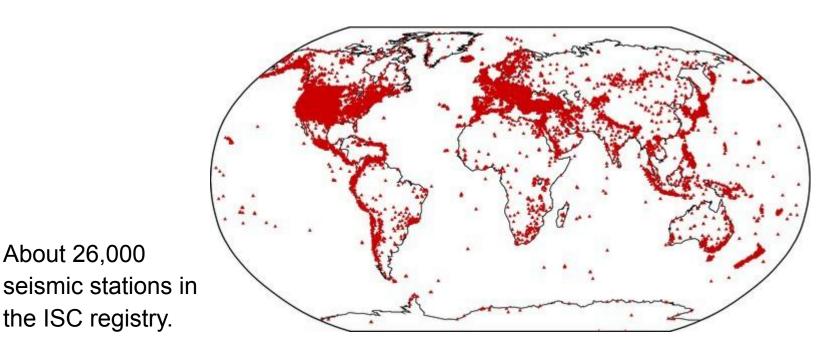
Developments in rapid large scale monitoring of underwater activities

Björn Lund
Swedish National Seismic
Network Uppsala University

Seismology: rapid large scale collaborative monitoring of earthquakes



About 26,000

the ISC registry.

Many hundred stations are openly available with continuous real-time data.



Seismology: rapid large scale collaborative monitoring of nuclear tests

170 seismic stations as purple and blue squares.



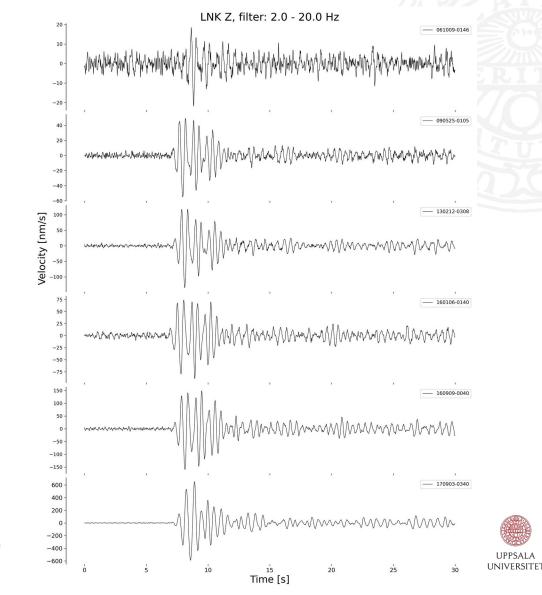


North Korean nuclear tests

High sensitivity instruments and good recording conditions:

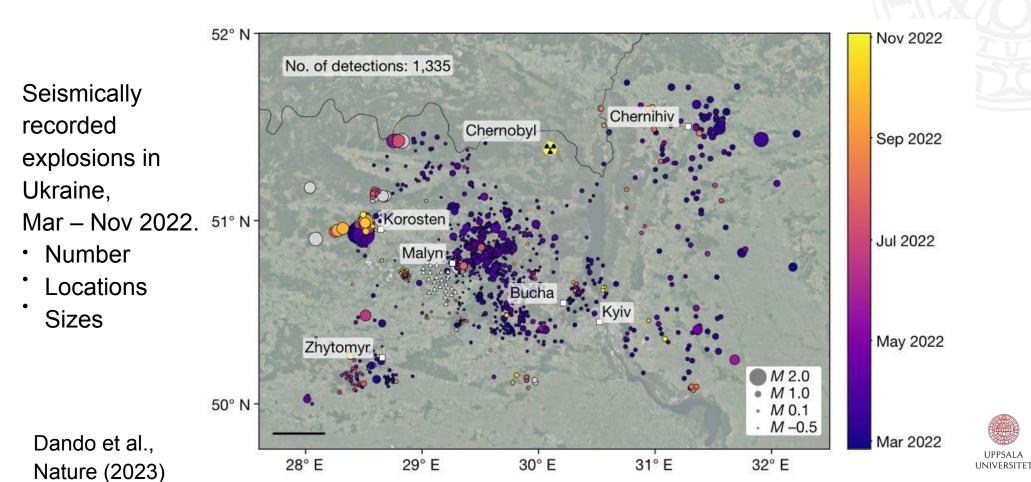
The six North Korean nuclear tests recorded on the vertical component at seismic station Linköping in Sweden.

