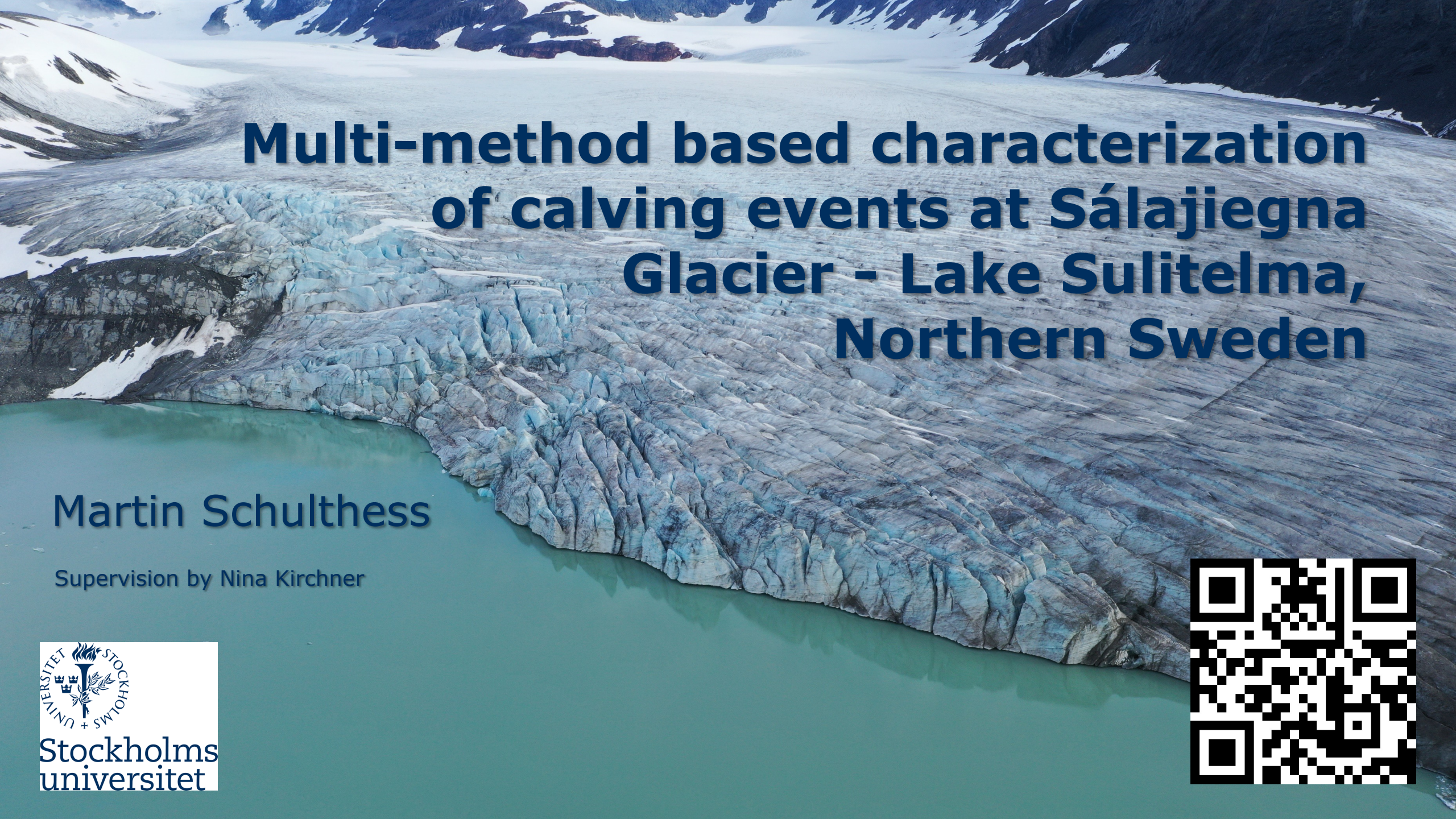

Multi-method based characterization of calving events at Sálajiegna Glacier - Lake Sulitelma, Northern Sweden

Martin Schulthess

Supervision by Nina Kirchner

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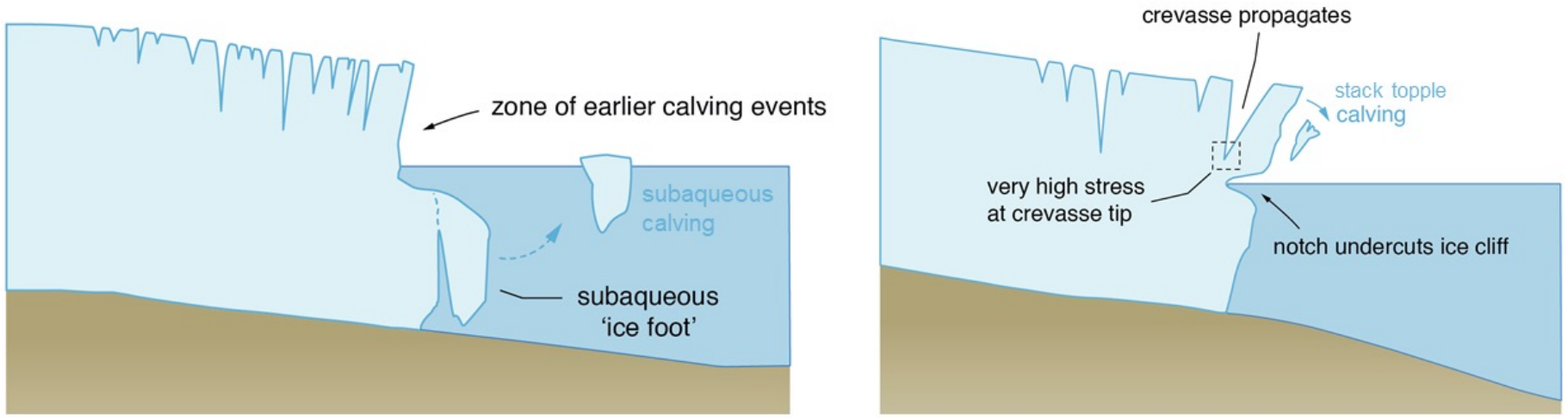
Motivation

- Millions of humans at risk by sea level rise (Hauser et al. 2020)
- Calving - a major uncertainty for future sea level rise projections (Moore et al. 2013)
- Freshwater calving constitutes a simplified system

Background

Styles:

- Ice-fall
- Collapse
- Stack topple
- Waterline
- Buoyancy-driven subaqueous calving



Source: adapted from AntarcticGlaciers.org

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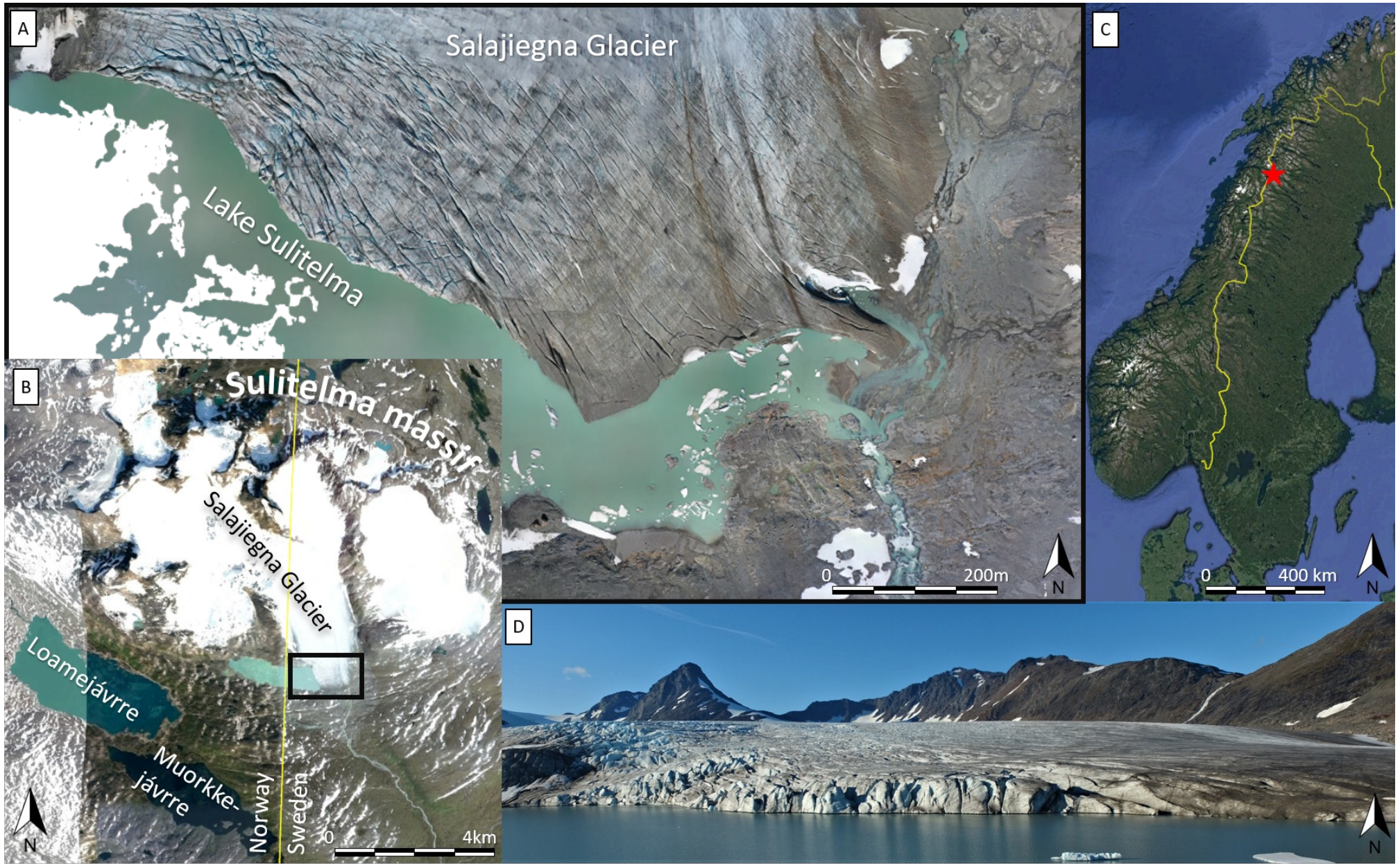
Aim

- Develop a methodology that allows detecting and characterizing of calving events based on acoustic signature and validation by visual methods.

