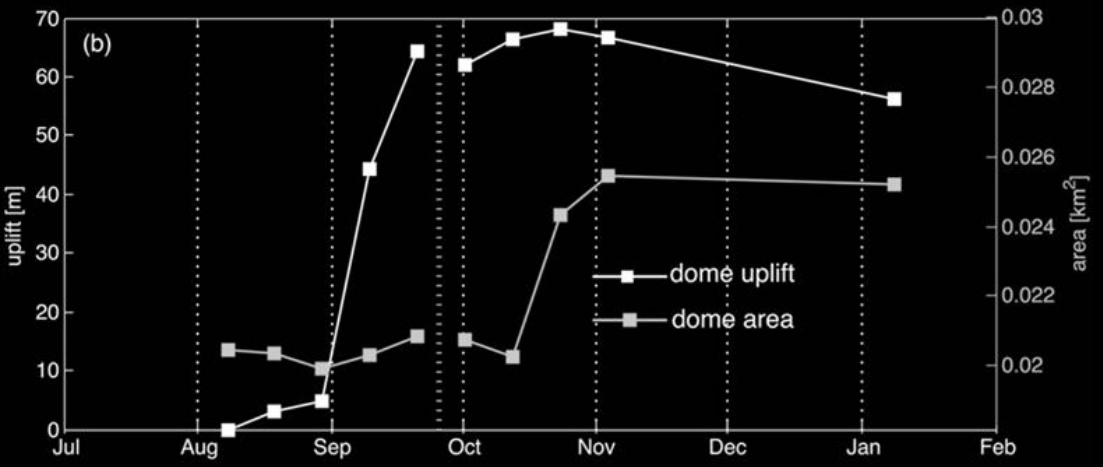






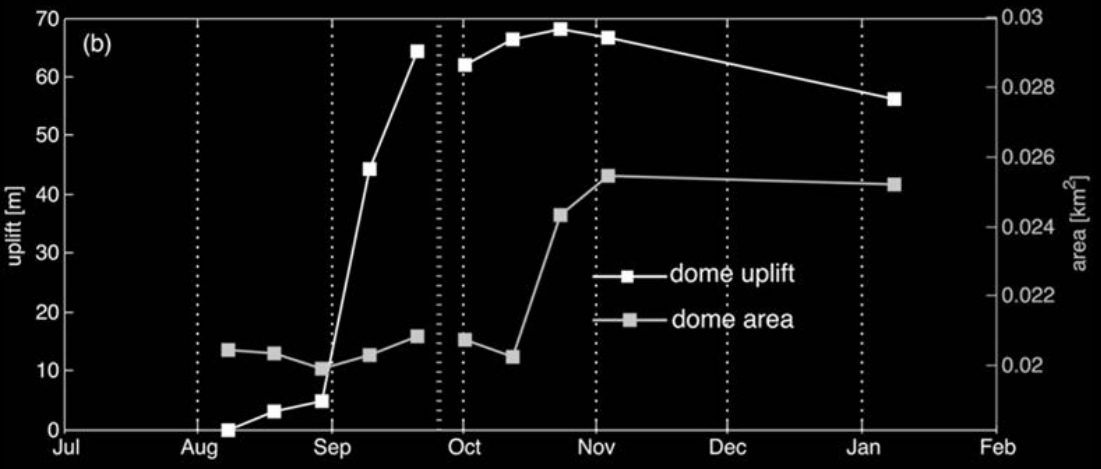
Validation with 2011-2012 Mt. Cleveland Dome Growth

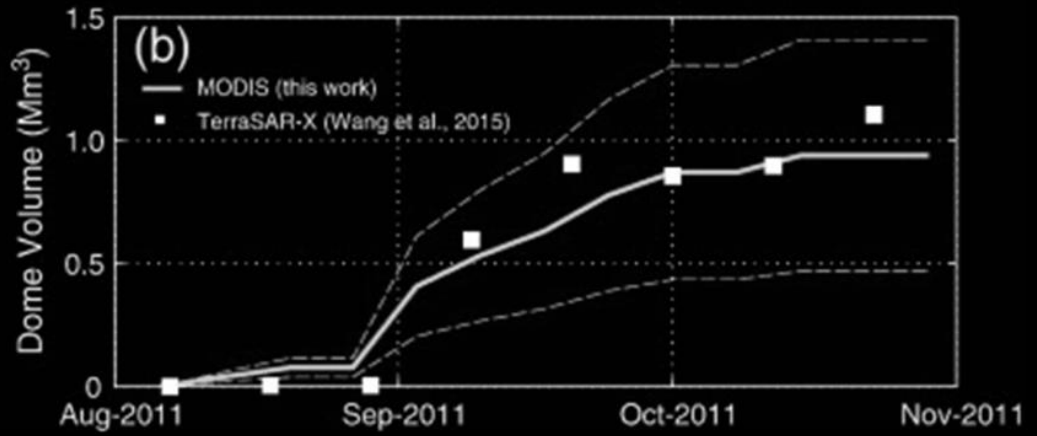
Wang et. al. (2015)



Validation with 2011-2012 Mt. Cleveland Dome Growth

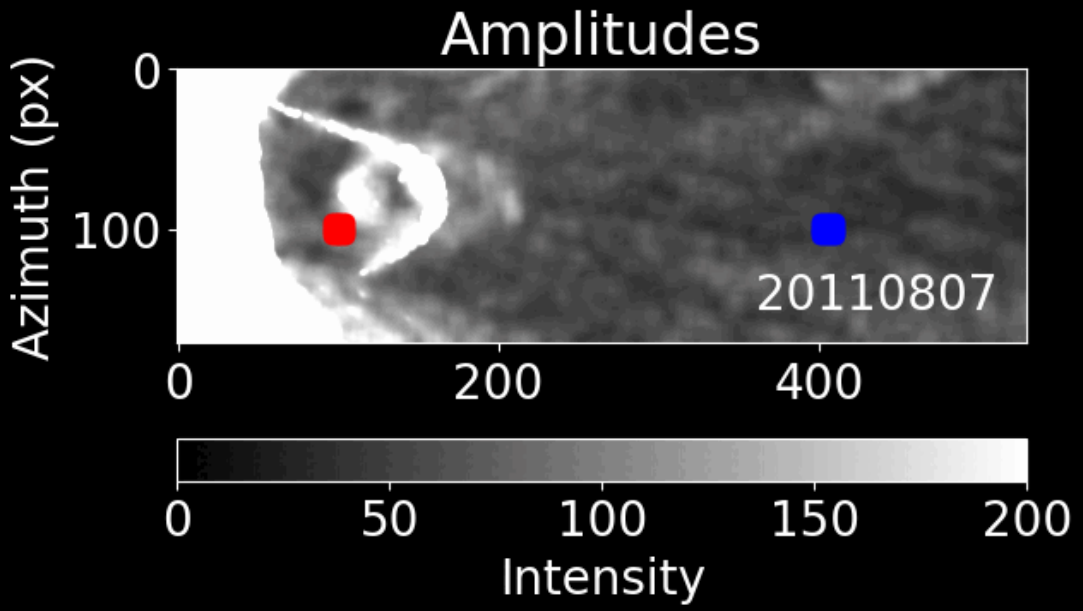
Wang et. al. (2015)





Werner et. al. (2017)

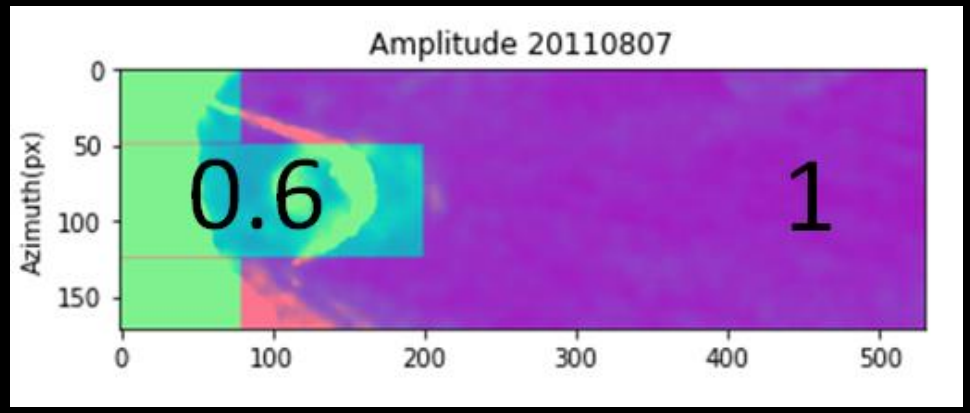
Validation with 2011-2012 Mt. Cleveland Dome Growth



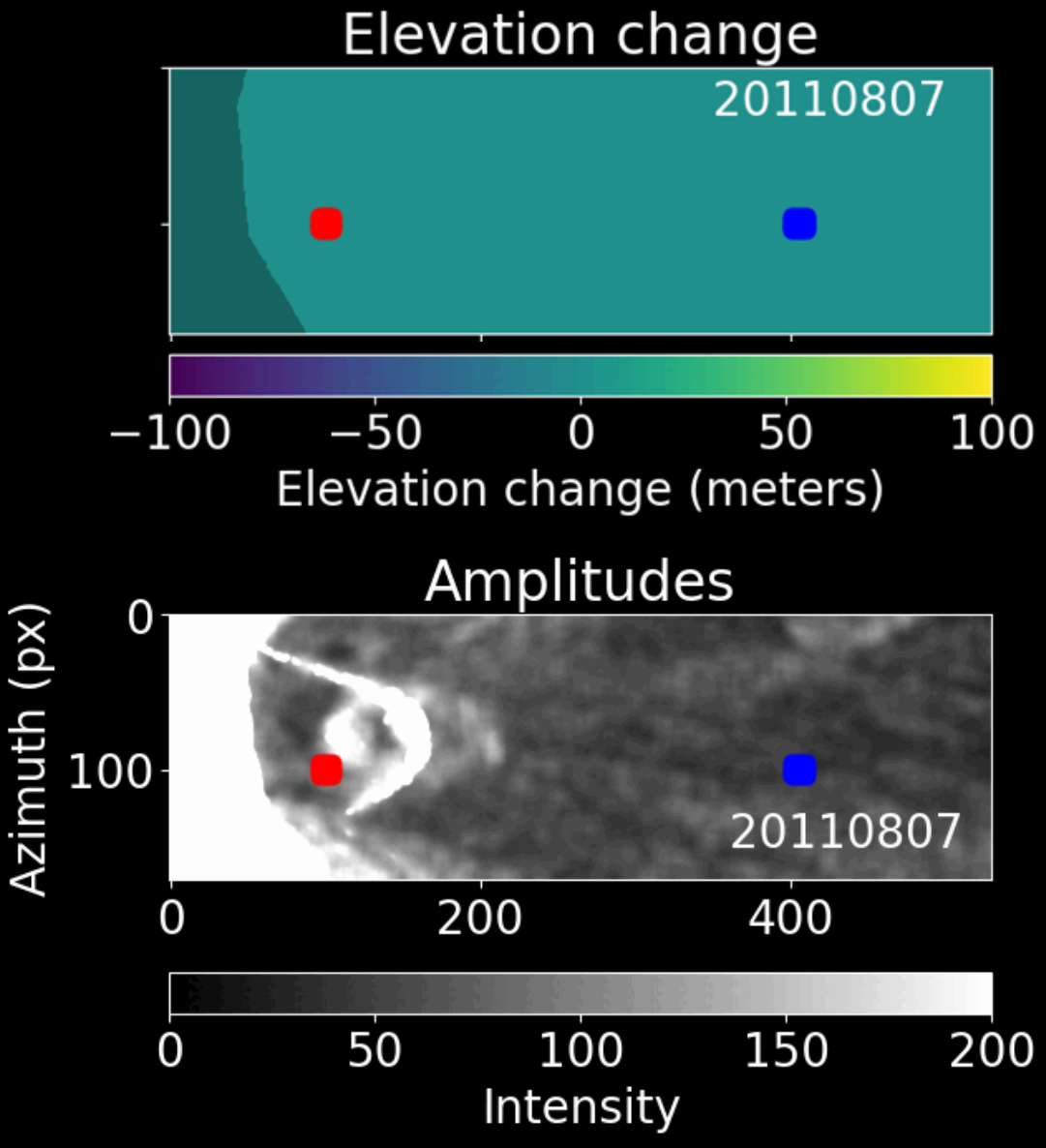
Weighted optimization

We can perform a weighted inversion assigning less weight to pixels close to the satellite.