Distance about 7,400 km.



SNSN (2017)

A tool for conflict monitoring



Seismology around the Baltic Sea

- 150+ seismic stations with available continuous real-time data through bilateral agreements.
 - Processing and analysis mostly done on subsets of the stations, at data centers in the individual
- countries.

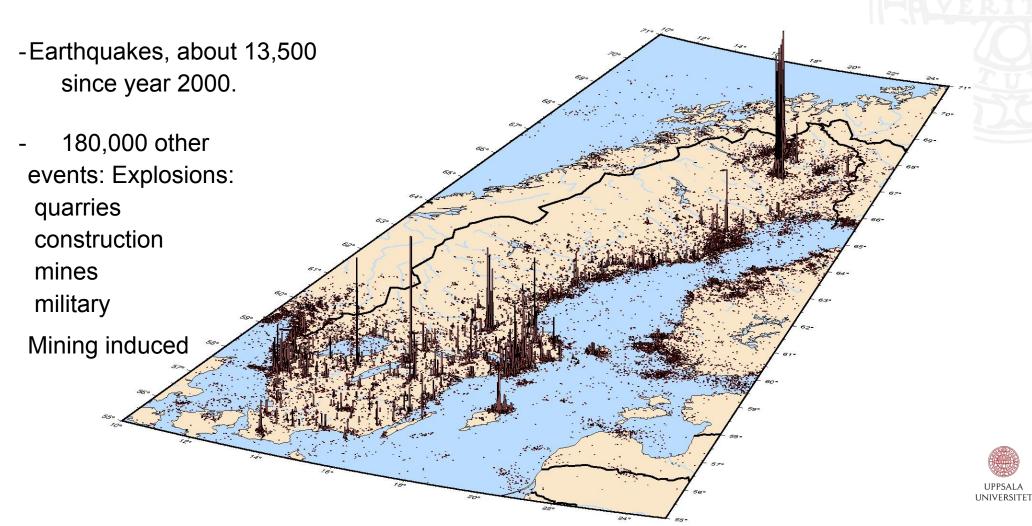
Room for more joint analyses.

Colours indicate individual networks. The map is





Seismic events analysed by SNSN over 20 years

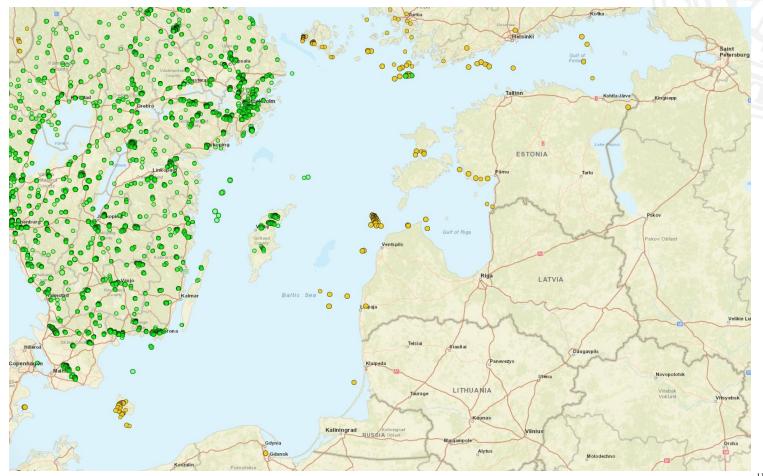


The last two years in the Baltic

Manually analysed events.

