Acoustic measurements with iDAS for detection of defects in embankment dams

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SILIXA

SISPROBE

Content

- Research projects/publications
- Seismic fundamentals
- Application for dams
- Seismic monitoring
  (Distributed Acoustic Sensing)
- Result from large dams
- Result from experimental dam
- Conclusions – Lessons learned

Project organisation

- ✓ HydroResearch
  - ✓ Project and research leader
  - ✓ Field work and measurement set-up, data transfer
  - ✓ Application/dam engineering aspects
- ✓ Silixa (UK)
  - ✓ Providing monitoring equipment and everything else needed
  - ✓ Responsible for the monitoring set-up and data evaluation
  - ✓ Evaluation of MASW
- ✓ Sisprobe/EGIS (France)
  - ✓ ANI - evaluation

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Publications

The content is based on three projects funded by Energiforsk

- 2020:682
- 2021:732
- 2022:874

Co-Authors:
Ari David, Michael Mondanos and Anna Stork, Silixa Ltd, United Kingdom

Aurélien Mordret, Sophie Beaupretre Sisprobe, UGA, ISTerre, France

Other publications

- ICOLD Q106—R 22
- EAEG, October
- ASDSO 2022 Annual Conference, Sep

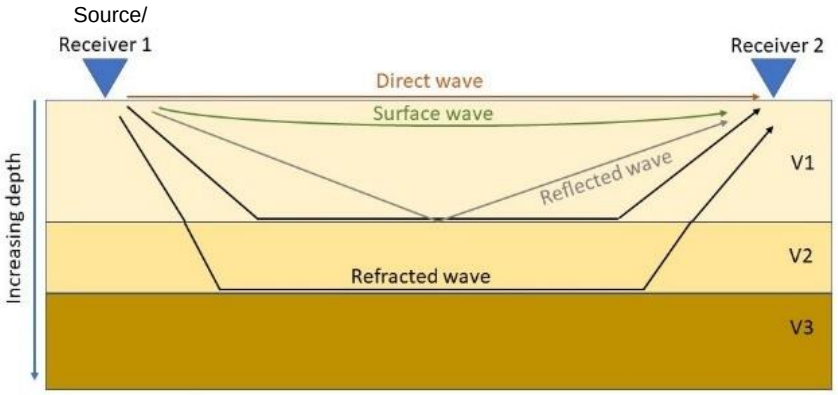
ACOUSTIC METHODS TO DETECT ANOMALIES IN AN EMBANKMENT DAM – A COMPARISON WITH OTHER GEOPHYSICAL METHODS

Sam Johansson, HydroResearch AB (Ph.D.)
Ingvar Ekström, Sweco (M.Sc.)
Mats Persson, Vattenfall Vattenkraft (M.Sc.)

Application of Seismic methods

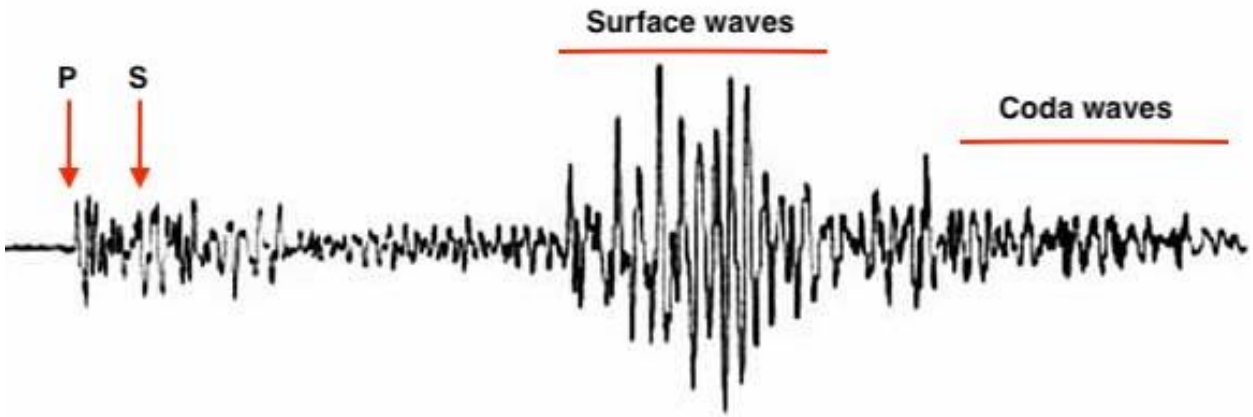
- Seismic velocities depends mainly on density, porosity and gas/water content
  - Bedrock level
  - Rock properties
  - Oil exploration, fracking etc
  - CO2- storage (gas content)
  - Embankment dams
- Active methods - single investigation
  - Refraction seismics
  - Reflection seismics
  - Multichannel Analysis of Surface Waves, MASW
- Ambient Noise Interferometry, ANI
  - Imaging
  - Monitoring
- Hydroacoustic sounding
  - Sounds from whale
  - Embankment dams

Seismic velocities



Body waves
(direct arrival)

Surface waves are dispersive, meaning that their phase velocity depends on frequency.



Coda waves are randomly scattered waves due to inhomogeneities. They are more sensitive to changes in the medium than direct waves and tend to be more stable with a varying noise sources than body or surface waves.

Seismic velocities

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Compression wave *Vp*

$$V_P = \sqrt{\frac{K + {}^4/_3\mu}{\rho}}$$

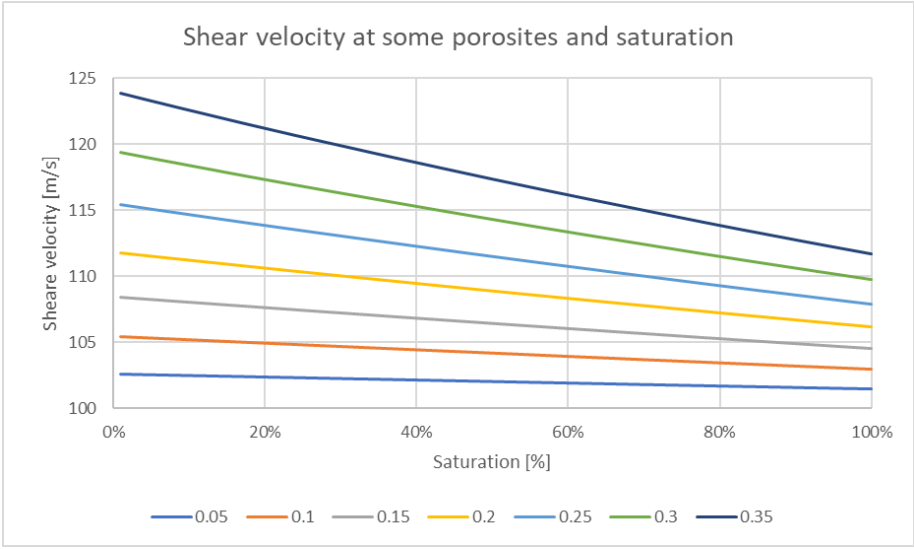
Shear wave, *Vs*

$$V_S = \sqrt{{}^{\mu}/_{\rho}}$$

where:
K is the bulk modulus,
μ is the shear modulus, and
ϱ is the density.

