

Automated crevasse mapping: assisting with mountain and glacier hazard assessment

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**British
Geological Survey**
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Why?

Initial development

- surface expression of glacier movement dynamics

More high resolution data available today than ever before

- satellite imagery, UAVs, mobiles
- data only valuable if they are used!

Crevasses pose a serious danger to:

- skiers
- climbers
- those effecting higher altitude rescue operations

Glaciers are dynamic!

- crevasses patterns change
- potential hazard areas evolve
- manual mapping is time consuming

This is...

- Generalising surface crevasse patterns
- Providing additional information
- Only as good as the data on which it is based
- Based on user defined search variables

This is not...

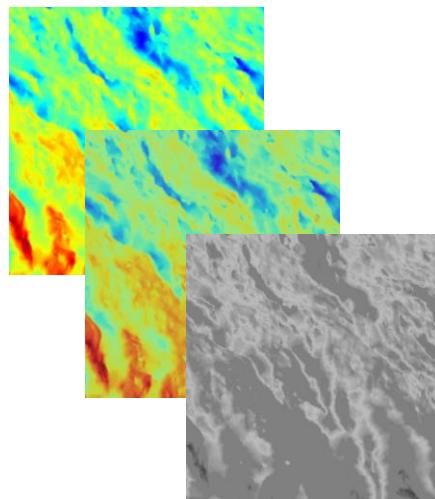
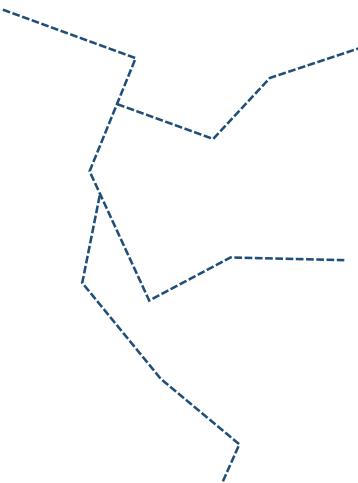
- Mapping/extracting individual crevasse features
- Supposed to be fool-proof solution

Existing approaches

“...visual interpretation of crevasse patterns is often difficult and misleading” (Haeberli et al., 1989)

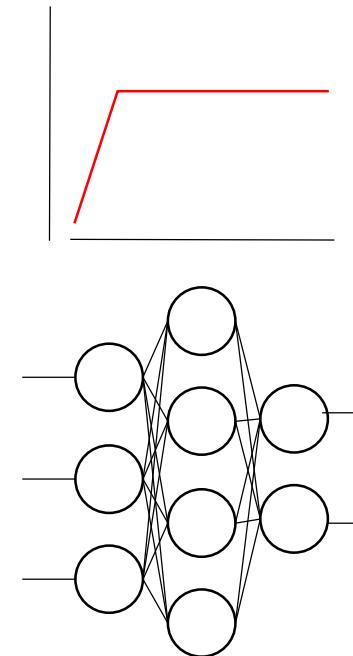
Existing approaches

?

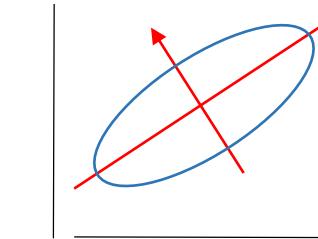


Rivera et al., 2014

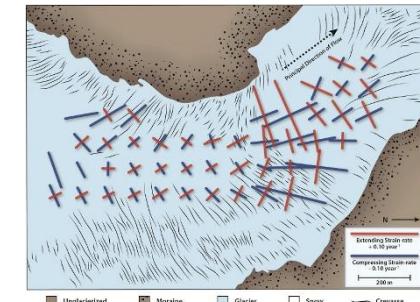
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Herzfeld, 2008, 2011



Jóhannesson et al., 2011

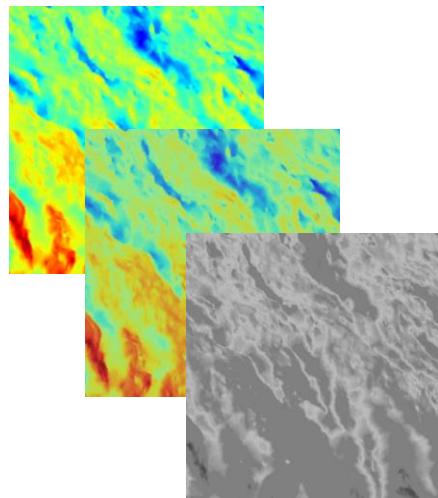
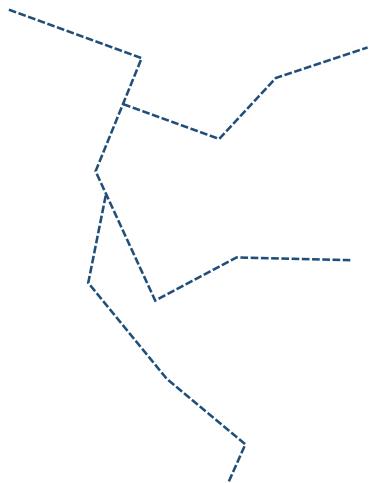


Reproduced from Colgan et al., 2015

see Colgan et al. (2015) for a review...

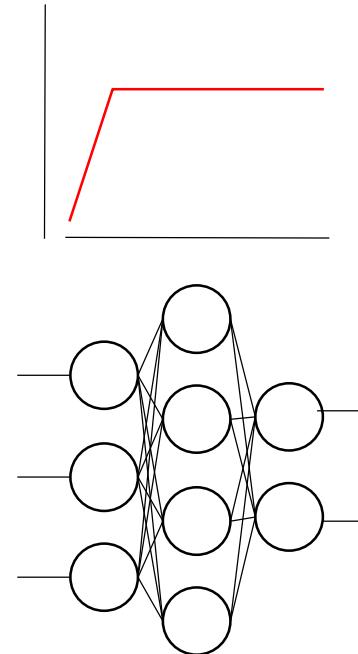
Existing approaches

?

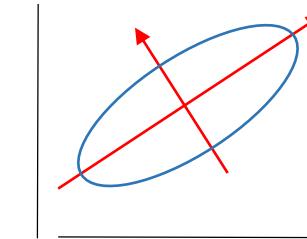


Rivera et al., 2014

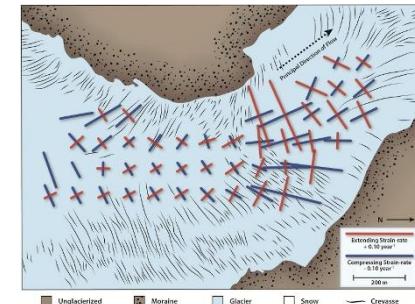
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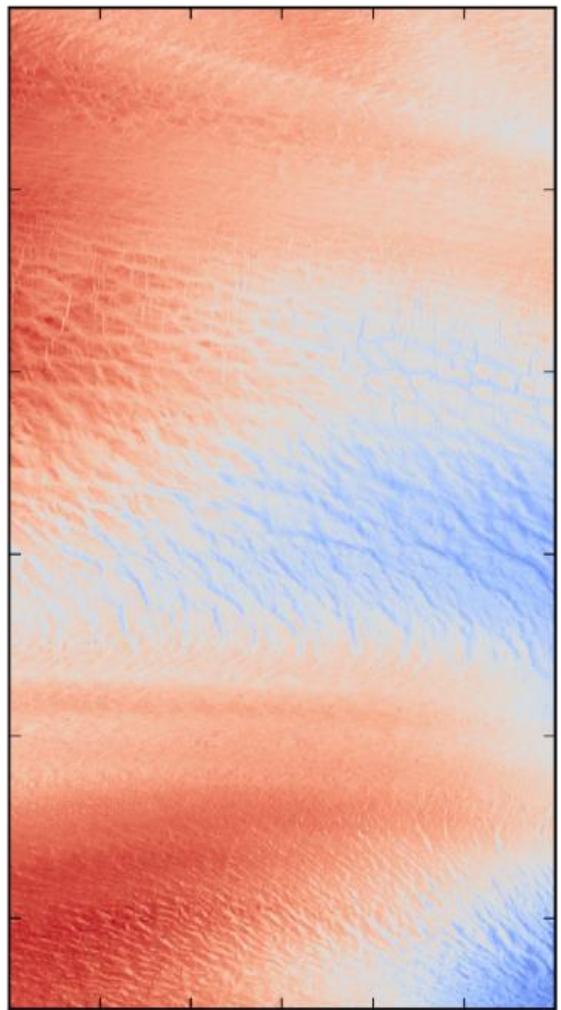
Problems

- Time consuming
- Code often not available!
 - Presence/absence
- Complex nature of crevasses

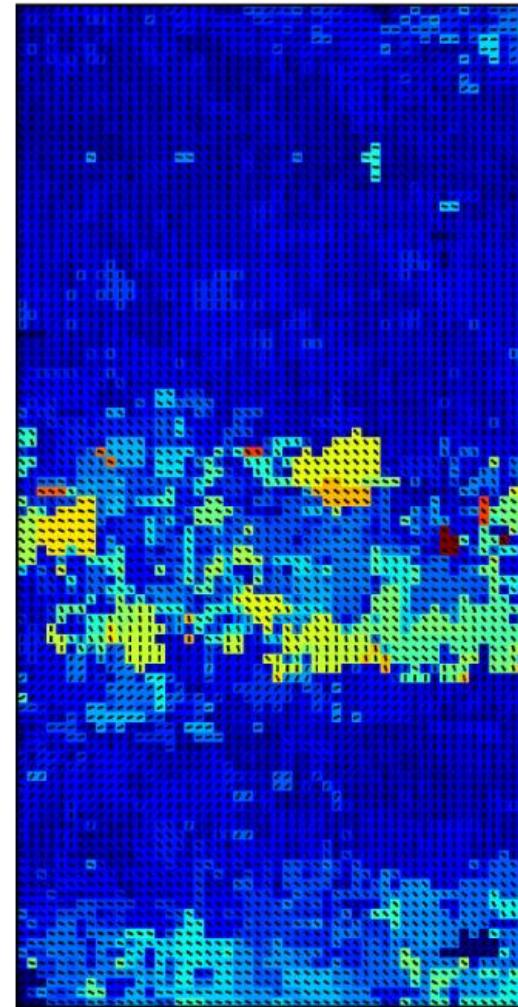
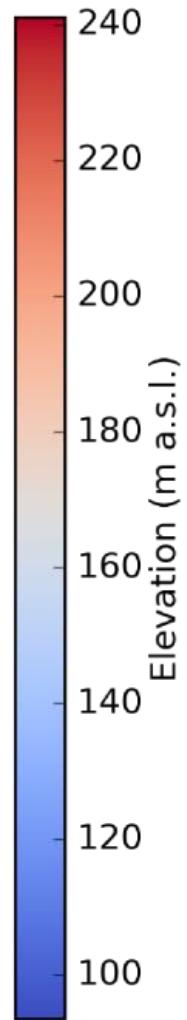
What we present

- Fast, scalable and repeatable procedure
- Generalisation of areas in an image
- Extraction of metrics
 - *spacing, orientation, SnR*

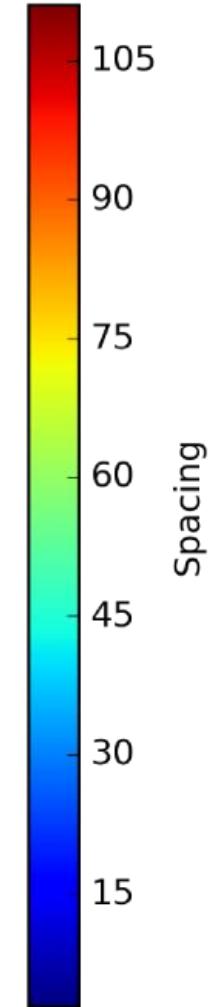
LFMapper: Using the Fast Fourier Transform for feature classification



*Glacier surface raster
(image or DEM)*



*Orientation and spacing matrix
(raster)*

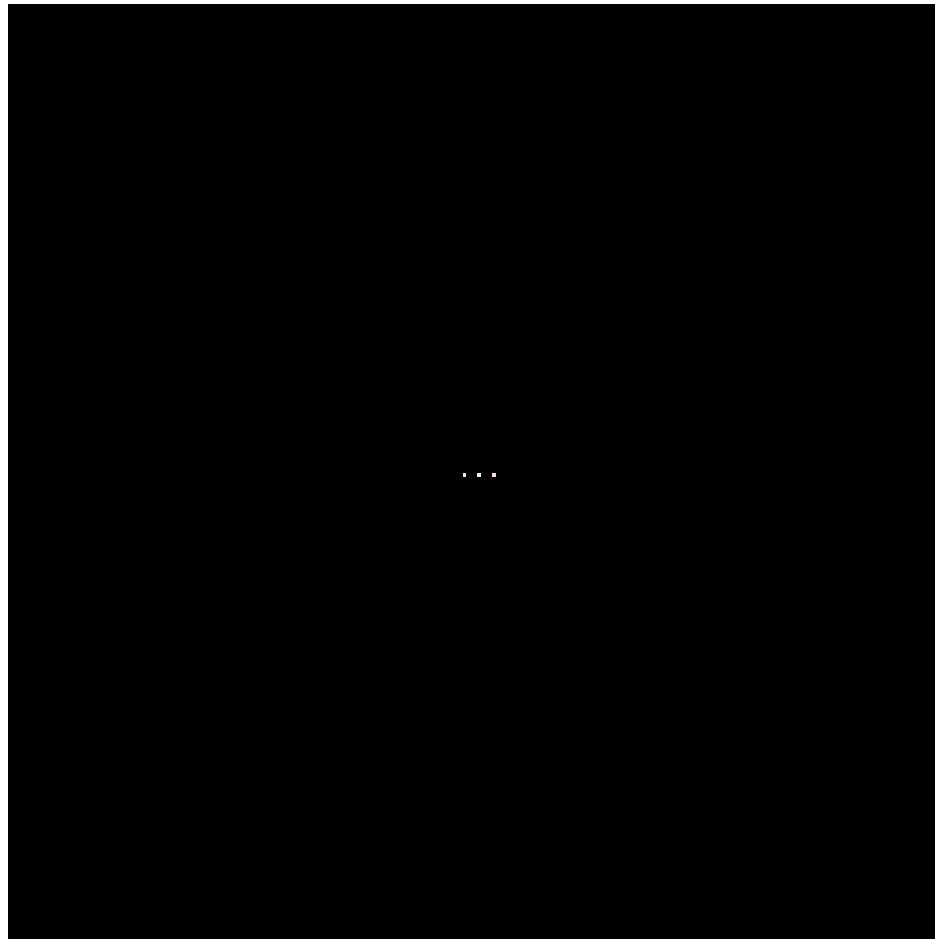


Visually interpreting an Fourier Transform plot

Space



Frequency



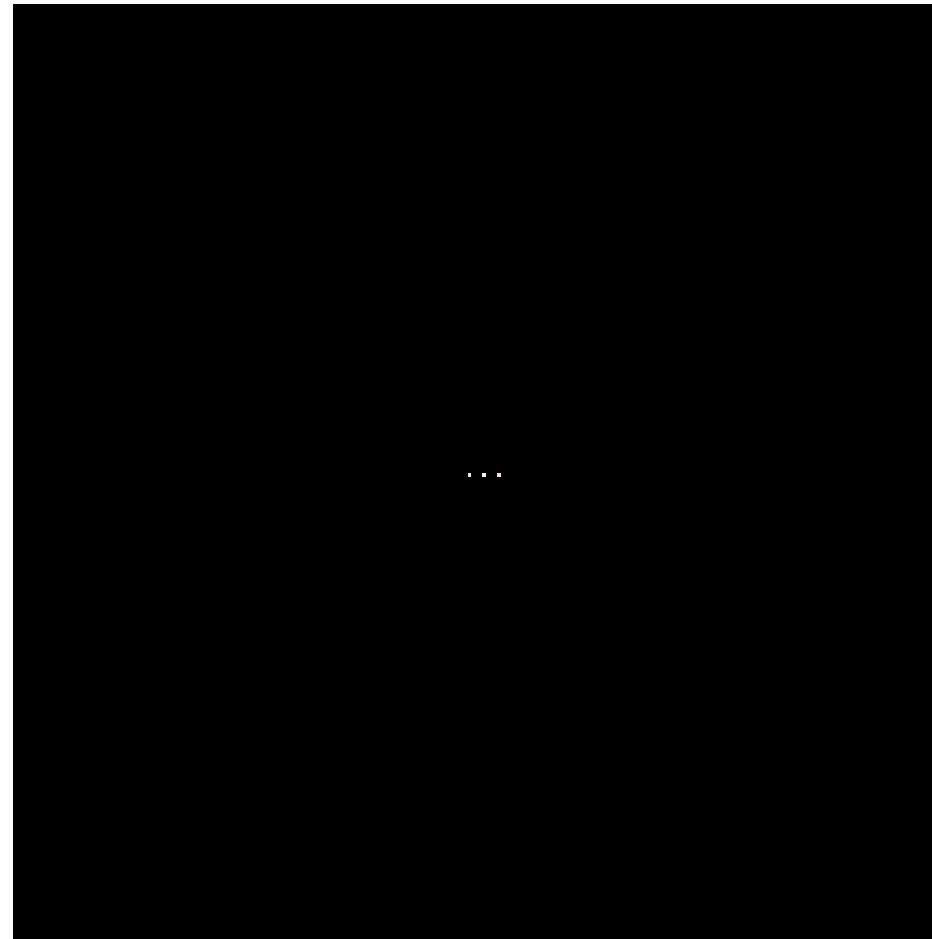
Visually interpreting an Fourier Transform plot

Rotationally symmetrical

Space



Frequency



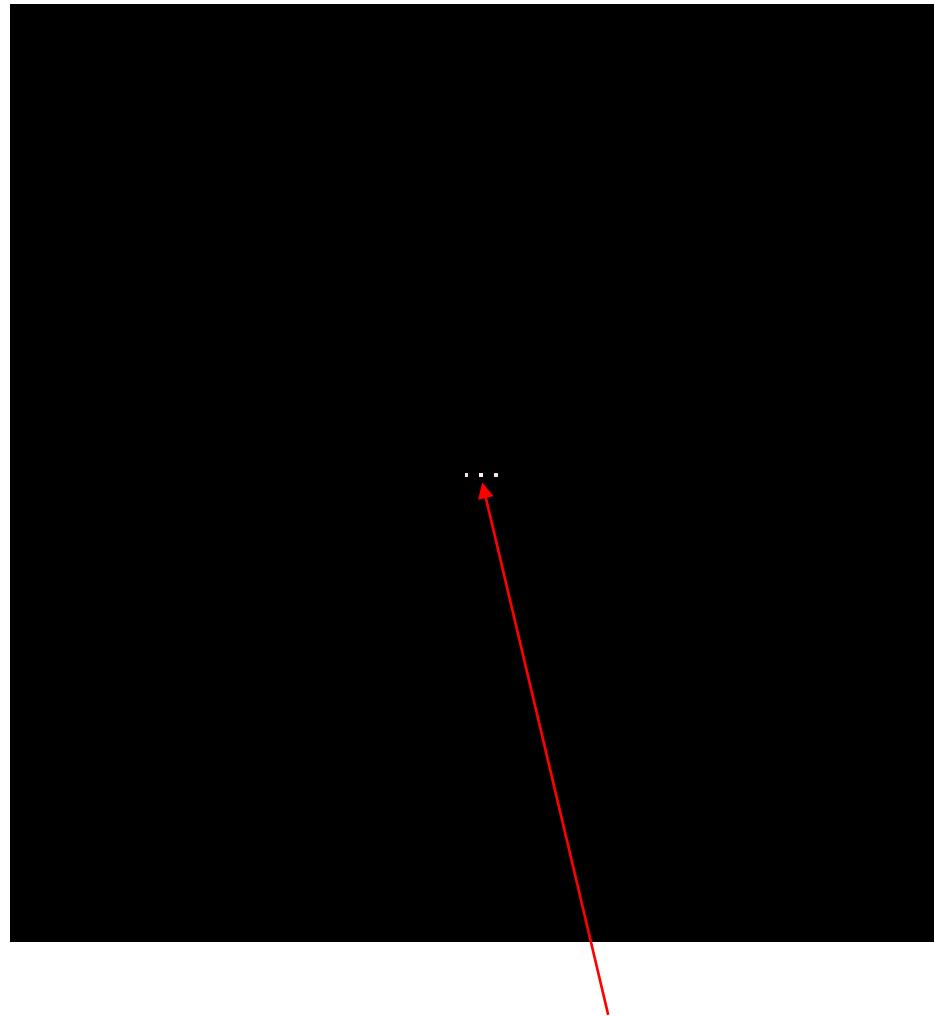
Visually interpreting an Fourier Transform plot