Green: explosions

Yellow:
Outside Sweden,
mostly not
assigned type



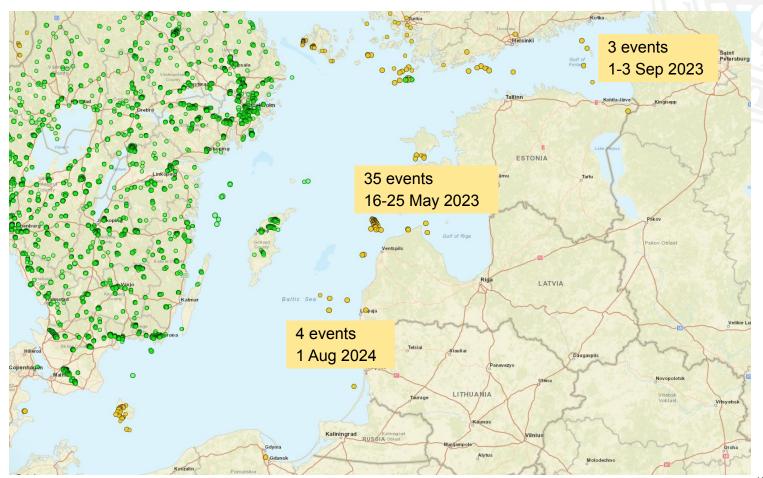


The last two years in the Baltic

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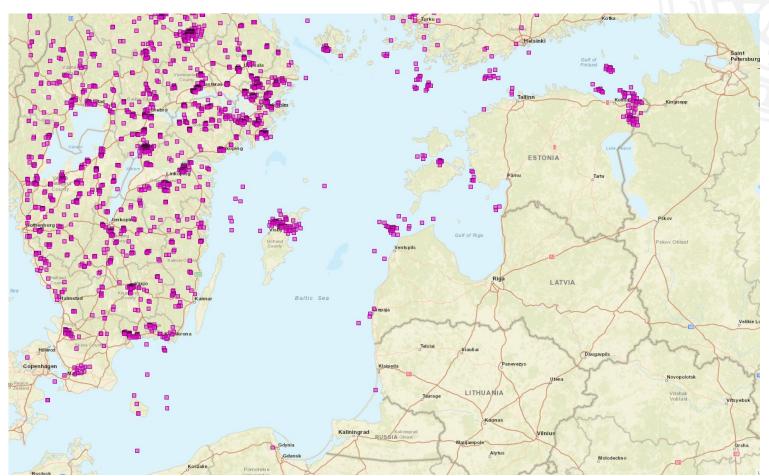


The last two years in the Baltic

Automatically defined events.

Come with a type assigned by a machine learning algorithm.

These are all explosions or unknowns.





Current SNSN automatics

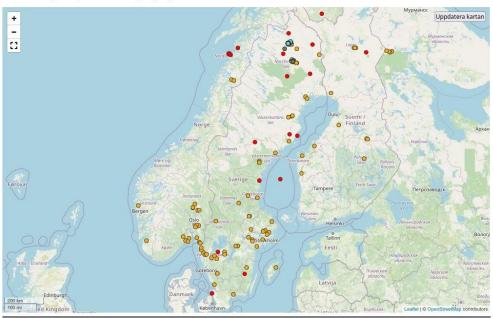
Automatic detections, locations, magnitudes and classifications.

Uses seismic stations around the Baltic and in Norway.
2 – 4 minute delay.

https://www.snsn.se/combull/







Troliga jordskalv senaste två veckorna

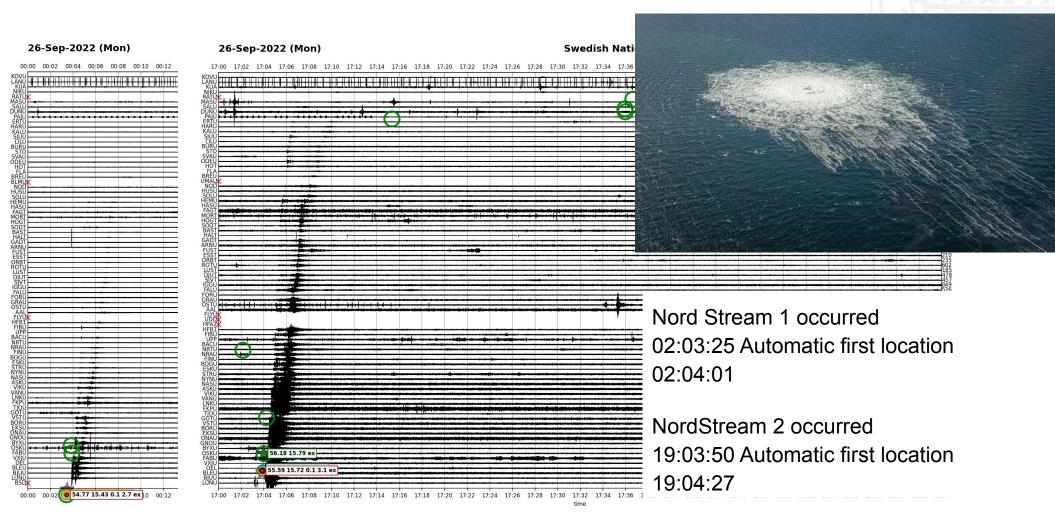
Tid	Latitud	Longitud	Magnitud	[Kommun, Län,] Land eller område
09/02 08:45:56	63.82	16.82	1.7	Sollefteå, Västernorrland, Sverige
08/02 06:18:52	66.58	20.10	1.3	Jokkmokk, Norrbotten, Sverige
06/02 05:15:15	67.47	19.67	1.2	Gällivare, Norrbotten, Sverige
05/02 03:41:28	67.69	15.12	1.6	Norska havet
03/02 05:04:34	58.49	13.11	1.2	Lidköping, Västra Götaland, Sverige
03/02 01:07:53	67.45	14.32	1.8	Norska havet
03/02 00:54:55	67.48	14.24	1.3	Norska havet
03/02 00:49:34	67.47	14.21	1.9	Norska havet
31/01 08:19:21	62.13	19.37	1.2	Bottenhavet