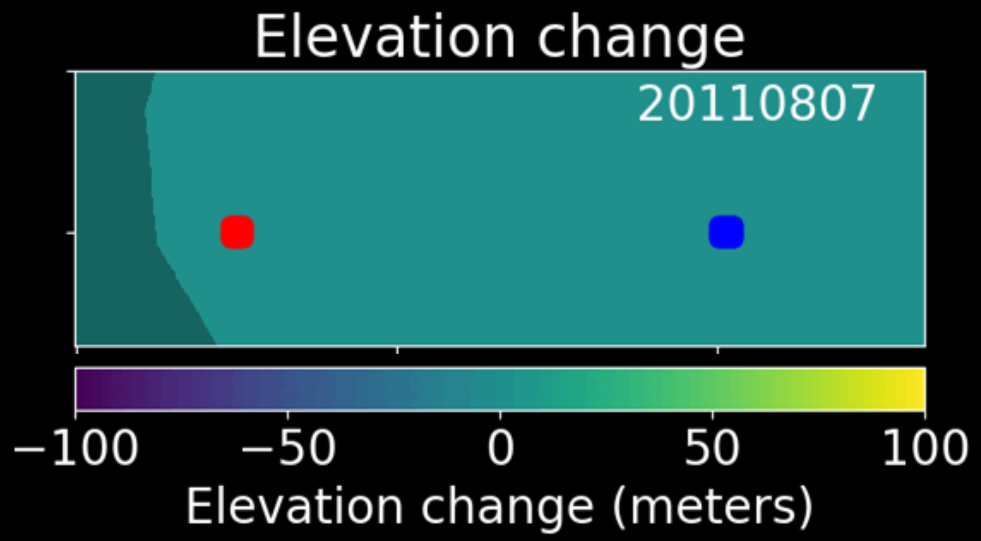
$$\mathbf{d}_w = \mathbf{G}_w\mathbf{m}$$
$$\mathbf{W}\mathbf{d} = \mathbf{W}\mathbf{G}\mathbf{m}$$

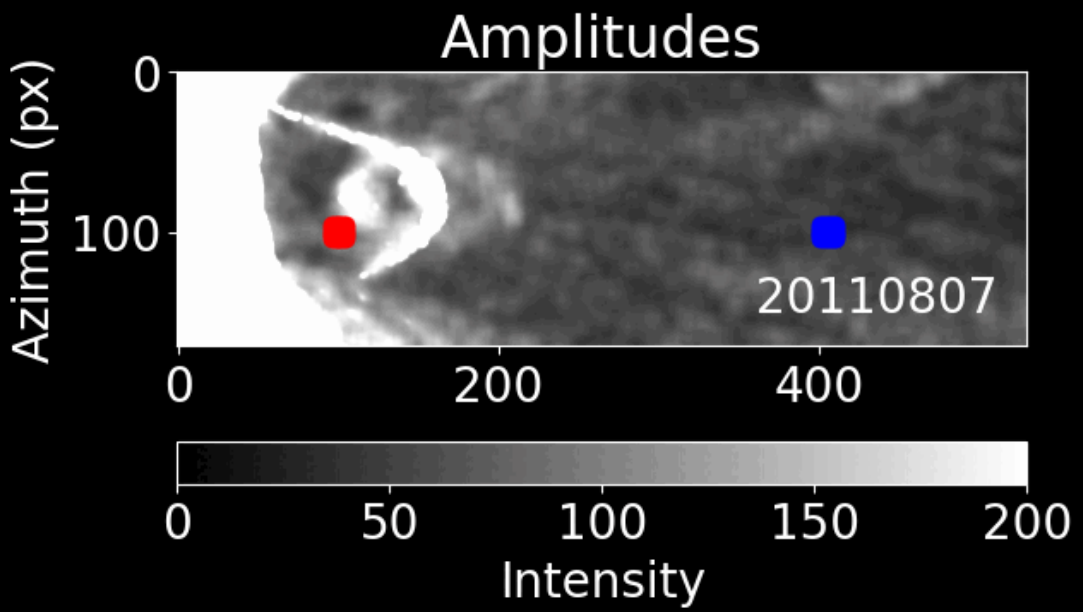


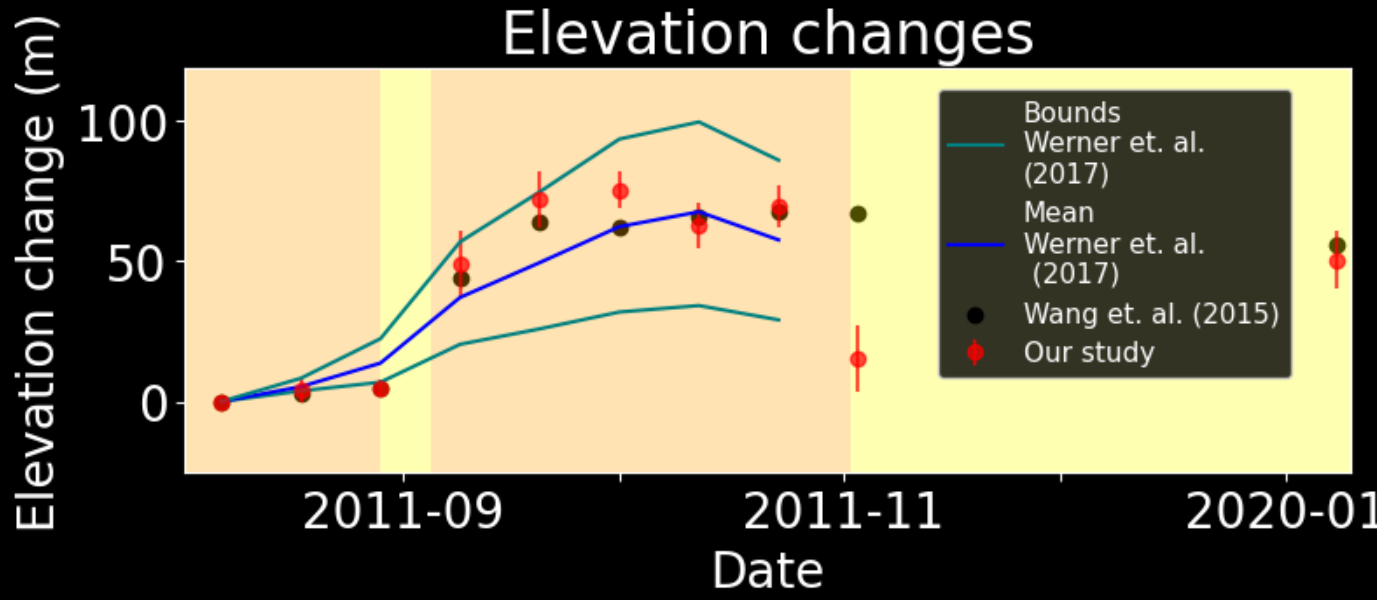
Validation with 2011-2012 Mt. Cleveland Dome Growth



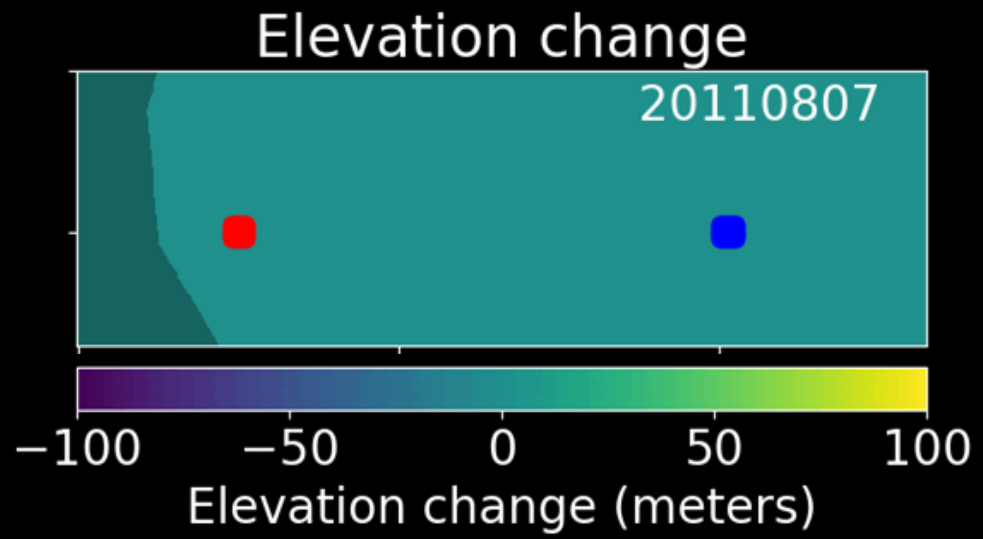
Validation with 2011-2012 Mt. Cleveland Dome Growth

