Induced seismicity monitoring for offshore CCS

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With thanks to all our partners in the HNET, ENSURE and SHARP collaborations.

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Overview and introduction

- Induced seismicity and the need for monitoring
- Outline of monitoring options – onshore and offshore
- Example – Quest CCS (in cooperation with ENSURE consortium)
- Example – HNET (Northern Lights CCS) detection performance
- Conclusion

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Induced seismicity and the need for monitoring

- Many examples of induced seismicity – subsurface injection, gas production, fracking, heavy oil production, ground water extraction.
- Monitoring is a risk mitigation measure:
  - Usually a Regulatory requirement (implied or explicit).
  - May be a process safety requirement, dependent on Risk Assessment Matrix (RAM) analysis.
  - Bowtie risk framework: monitoring + Traffic Light response protocol (TLS) is an active barrier for threat mitigation

S. Bourne et al. / International Journal of Greenhouse Gas Control 26 (2014) 109–126

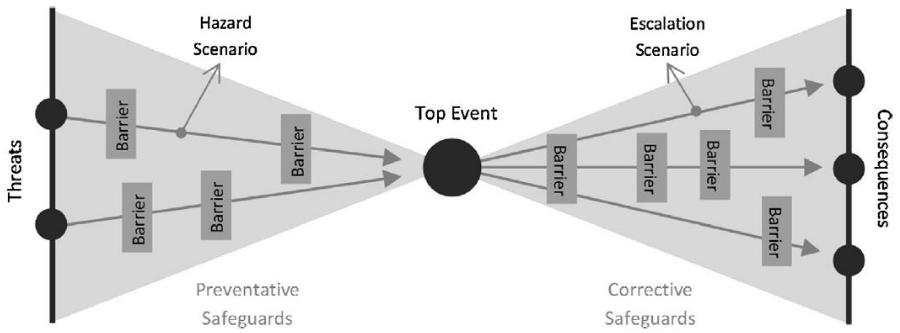
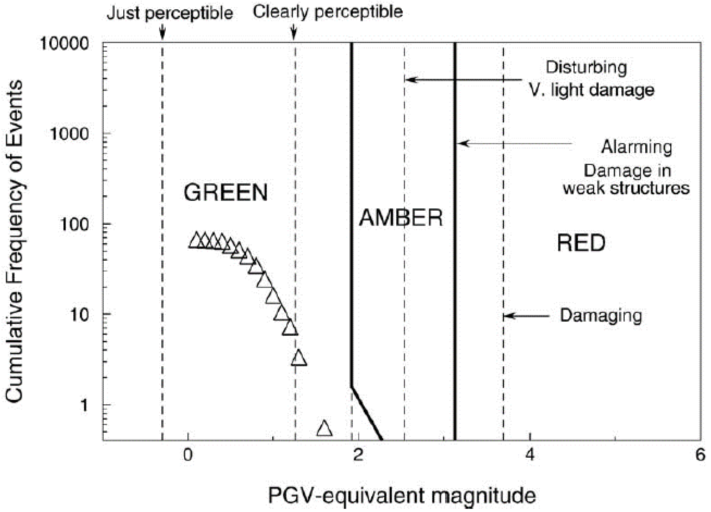


Fig. 3. Schematic illustration of the Bow-tie Method for risk mitigation.



Bommer, Oates, et. al./ Engineering Geology 83(4) (2006) 287–306

  - Provides instrumental data as input to TLS and to inform stakeholder engagements.
- What monitoring coverage is required?
  - MMV plan (Measure, Monitor, Verify) is risk-based to ensure safety and long-term effectiveness of CO_2 storage.
  - MMV plans are comprehensive and adaptable, based on updated risk assessments as storage operation evolves with time.
  - Overview of induced seismicity monitoring planning is given by Freudenreich, Oates & Berlang, Geophysical Prospecting (2012).