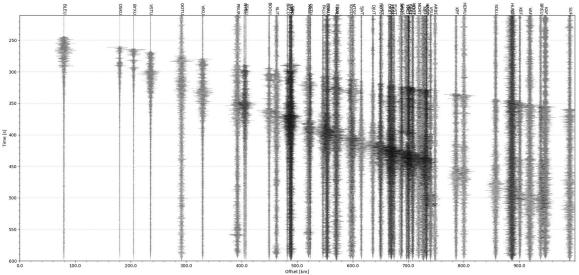
Troliga sprängningar (S), gruvskalv (G) och oklassificerade (O) händelser senaste veckan

Tid	Latitud	Longitud	Magnitud	Typ	[Kommun, Län,] Land eller område
9/02 15:54:16	67.85	20.17	1.5	G	Kiruna, Norrbotten, Sverige
9/02 13:38:21	67.86	20.20	1.6	G	Kiruna, Norrbotten, Sverige
9/02 03:42:43	67.17	20.66	1.2	0	Gällivare, Norrbotten, Sverige
9/02 01:19:57	67.84	20.17	1.5	S	Kiruna, Norrbotten, Sverige
9/02 01:17:45	67.82	20.21	1.6	S	Kiruna, Norrbotten, Sverige
9/02 00:07:42	67.19	20.66	1.3	S	Gällivare, Norrbotten, Sverige
9/02 00:03:45	67.15	20.64	1.1	S	Gällivare, Norrbotten, Sverige
9/02 00:02:27	67.16	20.70	0.9	S	Gällivare, Norrbotten, Sverige
8/02 22:06:33	67.88	20.20	1.0	G	Kiruna Norrhotten Sverige



Nord Stream, 26 September 2022





Northern Nord Stream event

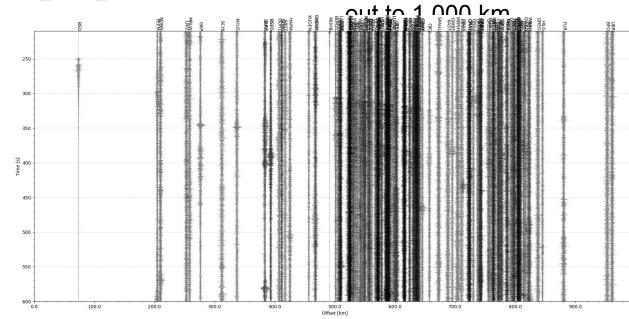
Stations to the south,

Stations to the north, out to 1,000 km

Large difference in signal-to-noise ratio between stations to the north and south.

- Tornquist zone
- Sediments in the south
- · Local site conditions

→ Makes collaboration important!



Bay of Finland, 8 October 2023

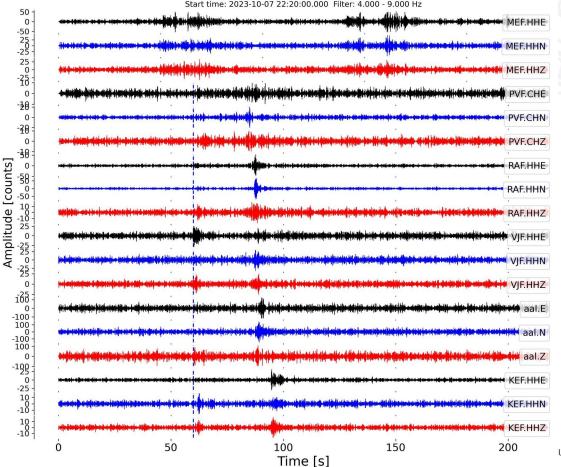
00:20:40 CEST

Balticconnector.