Objectives

- collect acoustic data near calving front – record calving signal
- collect time-lapse imagery of the subaerial part of the glacier front – ground truth evidence for calving
- collect high-resolution subaerial imagery of the calving front - 3D models and DEM’s as basis for volume measurements
- develop an algorithm - identify calving events in acoustic signal
- synchronize data sets - time-wise correlation by time-lapse imagery
- quantify + characterize calving events – by parameters (volume, duration, continuity,…)

Field site – Present 14.-21. August 2020



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Western front


West-mid front


East-mid front


Eastern front

Data sets and Methodology – Overview

Acoustic data

- Data collection
- Acoustic principles
- Detection algorithm – event detection
- Detection algorithm – event characterization

Time-lapse imagery

Photogrammetry

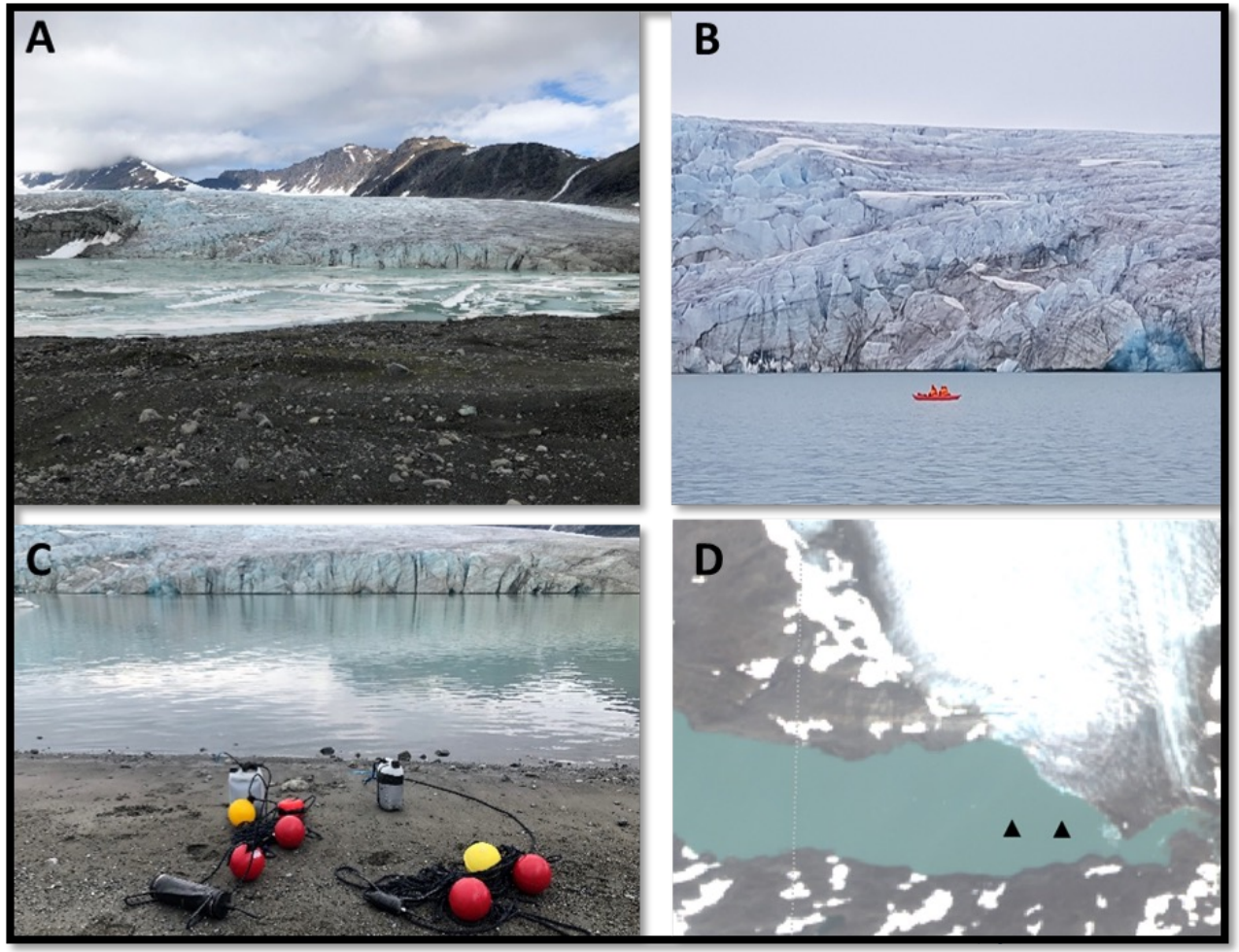
- Data collection
- Processing

Acoustic data – Data collection

2 Hydrophones

- ST500 (western) / ST300 (eastern)
- 59min .wav files, 96kHz sampling rate
- 2x Moorings: sand filled canisters, Hydrophones 5m above lake floor, at depth of 20m
- Data period: August 2020

  18th 17:15 – 21st 09:14



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Acoustic data – Acoustic principles

Signal-to-noise ratio: $$SNR[dB] = 10 * log_{10}\left[\left(\frac{A_{signal}}{A_{noise}}\right)^2\right]$$

NFFT (non-equispaced Fourier Transform):

- decrypts signal into its frequencies

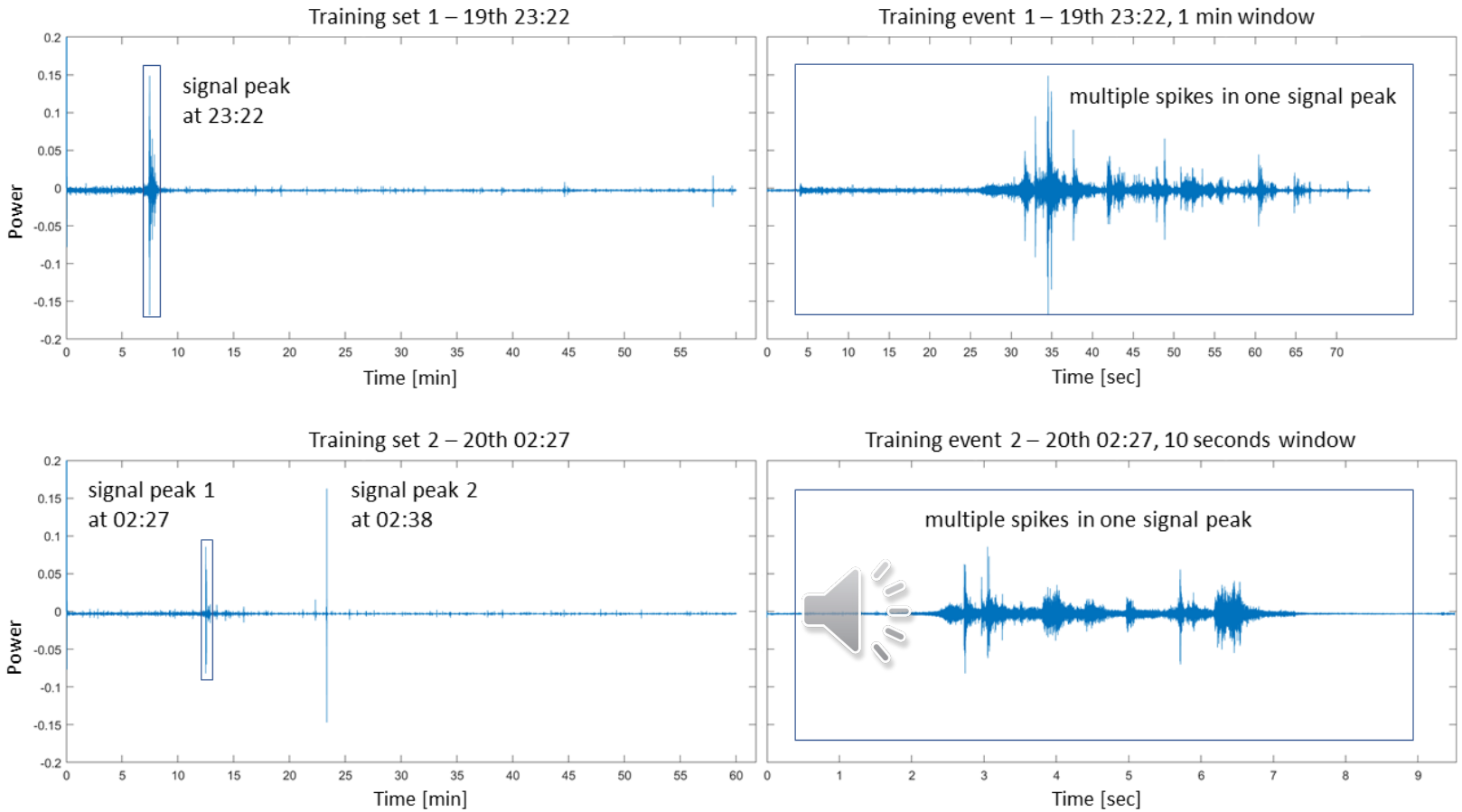
Periodogram:

- overall frequency distribution over signal period (window)

Acoustic detection algorithm – event detection

Training data ST500

- 2 training sets
- 1 training event each
- Training set 2: a second event



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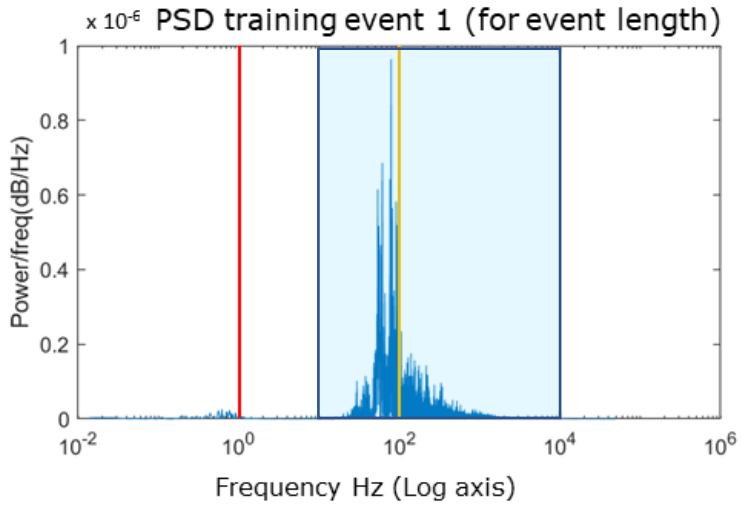
Acoustic detection algorithm – event detection

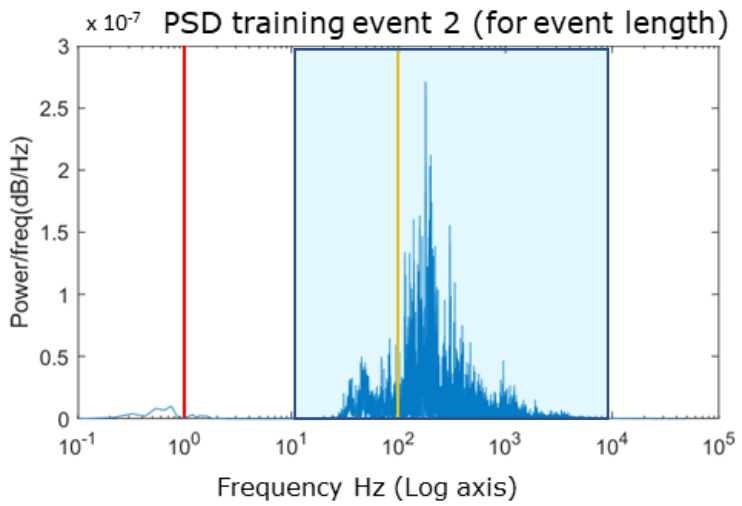
Periodogram

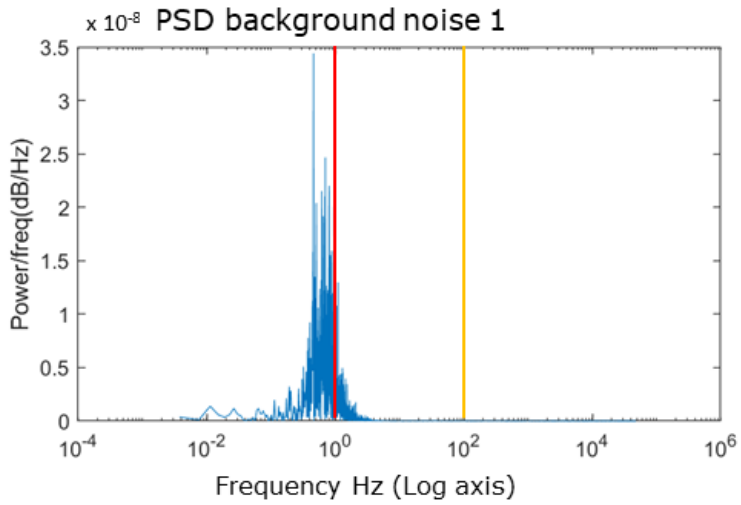
- Frequency spectrum:
  - 2 training events
    = 100Hz
  - 2 background noise
    = 1Hz

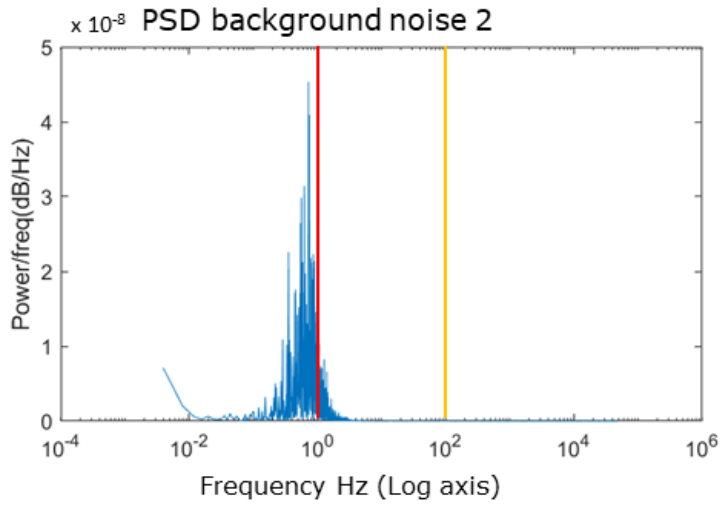
Filter:

- Bandpass:
  - 10Hz – 10kHz









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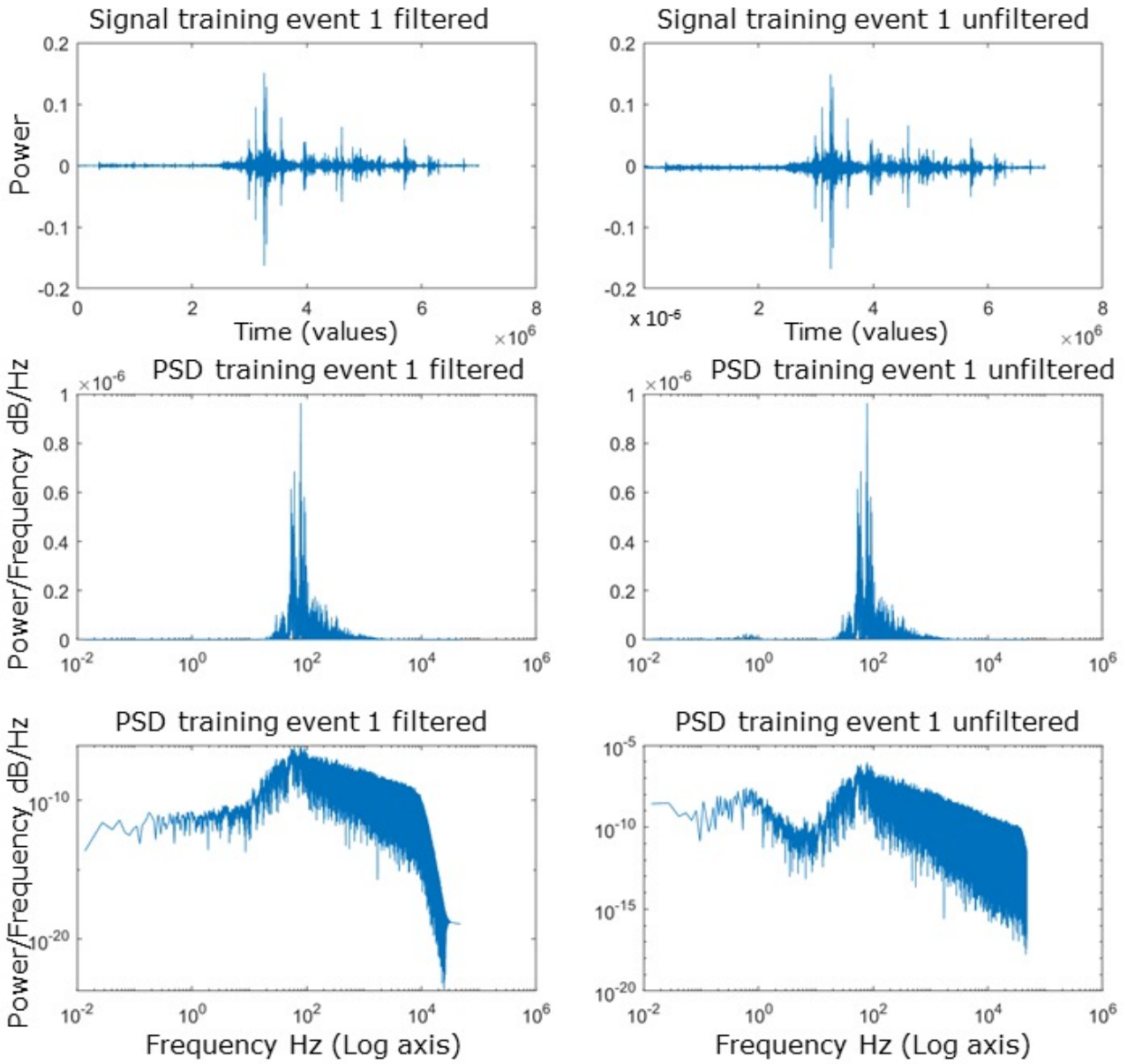
Acoustic detection algorithm – event detection

Filter

- Cut background noise 1Hz
- Butterworth filter
- Bandpass 10Hz – 10kHz
- Rectangular window

