

# Automated crevasse mapping: assisting with mountain and glacier hazard assessment

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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...***

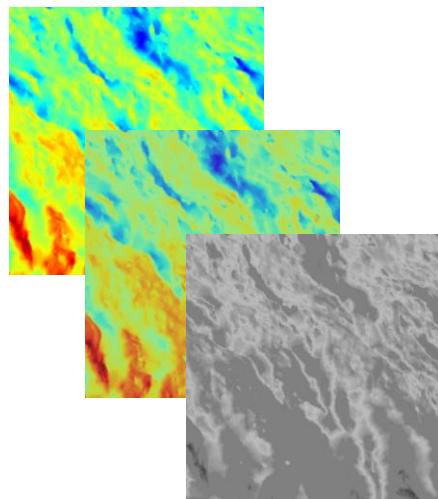
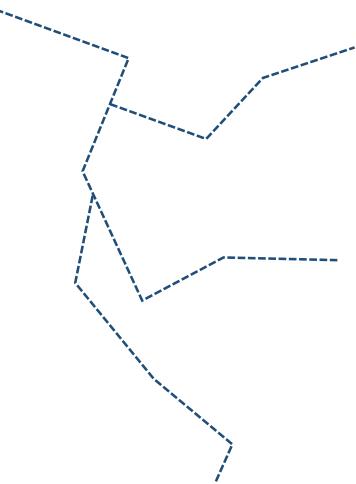
- Mapping/extracting individual crevasse features
- Supposed to be fool-proof solution

## Existing approaches

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

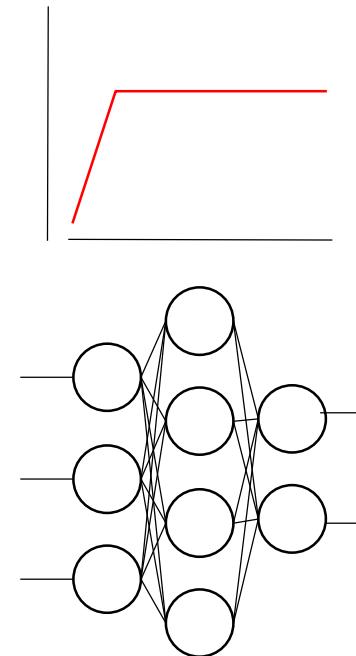
# Existing approaches

?

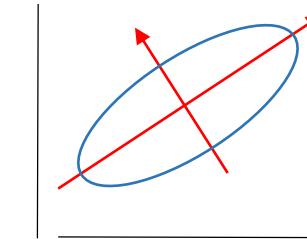


Rivera et al., 2014

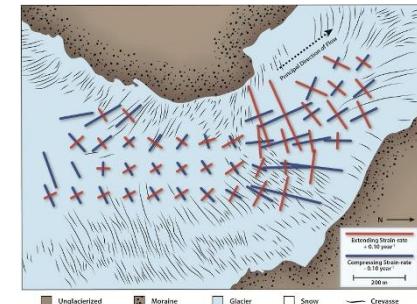
*“...visual interpretation of crevasse patterns is often difficult and misleading” (Haeberli et al., 1989)*



Herzfeld, 2008, 2011



Jóhannesson et al., 2011

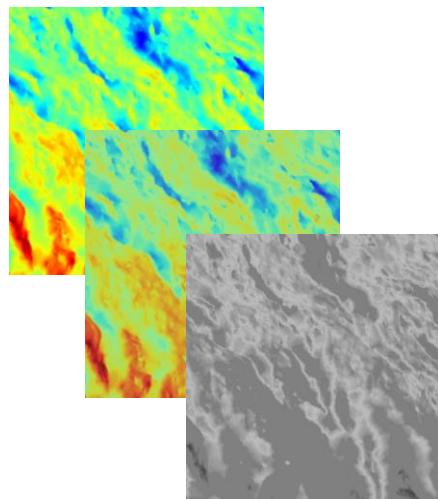
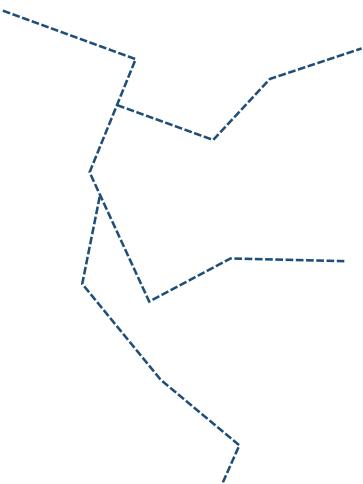


Reproduced from  
Colgan et al., 2015

*See Colgan et al. (2015) for a review...*

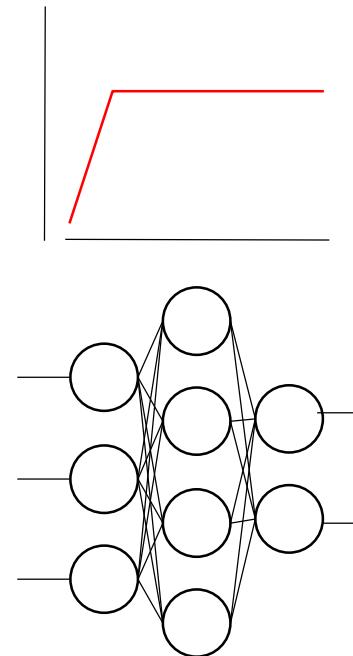
# Existing approaches

?

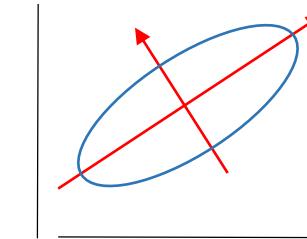


Rivera et al., 2014

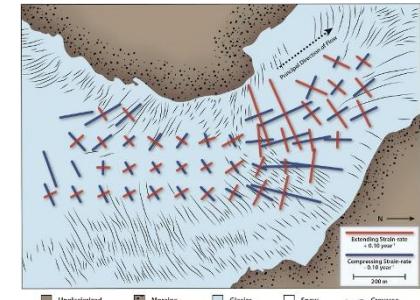
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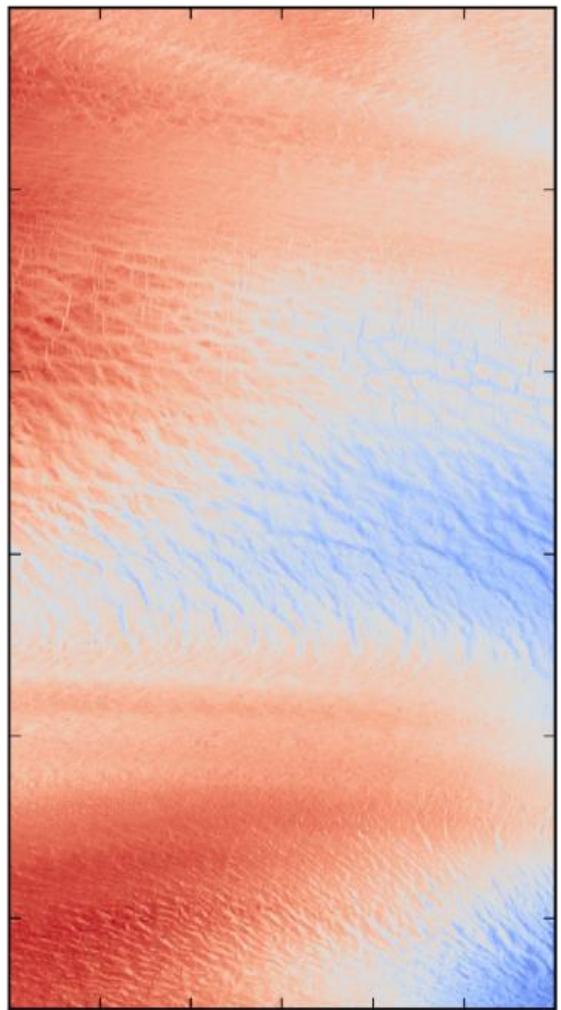
## Problems

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

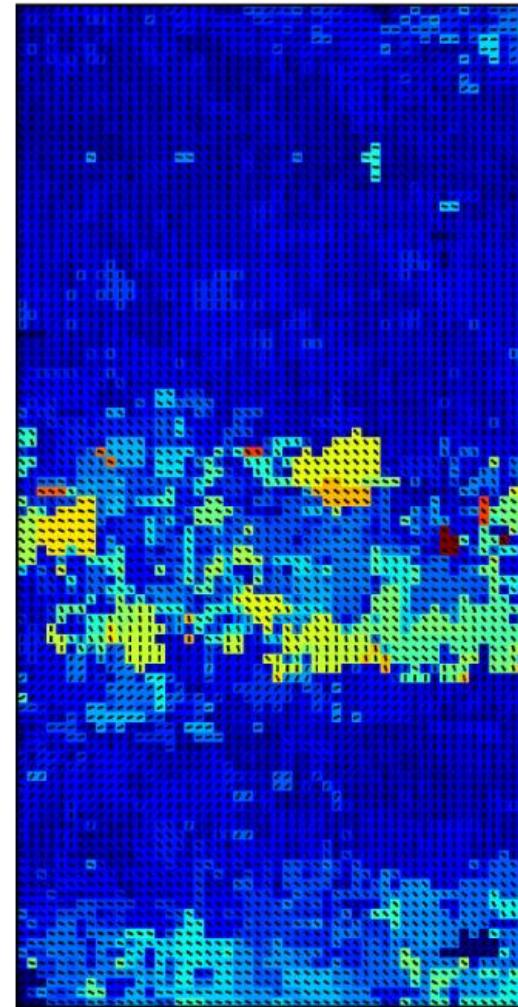
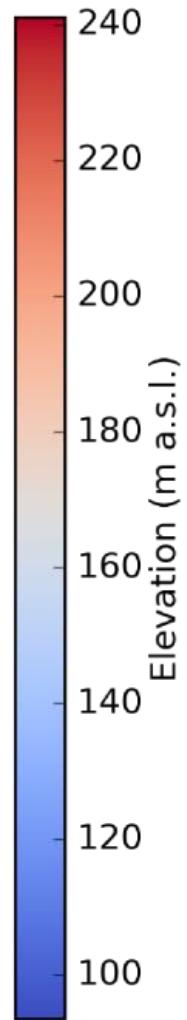
## What we present

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

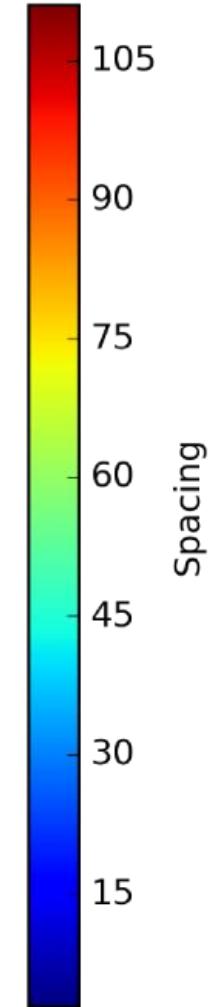
# LFMapper: Using the Fast Fourier Transform for feature classification



*Glacier surface raster  
(image or DEM)*



*Orientation and spacing matrix  
(raster)*

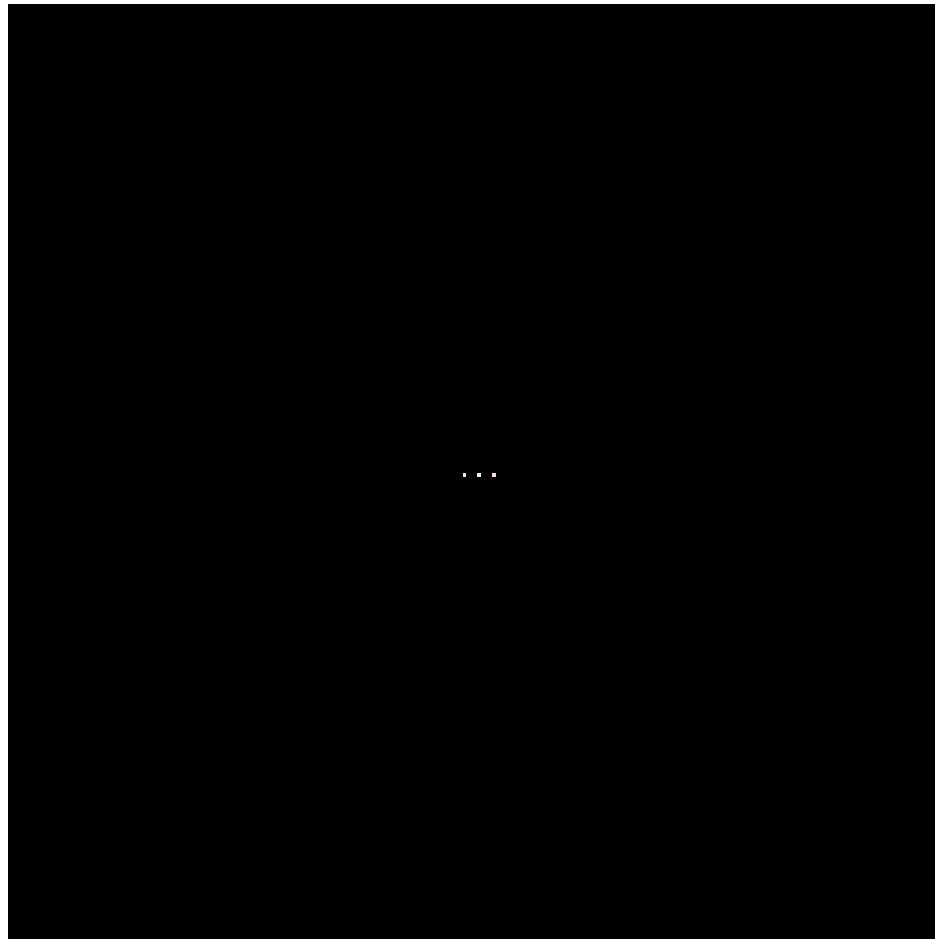


# Visually interpreting an Fourier Transform plot

Space



Frequency



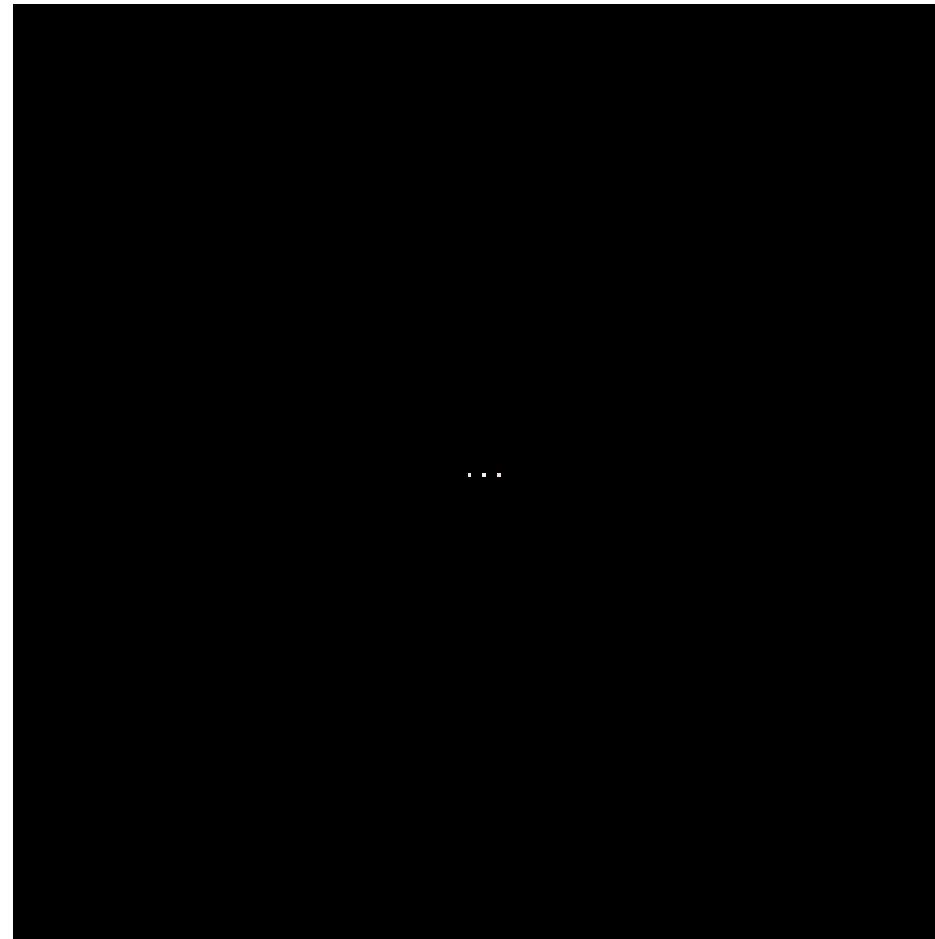
# Visually interpreting an Fourier Transform plot

*Rotationally symmetrical*

Space



Frequency



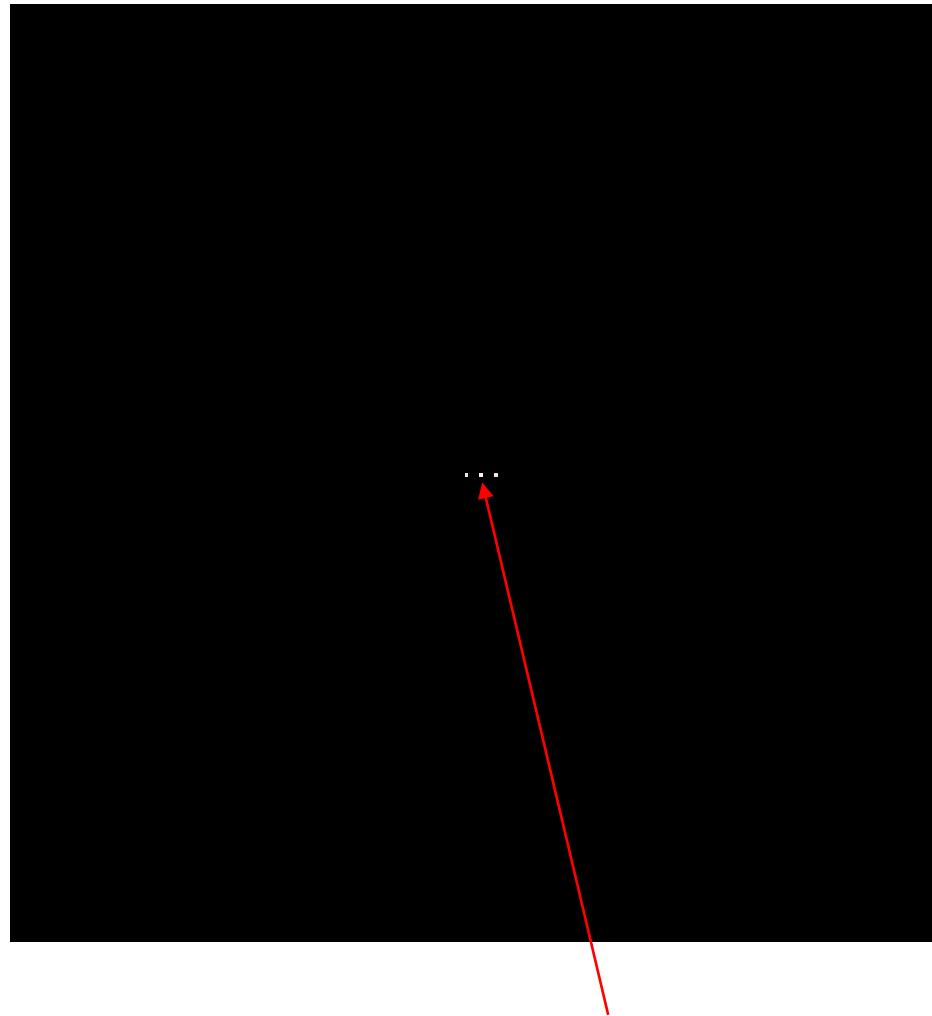
# Visually interpreting an Fourier Transform plot