Rotationally symmetrical

Space

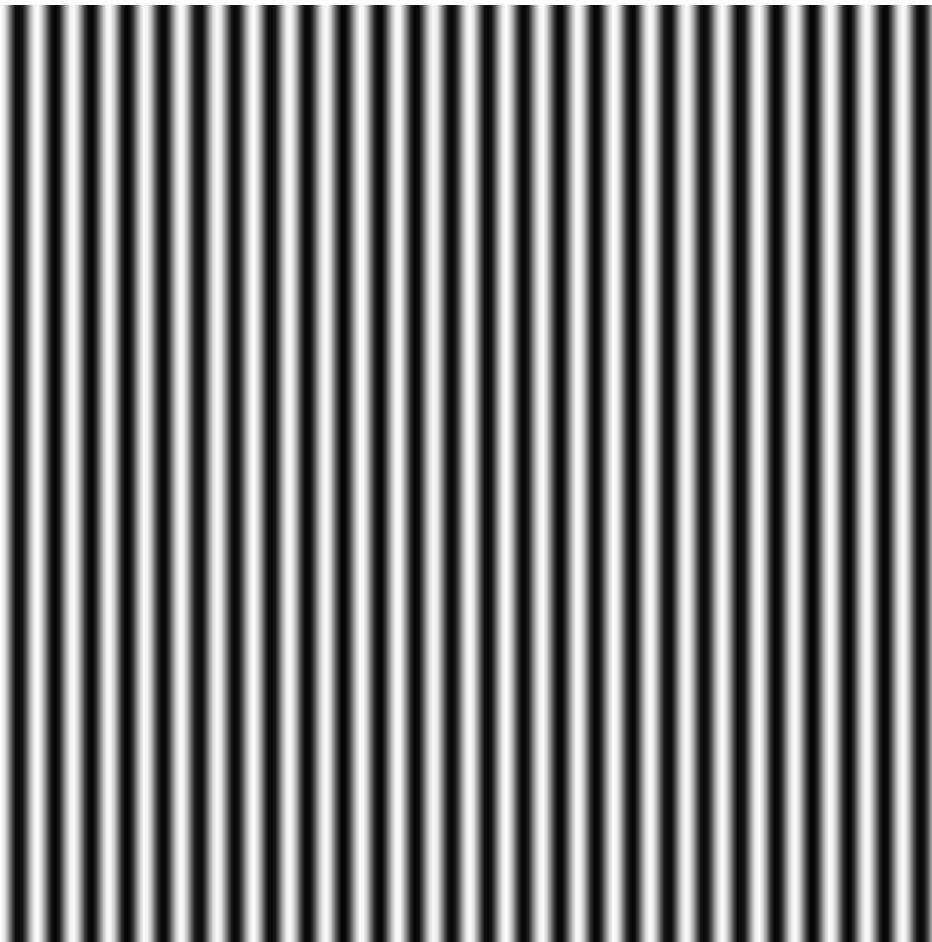


Frequency

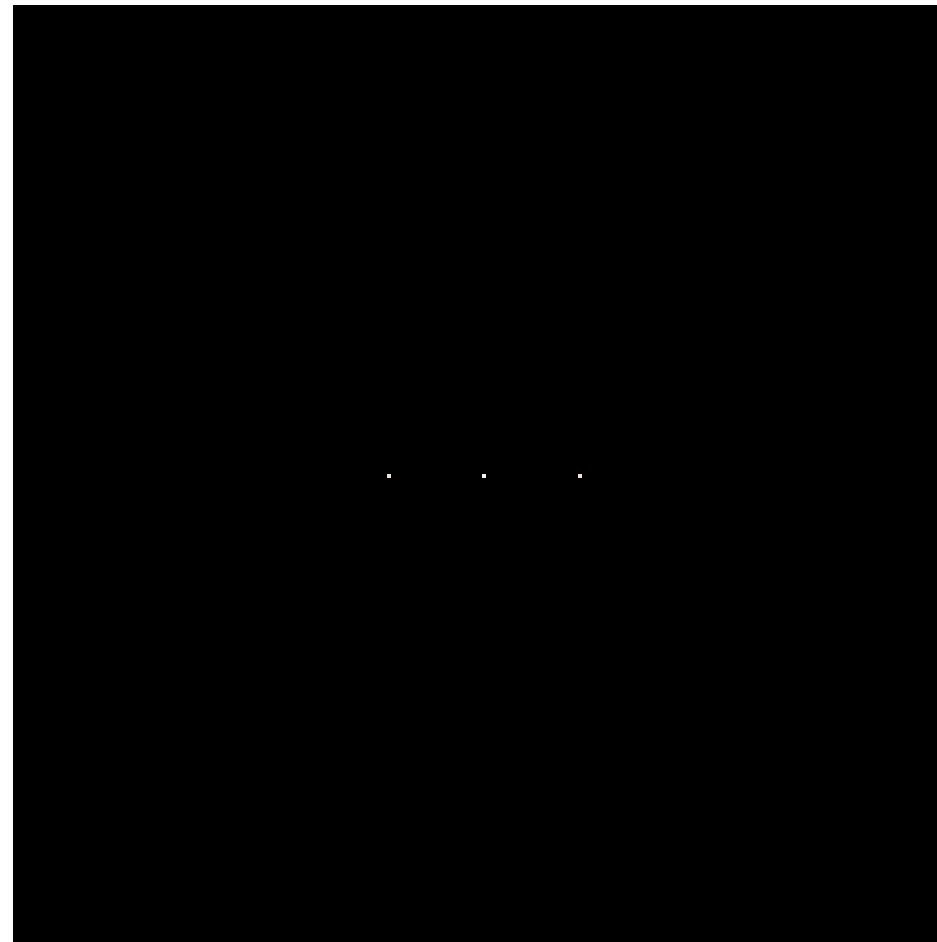


Visually interpreting an Fourier Transform plot

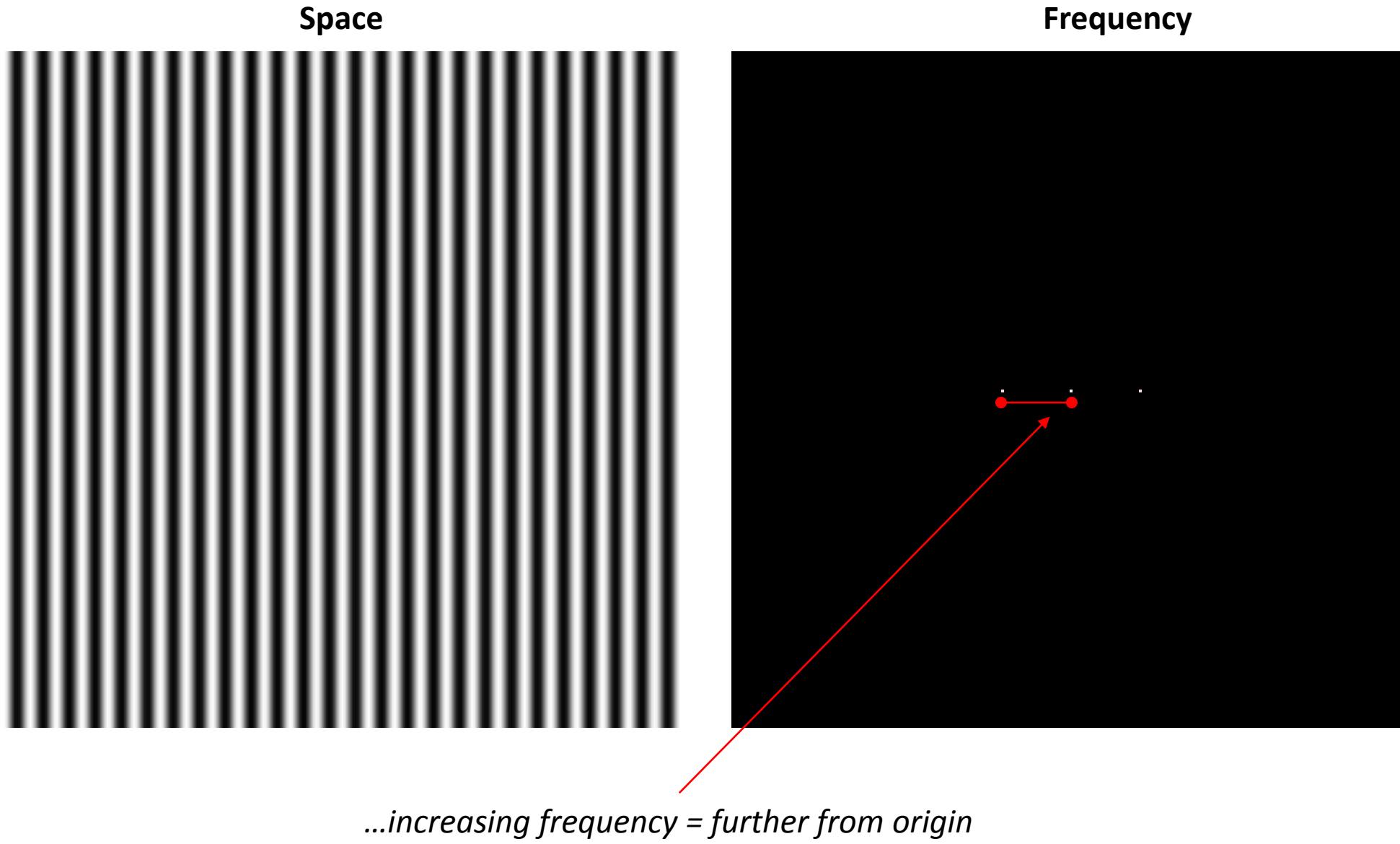
Space



Frequency

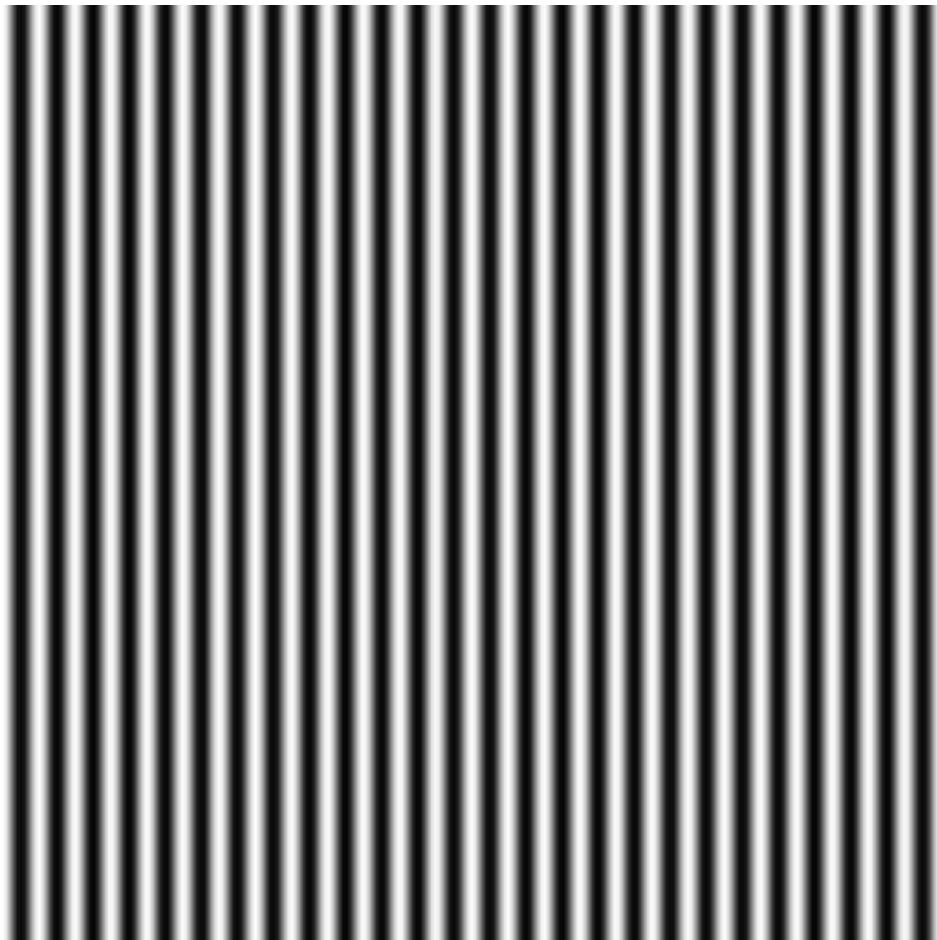


Visually interpreting an Fourier Transform plot

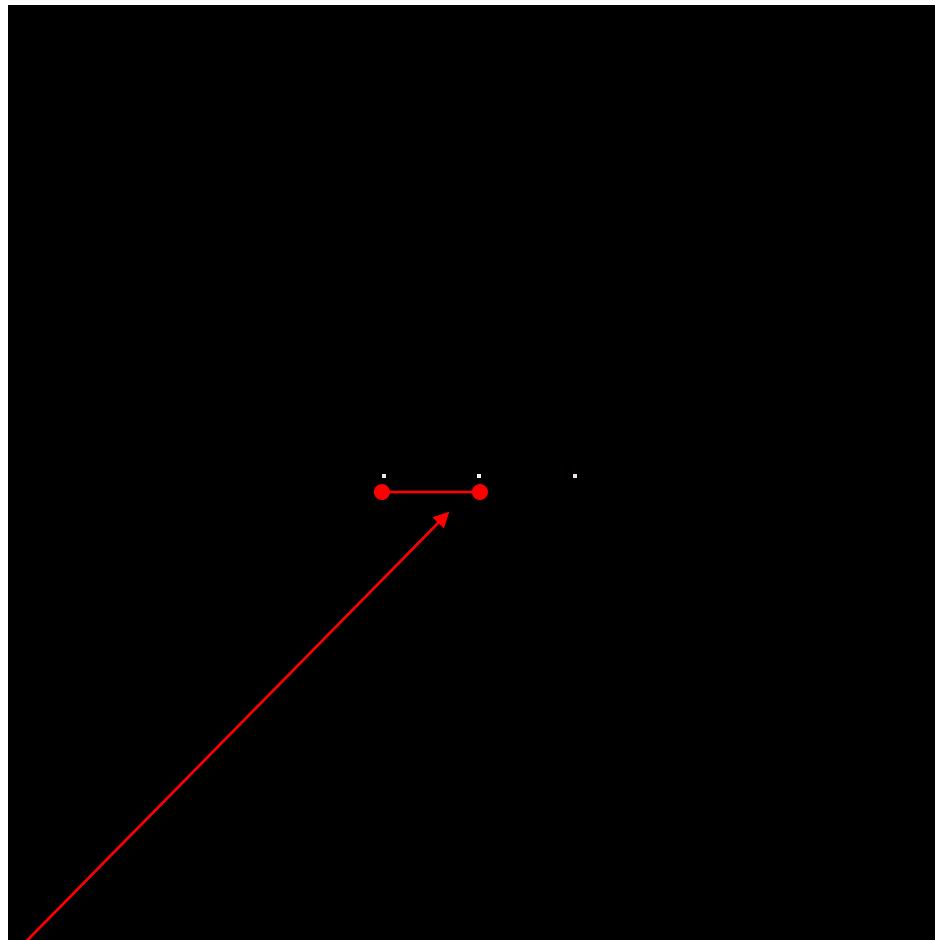


Visually interpreting an Fourier Transform plot

Space

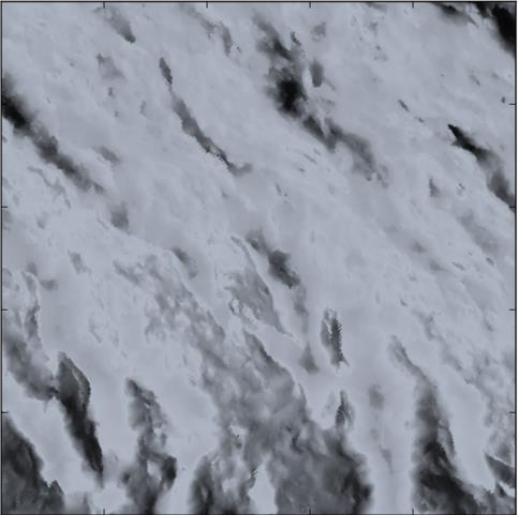


Frequency

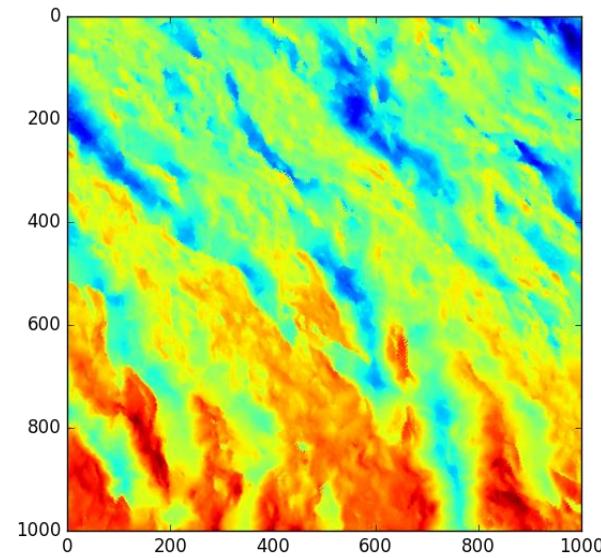


...increasing frequency = further from origin

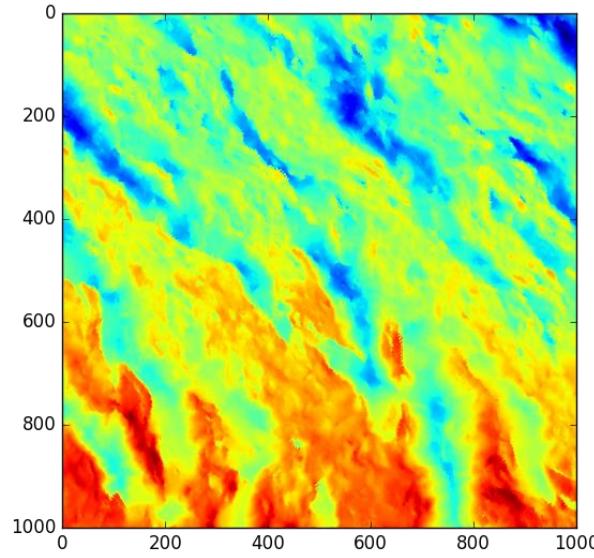
FFT: Fast Fourier transform



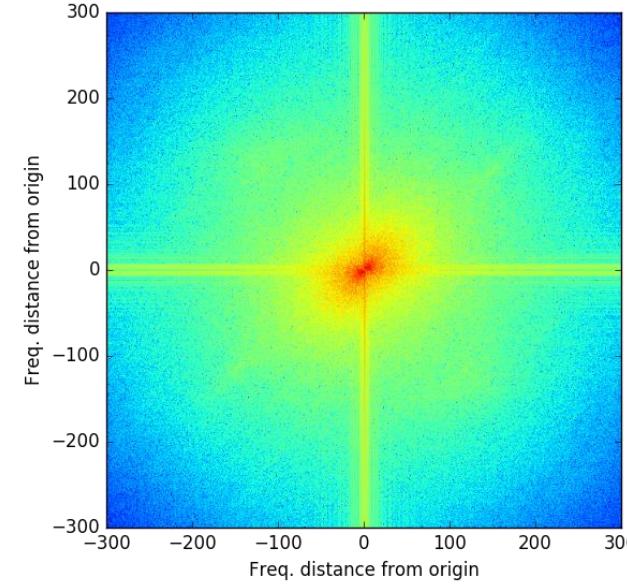
1. Original image



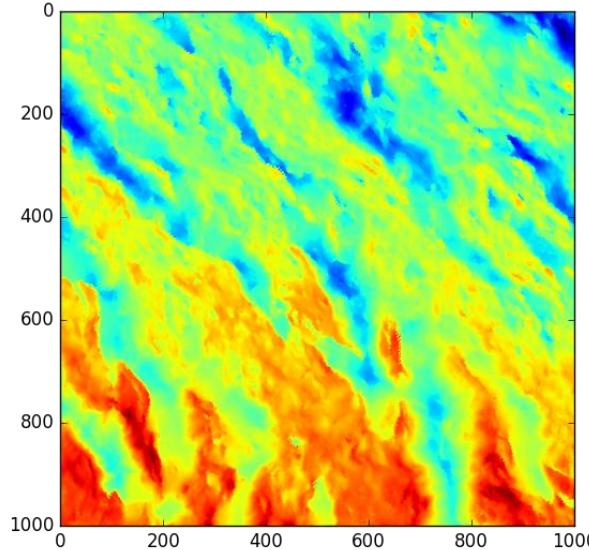
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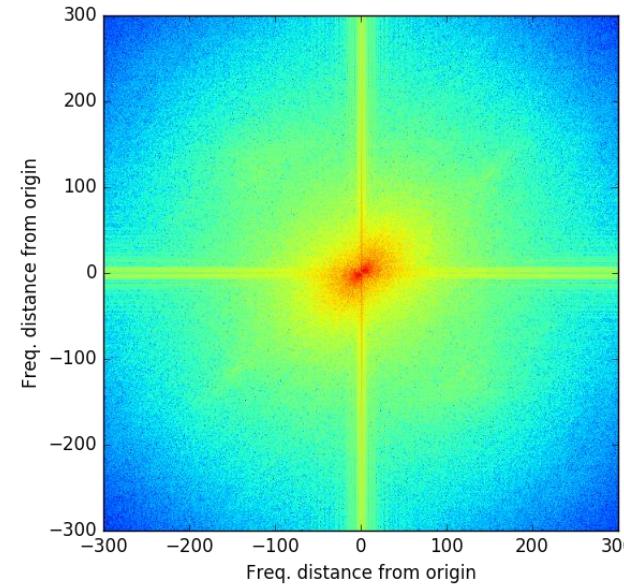
2. Calculate FFT