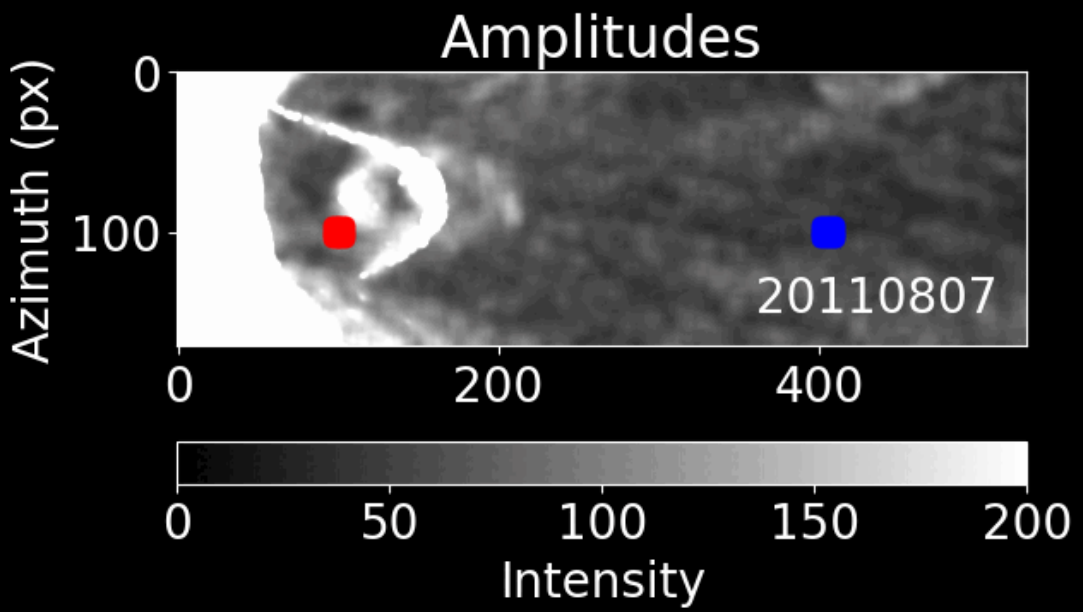


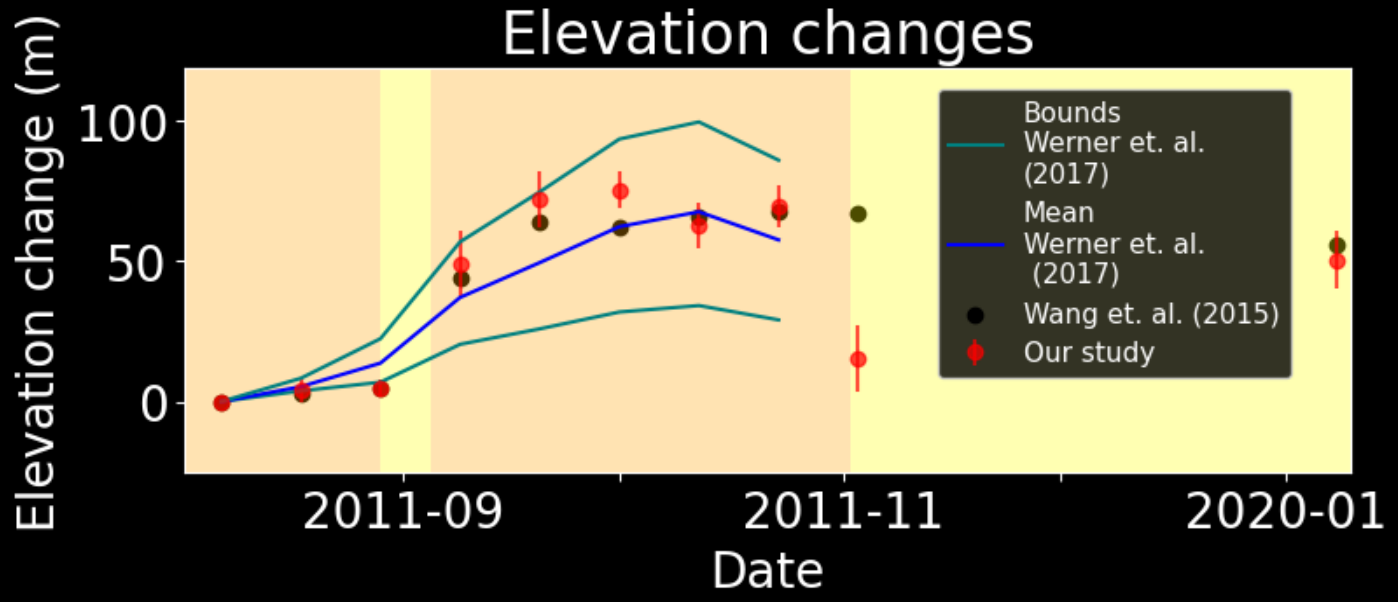


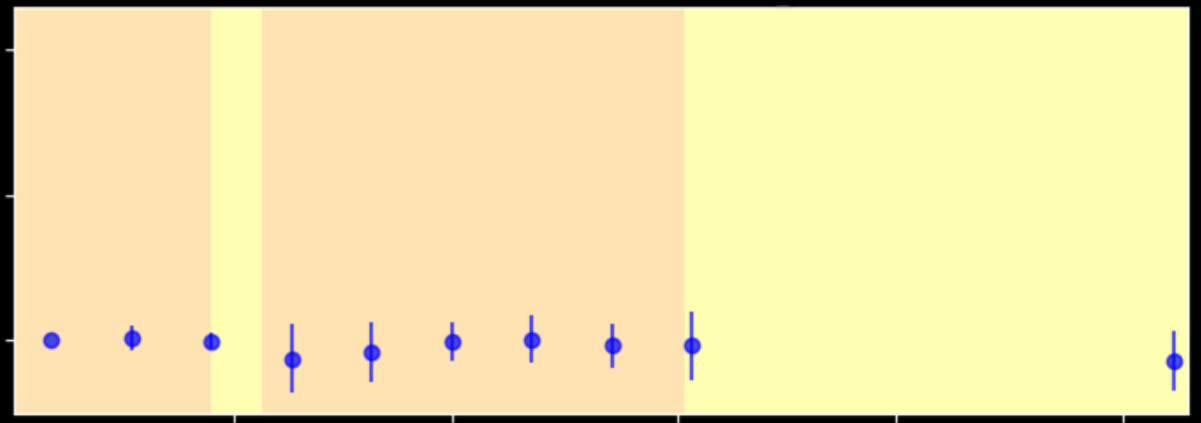


Validation with 2011-2012 Mt. Cleveland Dome Growth





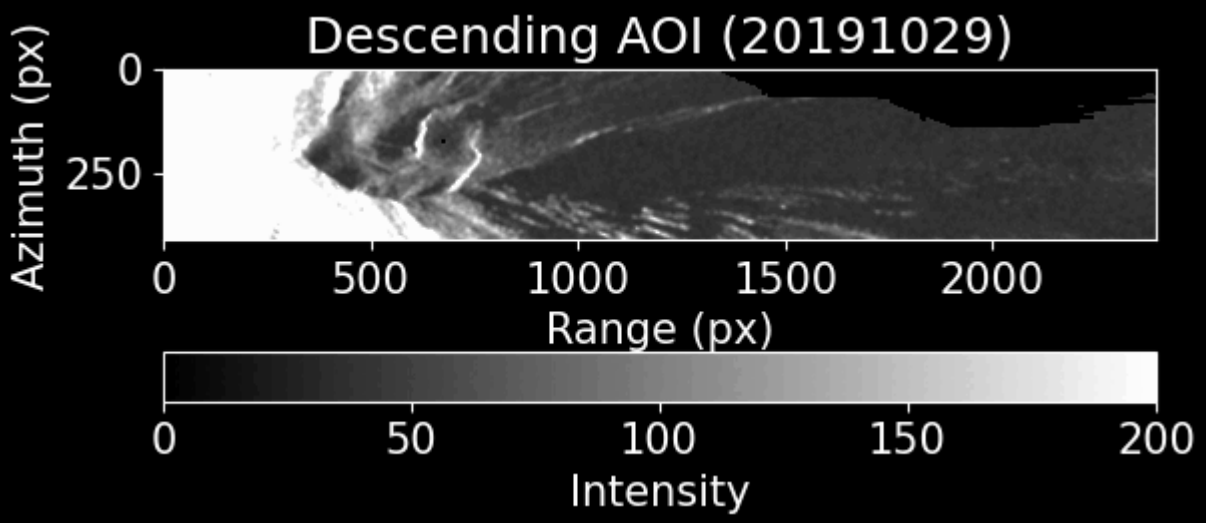




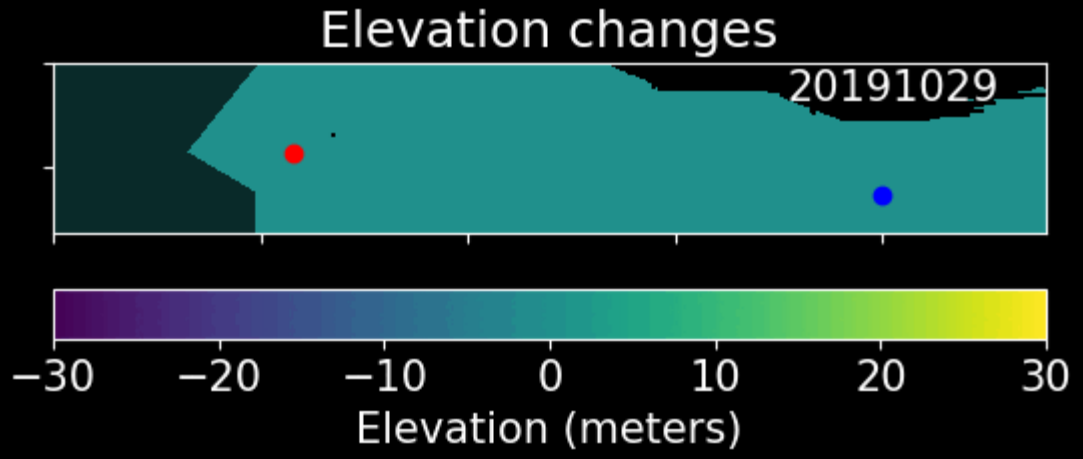
Shishaldin

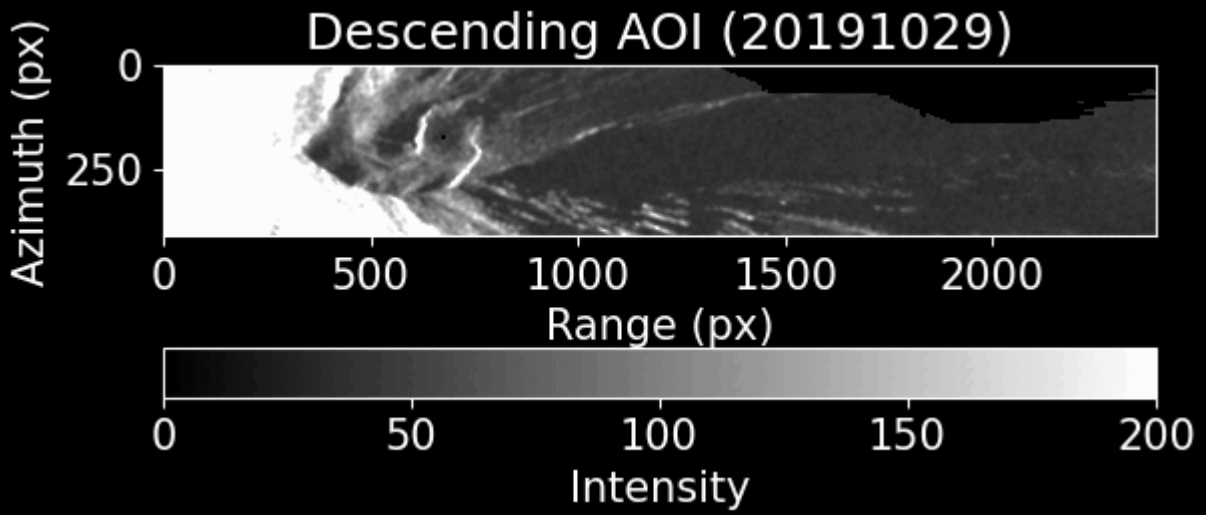
- We had access to several TerraSAR-X images that span the 2019-2020 Shishaldin eruption.

