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6.1 Some aspects of regional array processing at NORSAR

Introduction

NORSAR has for a number of years carried out processing and analysis of seismic events in the European Arctic, using the regional array network in Fennoscandia and NW Russia. In this paper we describe some aspects and potential improvements of this processing, with emphasis on the Novaya Zemlya region.

The regional processing system at the NORSAR Data Center is illustrated in Figure 6.1.1 and comprises the following steps:

- Automatic single array processing, using a suite of bandpass filters in parallel and a beam deployment that covers both P and S type phases for the region of interest.
- An STA/LTA detector applied independently to each beam, with broadband f-k analysis for each detected phase in order to estimate azimuth and phase velocity.
- Single-array phase association for initial location of seismic events, and also for the purpose of chaining together phases belonging to the same event, so as to prepare for the subsequent multiarray processing.
- Multi-array event detection, using the Generalized Beamforming (GBF) approach (Ringdal and Kværna, 1989) to associate phases from all stations in the regional network and thereby provide automatic network locations for events in all of northern Europe. The resulting automatic event list is made available on the Internet (www.norsar.no).
- Interactive analysis of selected events, resulting in a reviewed regional seismic bulletin, which includes hypocentral information, magnitudes and selected waveform plots. This reviewed bulletin is also available on the Internet.

Recent enhancements

In previous Semiannual Technical Summaries, we have described a number of enhancements made to the regional processing at NORSAR over the years. For example, Kværna et. al. (1999) have provided an overview of such enhancements as of May 1999. Among the more recent developments after that time, we mention in particular:

- Development of an experimental site-specific GBF algorithm, with application to Lop Nor and Novaya Zemlya (Kværna et. al., 2002a,2003)
- Development of experimental site-specific threshold monitoring technique, with application to Novaya Zemlya (Kværna et. al., 2002b) and Lop Nor, (Lindholm et. al., 2002)
- Automatic optimized single-array detection and location, with application to selected mining sites in the Kola Peninsula (Gibbons et. al., 2003). This project is in an initial phase.
- Improved detector recipes and detection algoritm for the ARCES array (Schweitzer, 2003).

Experience over the past several years has demonstrated that the automated event list generated by the GBF procedure is nearly “complete”, in the sense that it provides an exhaustive search of all possible detected phase combinations that could correspond to real events. The reviewed bulletin is more selective, since our current resources do not allow a complete analysis of all real seismic events that are associated through the automatic algorithms. An important topic of current research is to develop methods to enable the analyst to easily select events from areas of particular interest, and focus on these events in the interactive analysis.

Network processing

The initial grid system for GBF processing at NORSAR is shown in Figure 6.1.2, which also includes the locations of the small-aperture arrays available to the regional processing. This fig-Figure 6.3 illustrates a finer “beampacking” grid which is used to refine the locations provided by the initial GBF grid. Currently, the five arrays ARCES, SPITS, HFS, APA and FINES are used for routine regional processing at NORSAR.

The initial grid GBF system provides a number of possible event locations. For each grid point, the detection logs of the different arrays are searched for signals matching the predicted travel time, azimuth and slowness of phases originating at the grid point. When a given number of matching phases are found, initial event hypotheses are formed. A denser grid system (the beampacking grid) is then constructed around the grid point providing the largest number of matching phases, and the data are reprocessed for a shorter time interval around the initial origin time.

The basis for the processing is the detection logs from the individual arrays. These logs can be quite extensive, with the number of phase detections ranging from several hundred to more than one thousand per day. When these detection logs are processed by the GBF algorithm, the result is a list of typically about 200 candidate events for each day. Only a small subset of these events are analyzed interactively.

Monitoring the Novaya Zemlya region

The philosophy behind the automatic process at NORSAR is to ensure, as far as possible, that no real detectable event is lost. The penalty is that a number of false associations are generated. This problem is most significant for regions at large distances from the arrays, such as the Novaya Zemlya region. We describe below some initial steps undertaken to eliminate many of these false associations.

