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

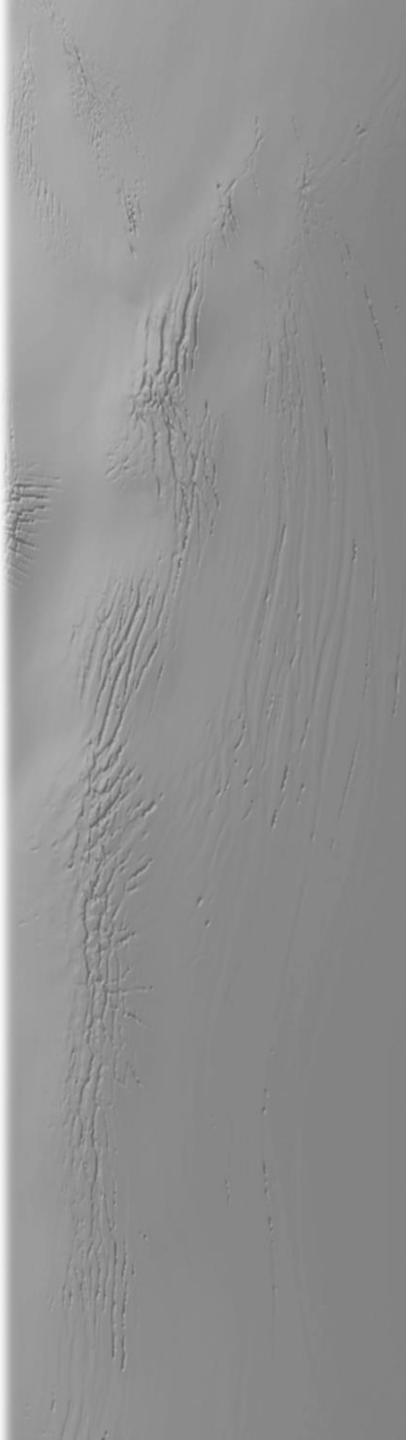
- satellite imagery, UAVs, mobiles
- data only valuable if they are used!

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

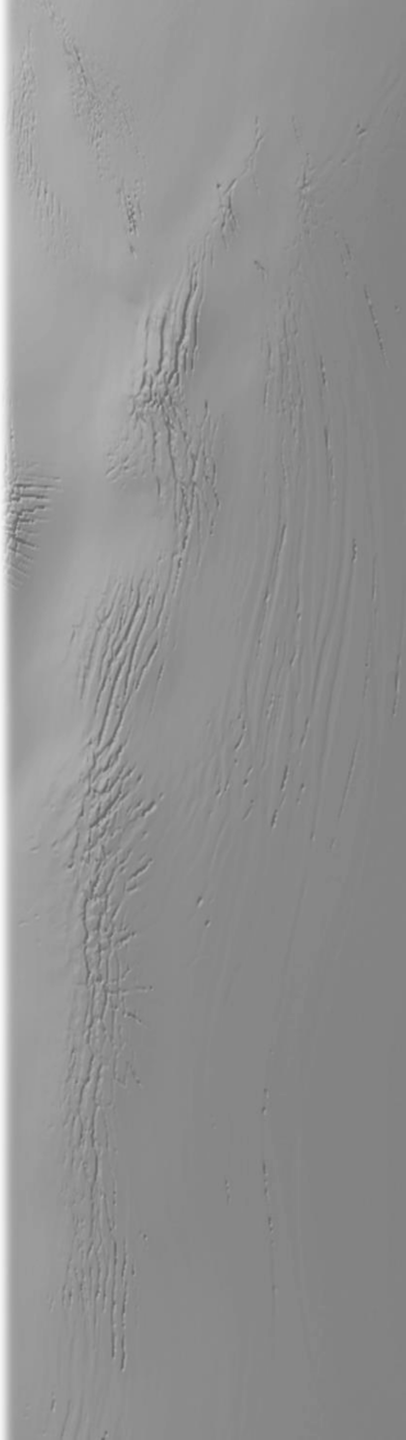


This is…

- 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)

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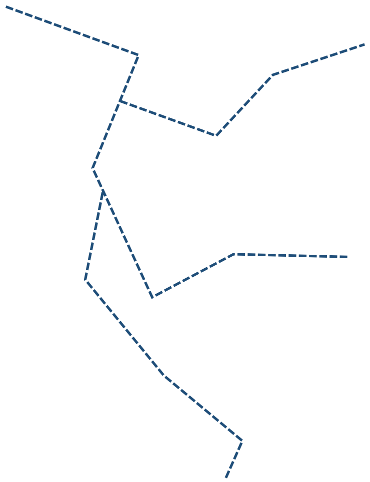
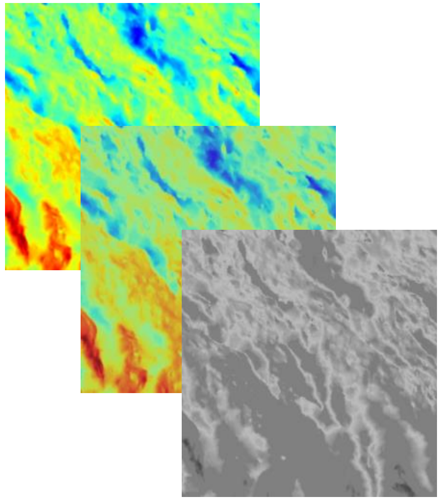
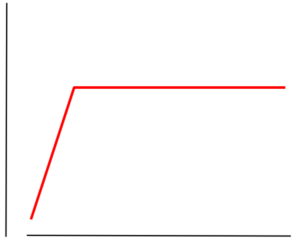
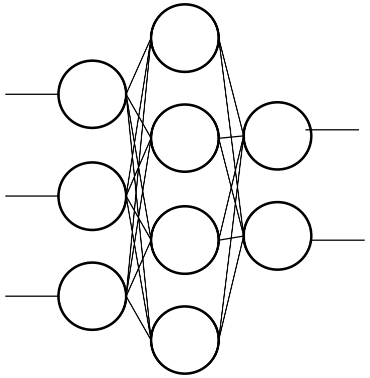


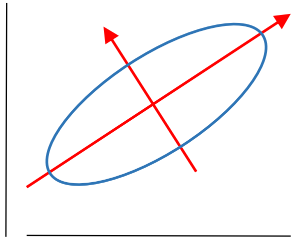


Rivera et al., 2014

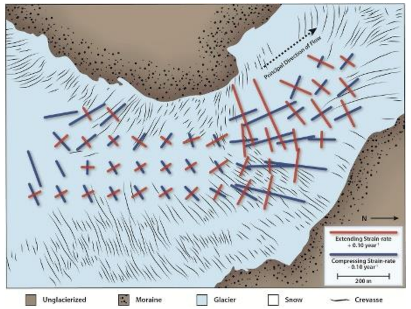




Herzfeld, 2008, 2011



Jóhannesson et al., 2011



Reproduced from Colgan et al., 2015

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

Existing approaches

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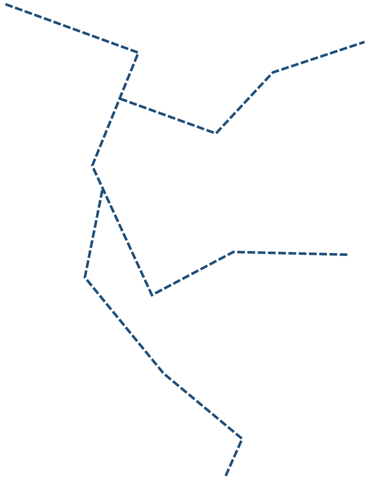

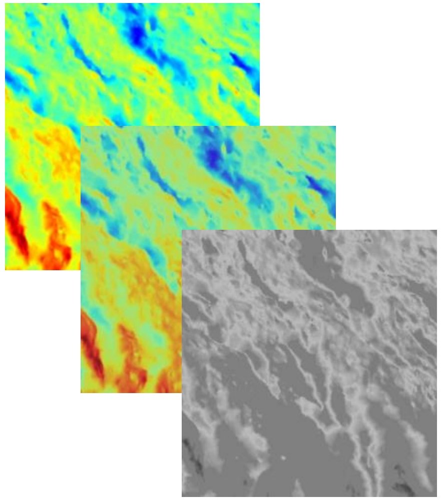

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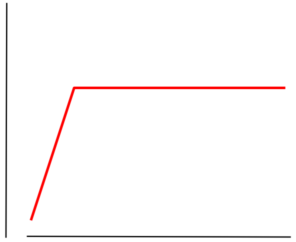

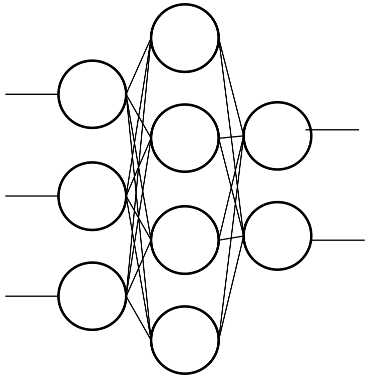

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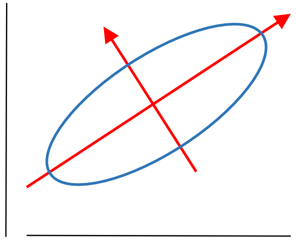

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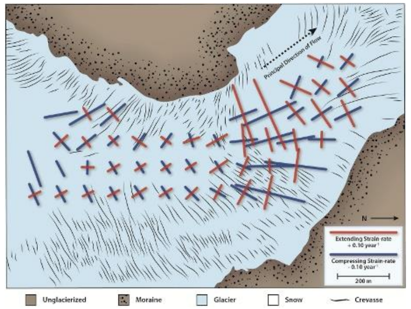

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See Colgan et al. (2015) for a review…

Problems

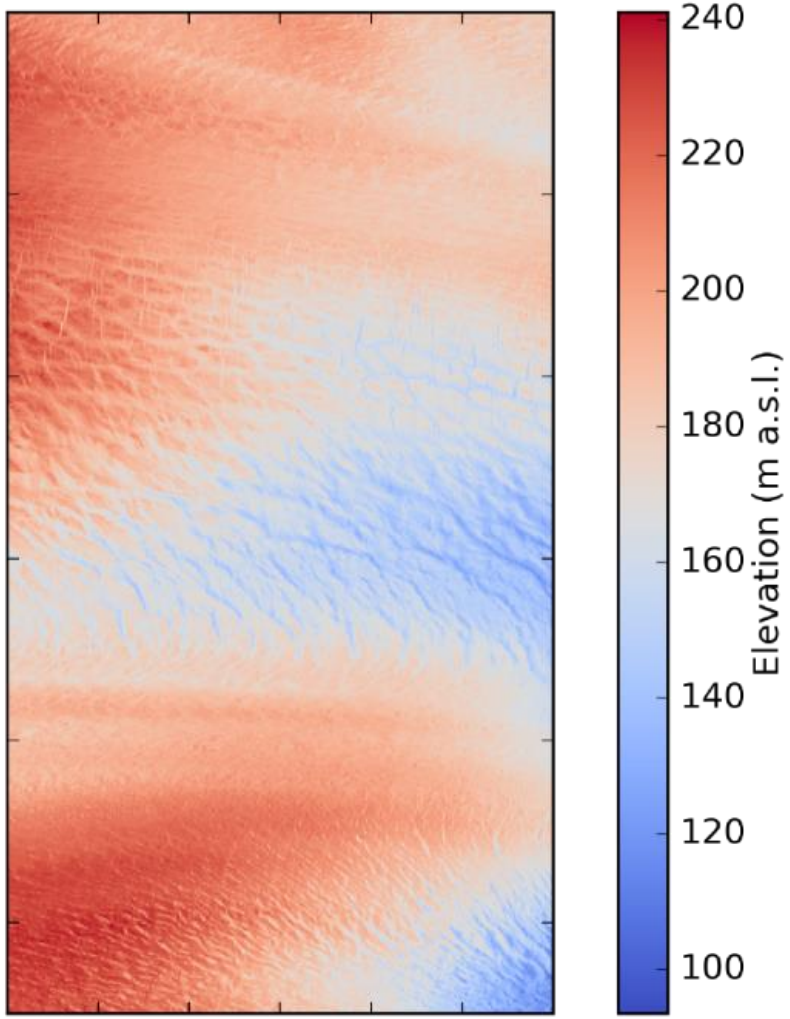
- Time consuming
- Code often not available!
- Presence/absence
- Complex nature of crevasses

What we present

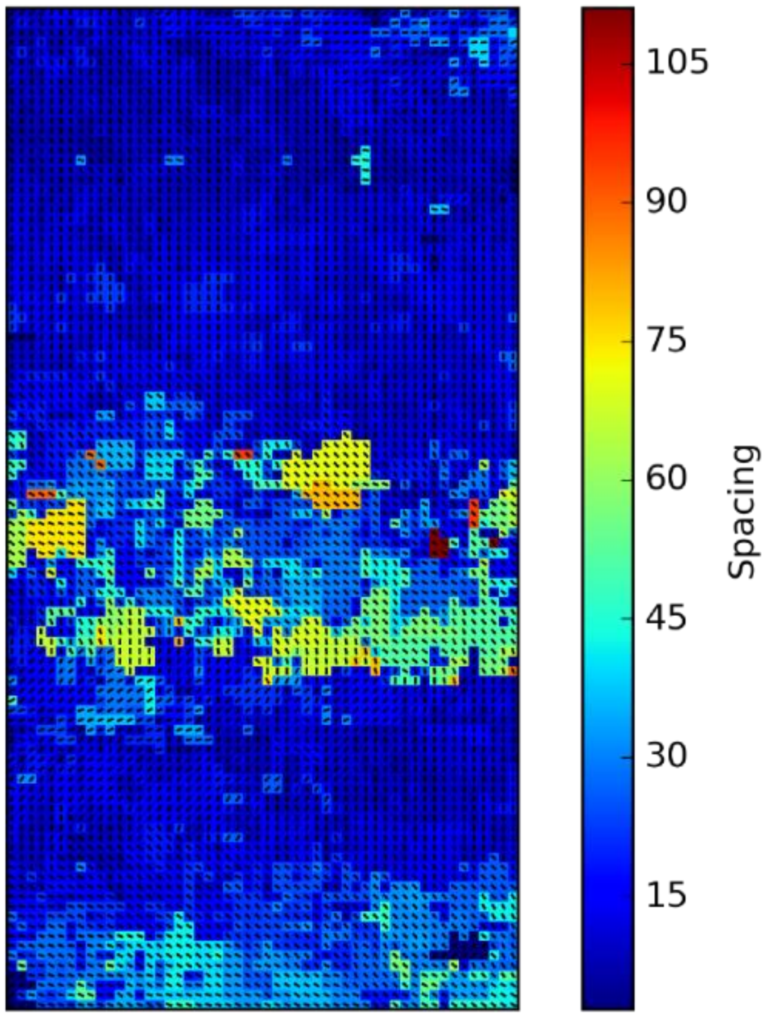
- Fast, scalable and repeatable procedure
- Generalisation of areas in an image
- Extraction of metrics

spacing, orientation, SnR

LFMapper: Using the Fast Fourier Transform for feature classification

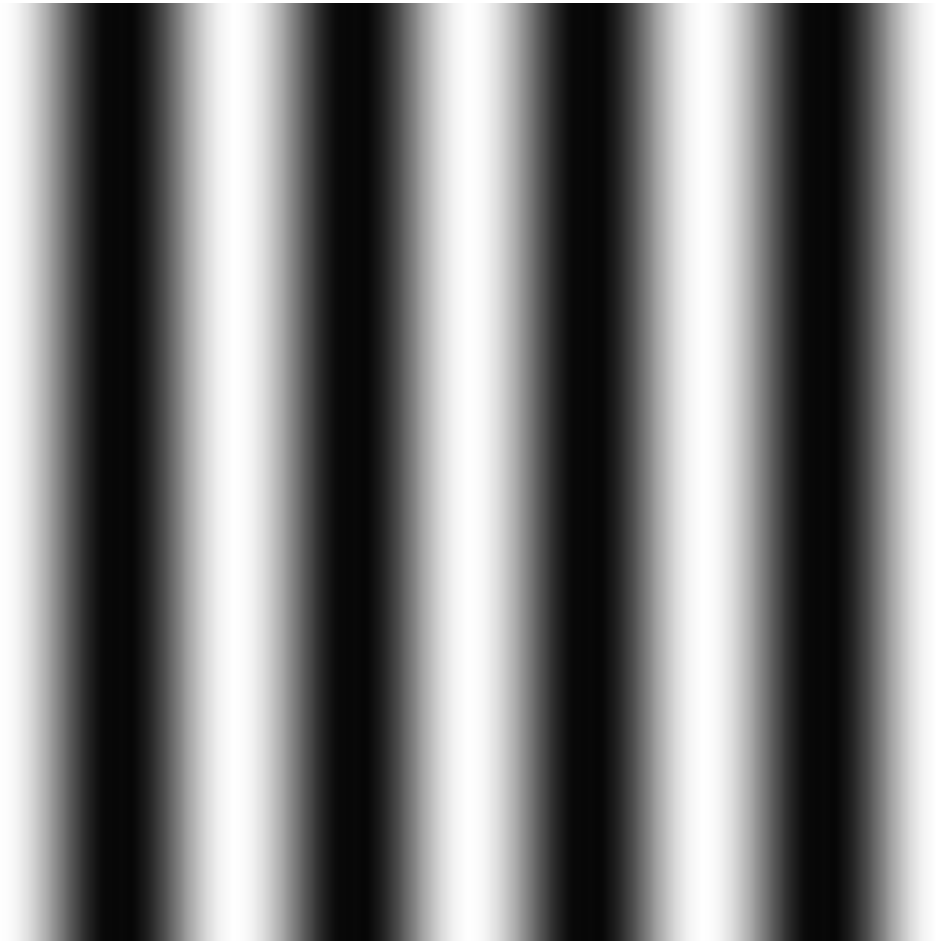


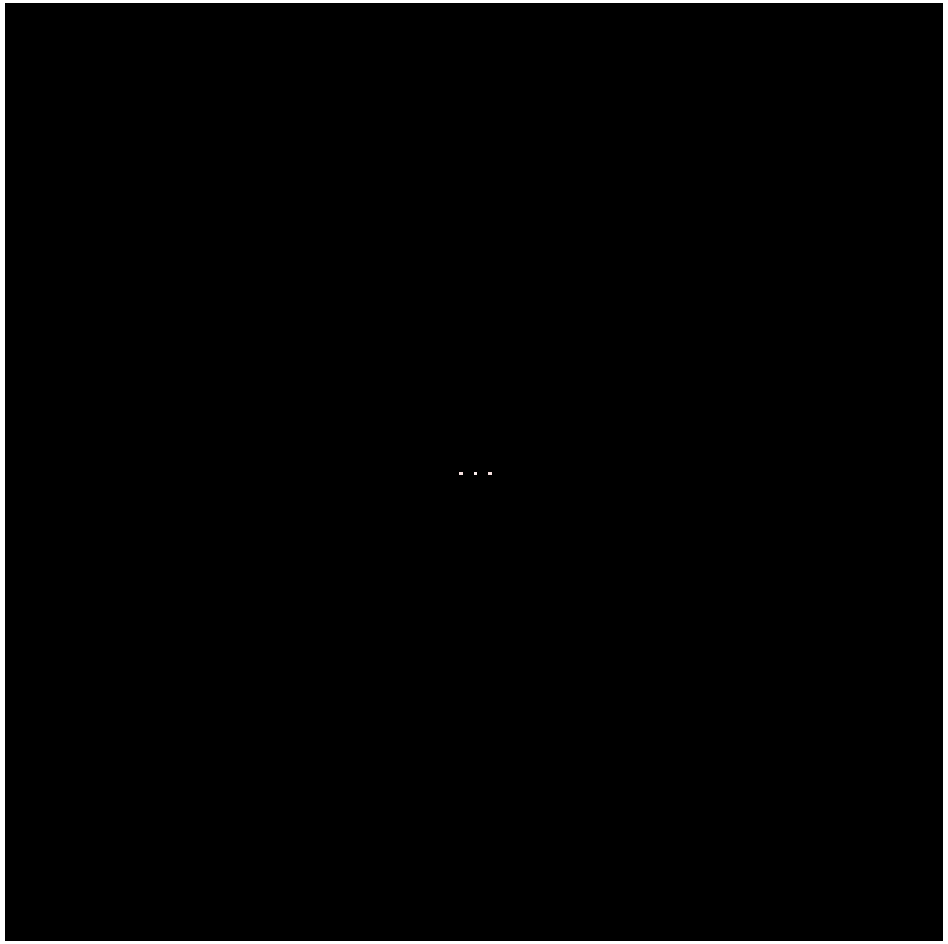
Glacier surface raster (image or DEM)