A small explosion or a gas leak. Magnitude 1 agrees with gas only.

Multiple Nordic analyses.



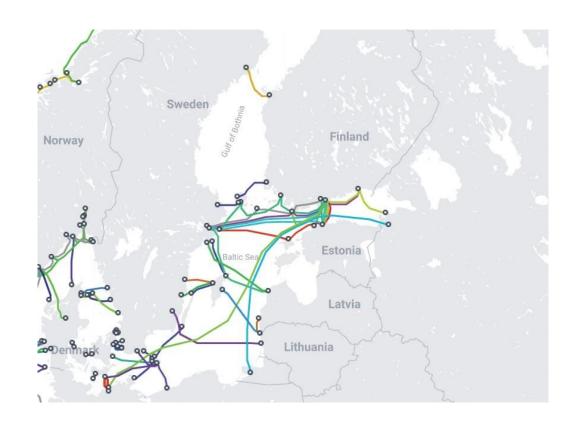




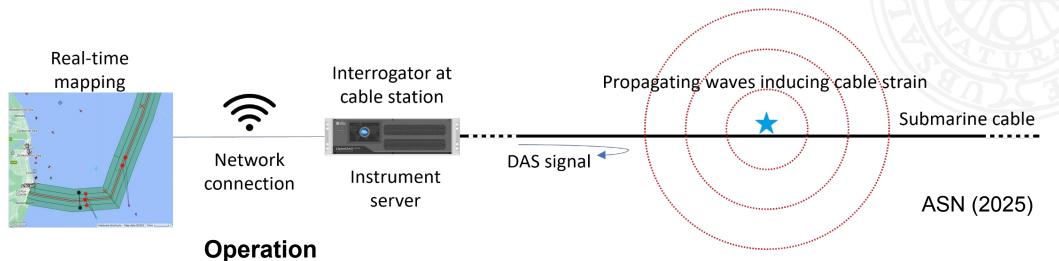




Distributed Acoustic Sensing (DAS) in fibre-optic cables



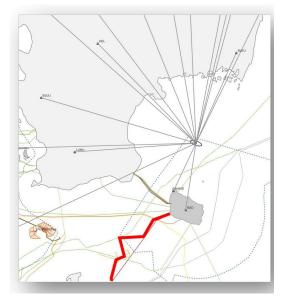




- Vibrations from earthquakes, explosions or gear dragging on the sea bottom cause strain in the fiber The strain makes laser pulses reflect to give a signal
- Long range > 120 km, high resolution 1 m.
- Massive amounts of data, 1+ TB/day, ripe for
- AI/ML No offshore installations

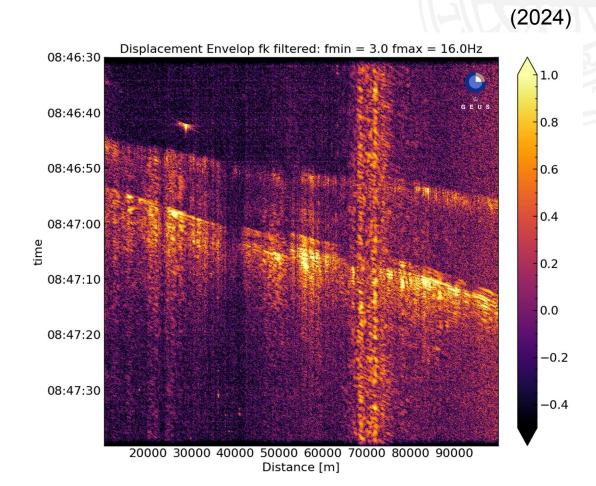


Cable from Rønne to Sassnitz



Underwater explosion on 30 November 2024. Unclear origin.