Increasing density – decreasing Vs

At constant bulk and shear modulus



Ambient Noise Interferometry, ANI

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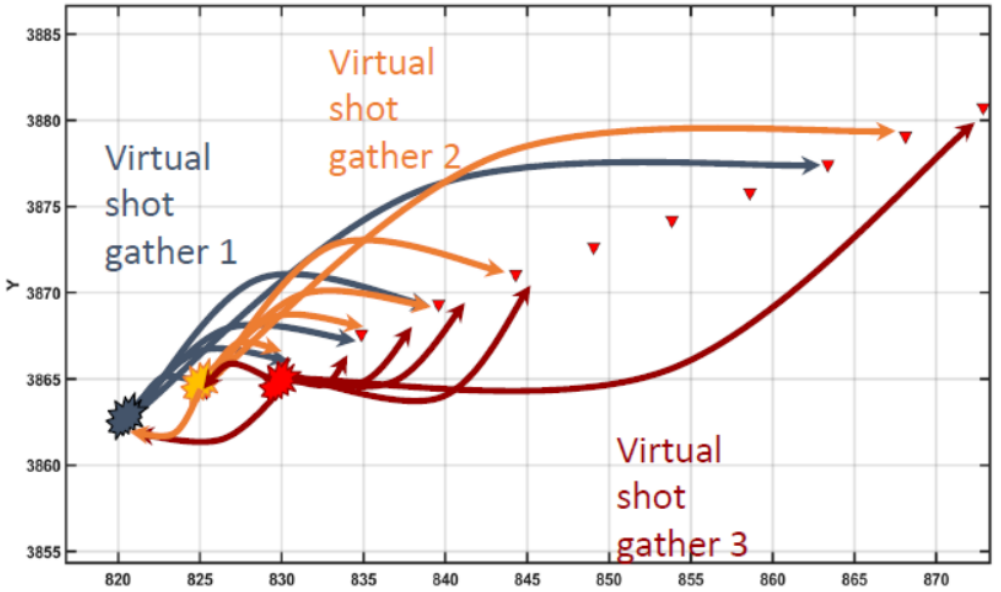
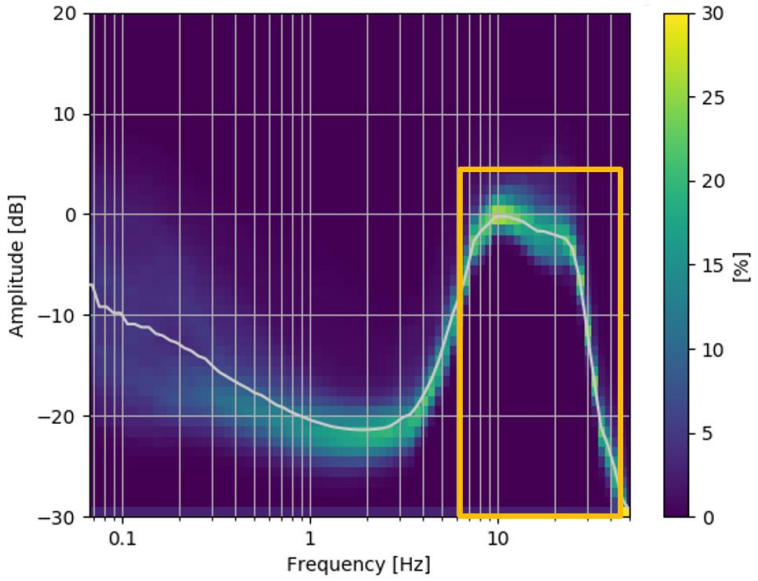
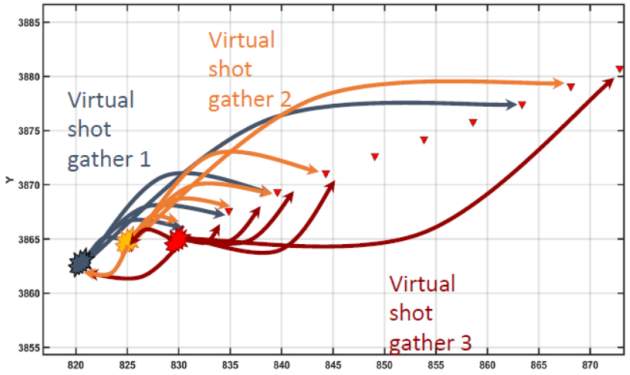
Use of naturally occurring background noise to calculate seismic velocities.

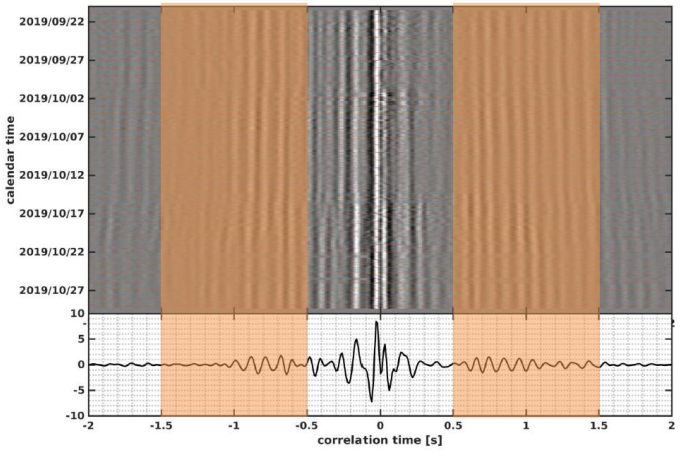
By cross-correlating noise records between two sensors, it is possible to reconstruct the response as if one sensor were a seismic source and the other a receiver. Thus, a seismogram is produced.



ANI - Steps

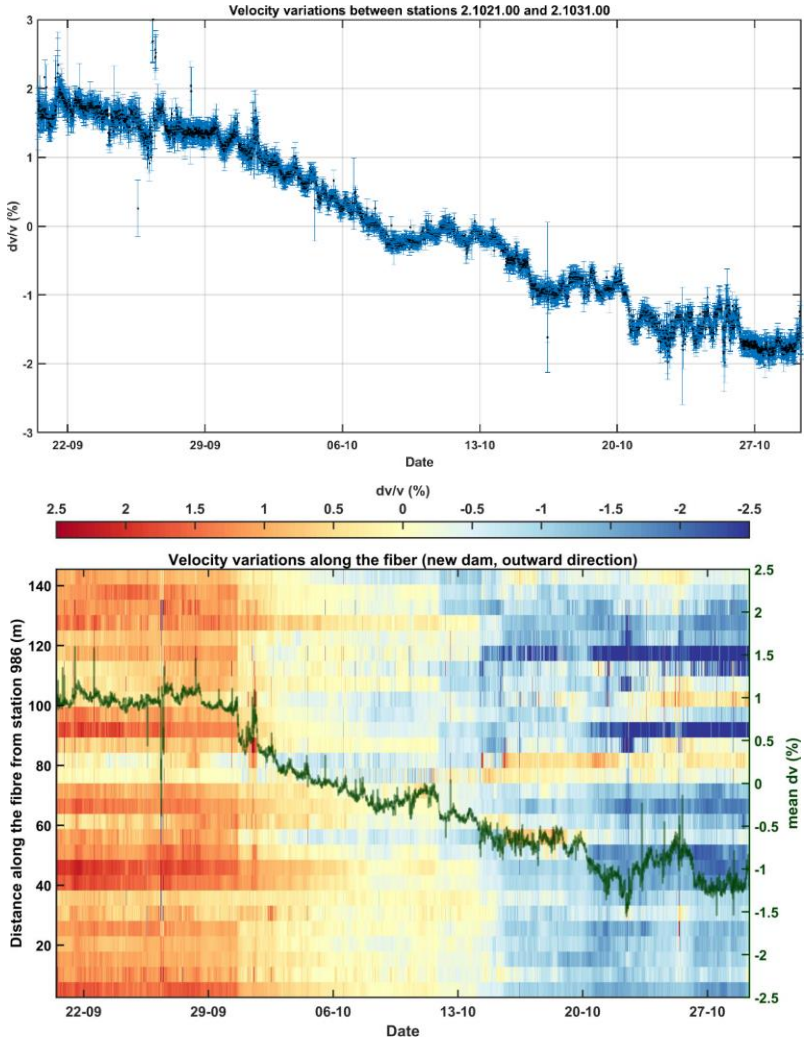






The cross-correlated waveforms for each 15-minute time interval, bandpass filtered 5 – 20 Hz.