Orientation and spacing matrix (raster)

Visually interpreting an Fourier Transform plot



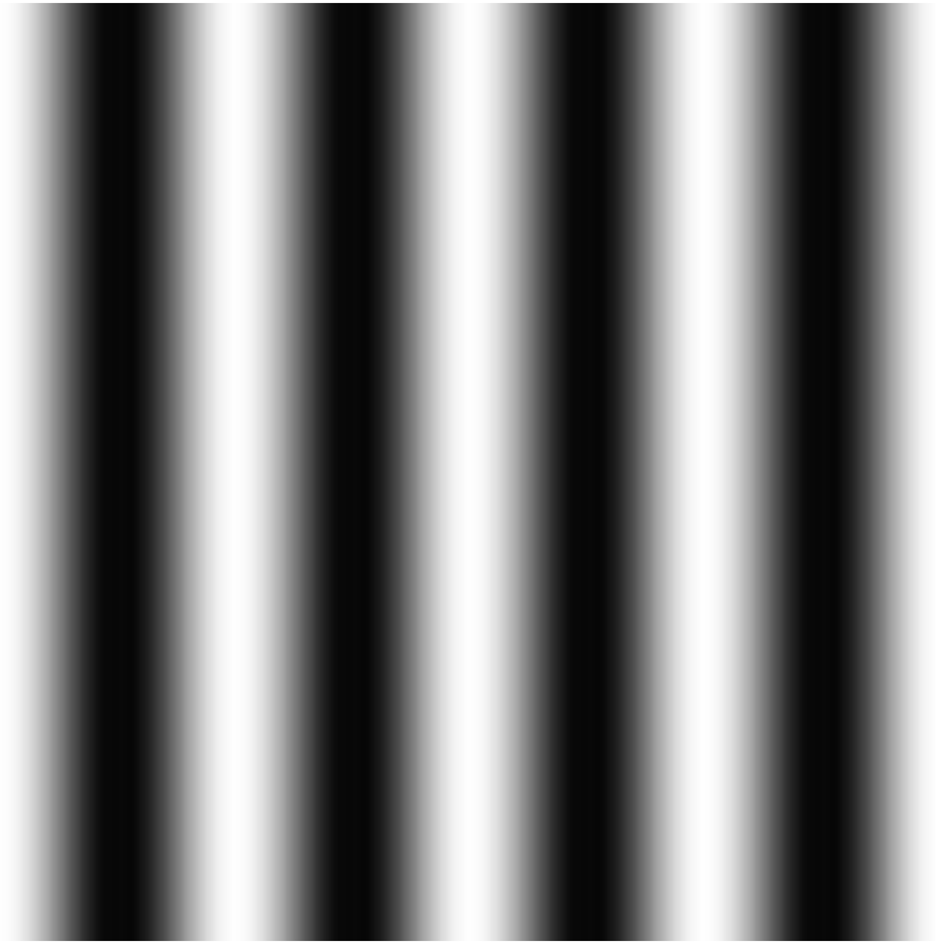


Taken from http://www.qsimaging.com/ccd_noise_interpret_ffts.html

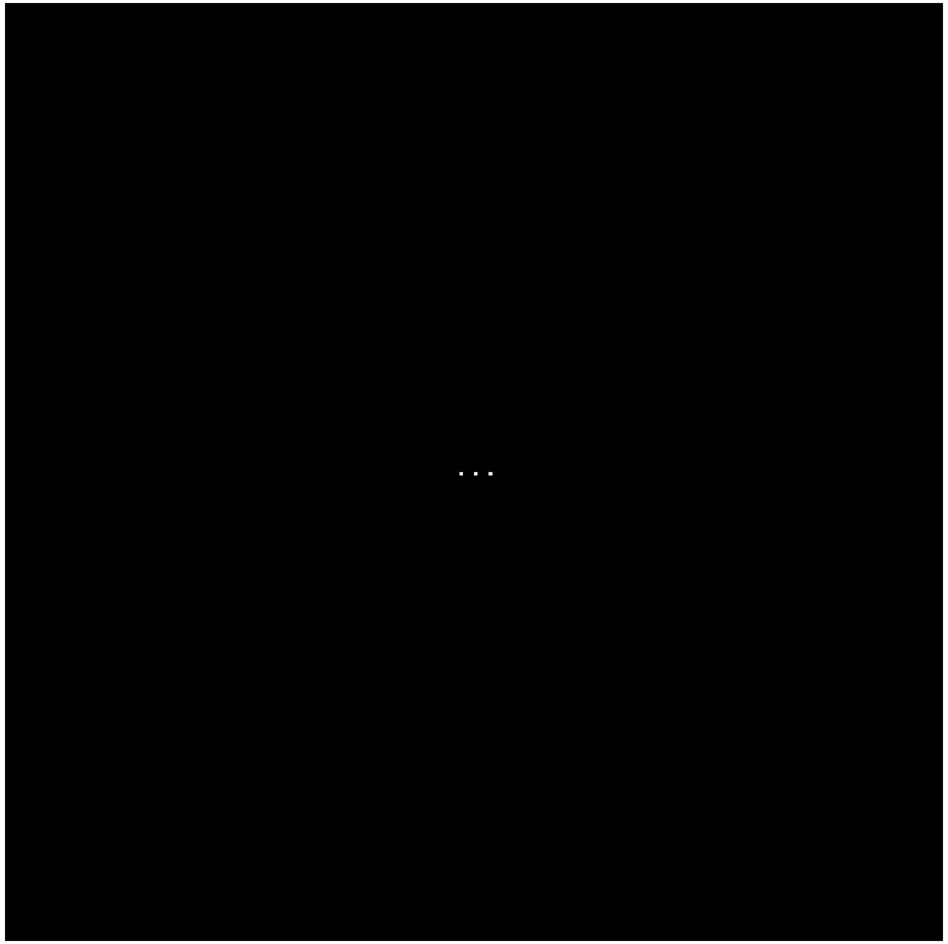
Visually interpreting an Fourier Transform plot

Rotationally symmetrical

Space



Frequency



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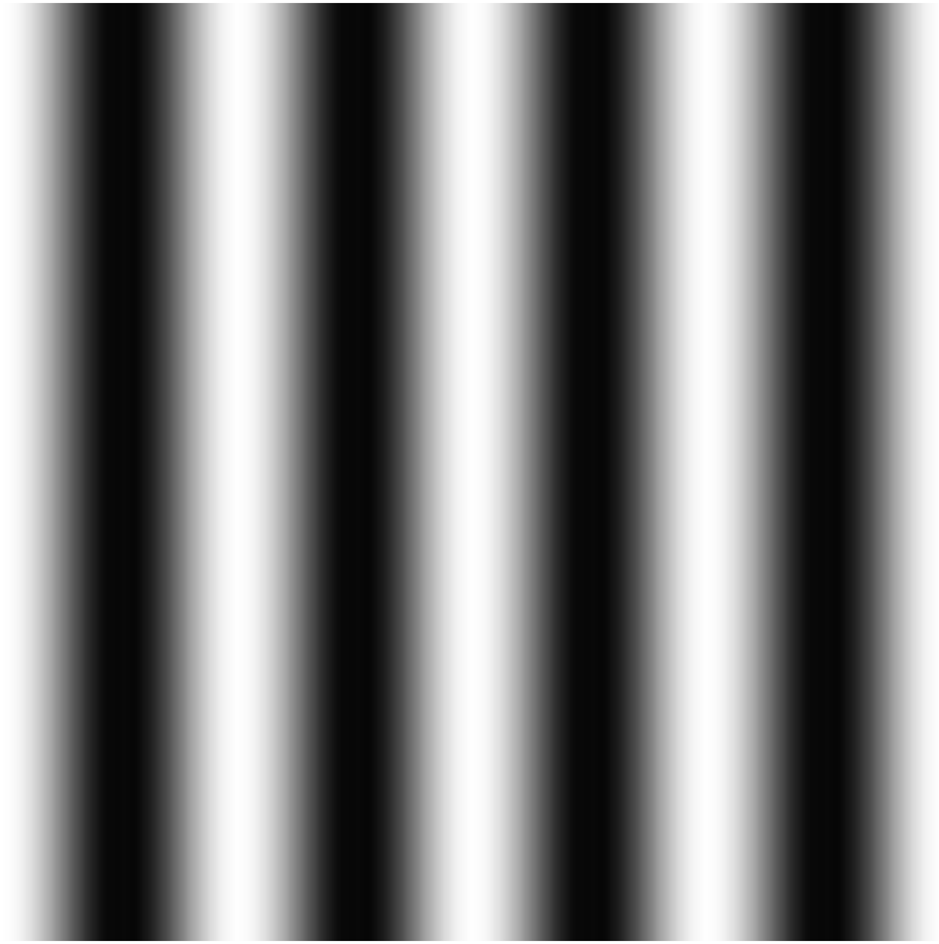

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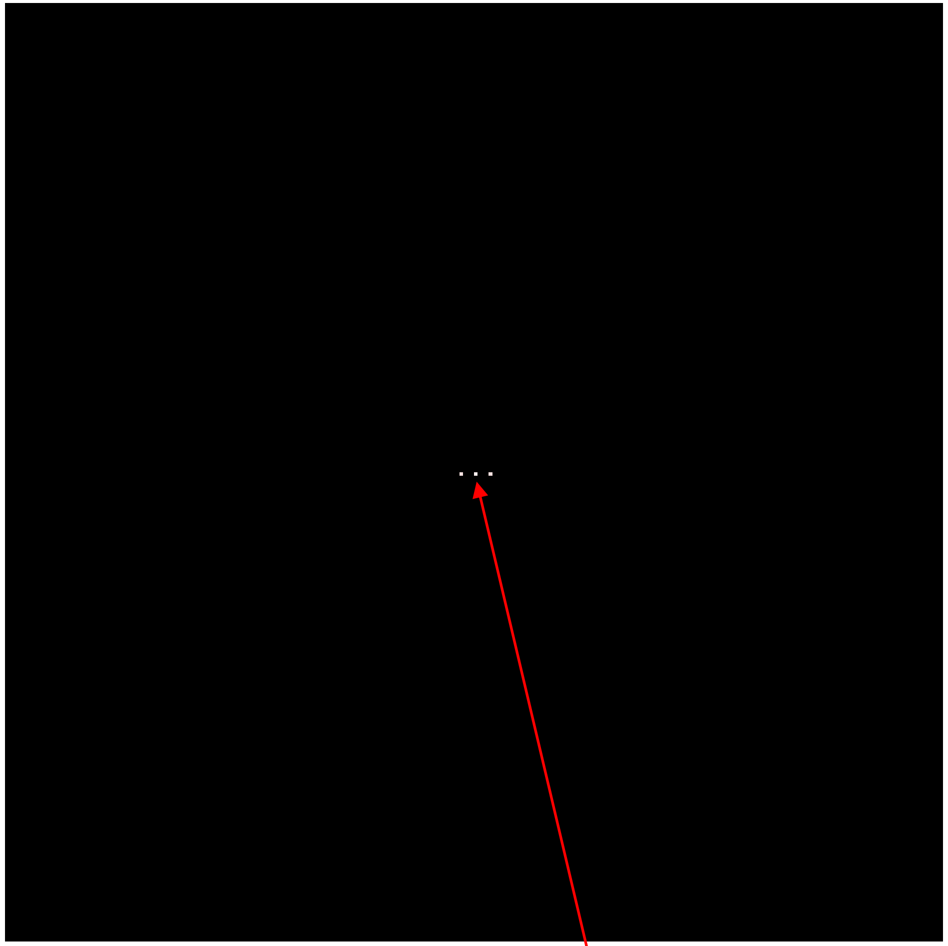
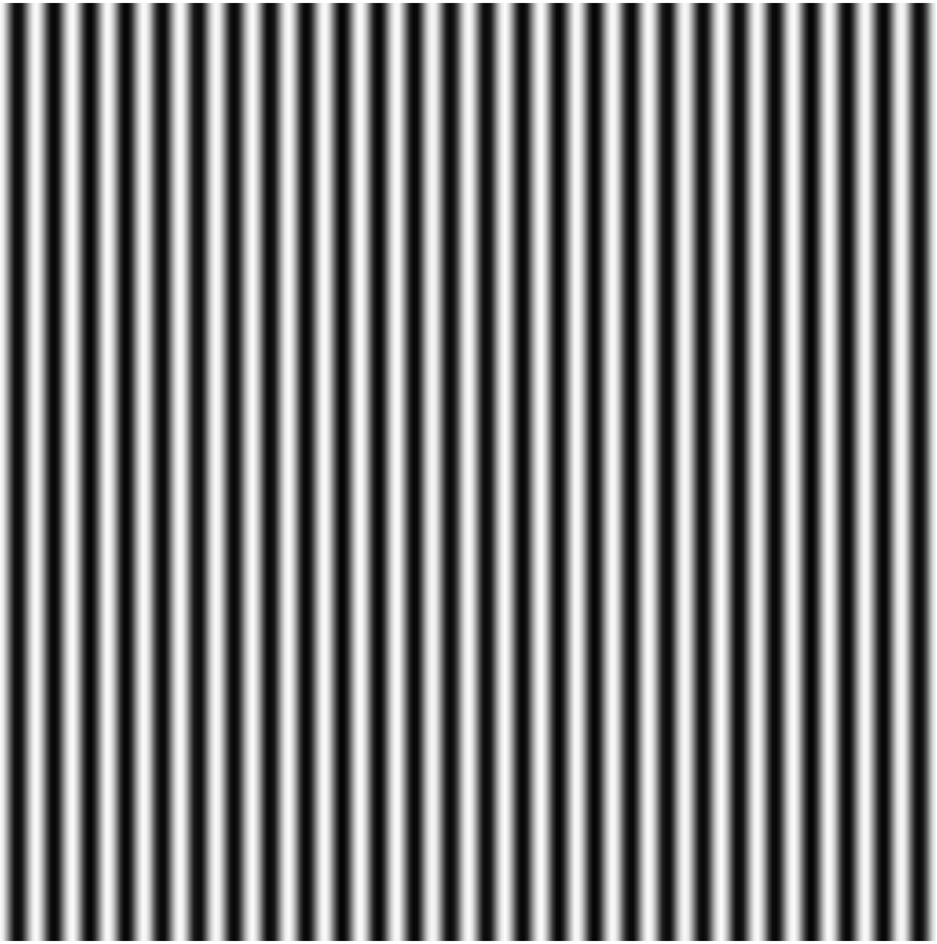


Centre point represents the mean brightness of the image

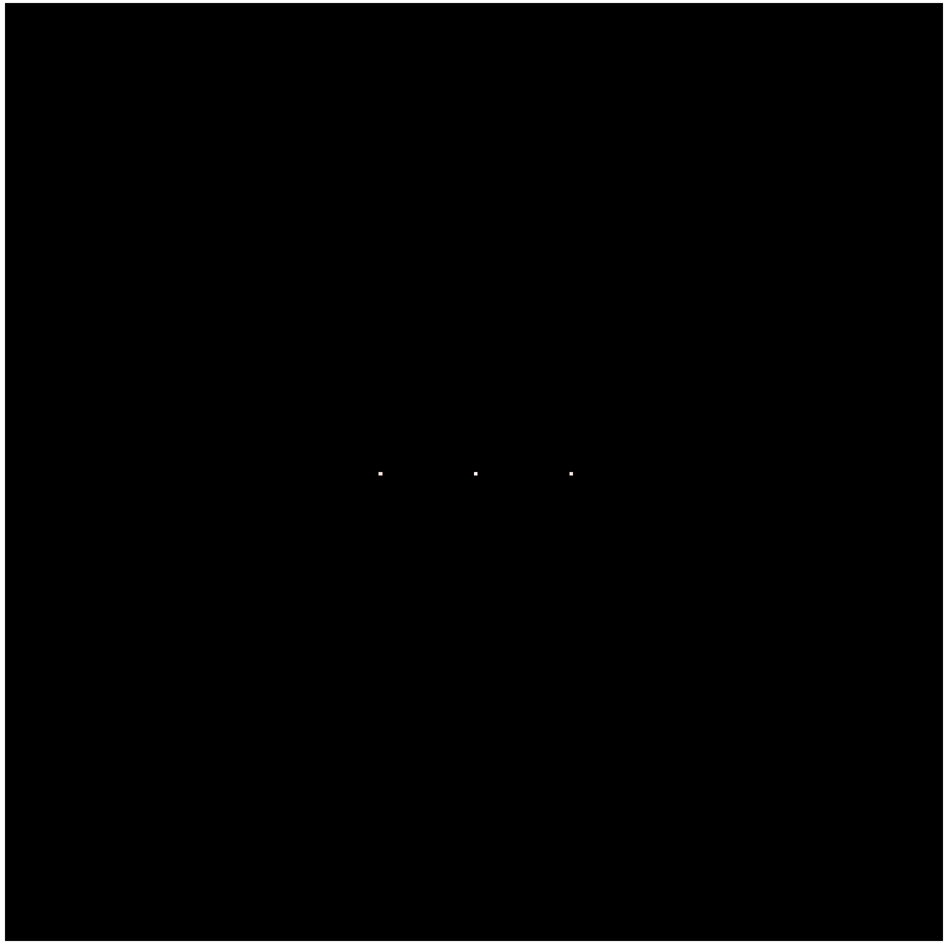
Taken from http://www.qsimaging.com/ccd_noise_interpret_ffts.html

Visually interpreting an Fourier Transform plot

Space



Frequency



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Visually interpreting an Fourier Transform plot

