Onshore passive seismic monitoring for offshore CO_2 storage projects

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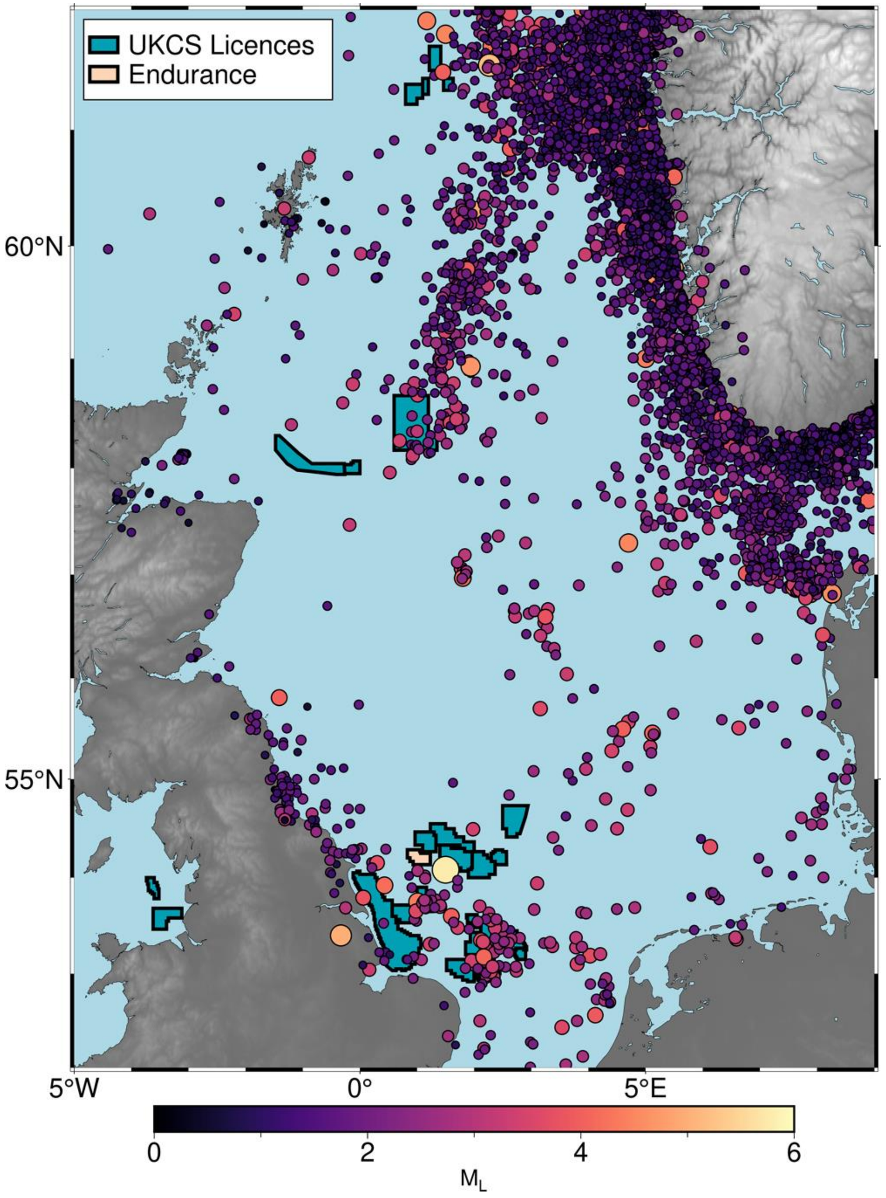
Motivation

- Many CO_2 storage projects are being developed in the North Sea.
    - First-moving UK project, Endurance, made FID this week!
- Passive seismic is an important part of the monitoring mosaic
    - Injection will likely induce *some* microseismicity
- Seismicity data can improve constraints on **stress state,** fault failure risk etc.,
    - **See Poster S53B-3321** "Seismic anisotropy as a measure of *in-situ* stress" this afternoon!
- SNS is seismically quiet, with a few notable events (e.g., 1930 M_L 6 Dogger Bank).