*Rotationally symmetrical*

Space

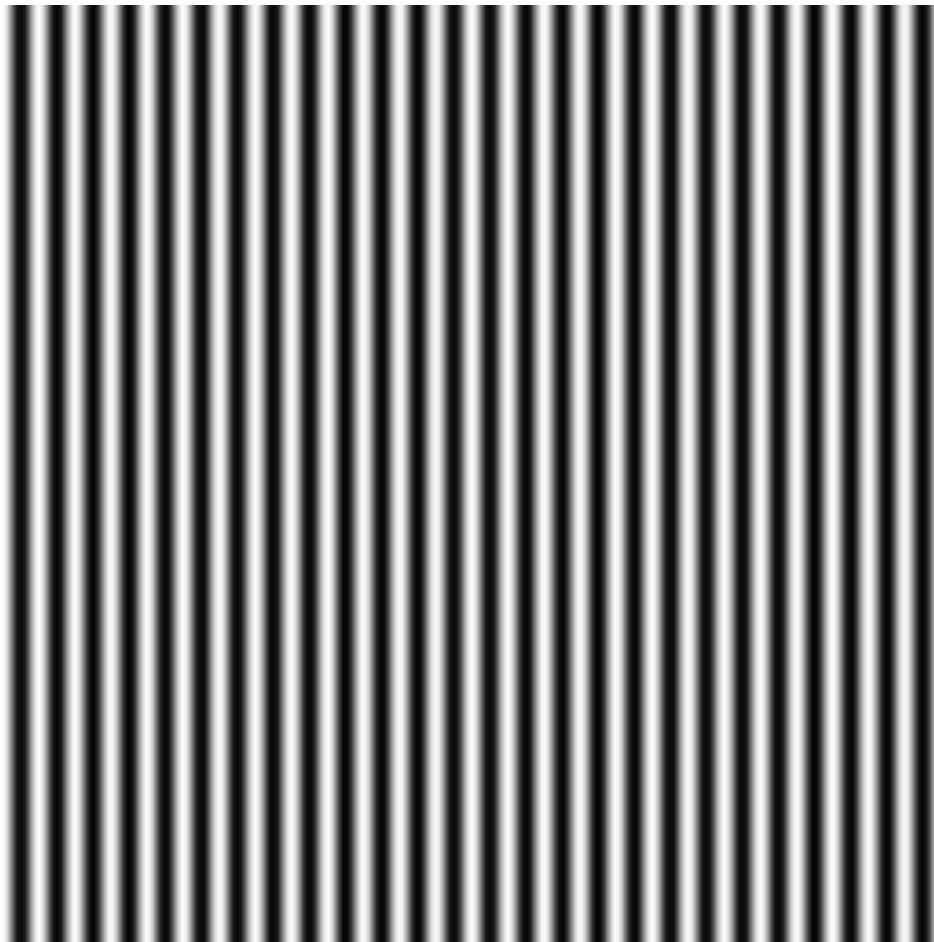


Frequency

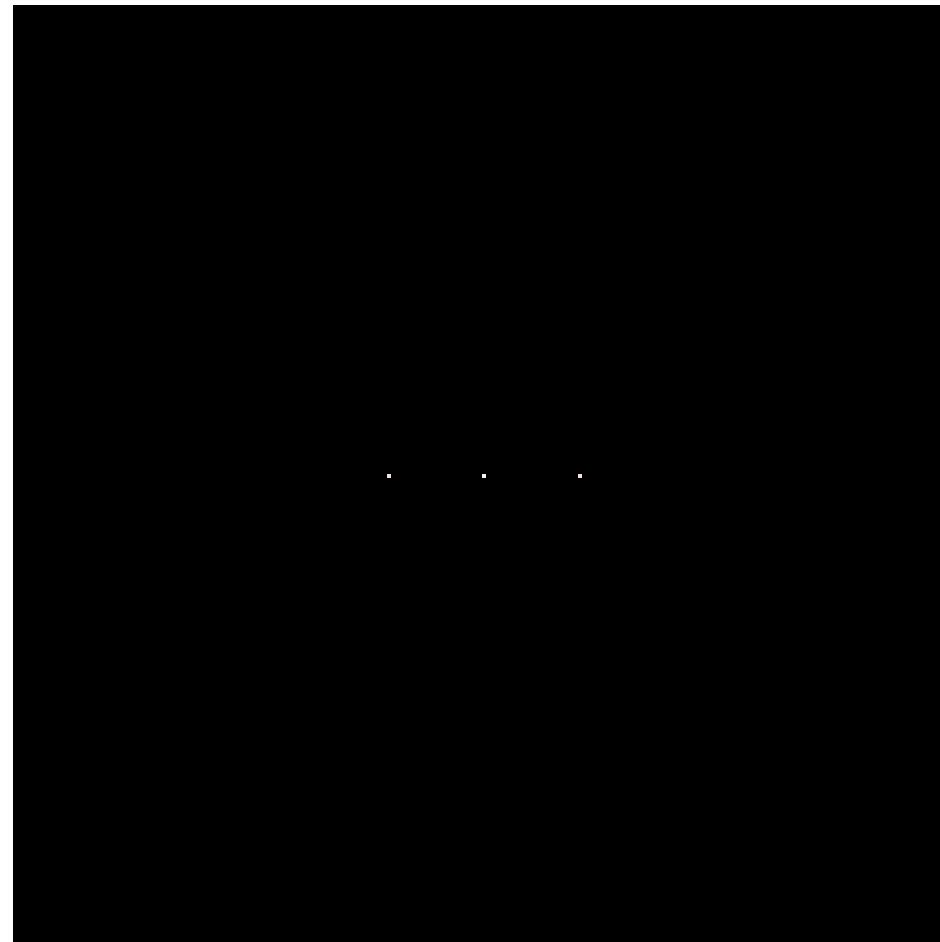


# Visually interpreting an Fourier Transform plot

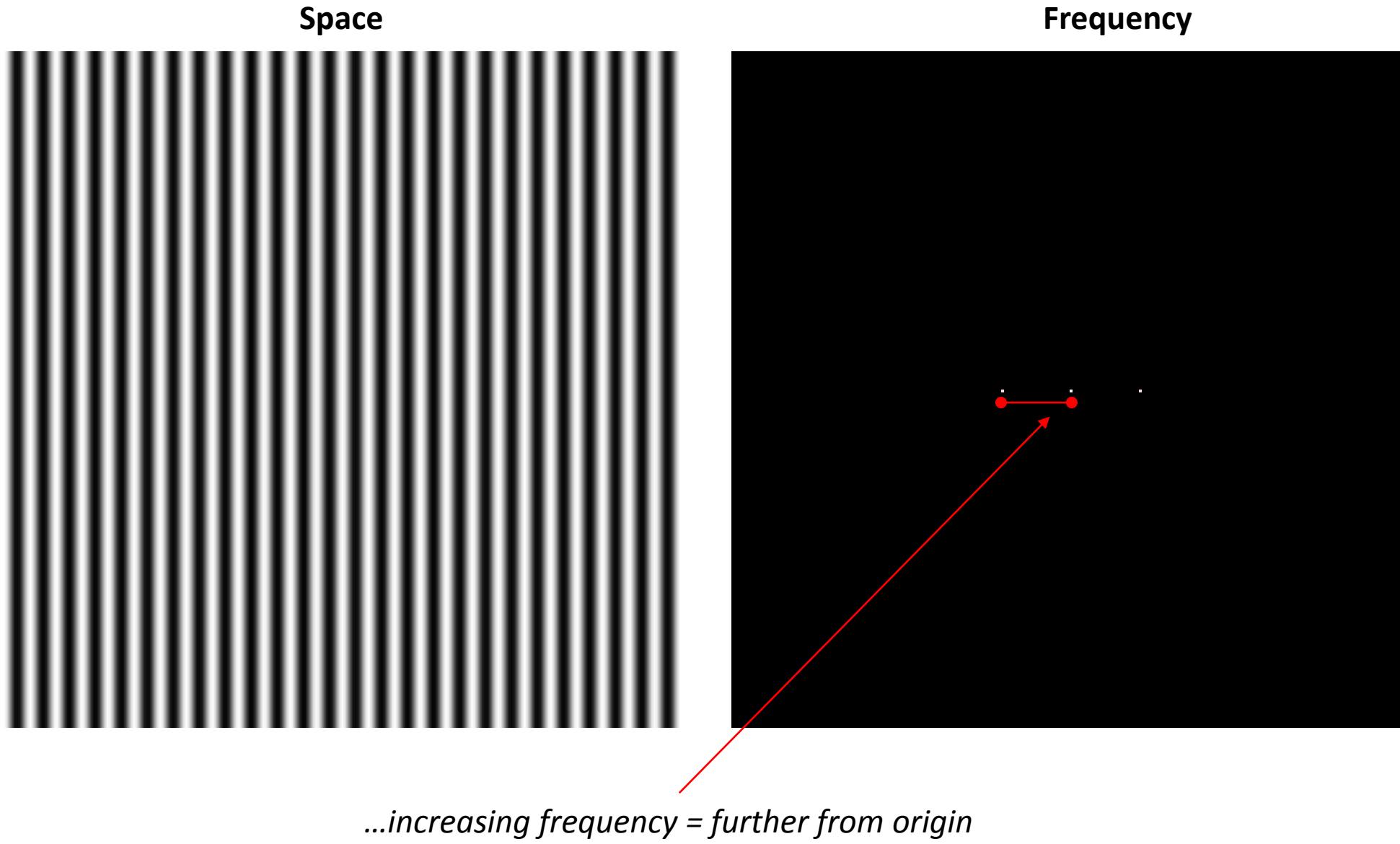
Space



Frequency

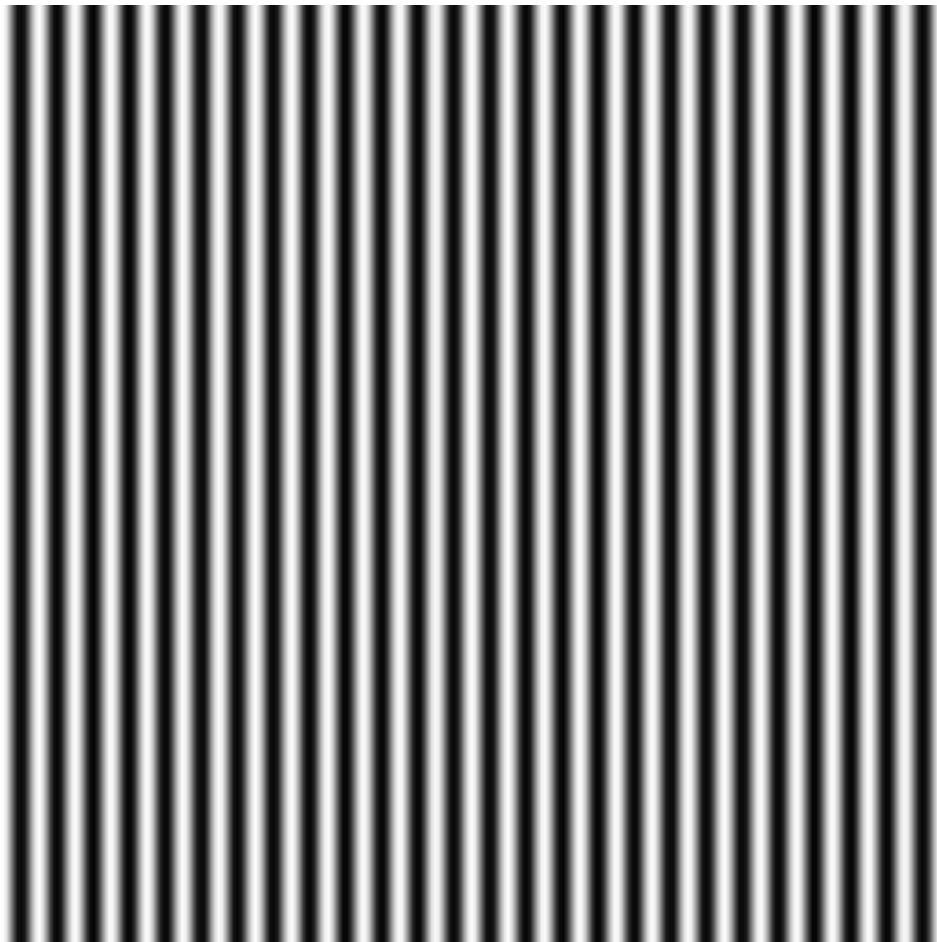


# Visually interpreting an Fourier Transform plot

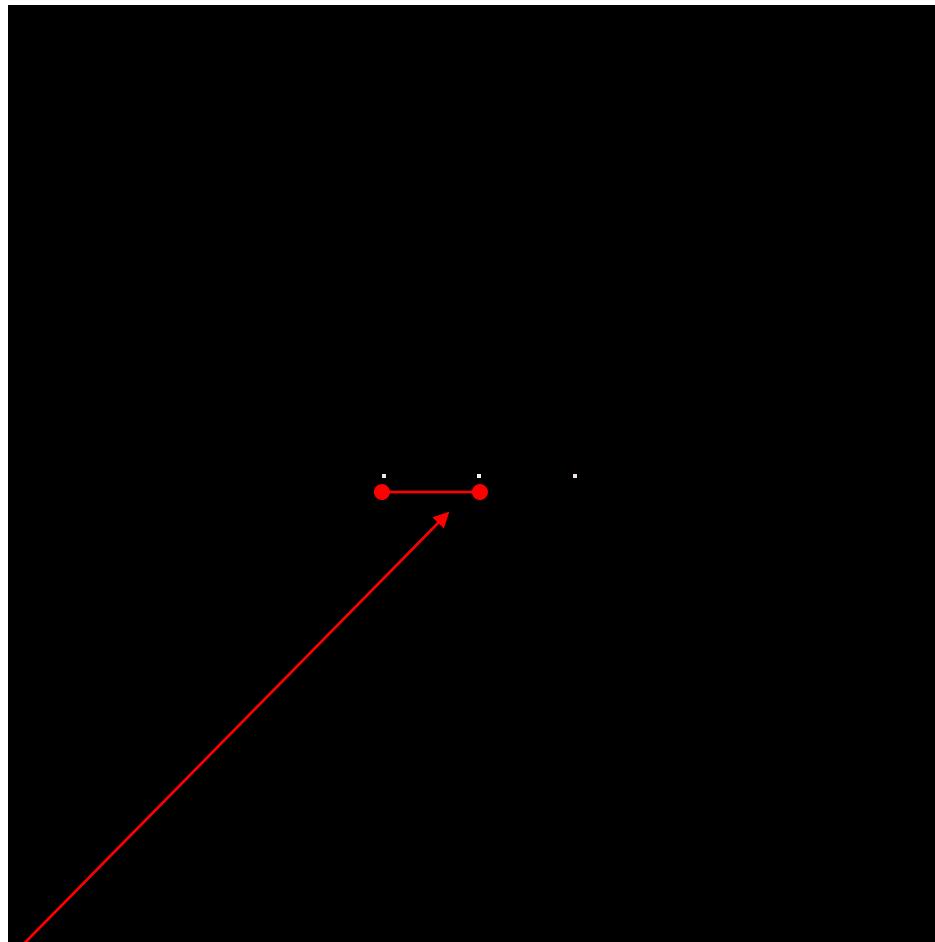


# Visually interpreting an Fourier Transform plot

Space

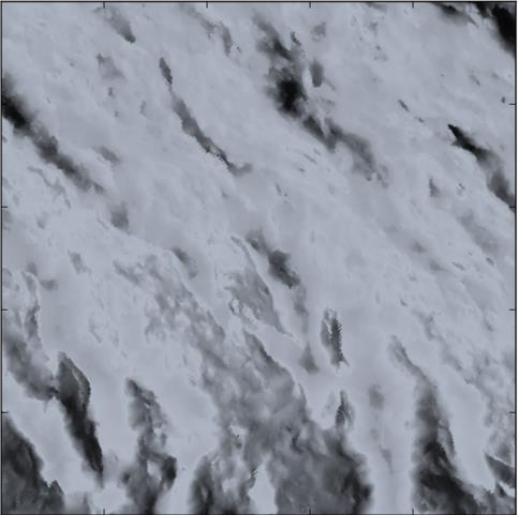


Frequency

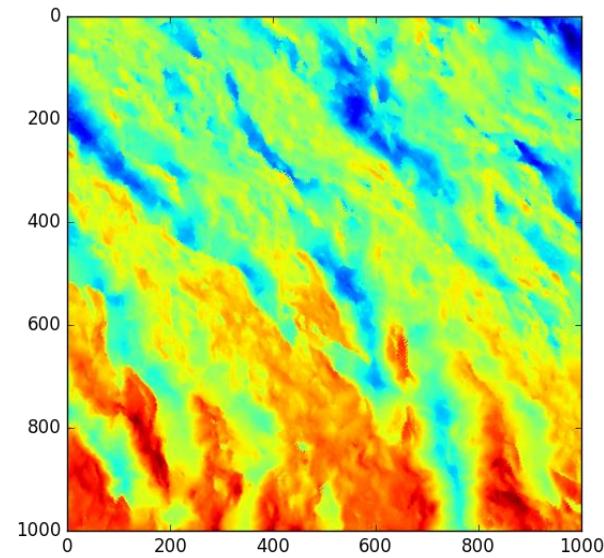


*...increasing frequency = further from origin*

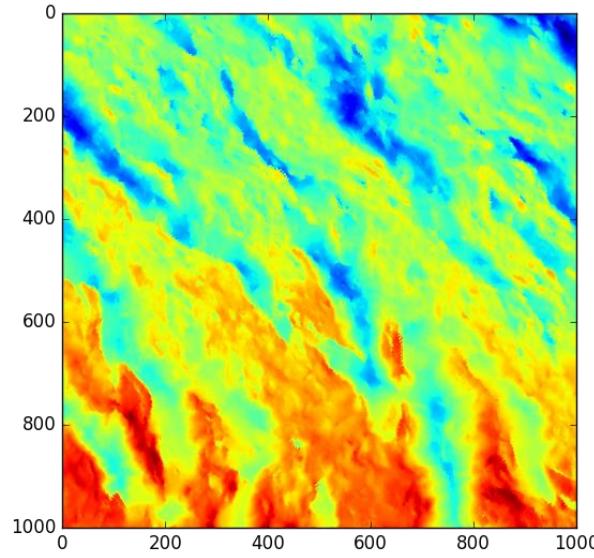
**FFT: Fast Fourier transform**



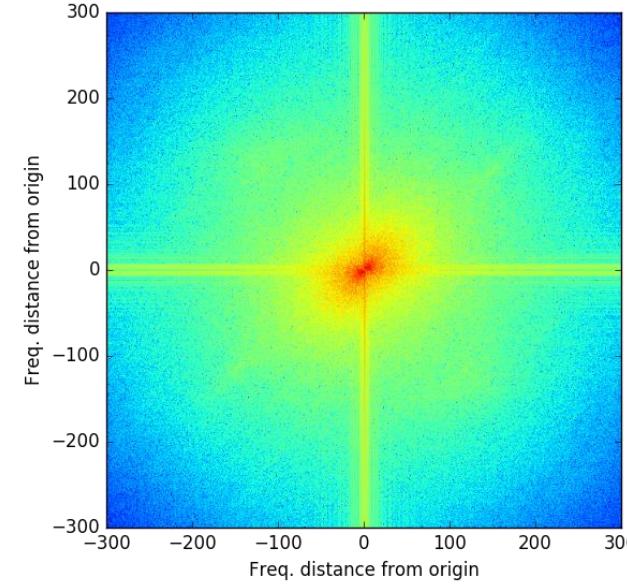
1. Original image



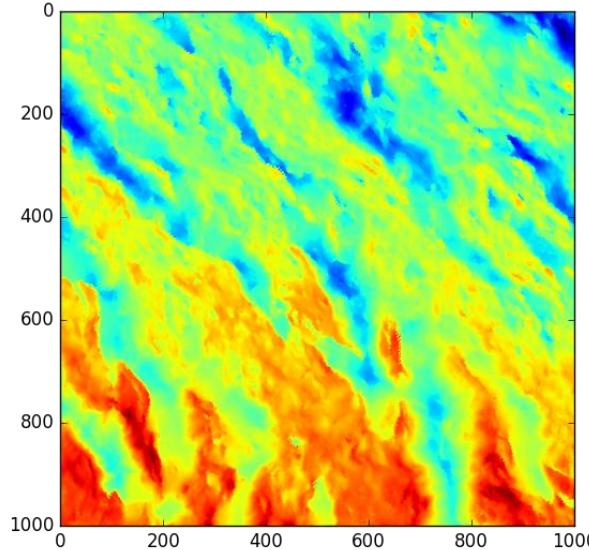
1. Original image



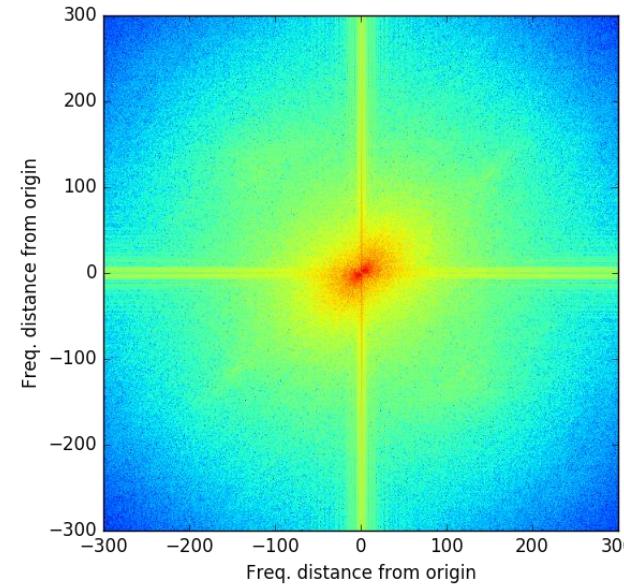
2. Calculate FFT



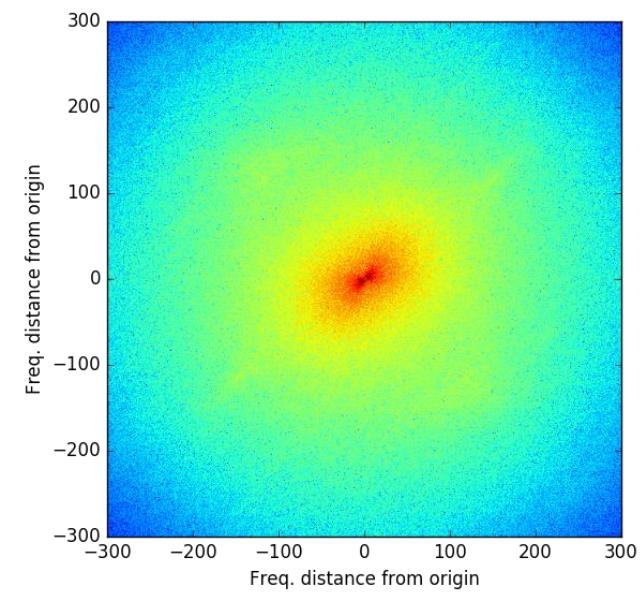
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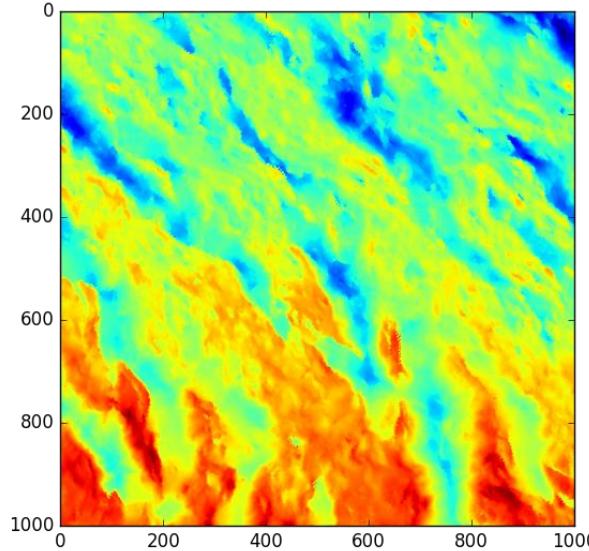
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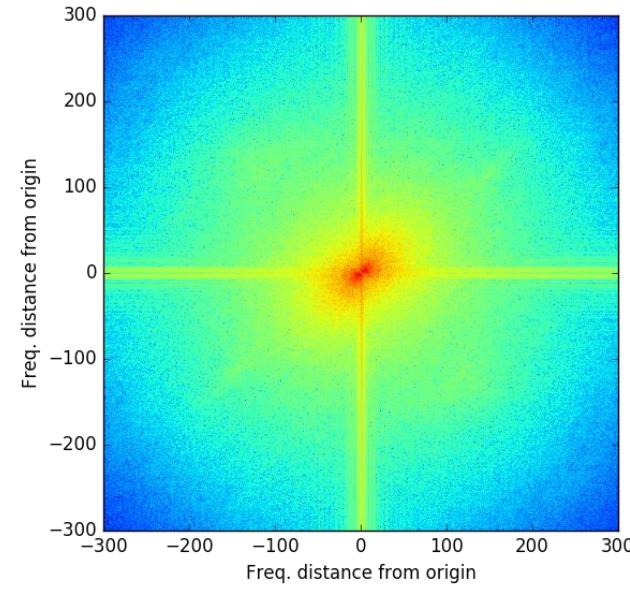
