




G E U S

SECURE – Subsurface Evaluation of Carbon capture and storage and Unconventional Risks

Stenseis – seismological monitoring network at Stenlille

Geological Survey of Denmark and Greenland
Ministry of Climate and Energy



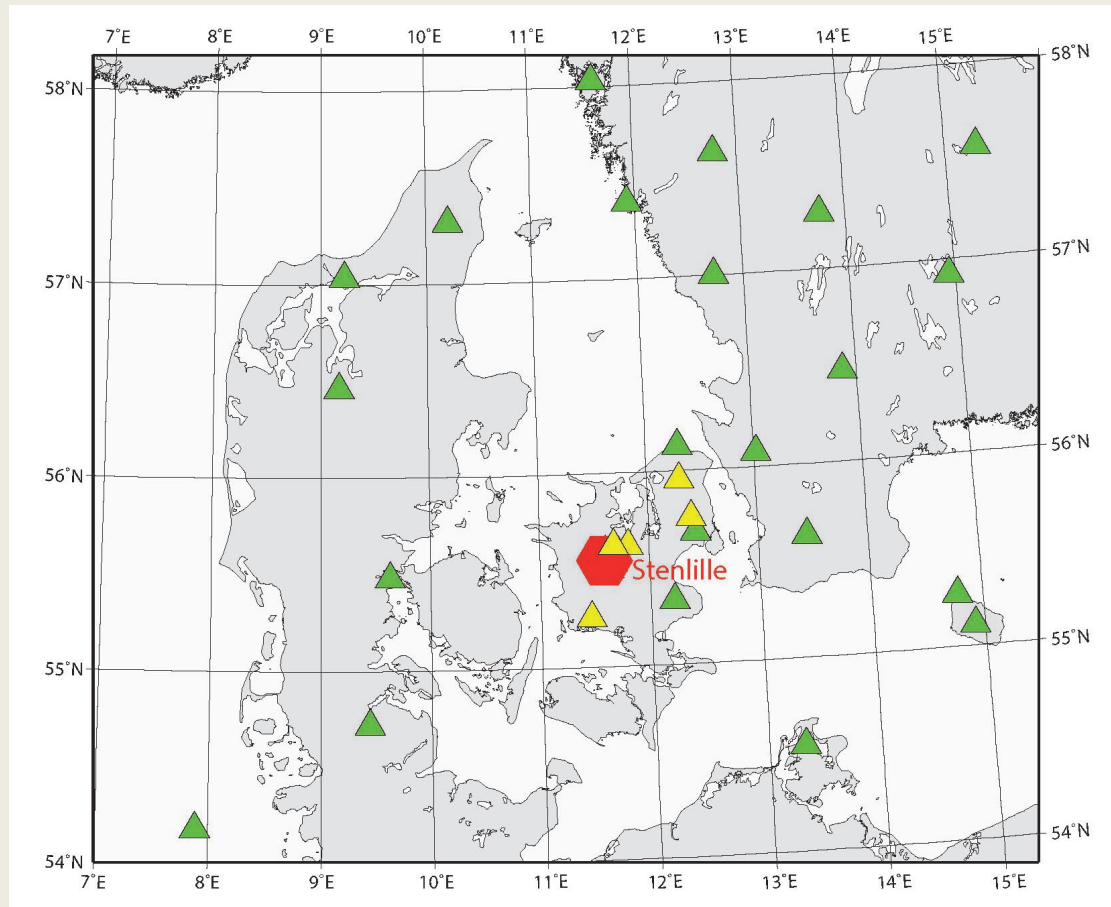
The Stenlille gas storage facility has been in operation since 1986, and annually pumps 500 mill. m³ of gas in during the summer and out during the winter.

In August 2018 six seismic stations were placed close to the facility, with the aim to monitor any induced or triggered seismic events caused by the pumping activities.

Several Raspberry Shake stations were added at larger distances (yellow triangles).

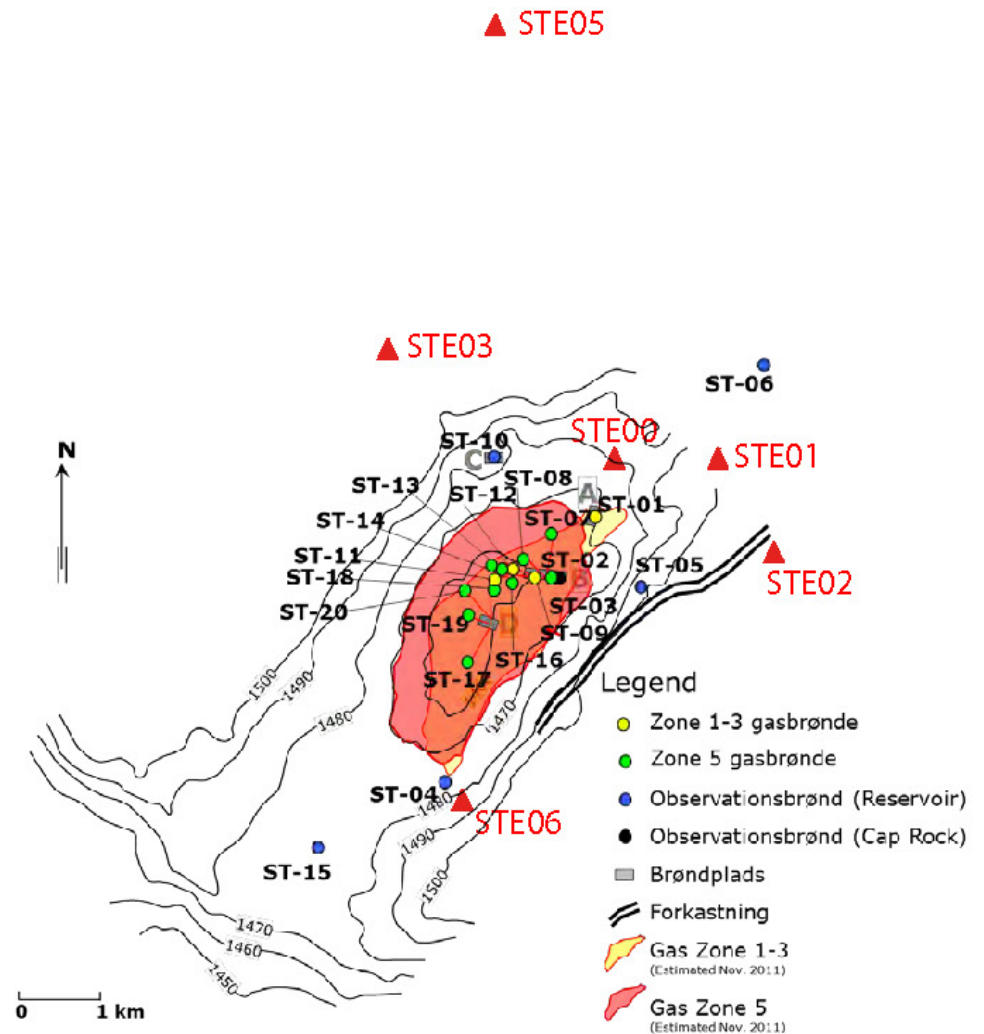
The national networks of Denmark and neighbours are green triangles.