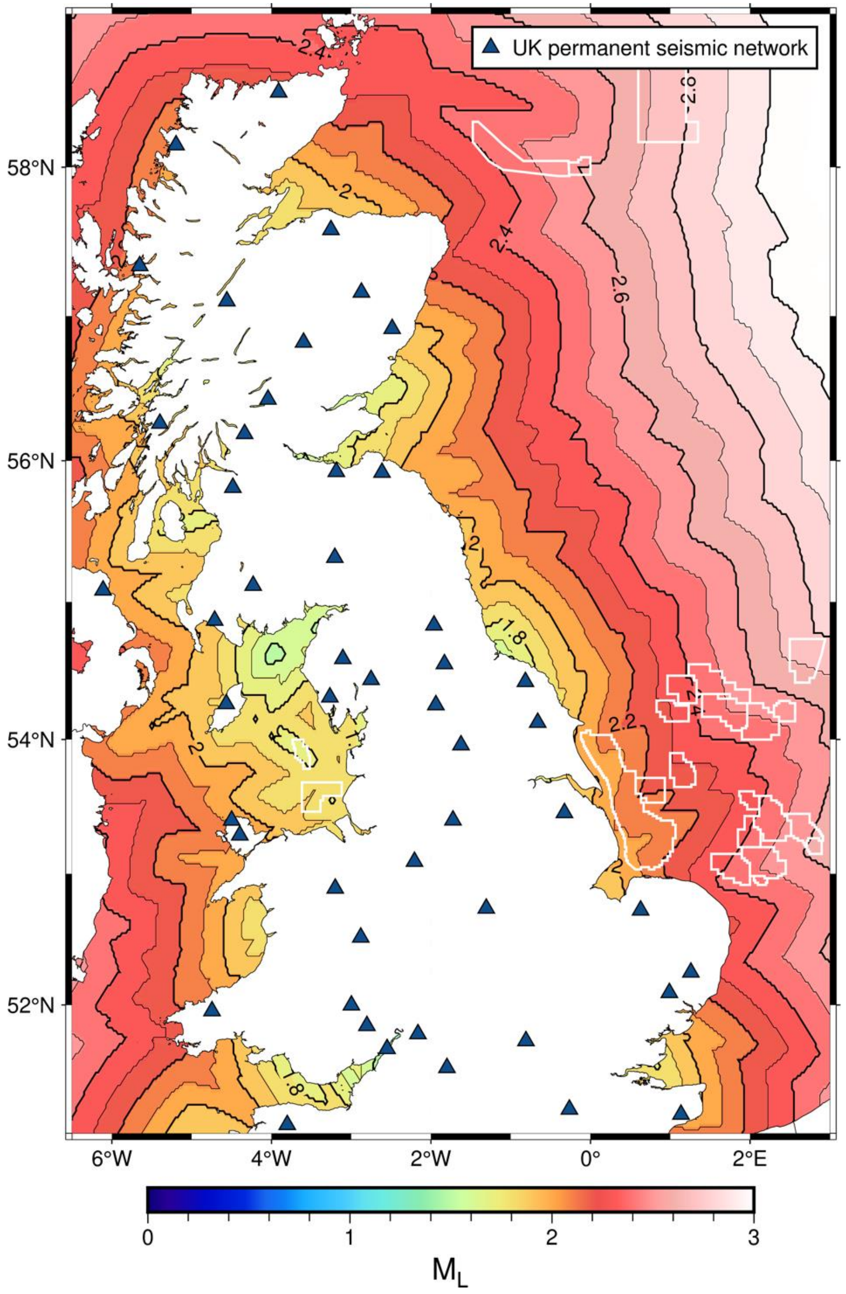
North Sea Seismicity 1930-2022



Seismicity data complied by Kettlety et al., (2023)

Current picture

- A good baseline of natural, pre-injection, seismicity is vital for monitoring induced seismicity
- Current UK permanent seismic network reliably detects ~M_L 2 – 2.5 in Southern North Sea
  - Estimated monitoring threshold ~ M_L 1 – 1.5 (Verdon and Bommer, 2019)
- Seismic array (HNAR) in Norway has shown potential to improve offshore detection capability to M_L 1.5 (Zarifi et al., 2023).
- Can we achieve similar performance in the UK?