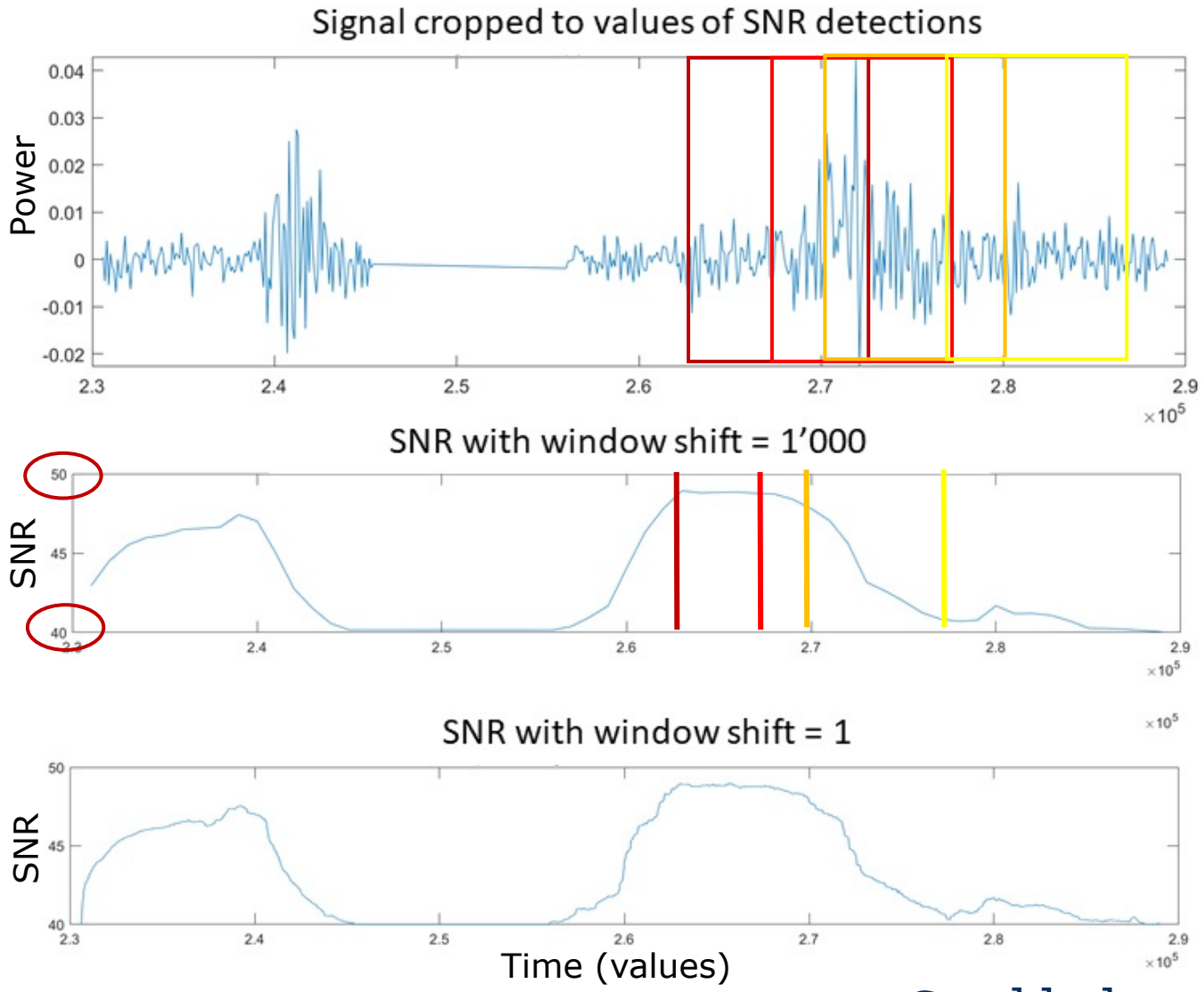


Acoustic detection algorithm – event detection

SNR – implementation:

- Iterate Matlab snr-function
- Running signal window
- Fixed background noise

➡ SNR data



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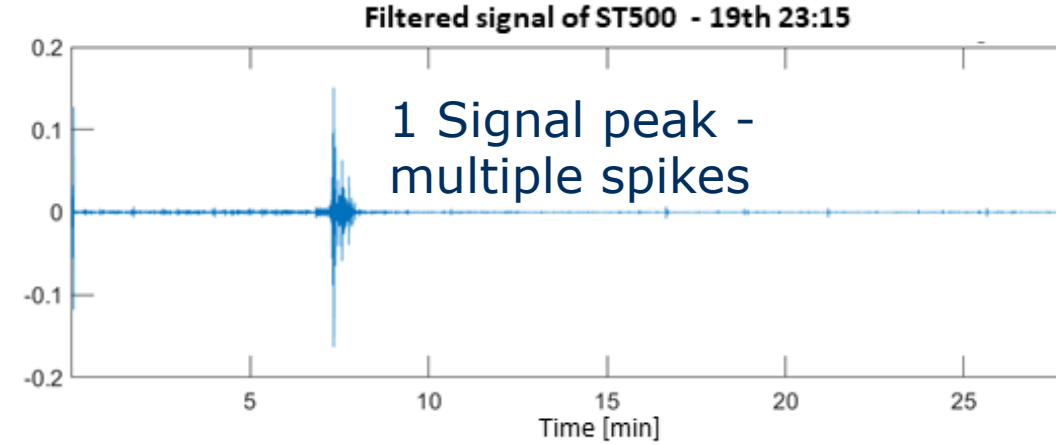
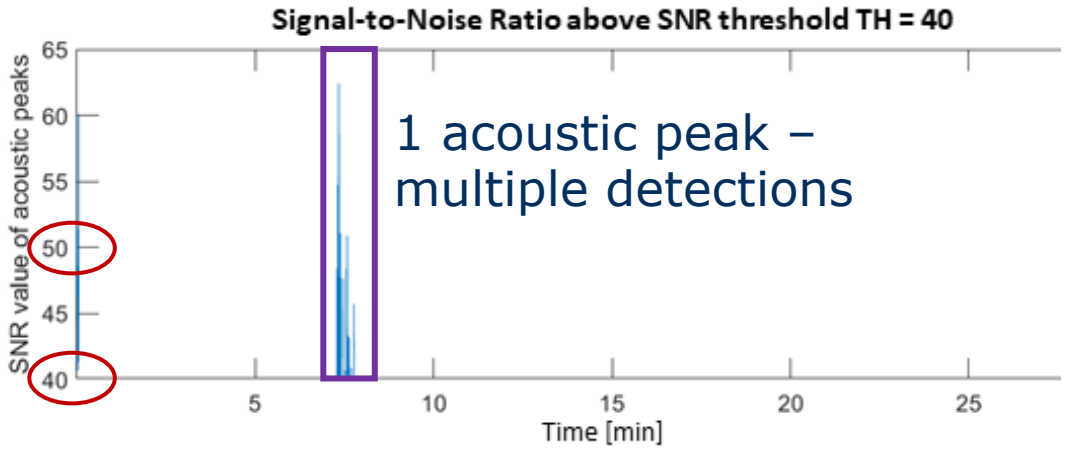
Acoustic detection algorithm – event detection

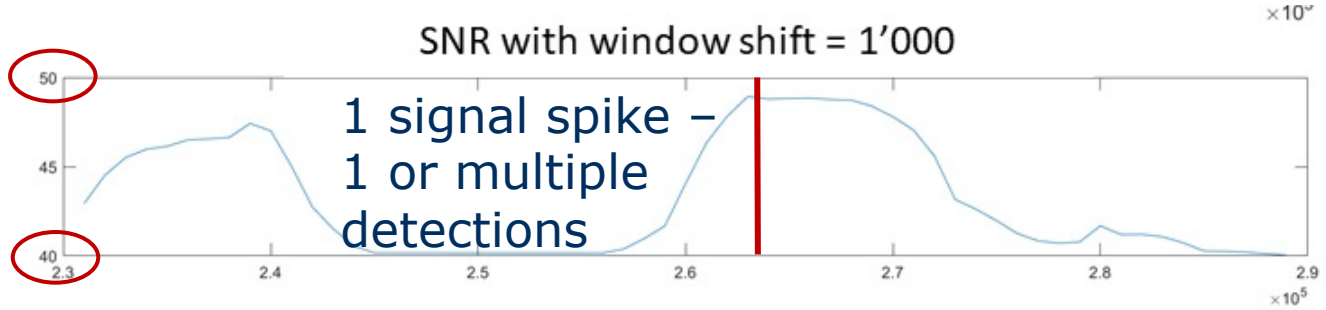
SNR – threshold:

- SNR threshold = 40
- SNR>40 ➟ ***detections***
- Cluster of detections

  ➟ ***1 Acoustic peak***







Acoustic detection algorithm – event characterization

Continuity of detection

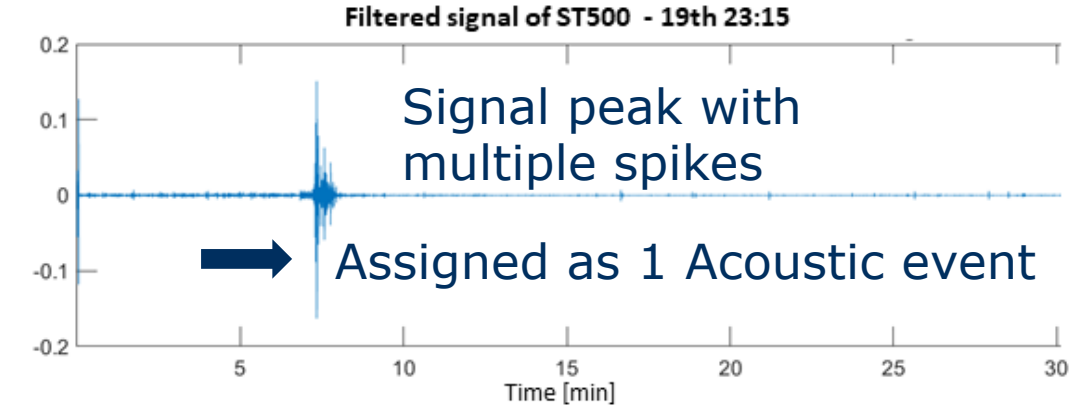
- # Detections per second

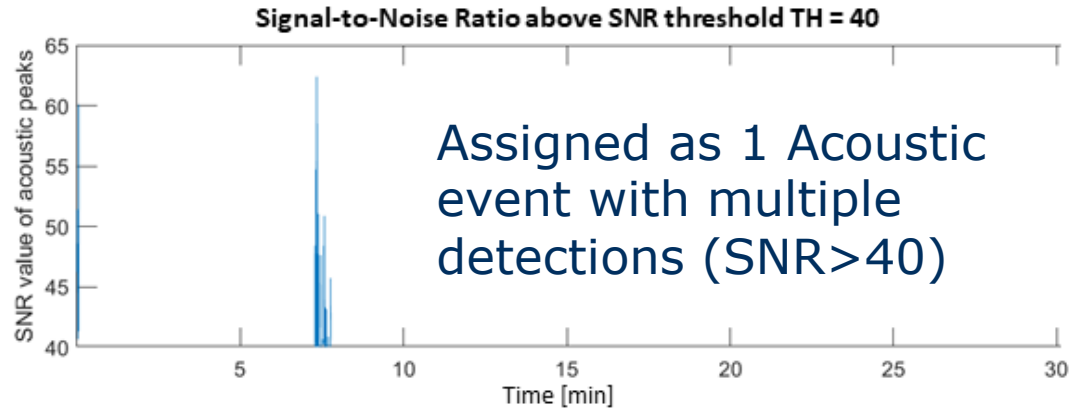
Acoustic event threshold

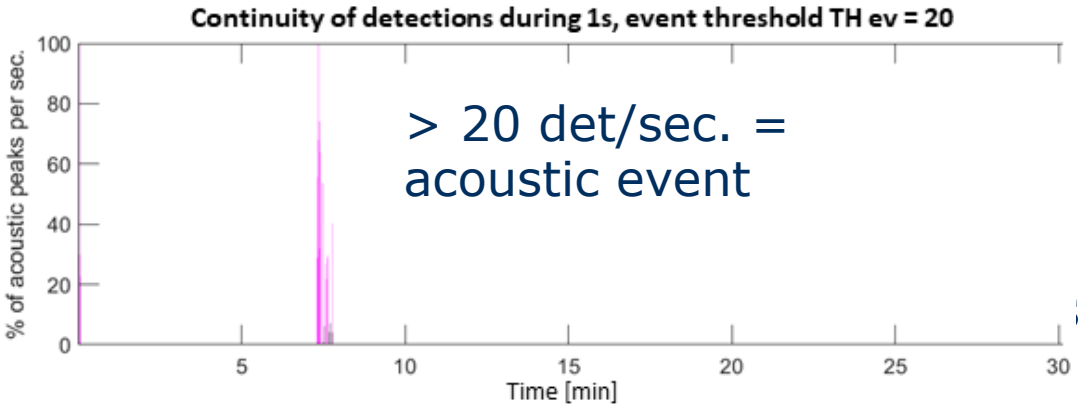
- 20 detections per second

➡ ***Acoustic event***

Seconds with detections







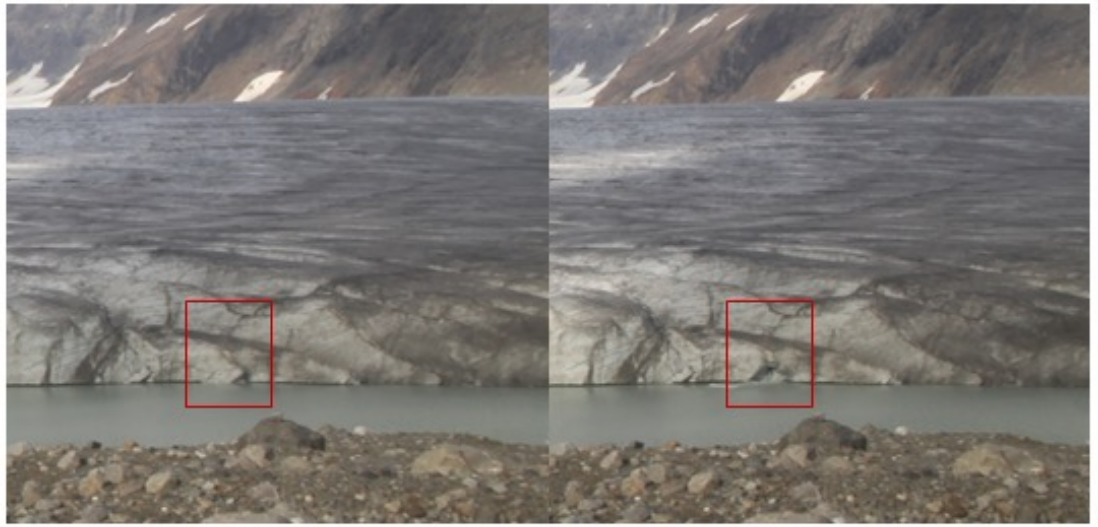
Time-lapse imagery

Cyclapse/GoPro:

- 18MP/12MP
- 5 frames/s
- Western/Eastern front

Processing:

- Manual investigation
- Periods of 10min
- Image recovery (night/fog)



Photogrammetry

DJI Mavic 2 Pro:

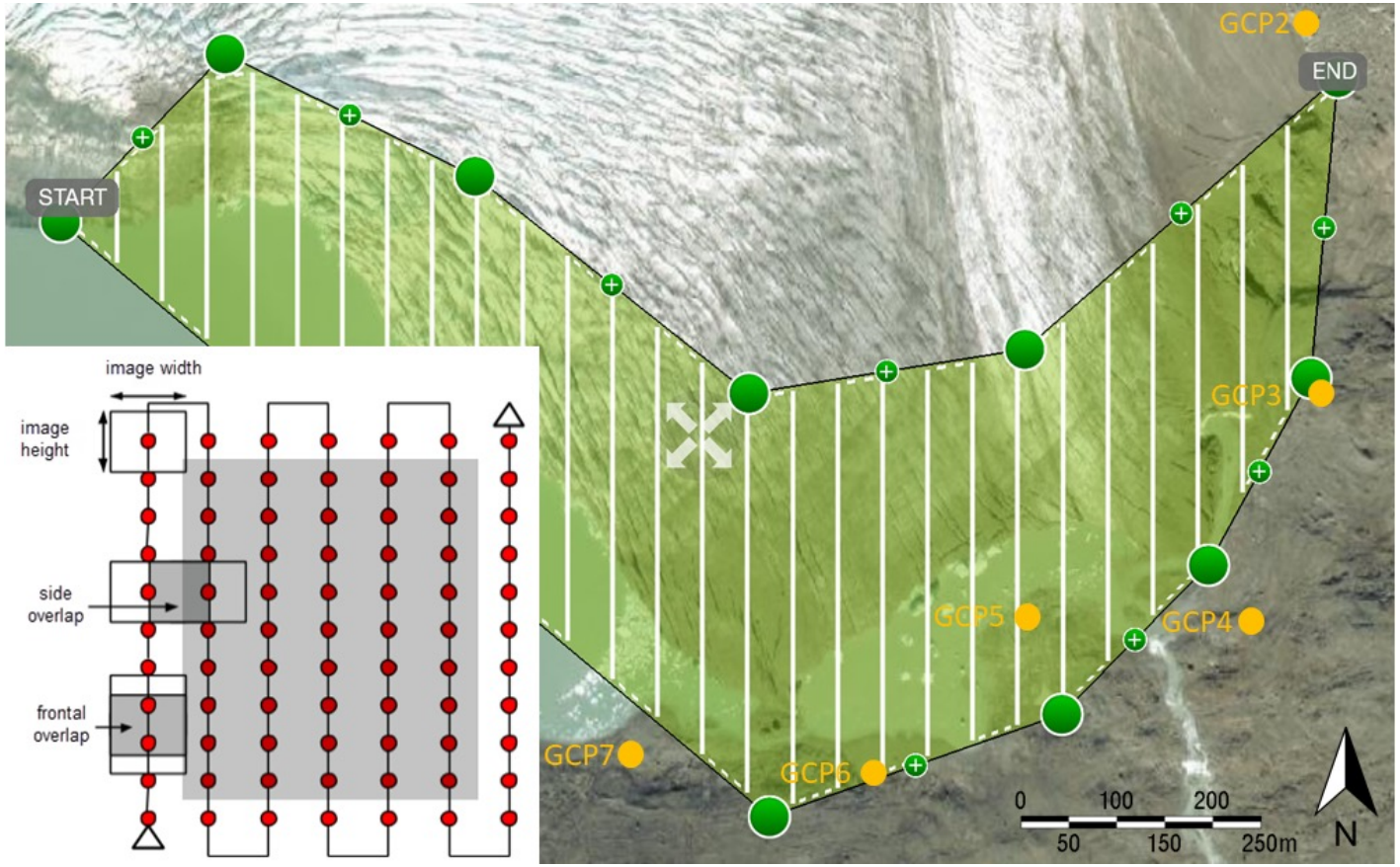
- 20MP, ~ 25min flights
- Resolution of cm's