It is well known that the most sensitive arrays for seismic events in the Novaya Zemlya region are ARCES and SPITS. Our initial step to reduce the number of false associations is therefore to require detection by one or both of these two arrays, using a combination of the following criteria:

1. Pn and Sn detections by SPITS
2. Pn and Sn detections by ARCES
3. Pn detections by both SPITS and ARCES

In addition, we have experimented with additional constraints on Pn phase velocities for the two arrays, in order to eliminate obvious teleseismic or near-regional phases. Reasonable constraints,based on observational evidence, are:

- For ARCES: Pn velocity between 8-12 km/s
- For SPITS: Pn velocity between 7-10 km/s

Furthermore, we have considered the effects of constraining the acceptable difference in estimated azimuth for the P and S phase, by removing single-station events that have an azimuth difference (P-S) exceeding 15 degrees.

Table 6.1.1 gives an overview of the number of GBF event candidates located in the region surrounding Novaya Zemlya for the years 2002 and 2003. The geographical limits are 70-78 degrees North, 50-70 degrees East. The counts using the current on-line GBF algorithm as well as the counts requiring detection by ARCES and SPITS, and counts imposing additional constraints are given.

The criteria specified in the table are conservative in the sense that they should not eliminate any potential real seismic events occurring in this region. Nevertheless, we see from the table that the number of event candidates is reduced by about 90 per cent when applying the final (strongest) test.

We note that the significant reduction in false detections when imposing the azimuth constraint is due to a too wide azimuth window currently applied in the GBF processing. The GBF algorithm allows phases to be associated with the same event if they deviate less than 30 degrees from the grid point toward which the generalized beam is steered. This implies that P and S phases associated to a given event could (in extreme cases) differ by up to 60 degrees, which is clearly excessive. There is therefore a good argument for adding a more restrictive azimuth test in the second step of the on-line GBF process.

Examples of recent low-magnitude events

Table 6.1.2 lists small events in the Novaya Zemlya region, located outside the test site and detected over the years by the NORSAR regional processing. Recordings of the two most recent events are illustrated in Figures 6.1.4 through 6.1.6. The first two figures show a magnitude 3.0 event on 23 February 2002, as recorded by SPITS and ARCES respectively. In each figure, two filtered (4-8 Hz) array beams are displayed, corresponding to Pn and Sn velocities and directed towards the epicenter. Both arrays have high SNR for the P-phase, and the S-phase is clearly detected, with a particularly good SNR on the S-beams. A typical feature (also seen for other events) is that ARCES has a much stronger S-phase than SPITS. In fact, detection of S-phases using the SPITS array is often problematic, and improvements here is a topic of current research. With the planned refurbishment of SPITS, several 3-component sites will be included in the array, and this should improve the detection potential for S-phases in the future.

The second event (magnitude 2.5) occurred on 8 October 2003, and Figure 6.1.6 shows the SPITS Pn and Sn beams for this event. The waveforms have similar characteristics to those observed for the 23 February 2002 event. This event illustrates the importance of including in the detection criteria single-station detections (P and S phases detected at the same array) as well as events detected at both arrays. In fact, there was no automatic detection of this event at ARCES. However, by inspecting the ARCES waveforms visually, P and S onsets could be found, and were included in the reviewed event location (Table 6.1.2).

Discussion

Although the criteria listed above succeed in reducing the number of false associations significantly, there is still room for considerable improvement. A promising approach is to use fixed-frequency filter bands for the broad-band f-k estimation, as initially suggested by Kværna and Ringdal (1986). In this way, one can hope to obtain more stable azimuth estimates, thereby enabling a much lower tolerance than 15 degrees for the difference in P and S azimuths. We will continue our work on reducing the false alarm rate in the automatic GBF lists, while retaining as many as possible of the real seismic events. Furthermore, the automatic detector algorithms could be further improved, and work towards this end is continuing.

This analysis has reconfirmed our previous estimates of the detection capability of the regional network in northern Europe, indicating that the network is capable of detecting seismic events at Novaya Zemlya down to about magnitude 2.5 (Ringdal, 1997). Our preliminary results on reducing the number of false associations in the GBF process are promising, but a more systematic post-processing algorithm to address this problem needs to be developed.