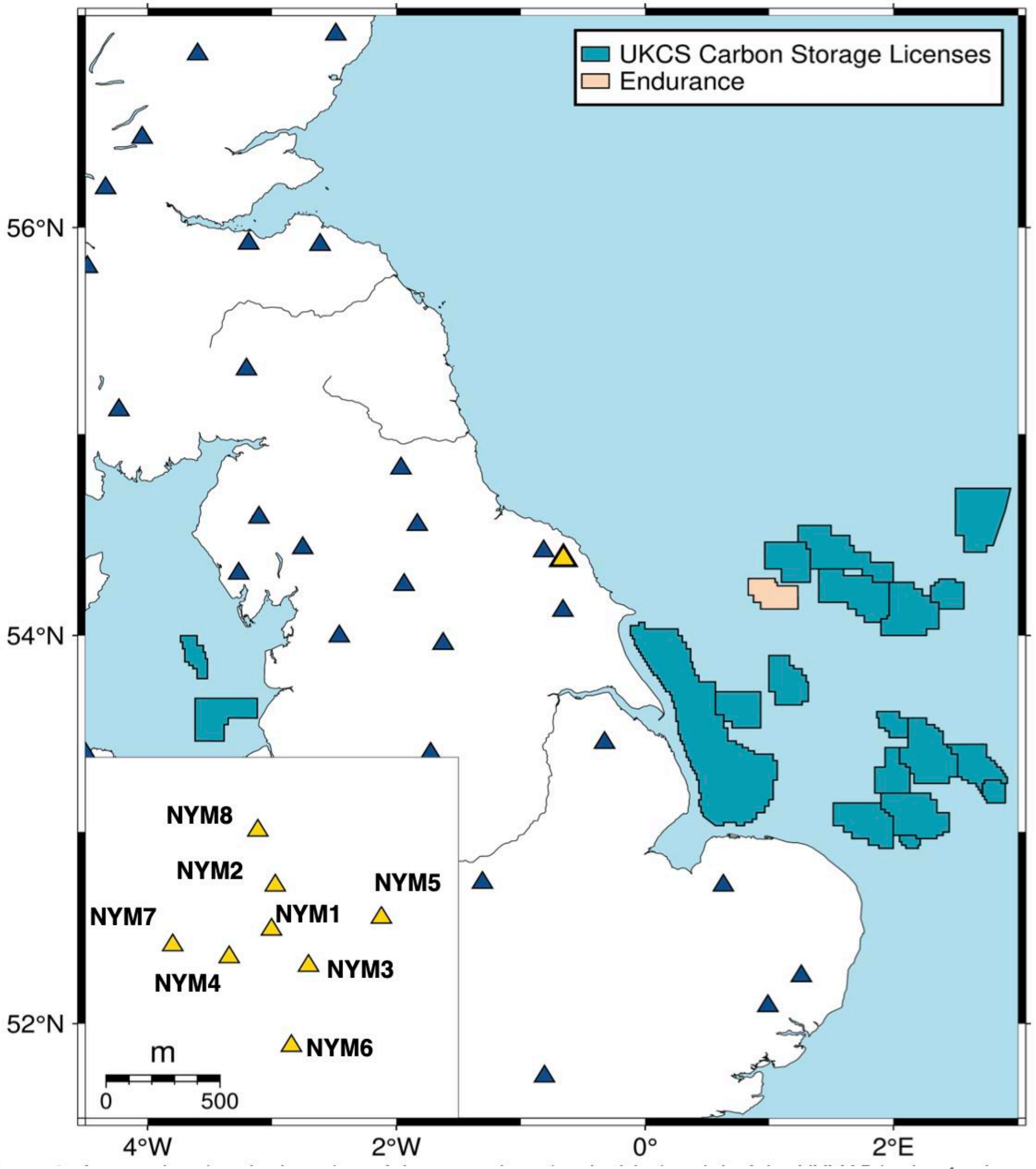
Reproduced after Baptie (2021)

North York Moors Array

- 8 station array of Güralp Certimus (broadband) seismometers

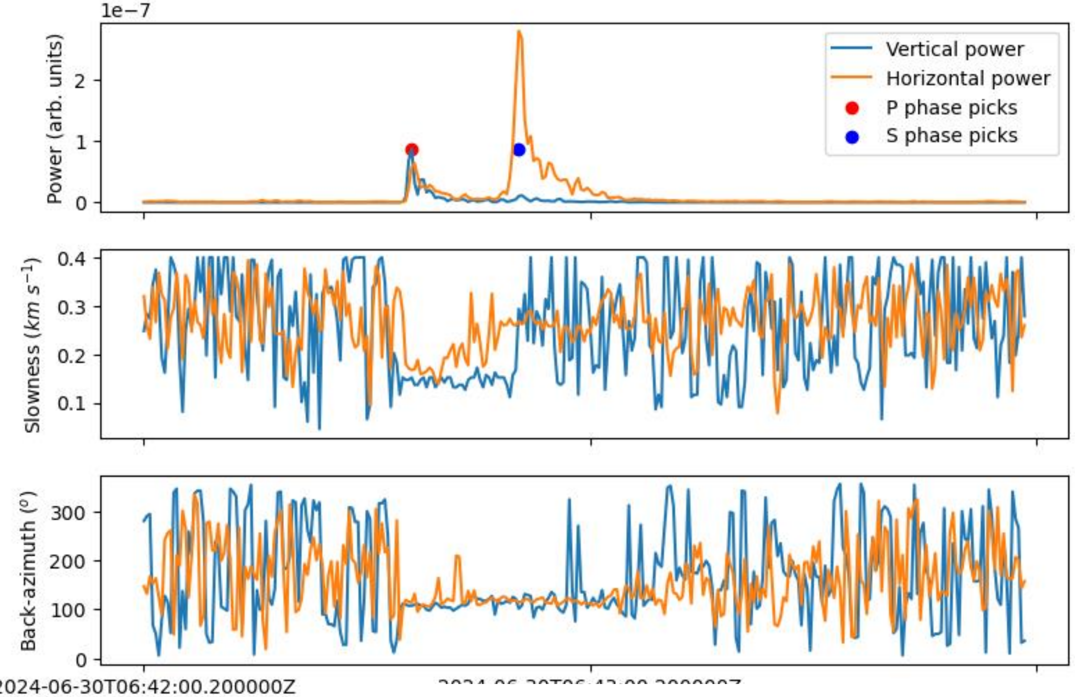
- 1km aperture and ca. 250m inter-station distance.
  Most sensitive to signals from 2 – 15 Hz.

