T1.1-P7

Detection and Interpretation of Seismoacoustic Events at German Infrasound Stations

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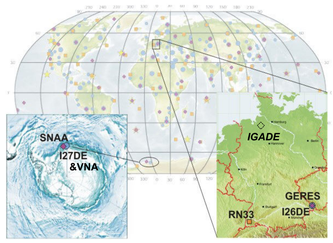
German infrasound/seismometer stations

The Federal Republic of Germany is involved in the operation and maintenance of five out of the 321 IMS (International Monitoring System) stations of the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO). Four out of these stations are operated by the Federal Institute for Geosciences and Natural Resources (BGR) as the German National Data Center for the CTBTO.
BGR operates and maintains the infrasound arrays I26DE in the Bavarian forest in Southern Germany and I27DE at Neumayer III research base in Antarctica, in cooperation with the German Alfred Wegner Institute (AWI). AWI also operates three broadband seismic stations (VNA1-3) and the 15 element Watzmann seismometer array (VNA-Array, not part of IMS) close to I27DE.
Additionally, BGR is responsible for the primary seismic array PS19 (GERES) co-located with I26DE as well as the auxiliary seismic station AS035 (SNAA) in Antarctica, operated in collaboration with the South-African Council for Geosciences (CGS). Apart from these IMS stations, BGR operates a third infrasound array (IGADE) in Northern Germany and a large national network of seismometer stations, the German Regional Seismic Network (GRSN).

Location of German infrasound and seismometer stations:

- Infrasound array **I26DE,** Bavarian Forest, Germany (BGR)
- Infrasound array **I27DE,** Neumayer III, Antarctica (BGR, AWI)
- Infrasound array **IGADE**, Garlstedt, Northern Germany (BGR)
- Seismometer array **GERES**, Bavarian Forest, Germany (BGR)
- Seismometer station **SNAA**, Sanae IV, Antarctica (BGR, CGS)
- Seismometer array **VNA**, near Neumayer III, Antarctica (AWI)

(also shown:
German IMS Radionuclide station RN33, Schauinsland (BfS))



Seismoacoustic sources

Seismoacoustic signatures are:

- either seismic waves recorded at infrasound sensors (supplementing seismometer recordings)
- or acoustic waves recorded at seismometers (supplementing infrasound sensor recordings)
- or seismic and acoustic signatures generated simultaneously by the same source and recorded by both seismometers and infrasound sensors

Seismoacoustic sources for example are:

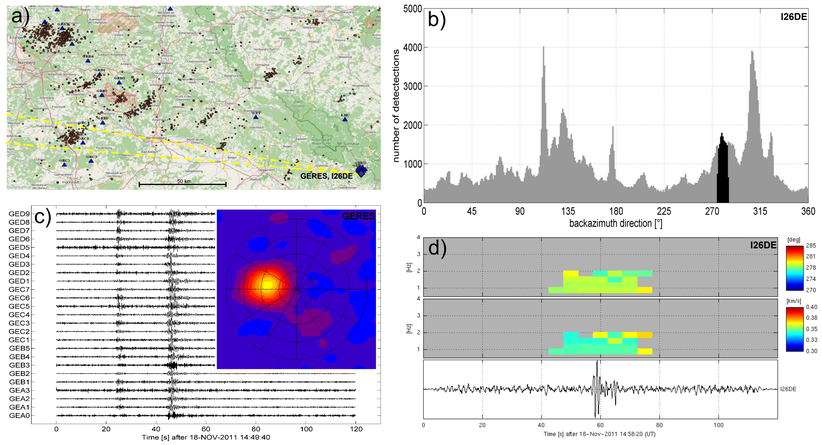
- **earthquakes** registered at microbarometers e.g. via surface waves or shaking landmass signatures and **atmospheric explosions** registered at seismometers via air-to-ground coupled pressure waves
- natural events (**bolides, volcanoes, oceanic low-pressure areas** generating microbaroms/microseisms) and artificial/anthropogenic mechanisms (**industrial activity, supersonic flights, wind turbine noise**) that generate detectable signatures at infrasound and seismic sensors
- surface, near-surface or underwater source processes that simultaneously generate pressure fluctuations in air and ground (e.g. **quarry and mining blasts, underwater explosions** as well as the **calving and cracking of glaciers and icebergs**)

Seismoacoustic detections at infrasound/seismometer stations reported here:

- at **I26DE** and co-located **GERES** seismometer array they are mostly of anthropogenic origin related to nearby mining activity, quarry blasts, storage lakes and nearby forestry activities
- at **IGADE** and Northern German **GRSN** seismometer stations they are mostly of anthropogenic origin related to supersonic flights, underwater explosions and wind turbines
- at **I27DE** and nearby **VNA/SNAA** seismometers they are mostly of natural origin related to the calving, cracking and breaking of glaciers and icebergs at the nearby Antarctic ice shelf edge