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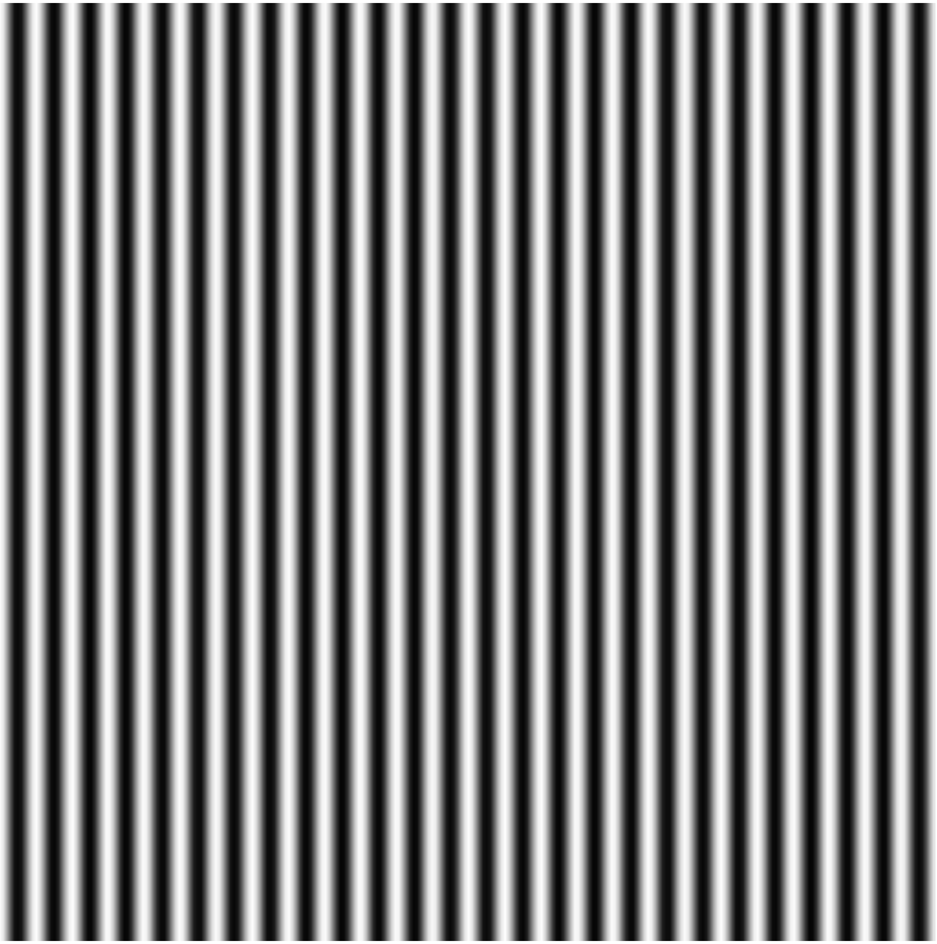
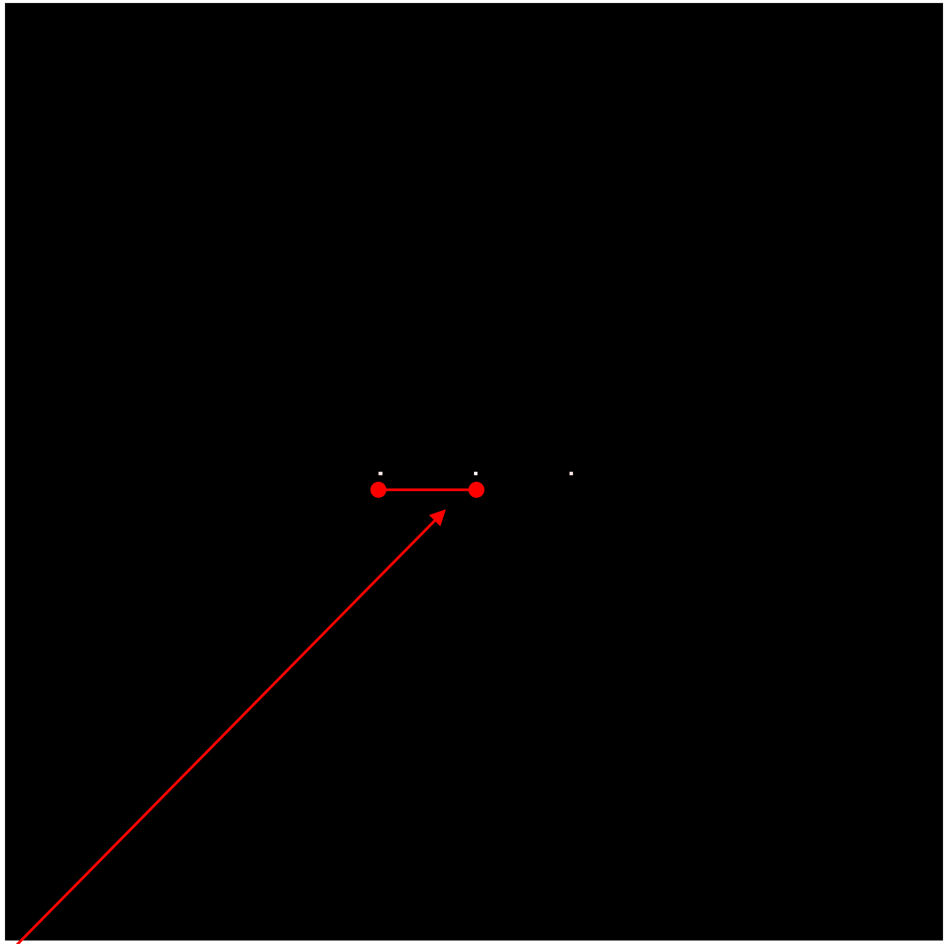


Frequency



…increasing frequency = further from origin

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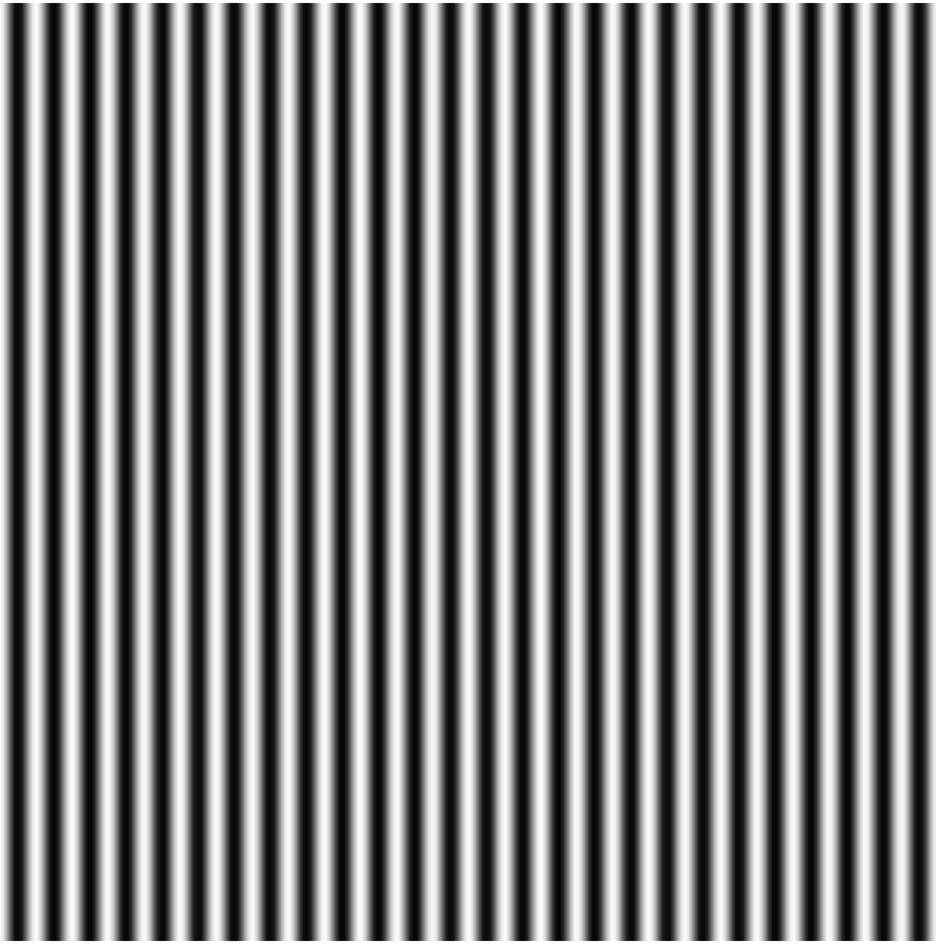
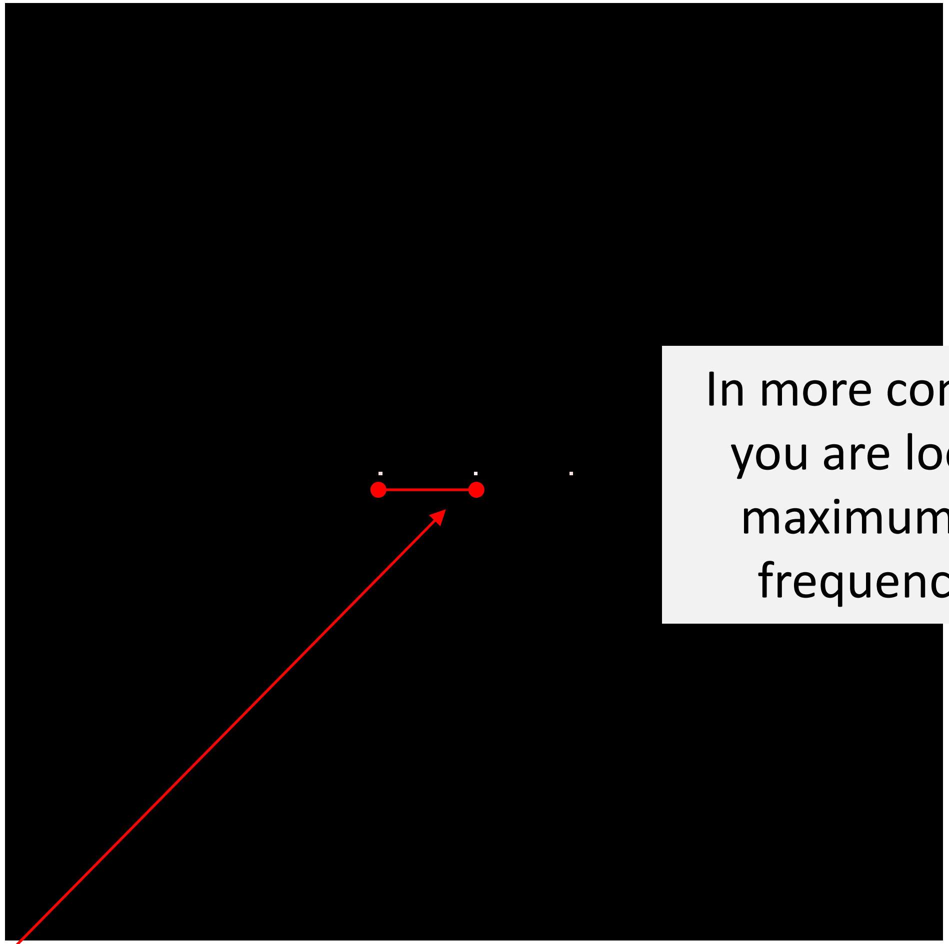
Visually interpreting an Fourier Transform plot

Space



Frequency



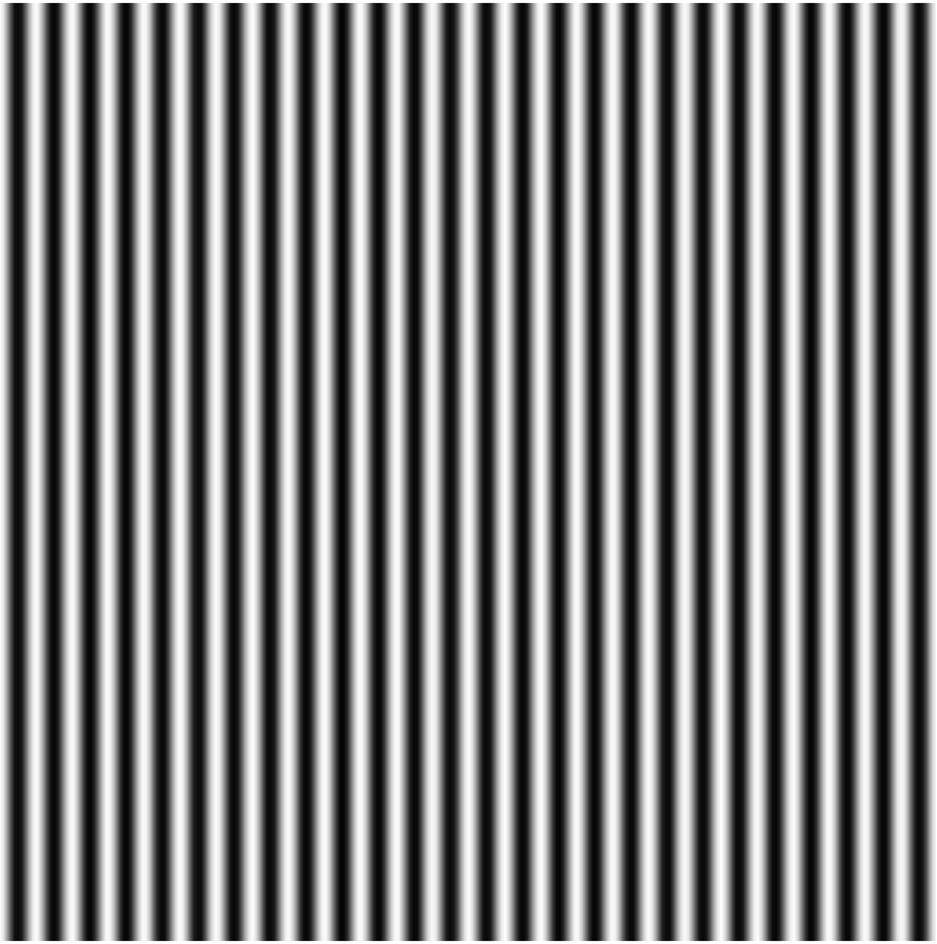
In more complex images, you are looking for the maximum peak in the frequency spectrum

…increasing frequency = further from origin

Taken from http://www.qsimaging.com/ccd_noise_interpret_ffts.html

Visually interpreting an Fourier Transform plot

Space



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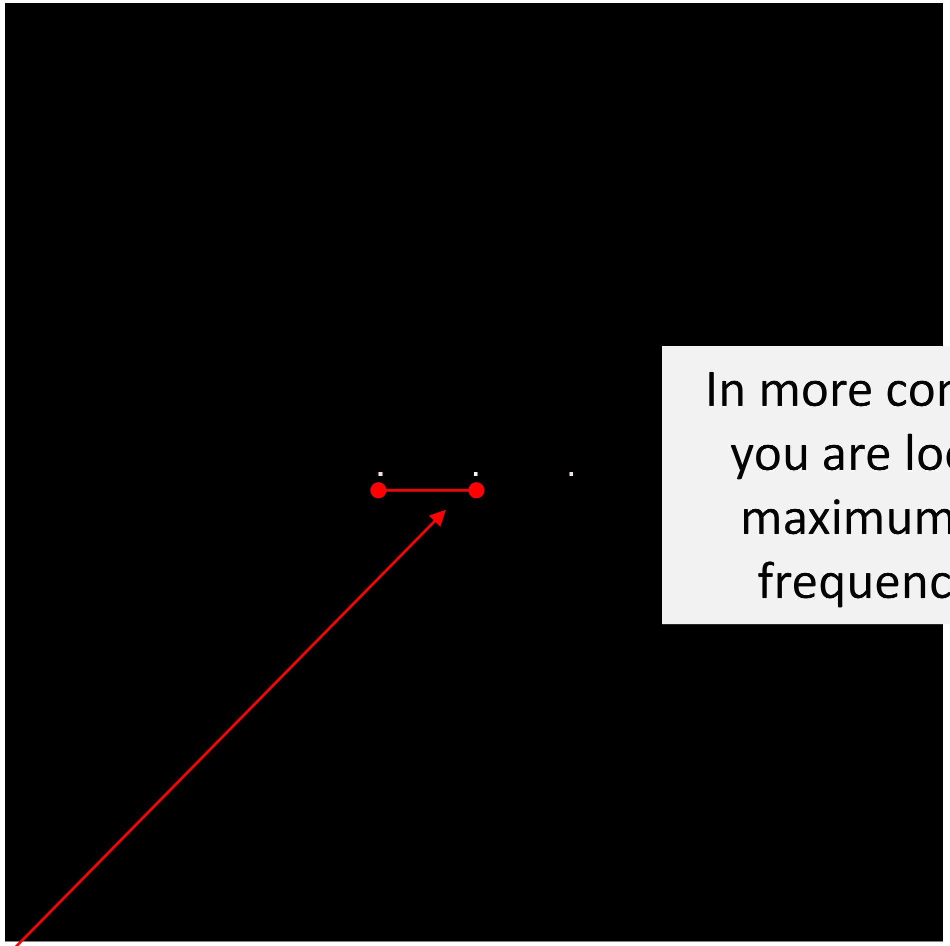

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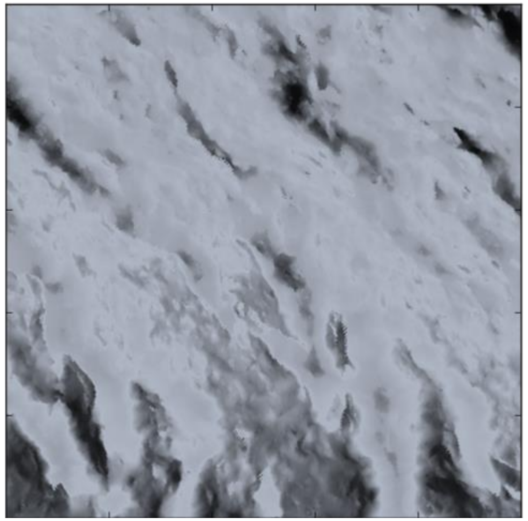
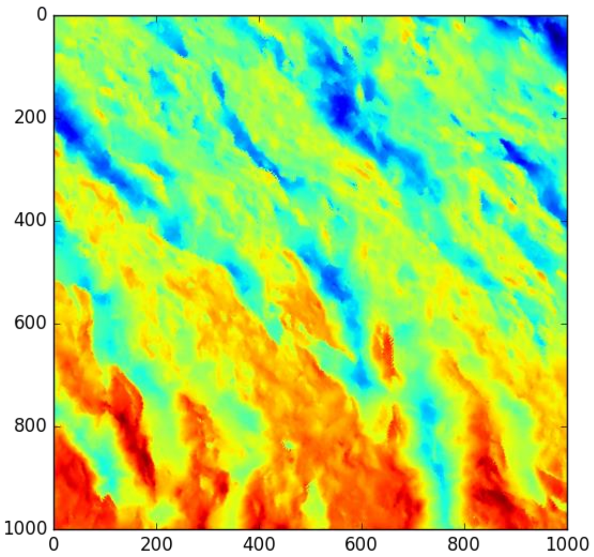
FFT: Fast Fourier transform

Taken from http://www.qsimaging.com/ccd_noise_interpret_ffts.html



1. Original image



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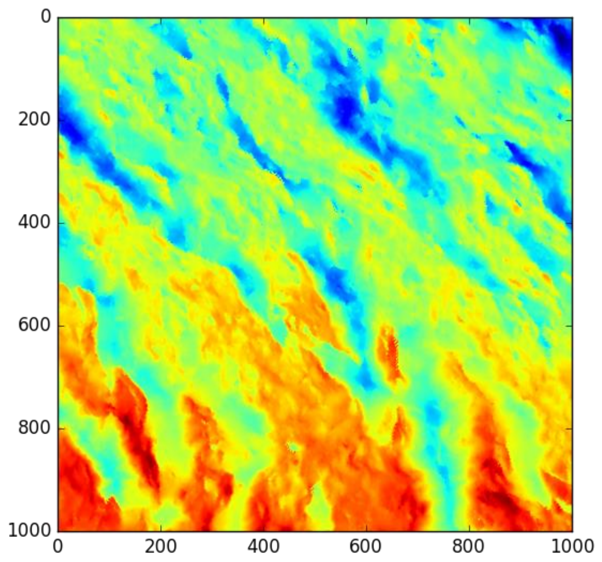
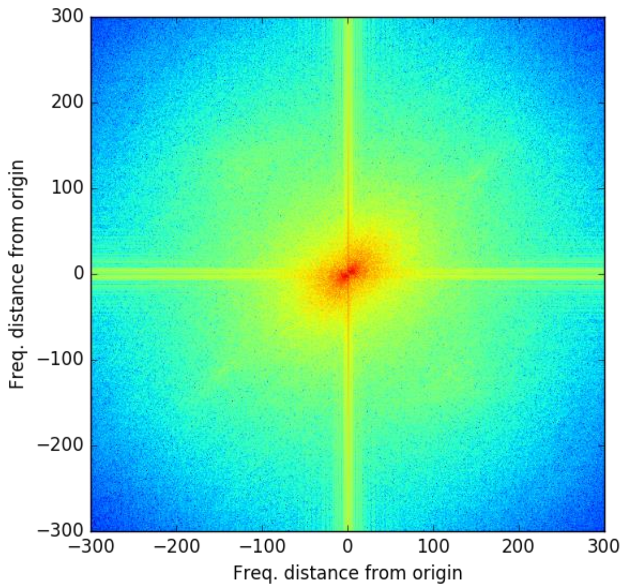