As an initial step, we have implemented a script to apply the criteria discussed in this paper to the GBF on-line output, so as to produce an abbreviated list of event candidates to be analyzed interactively at NORSAR. This should ensure that future small seismic events in the Novaya Zemlya region will be included in the reviewed regional bulletin, while involving only a modest additional analyst effort.

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Table 6.1.1 GBF event candidates 70-78 deg N, 50-70 deg E

Detection criterion	ARCES Pn velocity	SPITS Pn velocity	Az. diff.	SNR Pn (1 station)	Total 2002	Total 2003	Sum
All GBF	All	All	All	All	683	950	1733
1 or 2 or 3	All	All	All	All	294	382	676
1 or 2 or 3	8-12 km/s	7-10 km/s	All	All	177	211	388
1 or 2 or 3	8-12 km/s	7-10 km/s	<15 deg	All	66	81	147

Table 6.1.2: List of seismic events in or near Novaya Zemlya (1980-2003) located outside the test site

Date/time	Location	m_b	Comment
01.08.86/ 13.56.38	72.945 N, 56.549 E	4.3	Located by Marshall et.al. (1989)
31.12.92/ 09.29.24	73.600 N 55.200 E	2.7	Located by NORSAR
23.02.95/ 21.50.00	71.856 N, 55.685 E	2.5	Located by NORSAR
13.06.95/ 19.22.38	75.170 N, 56.740 E	3.5	Located by NORSAR
13.01.96/ 17.17.23	75.240 N, 56.660 E	2.4	Approximately co-located with preceding event
16.08.97/ 02.11.00	72.510 N, 57.550 E	3.5	Located by NORSAR
16.08.97/ 06.19.10	72.510 N, 57.550 E	2.6	Co-located with preceding event
23.02.02/ 01.21.14	74.047 N, 57.671 E	3.0	Located by NORSAR
08.10.03/ 23.07.10	75.645N, 63.345E	2.5	Located by NORSAR