Acquisition options – onshore and offshore

- Surface v. downhole
  - Higher ambient noise and near surface losses for surface deployments.
  - Downhole generally lower detection thresholds but more complex patterns of arrivals.
- Shallow boreholes v. deep wells
  - Trade off cost/depth/noise.
  - Hardware longevity issues with downhole electronics at reservoir temperature.
- Ocean Bottom Seismometers: Cabled & trenched v. autonomous
  - Cabled system needed if real-time data is required; high Capex.
  - Autonomous OBSs simple and cheap but data only available when harvested; high Opex
- Broadband seismometers v. accelerometers v. geophones v. DAS*
  - Broadband units: high sensitivity and low self-noise.
  - Force Balance Accelerometers: intermediate self-noise and flat frequency response.
  - High frequency passive geophones: low frequency response roll-off and high self-noise.
  - DAS: dense spatial sampling, large aperture and flat frequency response but high self-noise.
- Individual stations v. arrays
  - Array processing enhances S/N & location performance but more acquisition effort & exposure

*DAS = Distributed Acoustic Sensing. Uses laser pulses backscattered in a fibre to determine time-dependent strain, processed → seismogram.

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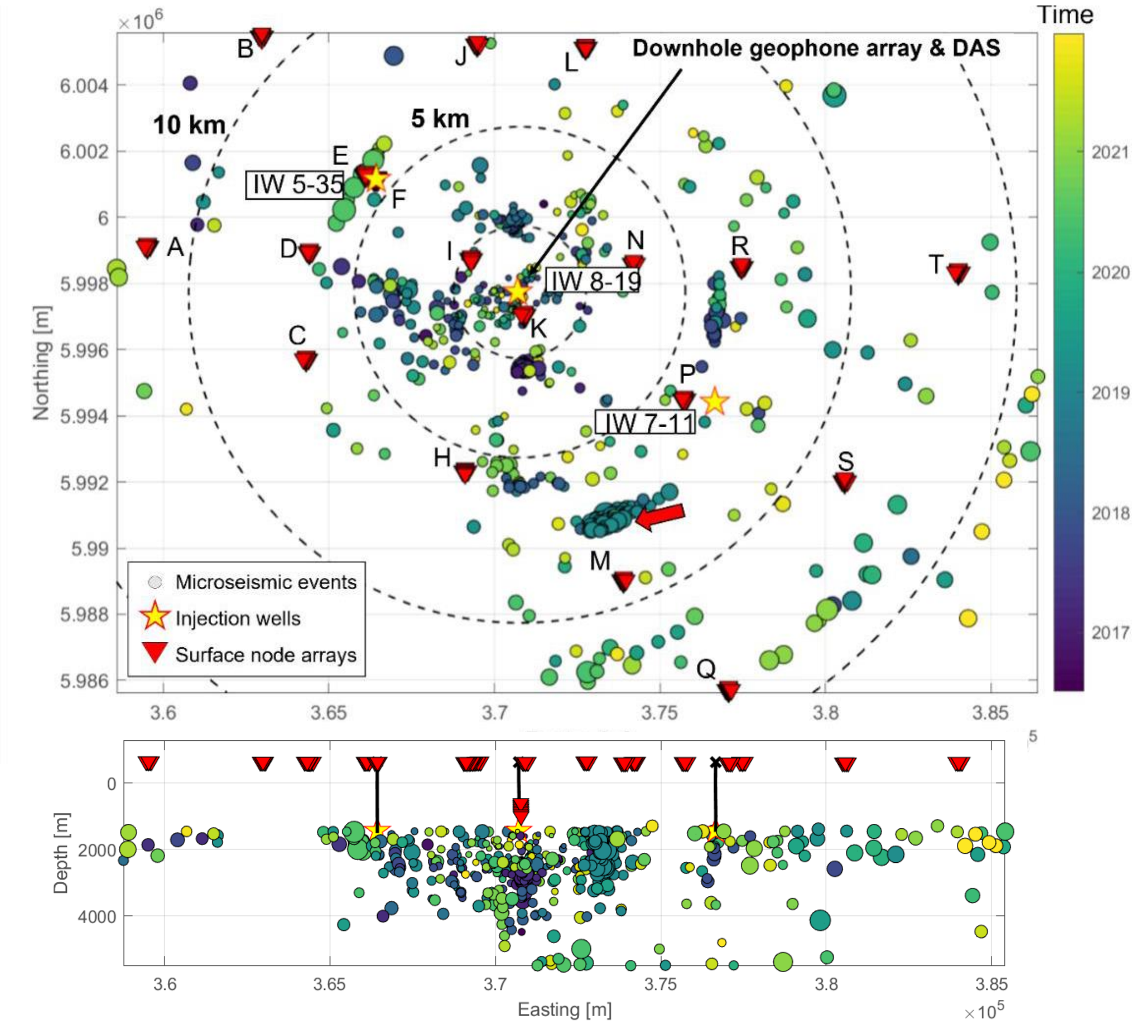
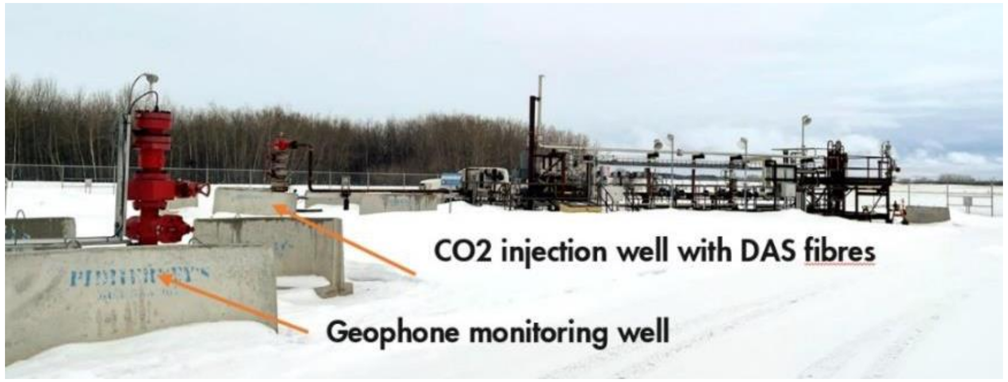
Microseismic monitoring with hybrid network at Quest