Flight plan:

- 80% / 65% overlap
- Vertical / tilted camera

Trimble GEO7x d-GPS

- 7 GCP's
- Georeference



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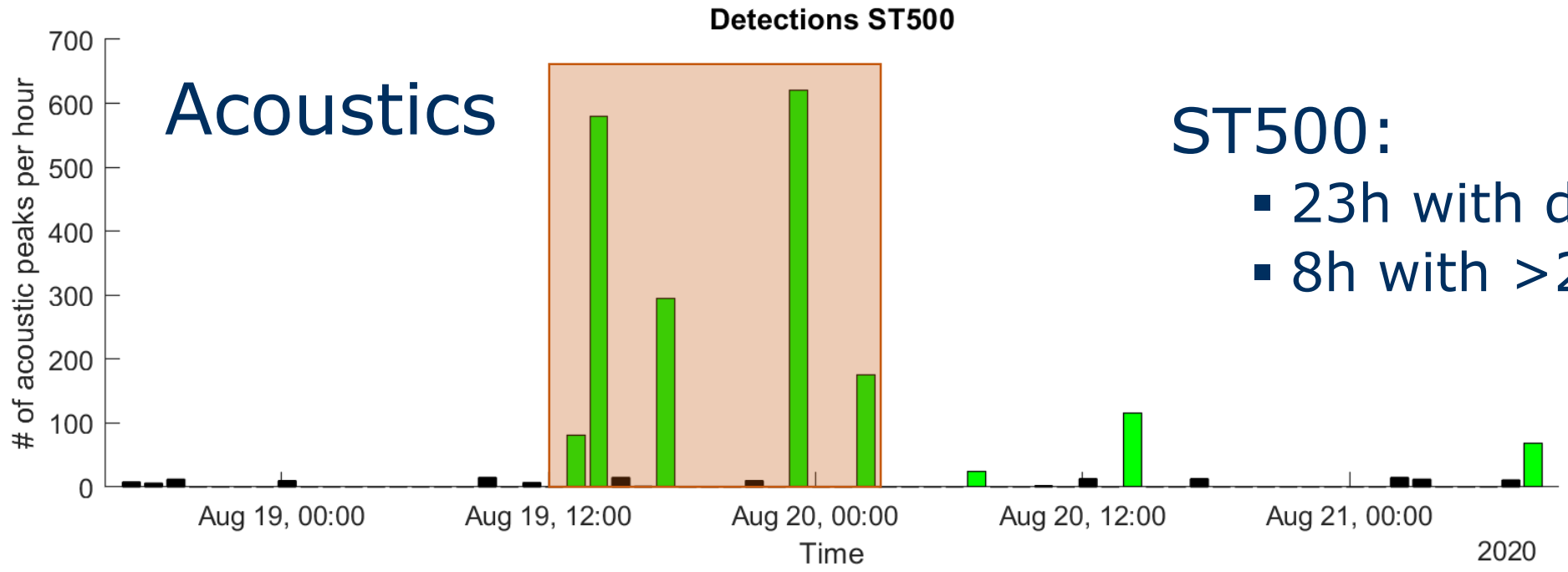
Photogrammetry

Agisoft Metashape:

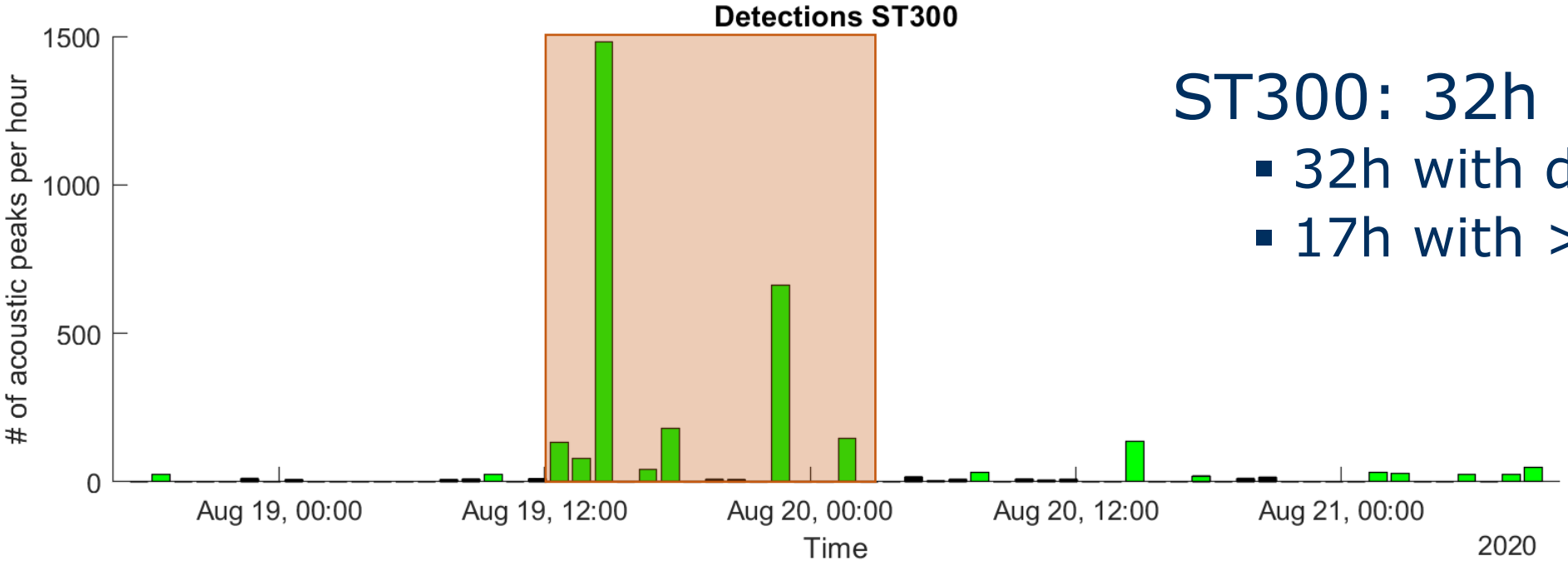
- Textured 3D models
- DEM’s
- Orthomosaic
- Georeferenced
- Measurement
  - Volume,
  - Length,
  - Elevation,…

Acoustics



ST500:

- 23h with detections
- 8h with >20 det. / h



ST300: 32h

- 32h with detections
- 17h with >20 det. / h

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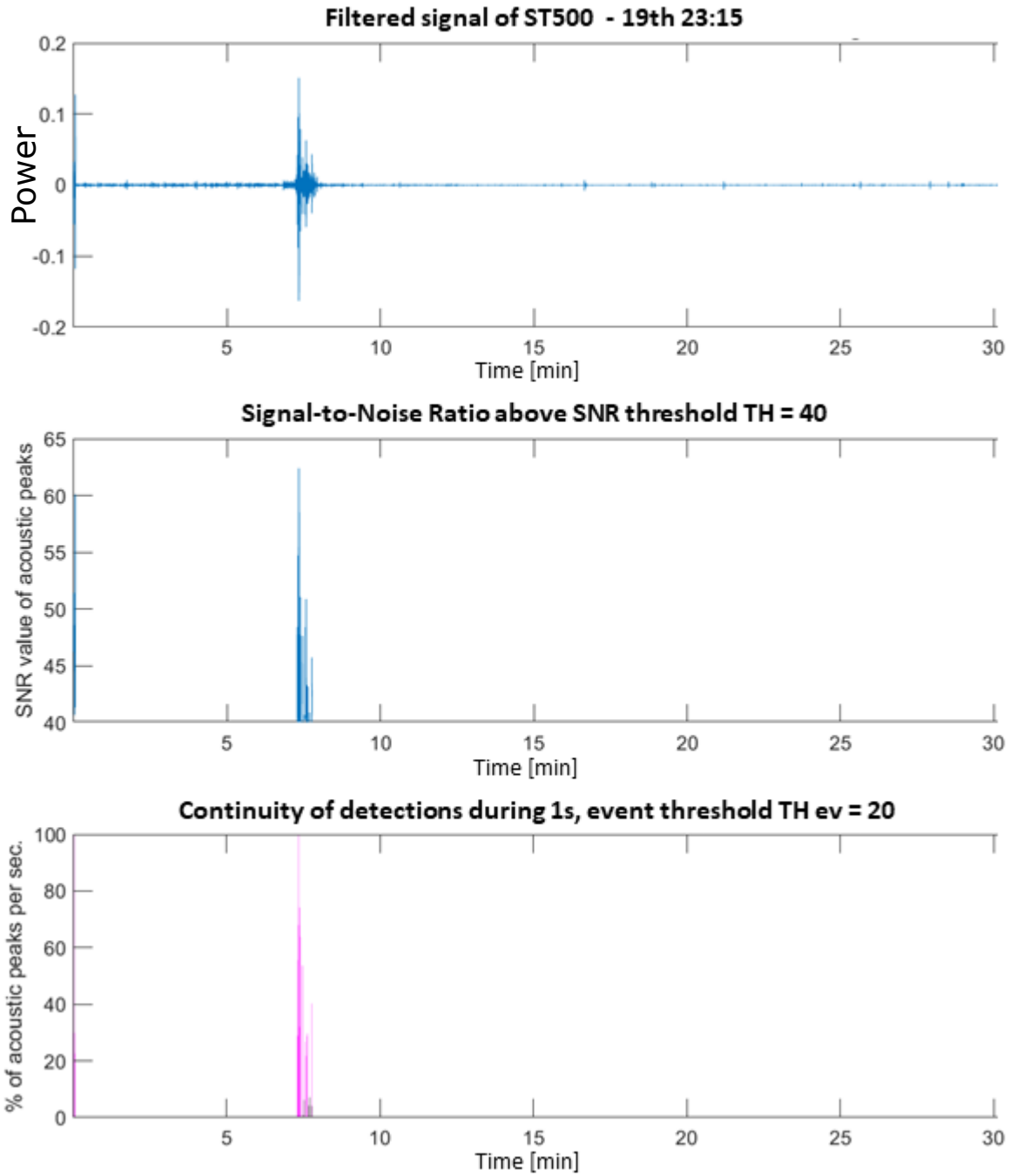
Acoustics