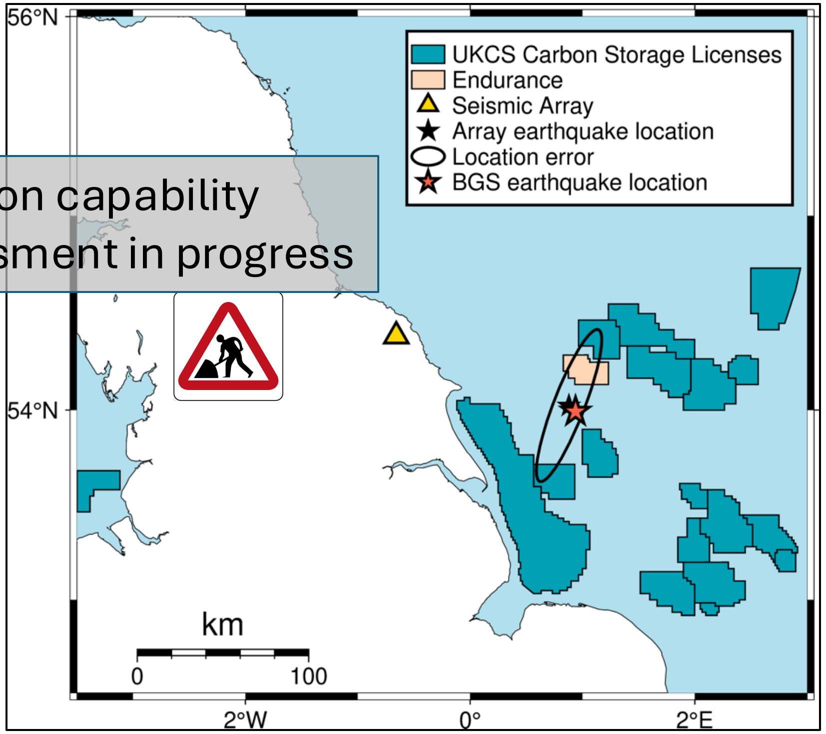
- Data recorded from October 2023 – present