Shishaldin 2019-2020 Eruption Analysis

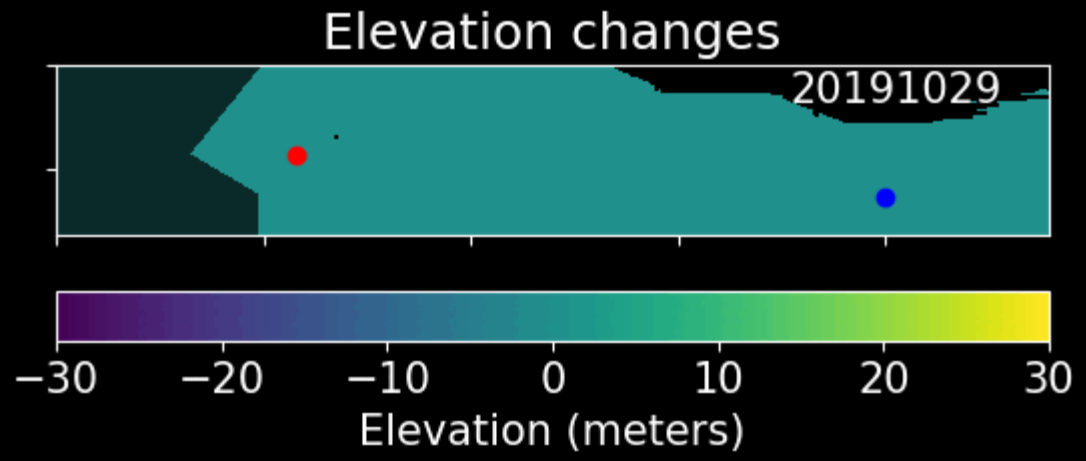


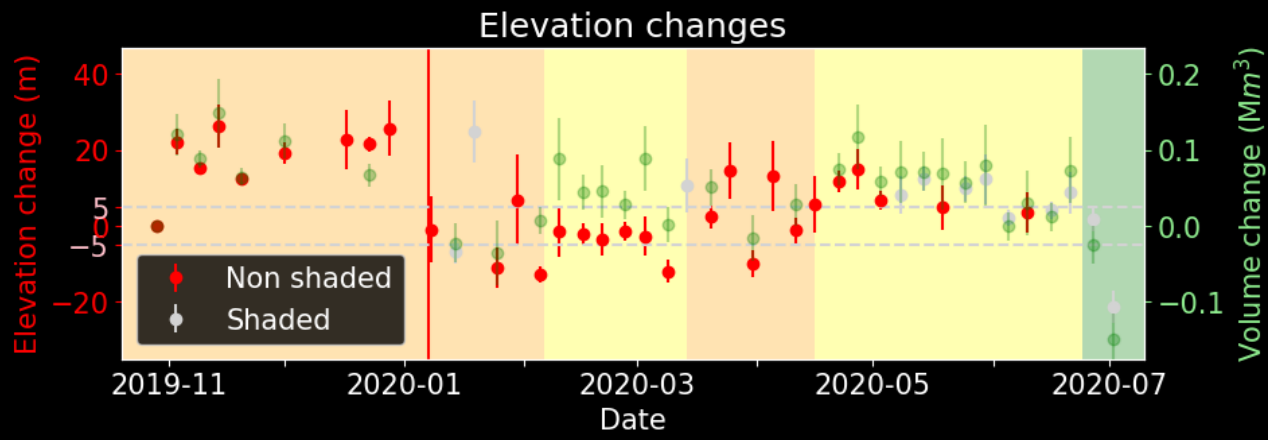
Shishaldin 2019-2020 Eruption Analysis

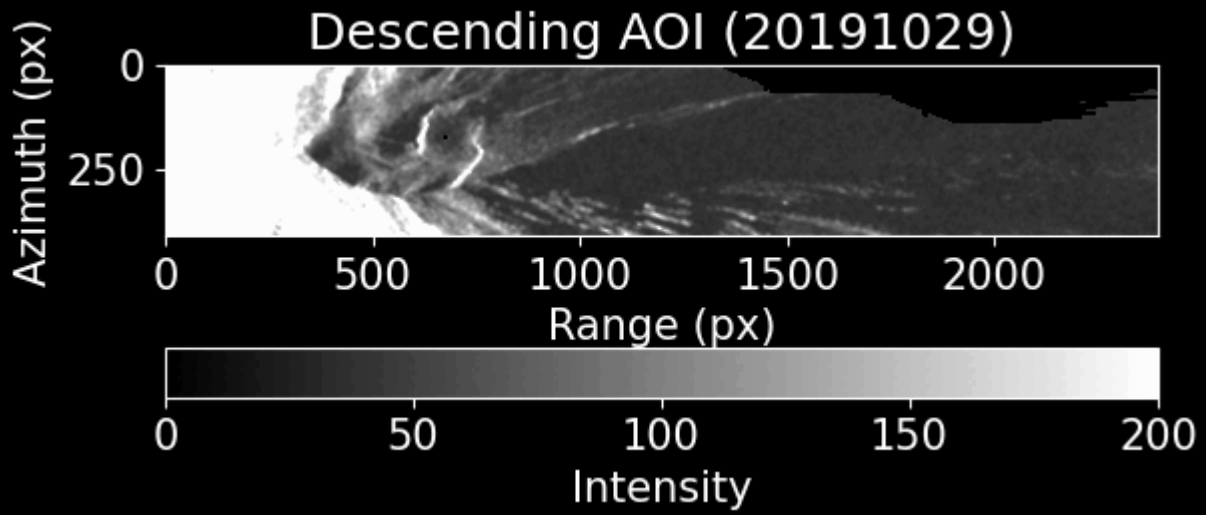




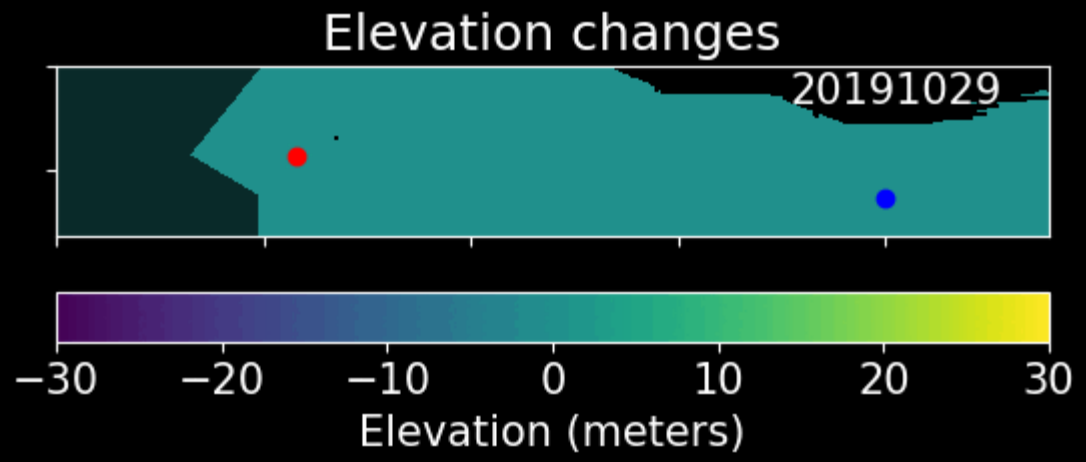
Shishaldin 2019-2020 Eruption Analysis

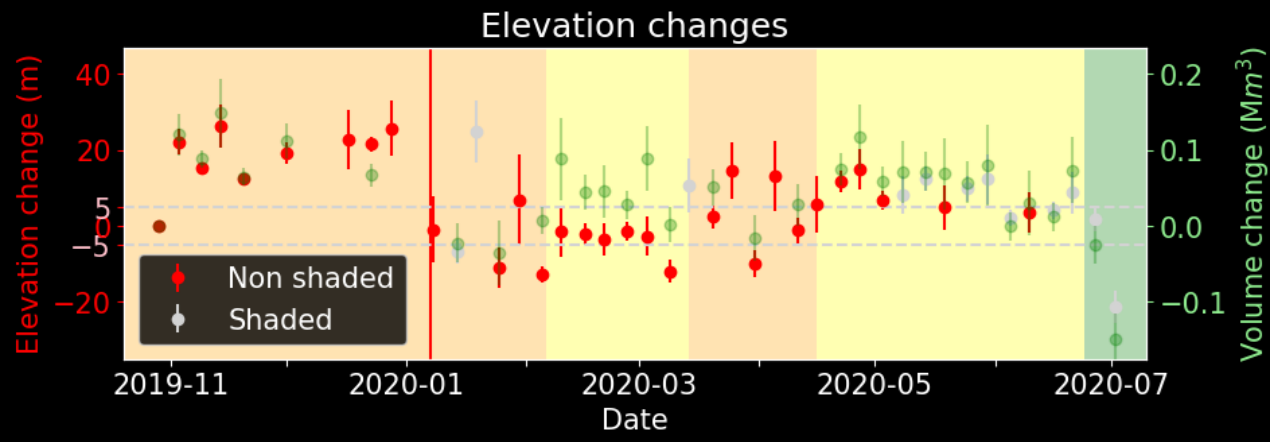


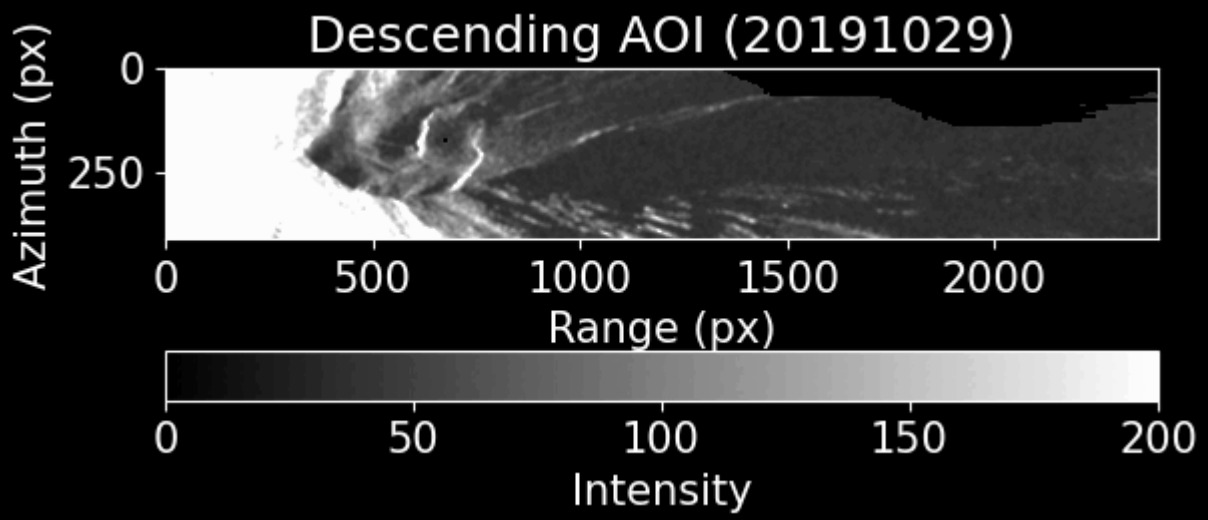


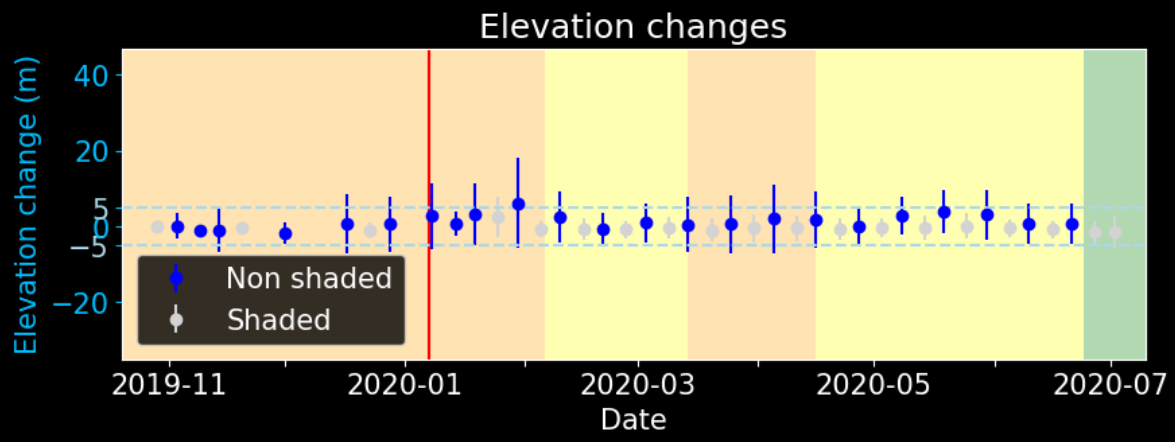


Shishaldin 2019-2020 Eruption Analysis









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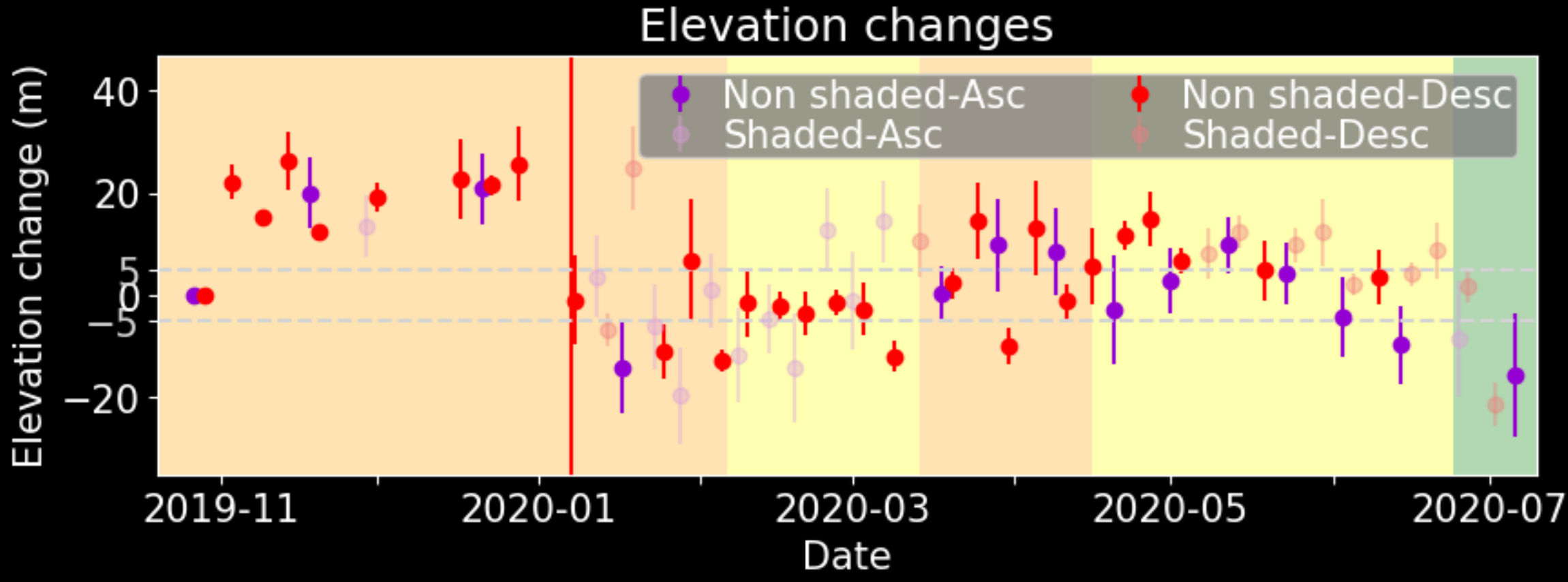
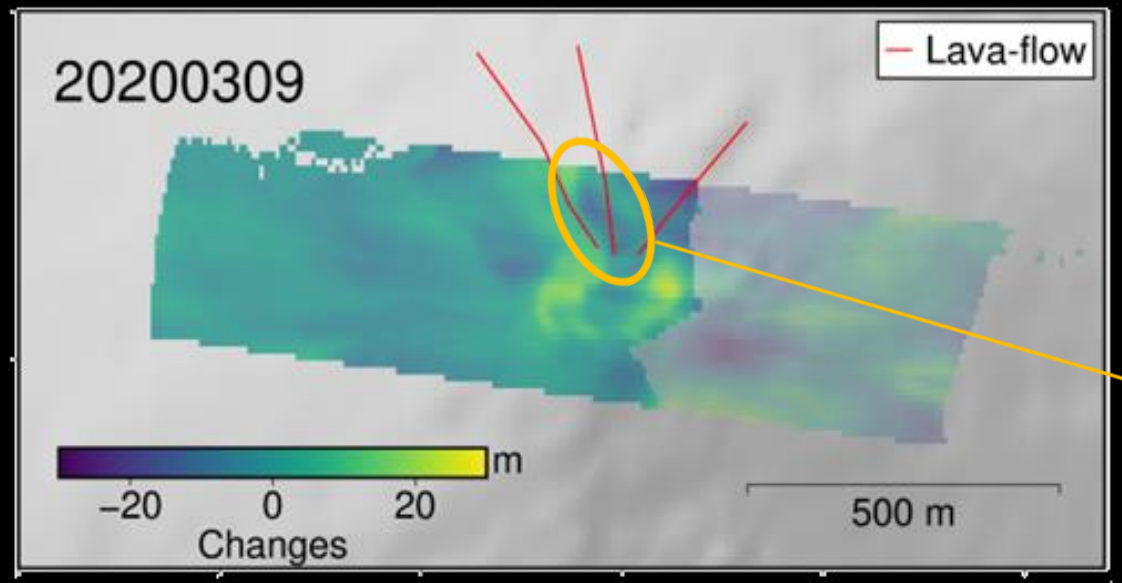