2. Calculate FFT



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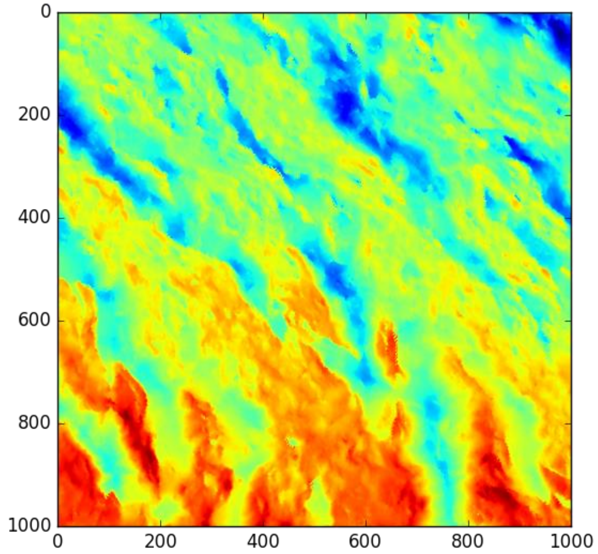

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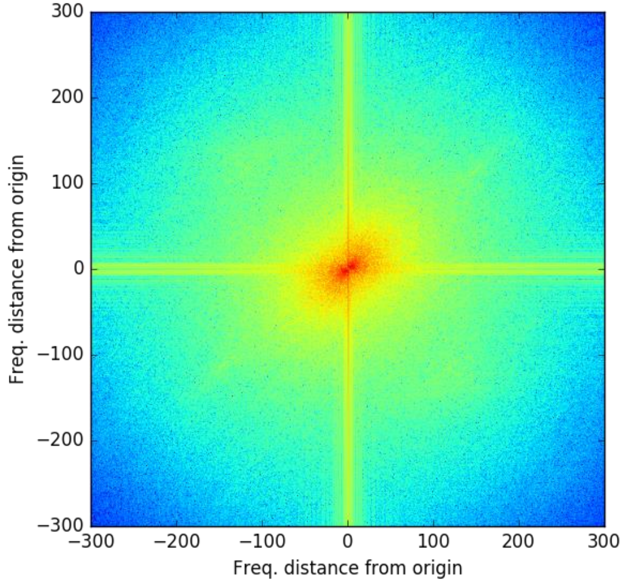
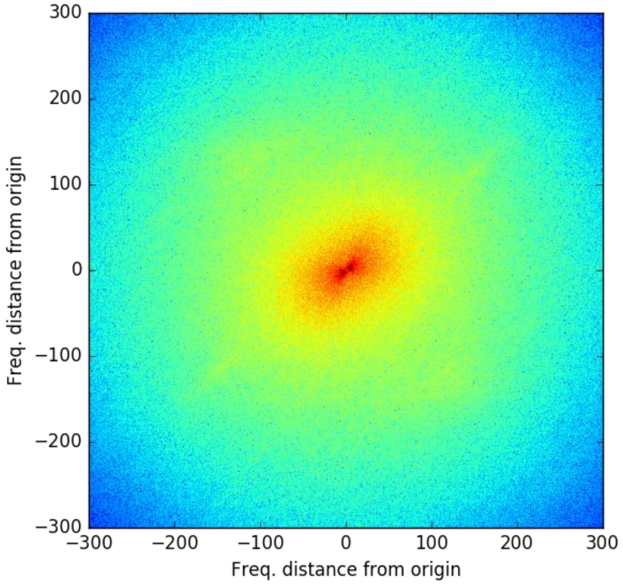


3. Smooth and Gibbs effect removal



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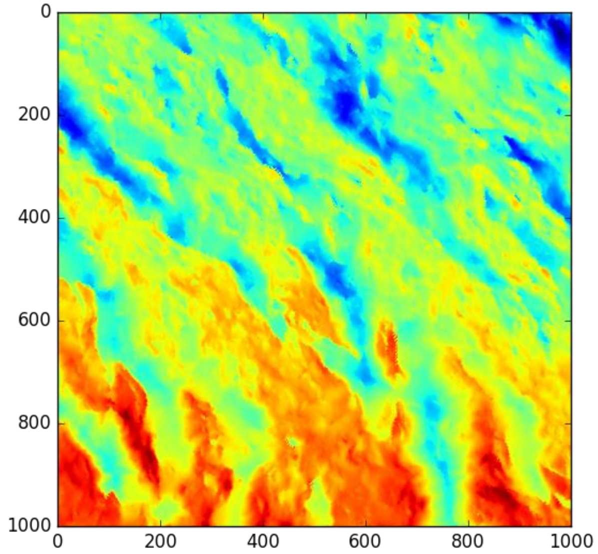

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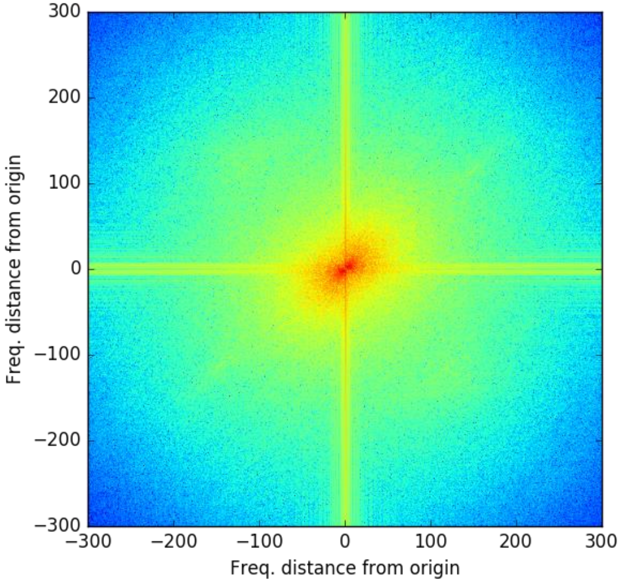

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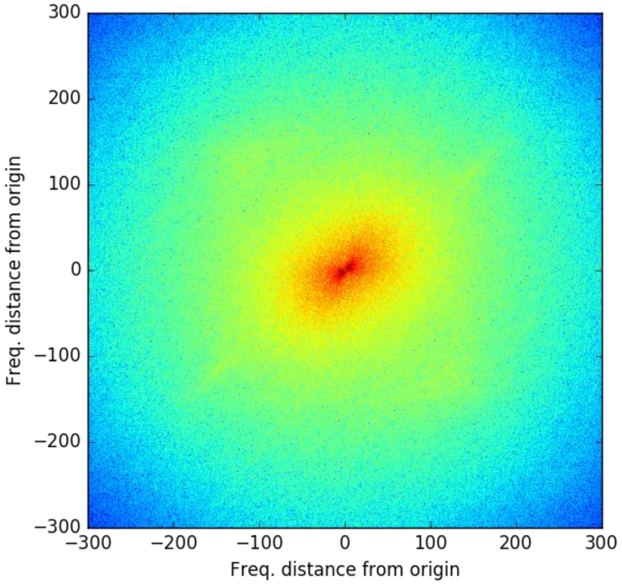
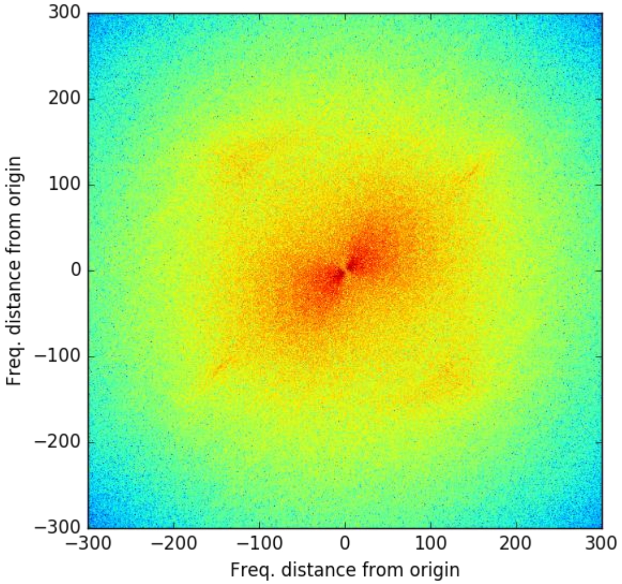
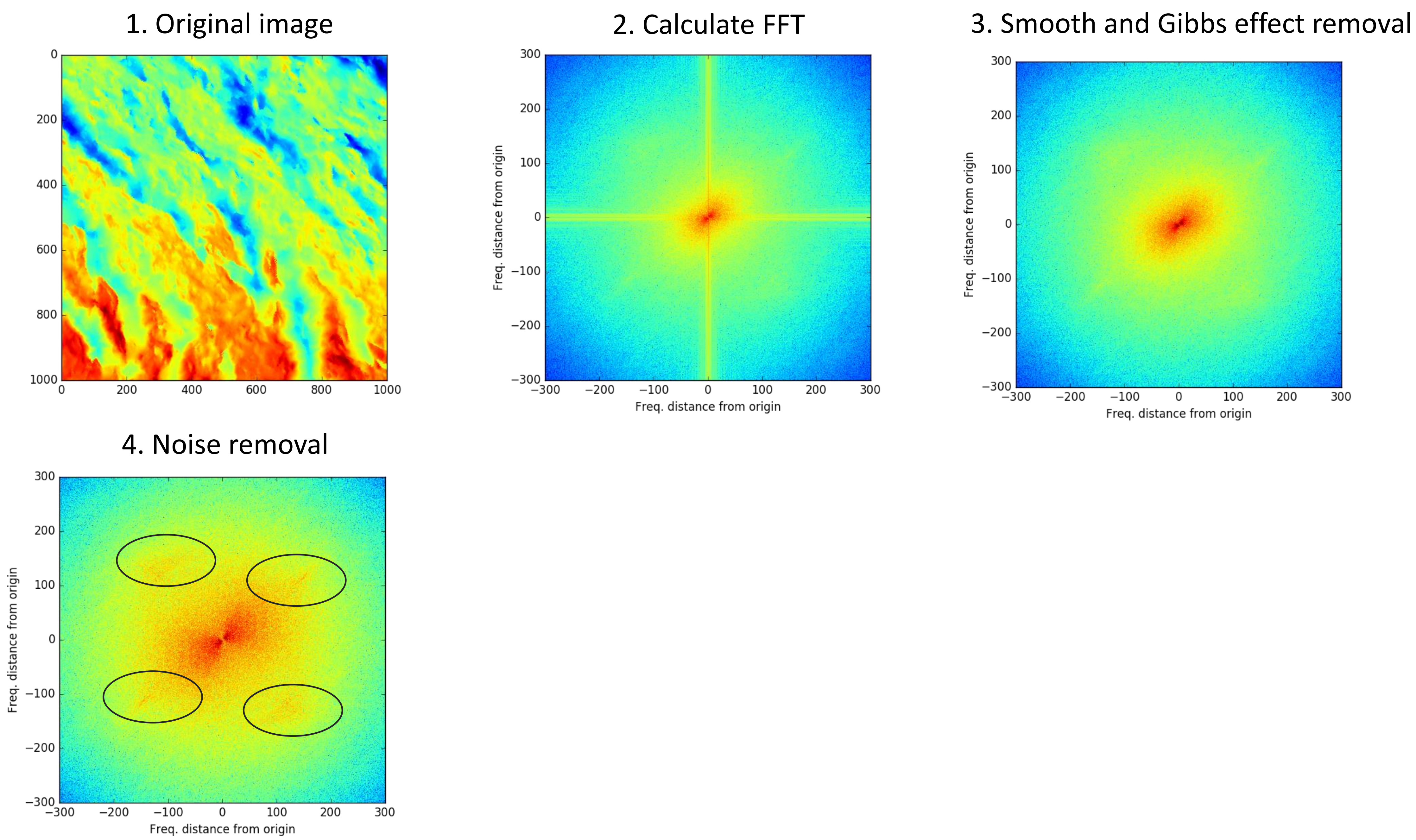
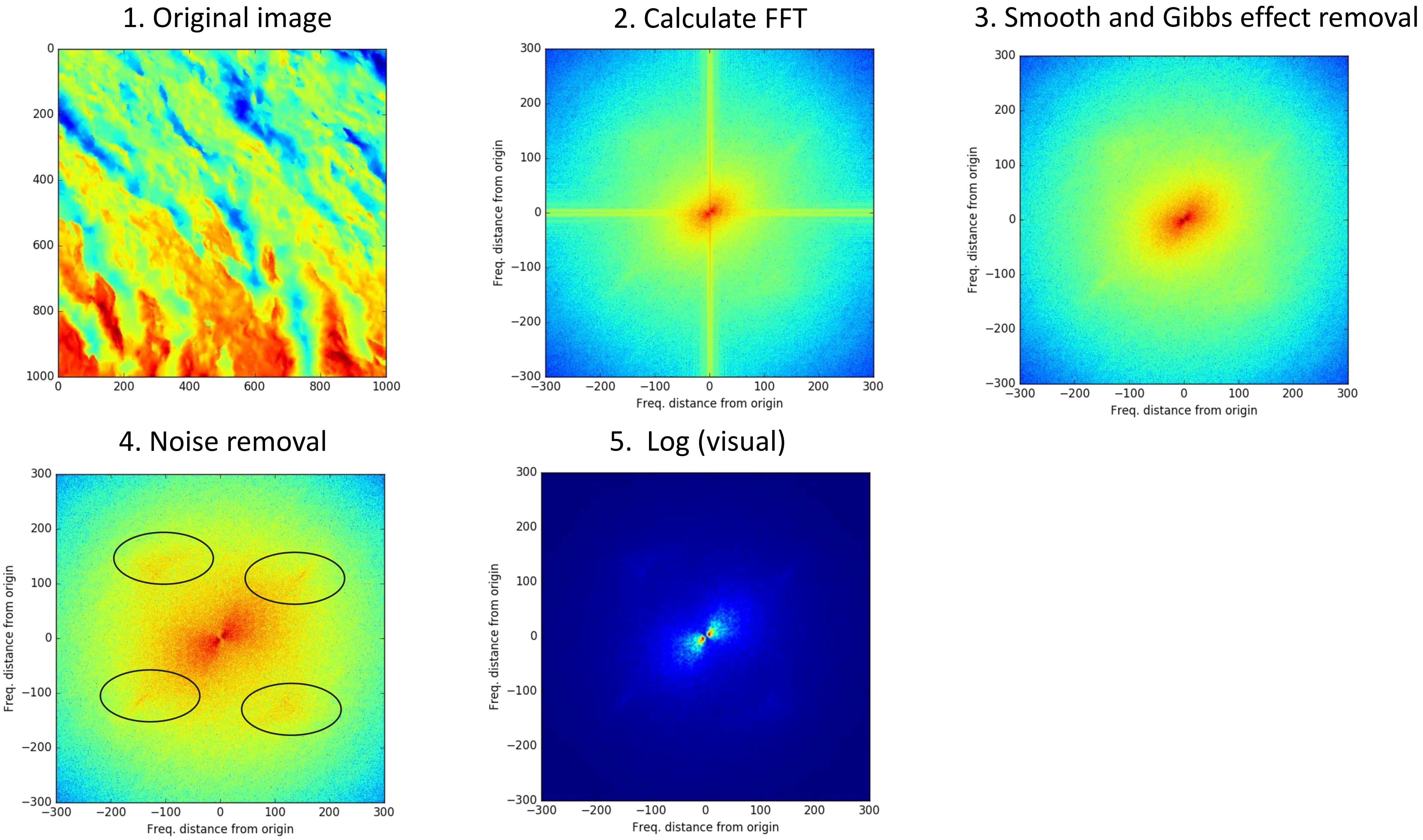
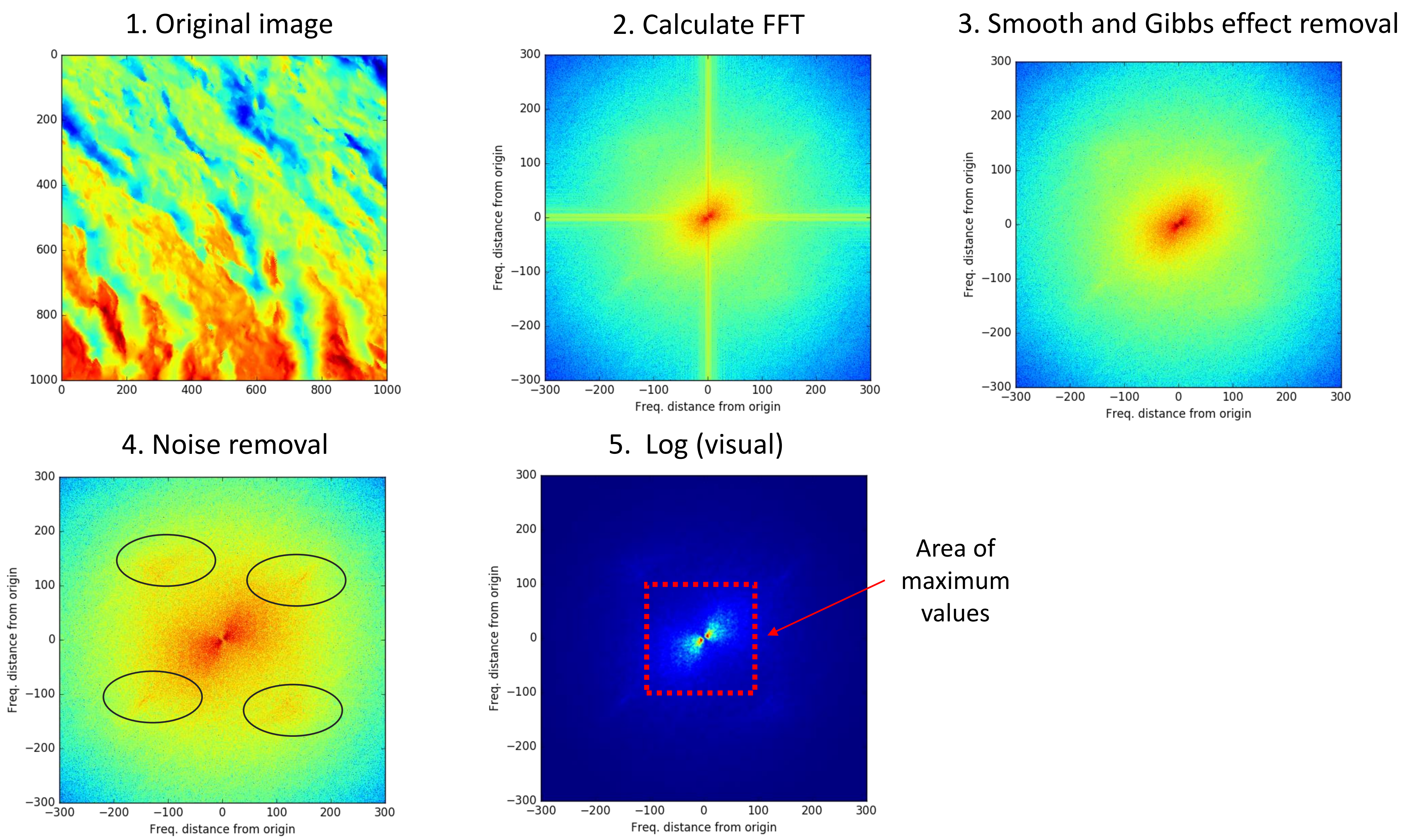


4. Noise removal




1. Original image
2. Calculate FFT
3. Smooth and Gibbs effect removal
4. Noise removal
Freq. distance from origin
Freq. distance from origin


1. Original image
2. Calculate FFT
3. Smooth and Gibbs effect removal
4. Noise removal
5. Log (visual)
Freq. distance from origin
0
200
400
600
800
1000
−300
−200
−100
100
300