3. Smooth and Gibbs effect removal



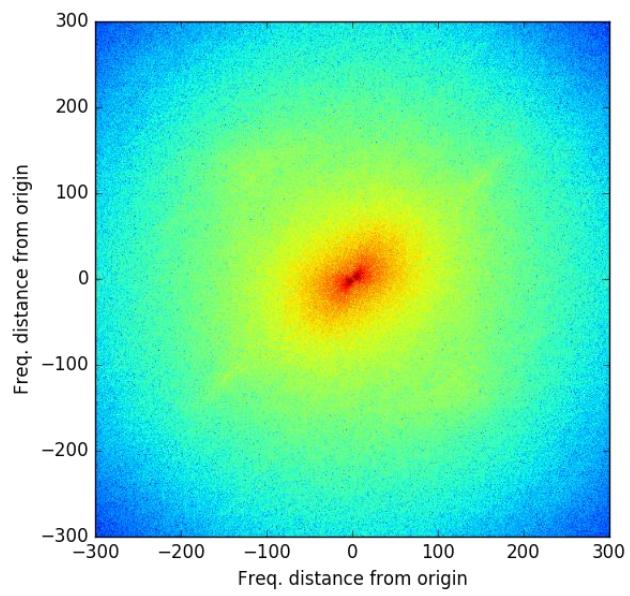
**1. Original image**



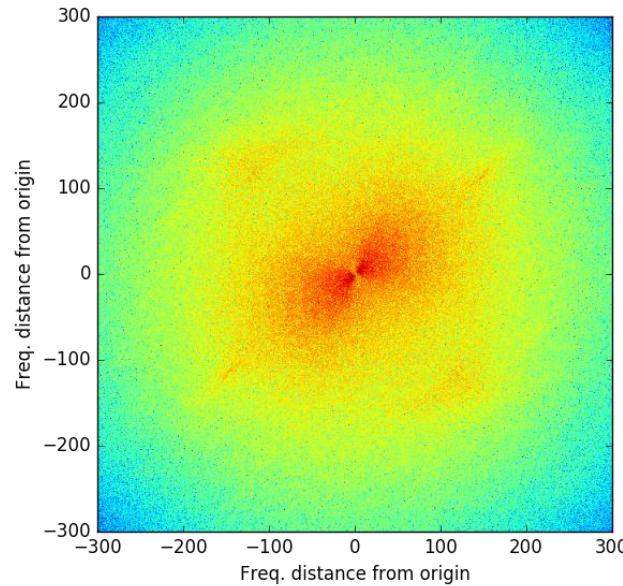
**2. Calculate FFT**



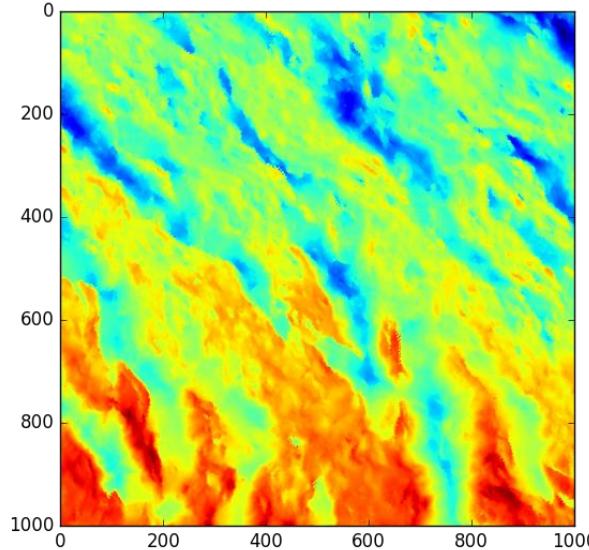
**3. Smooth and Gibbs effect removal**



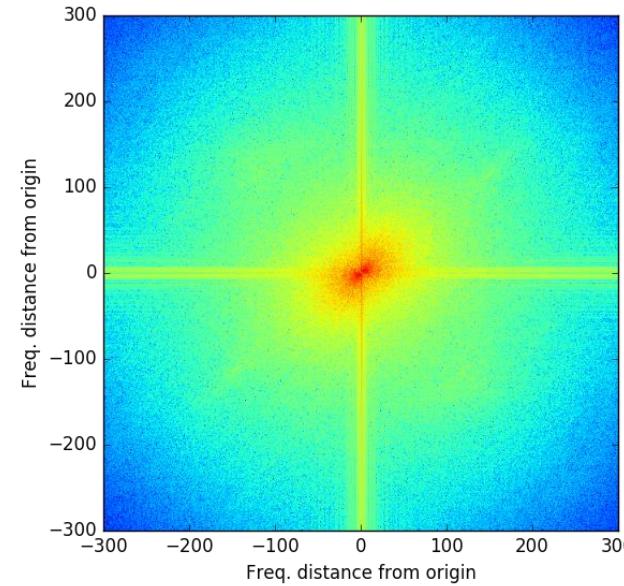
**4. Noise removal**



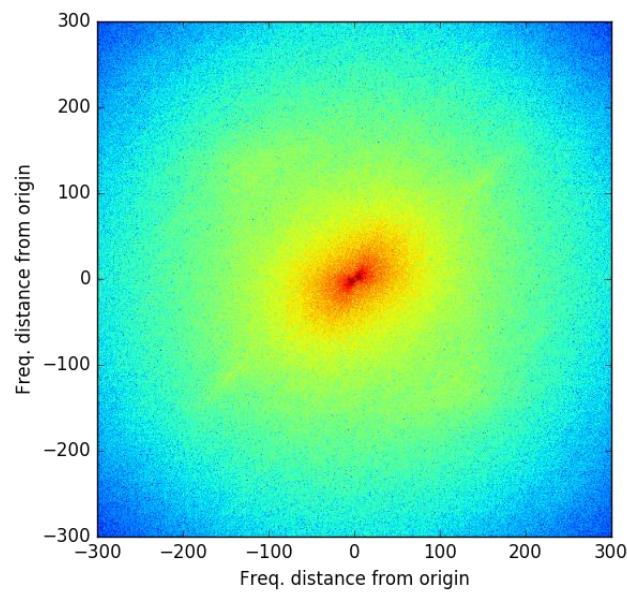
1. Original image



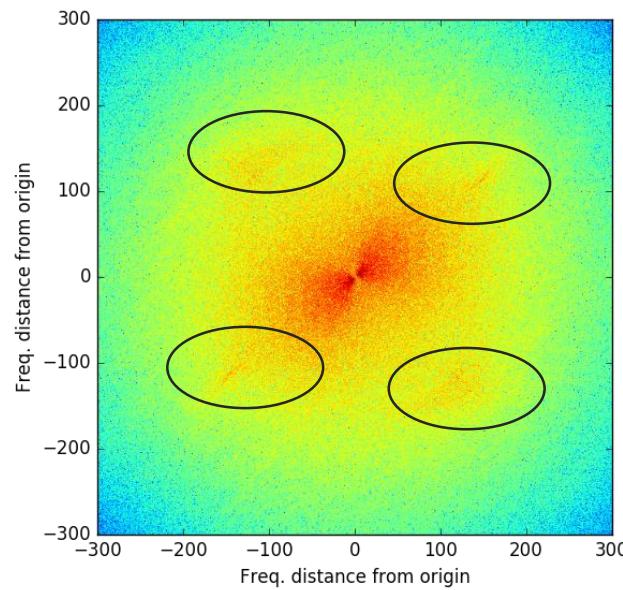
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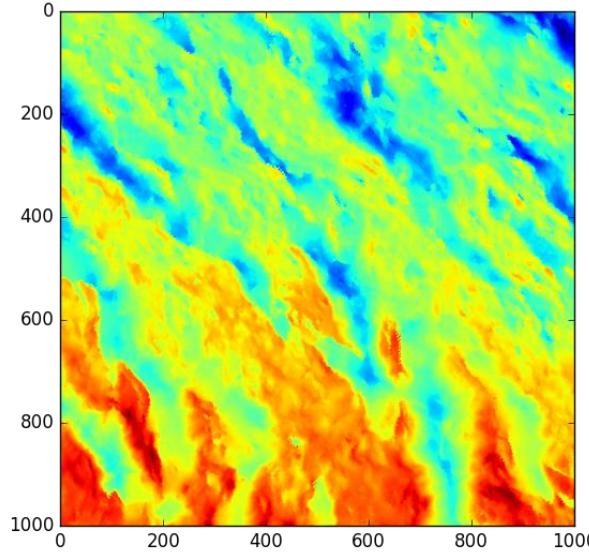
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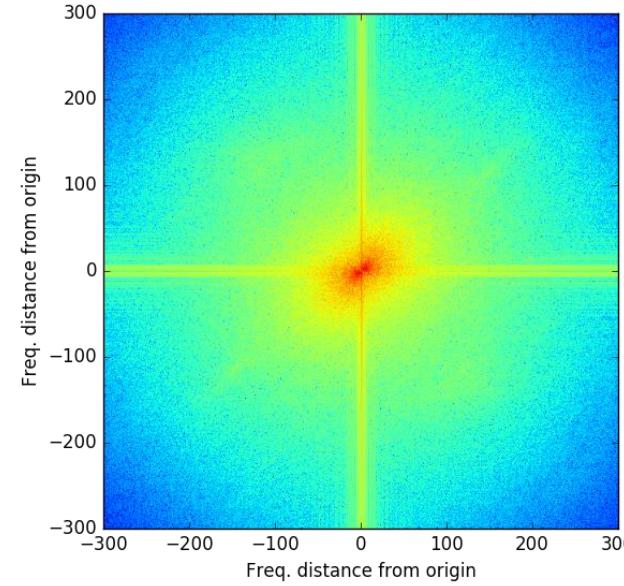
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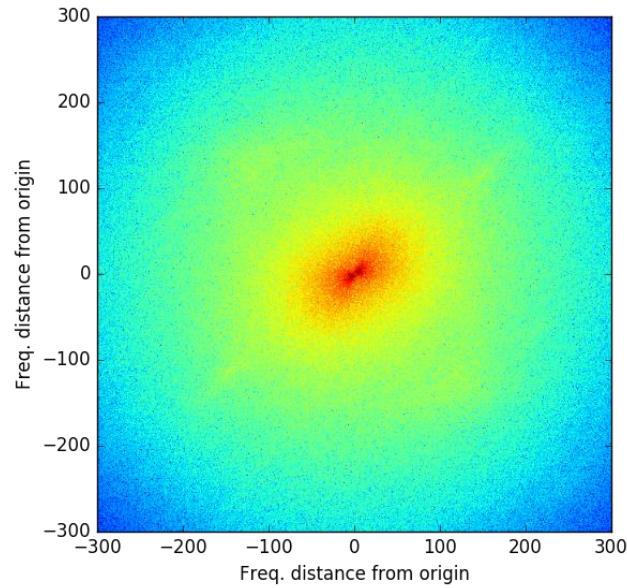
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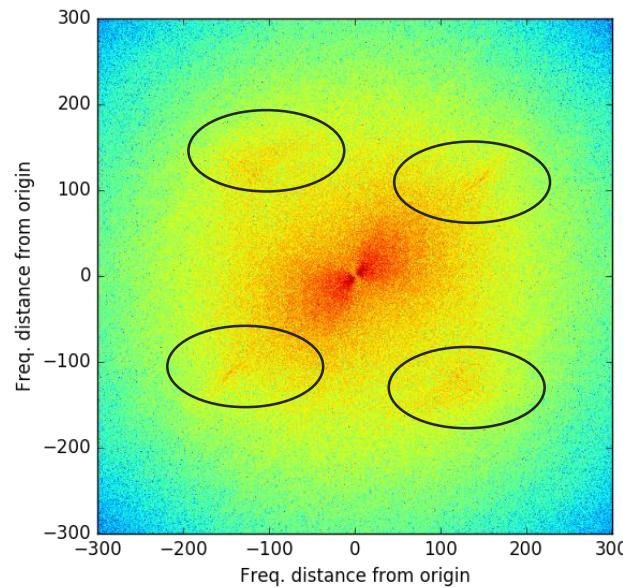
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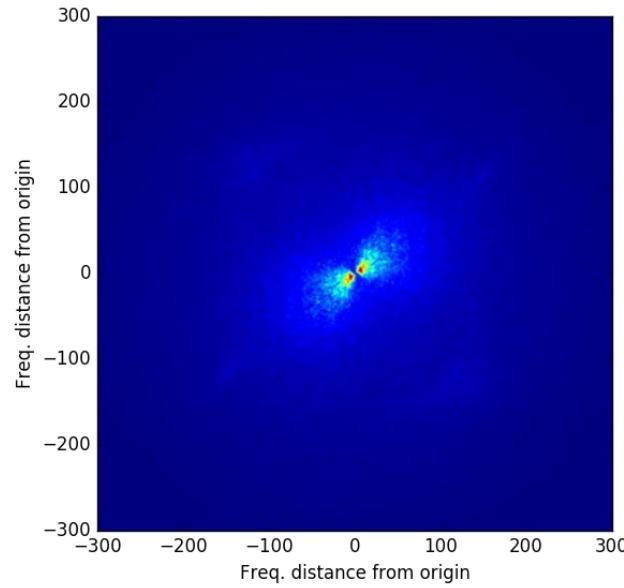
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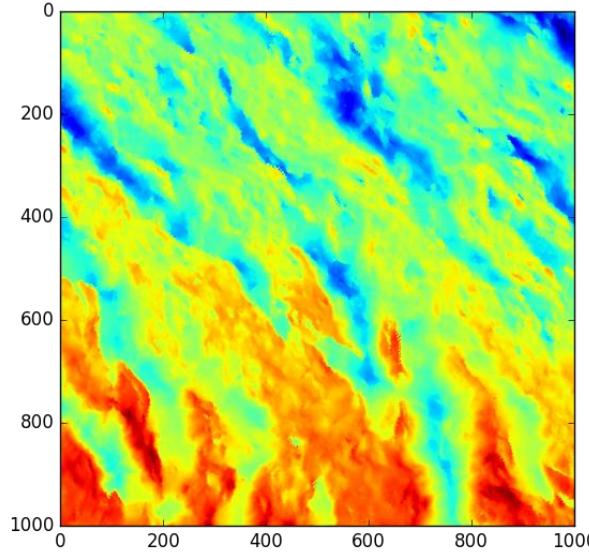
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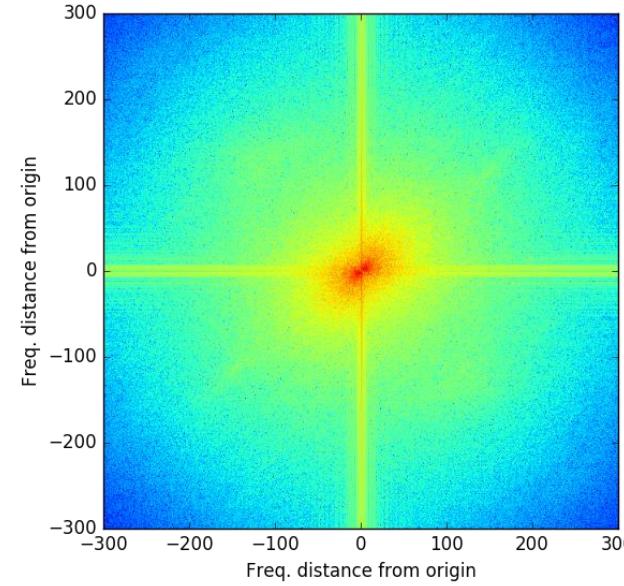
5. Log (visual)