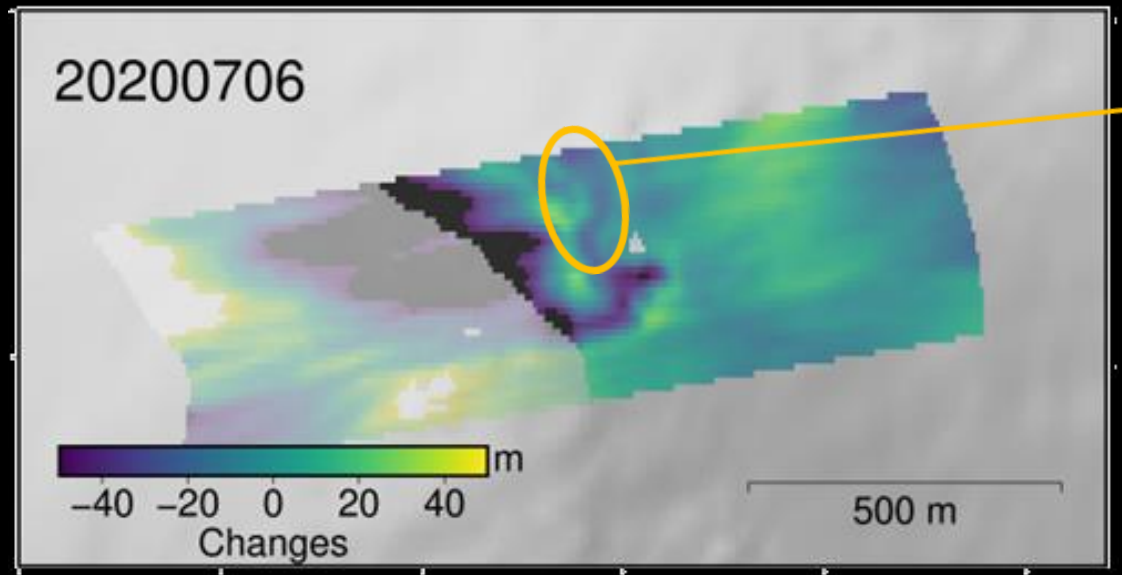
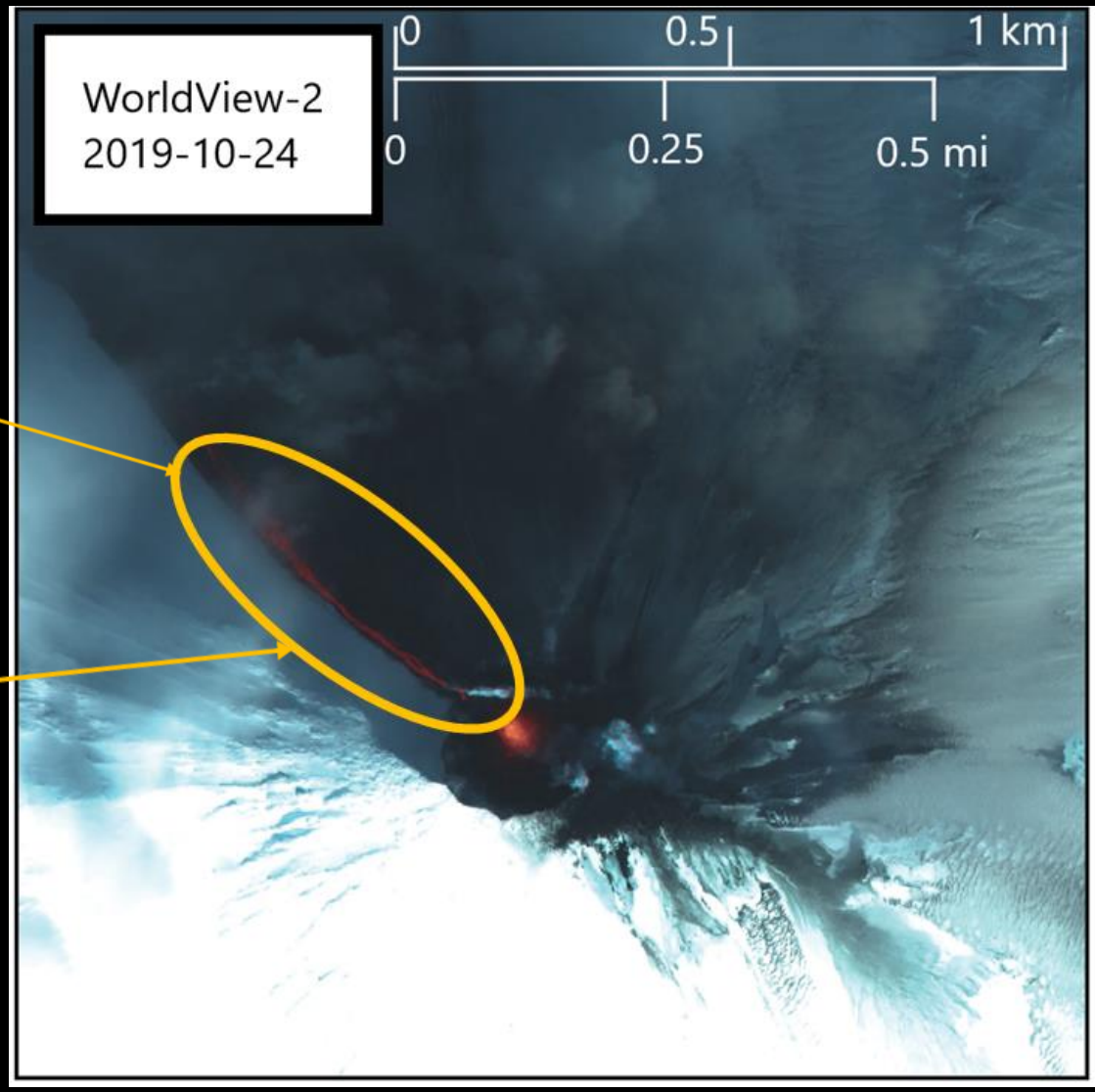


Shishaldin 2019-2020 Eruption Analysis







Find the code on Zenodo and all details in the paper

Elevation changes from SAR Amplitude images ¶

This notebook shows how to get elevation changes from SAR amplitude images using shape from shading techniques explained in (cite article). In this notebook we show the results for a Shishaldin dataset using TerraSAR-X images and an ArticDEM. Unfortunately the notebook cannot be rerun because it needs the original slc files and DEM that are not open source.