- 3 CO_2 injection wells connected by a pipeline to the Scotford facility.
- Downhole array with 8 geophones in monitoring well on 8-19 well pad.
- Downhole DAS system in 8-19 injector, close to the geophone well.
- 17 surface arrays each comprising 9 autonomous geophone nodes.
- Images show event locations up to December 2021.
- Events locate in the Precambrian Basement below the injection interval.
- In cooperation with ACT3 consortium project ENSURE.



8-19 well pad showing CO_2 injector with DAS, and geophone monitoring well

Surface node deployment

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Northern Lights CCS & the HNET consortium project

- CLIMIT consortium project HNET – monitoring trials of particular relevance to near-offshore CCS projects such as Northern Lights

Northern Lights onshore facilities at Øygarden, Norway

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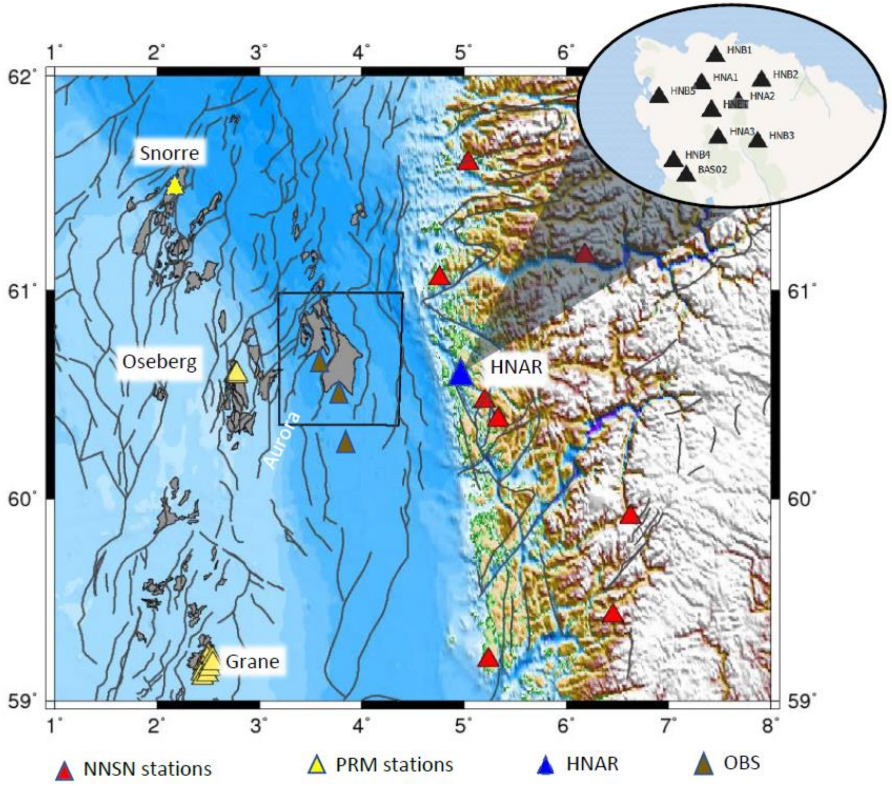
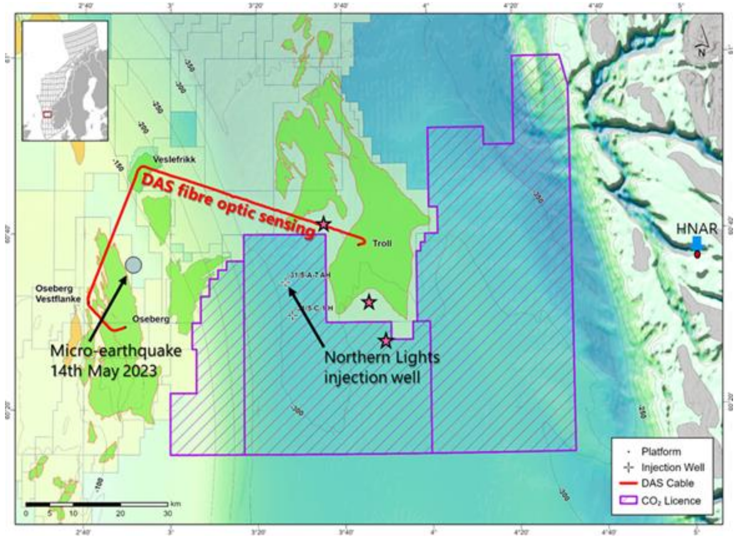
HNET(3) field trials: OBSs, PRM nodes, on-shore array, and DAS with NNSN network

- HNET3: Ocean bottom seismometers (OBSs) and onshore HNAR array deployed to complement NNSN onshore seismometer network and PRM nodes: improve event detection & location over Northern Lights area.
- Seabed DAS trial used Troll telecomms fibre: detection performance comparable to NNSN

Zarifi, Z., et al. (2022). Background Seismicity Monitoring to Prepare for Large-Scale CO2 Storage Offshore Norway, Seismol. Res. Lett. 94 (2A): 775–791. doi: https://doi.org/10.1785/0220220178
Bremaud, Rebel, Lemaistre & Vernier (2023). Capabilities of Fiber Optics Deployed at Seabed for Microseismic Monitoring: Northern Lights Case Study. EAGE GET 2023.





Seabed DAS trial. Data acquired for a period of 9 months using an interrogator connected to the comms fibre at the Troll platform. See also Bremaud et al.