1. Original image
2. Calculate FFT
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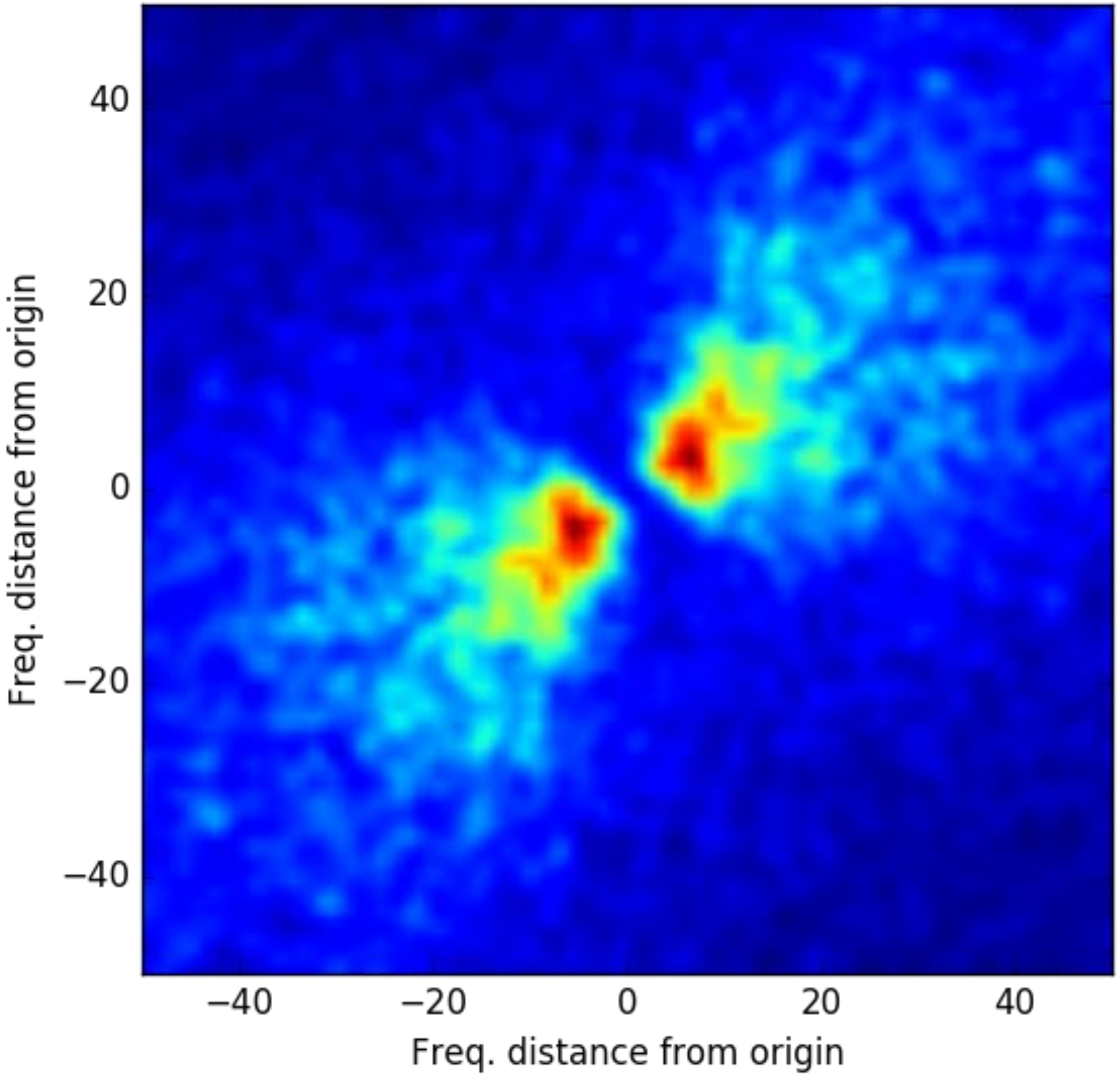
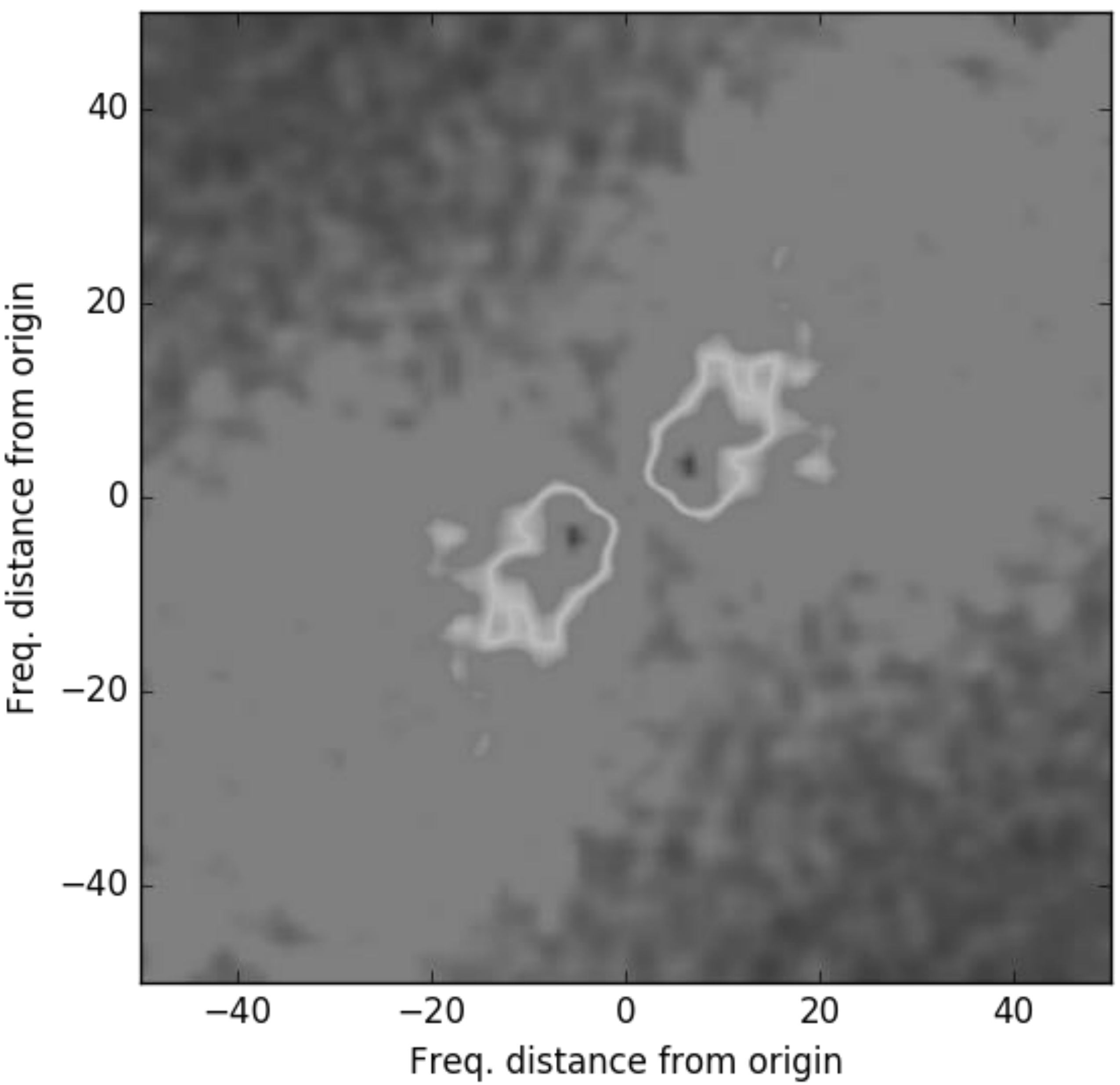
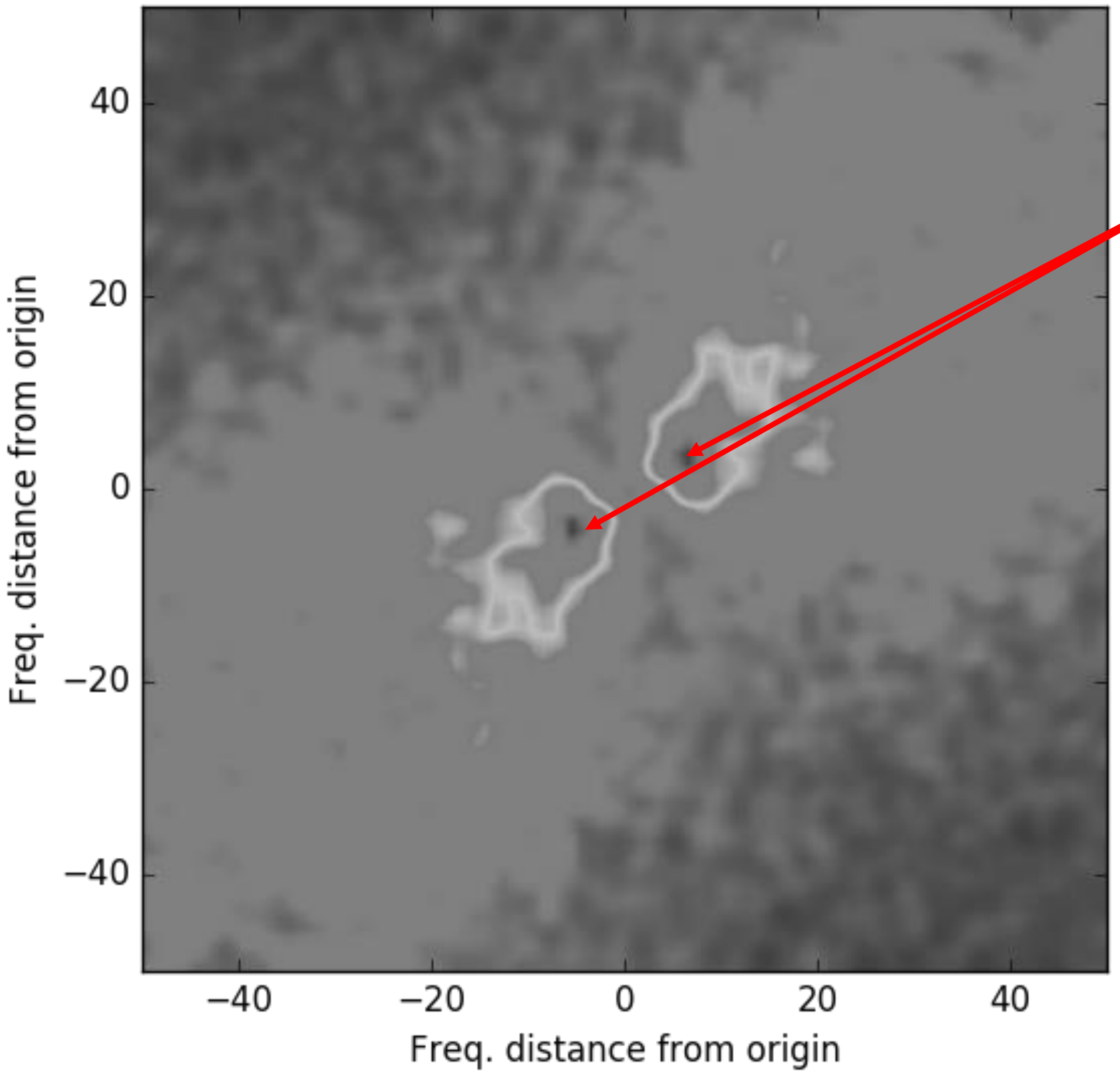
4. Noise removal
5. Log (visual)
Freq. distance from origin
Area of maximum values

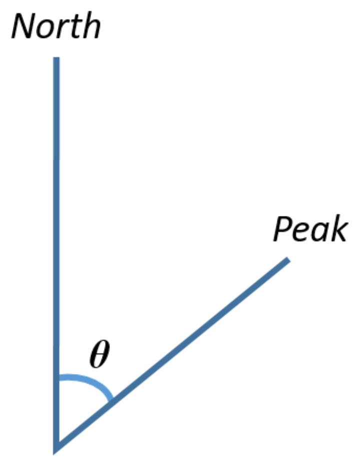

40
20
0
−20
−40
−40
−20
0
20
40
Freq. distance from origin
Freq. distance from origin



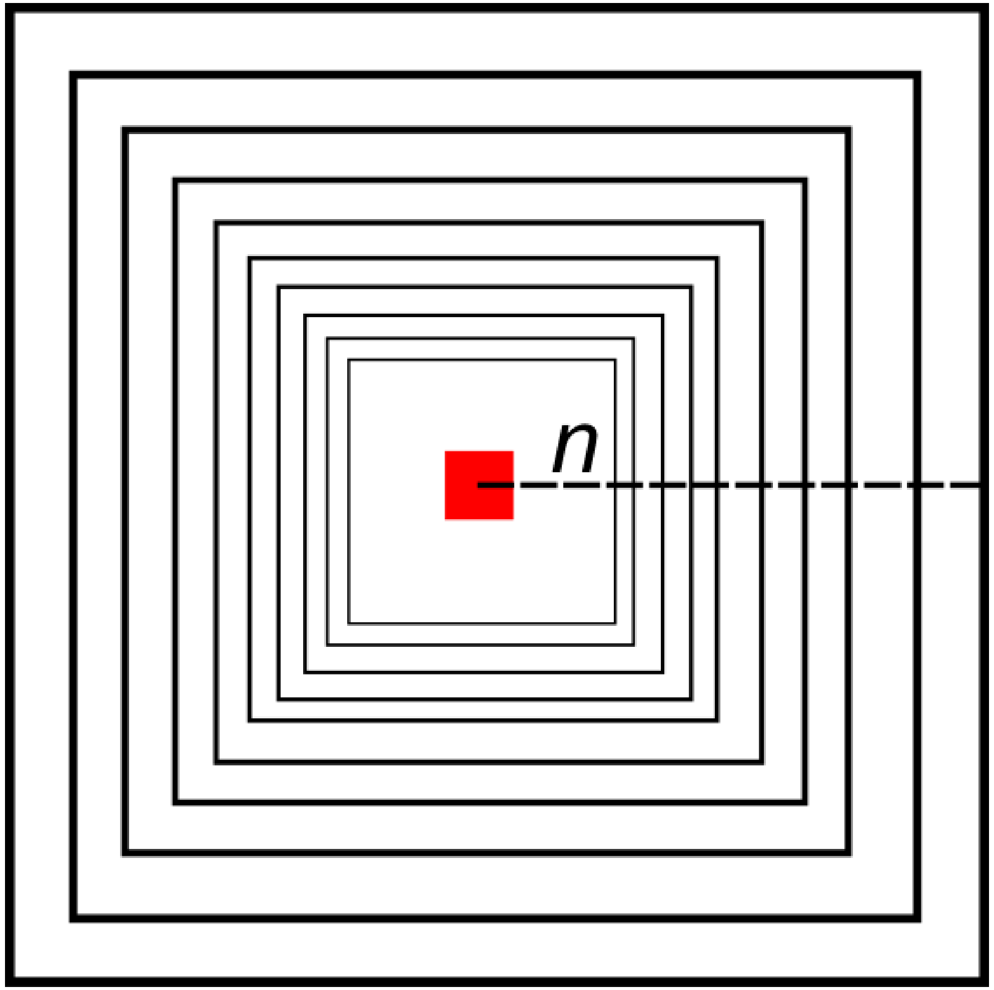
40
20
0
−20
−40
−40
−20
0
20
40
Freq. distance from origin
Freq. distance from origin



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!

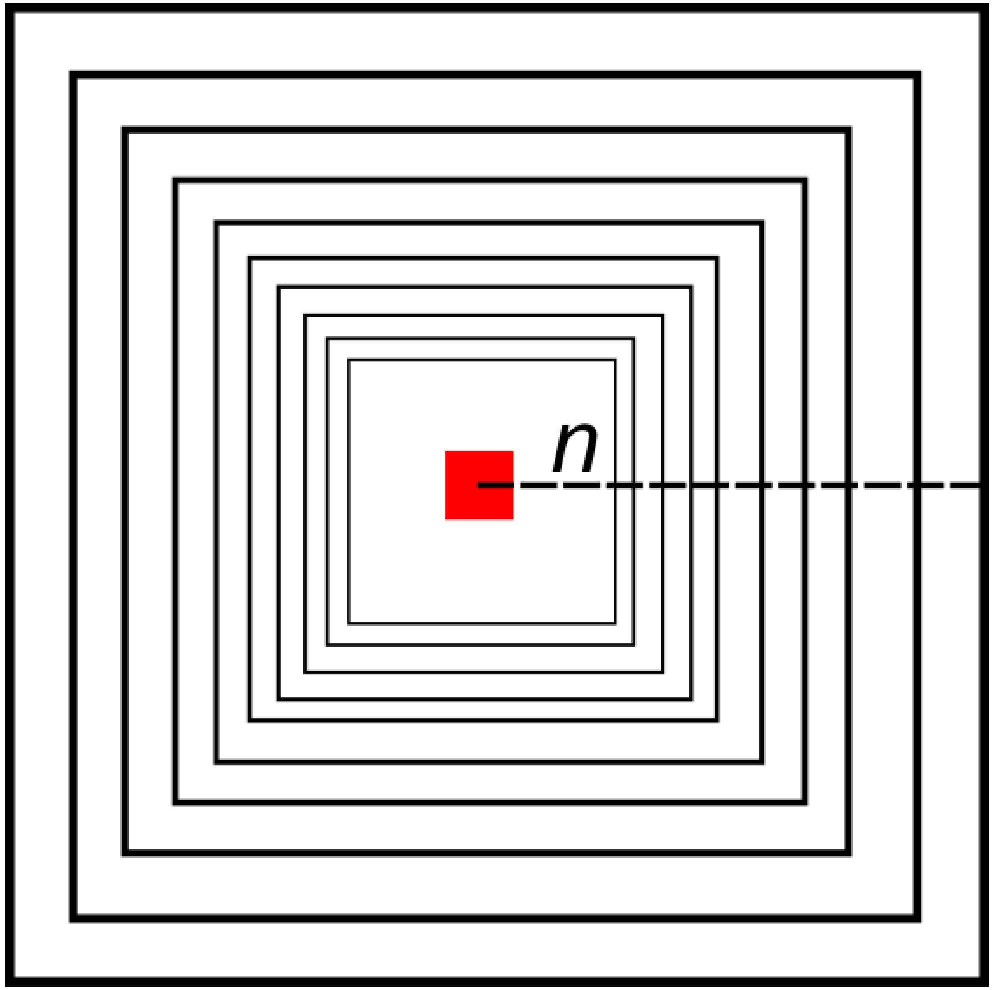


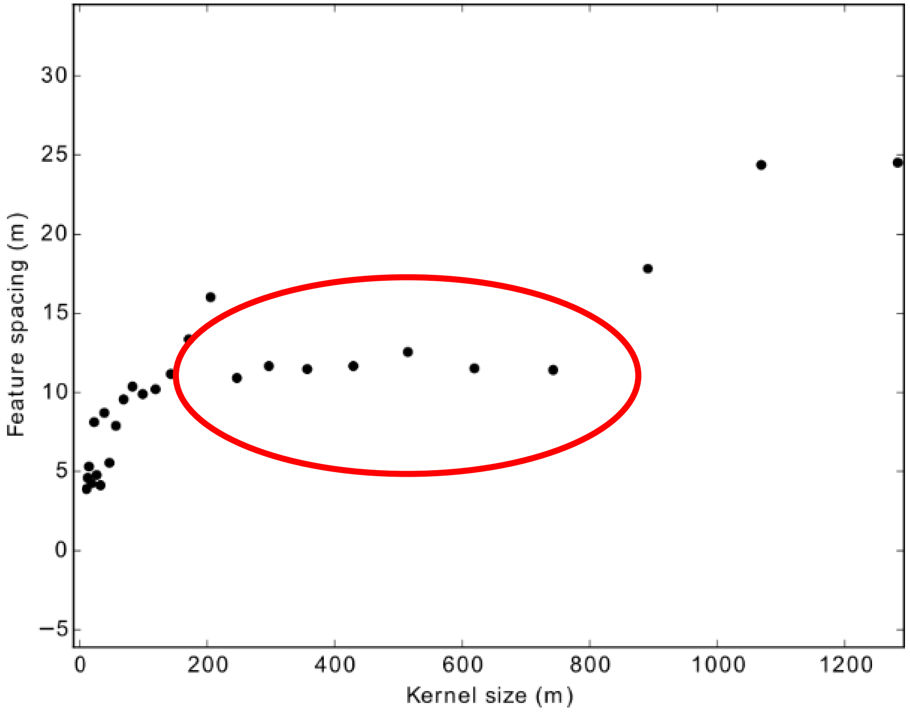
Effect of window size



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

Effect of window size





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

The code

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

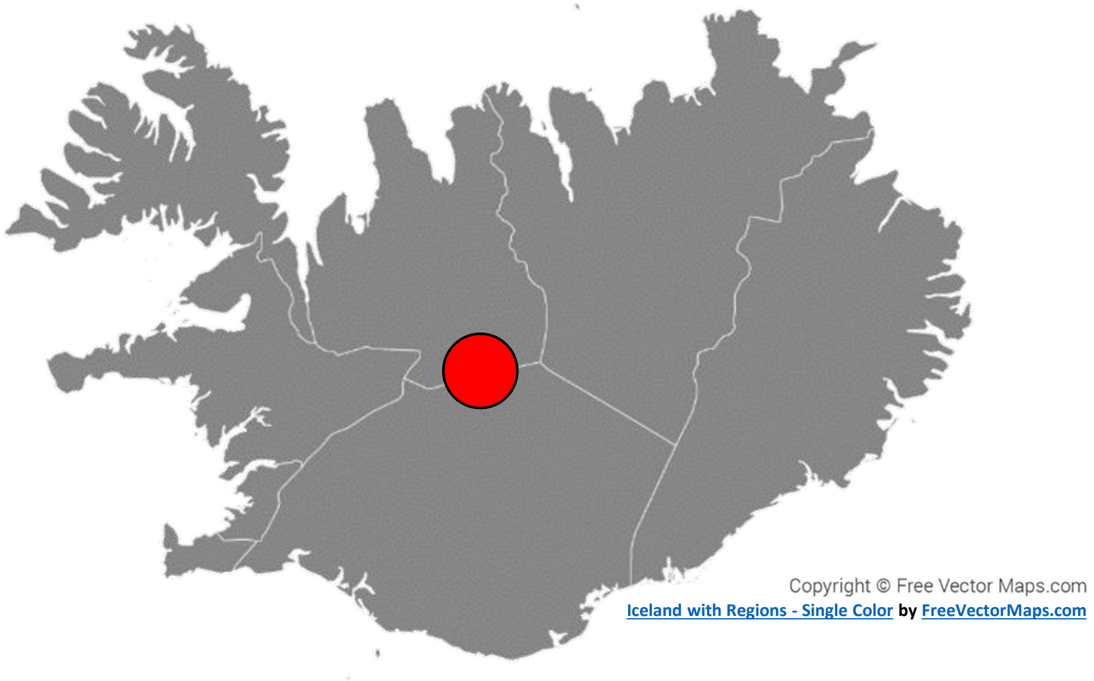
https://github.com/Chris35Wills/LFMapper