Importing libraries

'sfs' coregisters the slc images with a DEM

In [1]:
```
%matplotlib inline
import sfs
import lsquares
import matplotlib
import numpy as np
import matplotlib.pyplot as plt
import h5py
import multiprocessing
from functools import partial
import matplotlib.image as image
import datetime as dt
import matplotlib.style
import matplotlib as mpl
import datetime as dt
mpl.rcParams.update(mpl.rcParamsDefault)
```

H5 file names

The variable 'cor_stack' will contain the name of the h5 file where all the coregistered images and DEM will be. The variable 'pre_stack' will contain the name of the h5 file that will have the area of interest and the gradient of the given DEM.

In [2]:
```
cor_stack='../projectionsD.h5'
pre_stack='descending.h5'
```

Coregistration of slcs

In the next cell we have the rutine that coregisters all slcs images contain in the folder 'data/slcs'. The output filename will be given by cor_stack.

THIS RUTINE USES ISCE FOR COREGISTRATION.

AGU ADVANCING EARTH AND SPACE SCIENCE

JGR Solid Earth

RESEARCH ARTICLE
10.1029/2022JB024344

Quantifying Large-Scale Surface Change Using SAR Amplitude Images: Crater Morphology Changes During the 2019–2020 Shishaldin Volcano Eruption

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Key Points:
- We develop a method to estimate meter-scale elevation changes from SAR amplitude observations and validate it against independent analyses
- Applied to the 2019–2020 Shishaldin volcanic eruption, this quantifies elevation changes that correlate with observed volcanic activity
- We quantify unresolved cone growth at Shishaldin Volcano in November 2019, collapse events in spring 2020, and lava flow activity

Supporting Information:
Supporting Information may be found in the online version of this article.

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Citation:
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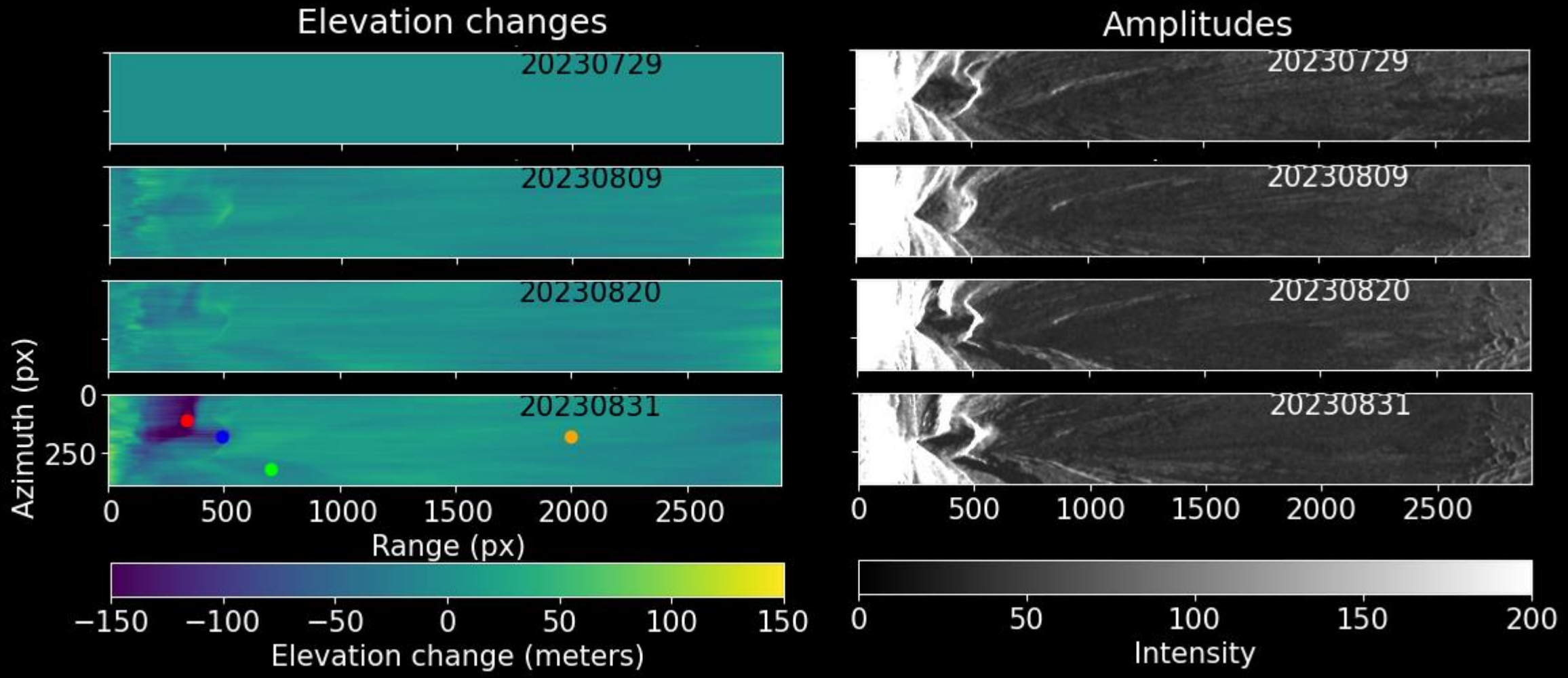
Abstract Morphological processes often induce meter-scale elevation changes. When a volcano erupts, tracking such processes provides insights into the style and evolution of eruptive activity and related hazards. Compared to optical remote-sensing products, synthetic aperture radar (SAR) observes surface change during inclement weather and at night. Differential SAR interferometry estimates phase change between SAR acquisitions and is commonly applied to quantify deformation. However, large deformation or other coherence loss can limit its use. We develop a new approach applicable when repeated digital elevation models (DEMs) cannot be otherwise retrieved. Assuming an isotropic radar cross-section, we estimate meter-scale vertical morphological change directly from SAR amplitude images via an optimization method that utilizes a high-quality DEM. We verify our implementation through simulation of a collapse feature that we modulate onto topography. We simulate radar effects and recover the simulated collapse. To validate our method, we estimate elevation changes from TerraSAR-X stripmap images for the 2011–2012 eruption of Mount Cleveland. Our results reproduce those from two previous studies; one that used the same dataset, and another based on thermal satellite data. By applying this method to the 2019–2020 eruption of Shishaldin Volcano, Alaska, we generate elevation change time series from dozens of co-registered TerraSAR-X high-resolution spotlight images. Our results quantify previously unresolved cone growth in November 2019, collapses associated with explosions in December–January, and further changes in crater elevations into spring 2020. This method can be used to track meter-scale morphology changes for ongoing eruptions with low latency as SAR imagery becomes available.

Plain Language Summary Rapidly occurring geologic processes, such as volcanic eruptions or landslides, can cause drastic, meter-scale changes in local surface elevation. Optical images often used to calculate these changes cannot be relied on under poor acquisition conditions such as inclement weather or nighttime. However, several satellite missions record radar signals reflected from Earth's surface, which are less affected by cloudy views or darkness. We develop a new method to estimate elevation changes directly from the strength of such reflected radar signals. To reference the results appropriately, we require a digital elevation model (DEM) with a known acquisition time such that it can be related to the process under investigation. We verify our software by simulating a crater collapse and recovering it from the data. We validate our method against independent observations of elevation changes at Mount Cleveland, Alaska, in 2011–2012. Lastly, we estimate surface elevation changes during the 2019–2020 eruption at Shishaldin Volcano, Alaska, for which the TerraSAR-X satellite mission acquired several radar images. We resolve increases in elevation in the first stages of the eruption and collapses associated with explosions in spring 2020, and changes due to lava flow activity. The method resolves processes to an accuracy of about 1–3 m.