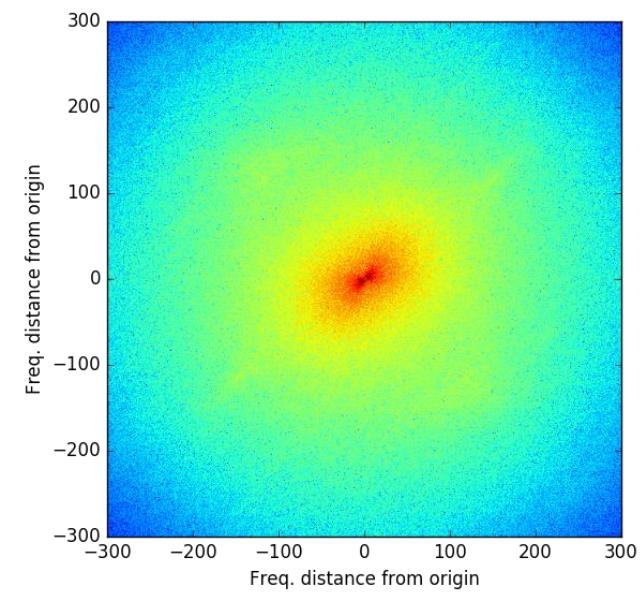
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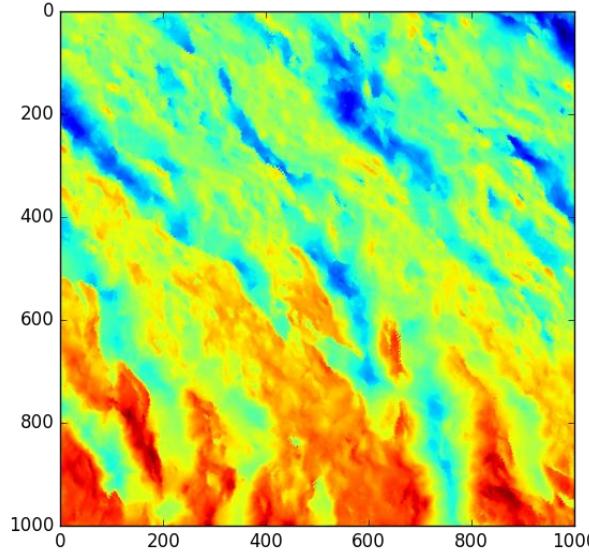
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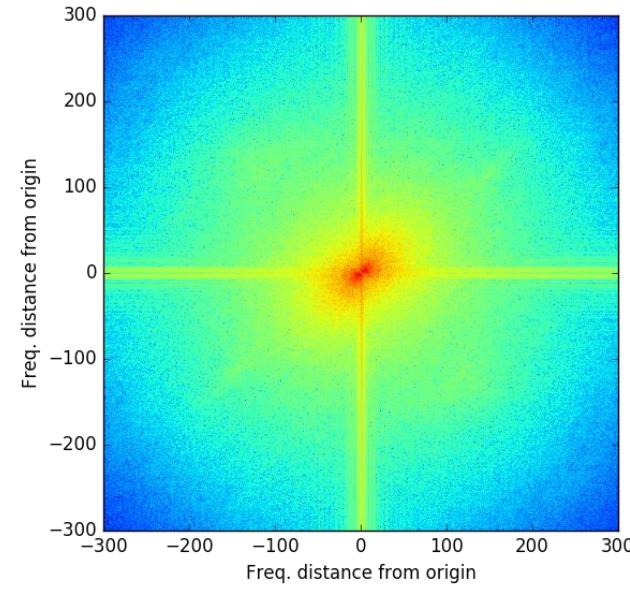
3. Smooth and Gibbs effect removal



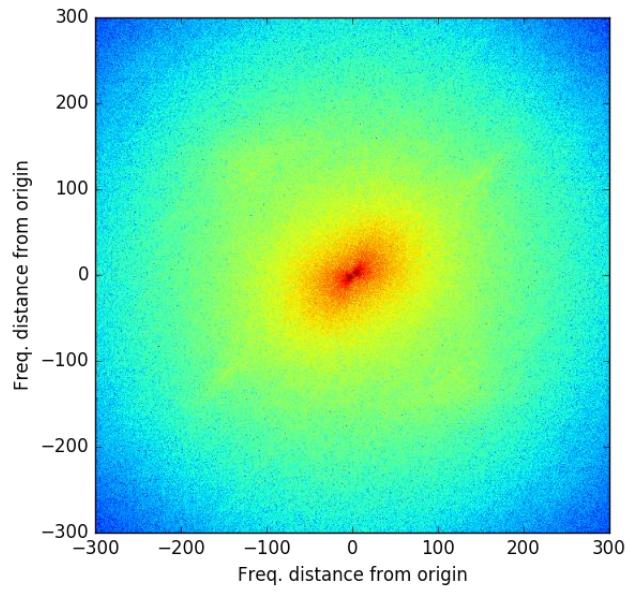
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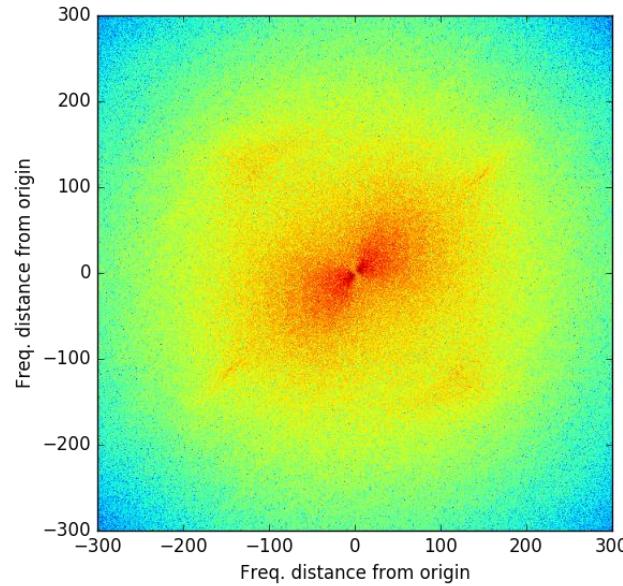
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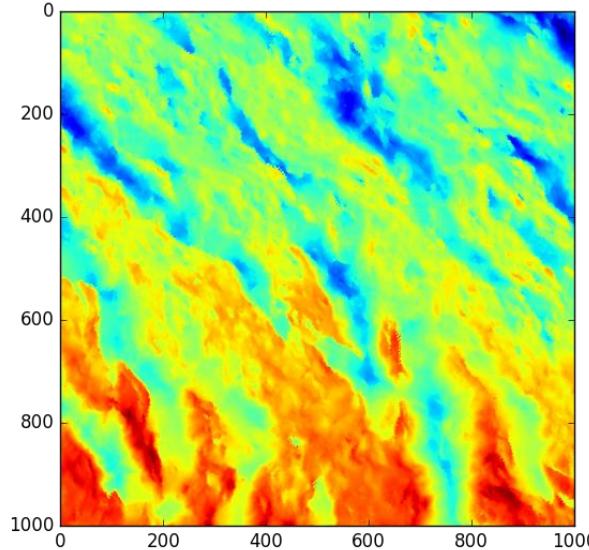
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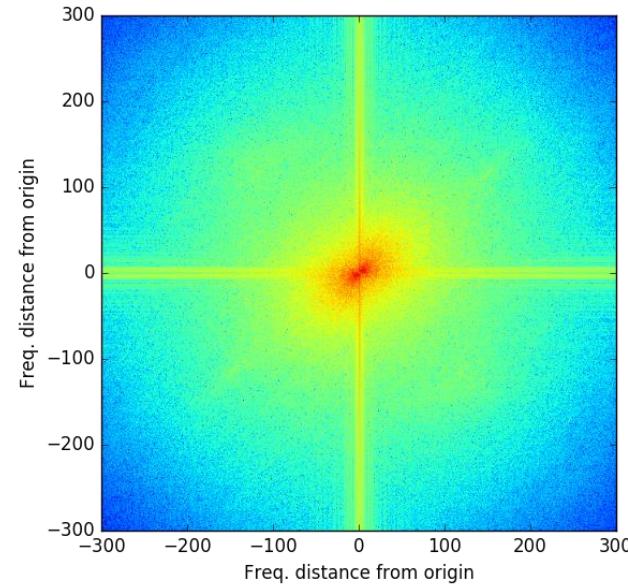
4. Noise removal



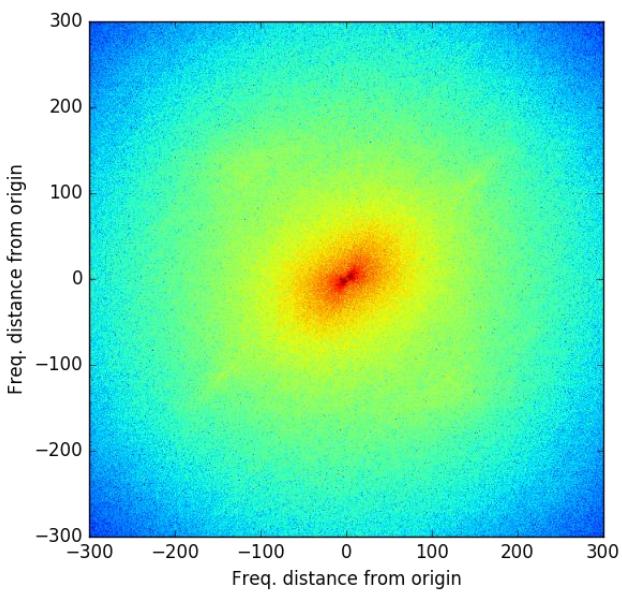
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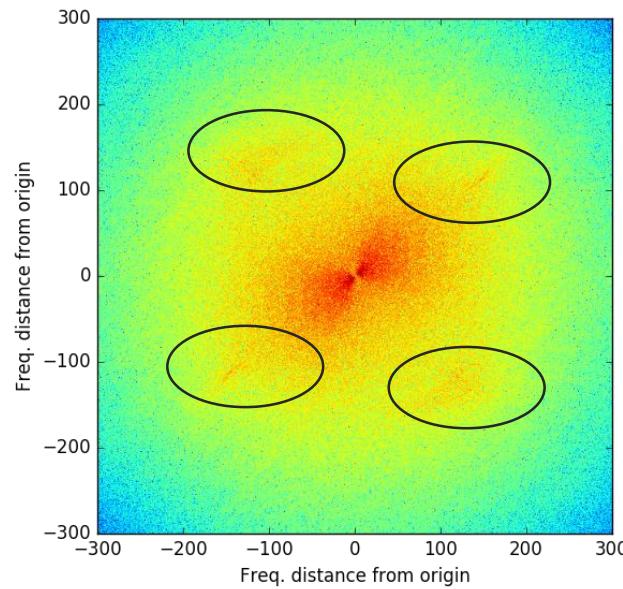
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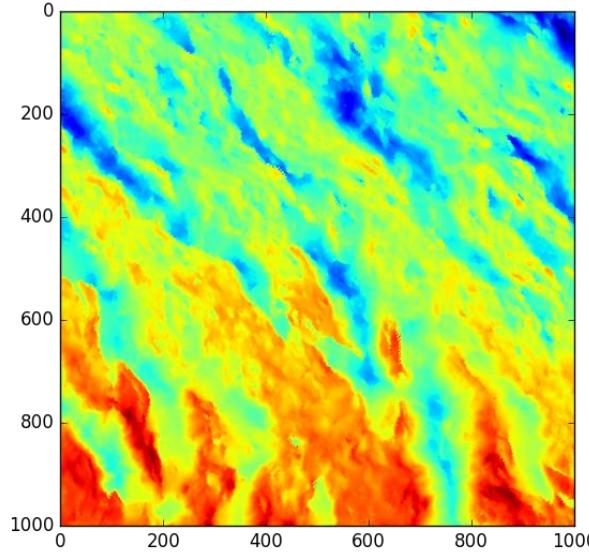
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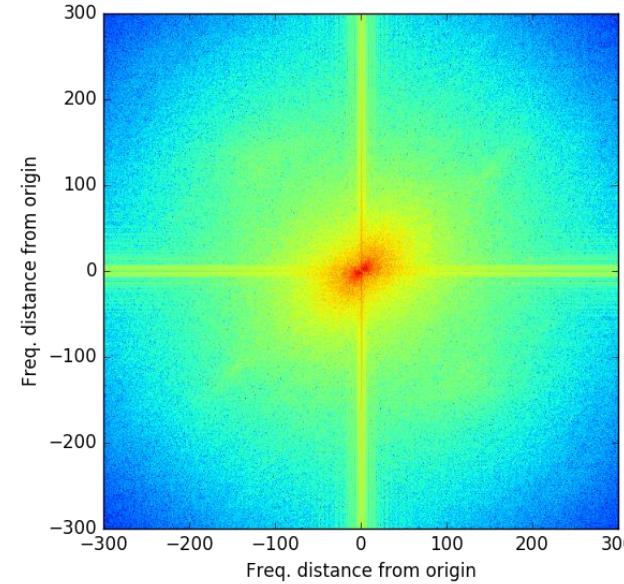
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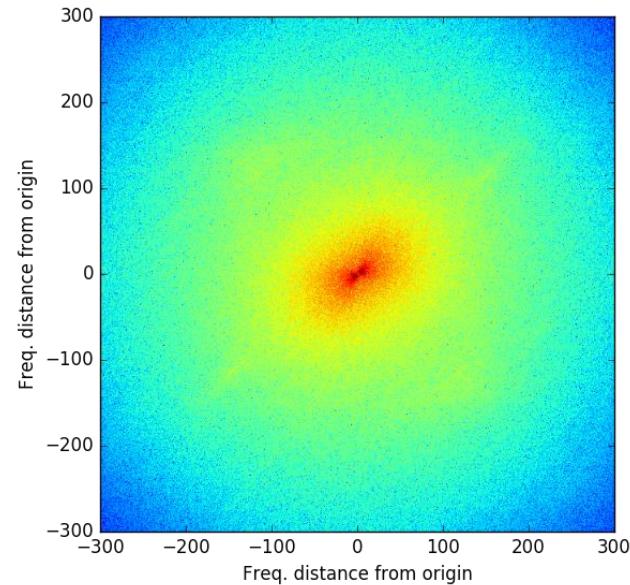
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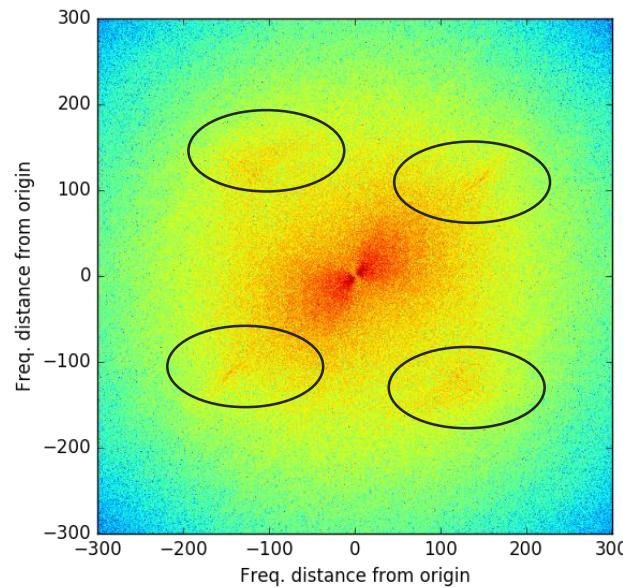
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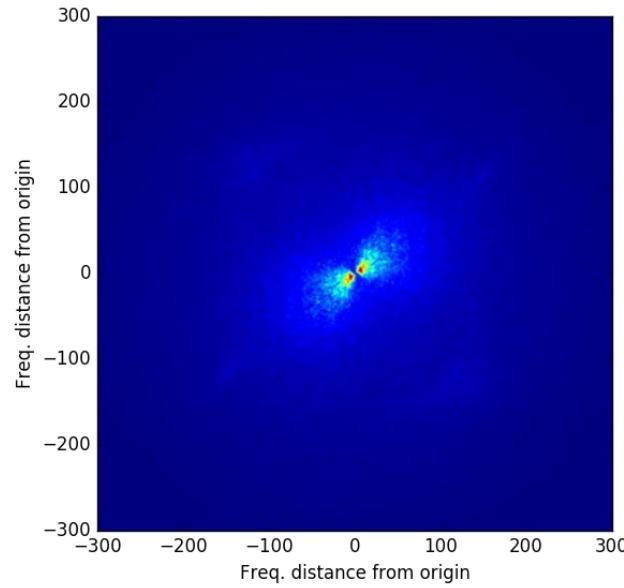
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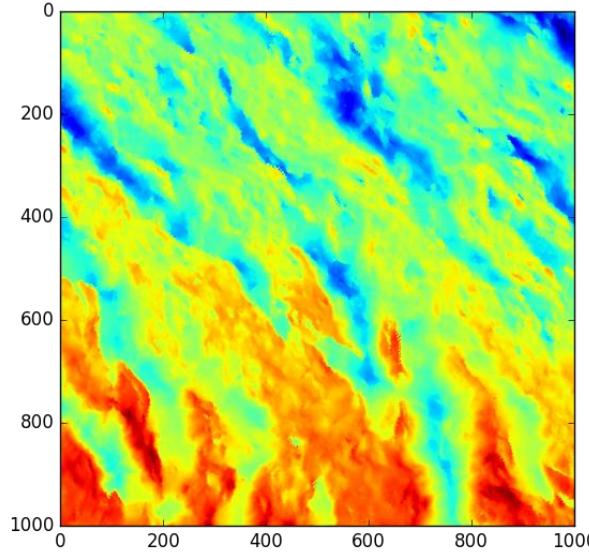
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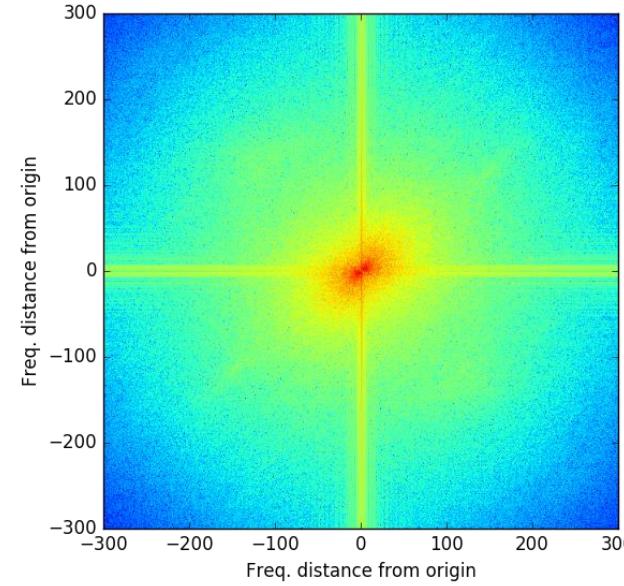
5. Log (visual)