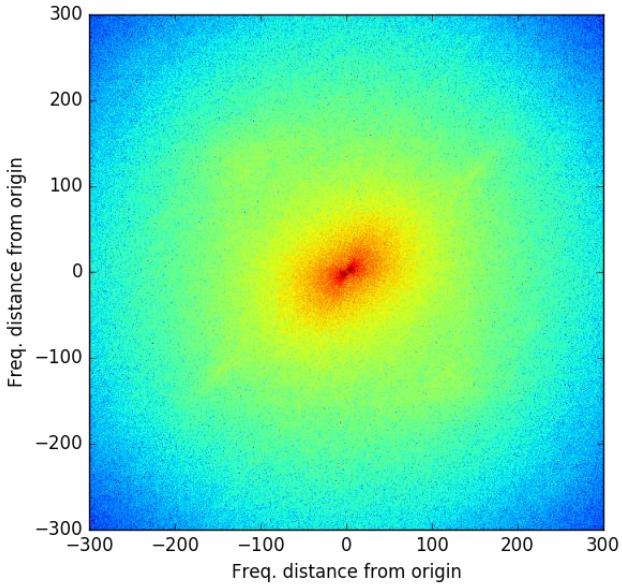
1. Original image



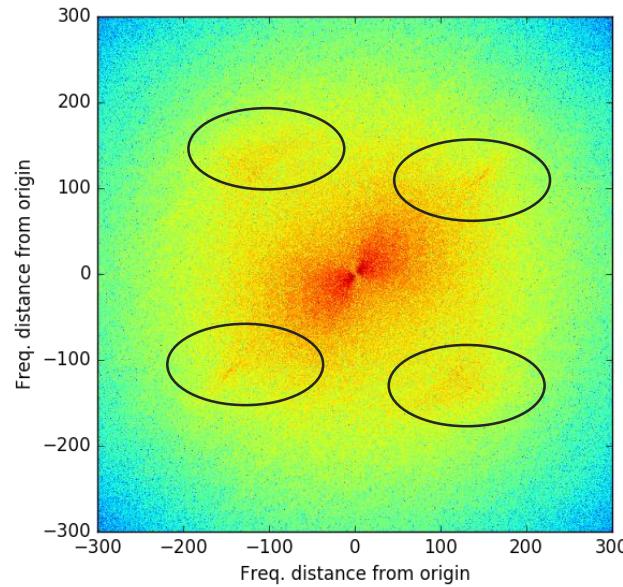
2. Calculate FFT



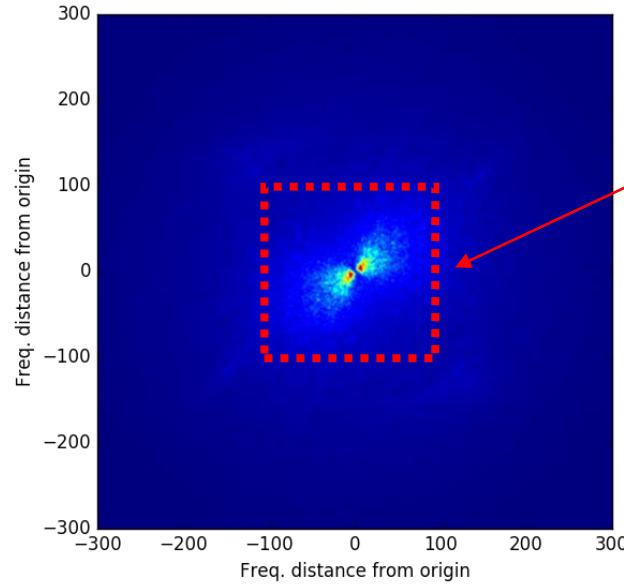
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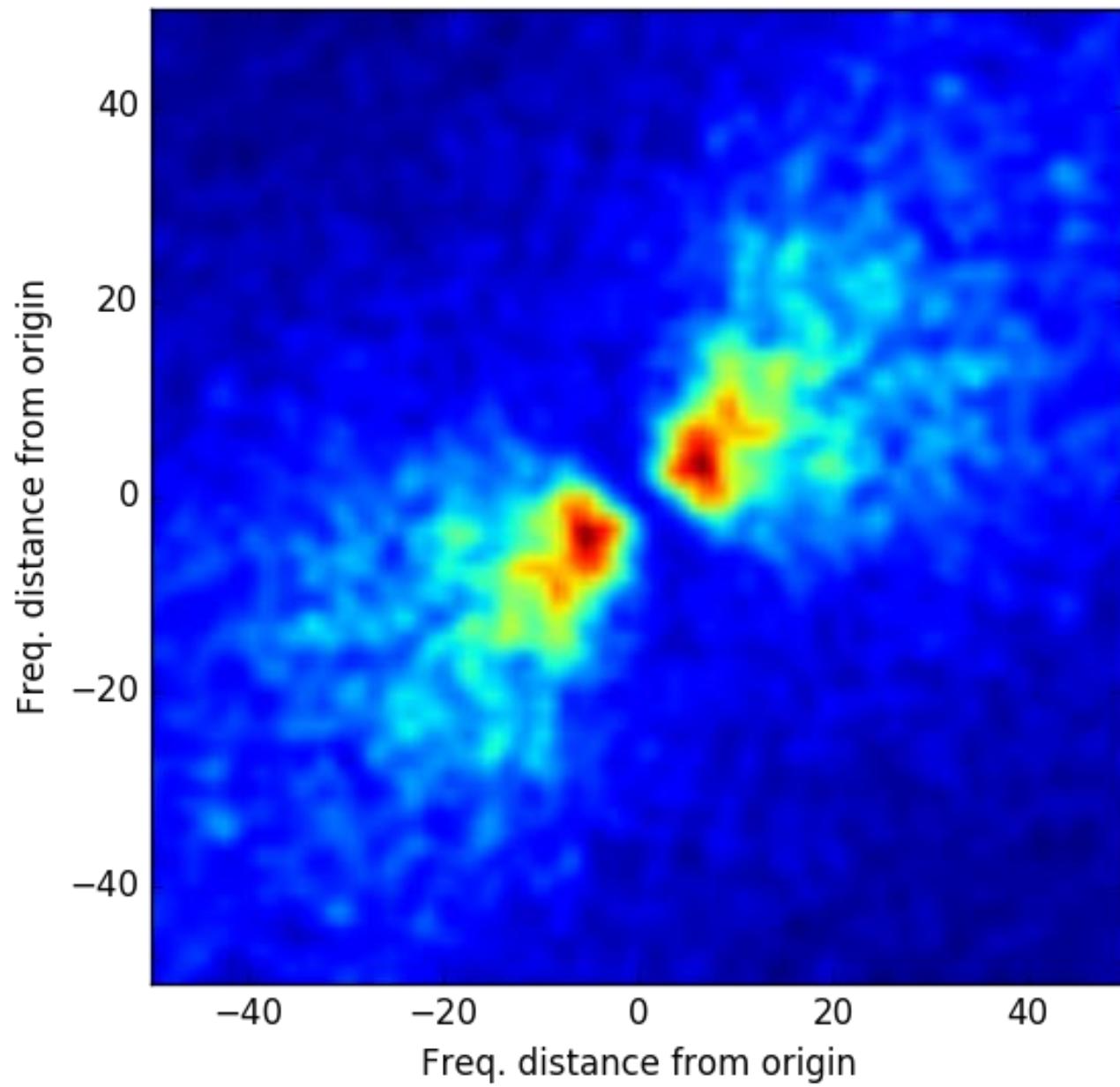
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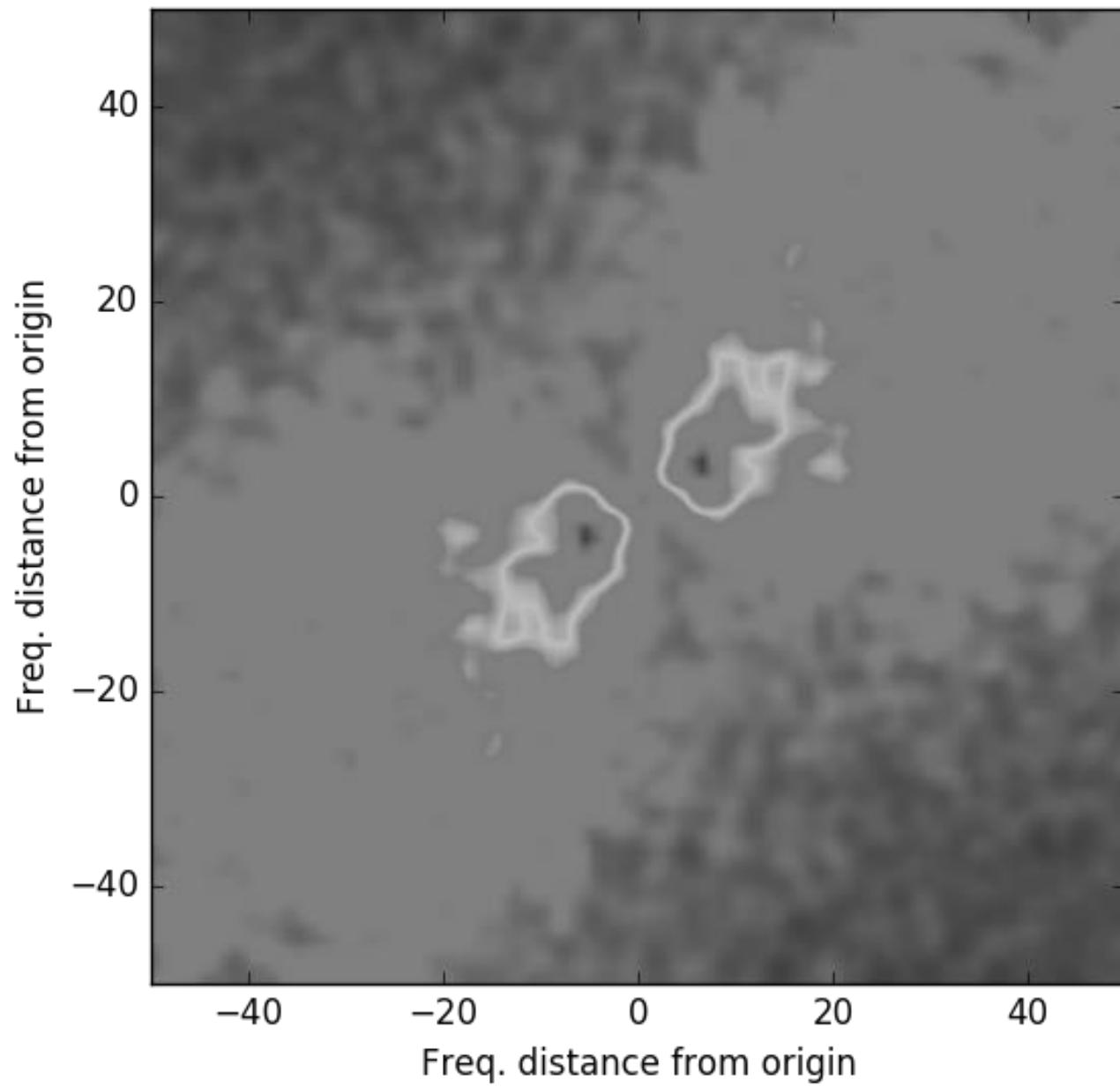


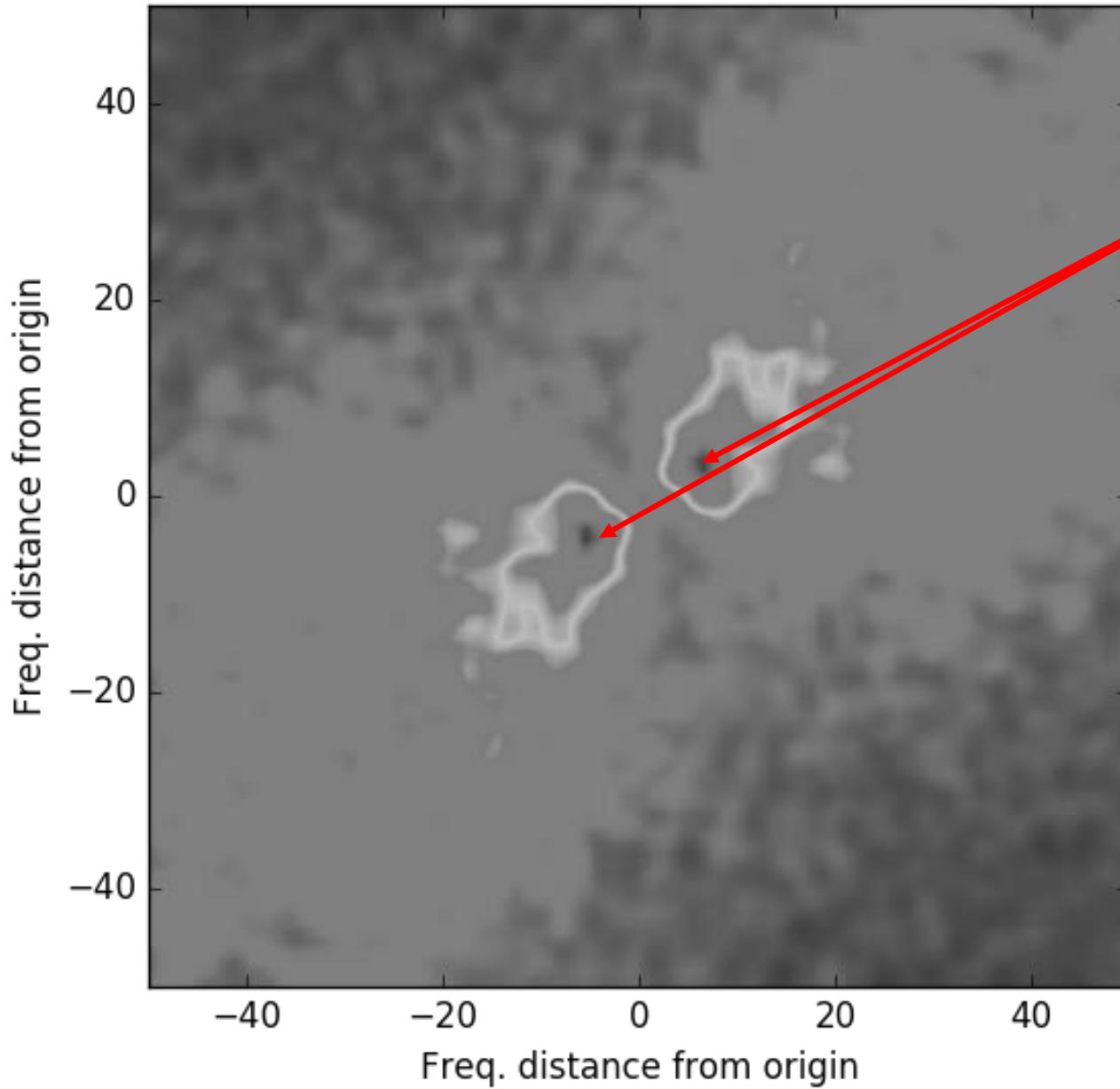
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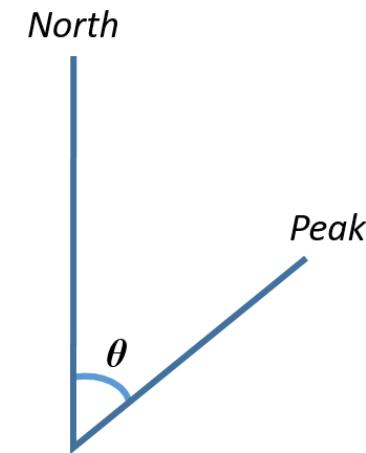
Area of  
maximum  
values



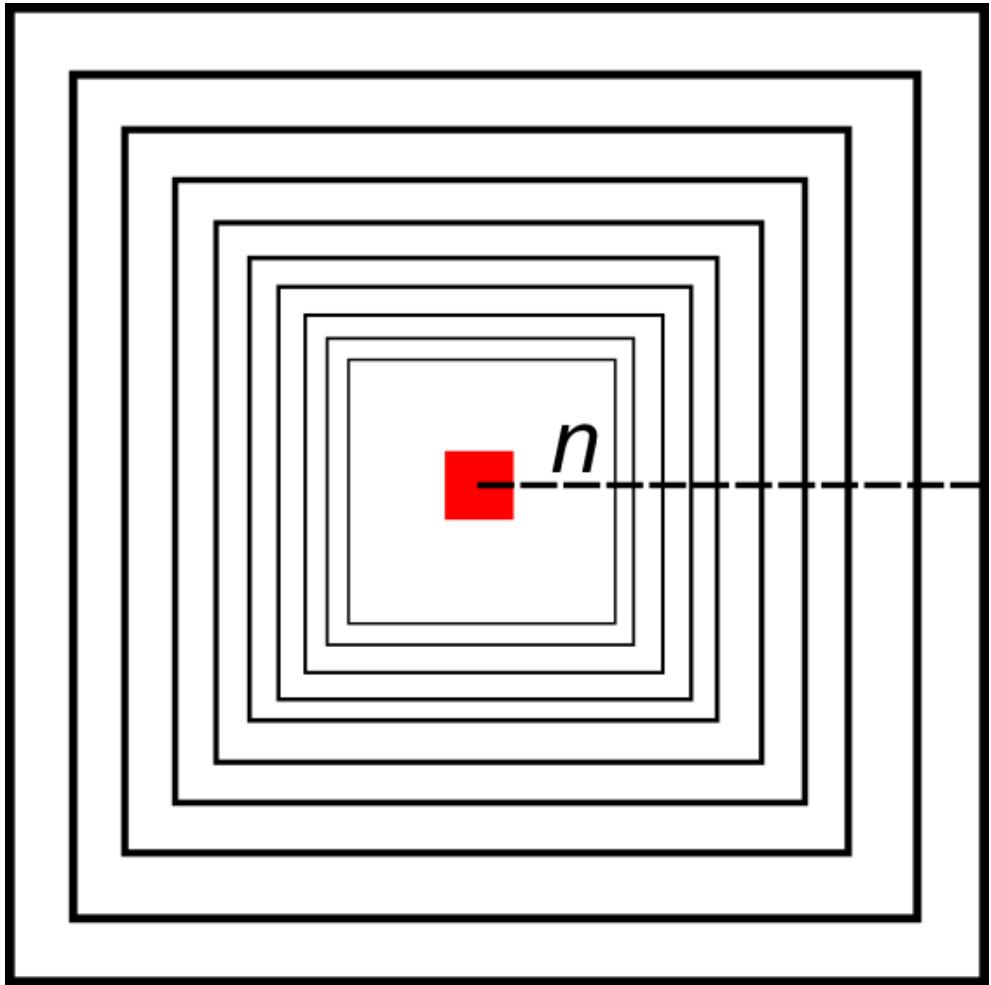




1. Identification of maximum peak
2. Calculate *signal-to-noise ratio*
3. Calculate distance from peak to origin  
(convert units from frequency to space)
4. Calculate orientation of peak  
– rotational symmetry!