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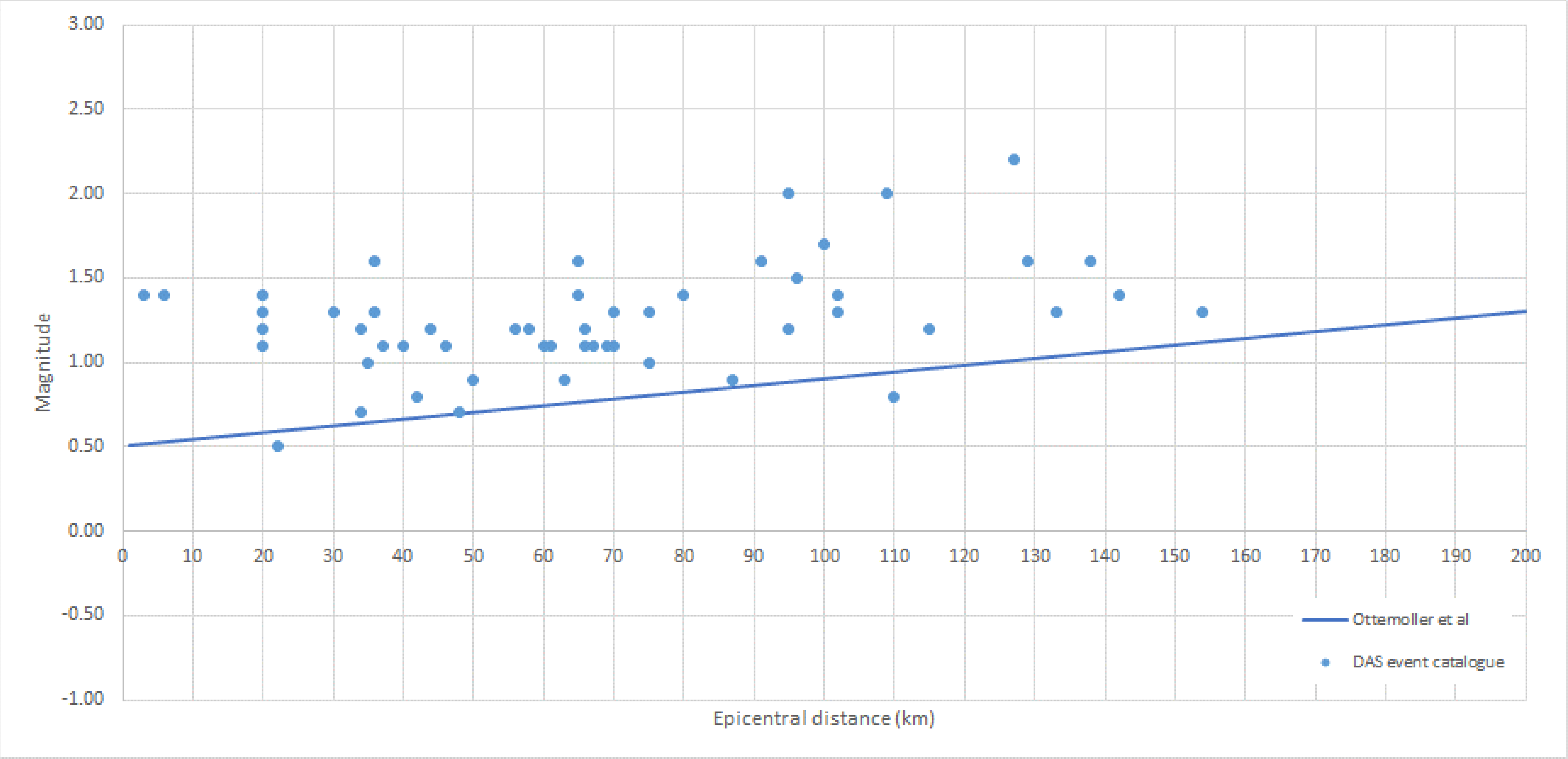
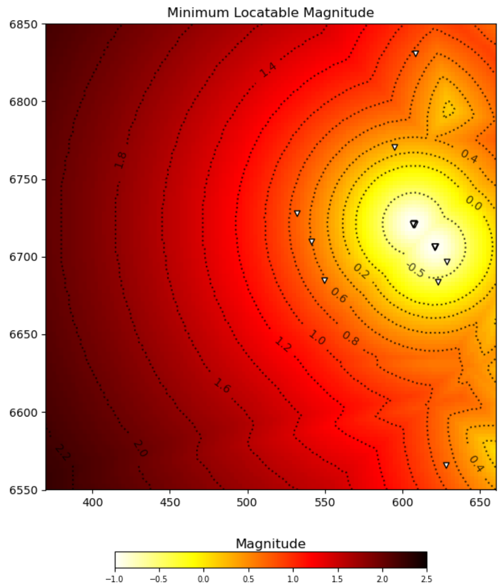
Seabed DAS & NNSN – comparison of detection thresholds

