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

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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

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

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

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

Taken from http://www.qsimaging.com/ccd_noise_interpret_ffts.html
Visually interpreting an Fourier Transform plot

Rotationally symmetrical

Taken from http://www.qsimaging.com/ccd_noise_interpret_ffts.html
Visually interpreting an Fourier Transform plot

Centre point represents the mean brightness of the image

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...increasing frequency = further from origin

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

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

...increasing frequency = further from origin

FFT: Fast Fourier transform

Taken from http://www.qsimaging.com/ccd_noise_interpret_ffts.html
1. Original image
1. Original image

2. Calculate FFT
1. Original image

2. Calculate FFT

3. Smooth and Gibbs effect removal
1. Original image

2. Calculate FFT

3. Smooth and Gibbs effect removal

4. Noise removal
1. Original image
2. Calculate FFT
3. Smooth and Gibbs effect removal
4. Noise removal
1. Original image

2. Calculate FFT

3. Smooth and Gibbs effect removal

4. Noise removal

5. Log (visual)
1. Original image
2. Calculate FFT
3. Smooth and Gibbs effect removal
4. Noise removal
5. Log (visual)

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$^2$)
- 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

Hofsjökull crevasse map (2011) from http://safetravel.is available here:
5 m LiDAR composite

Trend removed using a 35 x 35 m window mean

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
5 m LiDAR composite

Trend removed using a 35 x 35 m window mean

10 km
Spacing – window: 155 m | step: 35 m

Surface amplitude (m)

Crevasse spacing (m)

Signal-to-noise
Orientation – window: 155 m | step: 35 m
Spacing, orientation and SNR – window: 155 m | step: 35 m

- Surface amplitude (m)
  - -1 to 1

- Crevasse spacing (m)
  - 0 to 35+

- Signal-to-noise
  - 0 to 3.5+
Spacing, orientation and SNR – window: 155 m | step: 35 m

Surface amplitude (m)

Crevasse spacing (m)

Signal-to-noise

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

- **Surface amplitude (m)**
  - Scale: -1, 0, 1

- **Crevasse spacing (m)**
  - Scale: 0, 5, 10, 15, 20, 25, 30, 35+

- **Signal-to-noise**
  - Scale: 0, 1.5, 2.0, 2.5, 3.0, 3.5+

- **Distance marker**: 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.

Increasing likelihood (>SnR)  
Increasing spacing
Hazard mapping potential

- **Spacing and signal-to-noise key**
- **Outputs are a guide – not a final decision**
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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

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Please quote the DOI if you use the code!
References


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

Crevasses spacing (m)
Spacing, orientation and SNR – window: 155 m | step: 35 m

Surface amplitude (m)

Crevasse spacing (m)

Signal-to-noise

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

Surface amplitude (m)

Crevasse spacing (m)

Signal-to-noise