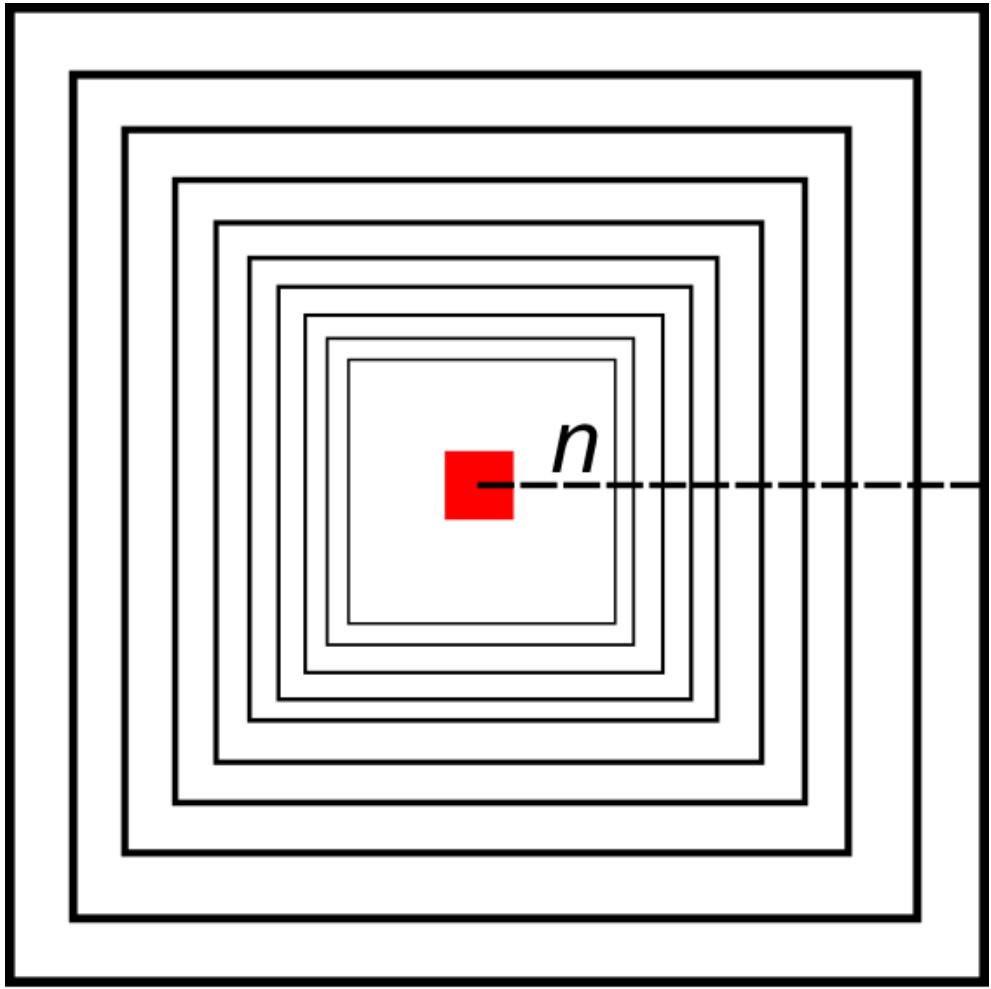


## Effect of window size

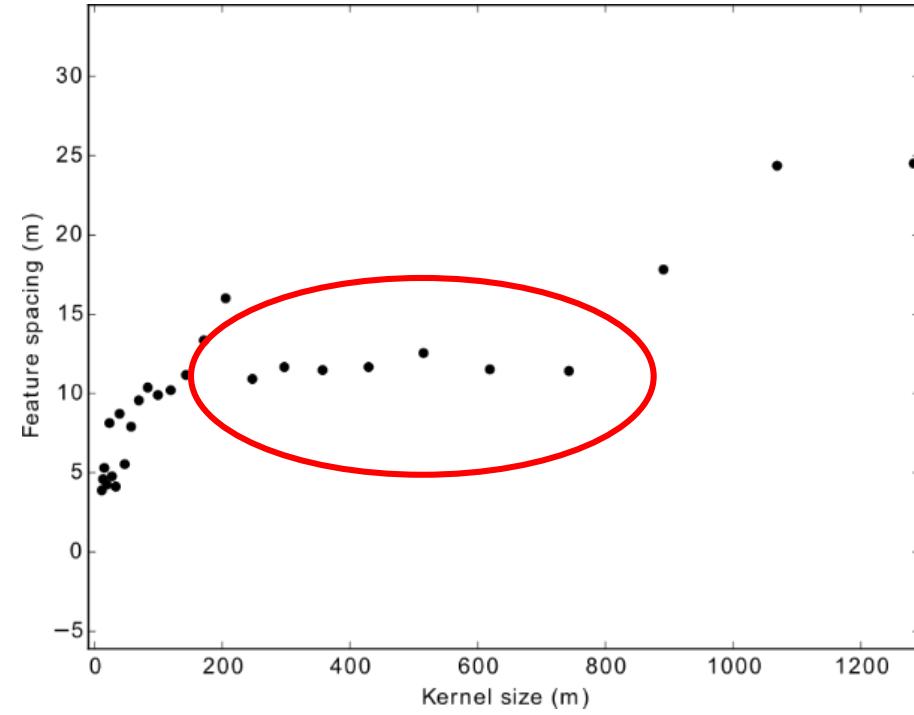


$$n = \text{maximum observable crevasse spacing} = \frac{\text{kernel length}}{2}$$

# 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)
- GNU General Public License

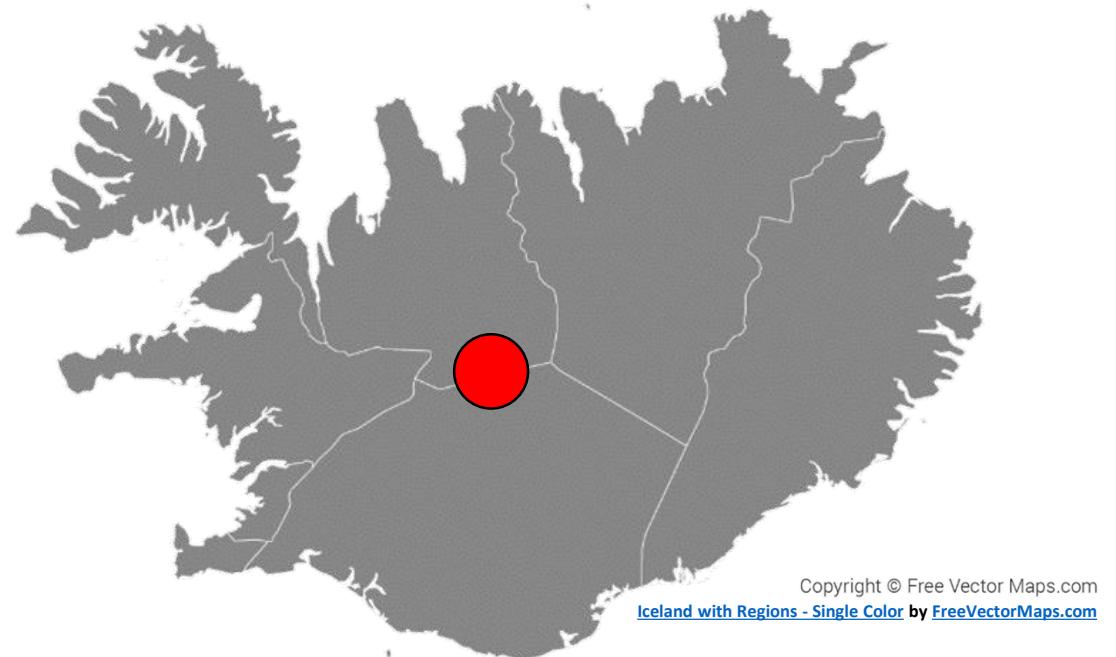
<https://github.com/Chris35Wills/LFMapper>

<https://zenodo.org/record/1216905#.Ws4JVH--m00>



# Application to Hofsjökull, Iceland

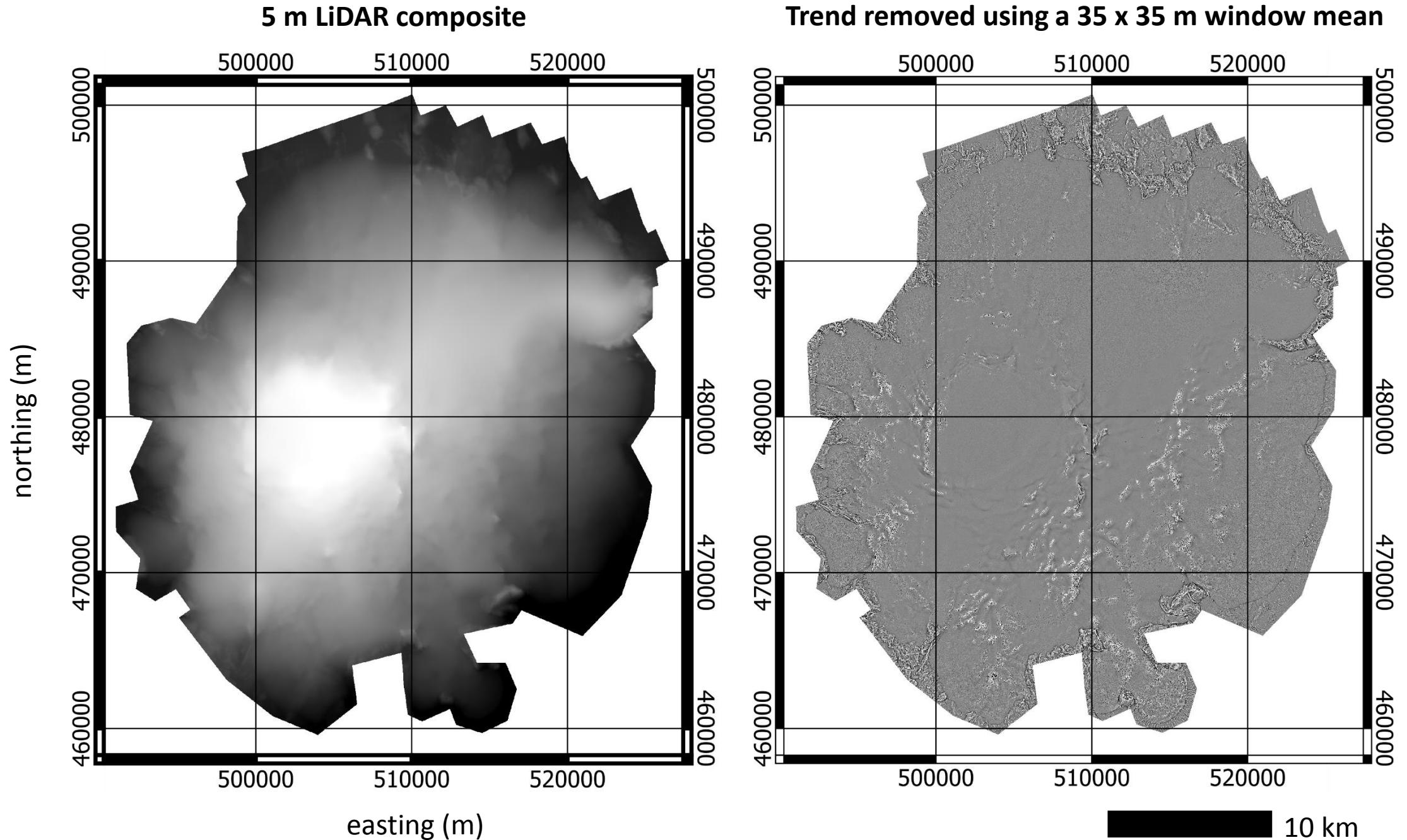
- Third largest glacier in Iceland (~900 km<sup>2</sup>)
- Located in the central highlands
- Large mass balance observation network (Icelandic Meteorological service)
- Mostly negative mass balance observed since 1995, positive in 2015
- Atop an active subglacial caldera volcano
- Airborne LiDAR data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

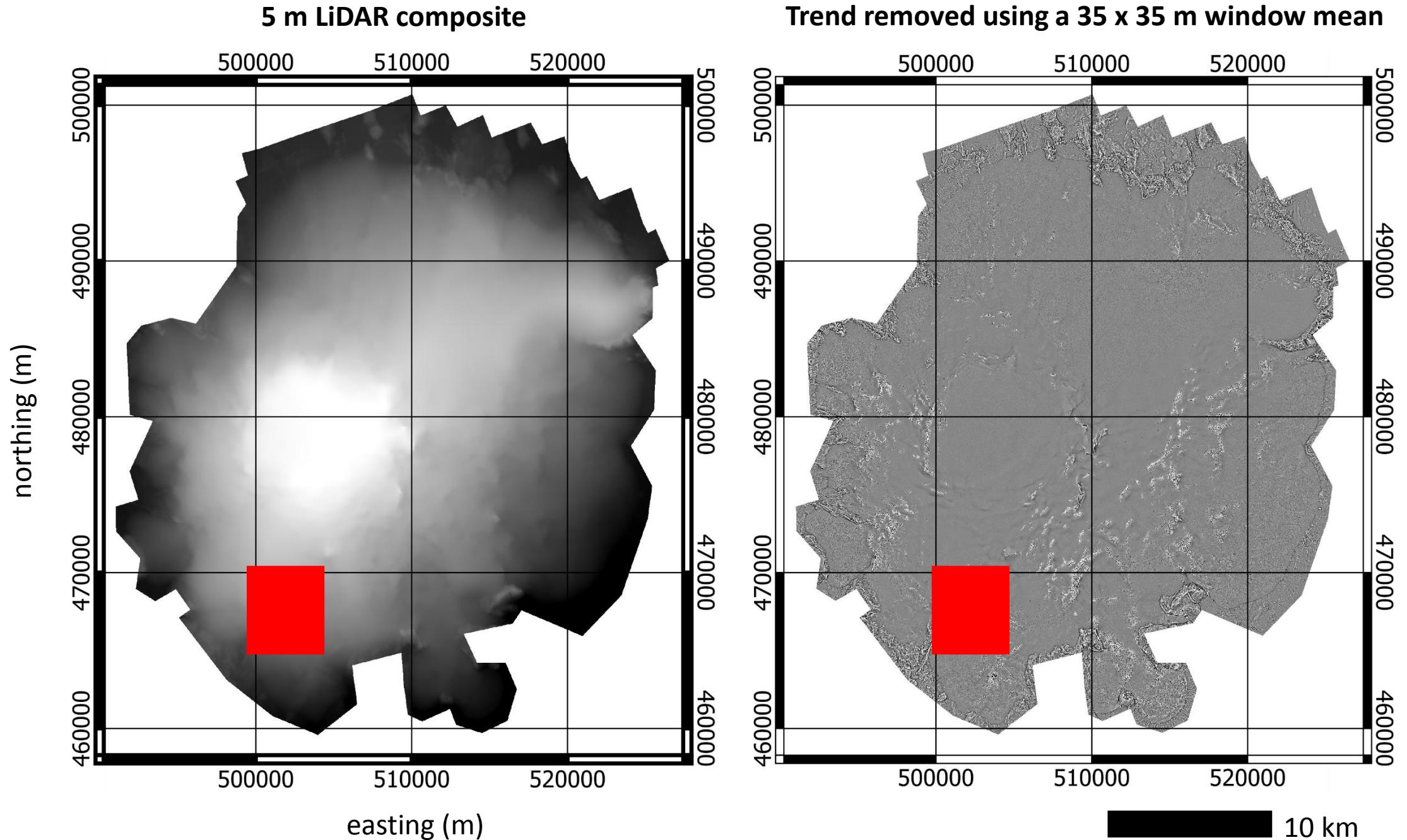


Copyright © Free Vector Maps.com

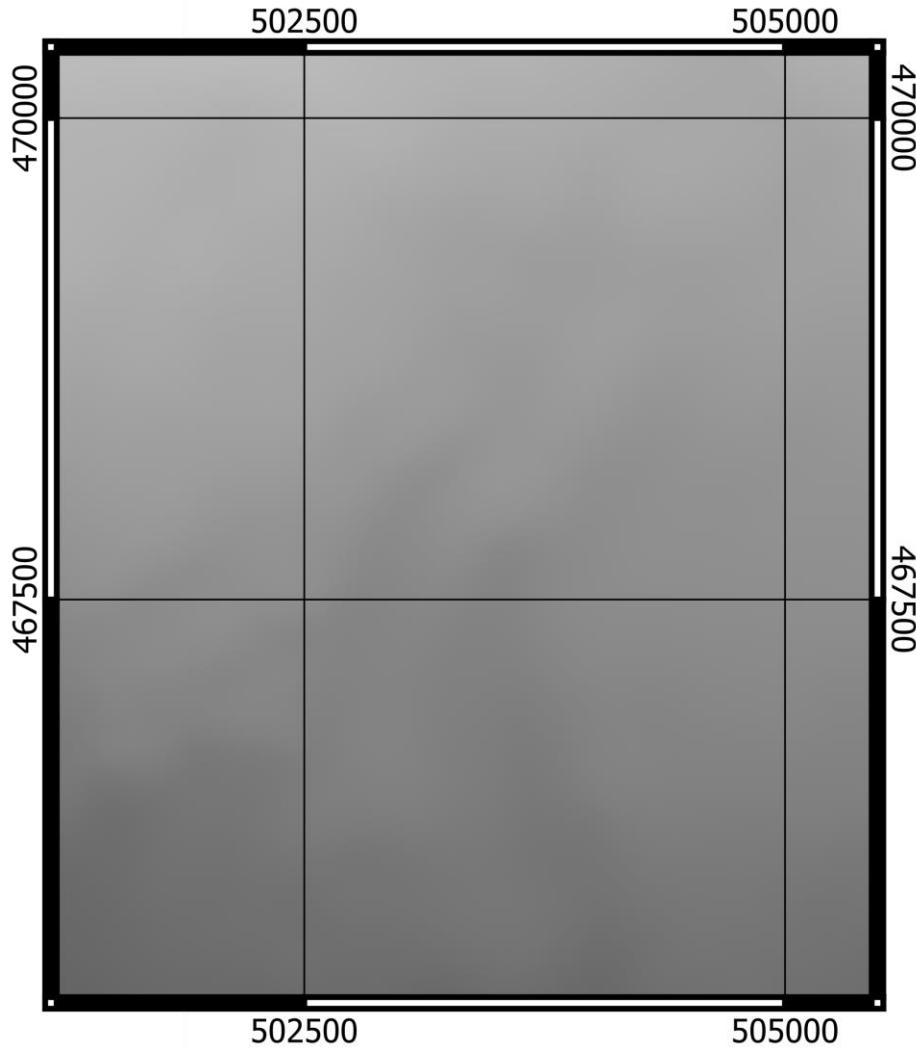
Iceland with Regions - Single Color by FreeVectorMaps.com