- HNET3 seabed DAS data compared with onshore Norwegian National Seismic Network (NNSN) detection function
- See similar detection thresholds (caveat – points show the NNSN catalogue events also visible on the DAS data)

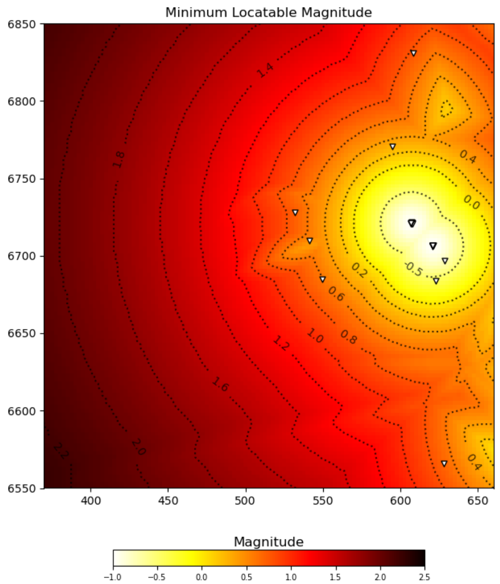


Detectability threshold modelling for hybrid NL networks (NNSN, HNAR, OBS & DAS)

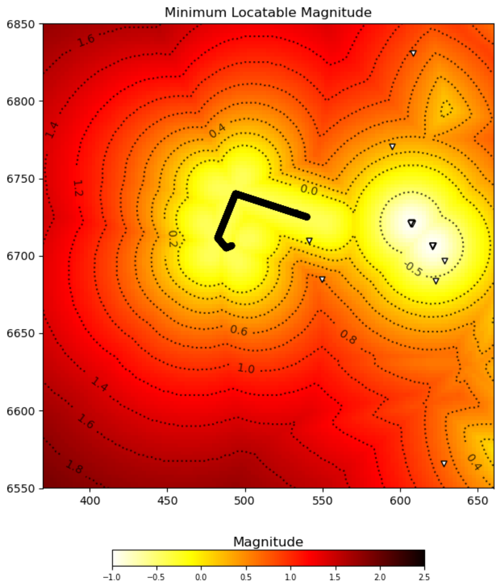
NNSN + HNAR

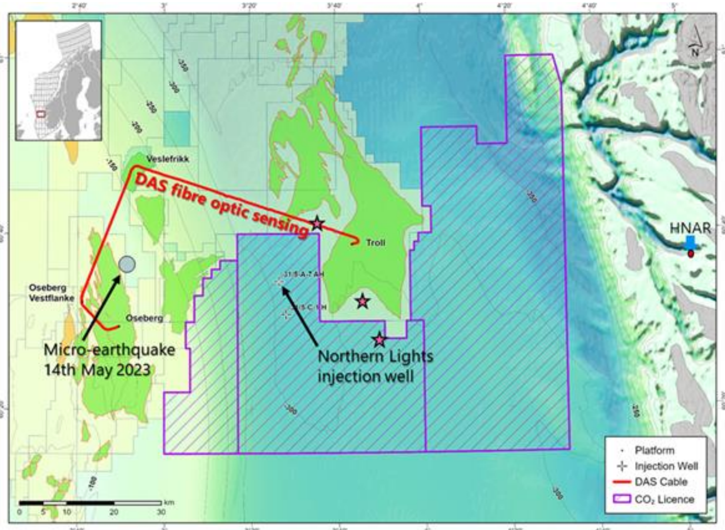


NNSN + HNAR + OBS



NNSN + HNAR + OBS + DAS





- Maps of smallest magnitude for which P & S arrivals can be picked above the noise on 3 or more stations for events at 15km depth.
- Modelling shows:
  - onshore NNSN + HNAR network provides remarkably good coverage offshore due to low noise at station locations;
  - inclusion of OBS units has limited impact on detection performance (but improves location performance);
  - inclusion of seabed DAS in the hybrid network significantly improves detection thresholds around Northern Lights concession area.
- Noise levels from field trials: NNSN & HNAR (onshore): 4*10^-9 m/s; OBS & DAS (seabed): 4*10^-8 m/s.