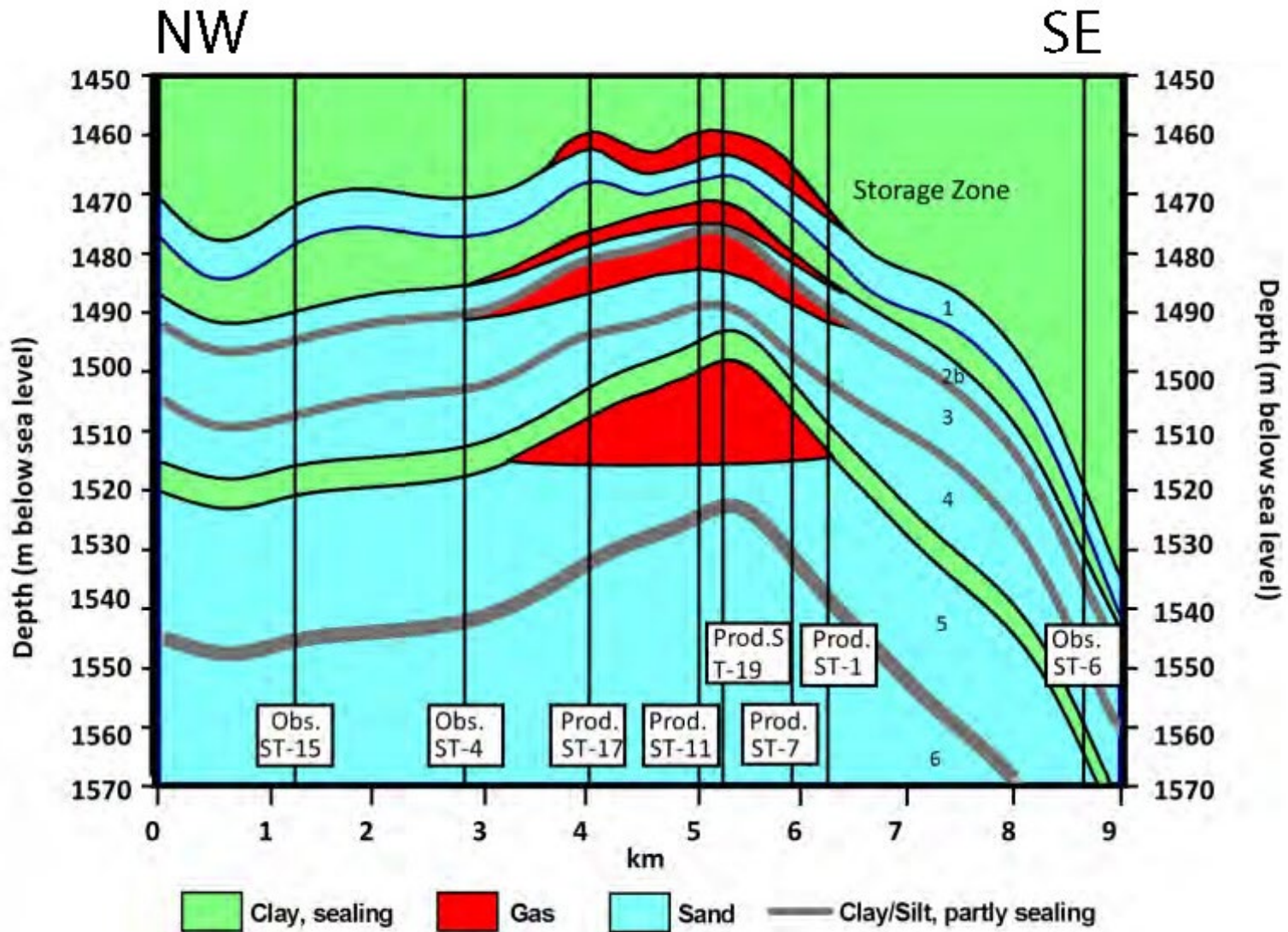
Stenlille network

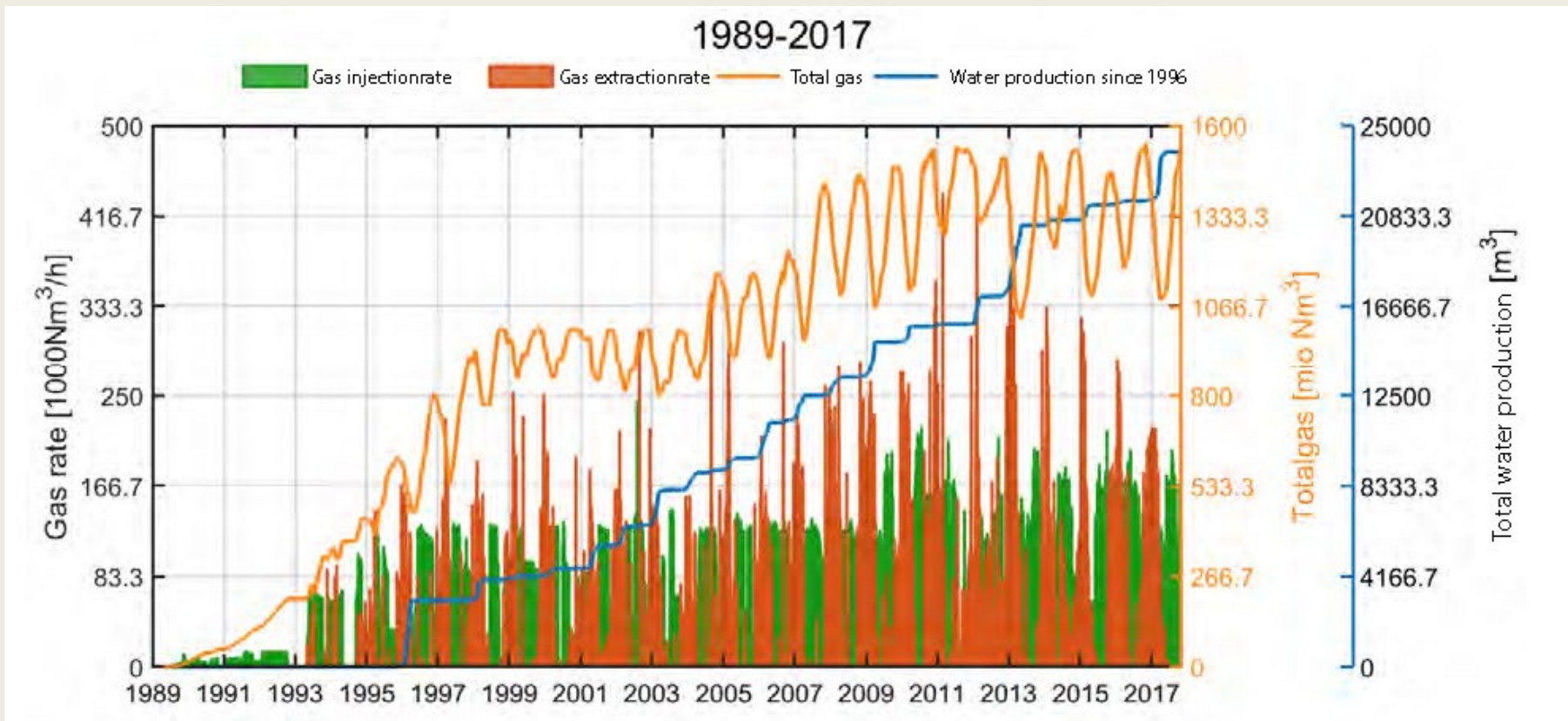


Well locations and extension of the different gas zones at the Stenlille gas storage facility. Contour lines indicate depth in metres to the top Gassum Formation.

Red triangles are the deployed seismographs for the SECURE project. The seismographs in the network are within 5 km of the main pumping station. Modified from Gasstorage Denmark årsrapport 2017.