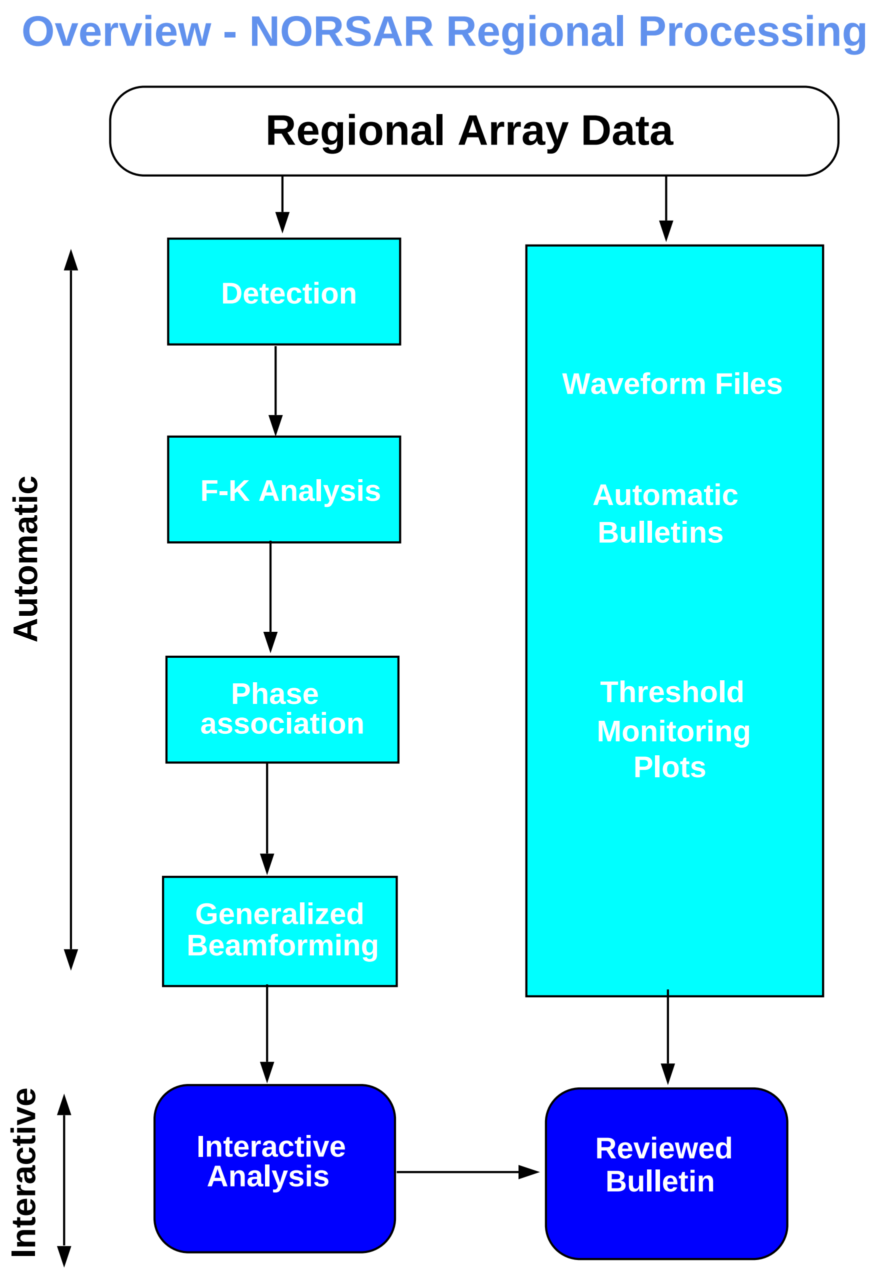

Fig. 6.1.1. Overview of the regional processing at NORSAR.