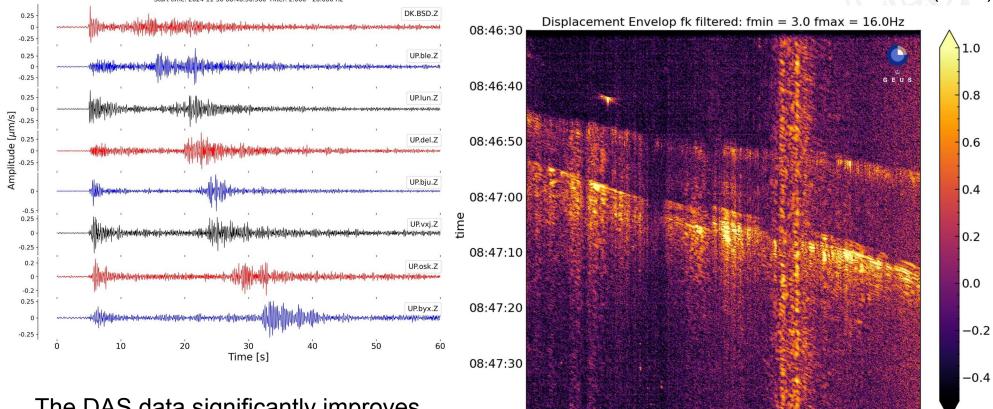
Recorded on seismic stations and the DAS system.



GEUS

SNSN (2024)

GEUS (2024)



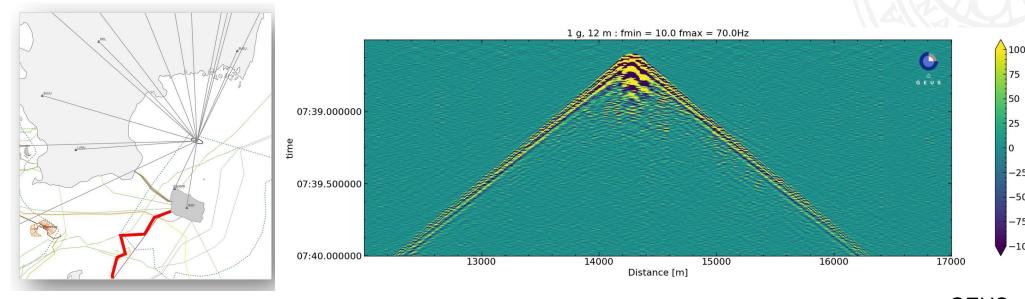
50000 60000

Distance [m]

70000 80000 90000

The DAS data significantly improves the analysis.

Cable from Rønne to Sassnitz



High sensitivity to nearby underwater activity.

1 gram of explosives detonated 12 m above the seafloor, clearly visible over 10 km of cable! GEUS (2024)







Narrow dragging marks corresponding in size to a chain without anchor photographed east from the damaged Balticconnector.

Oberle et al. (2017). Submarine Geomorphology: Bottom Trawling and other Fishing Activities.

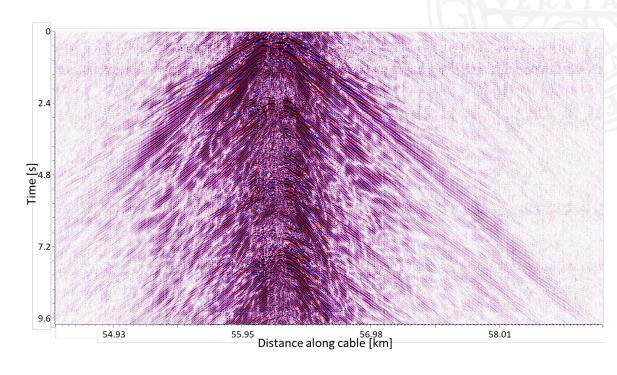
DAS operation

- Direct observations of seabed activity in near real-time
- Detection at offset 2-3 km from cable
- Real-time positioning, tracking seabed objects, automatic alerts



Include AIS information





DAS operation

- Direct observations of seabed activity in near real-time
- Detection at offset 2-3 km from cable
- Real-time positioning, tracking seabed objects, automatic alerts



ASN (2025)

Putting it all together: SEALION

Subsea Event Analysis: Location, Identification and ObservatioN for Resilient Critical Infrastructure

- Combine seismology, DAS, hydroacoustics and infrasound in a near real-time system. 10 countries, 30 partners
- Distributed data acquisition
- Distributed data analysis
- Central monitoring portal
- Collaborative, rapid, precise timing, good location, size, type