Pumping through one year



The stations

STE00
Gas storage HQ



The stations

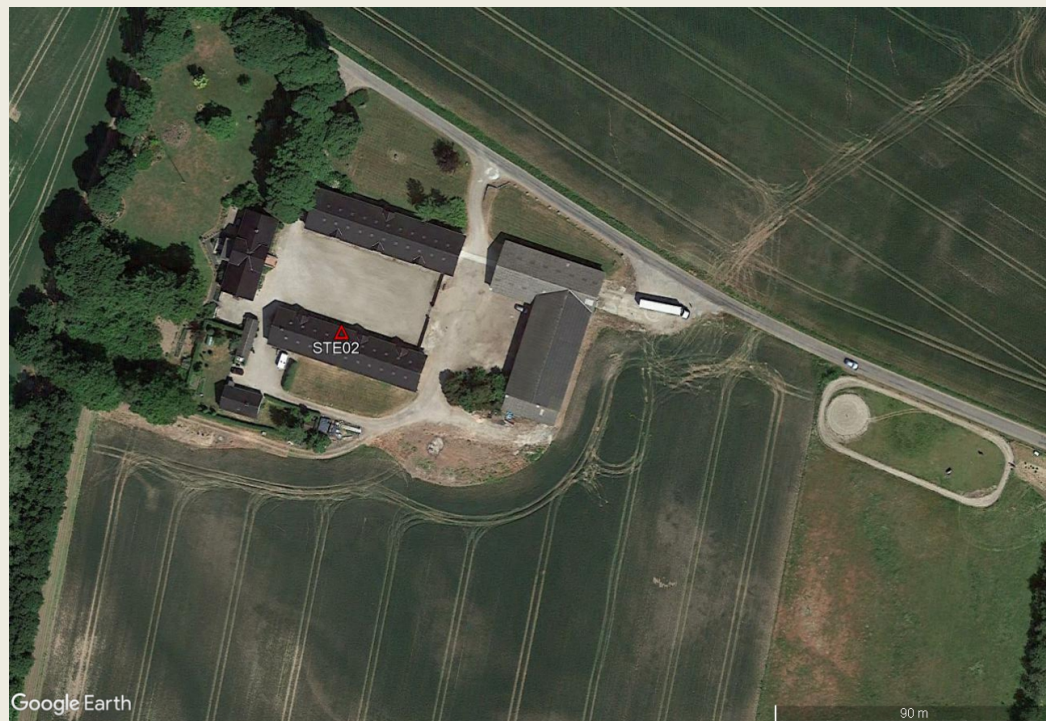
STE01
garage



The stations

STE02

The large place



The stations

STE03

Colleague's daughter



The stations



STE05
The pigs



The stations

STE06

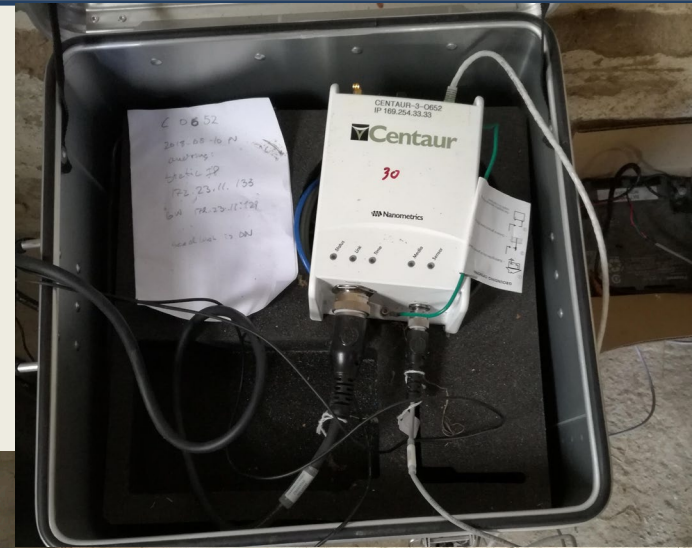
The horses



STE07

The stations

The barn (moved July 2020 from STE00)

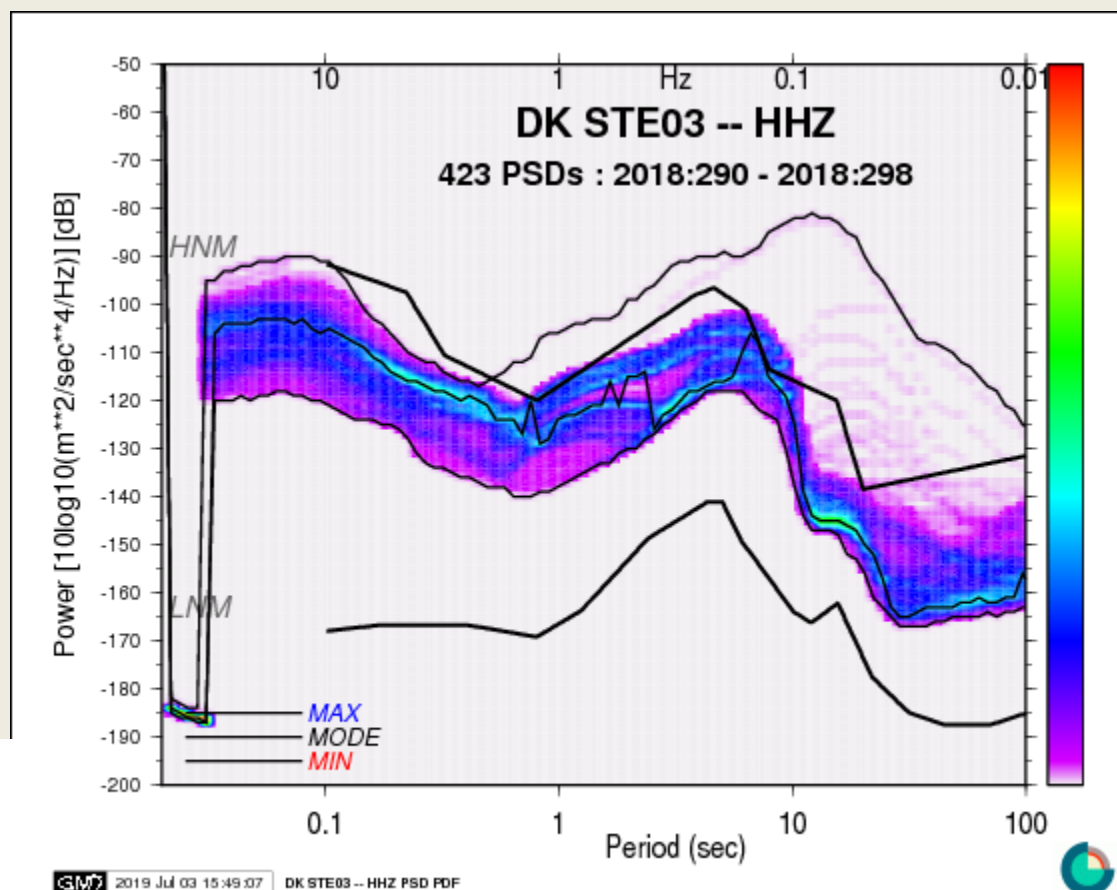


Data quality

Since installation of the Stenlille monitoring network, data from the 6 stations have been continuously recorded and transmitted in real time to GEUS, where it is stored on our servers.