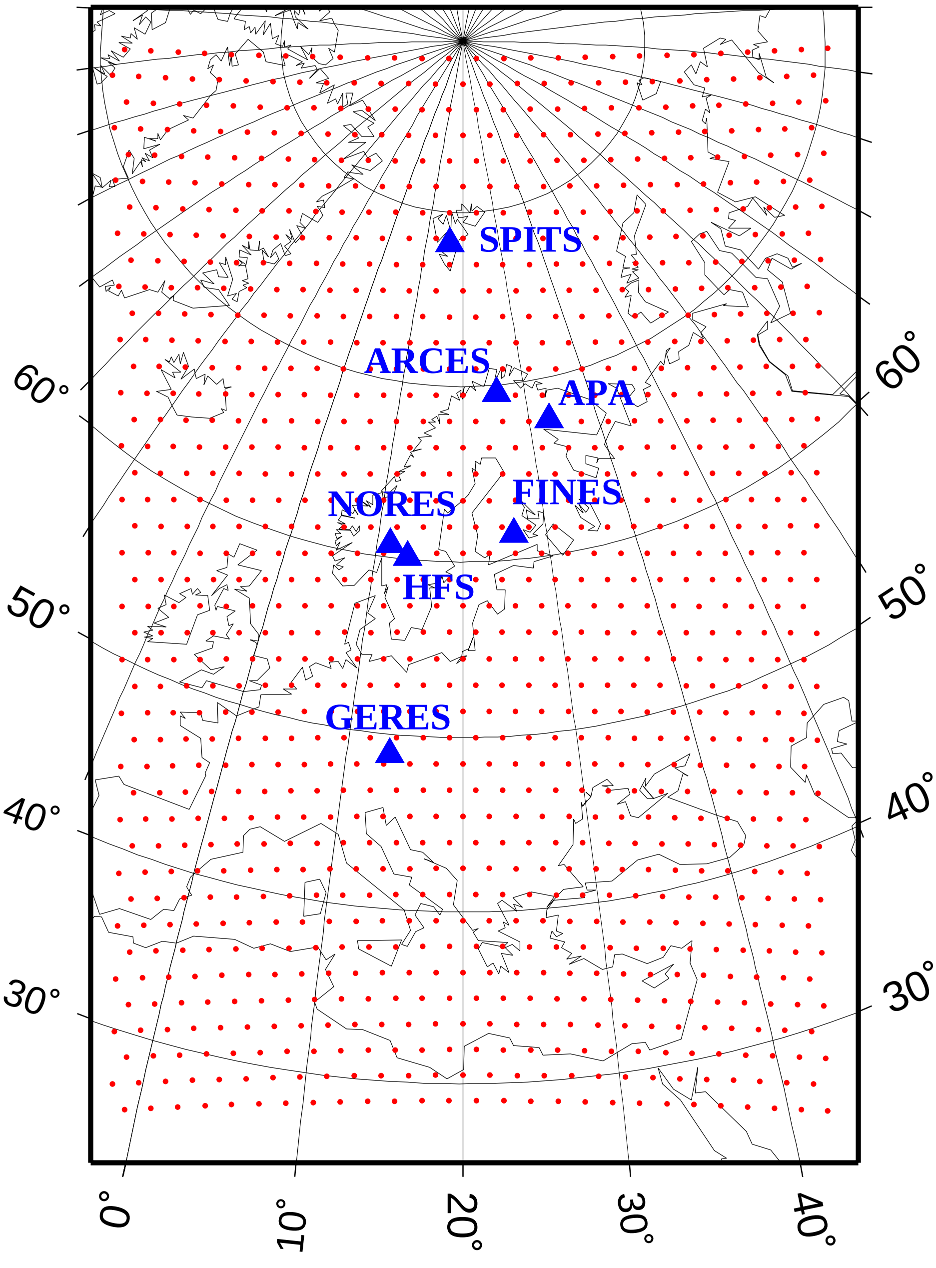

Fig. 6.1.2. *This map shows the array stations in the regional network and the initial grid system used by the GBF. Currently, the stations SPITS, ARCES, APA, FINES and HFS are used in the routine NORSAR regional processing. The distance between the grid nodes is 1.5 degrees.*