Event data:

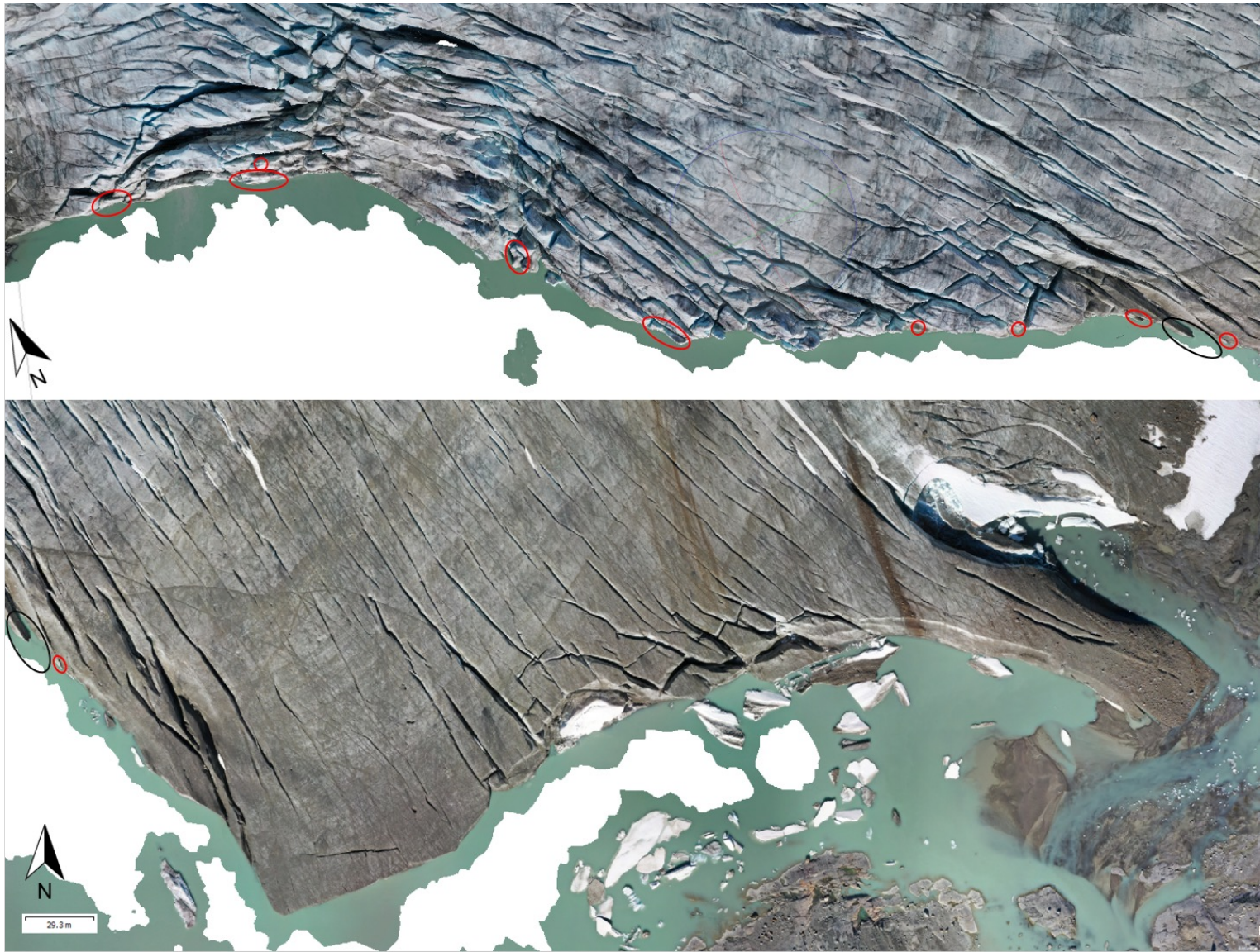
- 49 acoustic peaks
  - 28 in ST500
  - 46 in ST300
  - 24 in both
- 14 acoustic events
  - 9 in ST500
  - 13 in ST300
  - 8 in both
- ST500/ST300
  - ST300: 93% of total
  - ST500: ~60% of total
  - ST300 in ST500: 87%
  - ST500 in ST300: 57%



Time-lapse imagery

Ground-truth evidence

- 12 events
- 9 Locations
- Precise time



Photogrammetry

- 6 textured 3D models – 4 days
- Evidence for 10 events in textured 3D models (+ volume)
- Volumes between 1 – 600m^3
- 4 calvings > 200 m^3 ; 6 calvings < 30 m^3
- 4 calving events: no volume quantification


Perspective 30°
Snap: Axis, 30°
Z
Y
X

Synthesis

Time UTC	Volume [m³] calculated	Volume [m³] measured	Duration [s]	Detections ST500	Detections ST300	max. Continuity ST500	max. Continuity ST300	Seconds w/ detections ST500	Seconds w/ detections ST300	max. Amplitude ST500	max. Amplitude ST300	Frequency peak [Hz] ST500	Frequency peak [Hz] ST300	2 separate peaks	Precursor	Calving style
17:16	6	6	2	8	0	8	0	1	0	0.0143	0.0112	88.3	79.7	strong		waterline
19:00	4	4	2	0	15	0	10	0	2	0.0165	0.0311	108.5	55.9	strong		waterline
13:02	16	16	2	0	32	0	33	0	1	0.0243	0.0318	44.9	45	weak		waterline
13:21	28	26	4	81	101	57	67	2	2	0.0512	0.0983	103.2	54.1	No	precursor	waterline
14:57	640	630	13	579	611	100	100	12	11	0.2403	0.3225	69	58.61	No	precursor	waterline
18:08	280	360	6	284	182	91	53	6	6	0.0867	0.0502	64.9	92.6	No		unclear (fog)
23:22	510	535	31	621	655	100	99	18	17	0.1511	0.1654	79	79.1	No	precursor	waterline
2:27	230	205	5	151	116	43	55	5	4	0.0775	0.0576	179.3	186.9	No	precursor	waterline
6:22			4	0	4	0	4	0	1	0.0121	0.0181	103.3	55.7	No		waterline
7:50			1	24	22	25	18	1	2	0.0633	0.0704	264	307.5	strong		waterline
15:09			12	115	126	46	53	4	4	0.0425	0.0386	206.9	89.2	No	precursor	submarine
17:51			1	13	20	13	21	1	1	0.0192	0.0437	74.2	64.6	No		unclear (size and signal)
8:04	6	1.5	1	7	15	7	15	1	1	0.0198	0.0312	104.2	179.9	weak		waterline
8:48	12	5	2	68	50	38	32	2	2	0.1918	0.2143	40.4	50.6	strong		ice-fall