Seismic velocity or velocity changes



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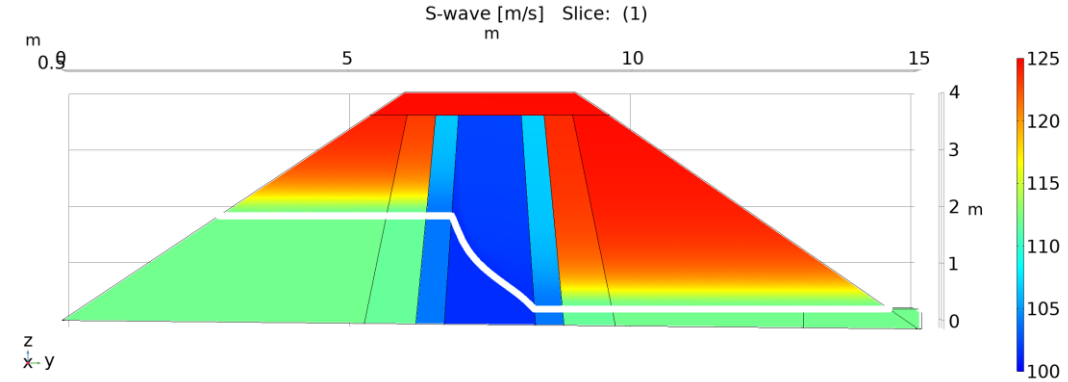
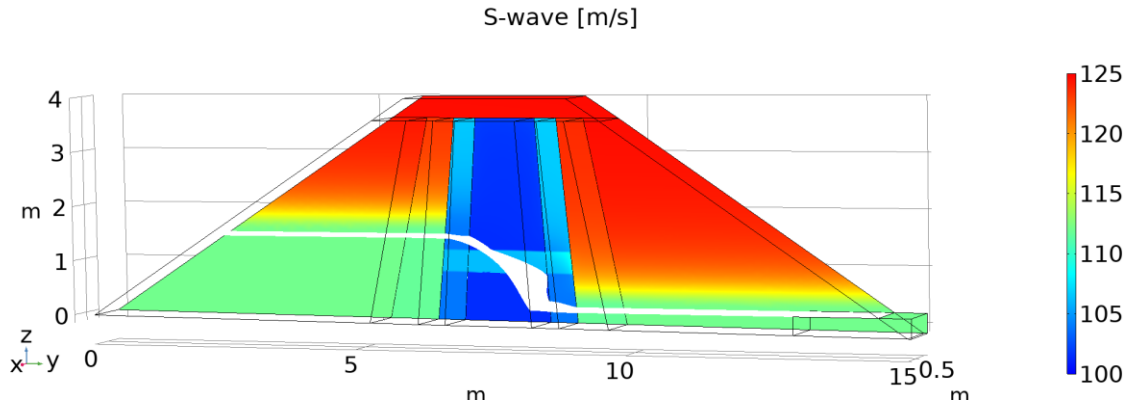
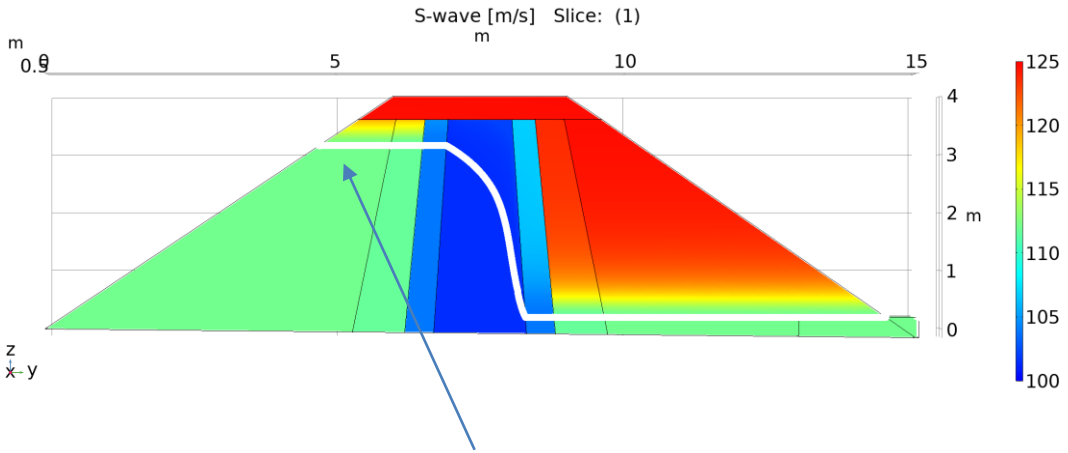
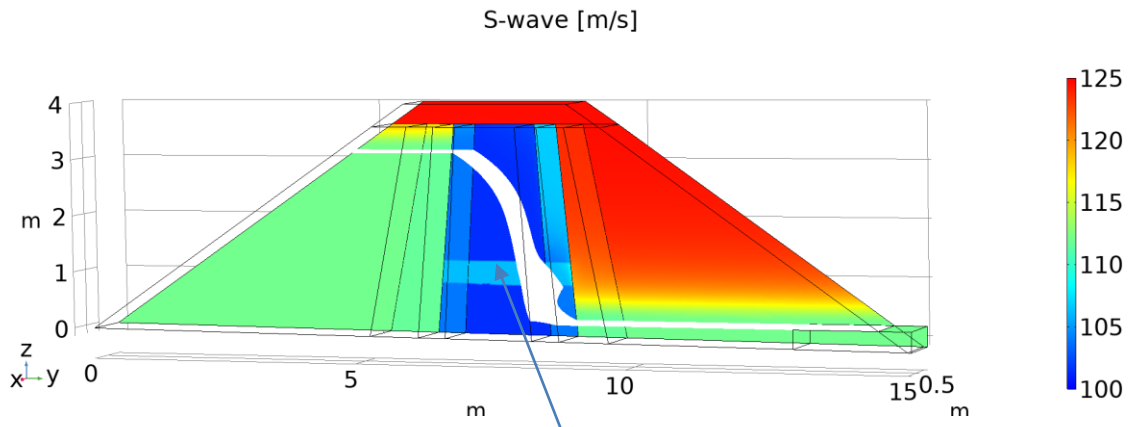
Shear wave velocity changes – Water level / defect









Increasing density – decreasing Vs

Decreasing density – increasing Vs

To be further studied in the new research project

Distributed Acoustics Sensing, DAS

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- Optical fibre instead of a string of geophones
- Same basics as used for temperature and strain measurements
- Same cables (if containing single mode fibres) or special cables
- Gauge lengths 3 and 10 m
- Improving technology

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Distributed Optical Fiber Sensing Technology

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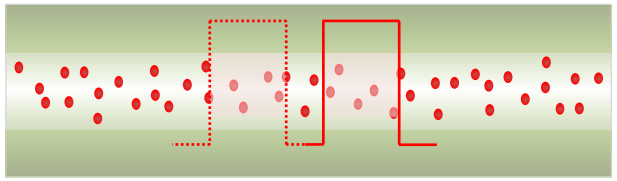
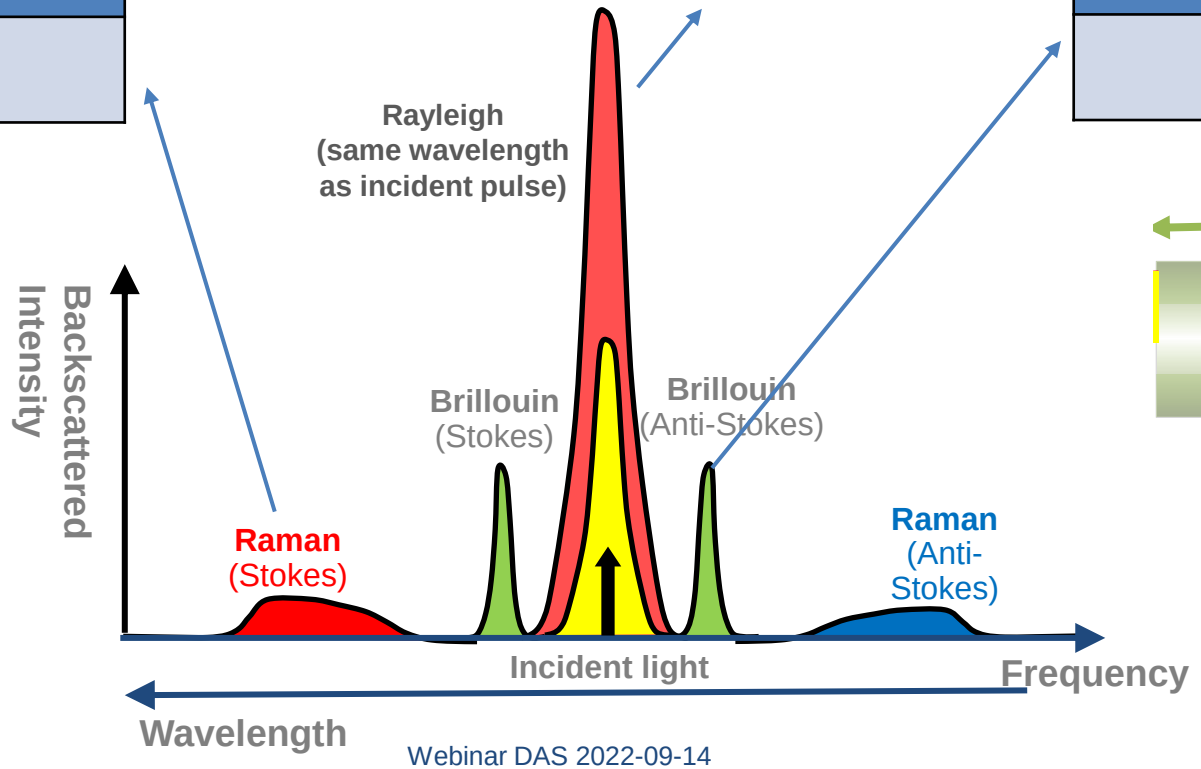
MK2 Ultima	MK2 XT
Temperature (DTS) 0.01°C Resolution	

IDAS v2	Carina v3
Acoustics (DAS) >120dB Dynamic range	

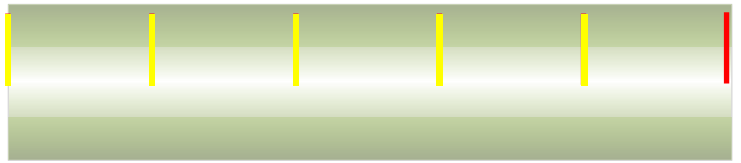
iDSS	Fiber Ruler
Strain (DSS) 1 με Resolution	