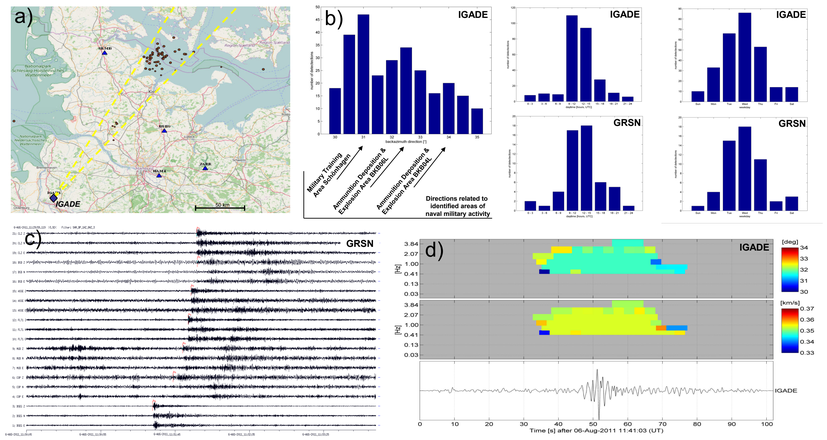
Anthropogenic source detections at I26DE

Seismoacoustic detections from a gravel quarry are registered at collocated sites I26DE and GERES from a well-defined backazimuth direction of 279° ± 2° (fig a). These correspond to a peak in the number of infrasound detections at I26DE (between January 2000 and December 2015, fig b). A high resolution analysis of one selected event (seismic: fig c, infrasonic: fig d) shows the backazimuth direction and a time delay of 9 minutes between seismic and acoustic arrivals (corresponding to 170 km true distance).



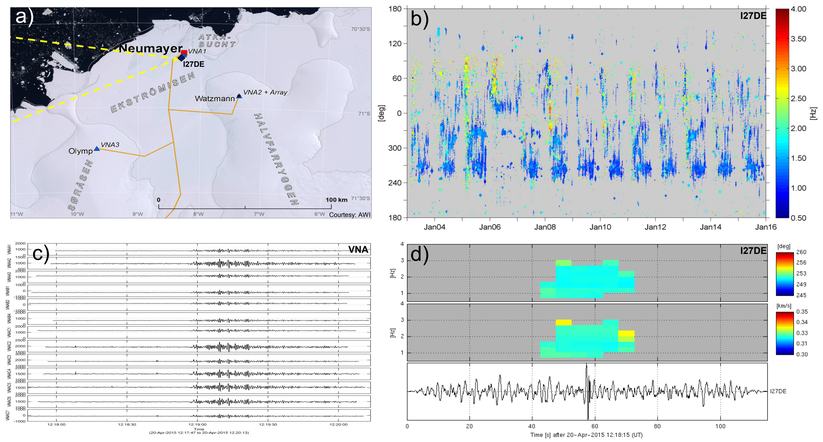
Underwater source detections at IGADE

Simultaneous detection of offshore seismoacoustic sources by Northern German GRSN stations and the IGADE infrasound array is most likely related to Navy activity in the western Baltic Sea (fig a). Histograms (fig b) of backazimuth direction at IGADE as well as daytime and weekday distribution of detections at IGADE and GRSN strongly indicate an anthropogenic origin of the signatures. A detailed analysis of one sample event (seismic: fig c, infrasonic: fig d) confirms the specific backazimuth direction as well as the characteristic of the source as an underwater explosion in contrast to a typical earthquake signature.



Natural source detections at I27DE

Seismoacoustic detections in Antarctica from the I27DE infrasound and Watzmann seismic array are most likely due to cracking and breaking of the ice shelf west of Neumayer station (fig a). A bulletin for 13 years of high frequency (>0.7 Hz) infrasound data (fig b) clearly identifies these signatures as the dominant source of I27DE detections. A comparison for one selected event (seismic: fig c, infrasonic: fig d) indicates that these acoustic “ice quake” signatures are also observed by nearby seismometers.



Conclusions and outlook

- **I26DE and GERES detections** from one specified azimuth direction (279°) are investigated in detail, are associated to **anthropogenic mining activity** in a gravel quarry and are representative for a multitude of anthropogenic sources around the I26DE/GERES seismoacoustic array.

  Outlook: A precise classification of the seismic and the infrasonic surroundings of I26DE/GERES will improve future analysis of specific events due to the opportunity to exclude known seismoacoustic sources and ambient noise signatures in advance.

- **IGADE and GRSN detections** from offshore seismoacoustic sources in the Baltic Sea can be associated to **anthropogenic marine activity.** Source location using both technologies identifies most of the sources within military areas for marine training and for ammunition deposition and destruction. Histograms of the daytime and weekday of the source occurrence associate most of the signatures to the hours between 9 and 15 UTC and the weekdays between Monday and Thursday, which clearly indicates the sources to be man-made.

  Outlook: Detection and localization of seismoacoustic sources (especially -but not exclusively- the given offshore events) is often difficult using only one technology and a sparse station coverage. The combination of seismic and infrasonic analyses could improve detection and localization capability. Furthermore, this study supports an improved understanding of the considered propagation media ground, air and in this case also water, providing a link to future hydroacoustic studies as well.

- **I27DE and VNA detections** from westerly directions are identified as the dominant sources in I27DE high frequency infrasound bulletins and are also observed at nearby seismometers with either a seismic or an acoustic signature. They can be associated to the **so called “ice quakes”**, when parts of the Antarctic coastal glacier crack and break from the ice shelf and hit the Ocean.

  Outlook: A systematic seismoacoustic analysis of ice quakes will improve the understanding of the mechanisms of signal generation and propagation and allow getting new insights in their directional, seasonal and climatological variation, e.g. for a better characterization of atmospheric dynamics.

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