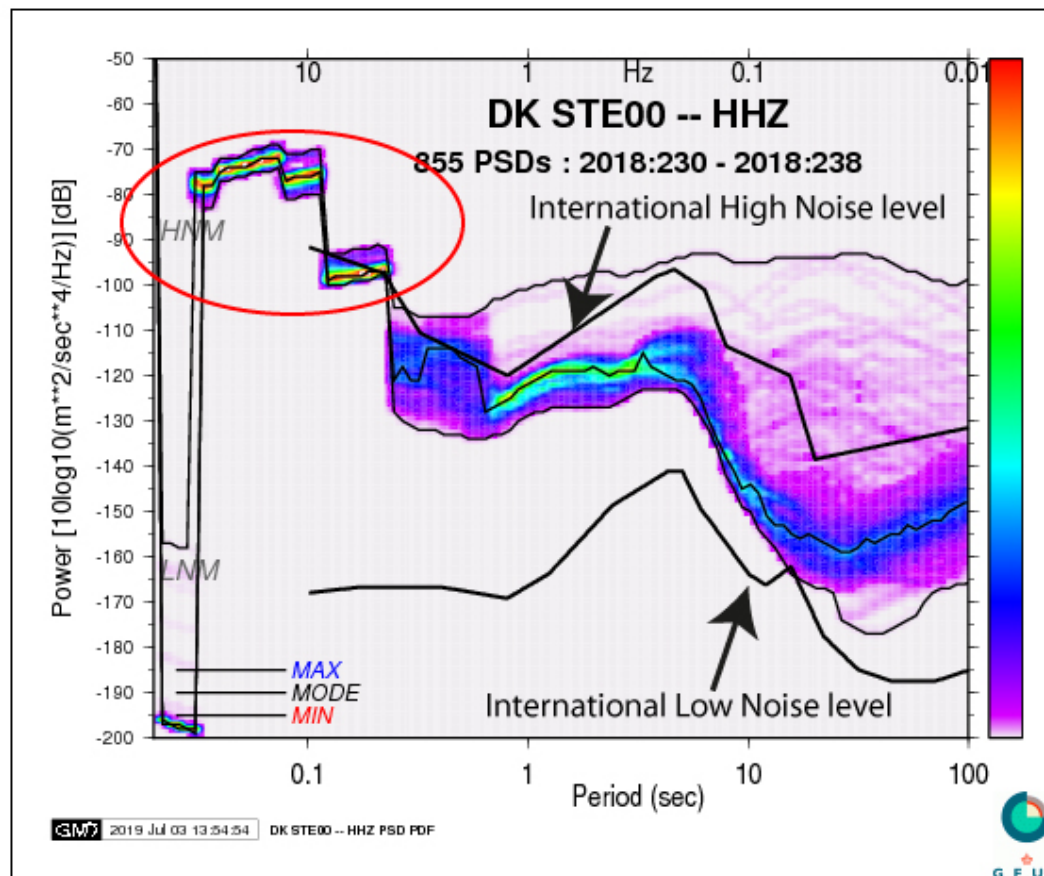
Analysis of the Stenlille data shows a high noise level, but slightly better than the Dybvad network.

The seismographs have noise levels below the international High Noise Model. Station STE03 is included in the daily earthquake monitoring at the GEUS' seismic service as an extra quality control.



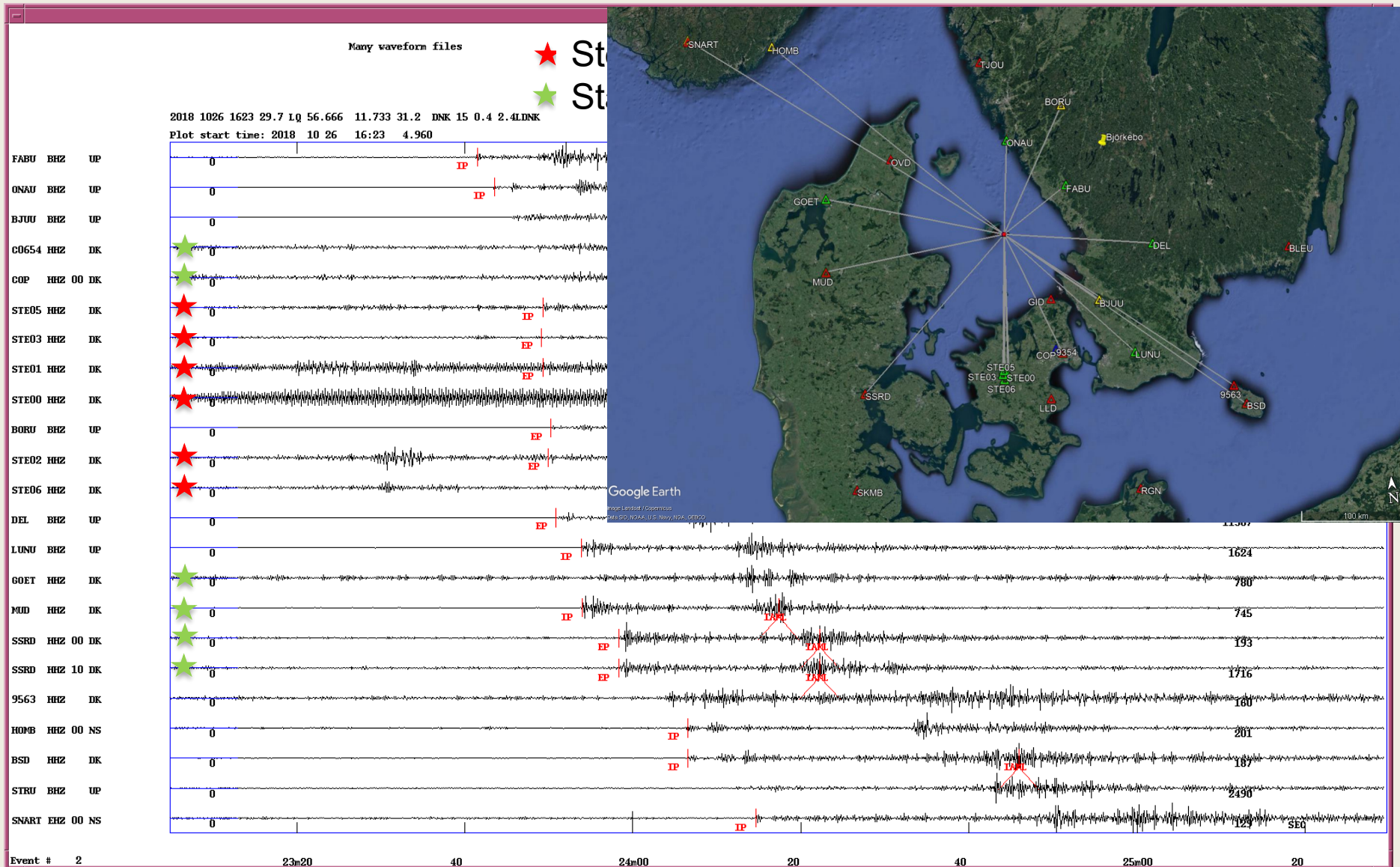
Noise analysis for the vertical component of STE03, located 3.2 km from the main pumping station.

Data quality



Noise analysis for the vertical component of STE00, located at the main pumping station.

2018-10-26 16:23 utc ML 2.4



Screening for events

Data for have been screened for events, using the CONDET code (see the SEISAN manual: <http://seisan.info/>).

The screening triggers hundreds of times on the data. The triggers are very unevenly spaced, depending thunderstorms and noise.

A manual analysis of the triggered events result in 32 locatable events.

Of these 20 are known (both earthquakes and explosions) which either are fairly closed to Stenlille, or large enough and with a frequency content within the range used to trigger on the Stenlille stations alone.