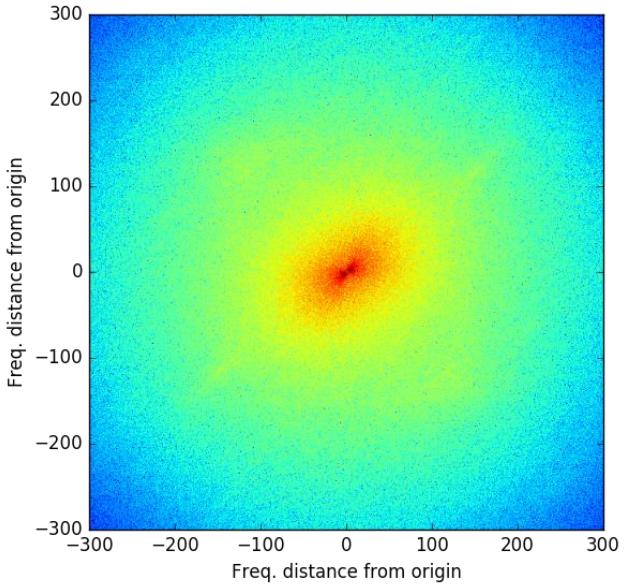
1. Original image



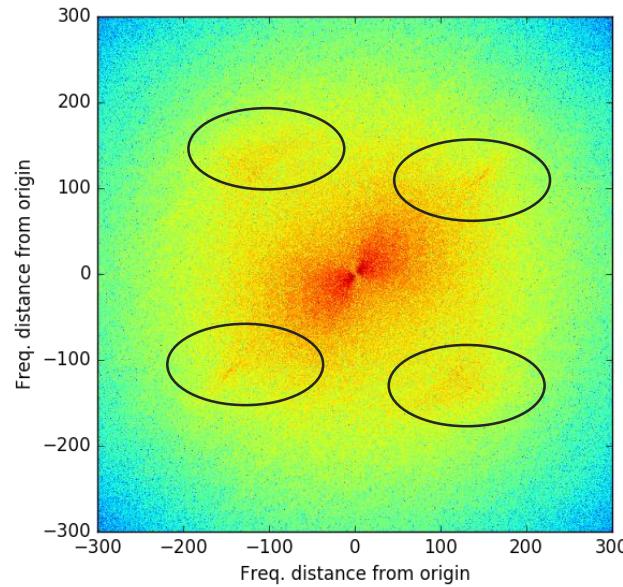
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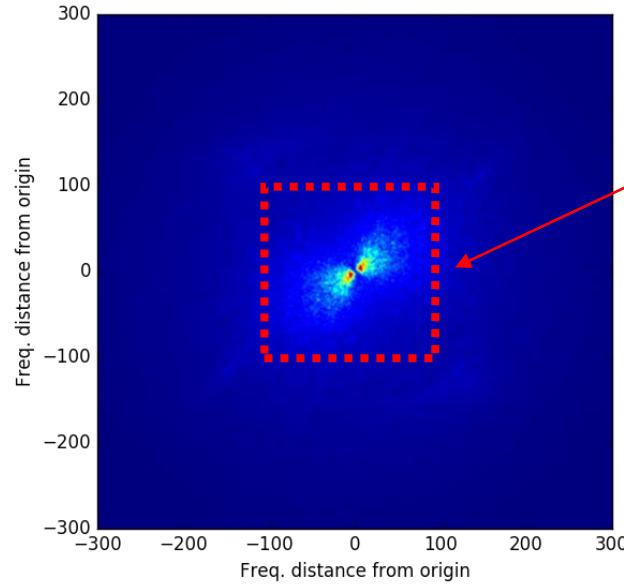
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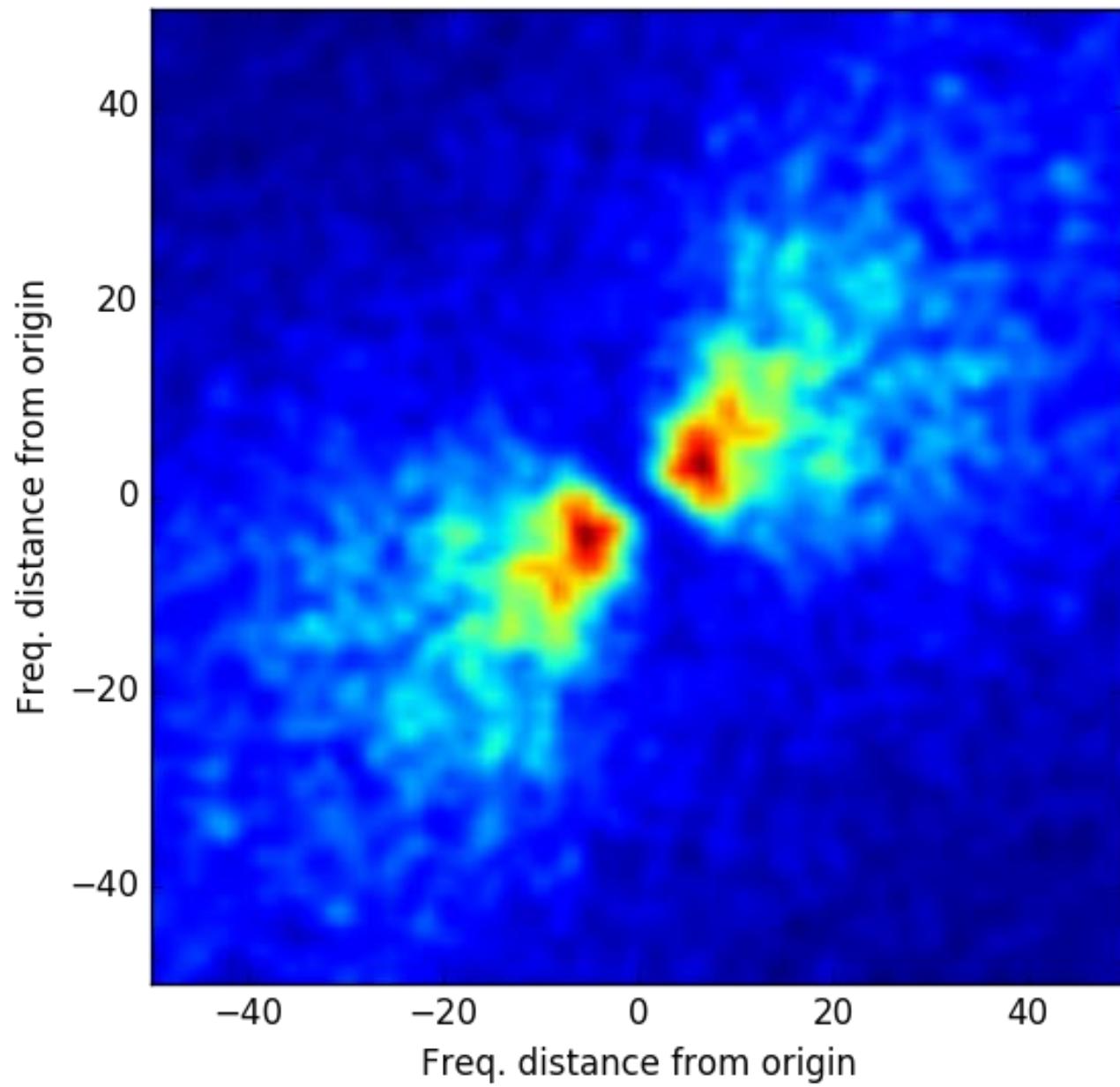
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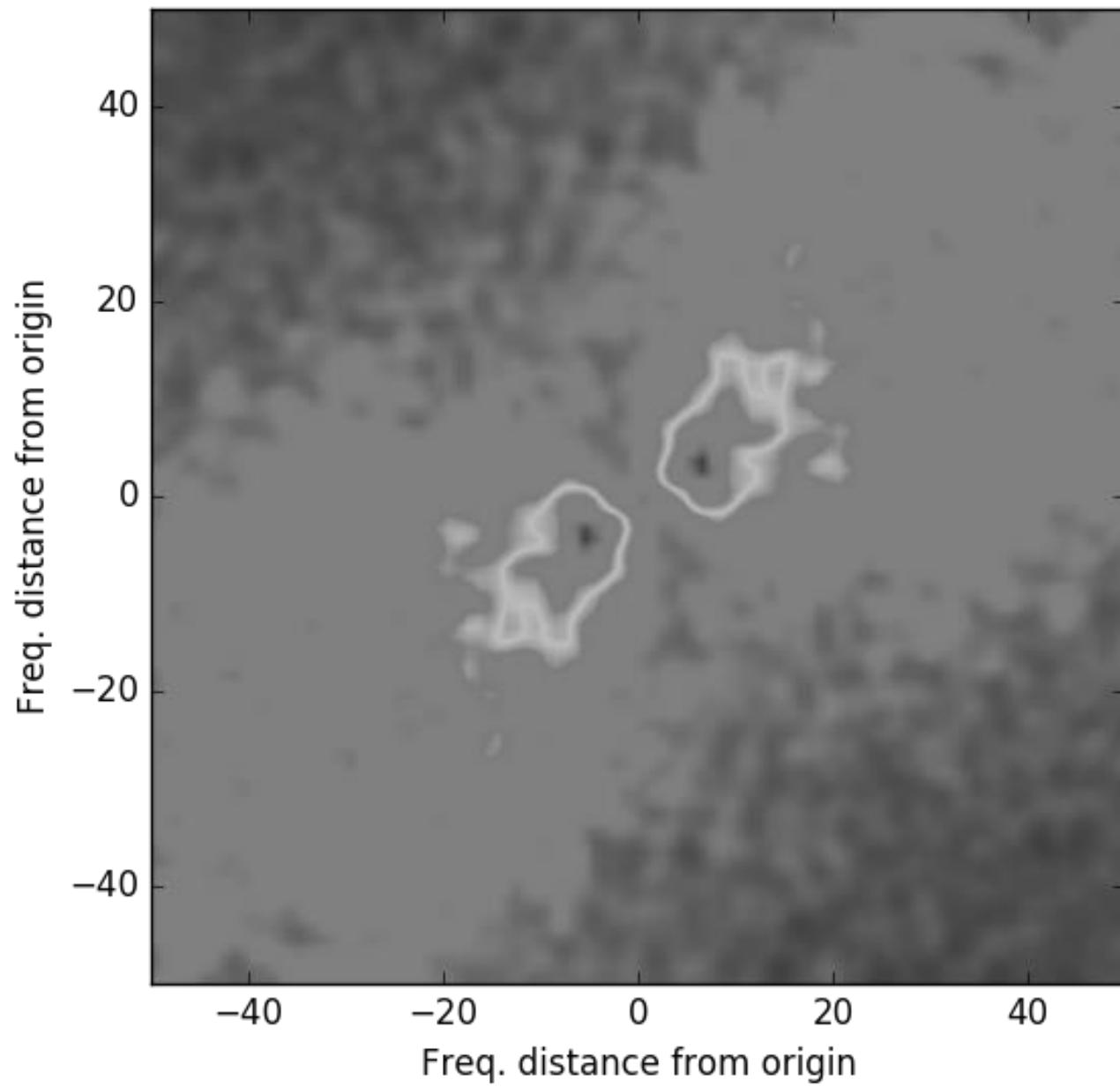


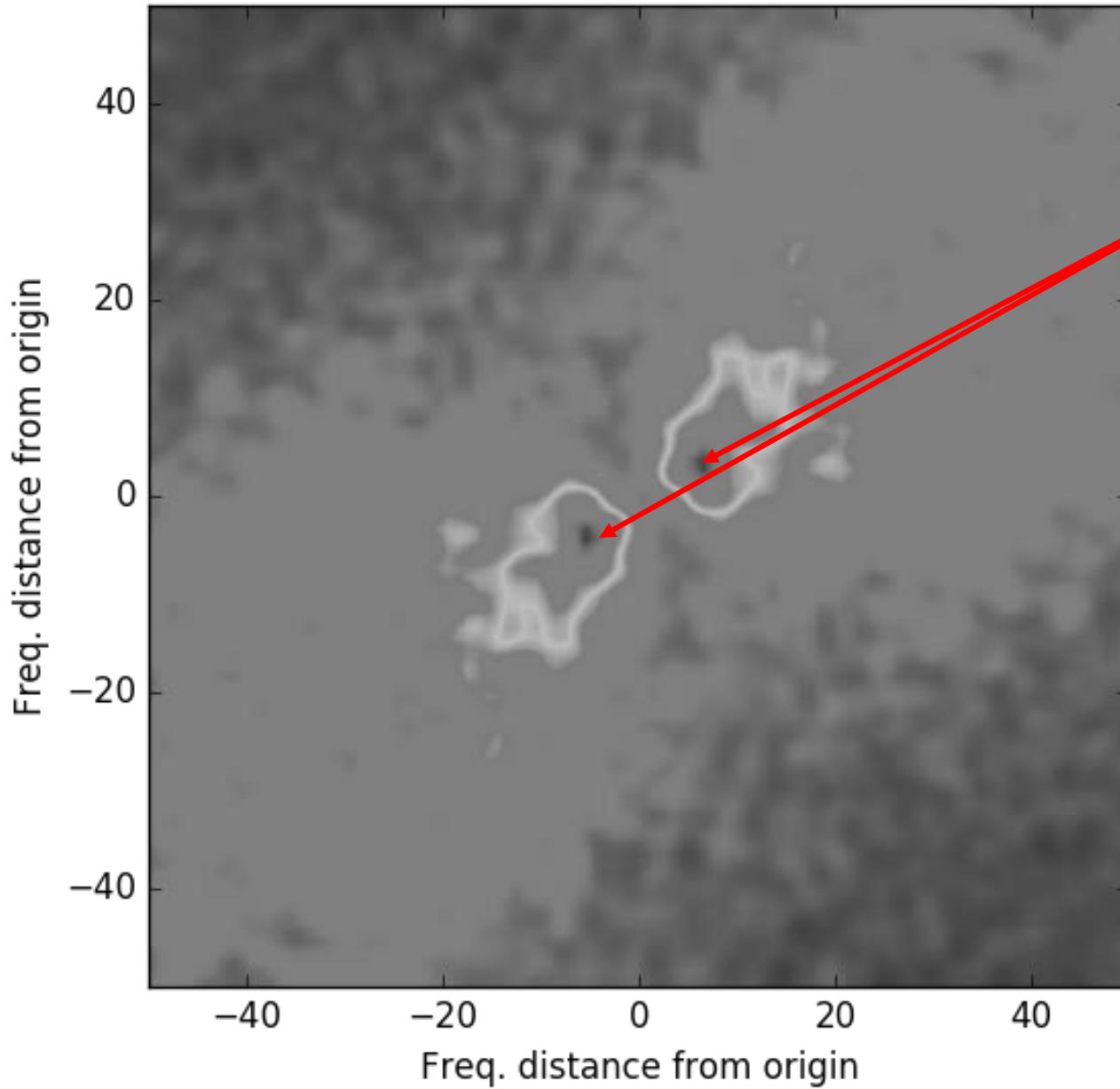
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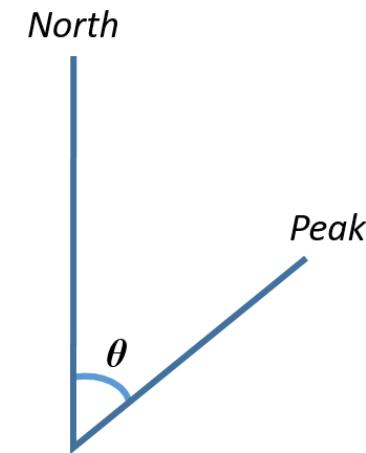
Area of
maximum
values



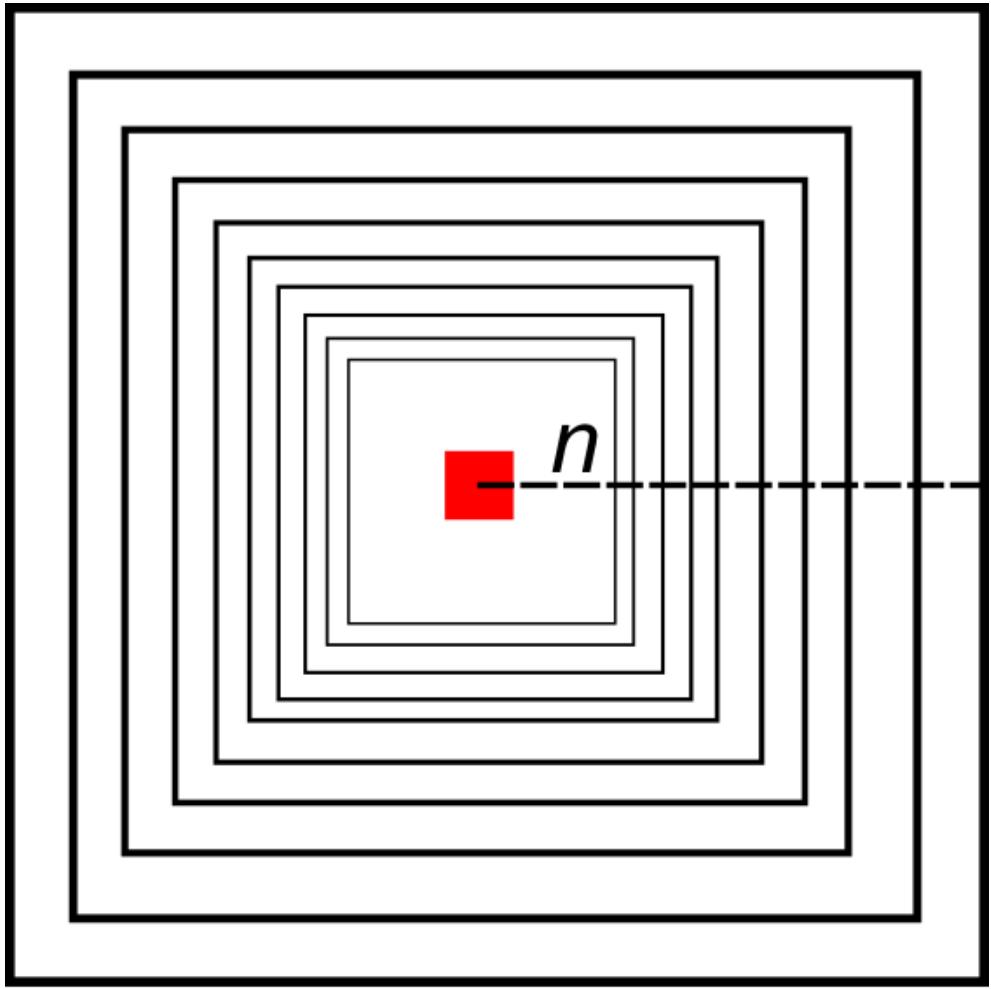




1. Identification of maximum peak
2. Calculate *signal-to-noise ratio*
3. Calculate distance from peak to origin
(convert units from frequency to space)
4. Calculate orientation of peak
– rotational symmetry!