Standard fibre



Enhanced backscattering



Engineered Fibre
US Patent No. US 10,883,861 B2
EP Patent No. 3265757

Distributed Acoustic Sensing

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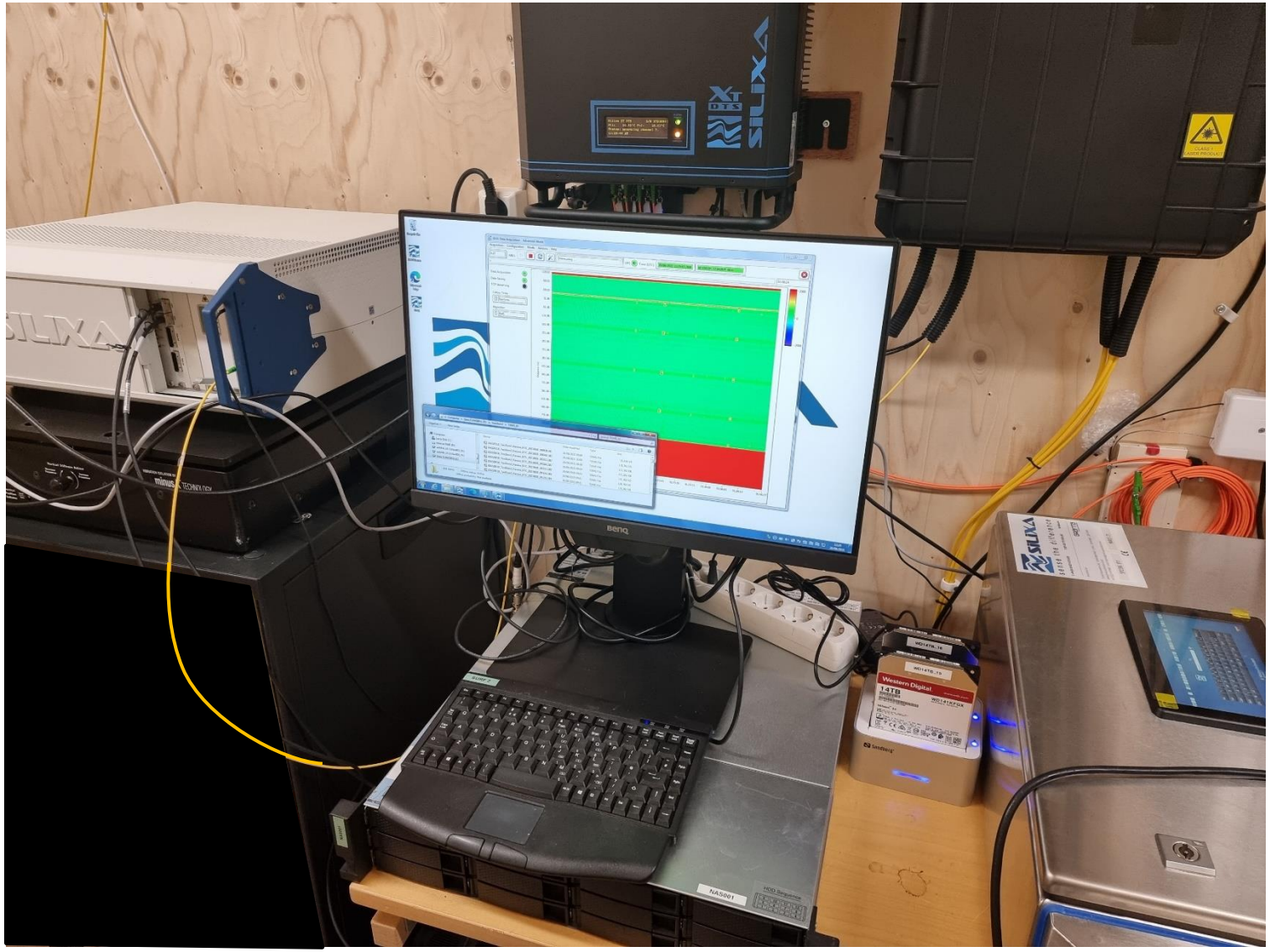
DAS Equipment

- Interrogator: Silixa iDAS v2
  - 3m gauge length
  - 1000 Hz Sampling frequency
  - 0.5m spatial sampling
- Anti vibration table
- 50TB QNAP RAID
- Remote connection
- 2 x 14TB HDD
- Screen and keyboard

Also

- DTS
- Cable box
- Modem, GPS-antenna outside
- (Heat Pulse unit)



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Active Seismic: MASW - result

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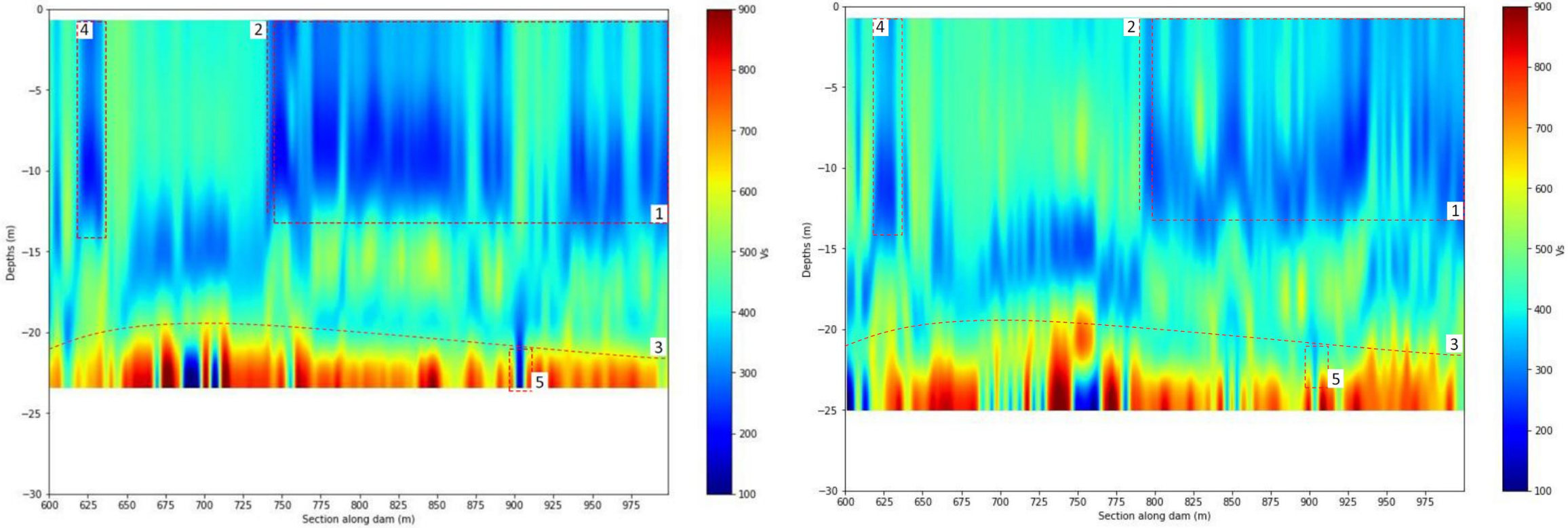
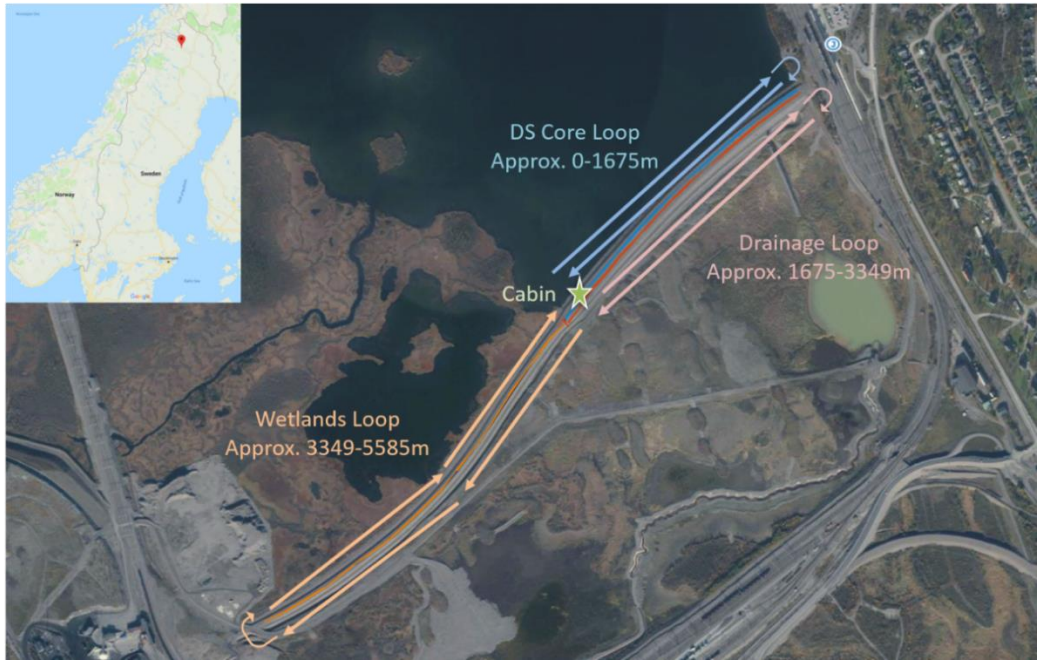
Similar analyses as with standard method using geophones.
Result from 3 and 10 m gauge length