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

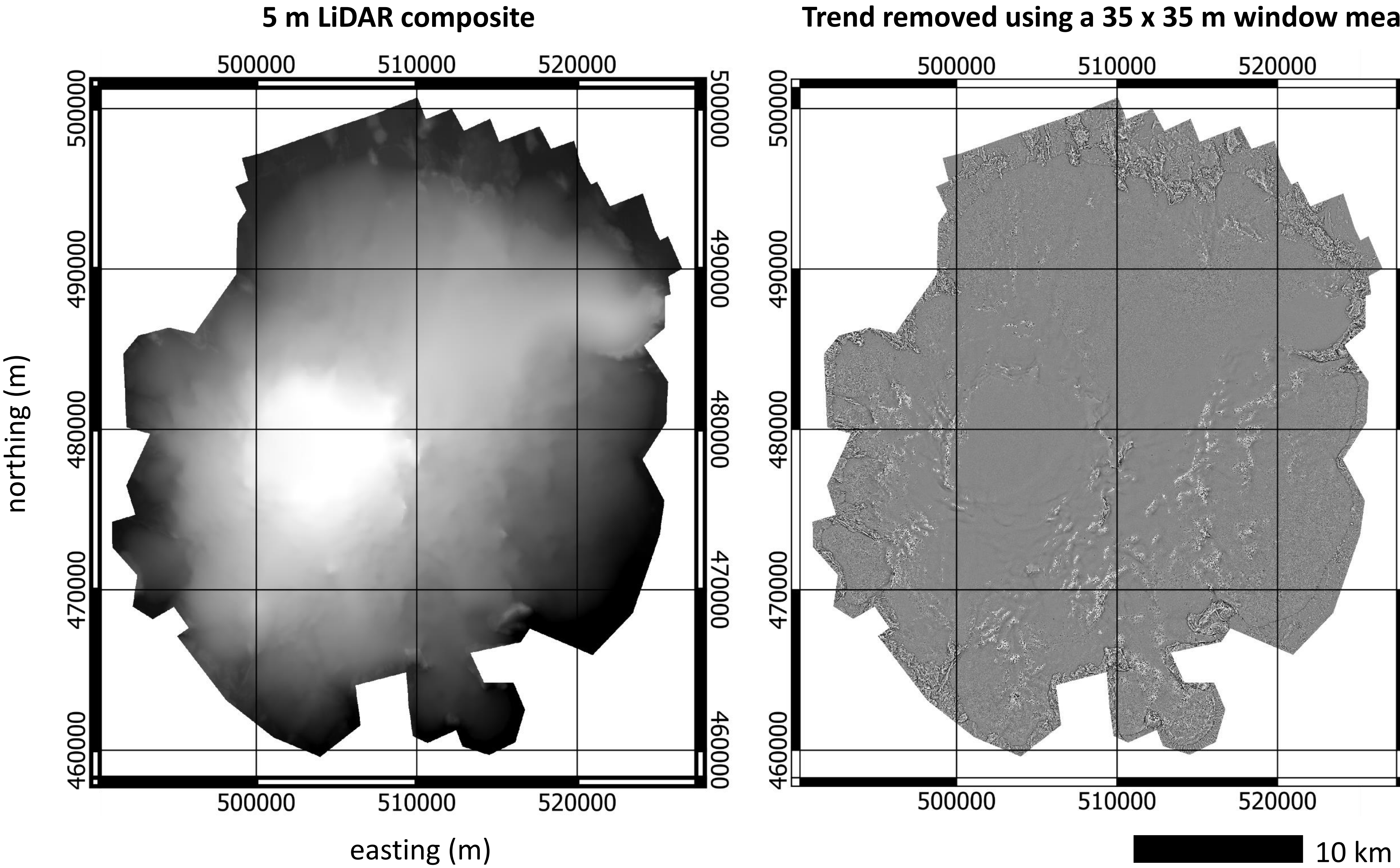
Application to Hofsjökull, Iceland

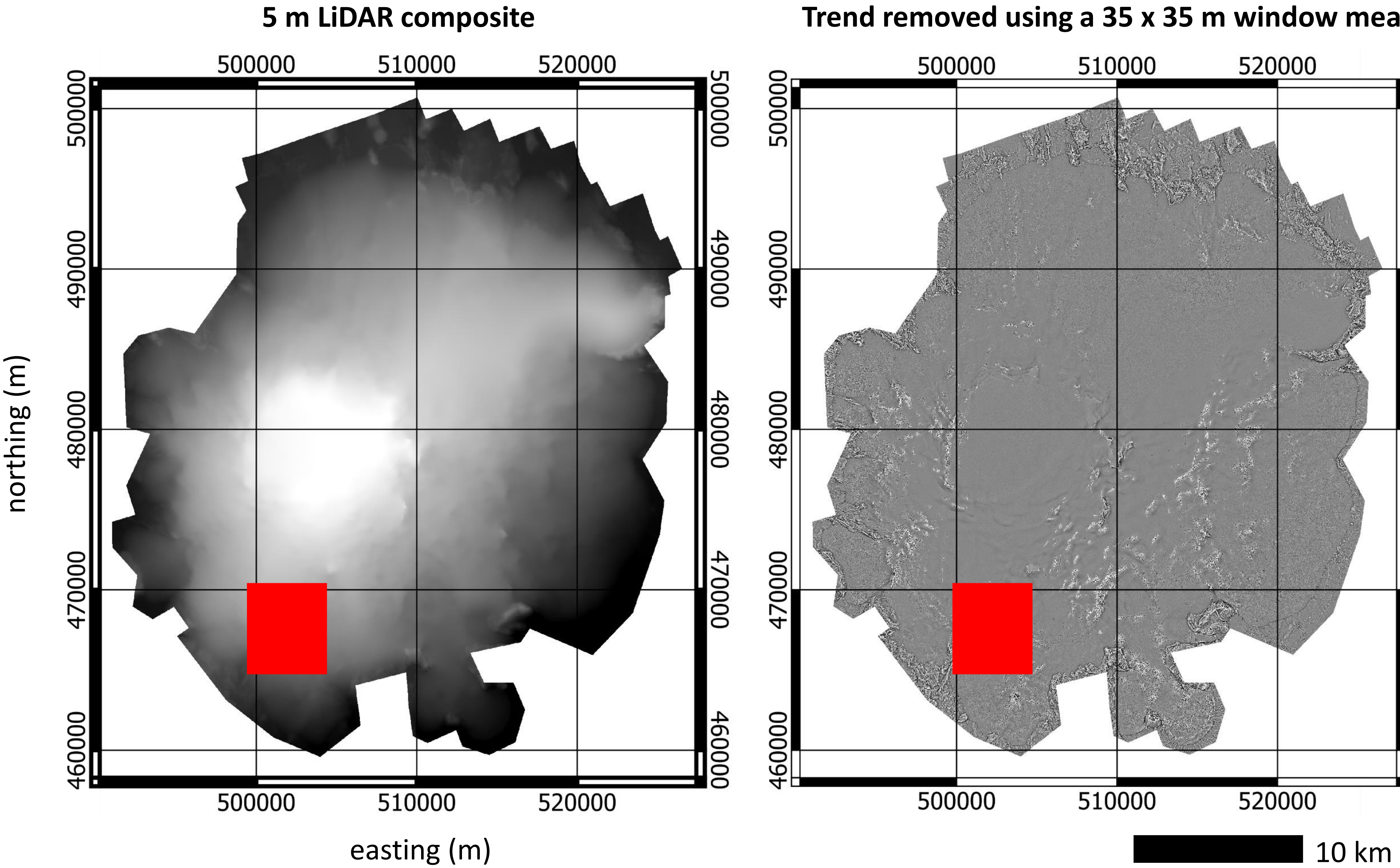
- Third largest glacier in Iceland (~900 km^2)
- Located in the central highlands
- Large mass balance observation network (Icelandic Meteorological service)
- Mostly negative mass balance observed since 1995, positive in 2015
- Atop an active subglacial caldera volcano

- Airborne LiDAR data available at 2 m resolution
  - 2008/2010, 2013



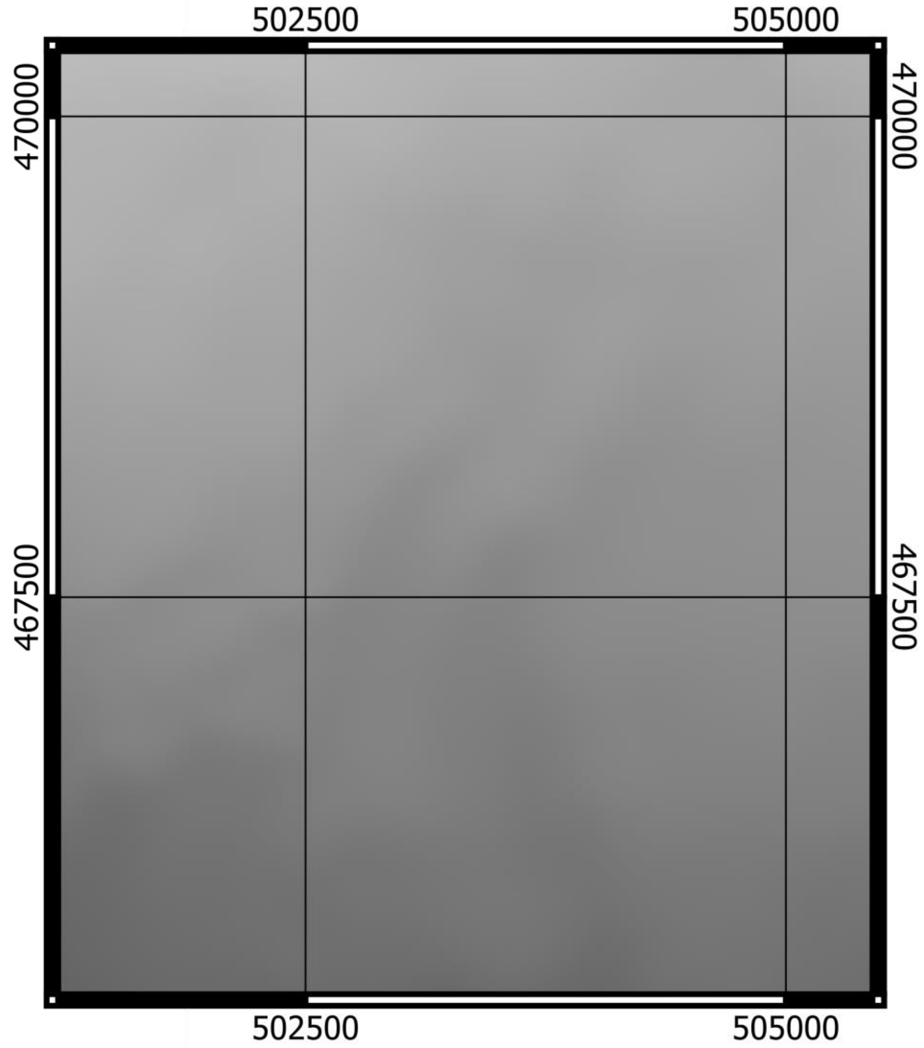
Hofsjökull crevasse map (2011) from http://safetravel.is available here:
https://safetravel.is/wp-content/uploads/2011/01/Hofsj%C3%B6kull-ens-2017.pdf


5 m LiDAR composite
Trend removed using a 35 x 35 m window mean
500000
510000
520000
460000
470000
480000
490000
500000
northing (m)
easting (m)
10 km

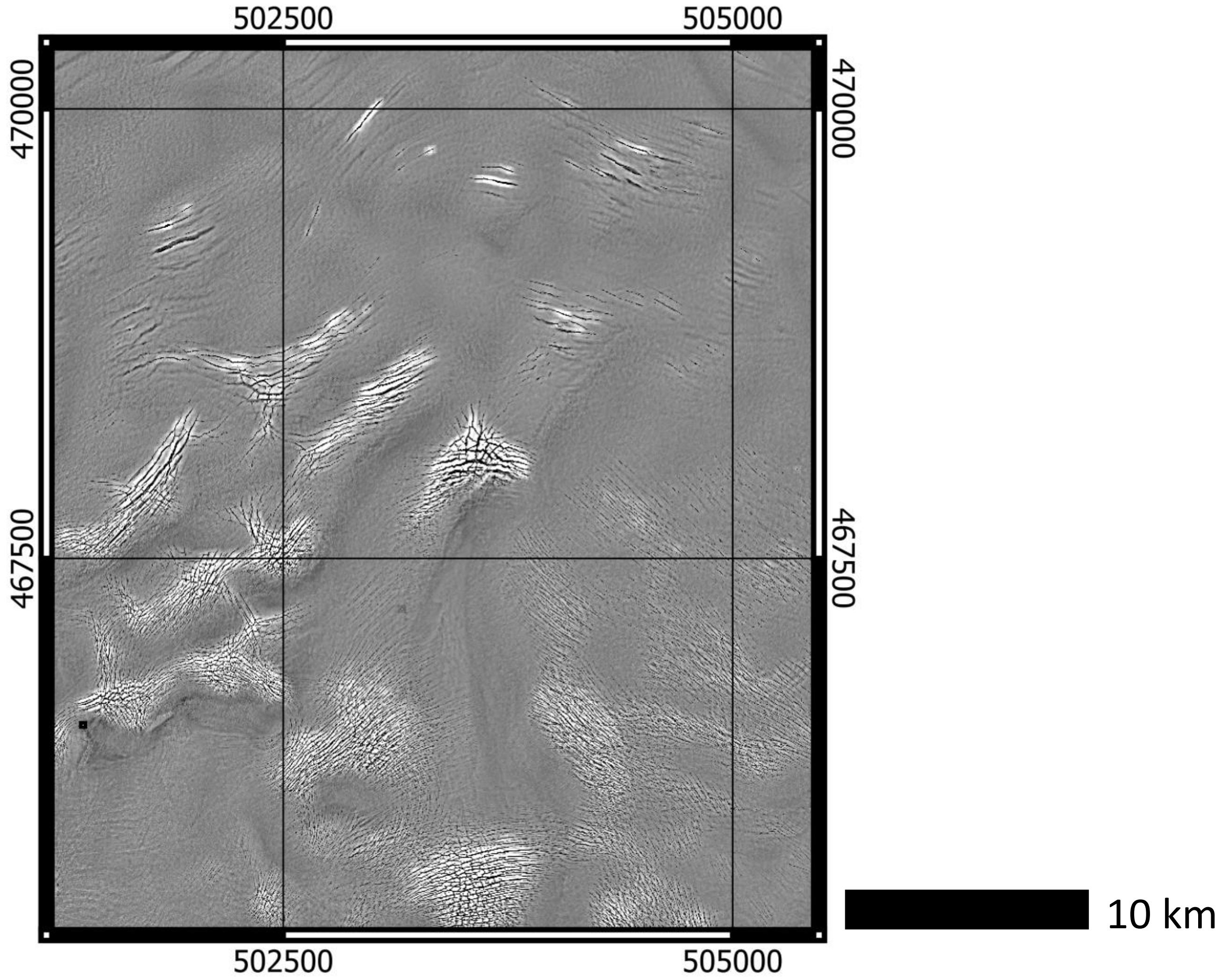


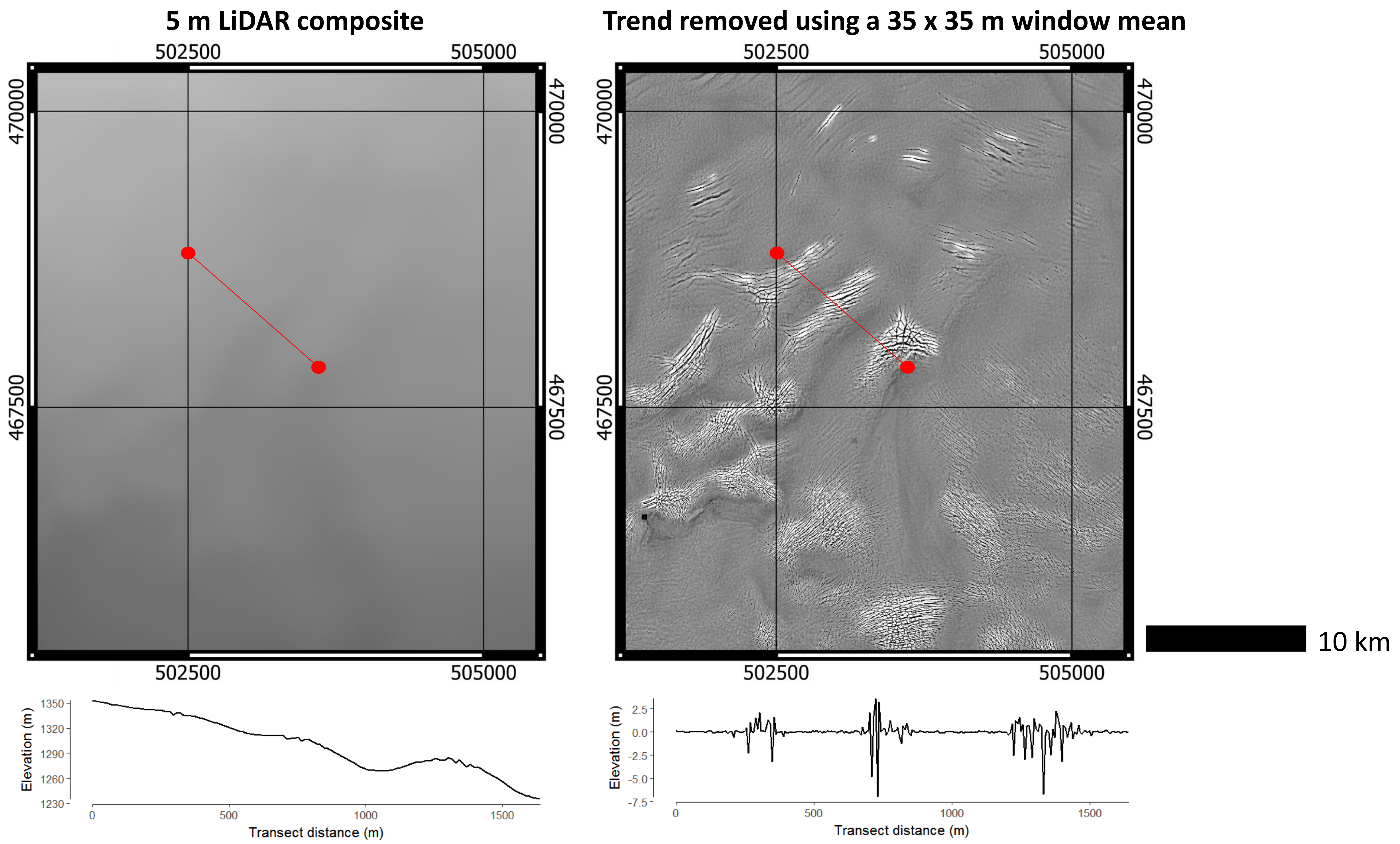
5 m LiDAR composite
Trend removed using a 35 x 35 m window mean
500000
510000
520000
460000
470000
480000
490000
500000
northing (m)
easting (m)
10 km