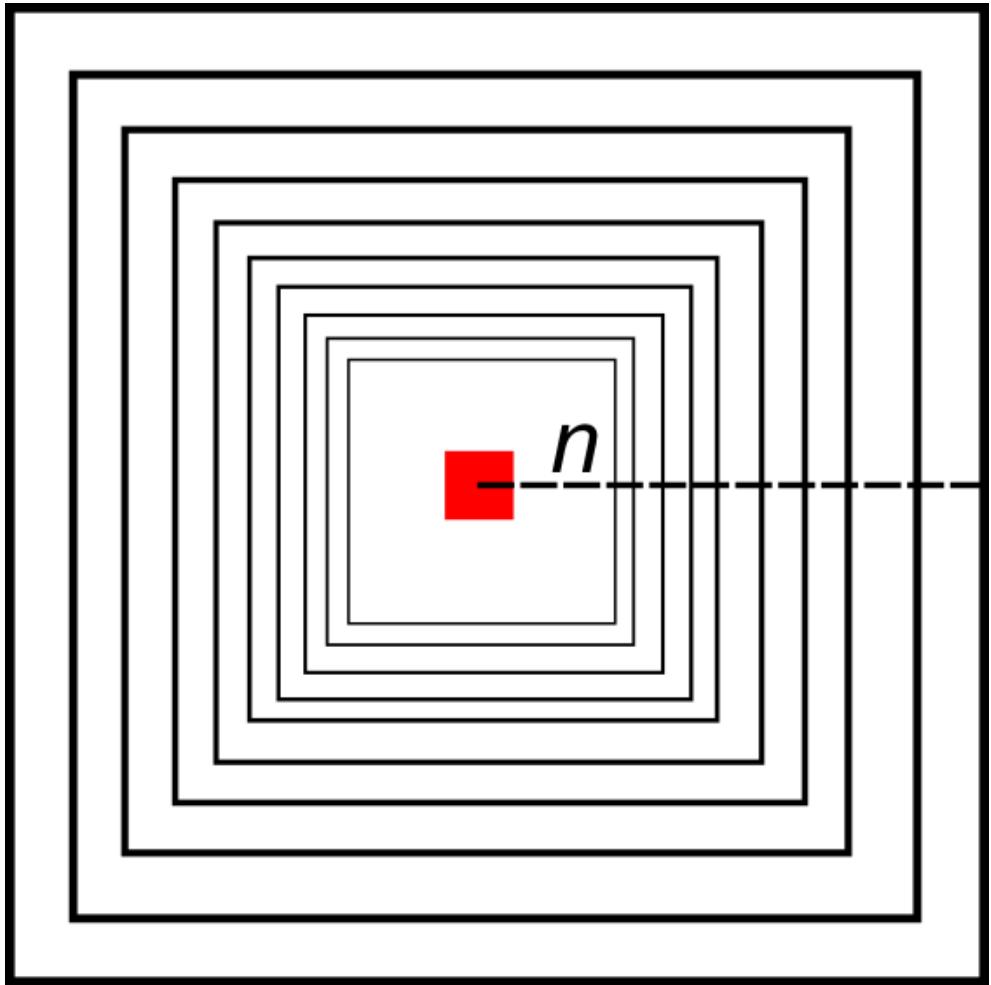


Effect of window size

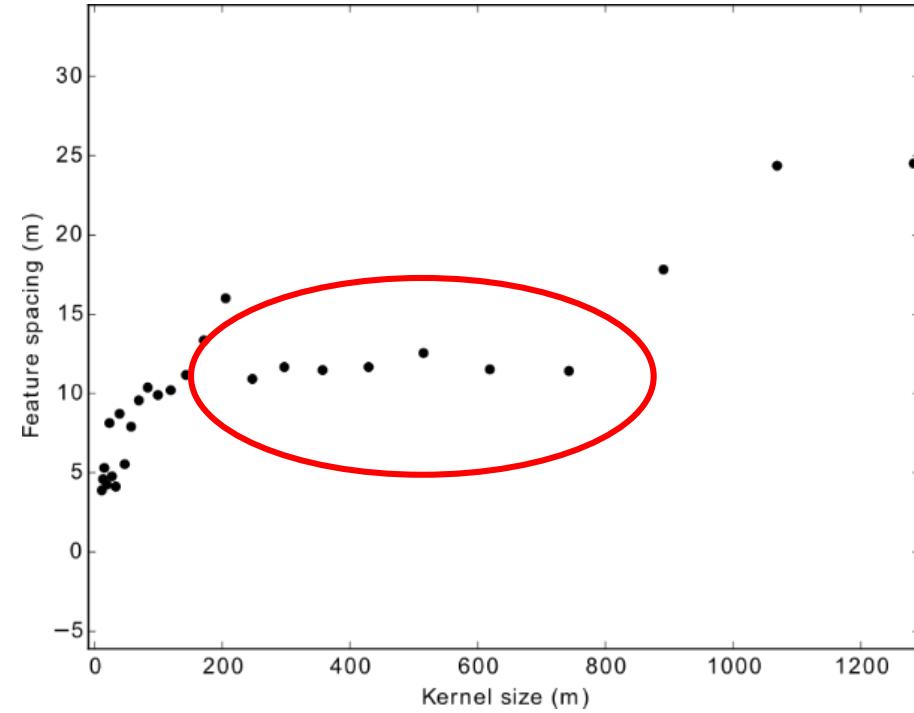


$$n = \text{maximum observable crevasse spacing} = \frac{\text{kernel length}}{2}$$

Effect of window size



$$n = \text{maximum observable crevasse spacing} = \frac{\text{kernel length}}{2}$$



The code

- All written in Python
- Available on Github
- Subject to further development (and contributions)

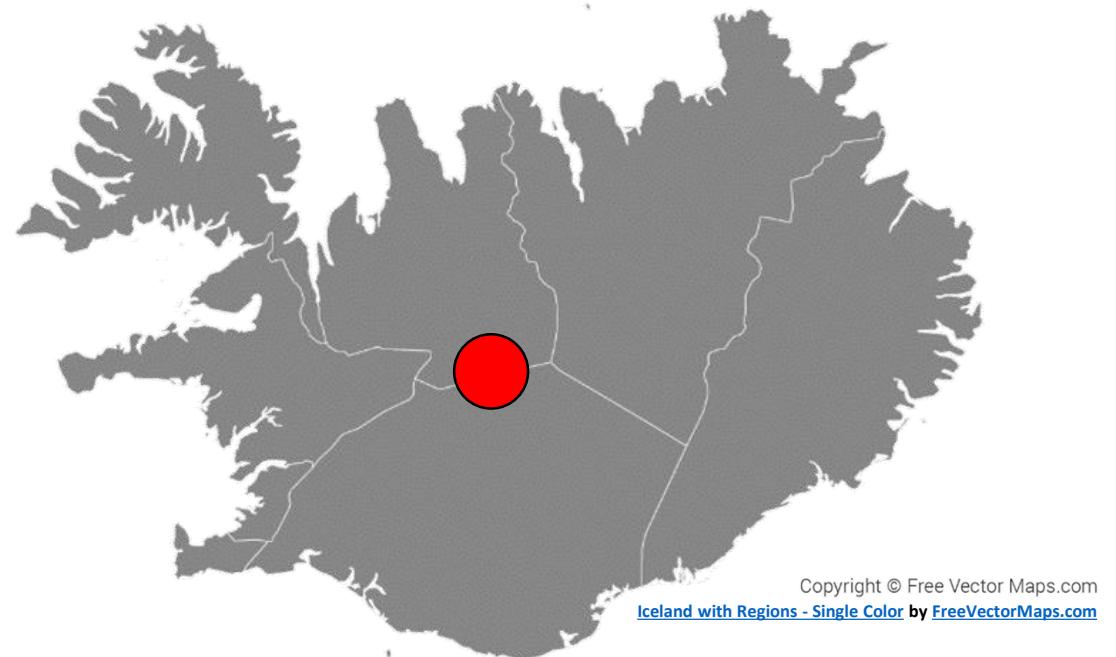
<https://github.com/Chris35Wills/LFMapper>

<https://zenodo.org/record/1186663#.WrOHMJfLfcs>

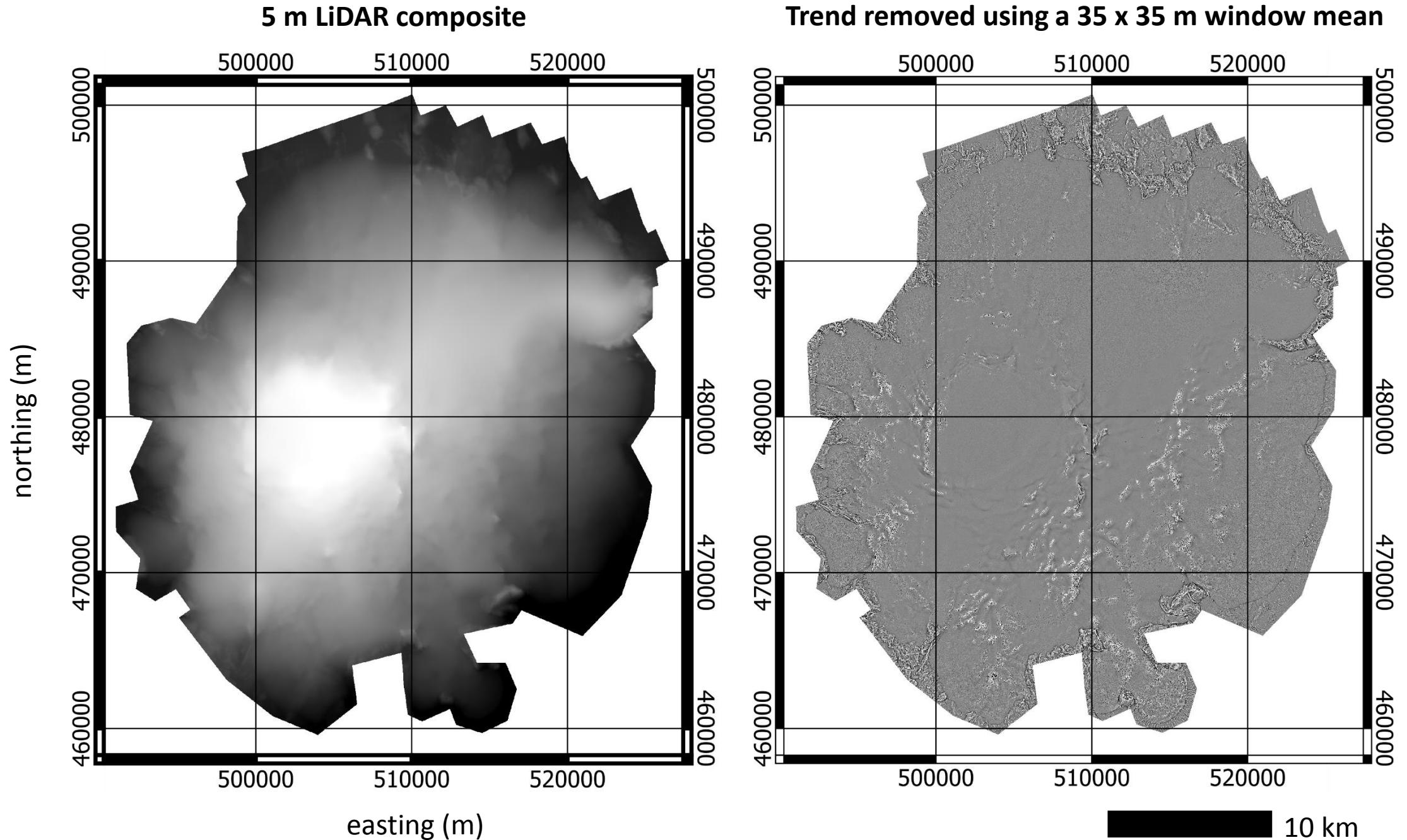


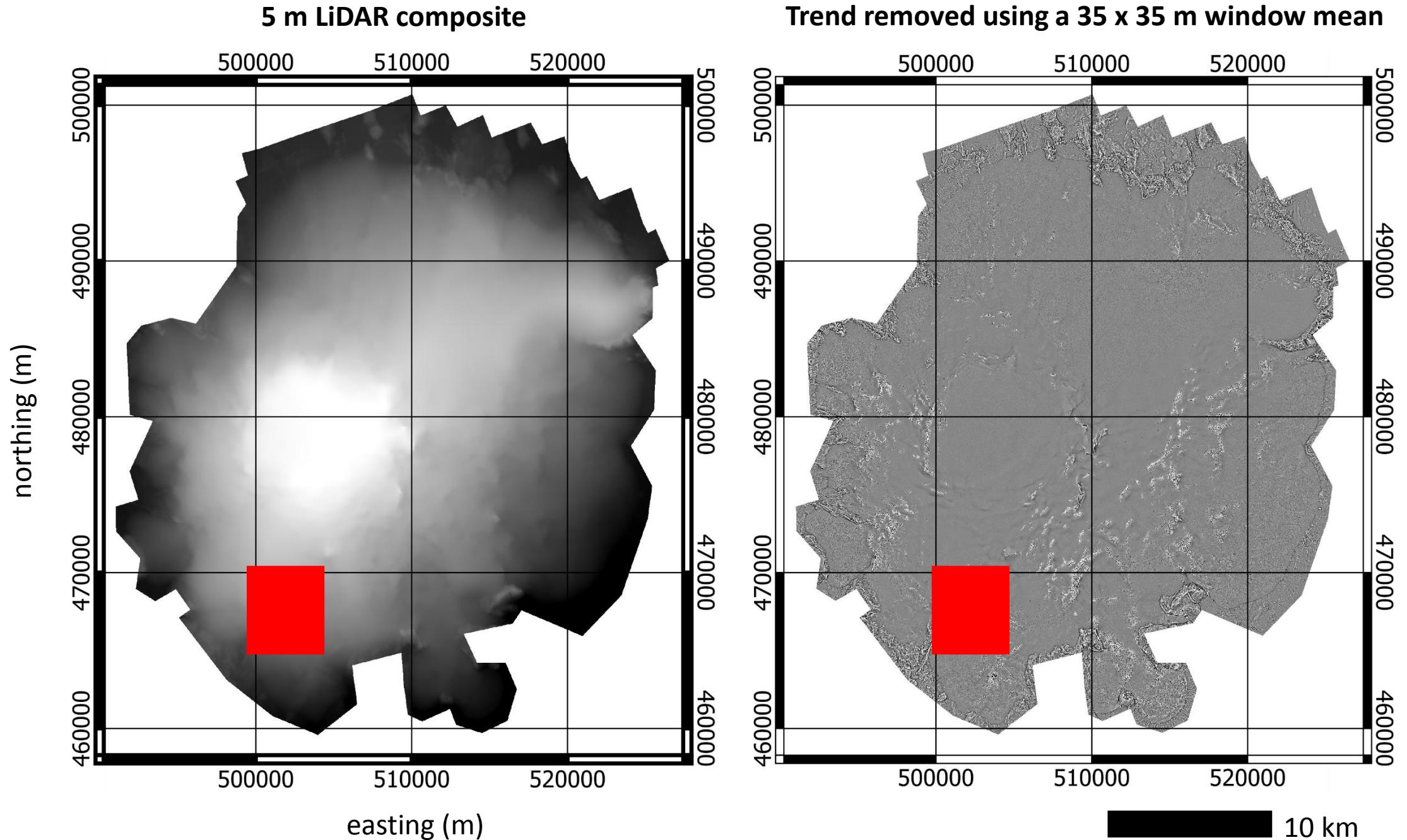
Application to Hofsjökull, Iceland

- Third largest glacier in Iceland ($\sim 900 \text{ km}^2$)
- Located in the central highlands
- Large mass balance observation network (Icelandic Meteorological service)
- Mostly negative mass balance observed since 1995, positive in 2015
- Atop an active subglacial caldera volcano
- Airborne LiDAR data available at 2 m resolution
 - 2008/2010, 2013

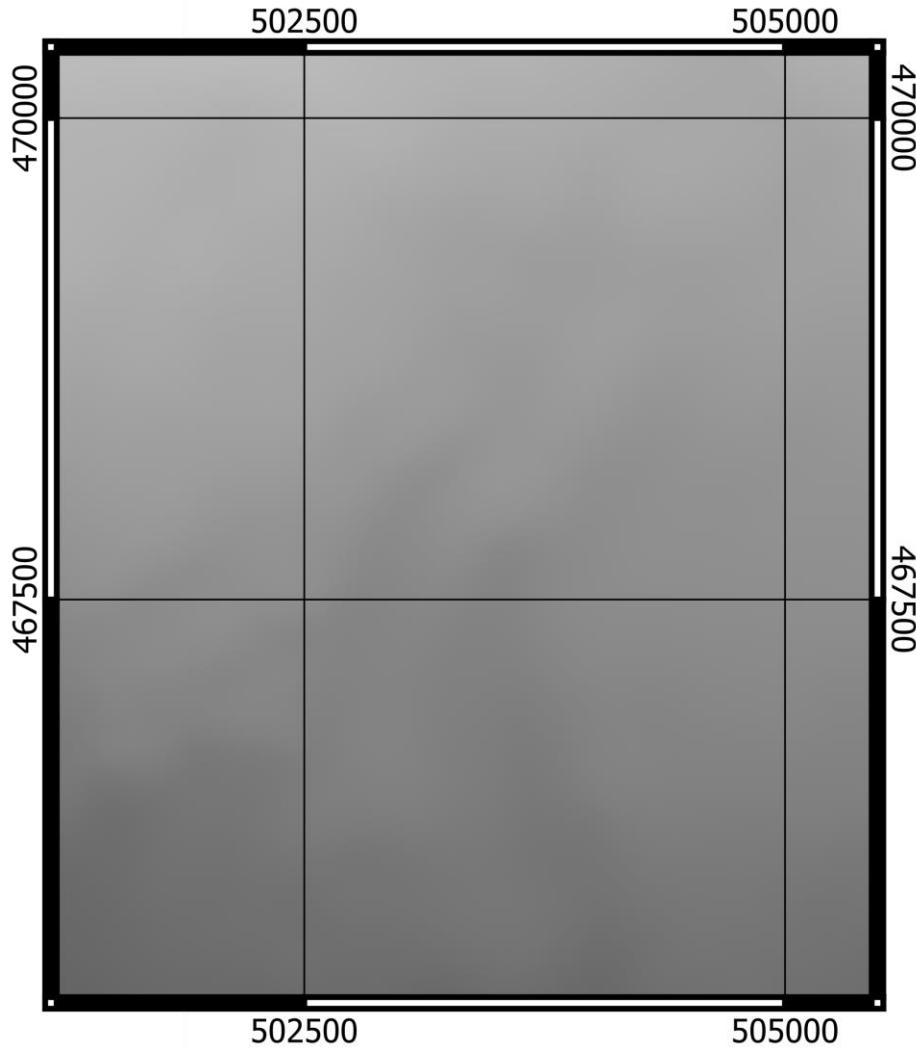


Hofsjökull crevasse map (2011) from <http://safetravel.is> available here:
<https://safetravel.is/wp-content/uploads/2011/01/Hofsj%C3%B6kull-ens-2017.pdf>