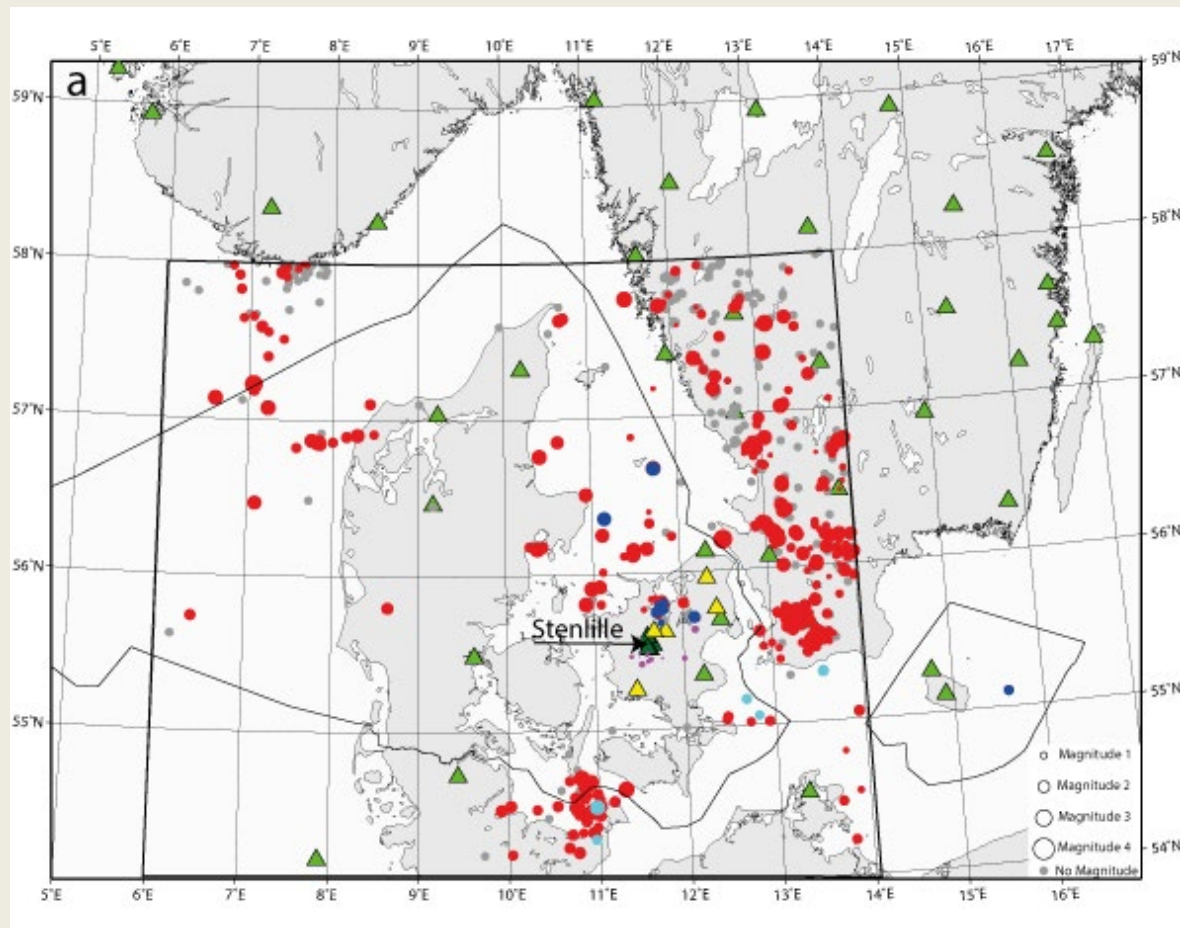
The rest at “spurious events” – I will get back to these.

No events are in the Gas storage area.

Red dots: Events (both earthquakes and explosions) located within the box by the general monitoring in Denmark for the time period 201810 – 202004.

Blue dots: The known events events found by the screening process. Light blue explosions; dark blue earthquakes. Lilaq – Spurious events.

Events found by the screening

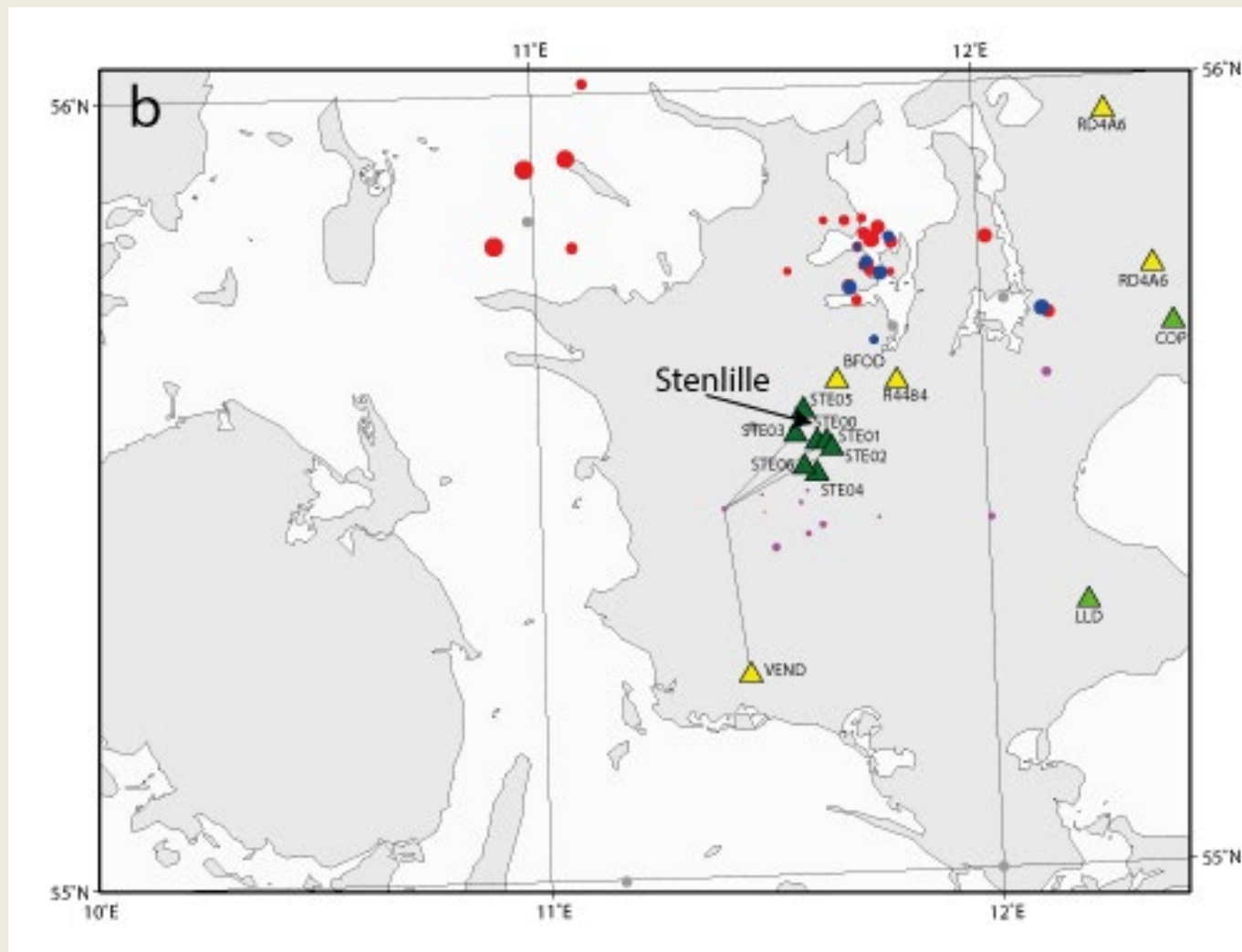


Triangles: seismological stations. Dark Green – Stenlille stations, yellow - Raspberry, light green – national network stations.

Spurious events

The spurious events are located from 10-20 km from the Stenlille gas storage, and not connected to the Stenlille facility.