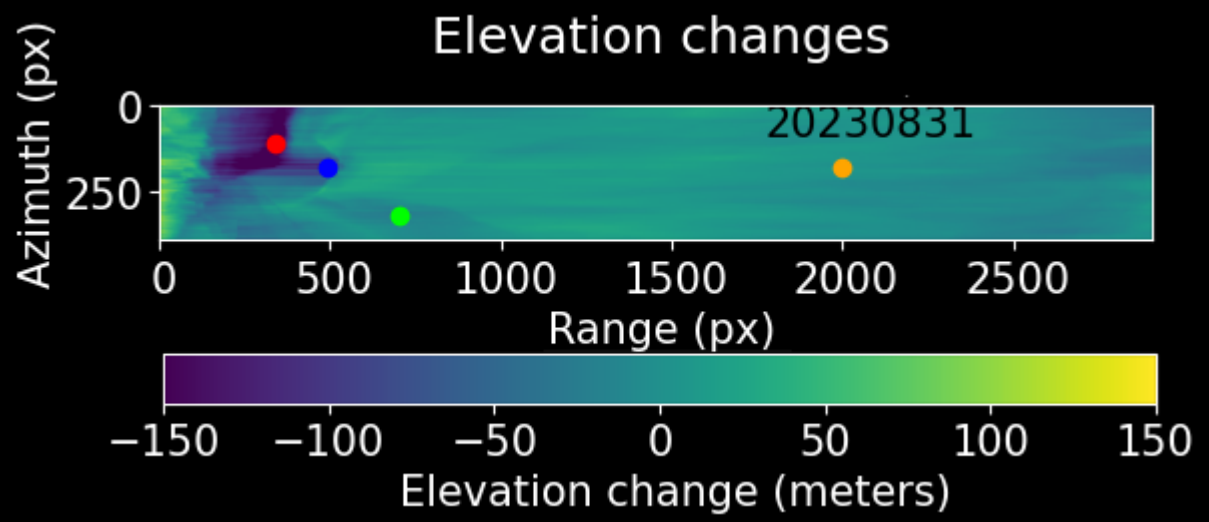
https://doi.org/10.5281/zenodo.6784982

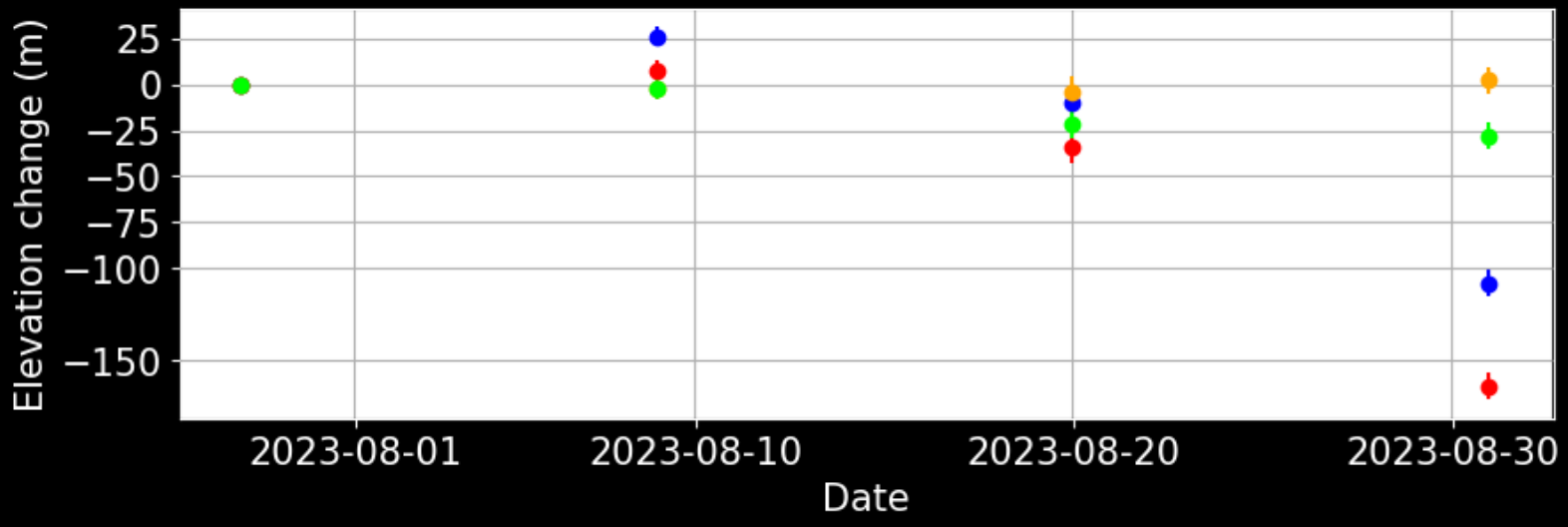
https://doi.org/10.1029/2022JB024344

Shishaldin 2023 eruption



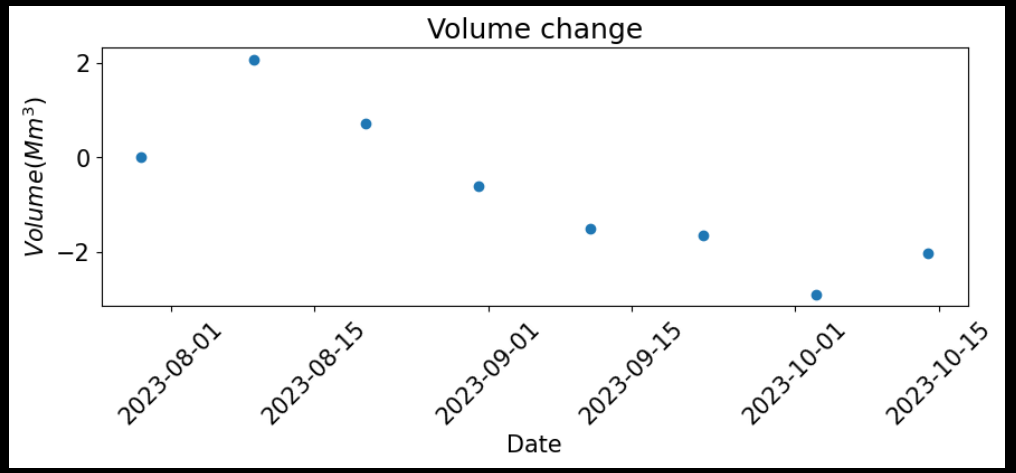
Shishaldin 2023 eruption

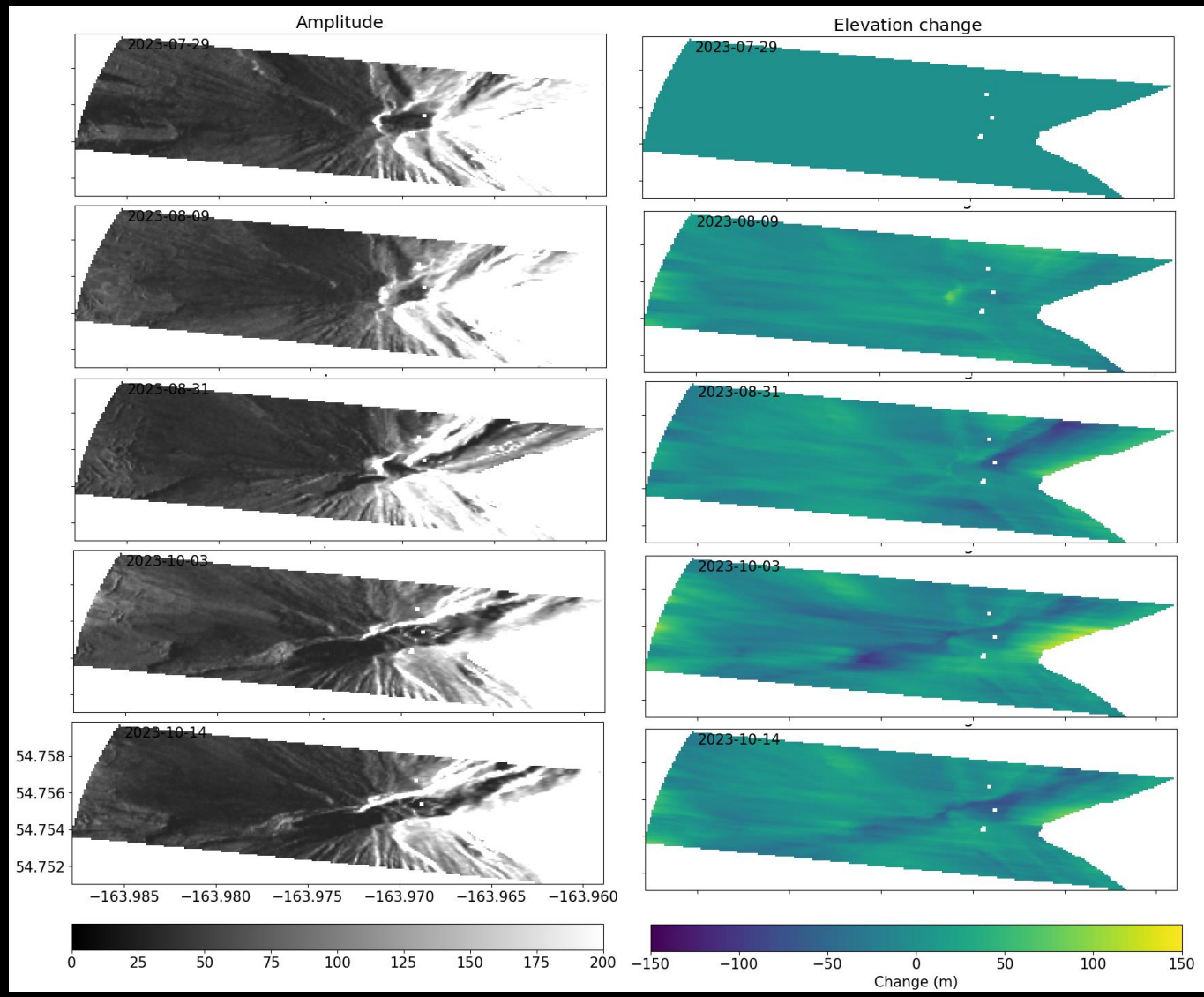




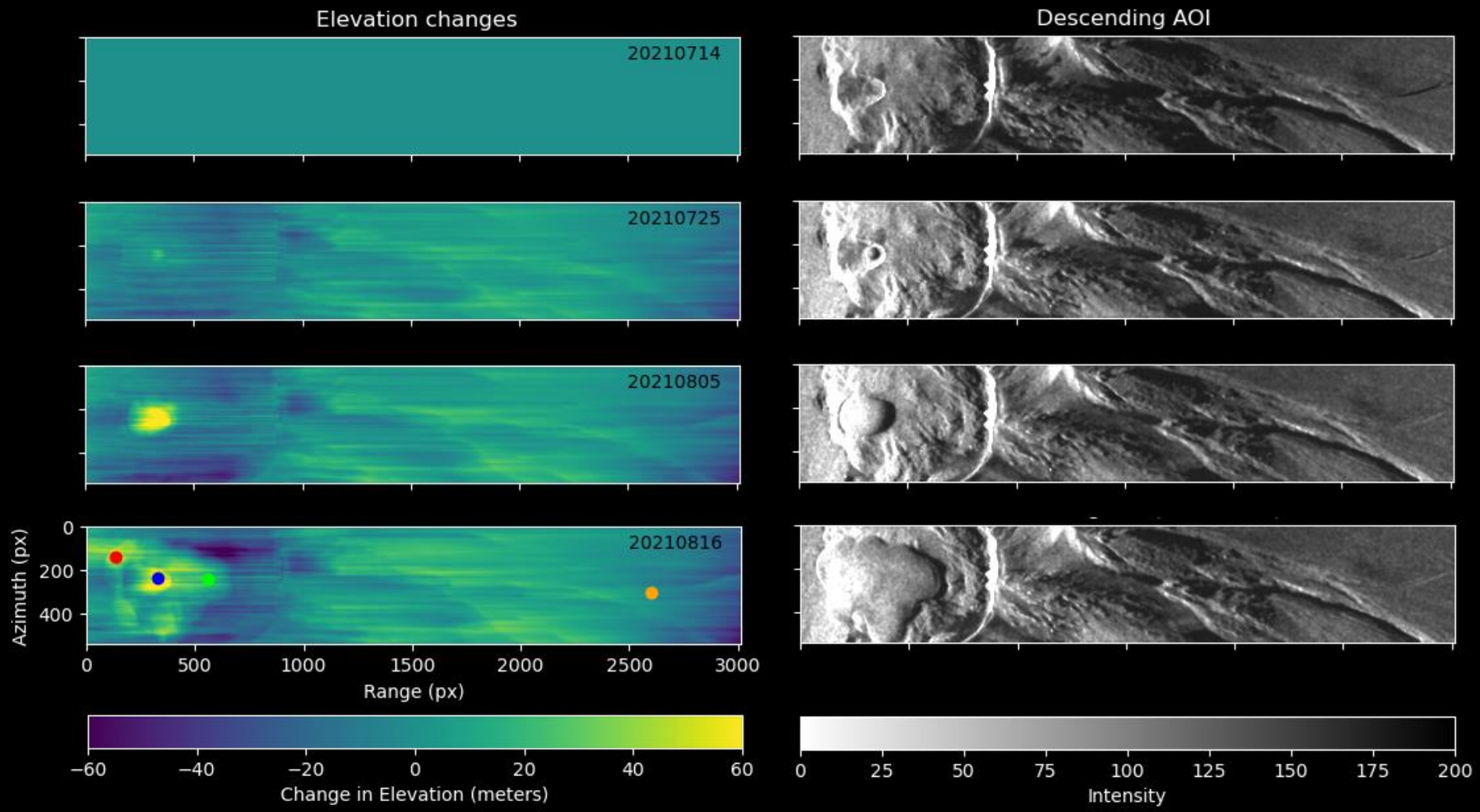
Shishaldin 2023 eruption

We quantified volume changes for the last Shishaldin eruption