5 m LiDAR composite

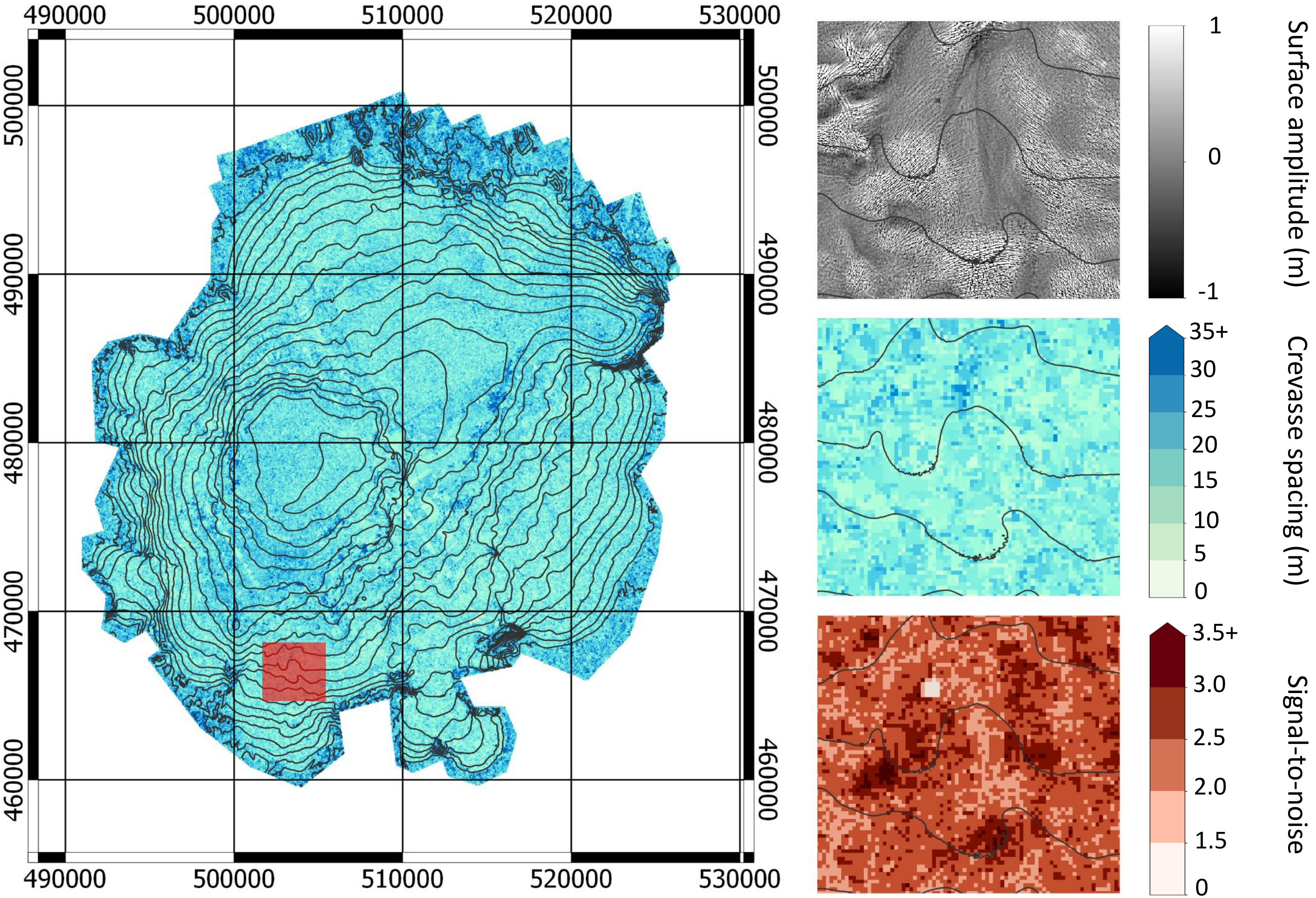


Trend removed using a 35 x 35 m window mean

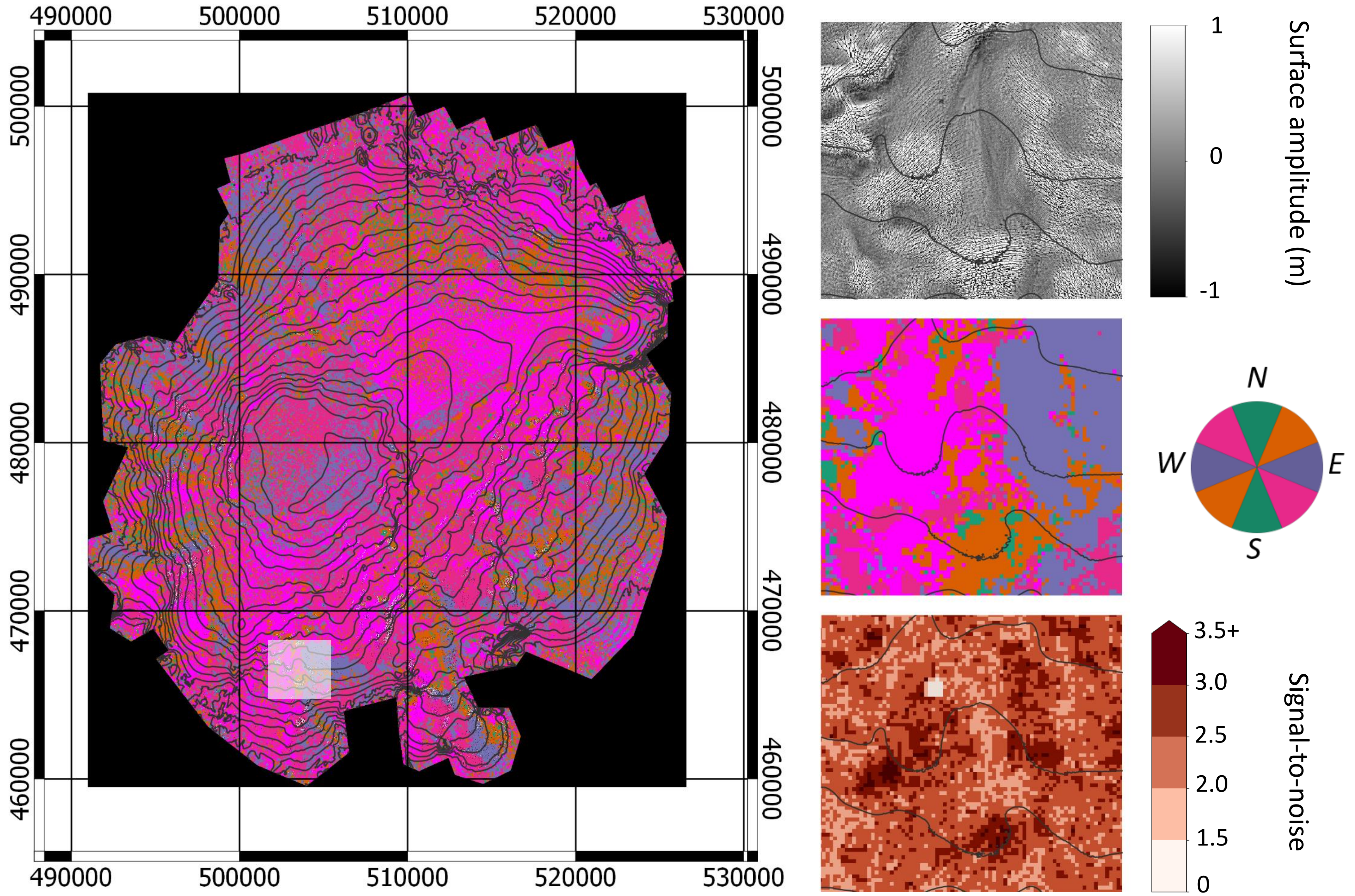



5 m LiDAR composite
Trend removed using a 35 x 35 m window mean
502500
505000
470000
467500
10 km
Elevation (m)
1350
1320
1290
1260
1230
0
500
1000
1500
Transect distance (m)
2.5
0.0
-2.5
-5.0
-7.5

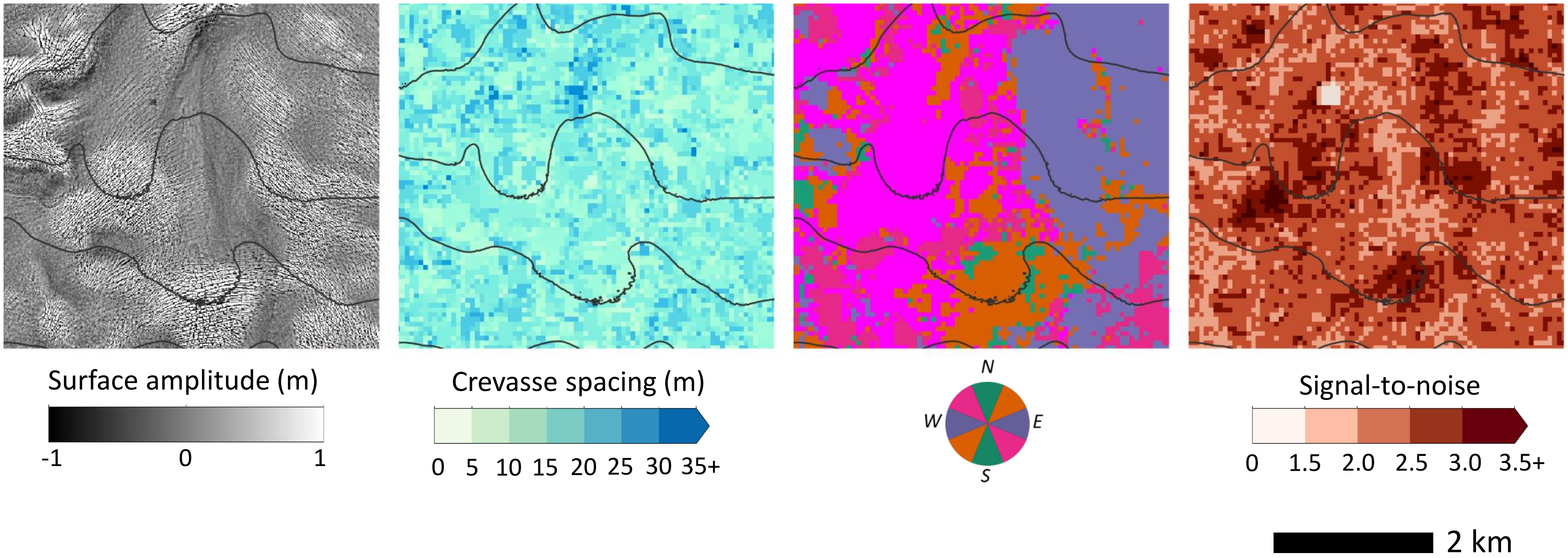
Spacing – window: 155 m | step: 35 m



Orientation – window: 155 m | step: 35 m



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



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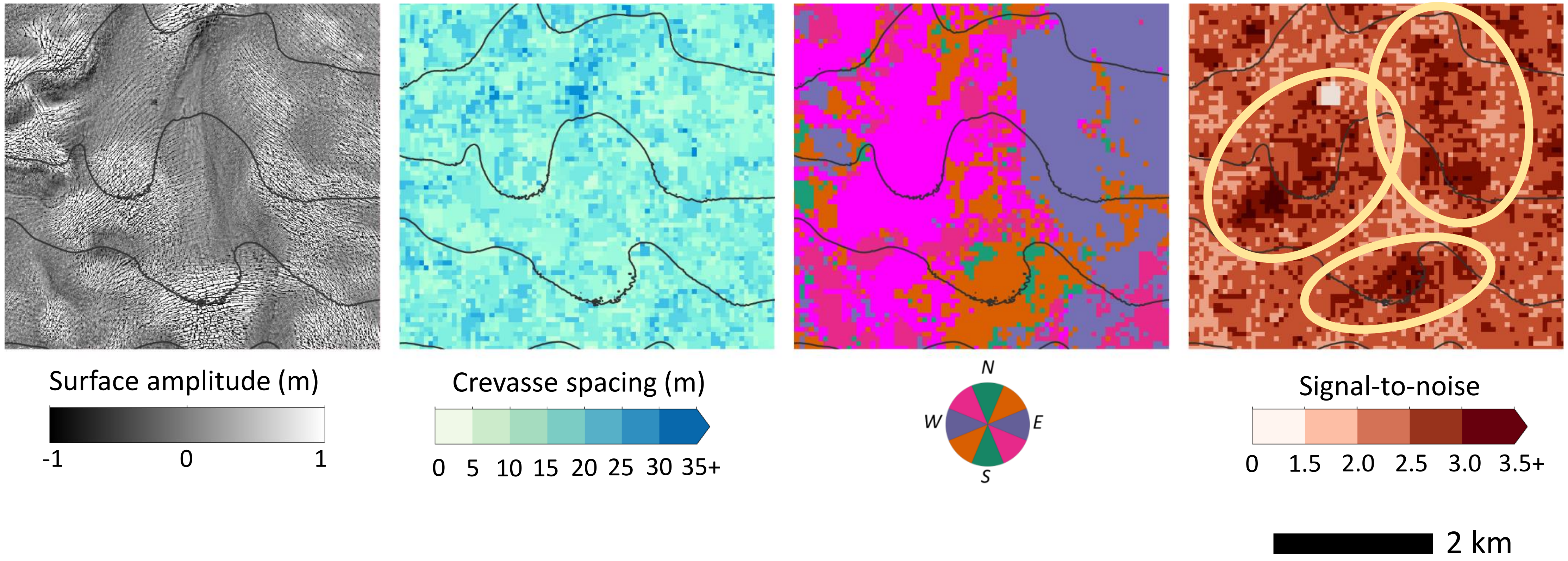
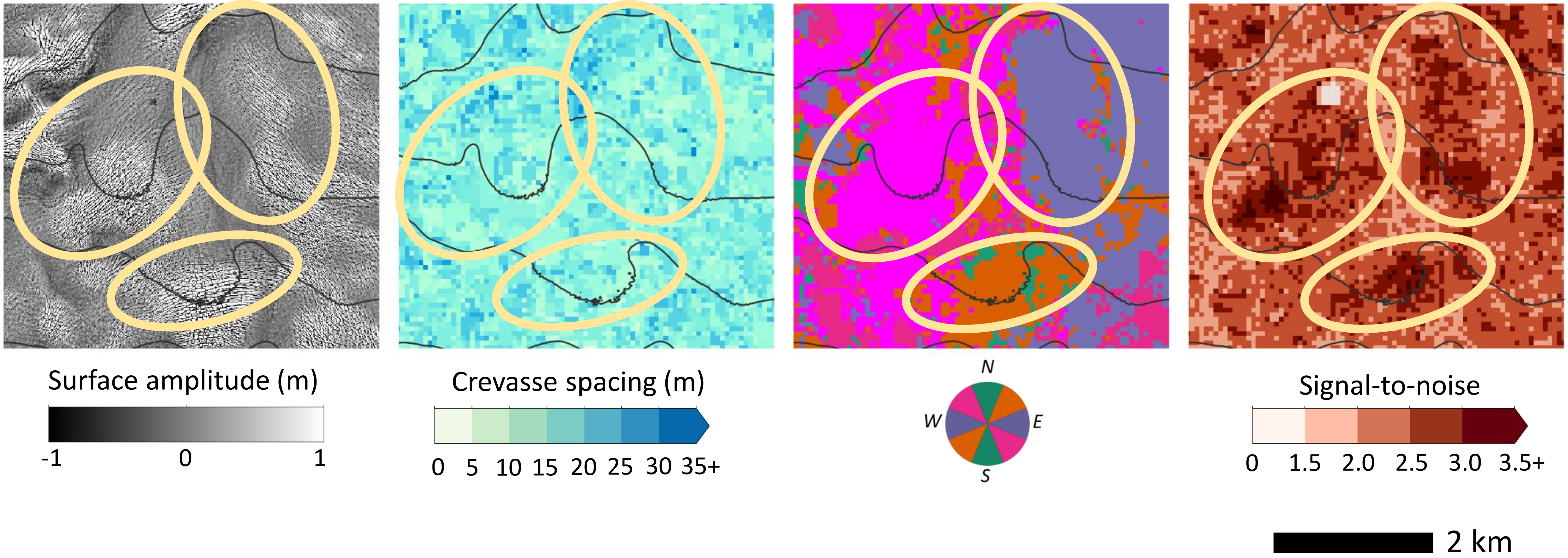


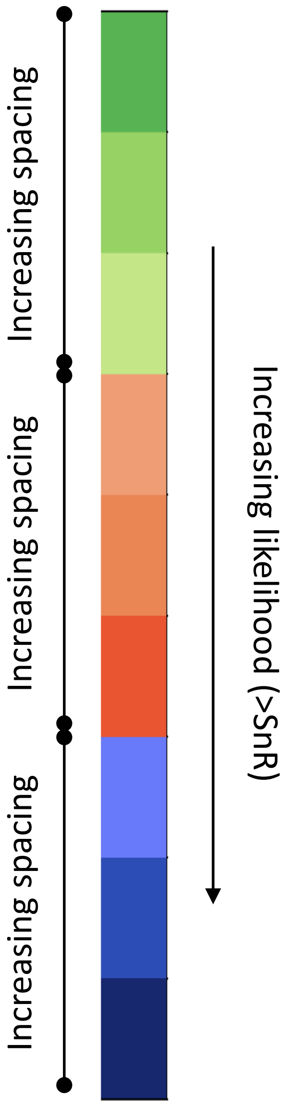
Spacing, orientation and SNR – window: 155 m | step: 35 m

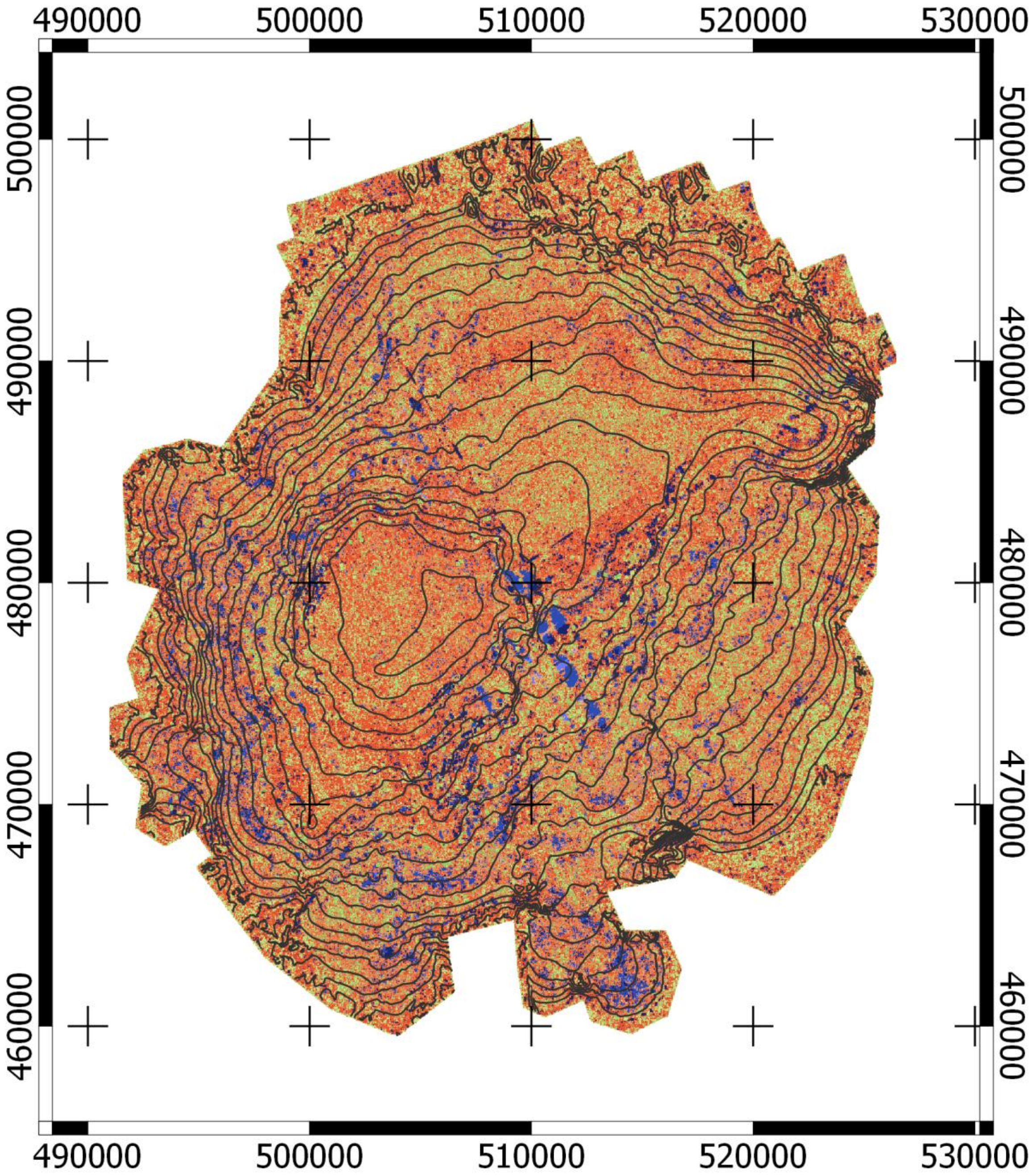


Hazard mapping potential

- *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.