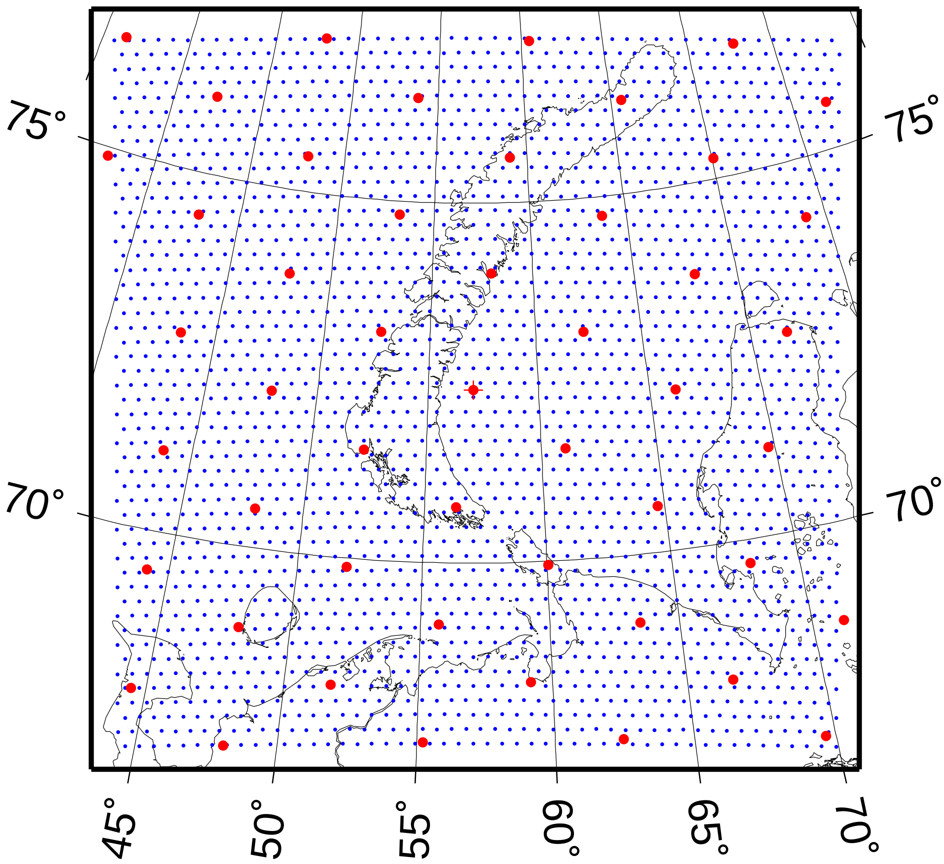

Fig. 6.1.3. *Example of a map of the "beampacking"grid system used by the NORSAR GBF, in this case constructed around an initial event location in the Kara Sea. This dense grid is used to refine locations provided by the initial grid (shown here as large dots). The distance between the grid nodes is 0.2 degrees.*

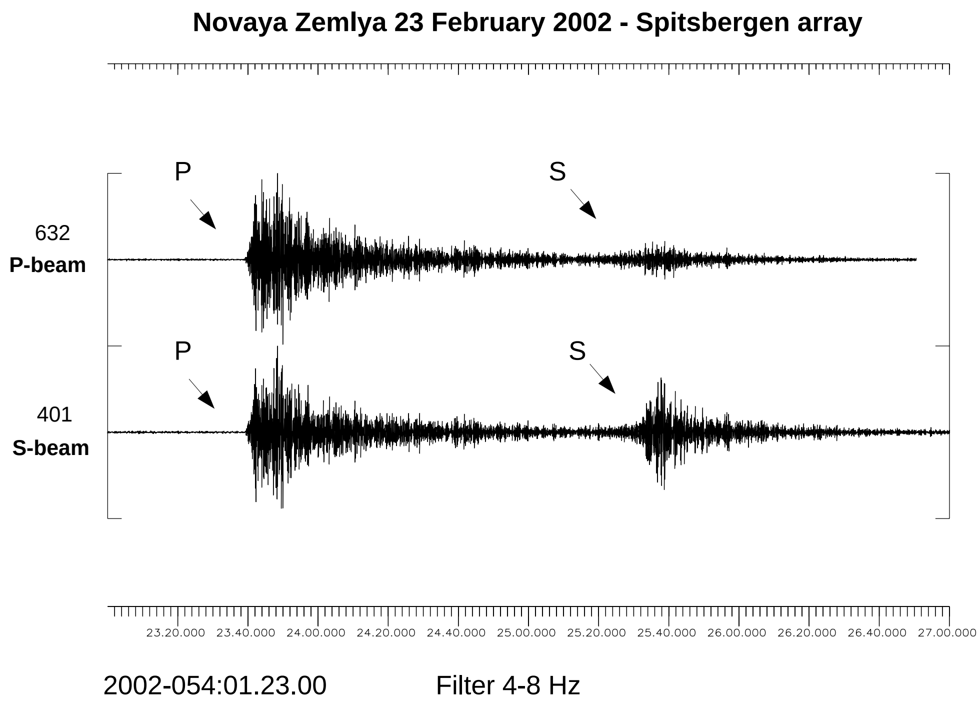

Fig. 6.1.4. Spitsbergen P and S beams for the Novaya Zemlya event on 23 February 2002