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

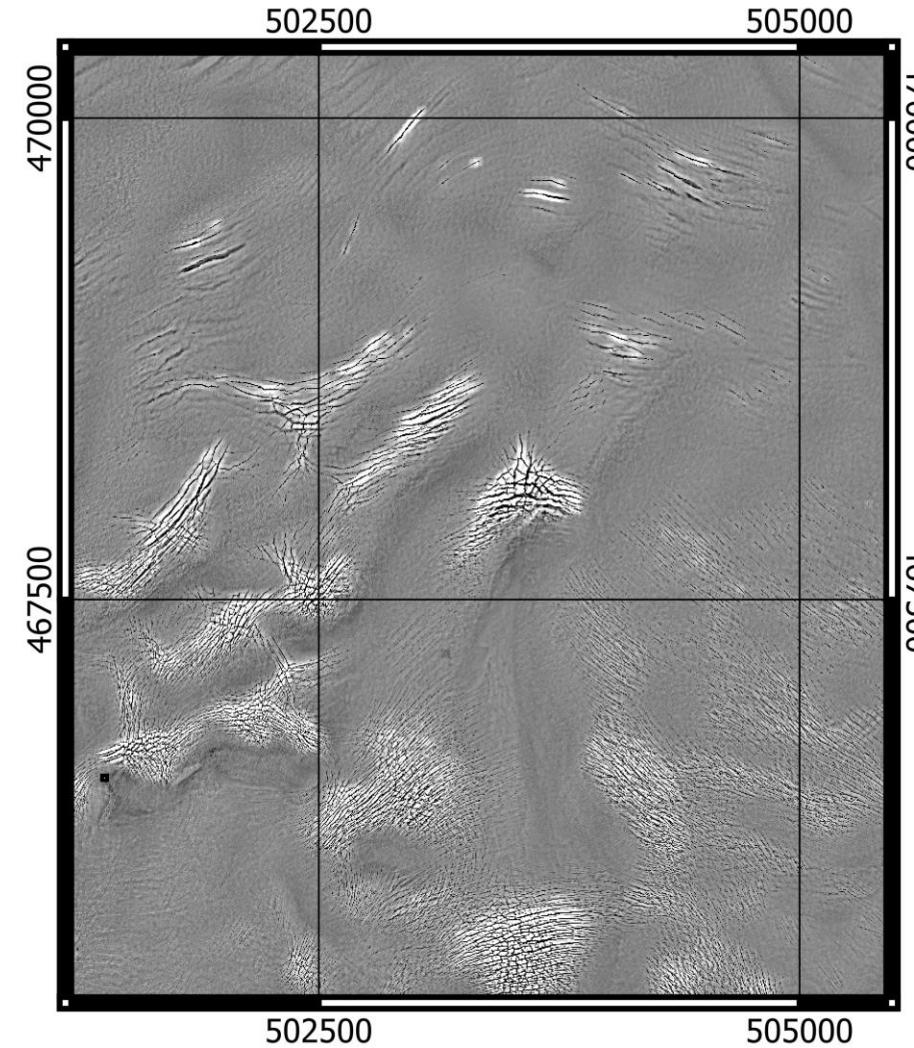




**5 m LiDAR composite**

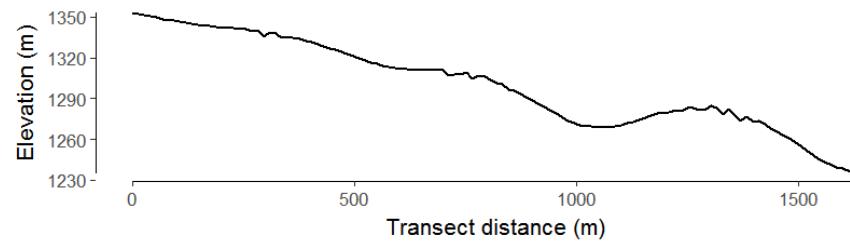
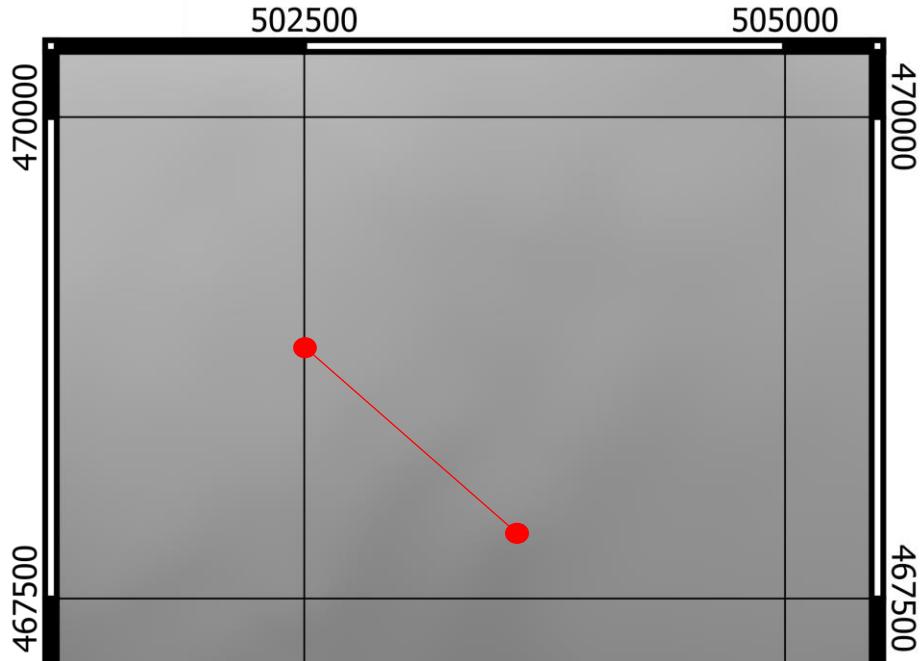


**Trend removed using a 35 x 35 m window mean**

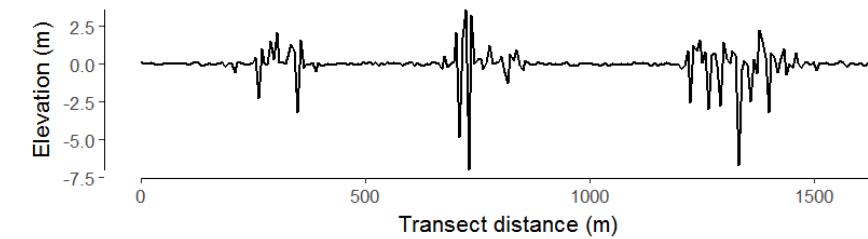
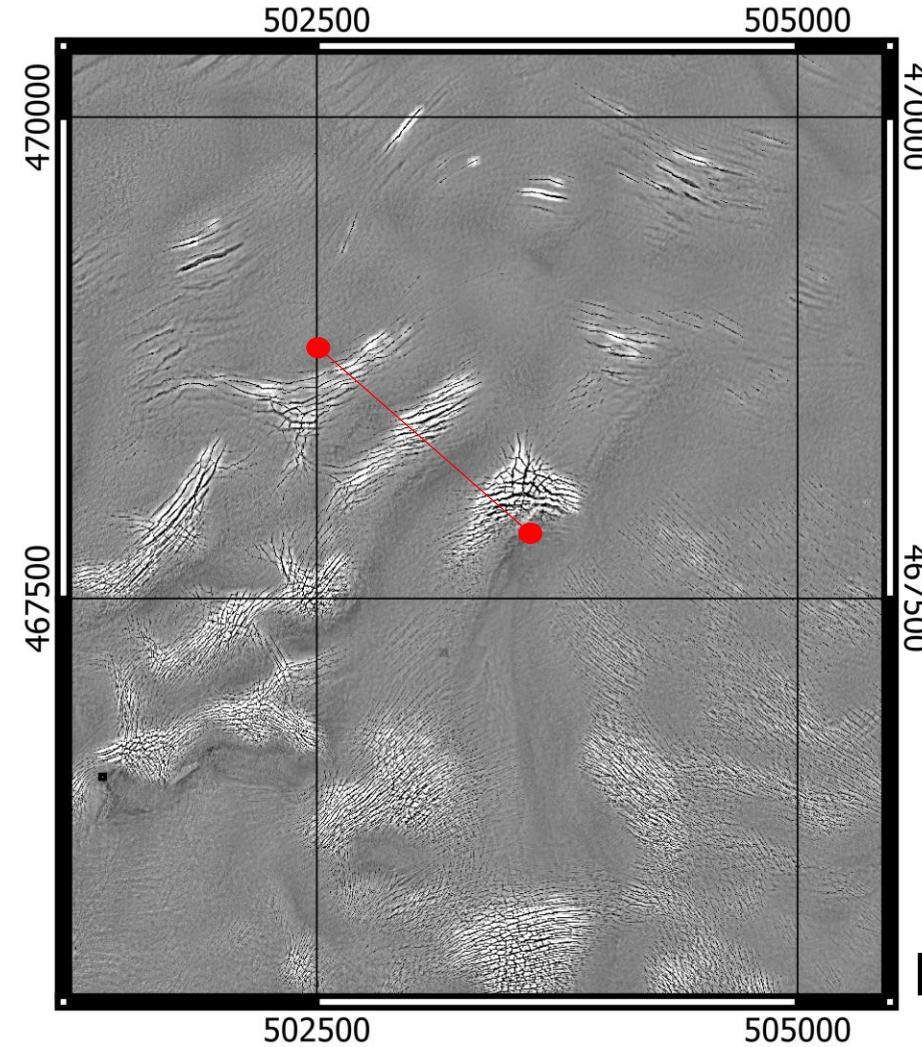