Fibre optics installation and measurements LKAB Kiruna - 2019

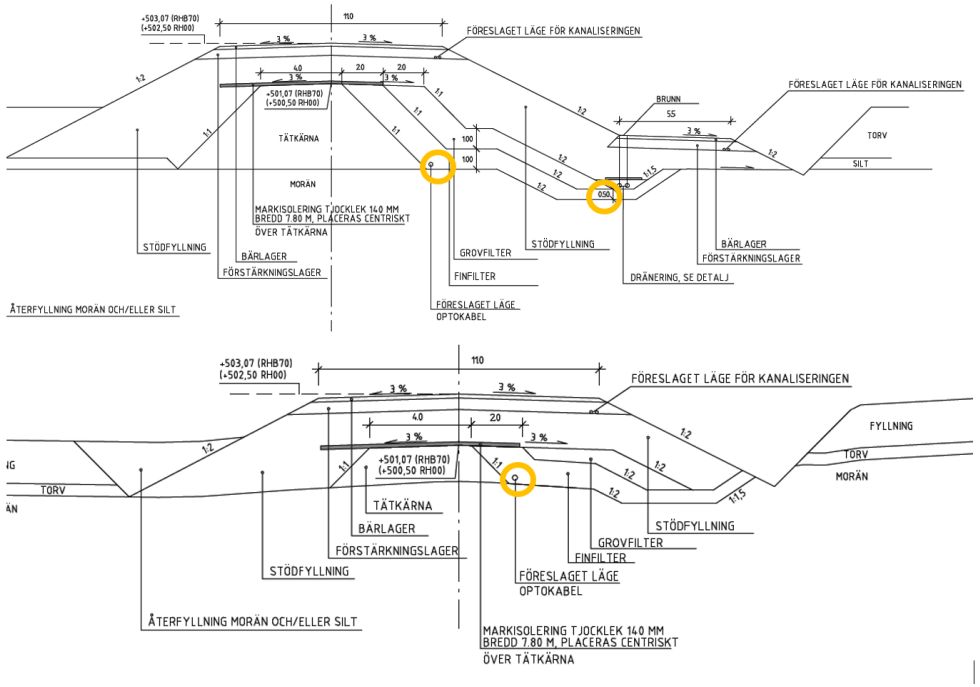
38 days (June-Aug) 2019

Measuring loop 3349 m



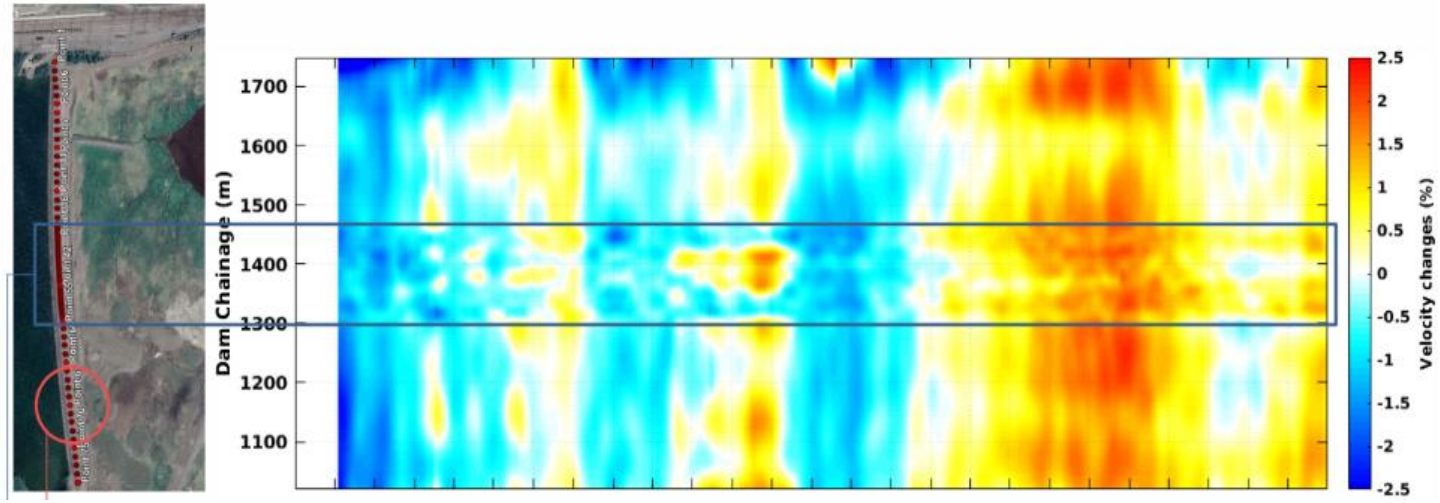
Cable and system installation – 2011

Seepage monitoring using temperature measurement in optical fibre

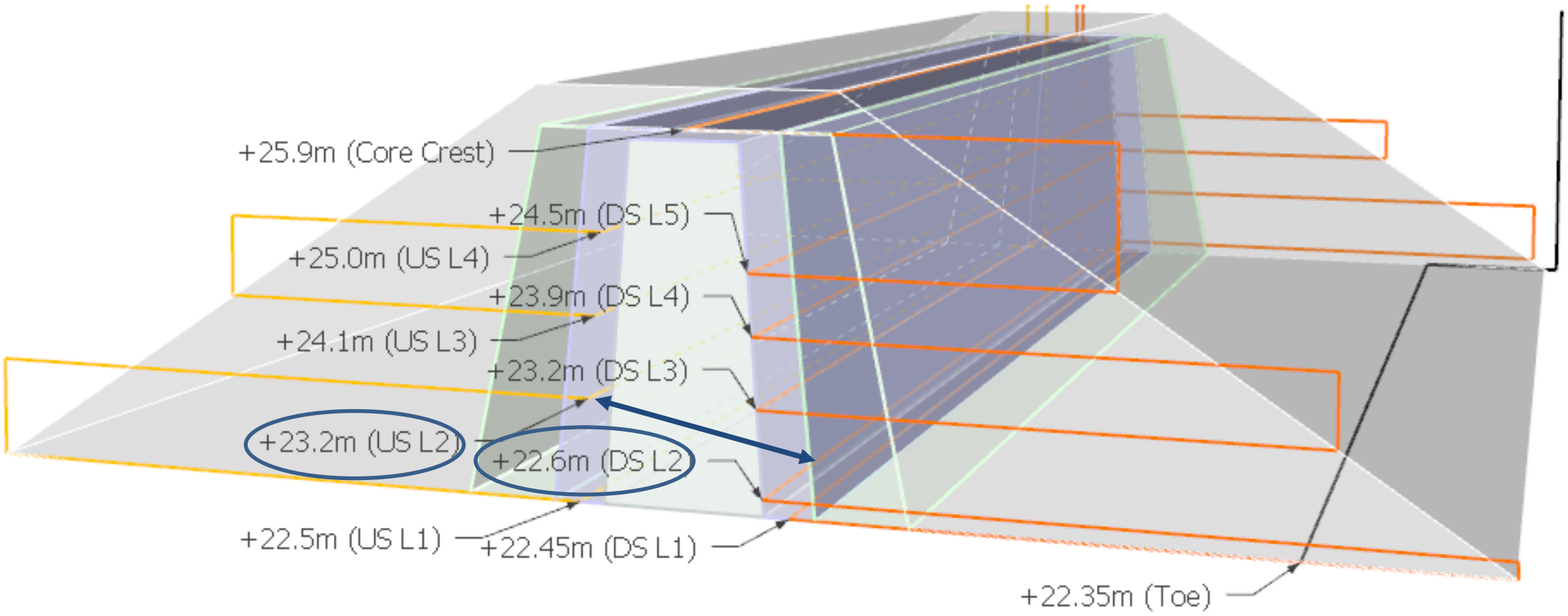


Result – LKAB Kiruna

- High frequency waves recorded are sensitive to the dam structure
- Low frequency waves are sensitive to the geology below the dam.
- These initial studies show promise for the combination of DAS technology and ANI techniques to highlight anomalous areas in dams and their surrounding materials.
- Spatial resolution OK