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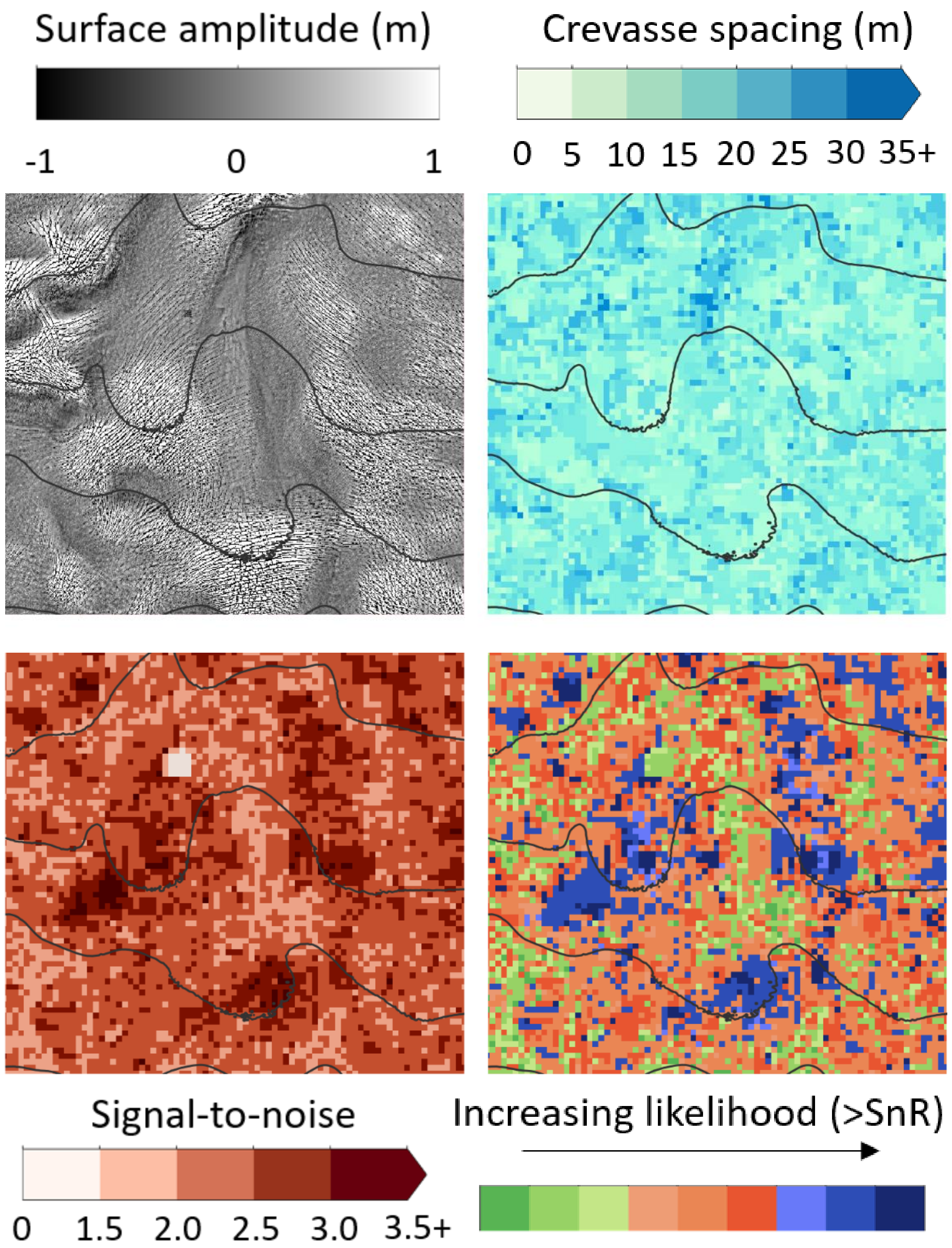
………..etc.



Benefits

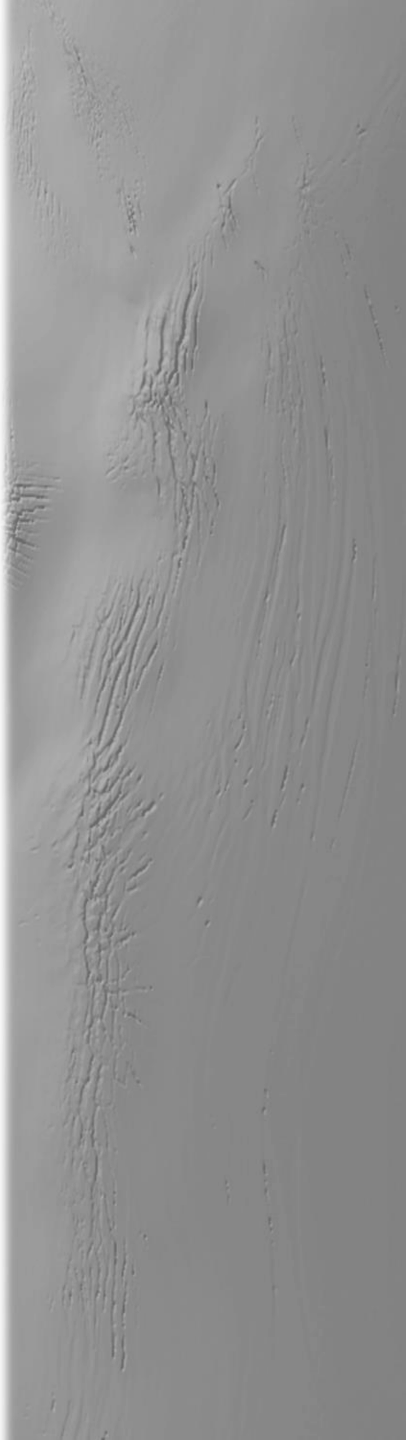
Scalable – 25cm – 100’s m
Quality of output determined by quality of input
Area ID for further investigation

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



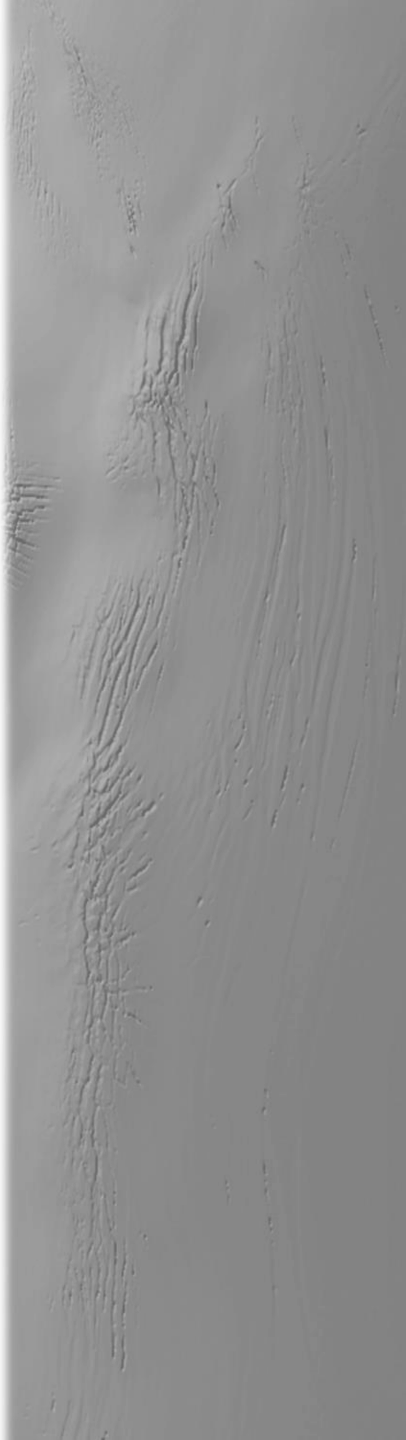
Potential applications

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

Climate Change Consortium of Wales
Consortiwm Newid Hinsawdd Cymru

British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

References and further reading

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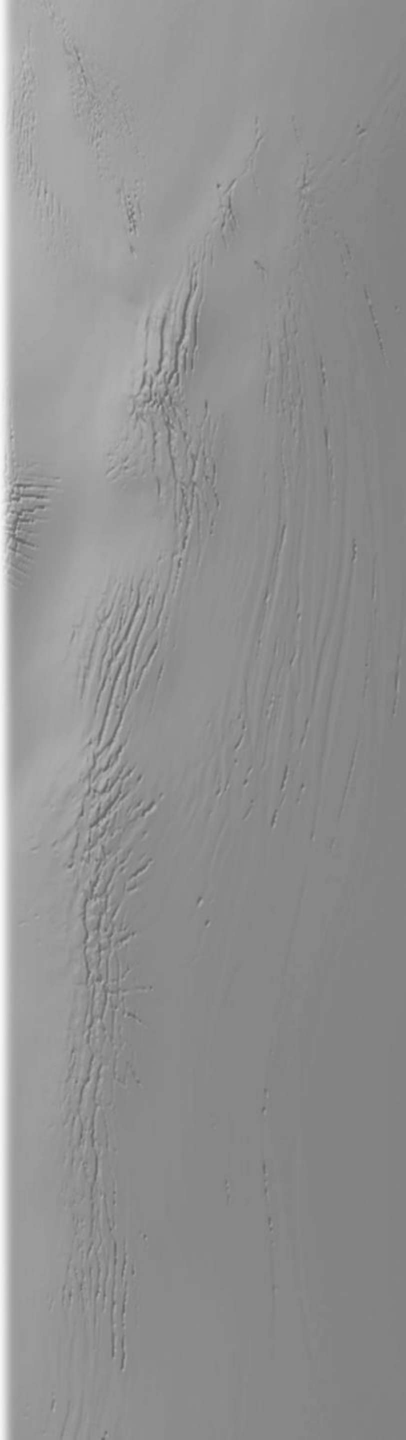
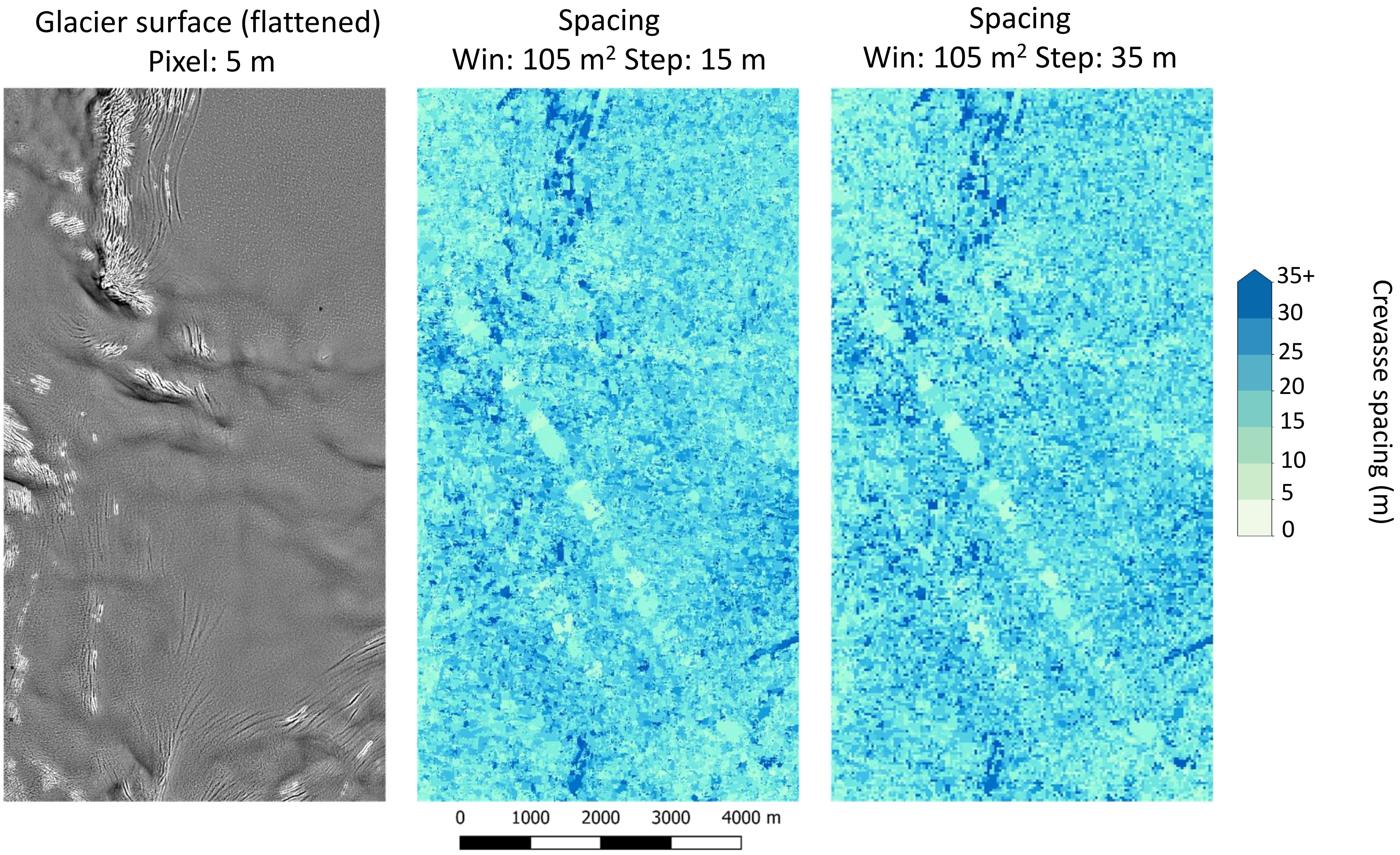
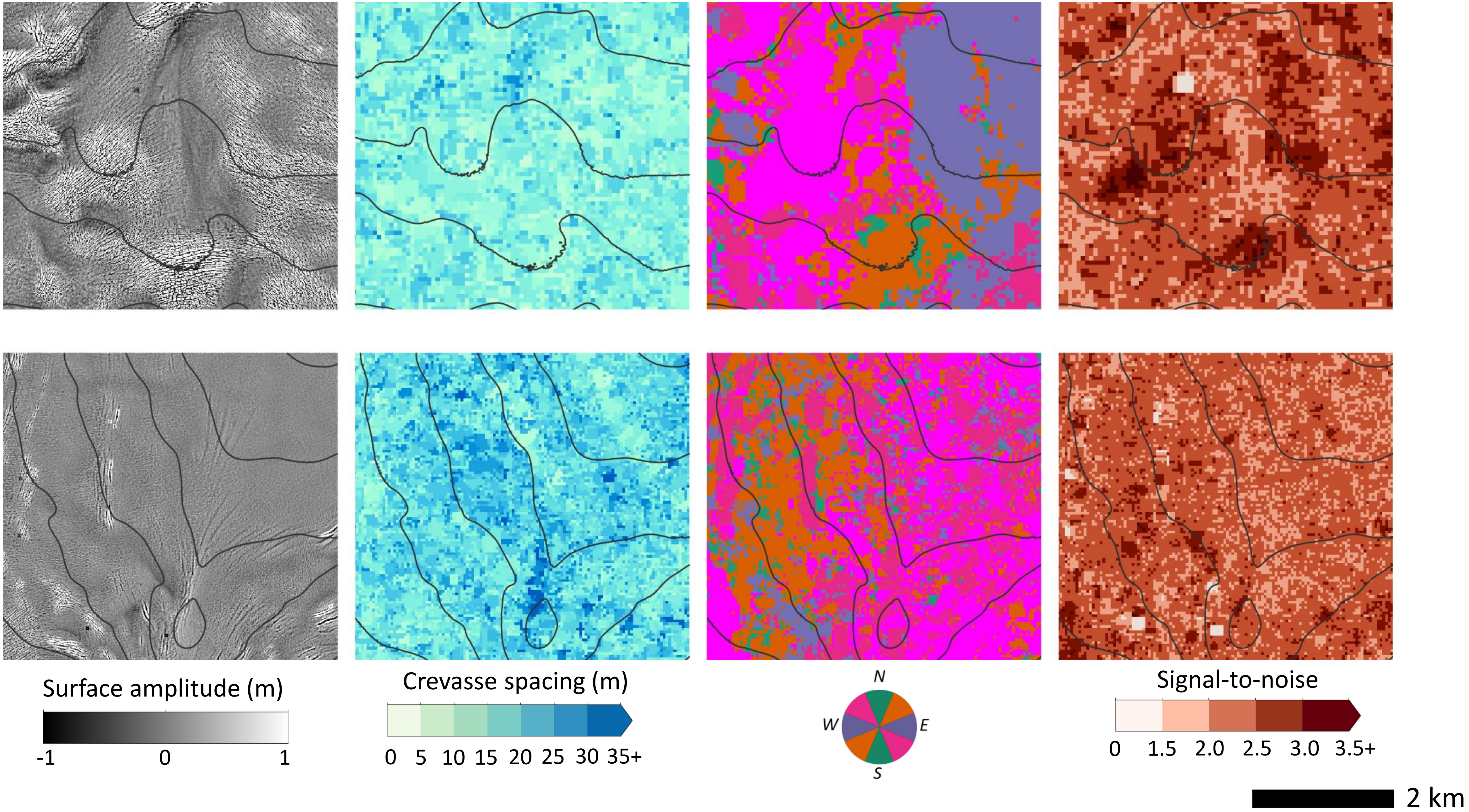


Sensitivity – step size increases coarseness of output



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



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