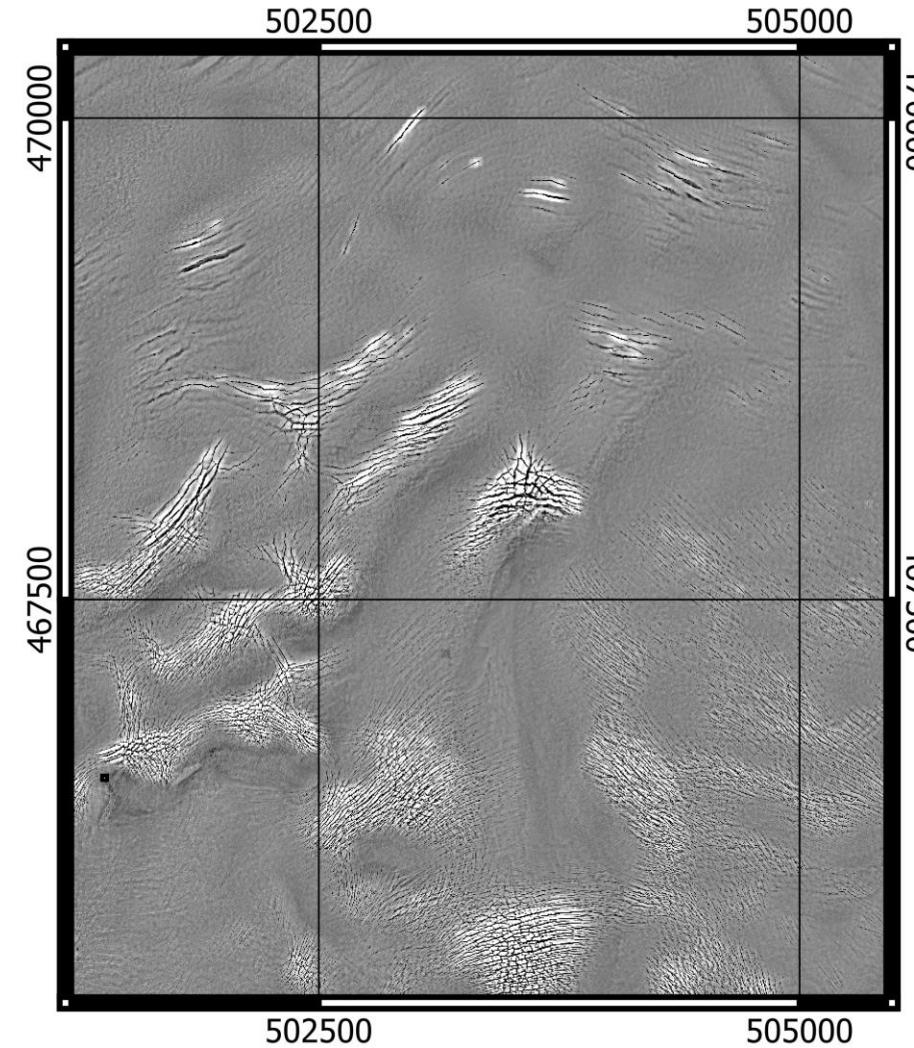




5 m LiDAR composite

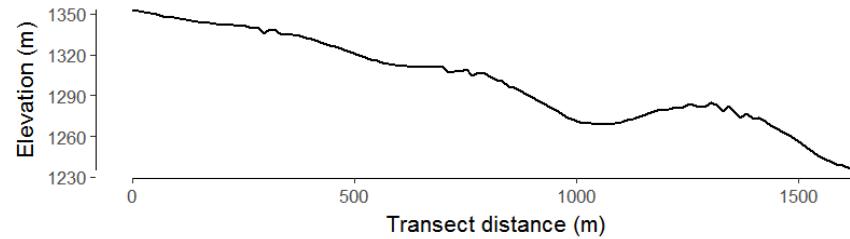
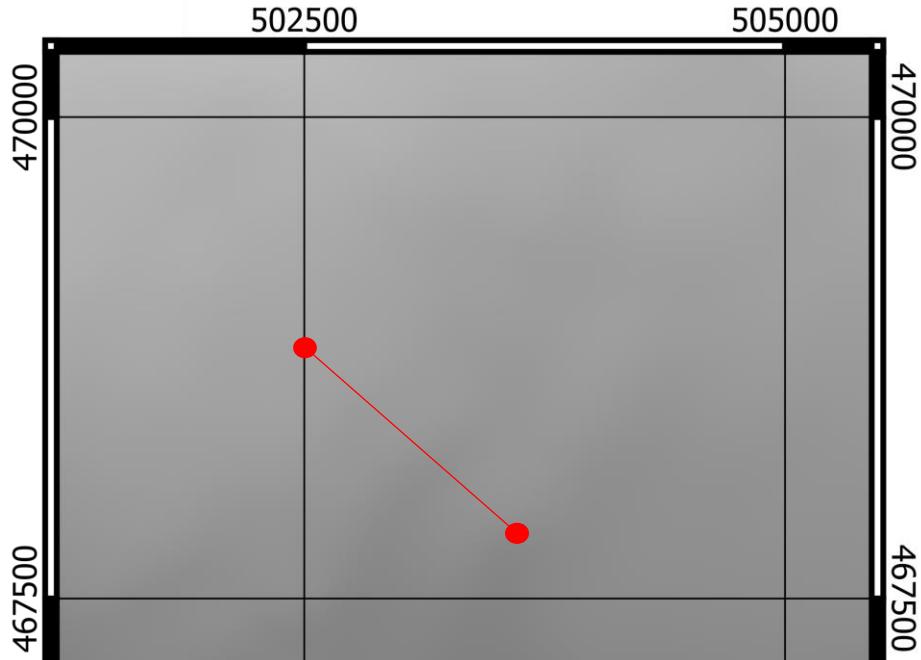


Trend removed using a 35 x 35 m window mean

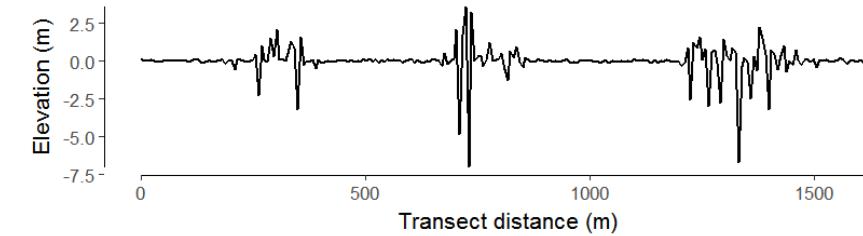
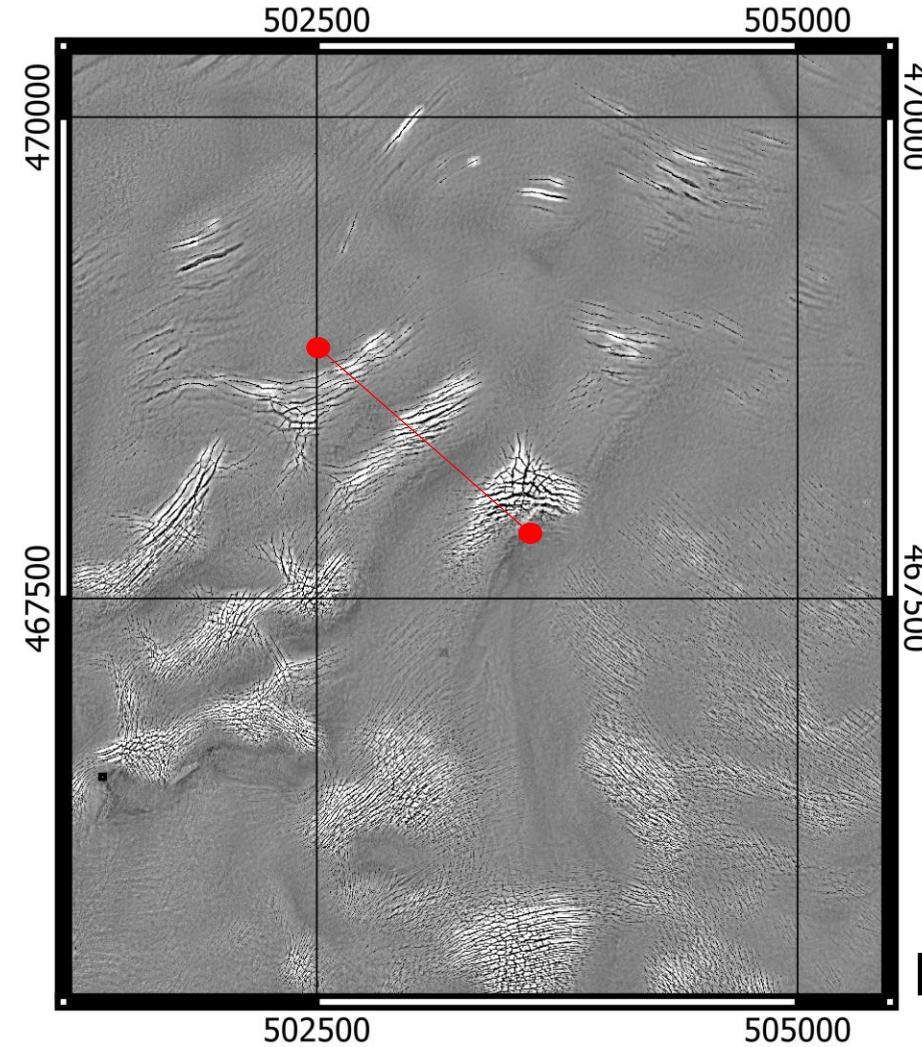


10 km

5 m LiDAR composite

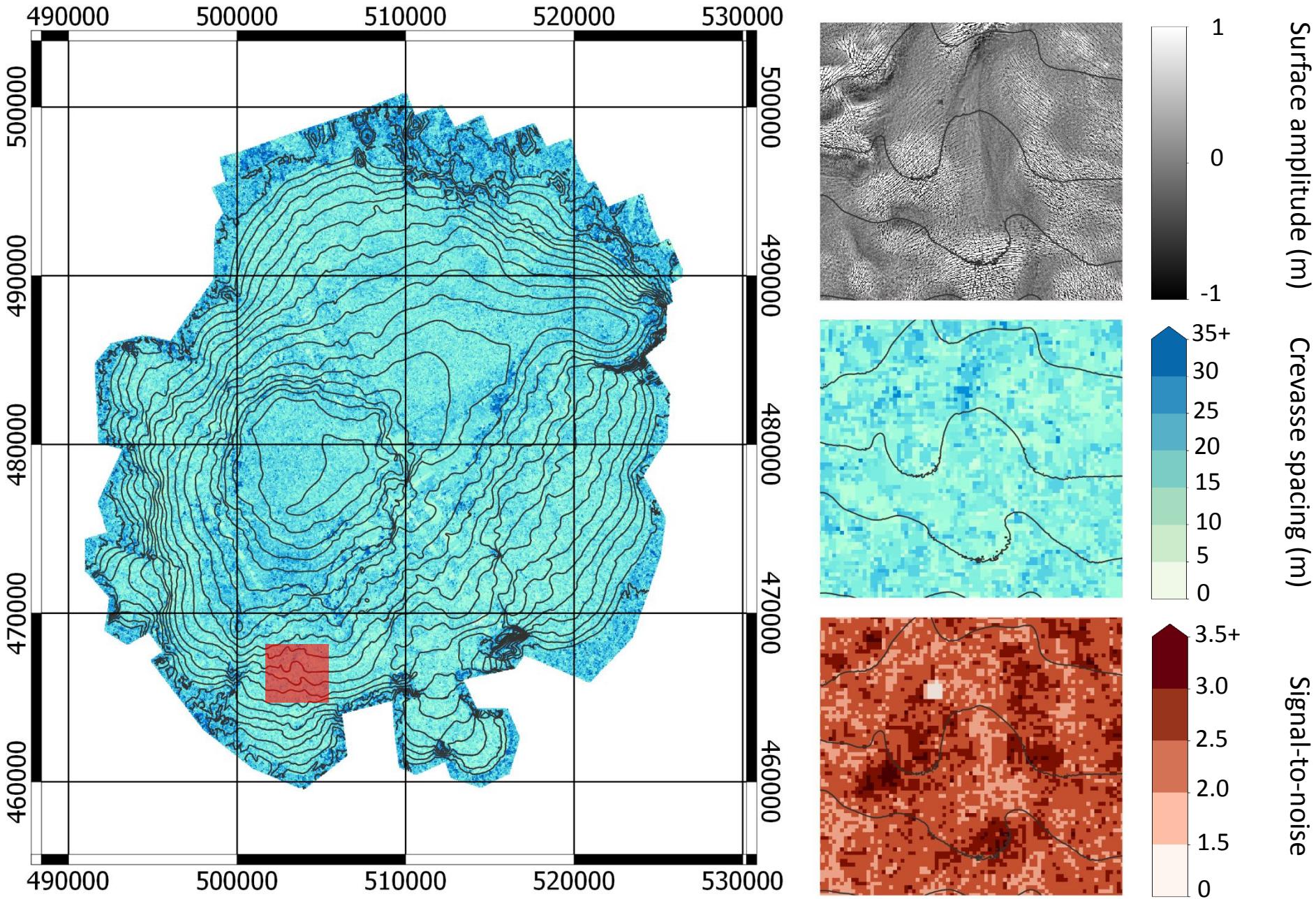


Trend removed using a 35 x 35 m window mean

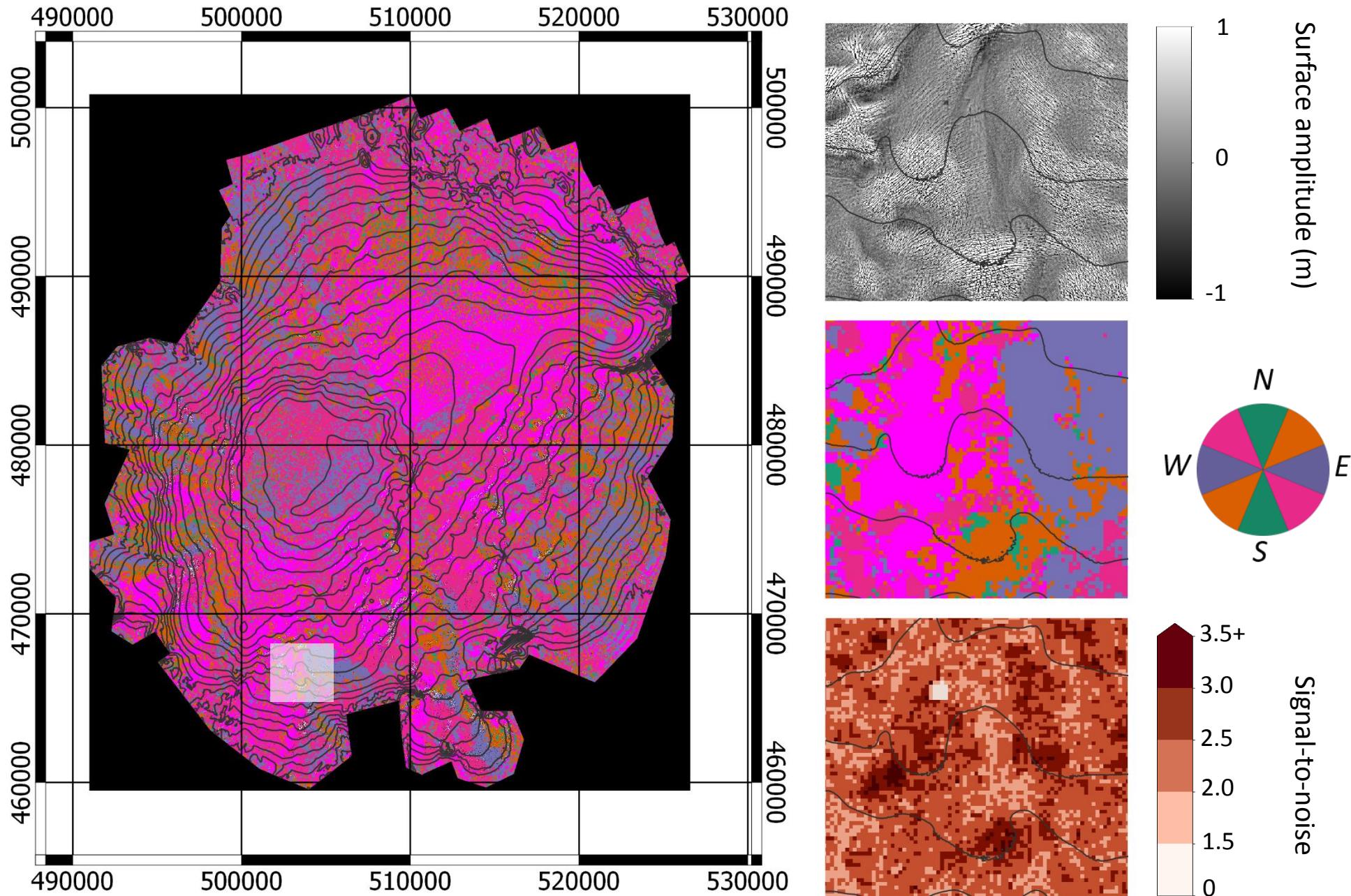


10 km

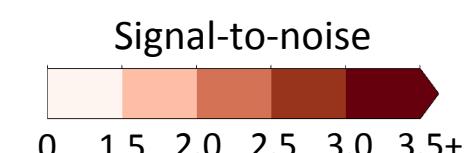
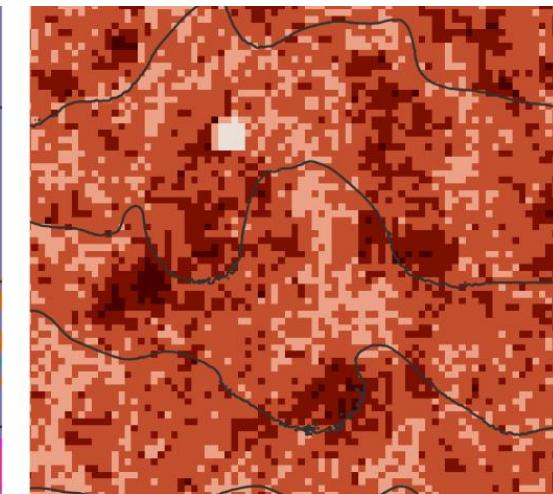
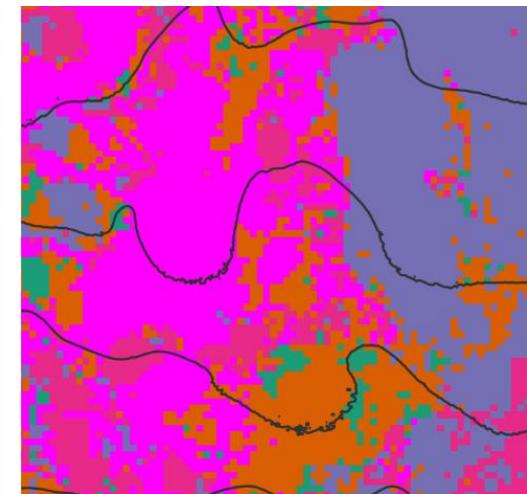
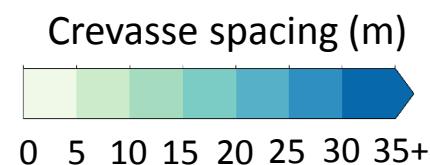
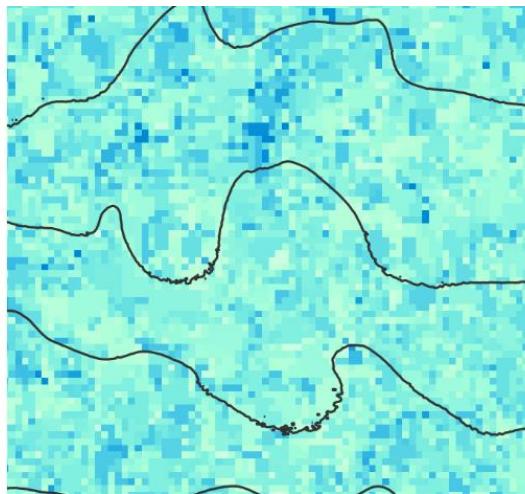
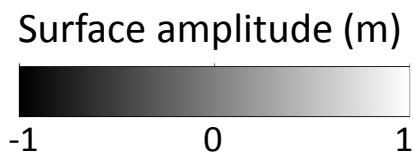
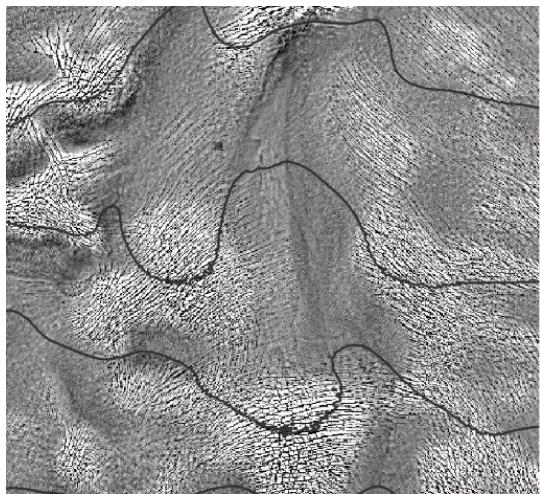
Spacing – window: 155 m | step: 35 m