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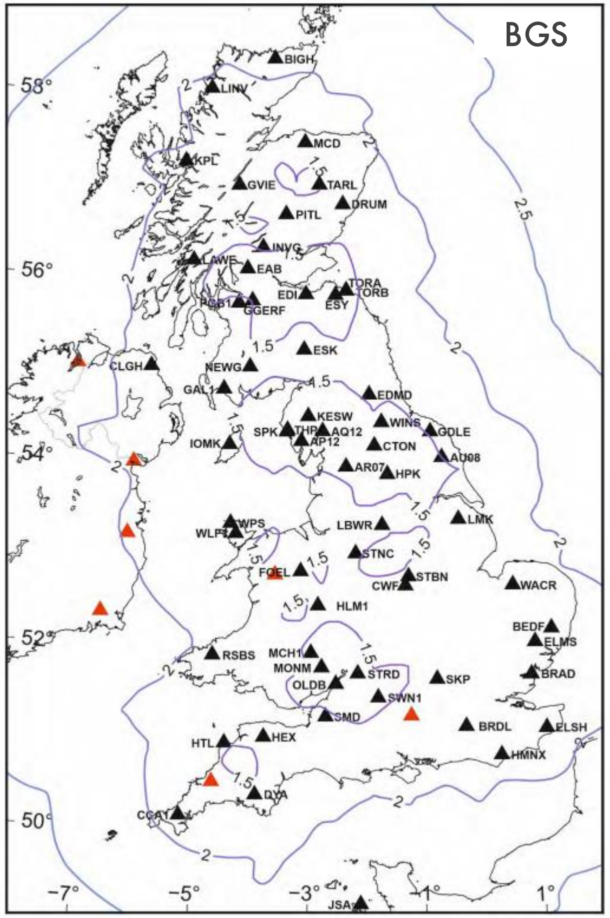
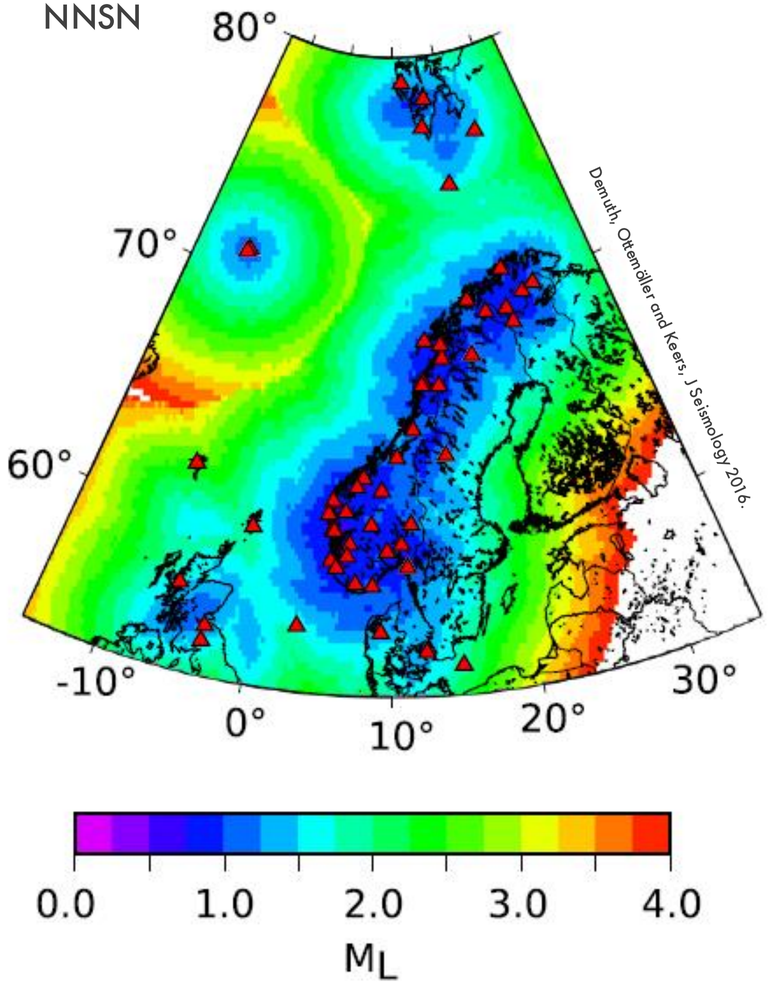
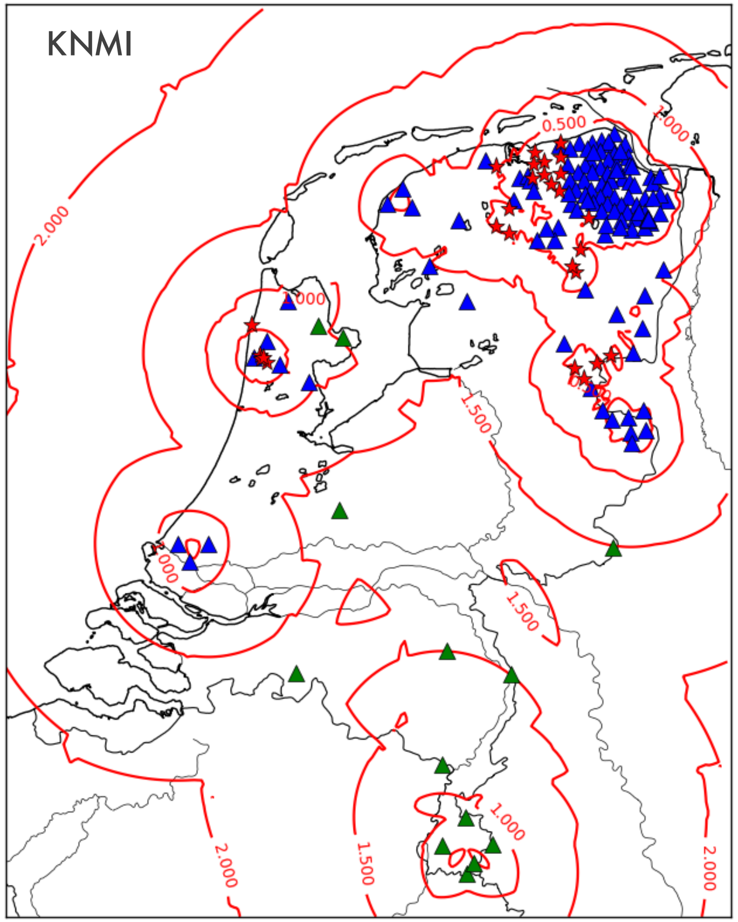
Minimum locatable magnitude around N Sea – onshore networks



The British Geological Survey Earthquake Bulletin for 2023, D.D. Galloway (Editor), REPORT OR/24/010



Demuth, Ottemöller and Keers, J Seismology 2016.



Dost, Ruigrok and Spetzler, NJG 2017

Maps of (modelled) minimum locatable magnitude for the UK, Norway and Netherlands networks.

Conclusions

- Field trials at Quest and Northern Lights show how hybrid networks can address the monitoring challenges we face.
- Different types of sensors complement each other when used together, extending coverage and improving detection and location performance:
  - surface, near-surface, downhole;
  - seismometers, accelerometers, geophones, DAS;
  - cabled, autonomous.
- Near-offshore acceptable coverage can be achieved with onshore networks/arrays + a few carefully chosen offshore stations + possibly seabed DAS.
- Using existing telecoms cables for seabed DAS may be an option and avoids need for deployment and trenching.
- Detailed planning requires numerical modelling of detection and location performance of individual elements and network as a whole.
- The experience gained at HNET is directly applicable to the near-offshore projects in the UK and The Netherlands.
- High value of CLIMIT and ACT3 consortium projects – HNET, ENSURE and SHARP.

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