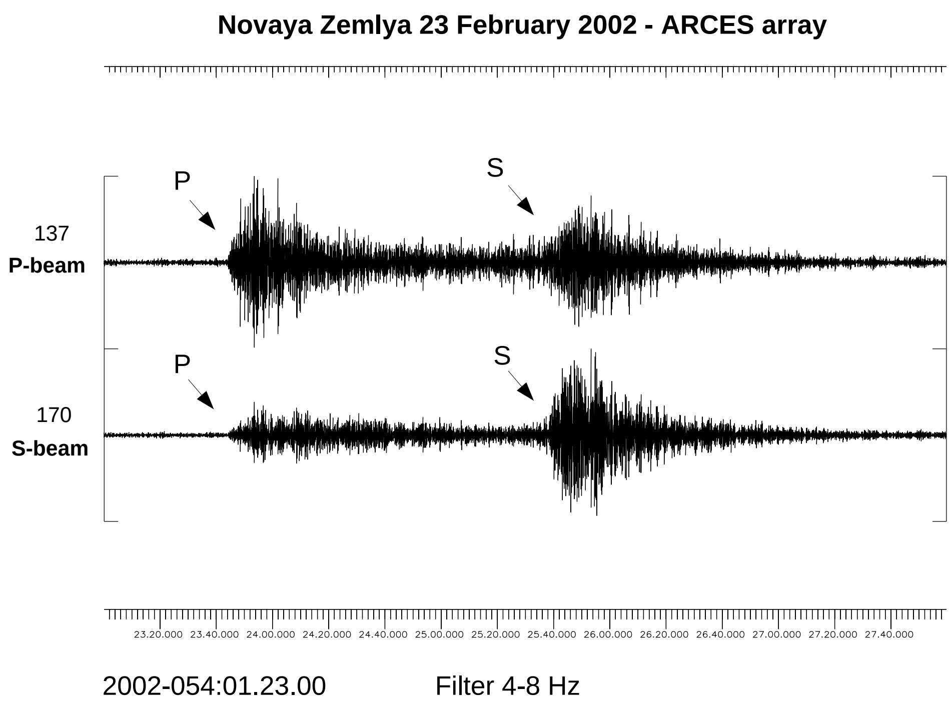

Fig. 6.1.5.*ARCES P and S beams for the Novaya Zemlya event on 23 February 2002*

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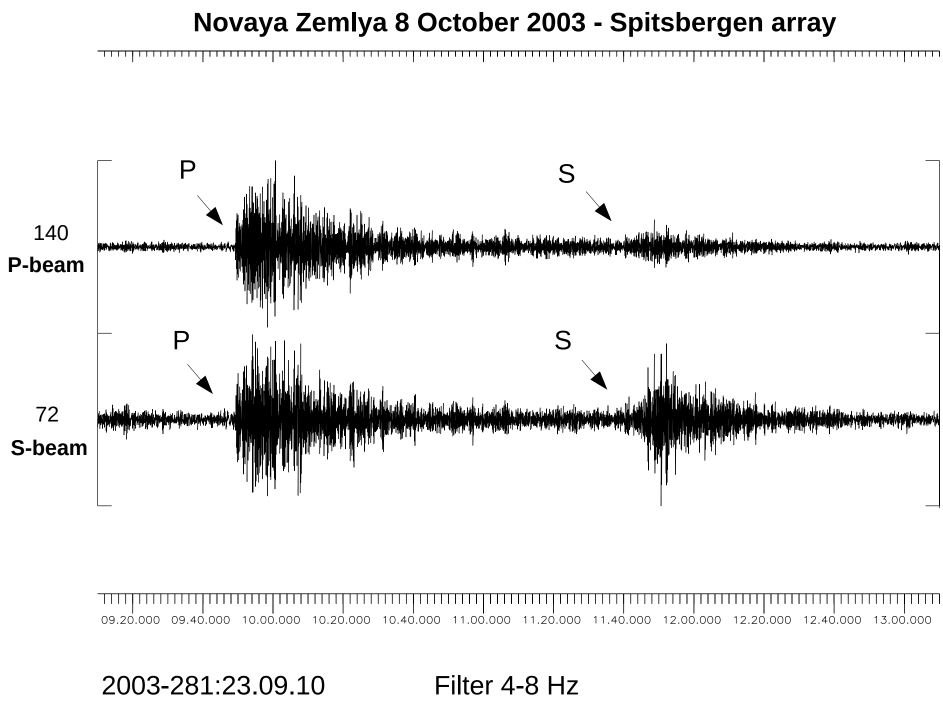

Fig. 6.1.6. *Spitsbergen P and S beams for the Novaya Zemlya event on 8 October 2003*