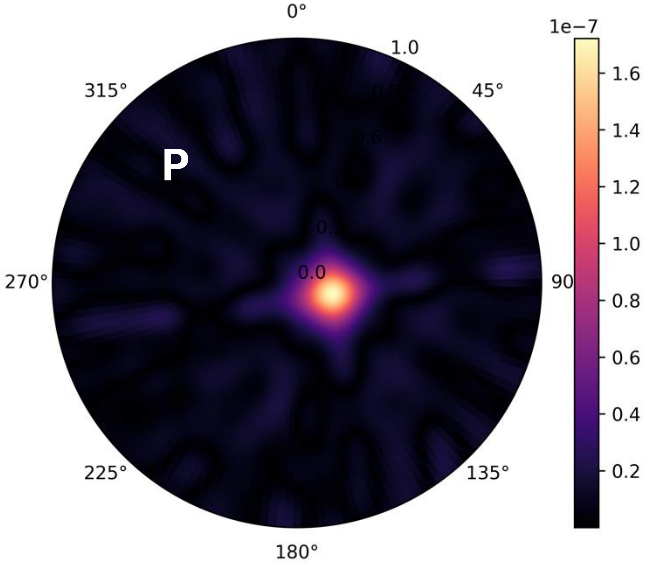
Array analysis

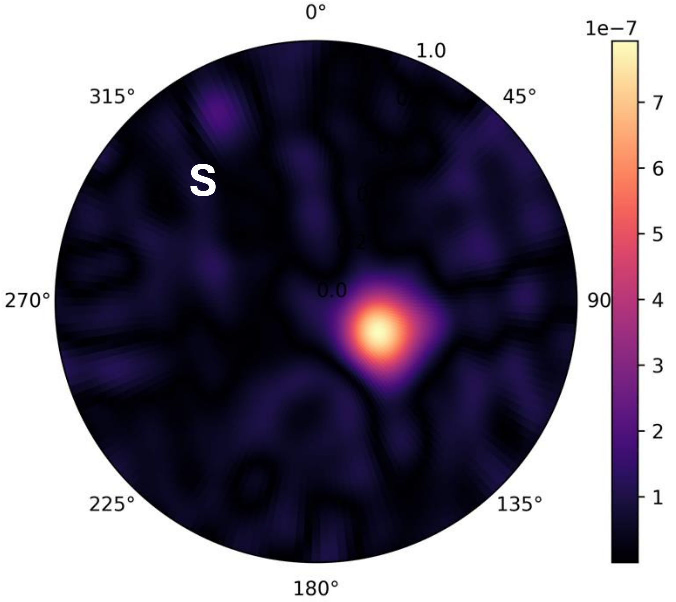
- Beamforming for a dense array will focus microseismic signal with a given backazimuth θ and a slowness u.
  - We use f-k beamforming (e.g., Rost and Thomas 2002)
- Example shows outputs for June 30th 2024, M_L 2.2 earthquake in North Sea





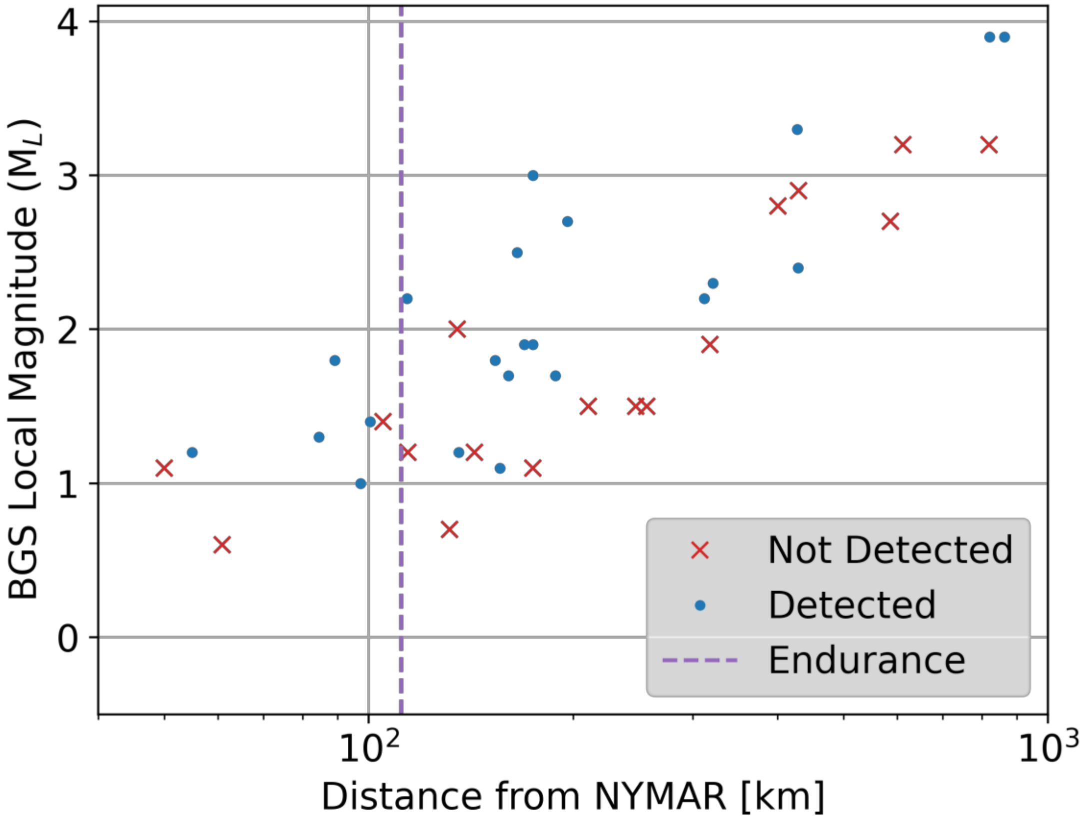
Location capability assessment in progress





Benchmarking array performance

- 265 earthquakes recorded by British Geological Survey October 2023 through August 2024 used to benchmark performance.
- Waveforms and f-k beamforming traces reviewed
- Able to detect M_L 1.0 at 100km hypocentral distance from NYMAR
- A single array is sensitive to specific focal mechanisms and radiation patterns.