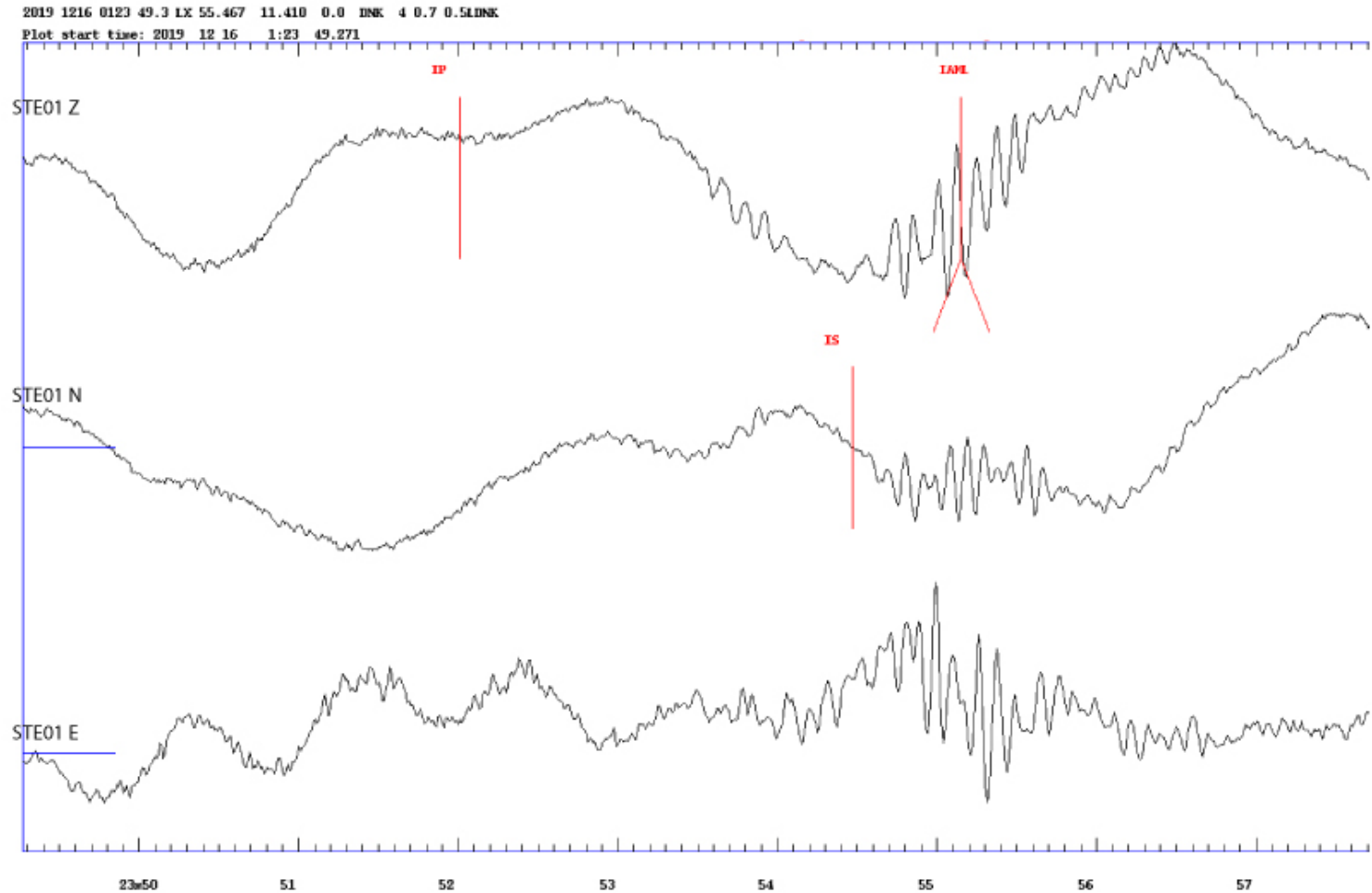
They are all very small – ML 0.8 down to ML -0.2. There are many more than we were able to locate.



Spurious events

Spurious event 2019-12-16 01:23 utc ML 0.5 as seen on STE01.

The data are unfiltered, and present frequencies of approx. 10 Hz, very low for an event this small.



Why does the pumping not trigger events?

We do not know but we can speculate.

GEUS has never recorded an event near Stenlille, so no larger events have occurred.

The Gas Storage facility has to our knowledge never received a complaint about shaking.

Through the close to four decades of pumping approx. 500 mill m³ in and out, all stresses have long since been relieved.

Detection level

We use the detected events to estimate the detection level of the Stenlille network.

The local magnitude scale is defined as:

$$ML = 0.925 \cdot \log_{10}(A) + 1.61 \log_{10}(\Delta) - 2.38$$

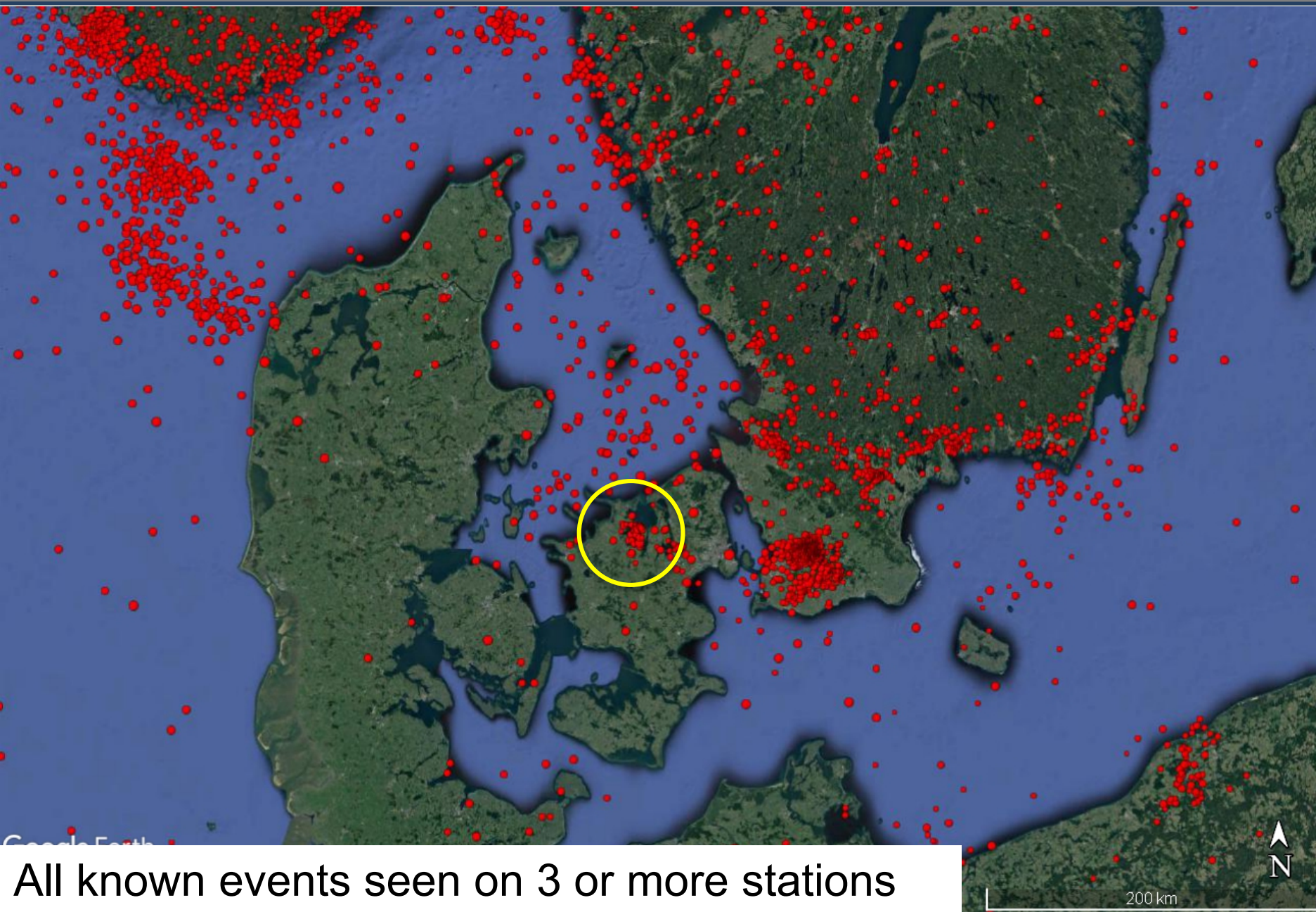
Where A is the amplitude in nm and Δ the distance in km

A natural earthquake occurring on 2018-10-26 16:23 utc with ML 2.4 at a distance of between 124 and 132 km from the stations in the Stenlille network was detected by the Stenlille network.