10 km

**5 m LiDAR composite**

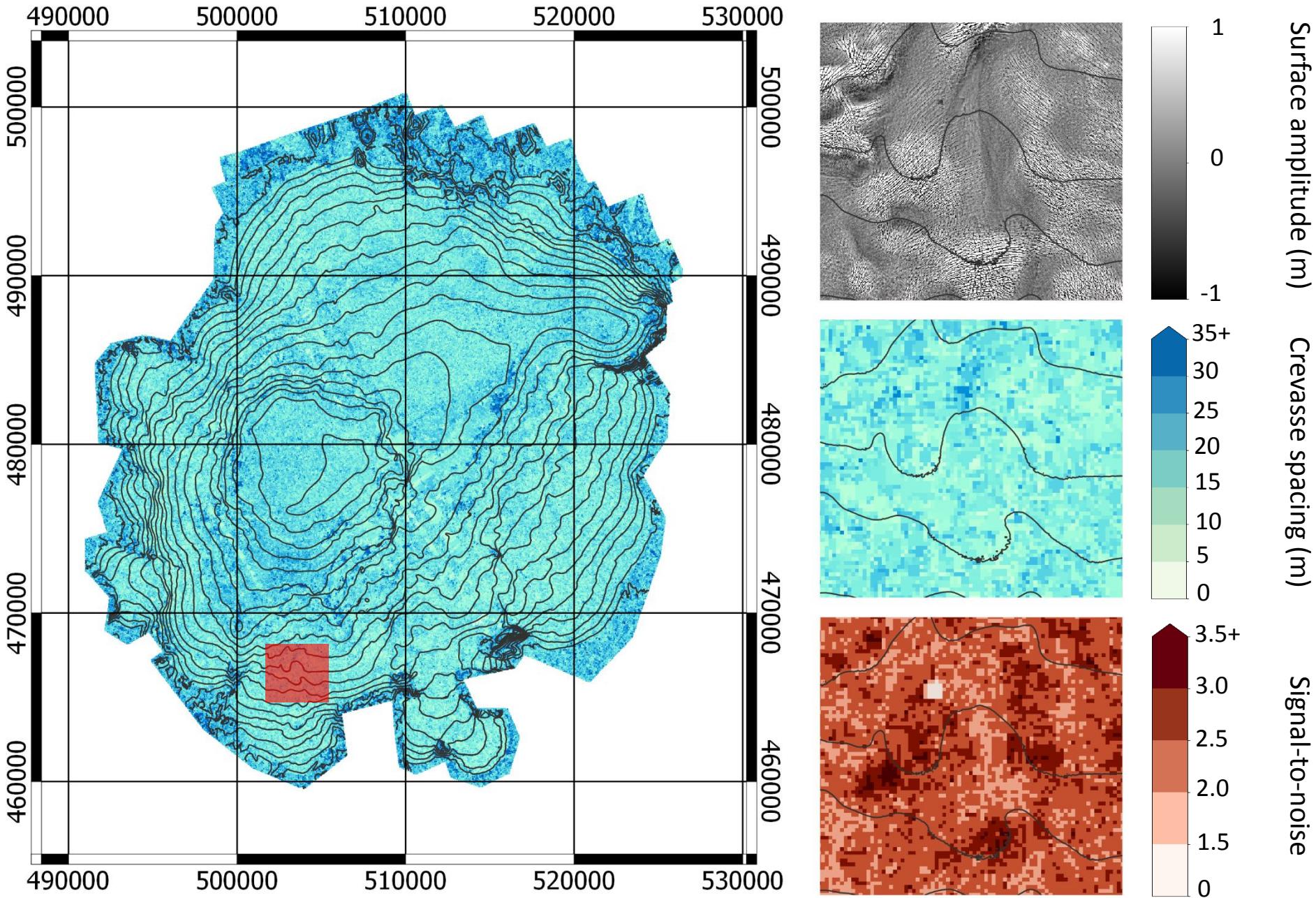


**Trend removed using a 35 x 35 m window mean**

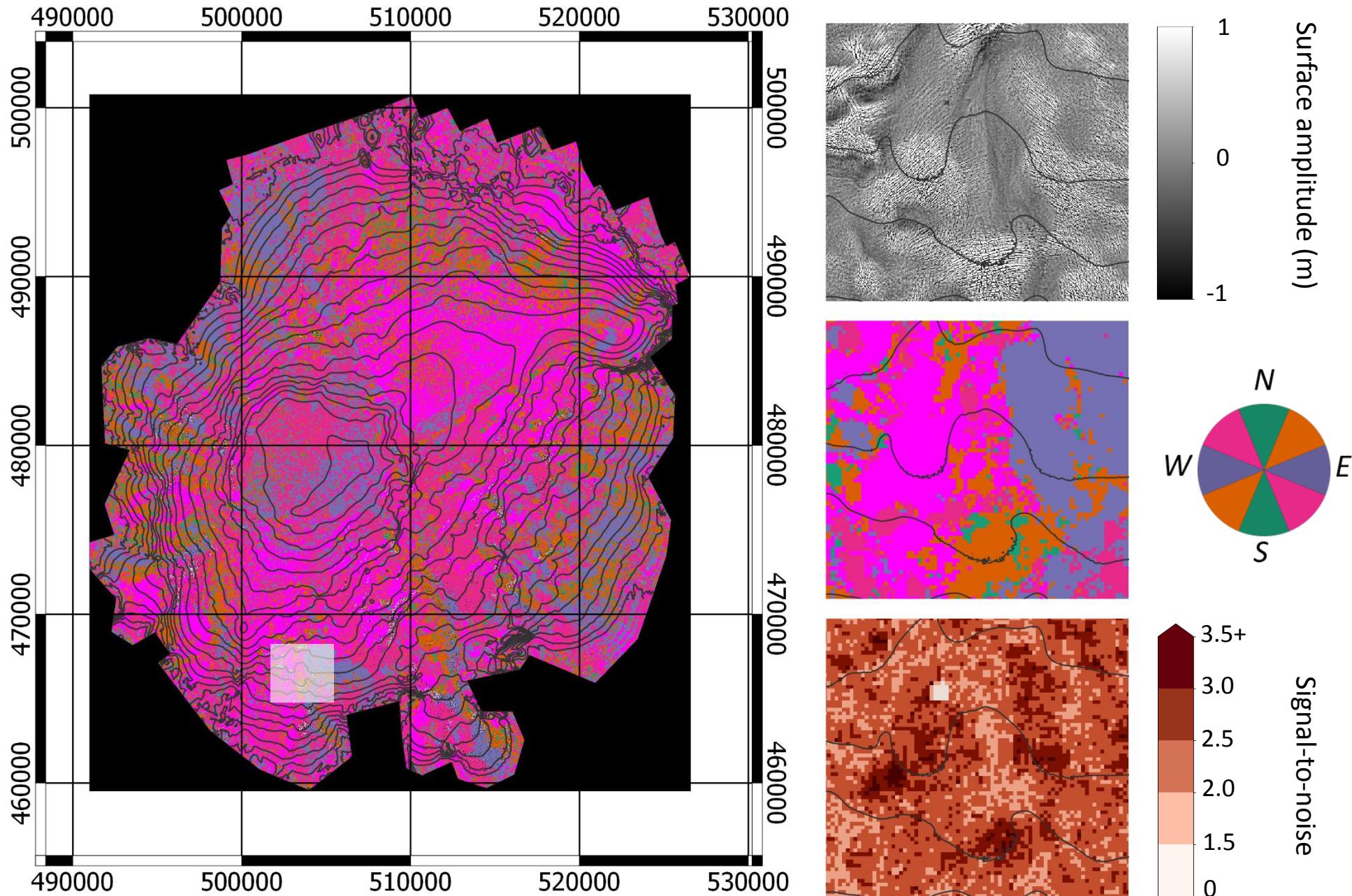


10 km

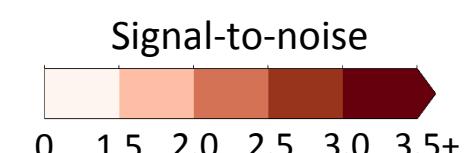
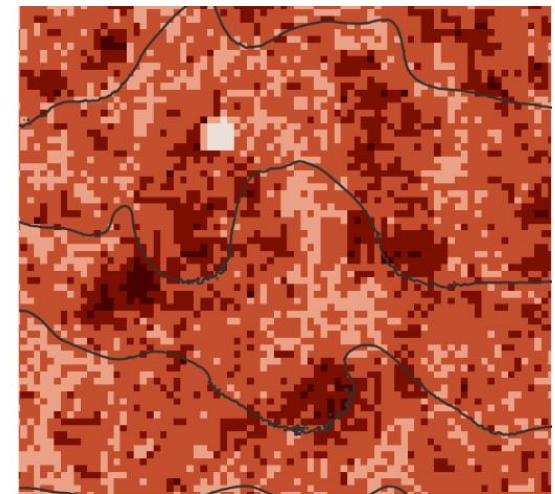
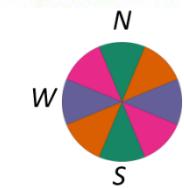
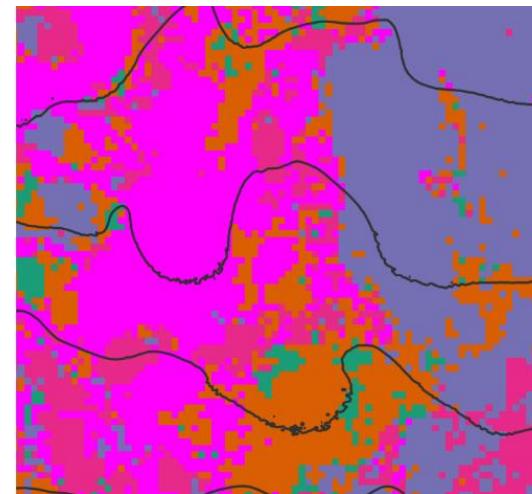
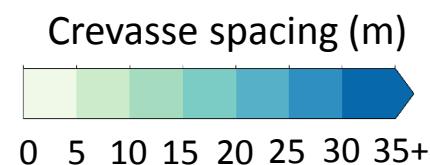
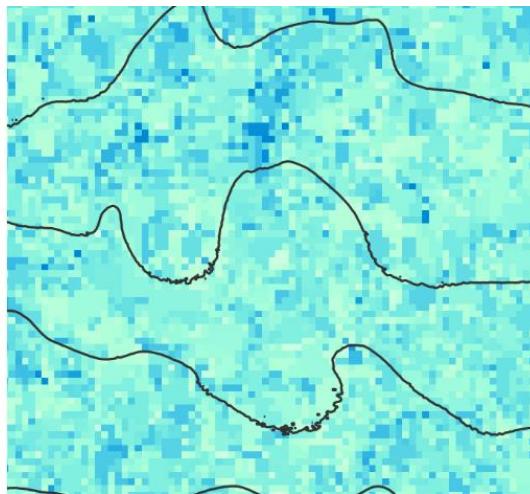
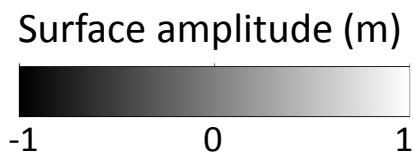
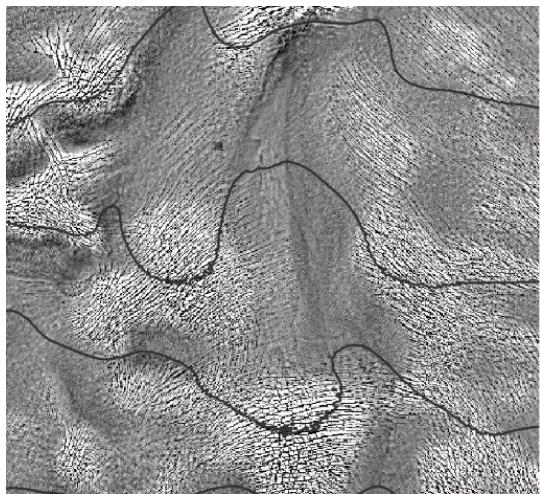
Spacing – window: 155 m | step: 35 m



# Orientation – window: 155 m | step: 35 m

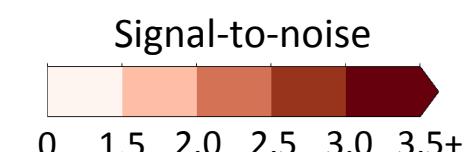
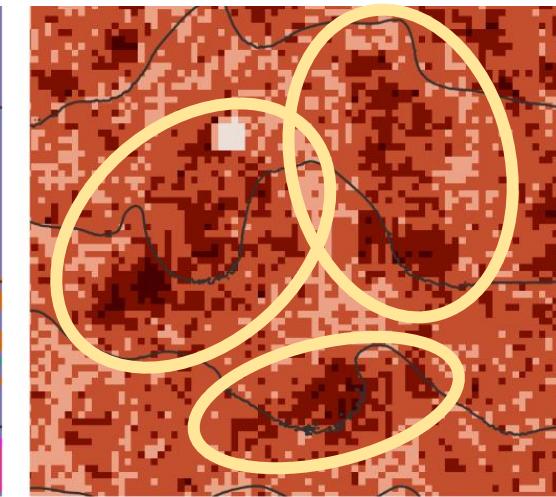
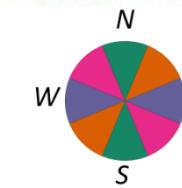
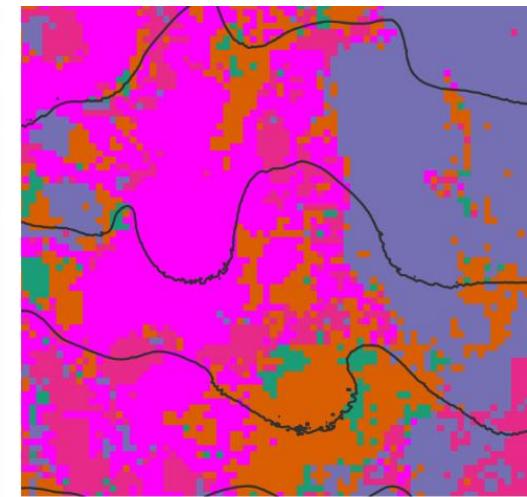
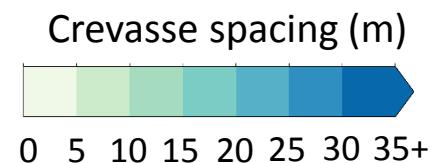
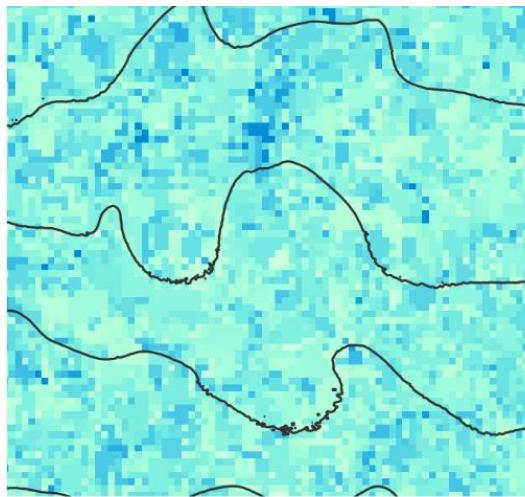
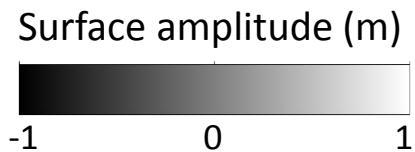
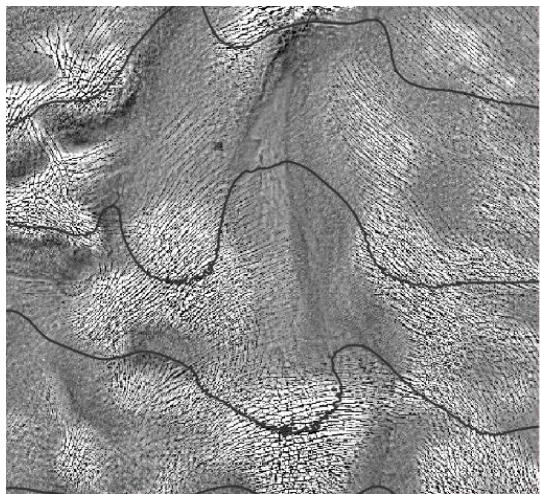


# Spacing, orientation and SNR – window: 155 m | step: 35 m



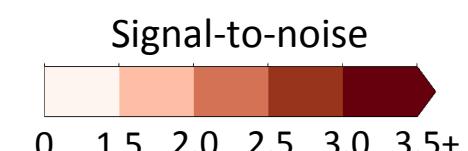
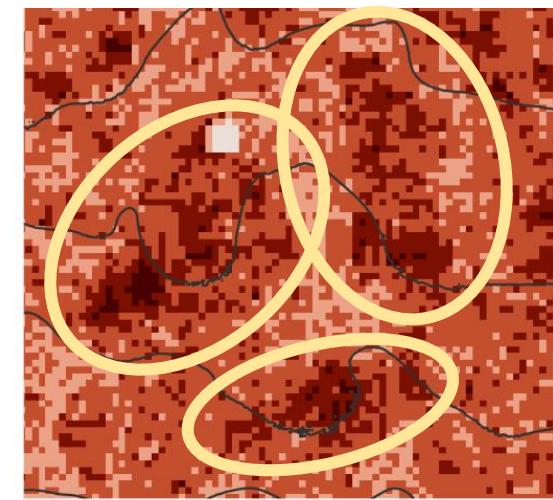
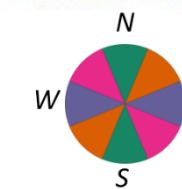
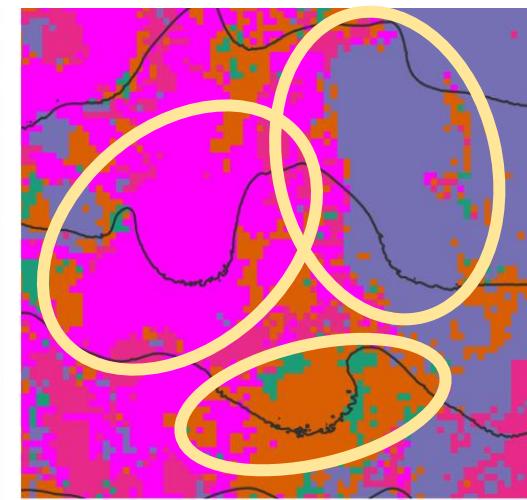
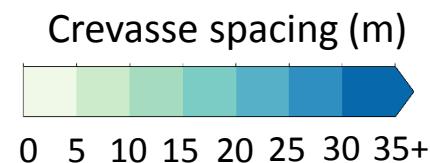
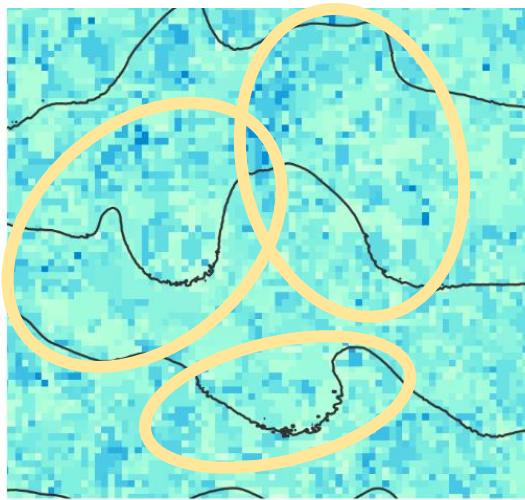
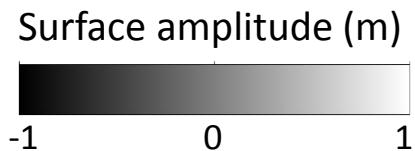
2 km

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



2 km

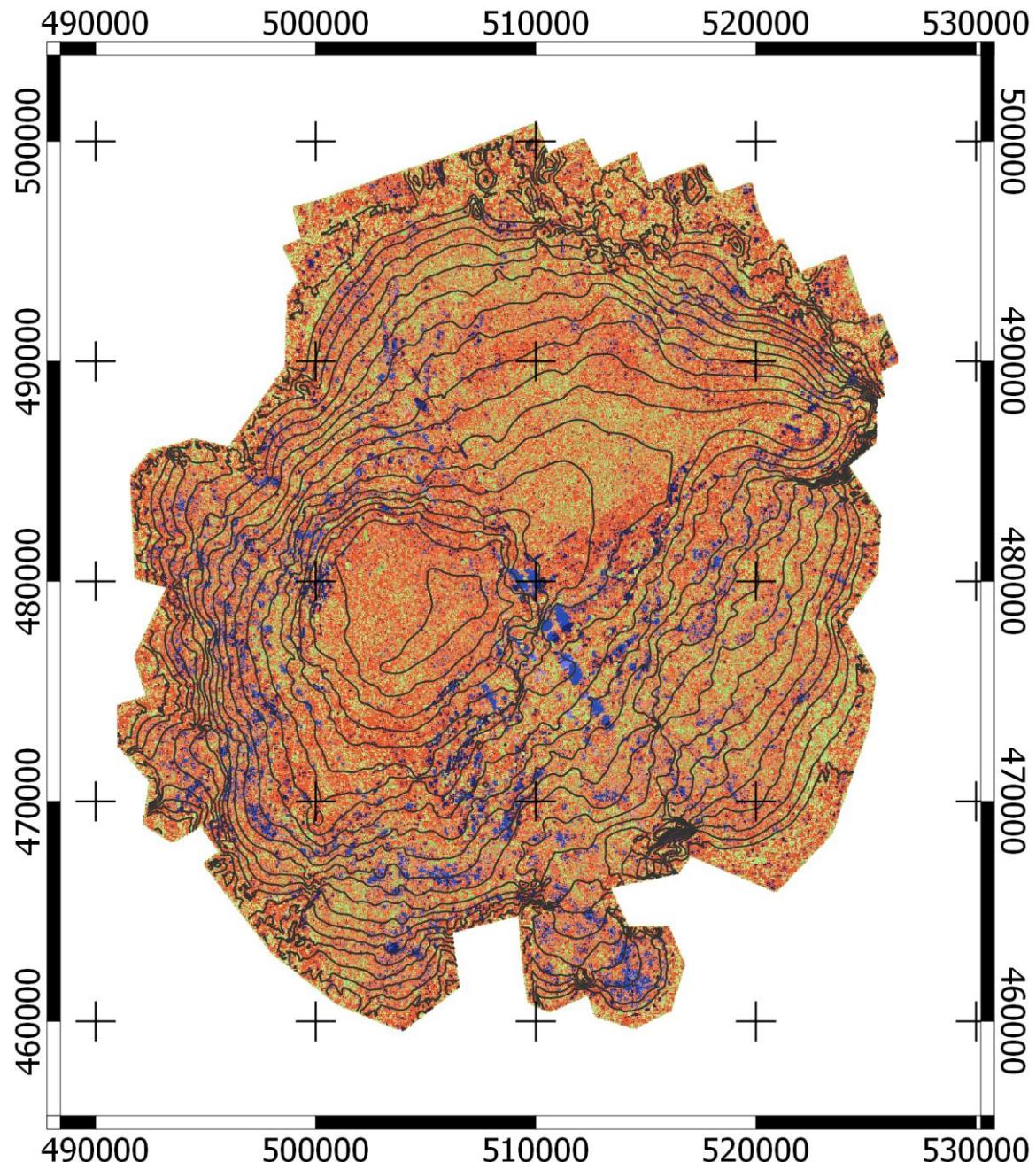
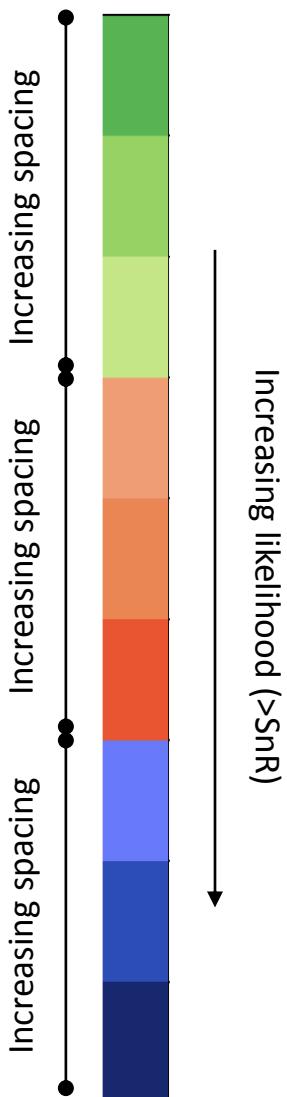
# Spacing, orientation and SNR – window: 155 m | step: 35 m



2 km

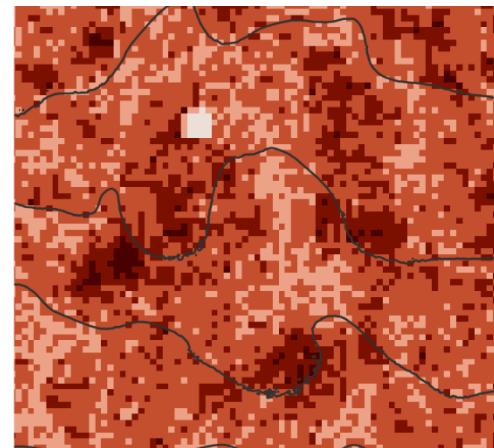
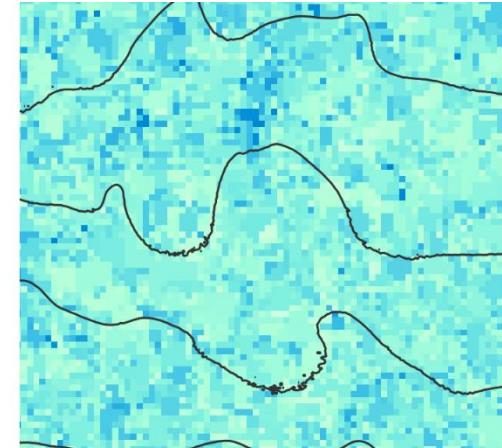
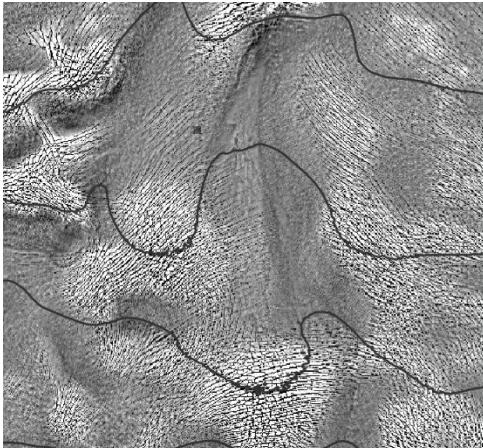
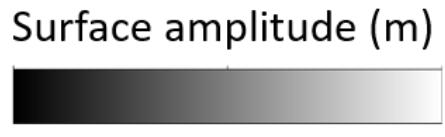
# Hazard mapping potential

- 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.