Modelling detection capability

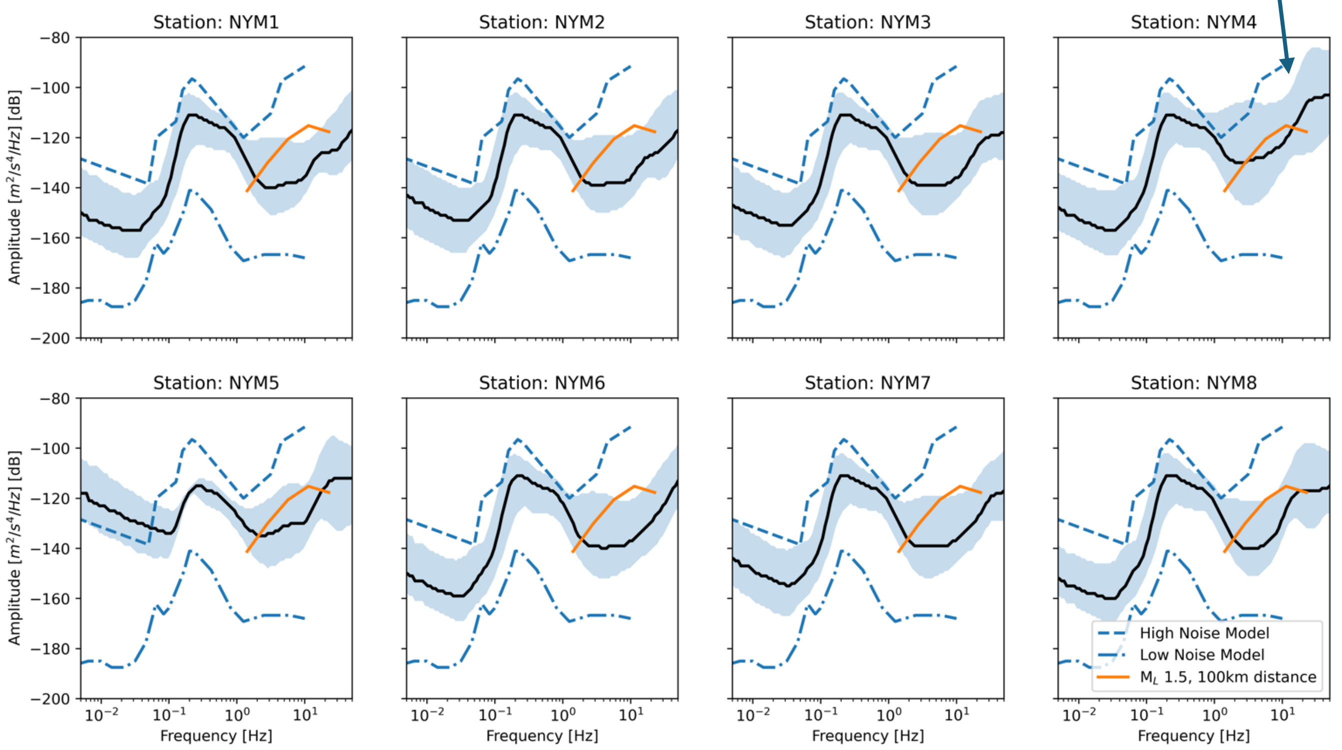
- We can use noise characteristics from whole deployment to model what ***we should be able to detect.***

- Estimate P95 noise displacement from probabilistic power density spectrum.

- Assume a $\sqrt{N}$ (i.e., correlated signals, uncorrelated noise) improvement in SNR.

- For a detection we model $A_S \geq\ 3\ A_N$
  - SNR used varies from 2 – 10 in literature (Mölhoff et al., 2019)