Assuming the same amplitude was detected by a station 4 km from an event within the network it corresponds to an event of ML between -0.3 and 0.2, depending on which station is used.

Averaging for the natural earthquakes detected the calculated detection level within Stenlille gas storage is estimated to be at least ML 0.0

Warning: the ML equation is not validated for distances under 100 km



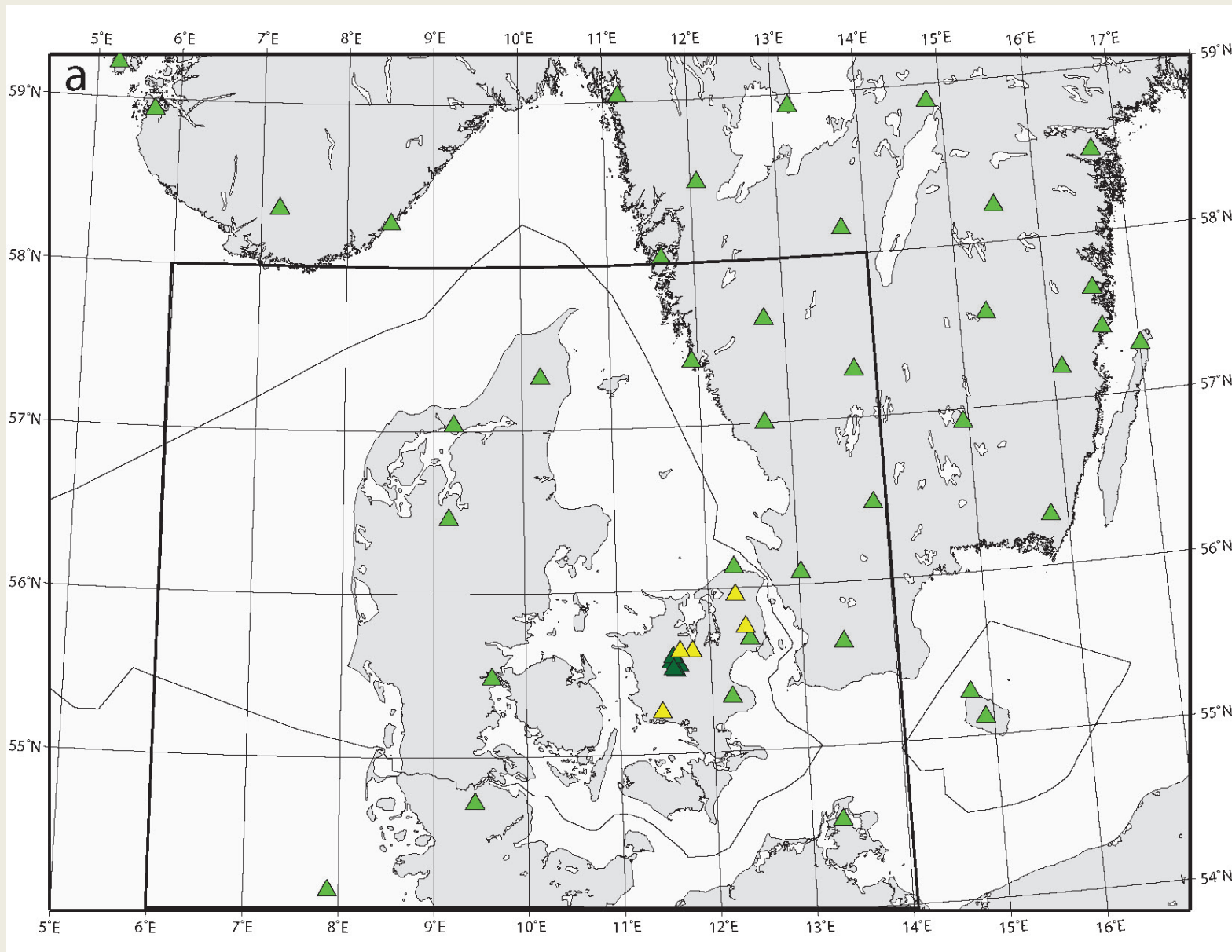
All known events seen on 3 or more stations