Experimental dam – Älvkarleby
Cables



Experimental dam – Blind test, 2020 and 2021

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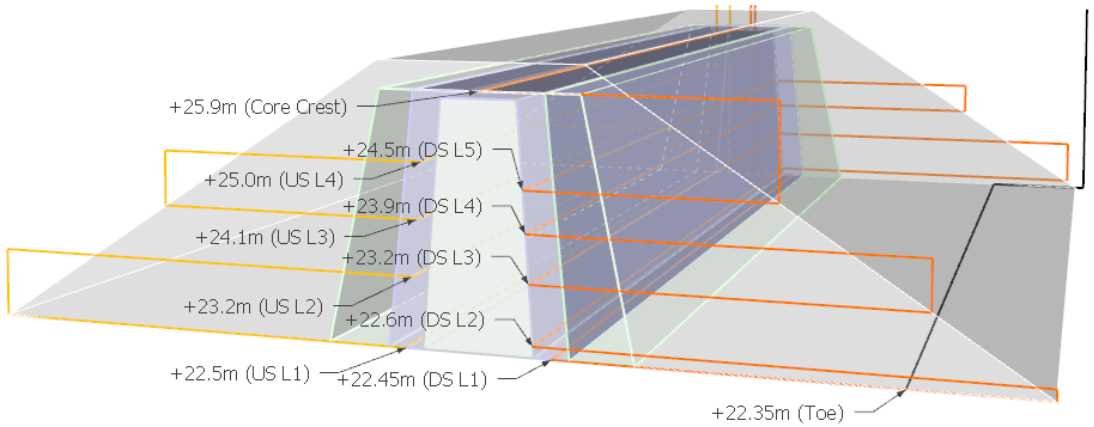
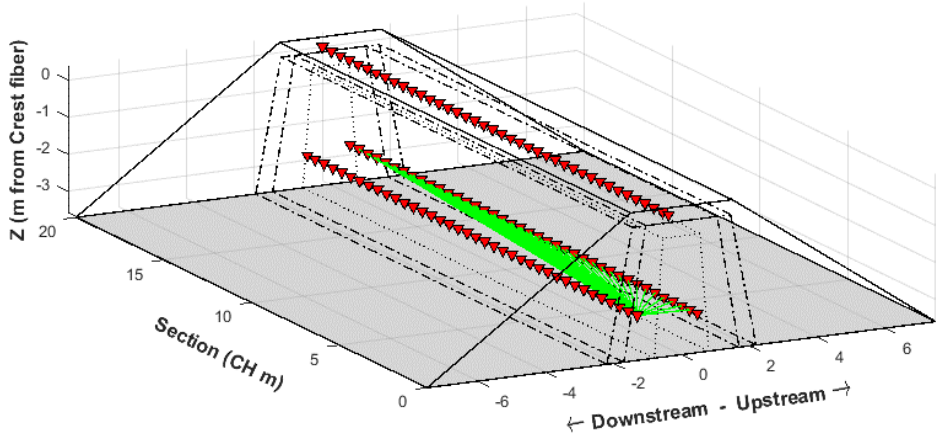
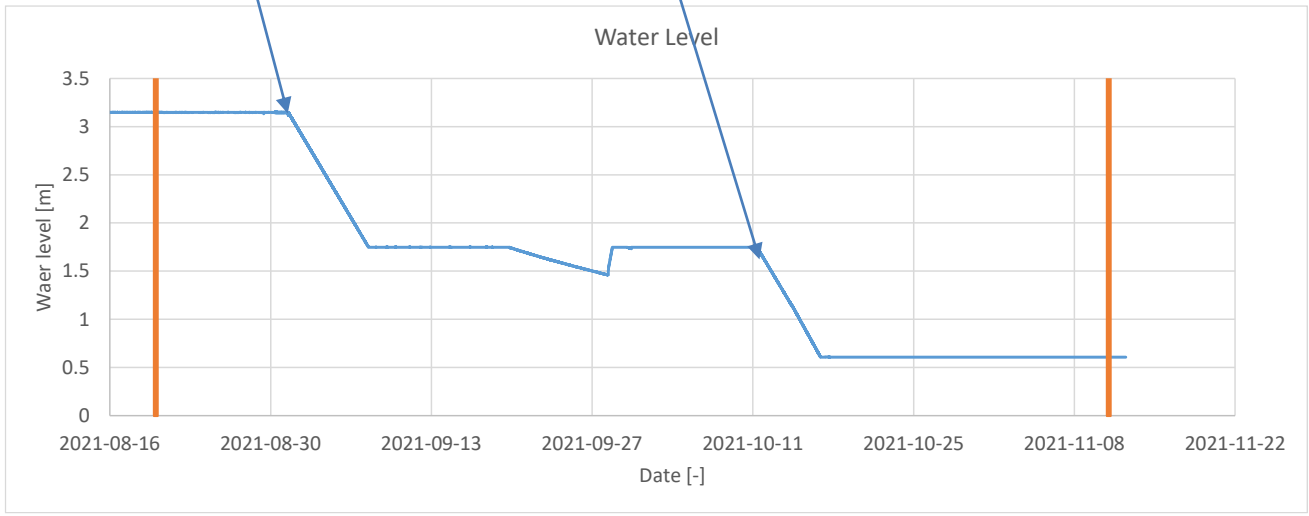




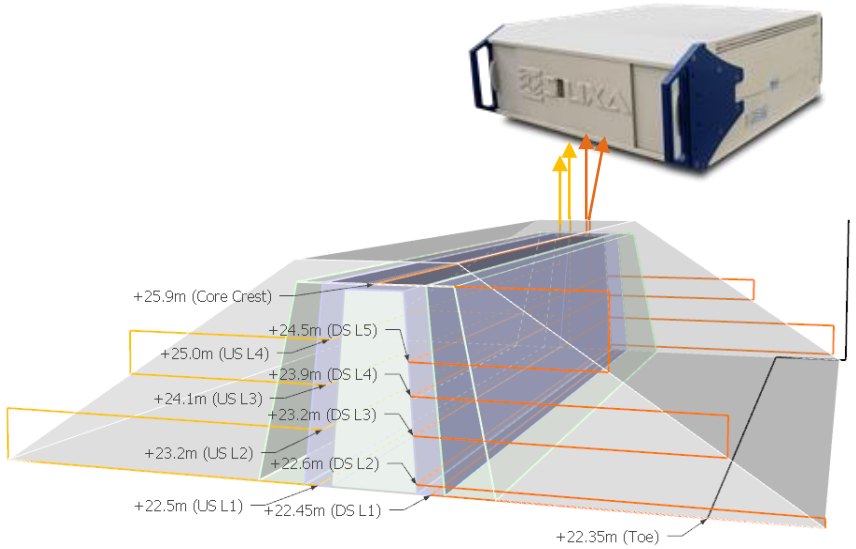
Test site activities - Water level changes

		Augusti			September					Oktober				November				
Aktivitet	Beskrivning	V32	V33	V34	V35	V36	V37	V38	V39	V40	V41	V42	V43	V44	V45	V46	V47	V48
1	Avsänkning till ny lägre nivå (samma sänkningshastighet som stigningshastighet vid dämningsupptagningen), och att ligga kvar på denna under 4 veckor.																	
2	Avsänkning till låg nivå och att ligga kvar på denna nivå under 4 veckor, följt av återgång till dämningsgräns.																	
3	Stresstester av tätkärnans beteende genom korttids-regleringar. Utförs med flera på varandra snabba avsänkningar till olika vattenstånd följt av återgång till dämningsgräns.																	
4	Frisläppande av skadornas lägen (under förutsättning att respektive forskargrupperna har hunnit med att tolka sina dataserier)																	
5	<Utrymme för ytterligare någon försöksserie>																	