Orientation – window: 155 m | step: 35 m

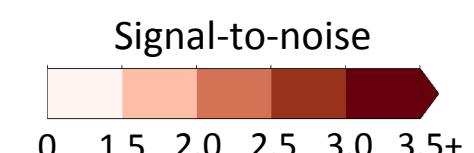
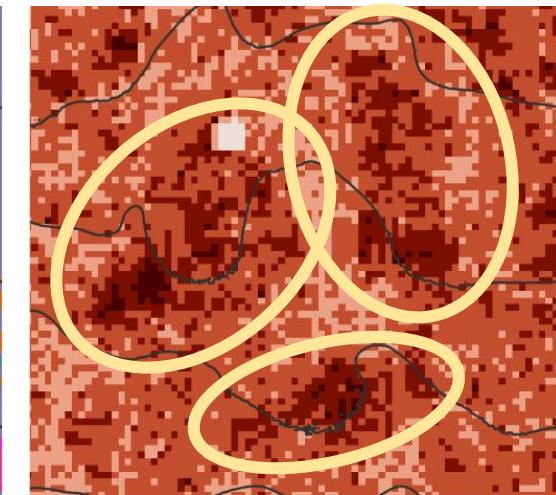
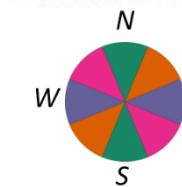
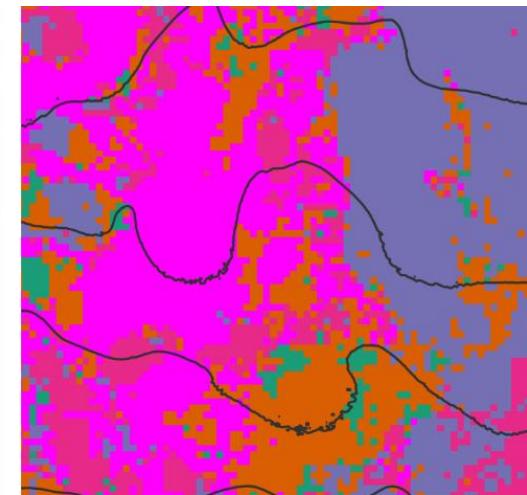
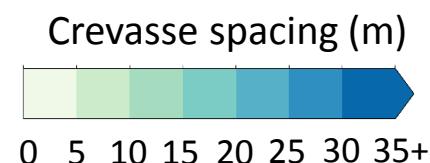
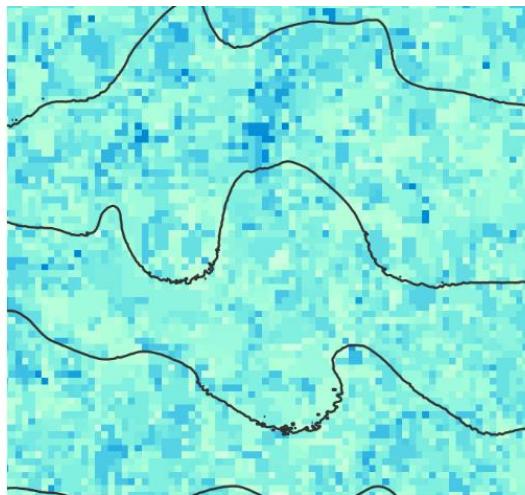
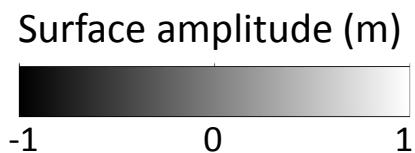
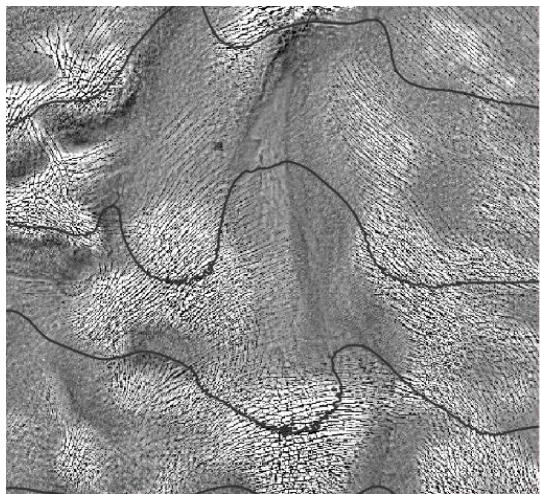


Spacing, orientation and SNR – window: 155 m | step: 35 m



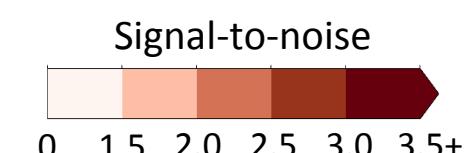
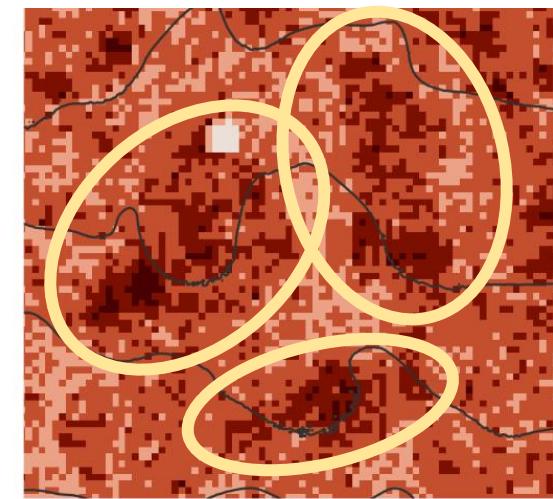
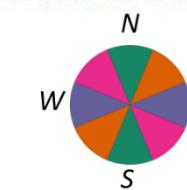
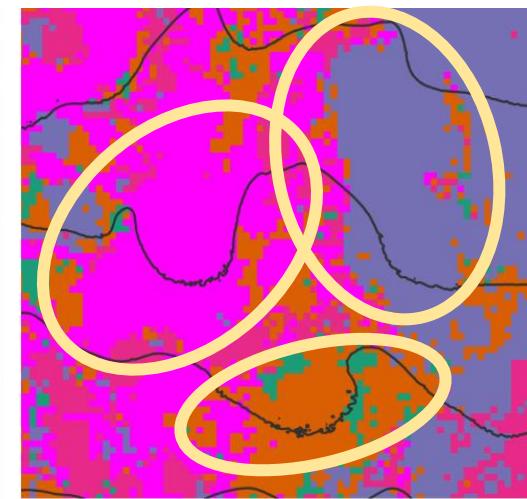
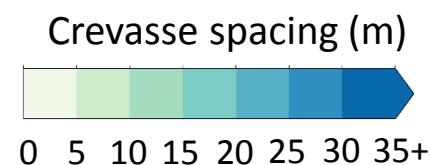
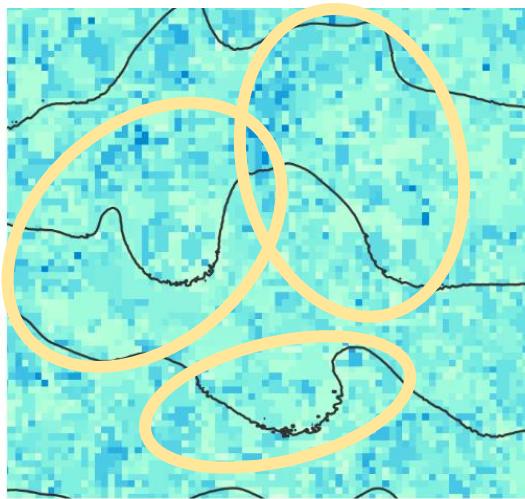
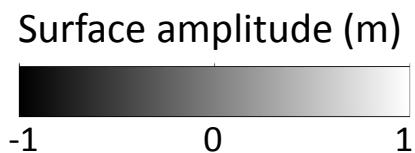
2 km

Spacing, orientation and SNR – window: 155 m | step: 35 m



2 km

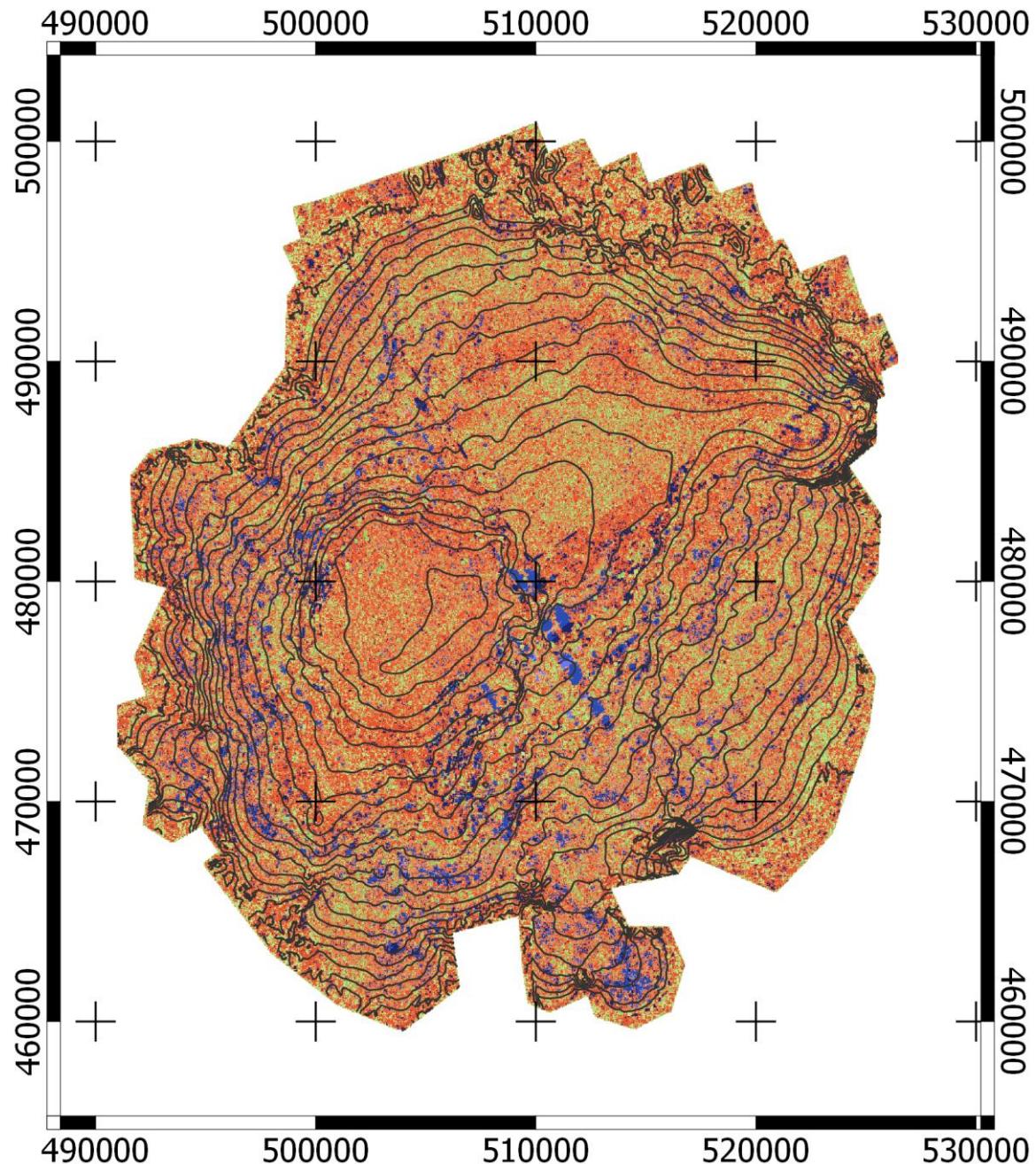
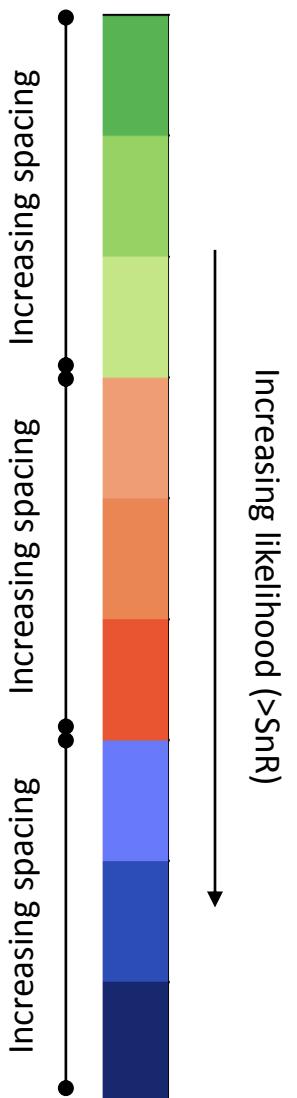
Spacing, orientation and SNR – window: 155 m | step: 35 m



2 km

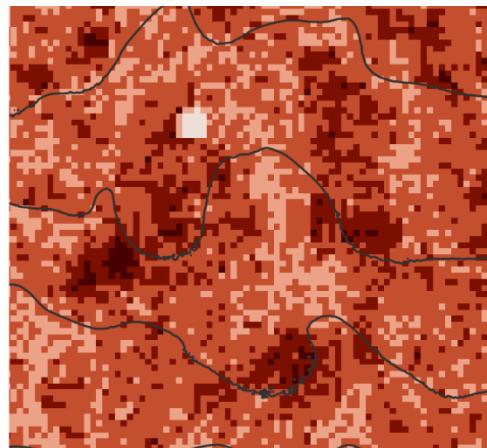
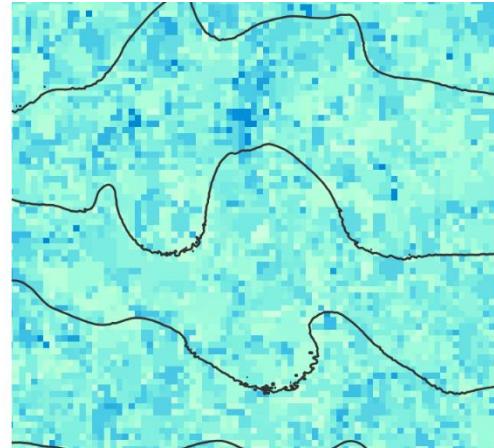
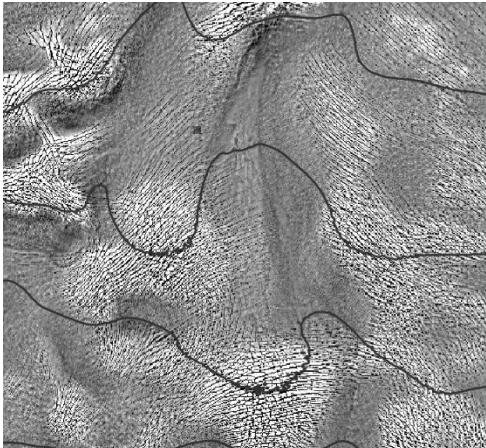
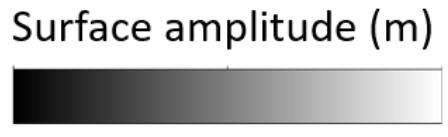
Hazard mapping potential

- Spacing and signal-to-noise key
- Outputs are a guide – not a final decision
- Opportunity for further categorisation and investigation
 - Small spacing & low likelihood
 - Medium spacing and medium likelihood
 -etc.

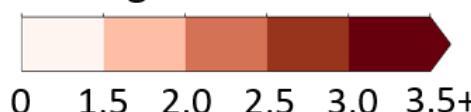


Hazard mapping potential

- *Spacing and signal-to-noise key*
- *Outputs are a guide – not a final decision*
- *Opportunity for further categorisation and investigation*
 - *Small spacing & low likelihood*
 - *Medium spacing and medium likelihood*
 -etc.