Noise from surrounding Heather



Modelling detection capability

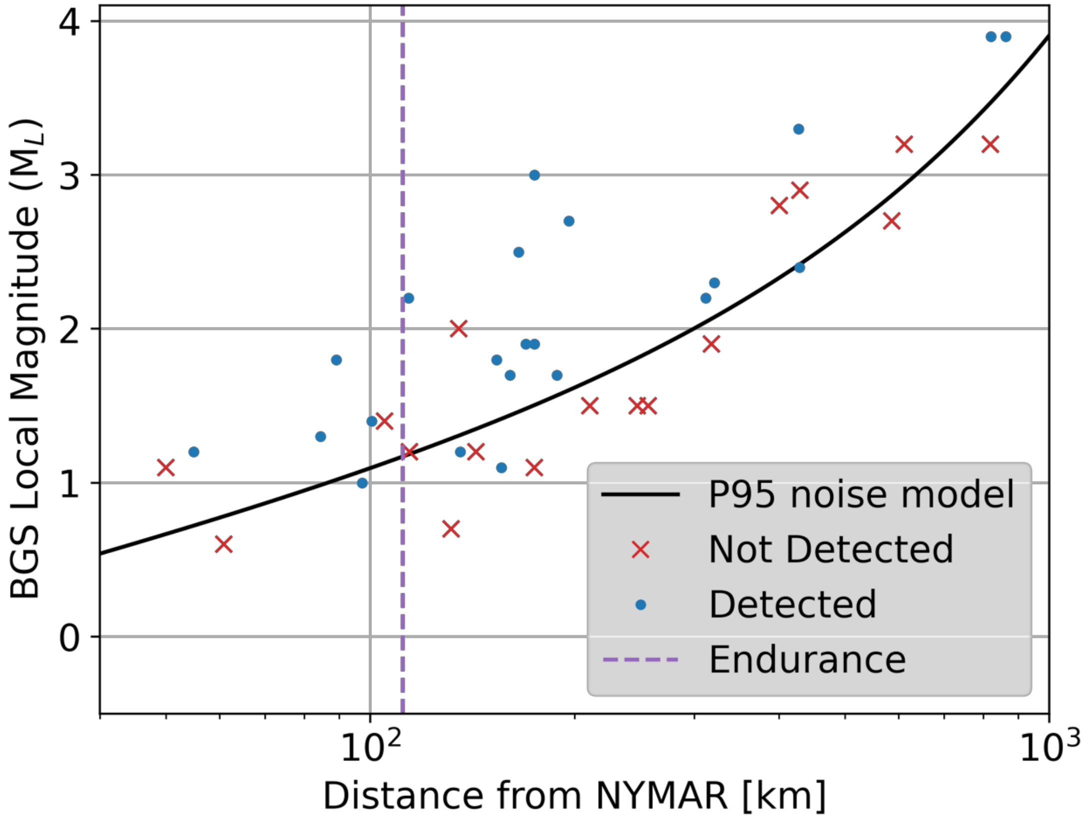
- For a detection we require $A_S \geq 3\ A_N$ (i.e., signal-noise ratio of 3).

- Calculate expected displacement for a given earthquake on the UK local magnitude scale (Luckett et al., 2018)

$$M_L = \log(3A_N) + 1.11 \log(r) + 0.00189r - 1.16e^{-0.2r} - 2.09$$

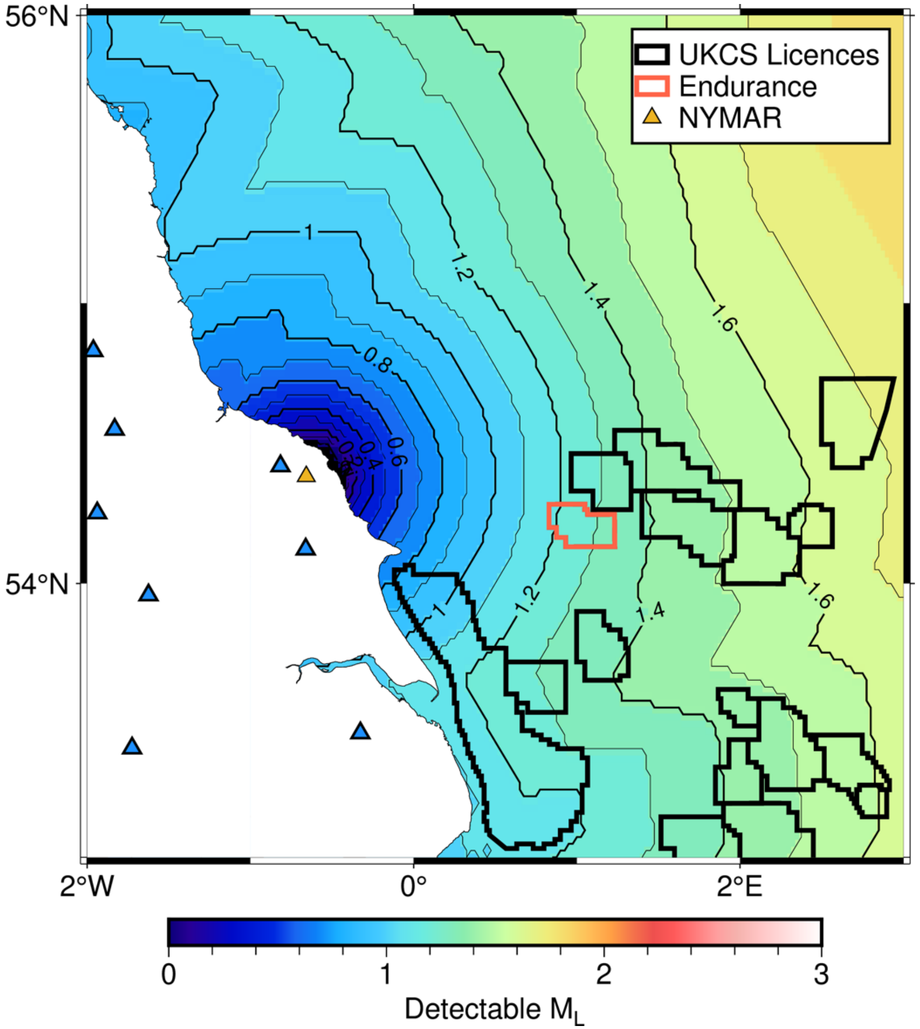
- At 100km, detection capability is ca M_L 1.1

- How much does the array improve on the UK network … ?