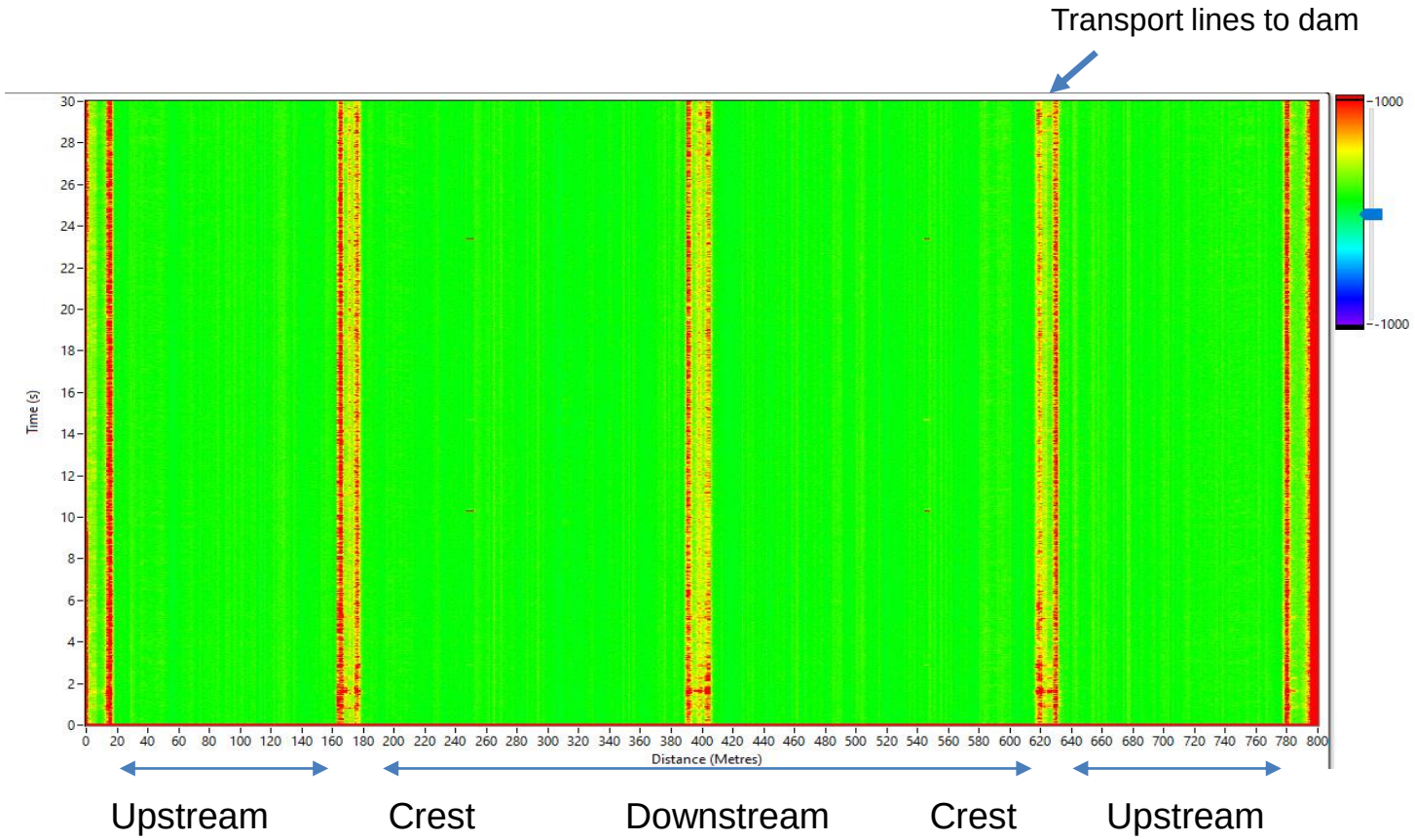


DAS Recording Parameters

- Gauge length 3m
- Sampling frequency 1 kHz
- Channel spacing 0.5m
- 20 August – 11 November



Raw acoustic data



Experimental dam 2020 and 2021 - Result

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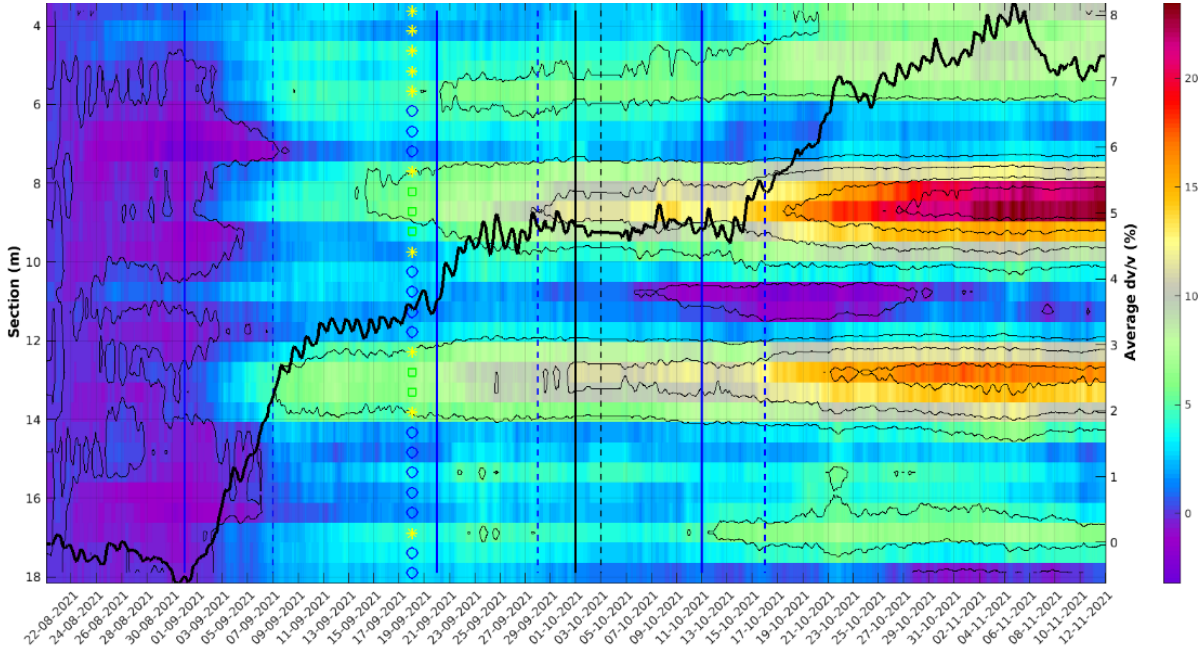
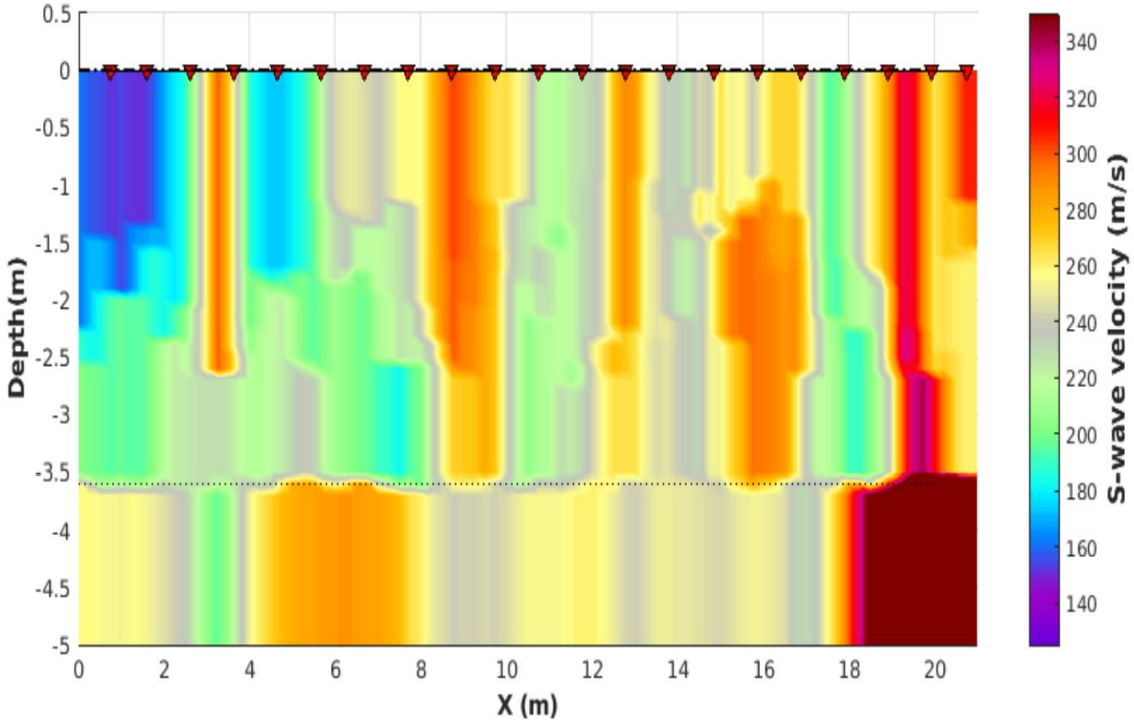
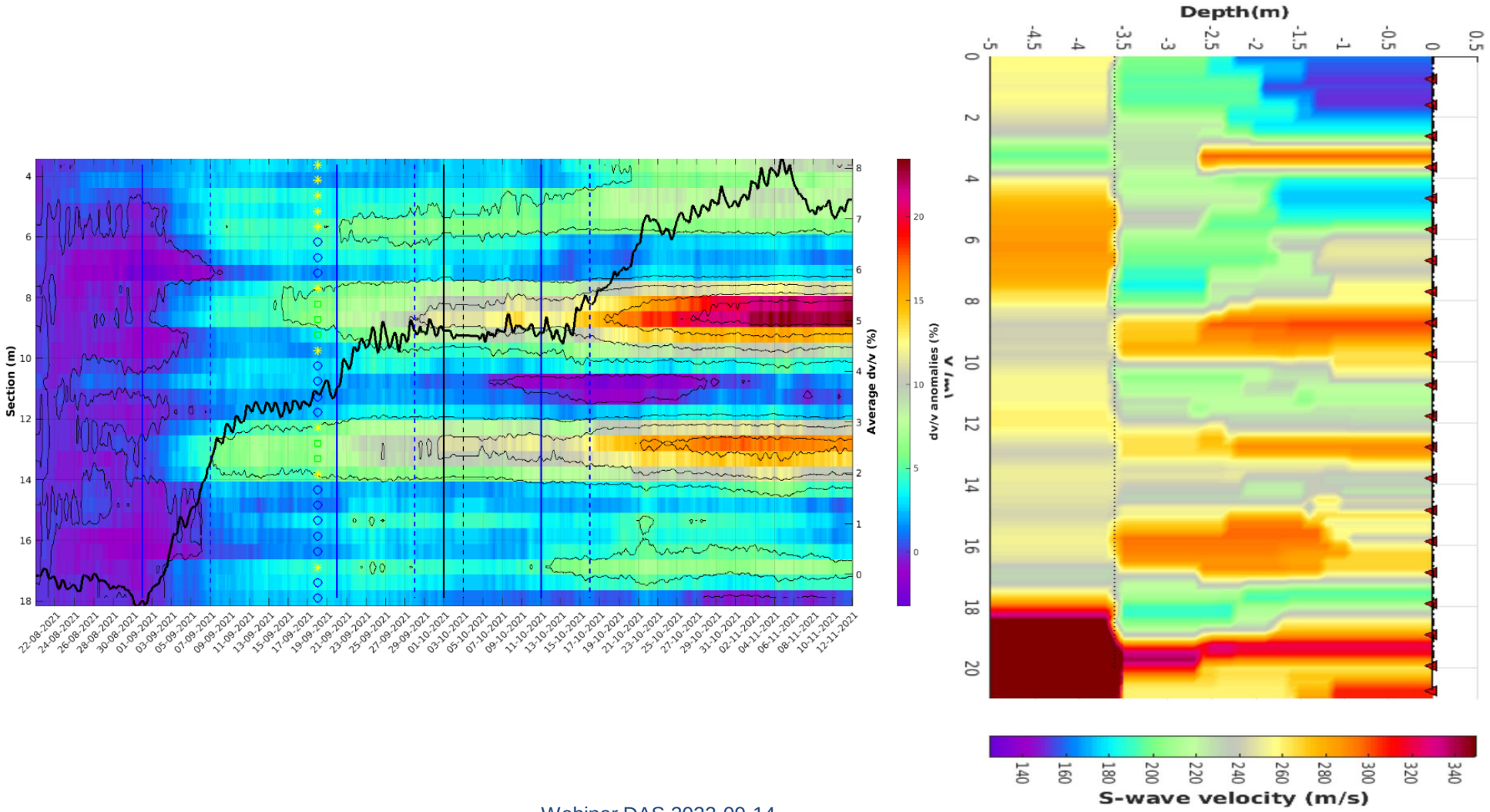
Monitoring – Relative velocity changes in time (a few percent change)