Signal-to-noise



Increasing likelihood (>SnR)



Benefits

Scalable – 25cm – 100's m

Quality of output determined by quality of input

Area ID for further investigated

Limitations

Nature of glacial environment – needs snow free images

Where an image is of both a glacier and non-glaciated terrain, the latter must be clipped

Warnings

Output must be verified by an expert

Provides only an initial assessment of potential crevasse hazards

Potential applications

Crevasse mapping

- search and rescue
- providing information to users (skiers, mountaineers...)
 - maps of a given summer may be useful for the following winter...*

Other applications

- sand dune migration
- rock core fracture pattern analysis
- geological lineament detection

*An automated approach to characterising linear features within imagery.
Developed using glacier surface data, providing information on crevasse orientation and spacing.
Outputs provide a first pass crevasse map useful for emergency planners in glacial environments.*

Slides

<http://chris35wills.github.io/publications/>

Code

<https://zenodo.org/record/1186663#.WrOHMJfLfcs>
<https://github.com/Chris35Wills/LFMapper/tree/v1.1>

Please quote
the DOI if
you use the
code!



chrwil@bgs.ac.uk



Climate Change Consortium of Wales
Consortiwm Newid Hinsawdd Cymru



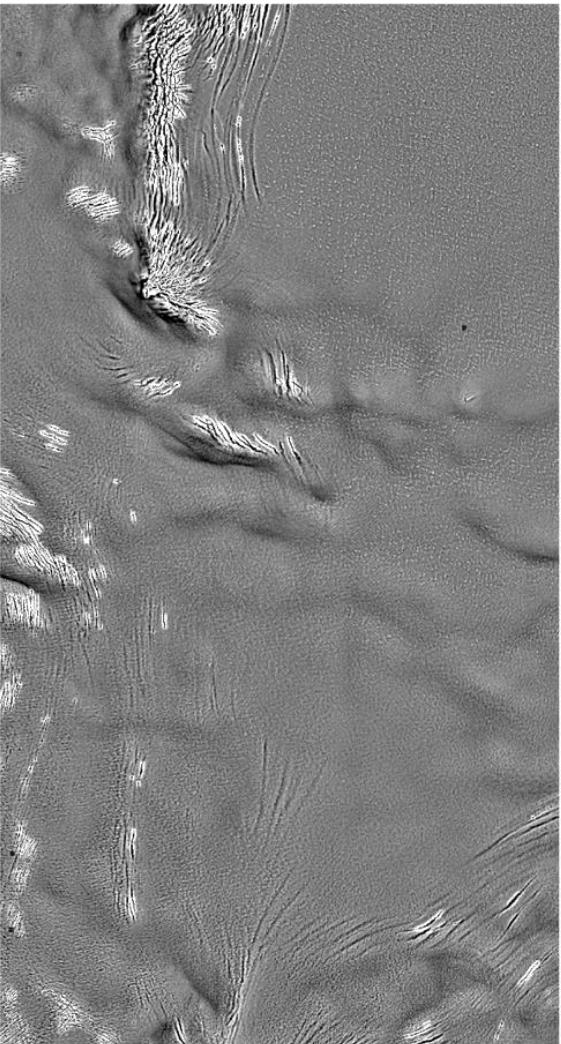
**British
Geological Survey**
NATURAL ENVIRONMENT RESEARCH COUNCIL

References and further reading

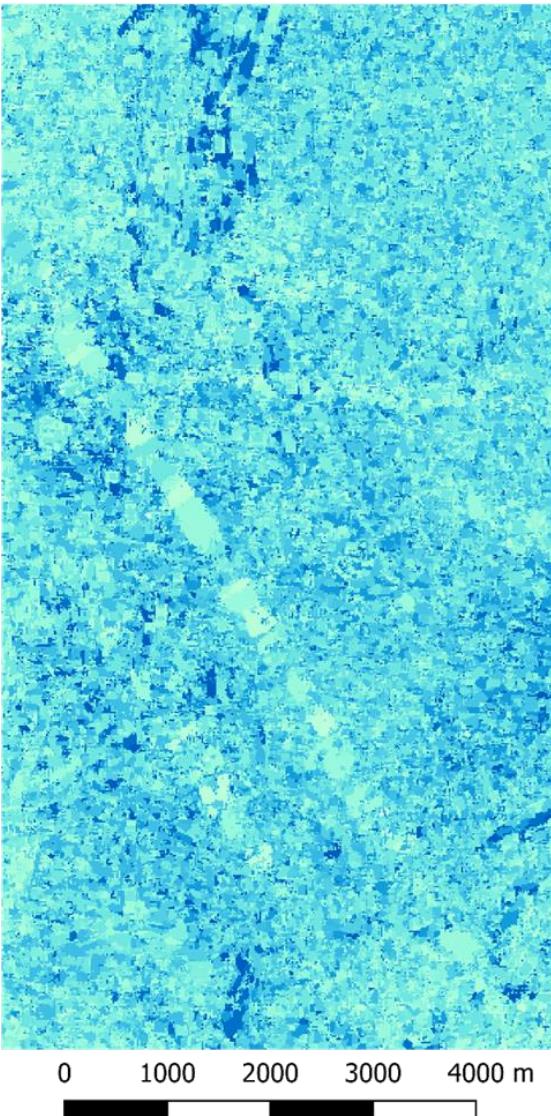
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Sensitivity – step size increases coarseness of output

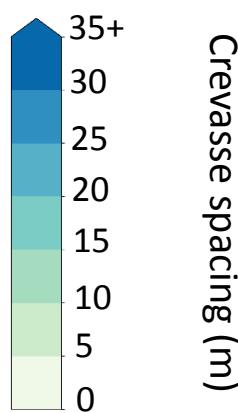
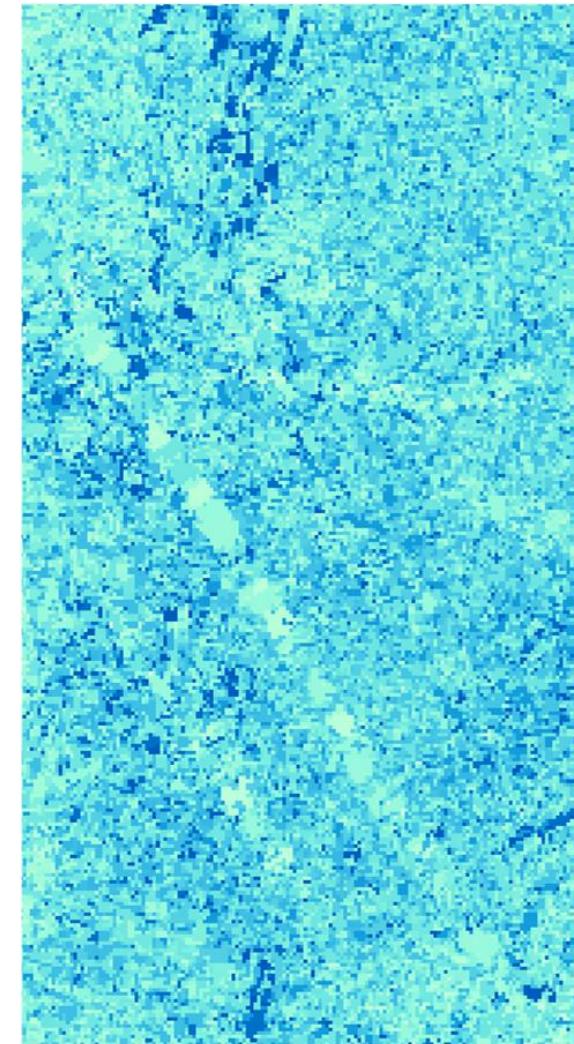
Glacier surface (flattened)
Pixel: 5 m



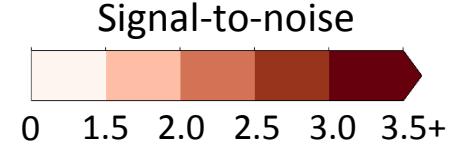
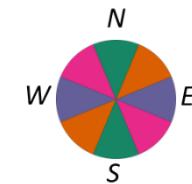
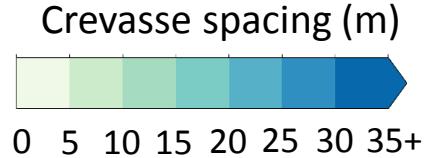
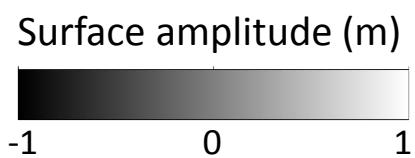
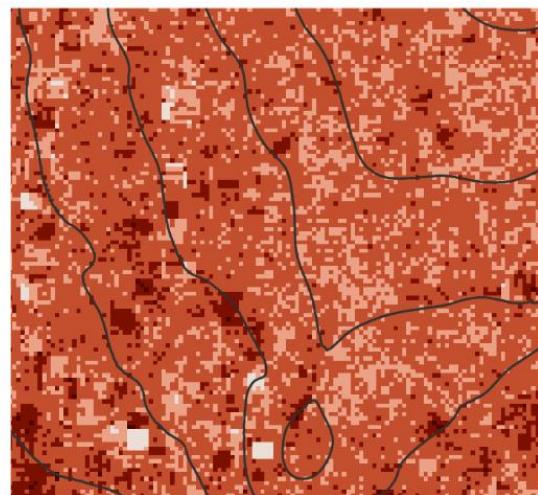
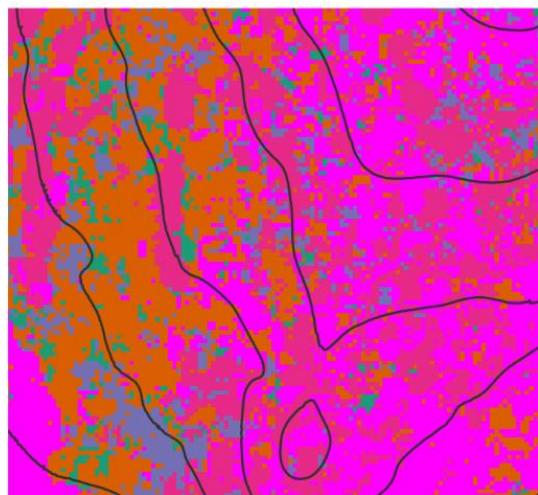
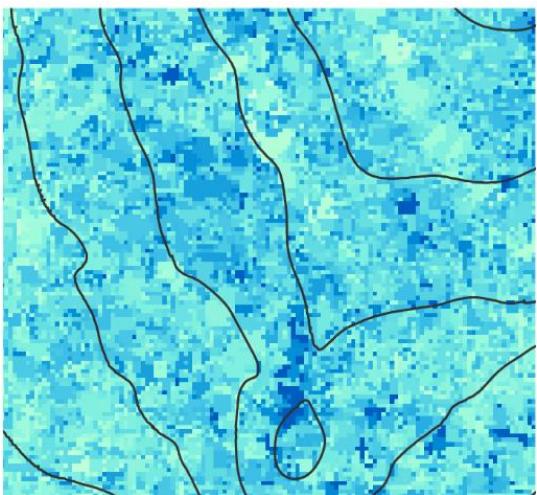
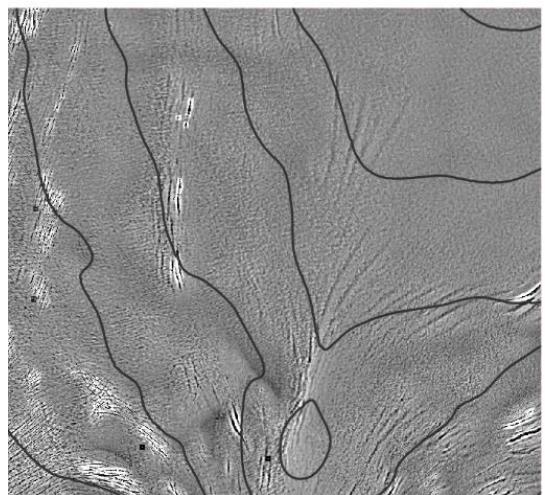
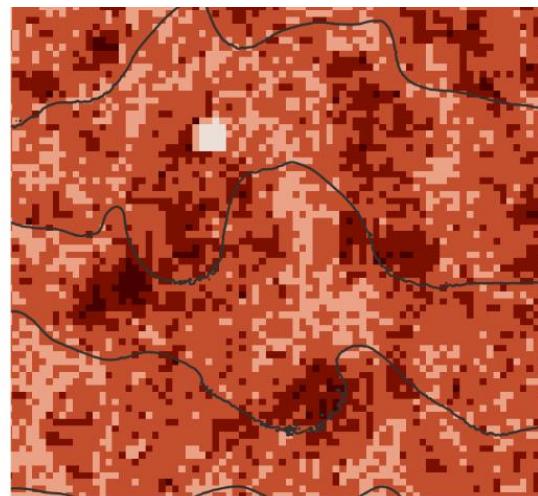
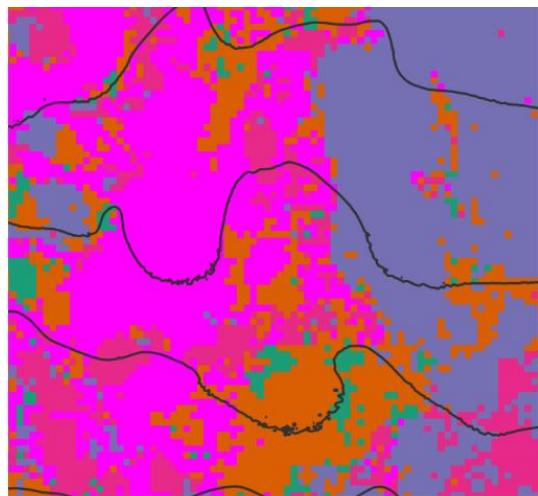
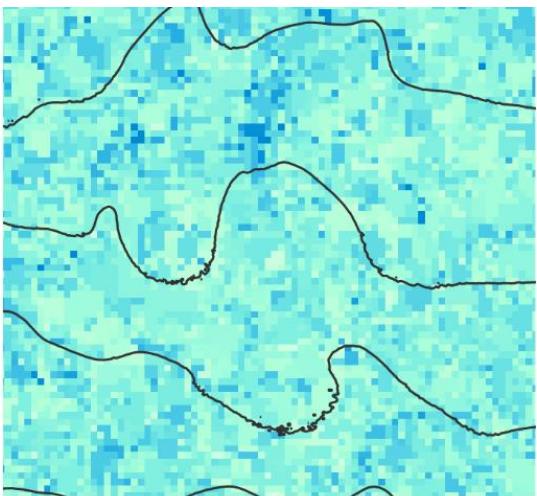
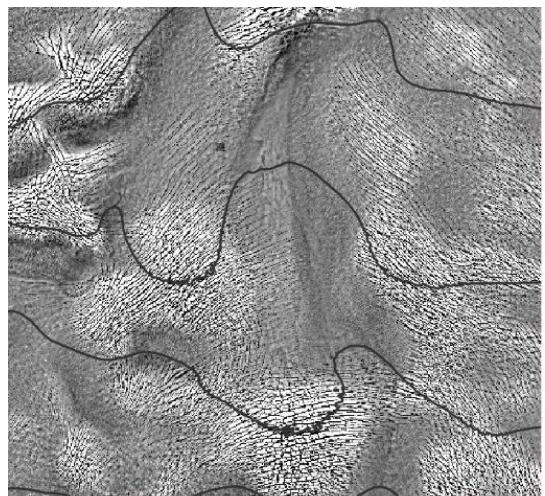
Spacing
Win: 105 m² Step: 15 m



Spacing
Win: 105 m² Step: 35 m

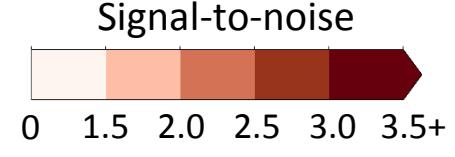
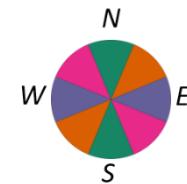
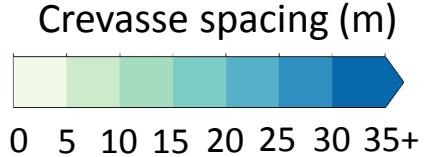
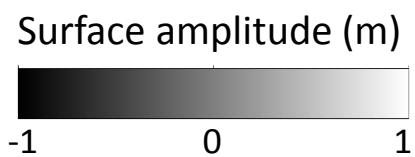
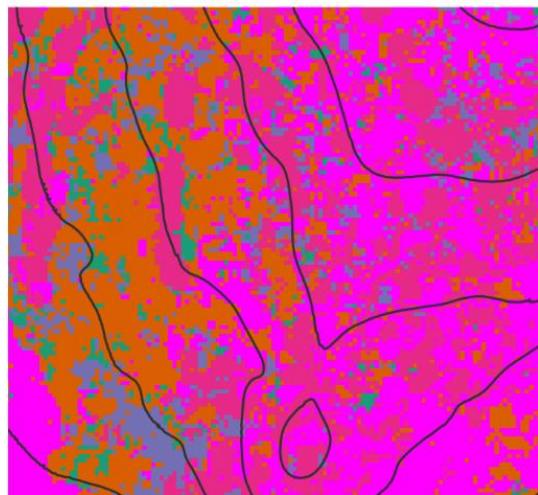
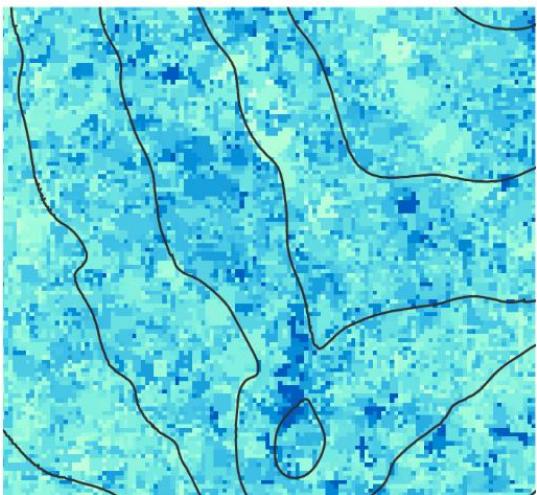
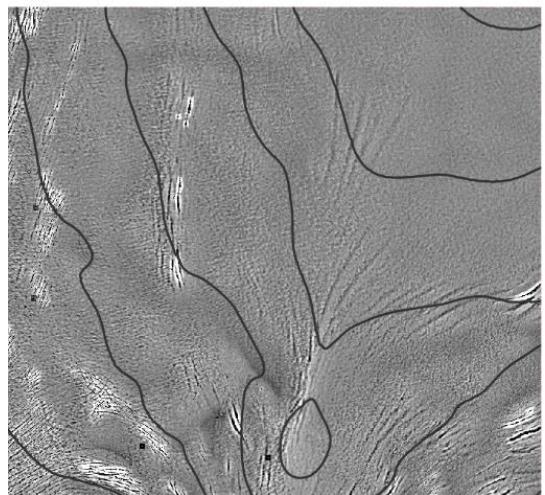
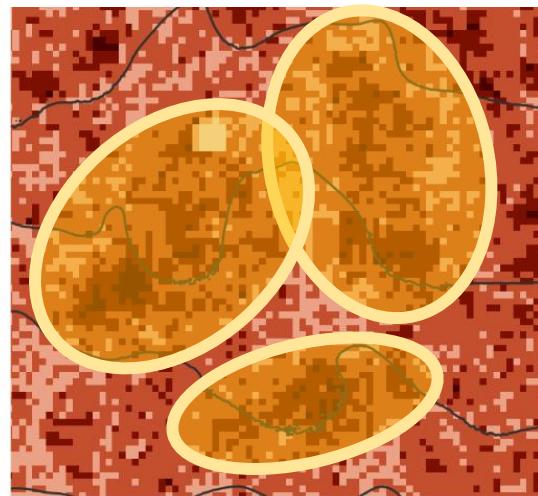
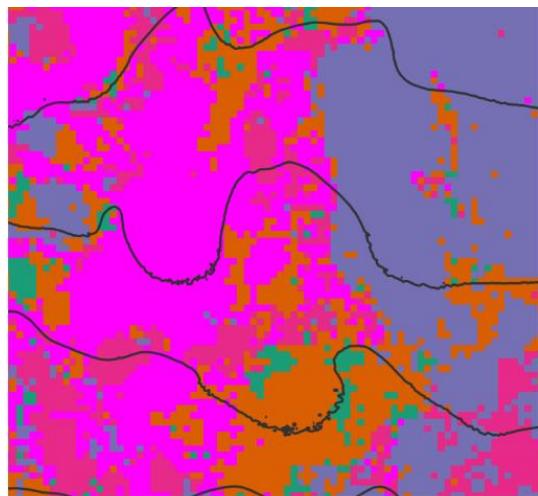
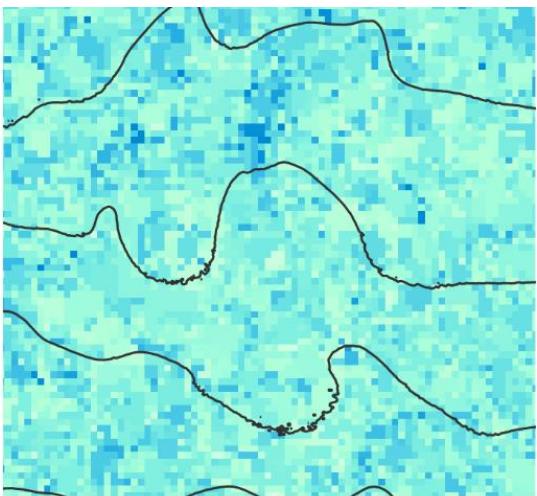
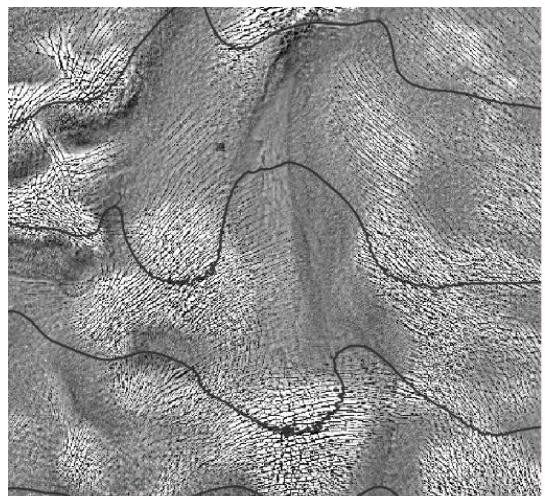


Spacing, orientation and SNR – window: 155 m | step: 35 m



2 km

Spacing, orientation and SNR – window: 155 m | step: 35 m



2 km