All known events



All known events since 201810

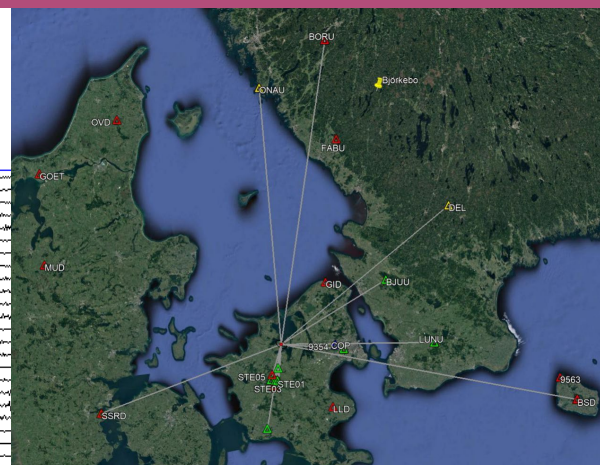


2020-01-01 12:49 utc ML 1.1

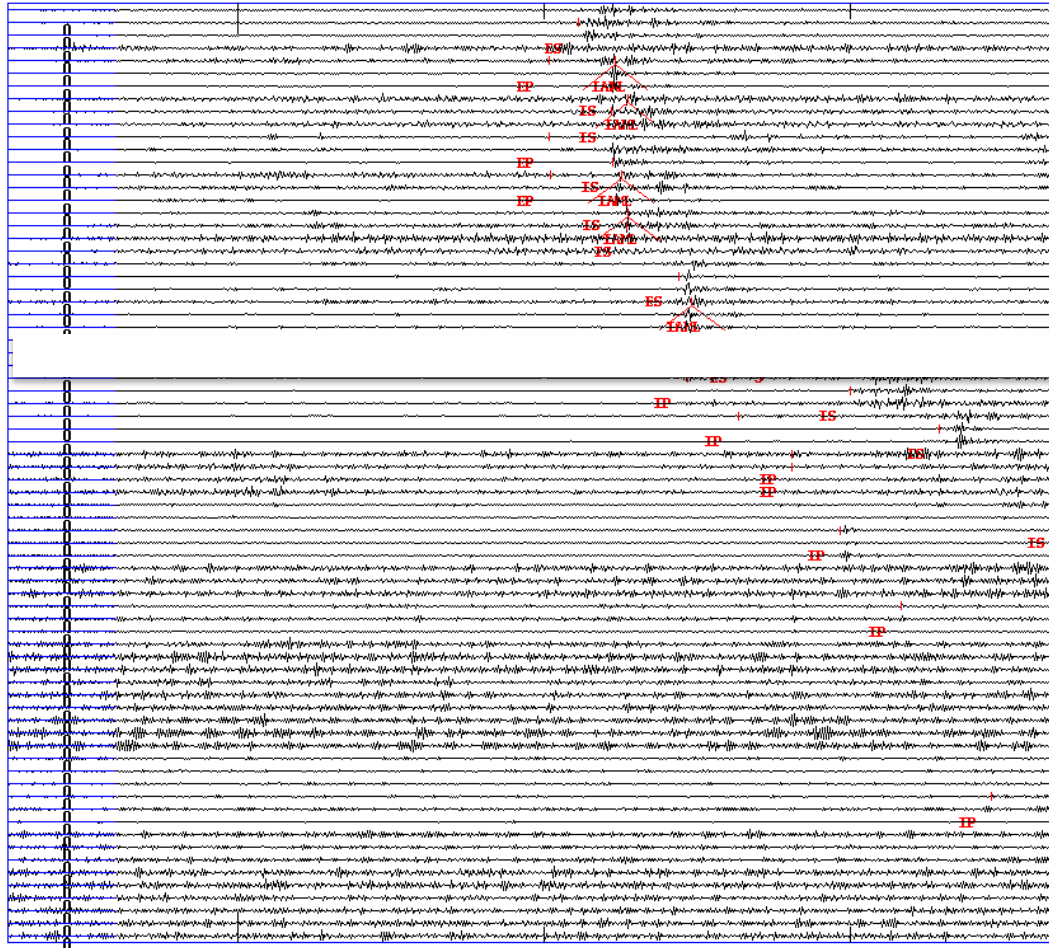
Many waveform files

Stenille and Raspberry stations

2020 1 1 1249 15.6 LQ 55.771 11.744 15.5 DNK 15 0.5 1.1LDNK
Plot start time: 2020 1 1 12:48 44.935



- BF00 HHZ 00 DK
- BF00 EHN 00 DK
- BF00 EHE 00 DK
- R4484 EHZ 00 AM
- STEO1 HHZ 00 DK
- STEO1 HHE 00 DK
- STEO0 HHZ 00 DK
- STEO0 HHE 00 DK
- STEO3 HHZ 00 DK
- STEO3 HHE 00 DK
- STEO2 HHZ 00 DK
- STEO2 HHE 00 DK
- STEO6 HHZ 00 DK
- STEO6 HHE 00 DK
- STEO6 HHE 00 DK
- RD446 SHZ 00 AM
- C0654 HHZ 00 DK
- C0654 HHE 00 DK
- C0654 HHE 00 DK
- COP HHZ 00 DK
- COP HHE 00 DK
- COP HHE 00 DK
- YEND EHZ 00 DK
- YEND EHN 00 DK
- YEND EHE 00 DK
- BJUU HHZ 00 UP
- BJUU HHE 00 UP
- LUNU HHZ 00 UP
- LUNU HHE 00 UP
- SSRD HHZ 00 DK
- SSRD HHZ 10 DK
- SSRD HHZ 10 DK
- SSRD HHZ 10 DK
- SSRD HHE 00 DK
- SSRD HHE 00 DK
- DEL HHZ 00 UP
- DEL HHE 00 UP
- MUD HHZ 00 DK
- MUD HHE 00 DK
- MUD HHE 00 DK
- QNAU HHZ 00 UP
- QNAU HHE 00 UP
- OVD HHZ 00 DK
- OVD HHE 00 DK
- 9563 HHZ 00 DK
- 9563 HHE 00 DK
- G0E1 HHZ 00 DK
- G0E1 HHE 00 DK
- G0E1 HHE 00 DK
- BSD HHZ 00 DK
- BSD HHE 00 DK
- BORU HHZ 00 UP
- BORU HHE 00 UP
- TJOU HHZ 00 UP
- TJOU HHE 00 UP
- HONB HHZ 00 NS
- HONB HHE 00 NS
- HONB HHE 00 NS
- STRU HHZ 00 UP
- STRU HHE 00 UP



Event # 1 49m00 20 40 50m00 20

What happens now?

We have completed Deliverable to EU about the monitoring

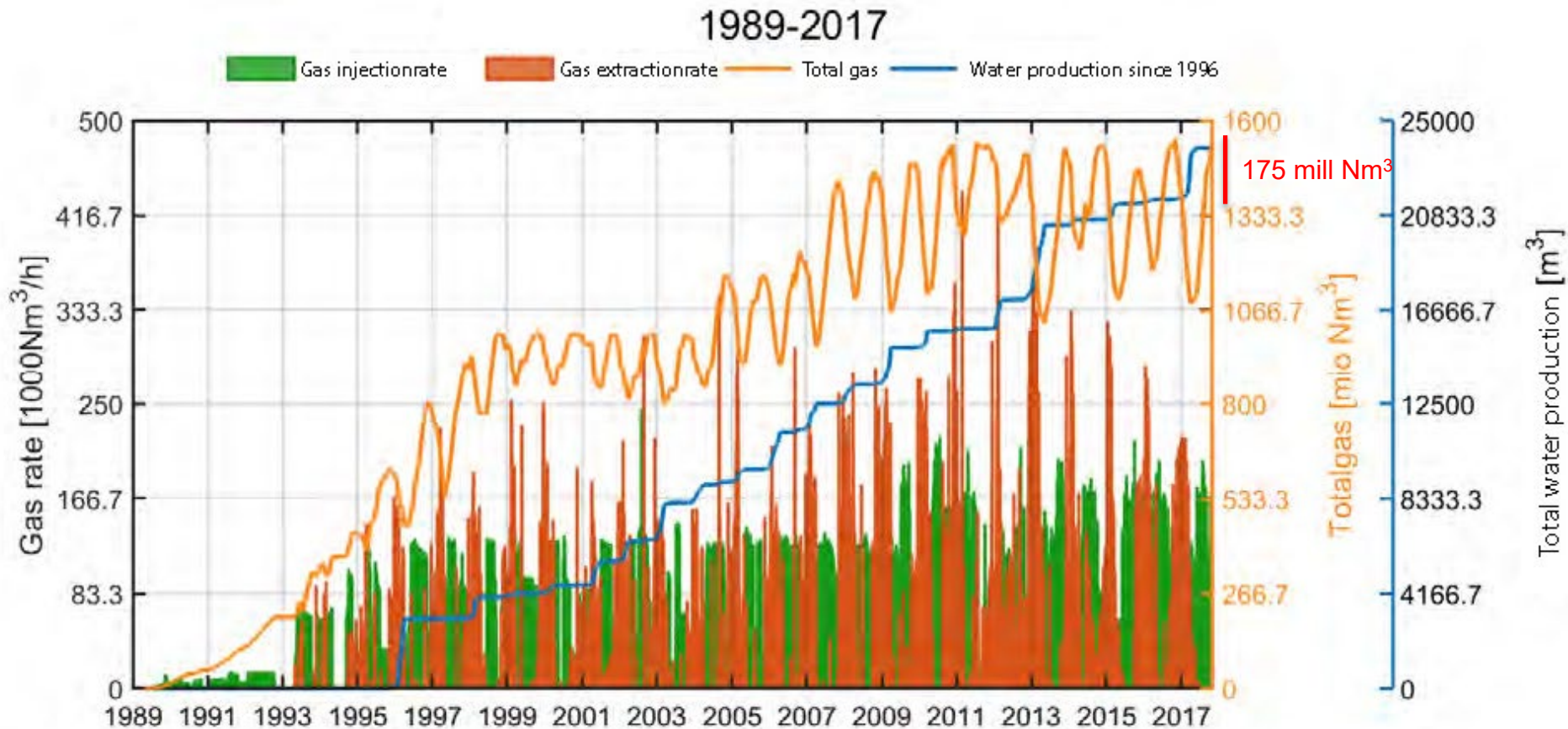
A paper for GEUS Bulletin is underway in collaboration with GEUS Geochemical department who monitors gas etc. at Stenlille.

Gas Storage Denmark has asked (and financed) an additional year of monitoring, as they are expanding the storage capacity.

Vi have moved STE00 (at HQ) to a new position away from pumping noise (to STE07 “The barn”).

Expansion in zone 5

The plan is to expand with c. 175 mill Nm³. Yearly variation is usually approx. 500 mill Nm³



Expansion in zone 5