Imaging – Distribution of Seismic velocities



Experimental dam 2020 and 2021 - Result



Imaging - Monitoring

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	Imaging (Vs)	Monitoring (dv/v)
Spatial resolution	Low, because we use surface waves. Depends on the velocity of the medium and sensor spacing.	Low, sensitive to a large bulk of medium because we use coda waves. Depends on the sensor spacing that can be used.
Accuracy	About 10% of absolute velocity with 5 days of recordings. Can be improved by longer recording duration.	Depends on the case. Here, and today, we estimate an accuracy below 1% using DAS.
Minimum recording duration	Depends on noise level, and sensor sensitivity, here we used five days.	Depends on noise source stability, but in general at least one month or at least few days before a change of reservoir level.
Continuous recordings	Over 5 days, ideally when reservoir water level is constant.	To detect a dam defect appearing, monitoring needs to be done. Daily measurements of 30 min are recommended.
Noise sources	Needs to be in line with the optic fiber. Frequency content not controlled.	Needs to be stable through recording period (no frequency content changes).

Timelaps imaging - Monitoring

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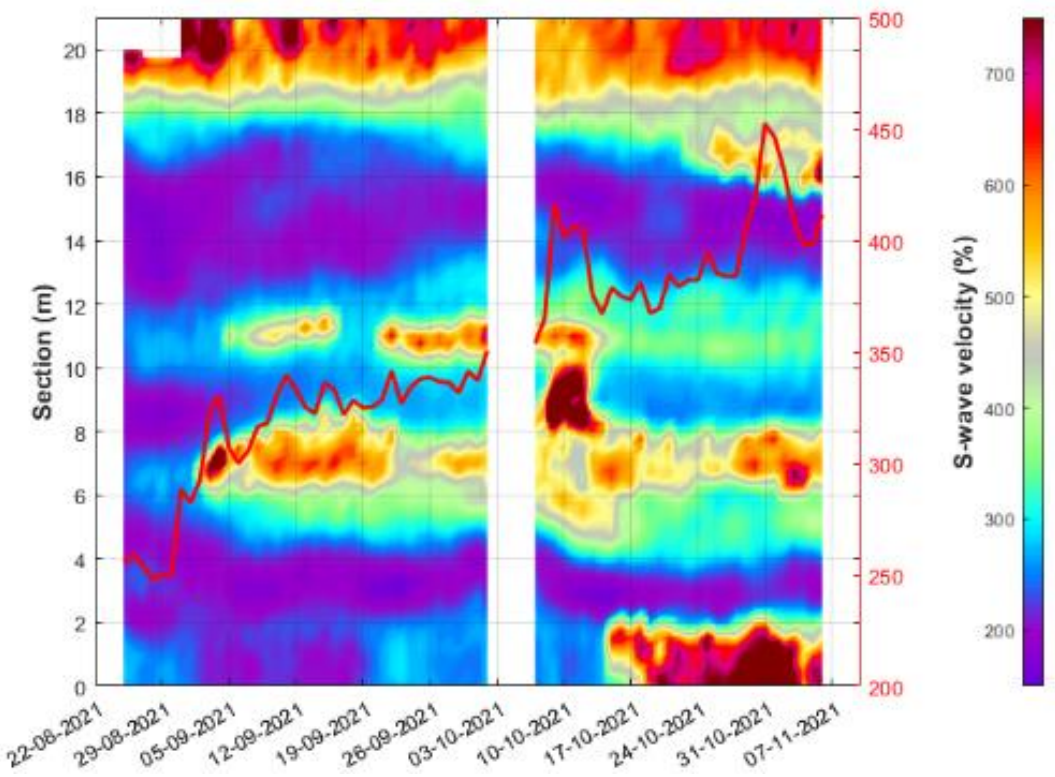
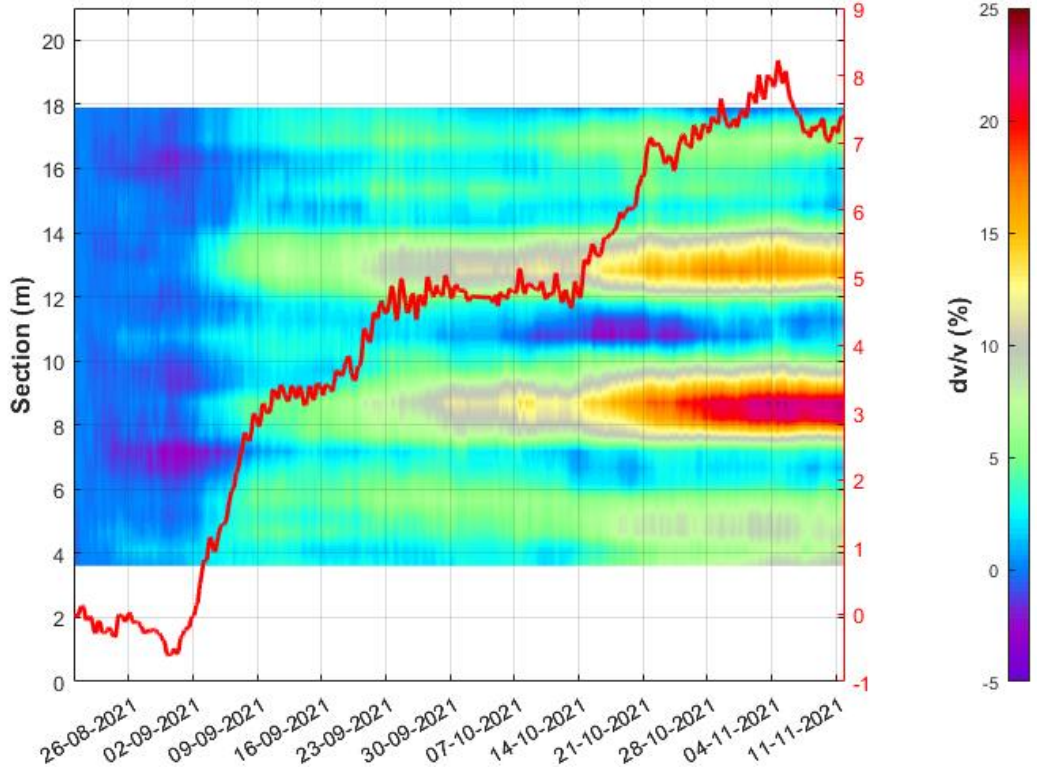
Timelapse imaging averaged



Monitoring



Conclusions

- DAS - Improved monitoring performance since 2018
- DAS+ANI can be applied where you have cables installed for temperature and strain measurements
- Good complement to temperature and strain measurements – information from larger distance
- Applicable for both hydropower and tailing storage facilities
- We see further potential in DAS/ANI in the future
- But it’s a new technology – Lessons to be learned

Thanks all !

- Questions