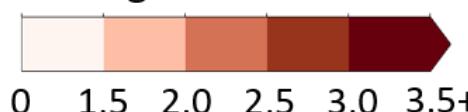


# Hazard mapping potential

- *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 investigation

## **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://github.com/Chris35Wills/LFMapper>

<https://zenodo.org/record/1216905#.Ws4JVH--m00>

Please quote  
the DOI if  
you use the  
code!



[chrwil@bgs.ac.uk](mailto:chrwil@bgs.ac.uk)



Climate Change Consortium of Wales  
Consortiwm Newid Hinsawdd Cymru



**British  
Geological Survey**  
NATURAL ENVIRONMENT RESEARCH COUNCIL

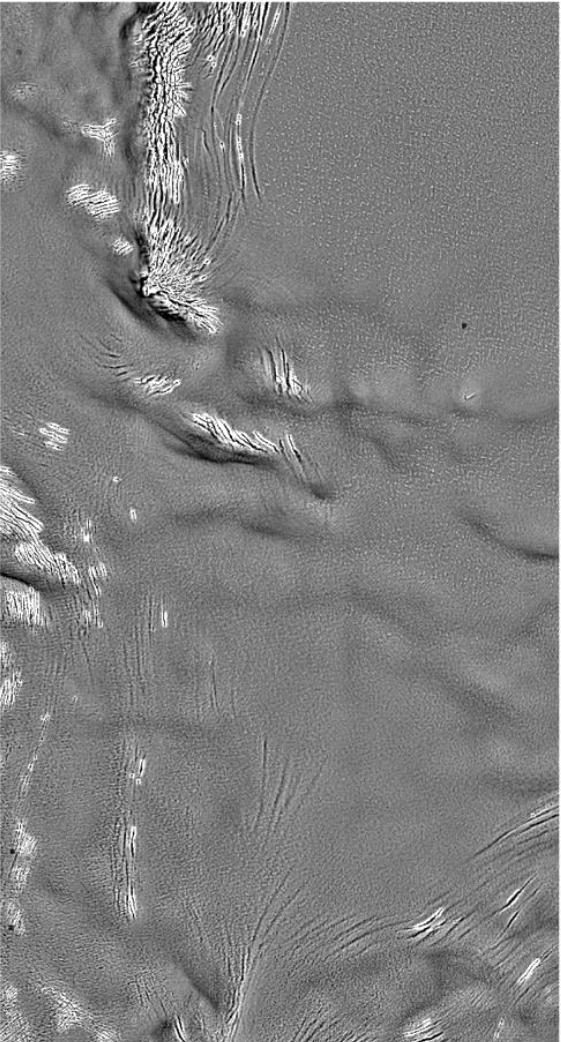
# References and further reading

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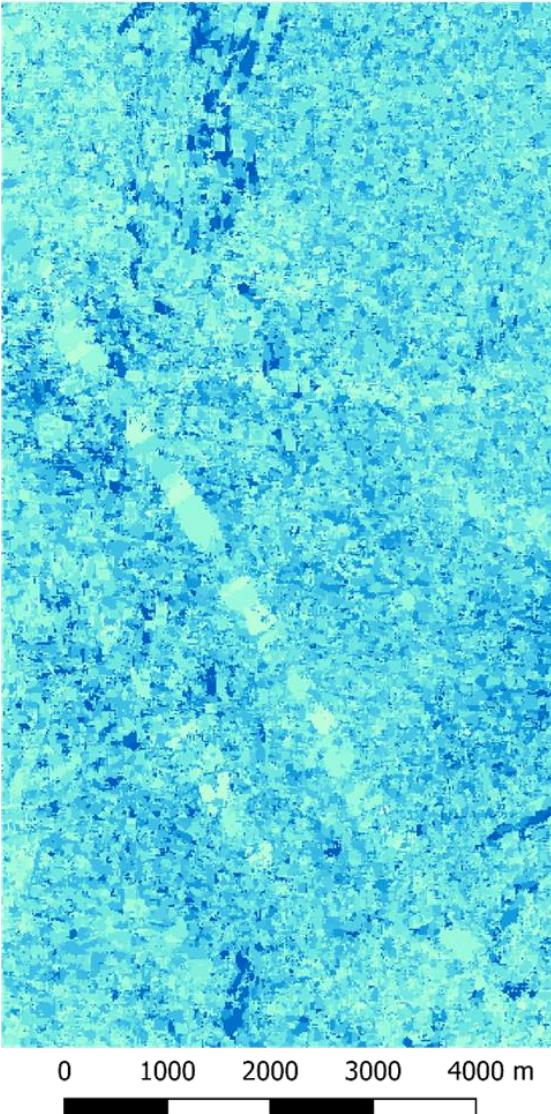


# Sensitivity – step size increases coarseness of output

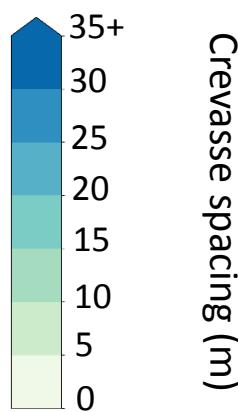
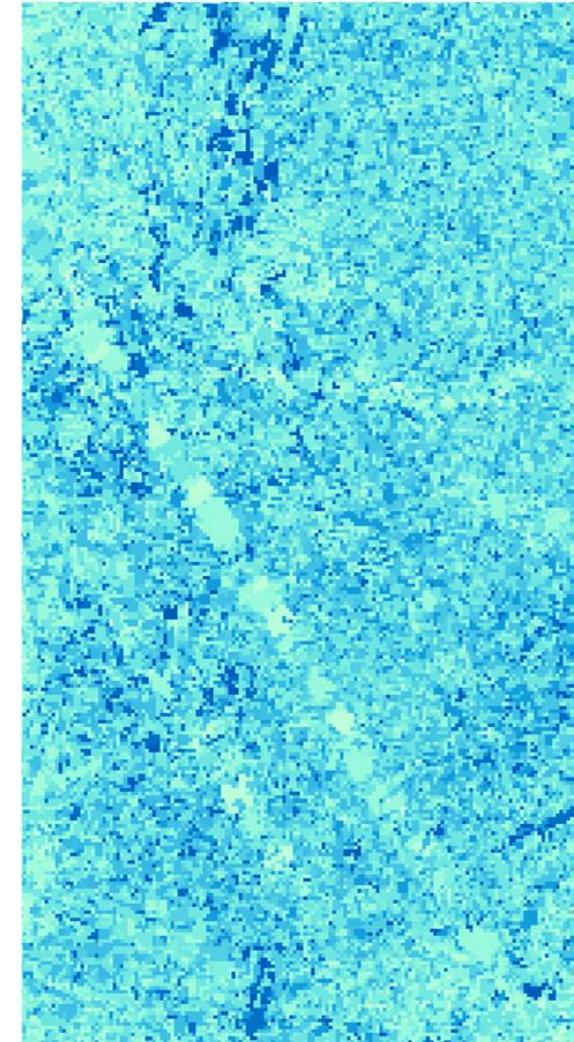
Glacier surface (flattened)  
Pixel: 5 m



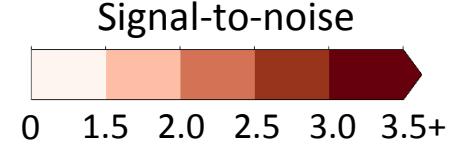
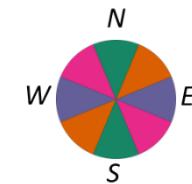
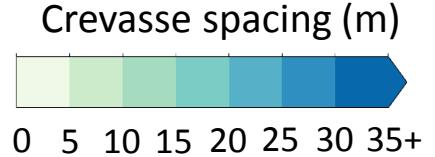
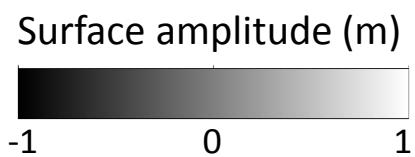
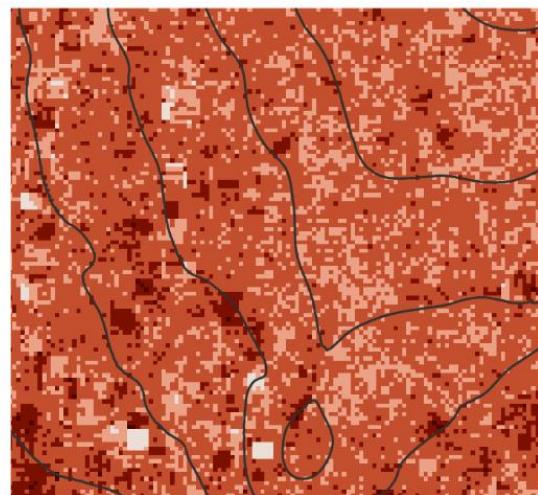
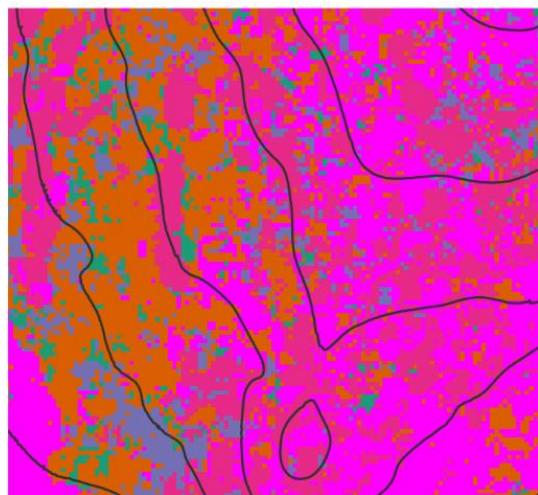
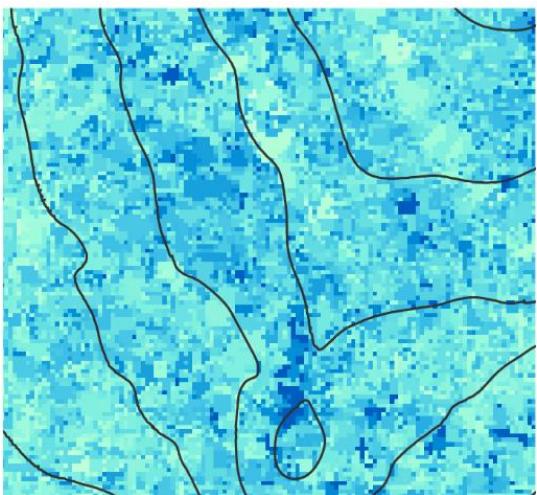
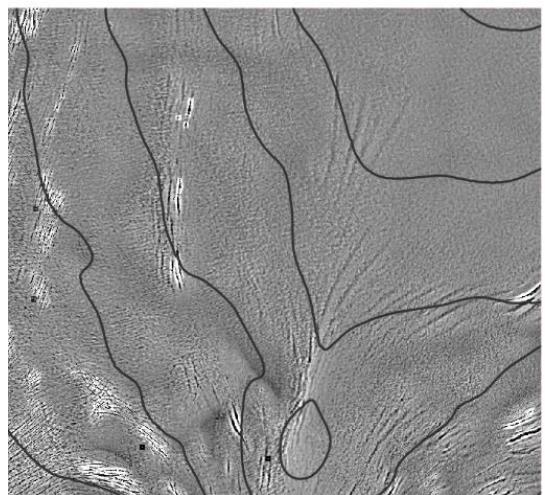
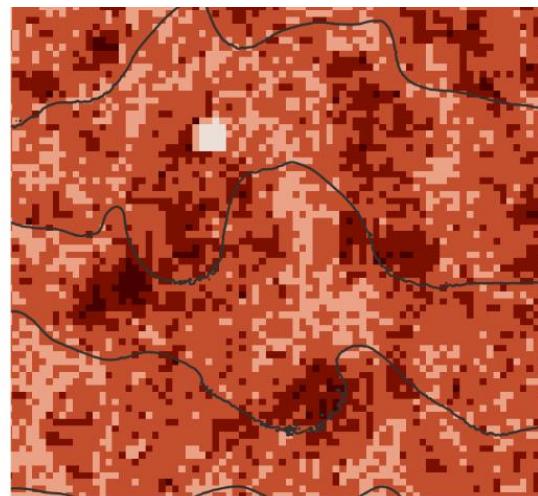
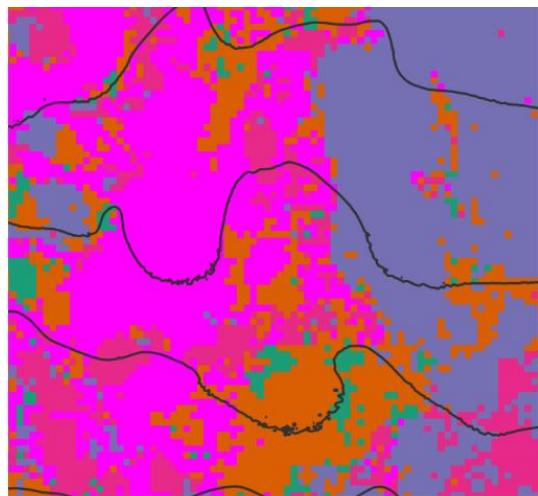
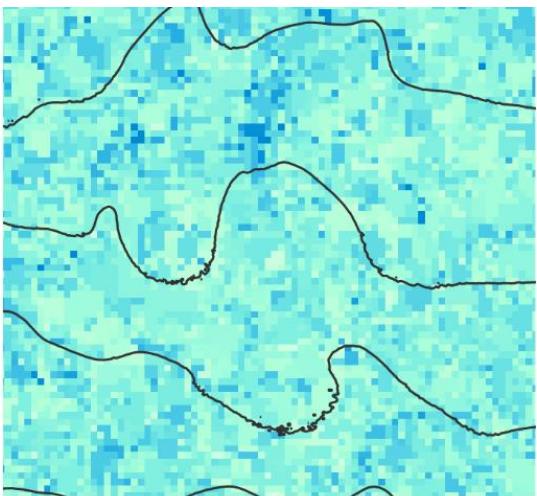
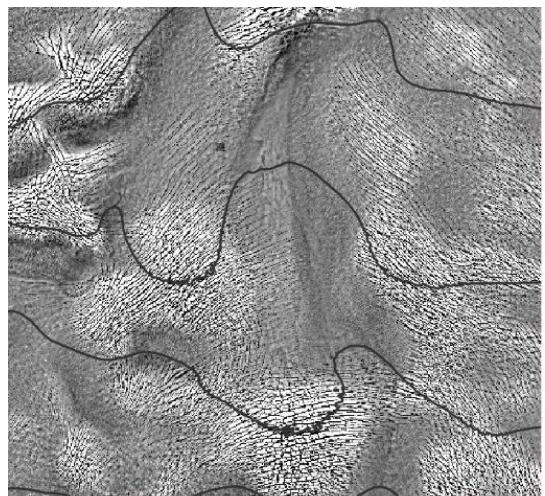
Spacing  
Win: 105 m<sup>2</sup> Step: 15 m



Spacing  
Win: 105 m<sup>2</sup> Step: 35 m

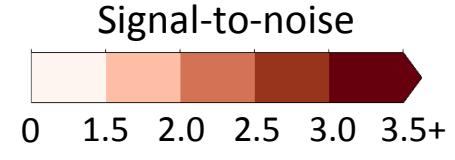
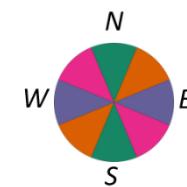
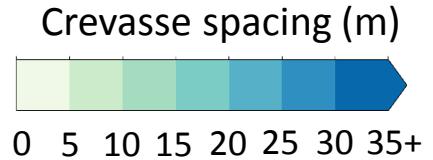
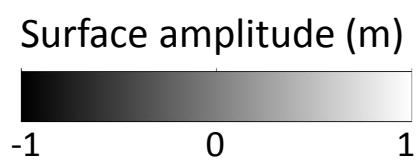
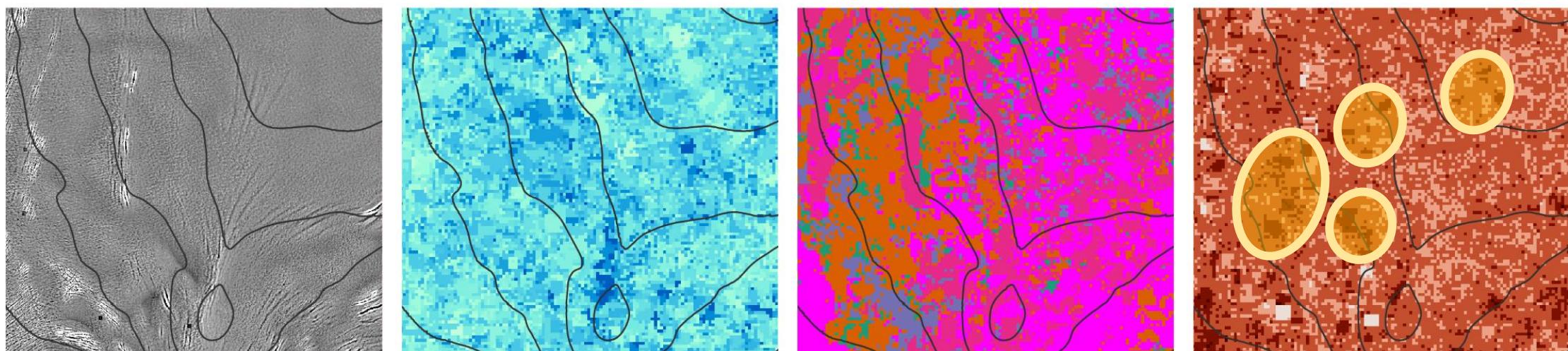
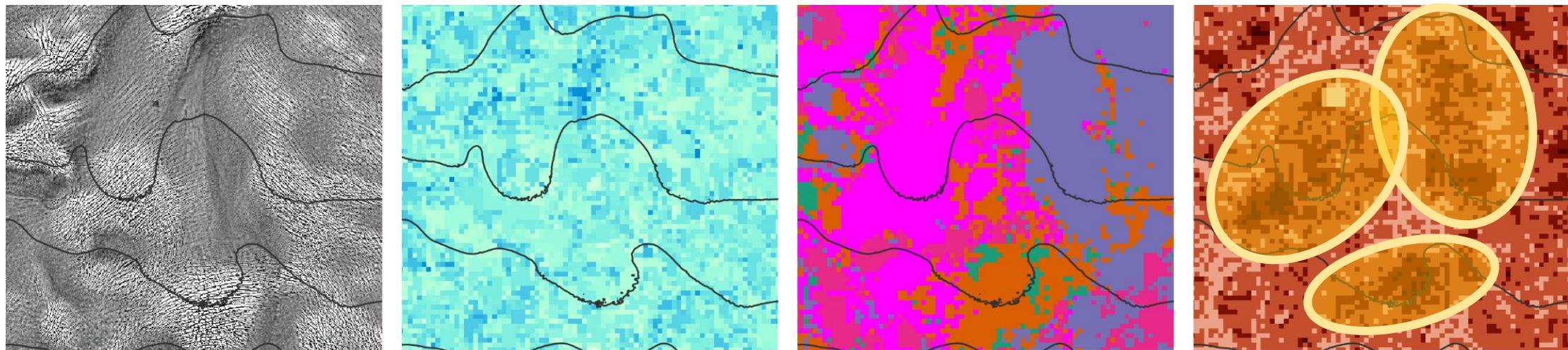


# Spacing, orientation and SNR – window: 155 m | step: 35 m



2 km

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



2 km