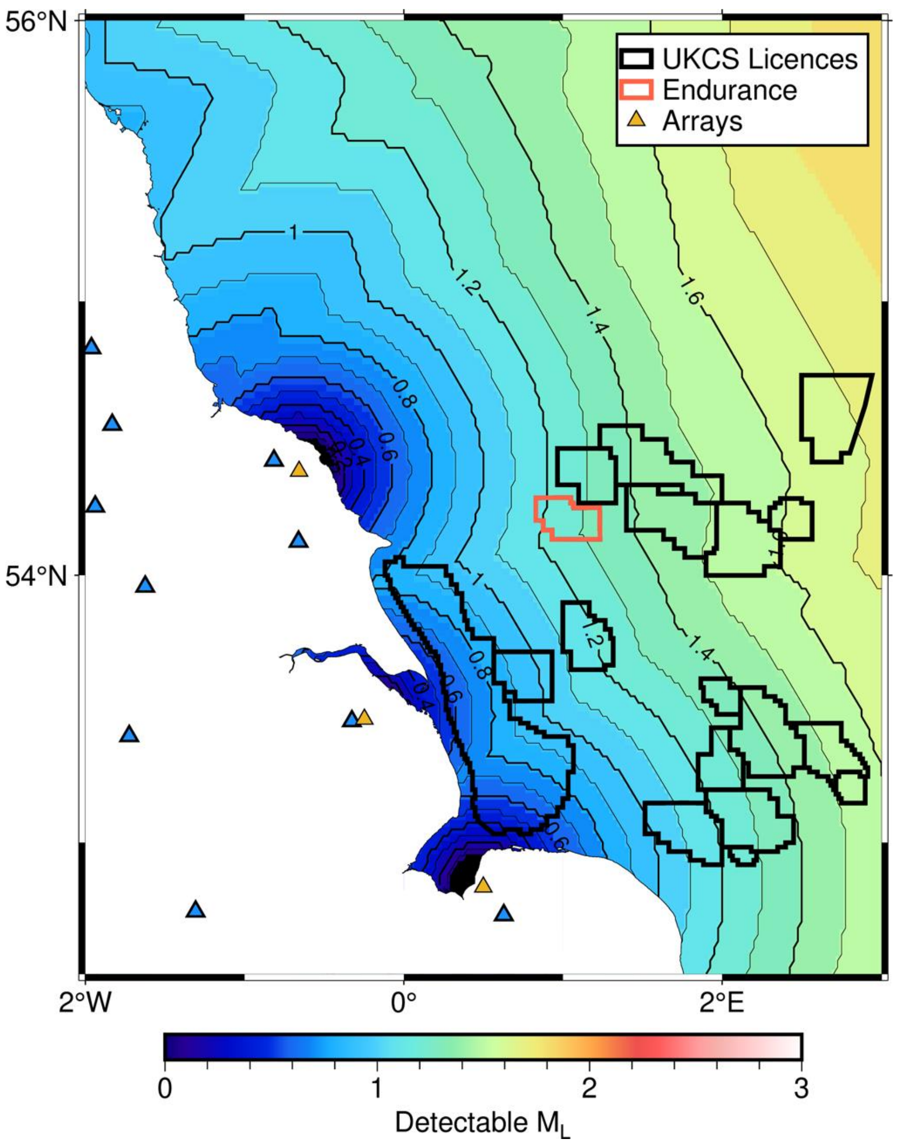
Southern North Sea Detection Capability

- Adapted network detection capability code SN-CAST (Molhoff et al., 2019).
  - Similar approach used by BGS (e.g., Baptie, 2021).
- Noise calculated at UK network stations using data for 2023.
- Events 'detected' if $A_S \geq 3\ A_N$ at 5 stations *or* at NYMAR.
- Likely to meet monitoring threshold of ~M_L 1 – 1.5 needed to avoid "intolerable" seismicity, particularly with deployment upgrades



Conclusions

- NYMAR deployment shows potential for onshore arrays to monitor North Sea seismicity ☺
  - Likely to meet monitoring threshold of ~M_L 1 – 1.5 needed to avoid "intolerable" seismicity (Verdon and Bommer, 2019).
  - Some more "calibration" events would be nice. NYMAR extended until Sep. 2025
- Potential for multiple arrays across UK East Coast.
  - Will improve azimuth constraint for detection and location
- Onshore detections could act as triggers for other monitoring methods/protocols.



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Questions?

Or see me at Poster S53B-3321 this afternoon!