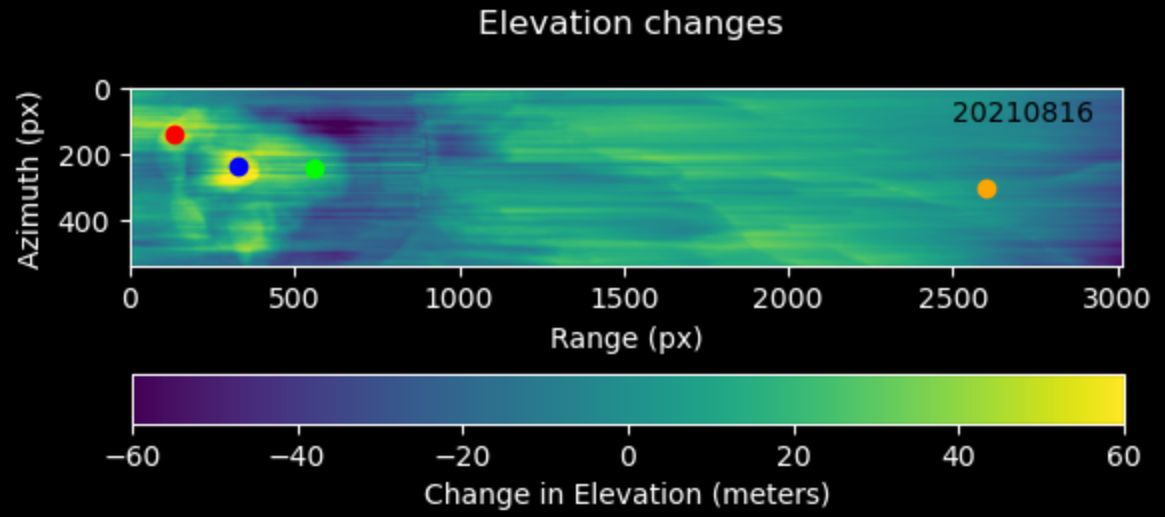


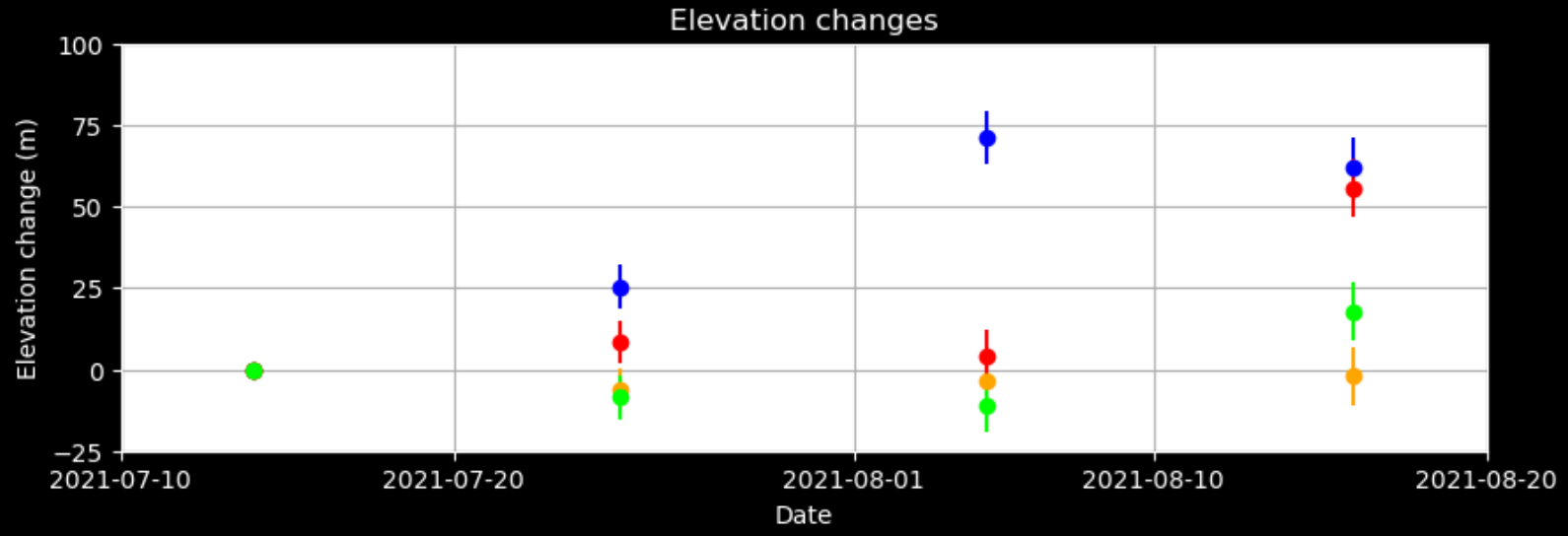


Great Sitkin 2021 eruption

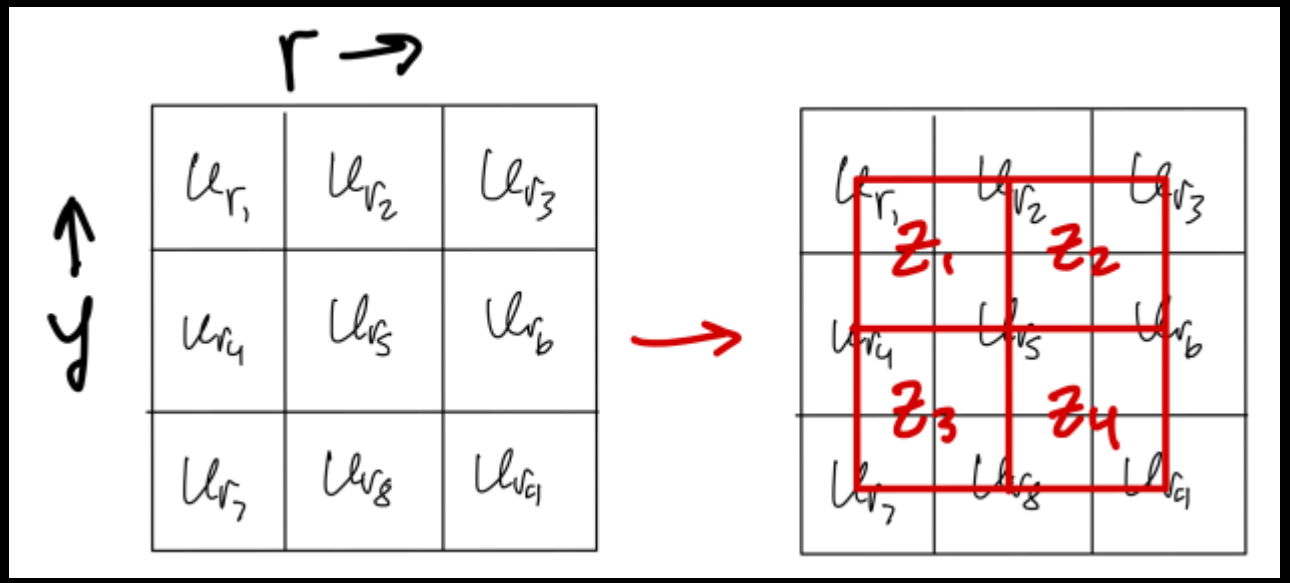


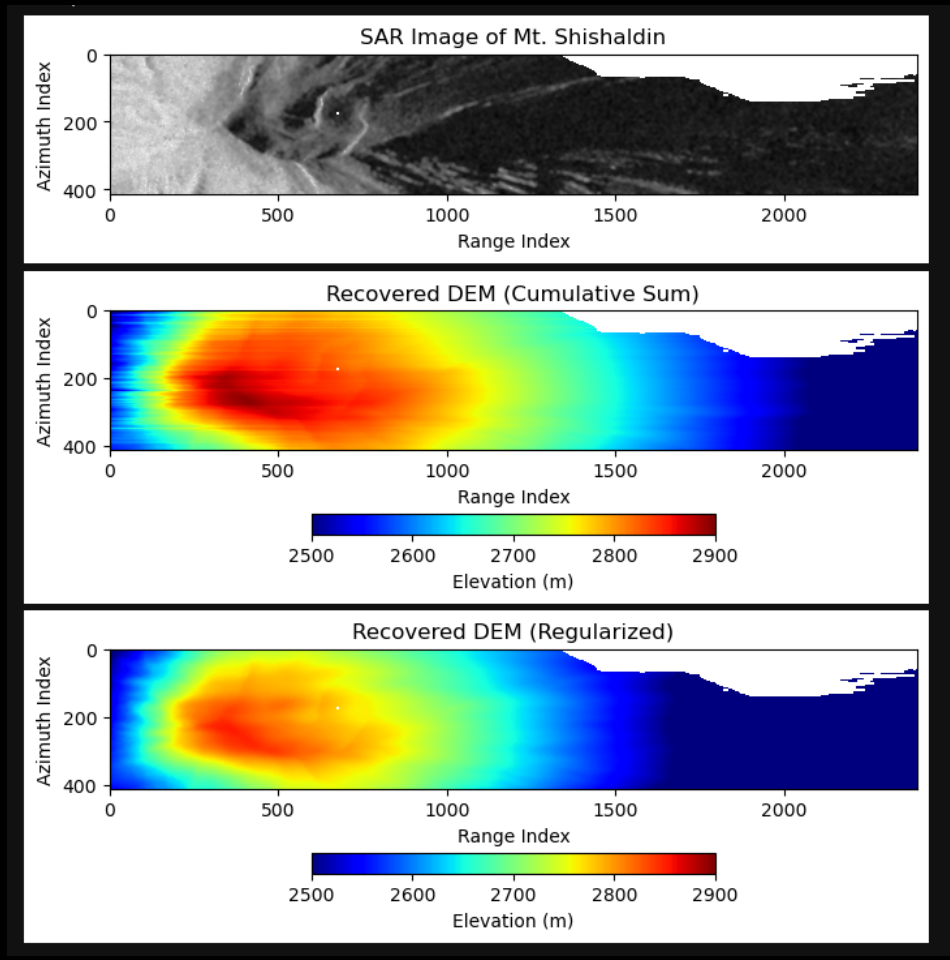
Great Sitkin 2021 eruption





Next steps


r
y
z1
z2
z3
z4


SAR Image of Mt. Shishaldin
Azimuth Index
Range Index
Recovered DEM (Cumulative Sum)
Elevation (m)
Recovered DEM (Regularized)
0
200
400
500
1000
1500
2000
2500
2600
2700
2800
2900