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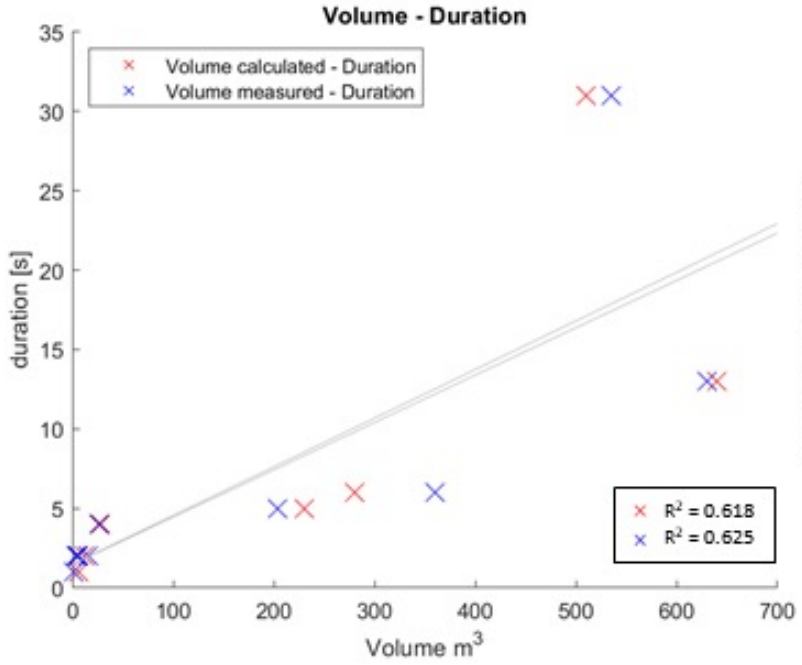
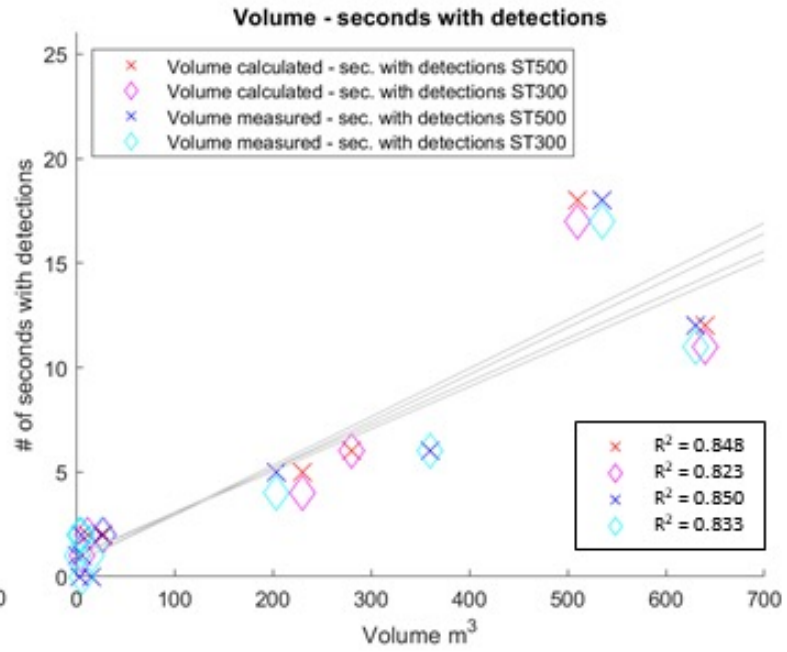
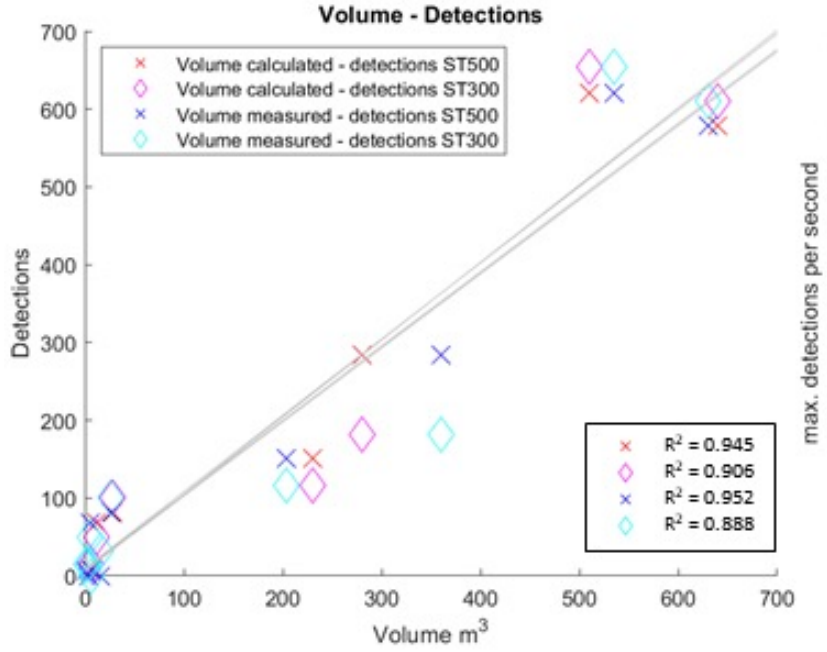
Synthesis

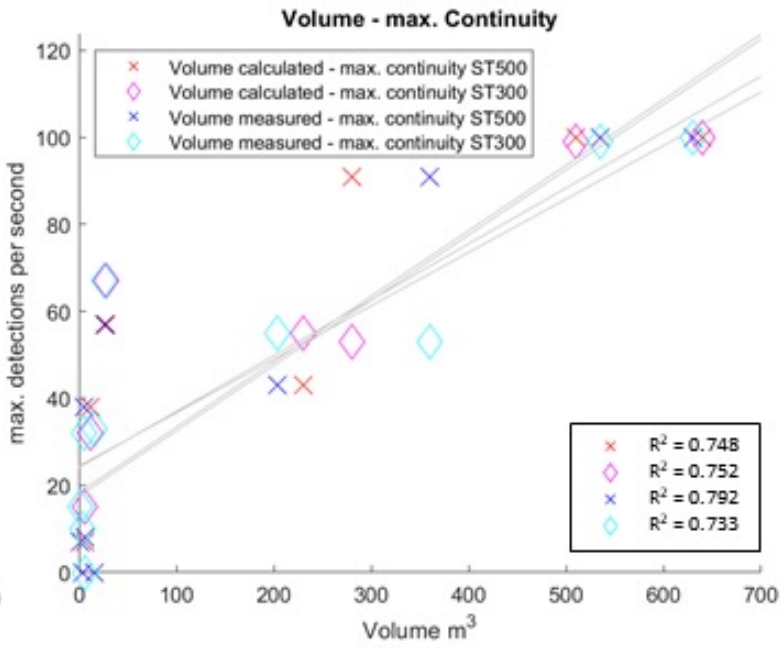
Corr. to Volume

- Detections: 0.92
- Sec. /w det.: 0.84
- Continuity: 0.75
- Duration: 0.62
- ST300/ST500: 95%









Discussion

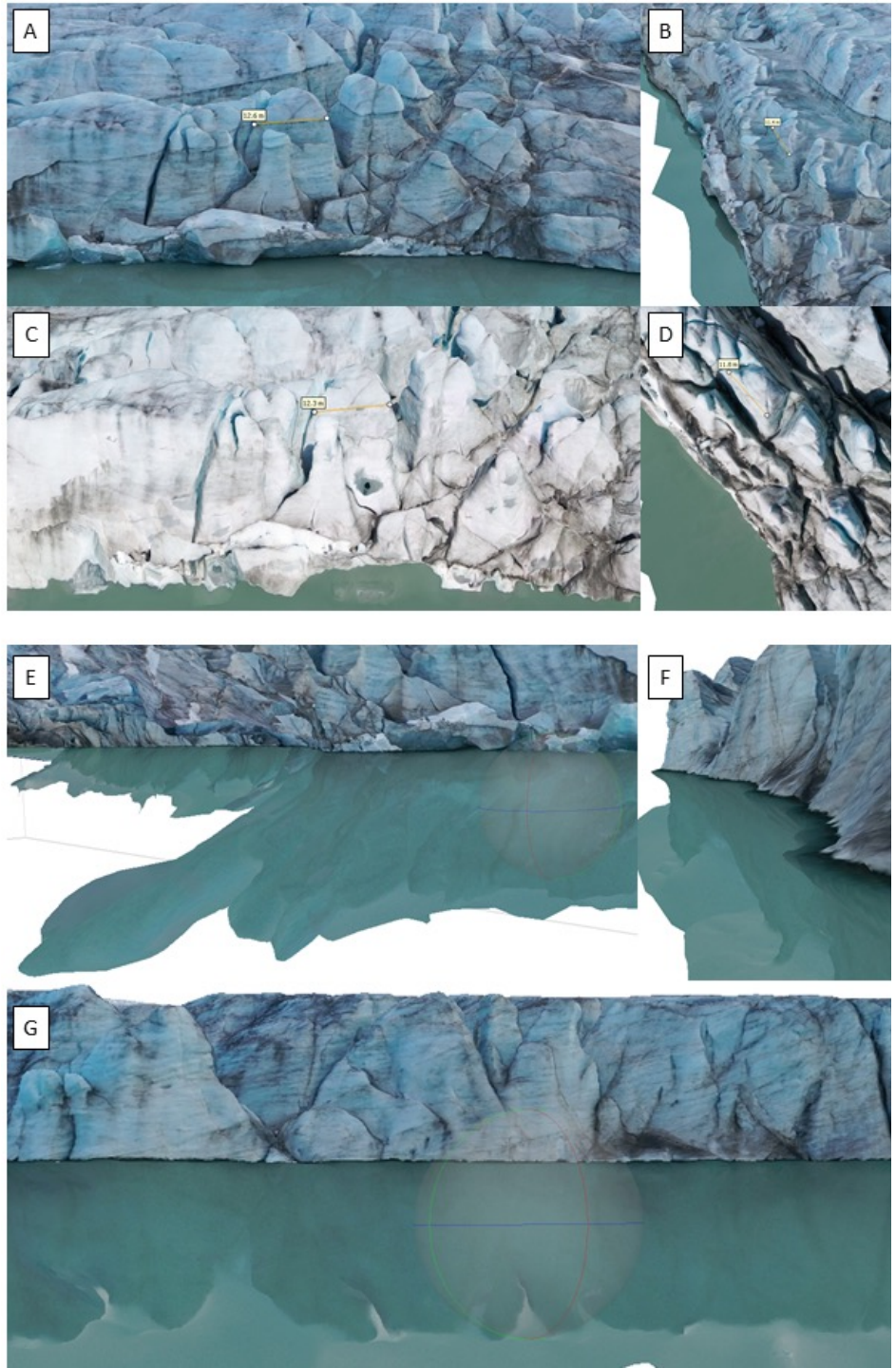
Restrictions:

- Limited data period: 4 days delay
- Inactive glacier system: lake ice
- Fog during most active day of calving front

Discussion

Interpretation:

- Reflectance of water
- Volume measurement
- Calving style (TLC rate)
- Precursor



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Discussion

Recommendations:

- Spectrogram
- Adjust flightplan: double grid,
- TLC closer to shore
- TLC automatic calving detection
- Compute 2021-2020 mass loss, front retreat, ice velocity
- Development of a basic model

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Conclusion

- All objectives accomplished
- Correlation between characteristics of acoustic signal peaks and calving volume with multi-method approach
- Robust but sensitive detection algorithm
- Established possibility to detect small calving events and high accuracy

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Please contact me:

Martin Schulthess

@M_Schulthess (Twitter)

m.schulthess@outlook.com

Have a look at my full Master Thesis about this topic: