NORSAR

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# Semiannual Technical Summary

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## 6.3 Seismic events in the Barents Sea at and near the site of the Kursk submarine accident on 12 August 2000

### *Introduction*

On 12 August 2000 signals from two presumed underwater explosions in the Barents Sea were recorded by Norwegian seismic stations. The first of these, at 07.28.27 GMT, was relatively small, measuring 1.5 on the Richter scale. The second explosion, 2 minutes and 15 seconds later, was much more powerful, with a Richter magnitude of 3.5.

It soon became clear that these seismic events were associated with the sinking of the Russian submarine “Kursk”, although the exact way in which this accident occurred has not yet been determined. In any case, it is clear that the second, very large explosion must have fatally damaged the submarine.

NORSAR informed Norwegian authorities after analyzing the recordings, and published selected analysis results on the Internet through NORSAR’s Web page (www.norsar.no). This paper gives a brief overview of the results of the data analysis, and also discusses some recent seismic activity in the Barents Sea near the Kursk site in September and October 2000.

### *Signals recorded on 12 August 2000*

The large underwater explosion on 12 August 2000 in the Barents Sea were recorded on seismic stations in several countries. Among these were all the seismic arrays operated in Norway by the NORSAR institution. Using detection data from several arrays in northern Europe, the explosion was located fully automatically by NORSAR’s Generalized Beamforming process (GBF) (see Fig. 6.3.1) with an estimated location only 14 km from the known position of the submarine. The GBF process is running on-line at NORSAR for the purpose of providing trial epicenters of seismic events in Europe and the European Arctic. Later interactive analysis gave a position that was as close as 5 km from the site of the accident (see Fig. 6.3.2). This high accuracy is due to the travel-time calibration available for the Barents region, as provided by the Fennoscandian/Barents velocity model.

The fact that the large explosion was preceded by a much smaller co-located event was noted by reviewing the GBF automatic output in more detail. It turned out that this smaller event was detected by at the ARCES array in northern Norway. For obvious reasons, the automatic location estimate was less accurate than that of the larger event, but still close enough to the Kursk site to be associated with the accident. The reviewed NORSAR location estimates, together with the true location, are listed in Tables 6.3.1 and 6.3.2.

Fig. 6.3.3 shows the waveforms at several stations for the largest event. A scaled-up plot for ARCES seismometers focusing on the small event is shown in Fig. 6.3.4. In this second figure, it is seen that the first event can be clearly identified (Pn, Pg and Sn phases), whereas the second event completely saturates the plot. A different perspective of the two events is shown in Fig. 6.3.5, which is a plot of estimated wave azimuth as a function of time (vespagram). The similarity of the two events is readily noticed, and the difference in size does not affect this particular figure. We note that we generated similar plots (azimuth and slowness versus time) for the entire 24 hour period of 12 August, in order to try to detect additional explosions in the area. However, we were not able to find any such additional events.

The similarity of the kinematic parameters of the two events can also be seen in Figure 6.3.6, which shows f-k analysis results of the Pn and Sn phases of each event. It is noteworthy that the azimuth bias between the Pn and Sn phases are almost exactly the same for the two events. This confirms previous studies indicating that azimuth calibration of each phase should be done individually to obtain optimum location estimates for a given site.

### *Signals recorded during September-October 2000*

The area in the Barents Sea where the Kursk accident occurred has no known history of significant earthquake activity. During September and October 2000, there were two sequences of seismic events in the area.The circumstances surrounding these events was initially unknown, but on 14 November 2000, the Russian authorities announced that they were small explosions set off using grenades or depth charges, with the stated purpose to protect the Kursk submarine.

Table 6.3.3 lists the origin times, estimated locations and magnitudes of those explosions detected automatically by the NORSAR GBF process. The locations in this table are based on data re-analyzed interactively, and are somewhat more accurate than the automatic results published on the Web. Note that the magnitudes have been adjusted from the NORSAR GBF values to a scale consistemt with the $m_b$ scale currently employed by the Prototype IDC. This means that an average bias of 0.7 magnitude units has been added.

The timing patterns of the two series of explosions are rather similar, with some single explosions and some compressed sequences with explosion intervals of 1-2 minutes. The explosions are all nearly the same size, in fact the small differences in the magnitude estimates are well within the uncertainty that could be caused by  variation of the shot location and depth. Comparing these magnitudes with those of the two explosions associated with the Kursk accident (Table 6.3.1), we note that the magnitude values in Table 6.3.3 are all somewhat larger than for the first (smaller) explosion on 12 August, but significantly smaller than for the second explosion that day.

Figure 6.3.7 shows a comparison of waveforms (ARCES center seismometer) for the first 6 events in the sequence. The data have been filtered in the band 2.5-8 Hz. We note that the waveforms have similar characteristics, although they are not identical. All of the events have clearly visible Pn and Sn phases at the single channel level. Analysis of the other waveforms from the sequence show similar patterns.

### *Concluding remarks*

The recordings by seismic stations in the IMS network  form the only publicly available evidence of the explosions associated with the Kursk accident. This information has been important in contributing to the study of the cause of the accident, although no definite conclusions can be drawn from these recordings alone.

The recording of numerous small explosions during September and October 2000 confirm the value of the IMS stations in monitoring seismic activity in the Barents Sea at very low magnitude levels. These explosions, although their magnitudes were only about 2.0 on the Richter scale, were well recorded by the ARCES array (distance 500 km), but also the FINES, SPITS and NORES arrays also detected several of the events. In addition, the Apatity array station in the Kola Peninsula (not an IMS station) provided useful recordings.

We plan to follow up these analyses by applying experimental site-specific Threshold Monitoring of the Kursk site, using the regional arrays in Fennoscandia and Spitsbergen. We expect that this technique will enable us to readily detect events in this region, and may enable us to detect additional small explosions that may have been undetected by the on-line process. In addition, such a monitoring should enable easy separation of multiple events close in time. This topic will be reported at a later date.

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The tables below show seismic events detected and located by NORSAR during August - October 2000 in the region surrounding the site of the submarine “Kursk” accident in the Barents Sea. Table 6.3.1 lists the two presumed explosions directly associated with the accident. Table 6.3.3 shows a sequence of seismic events occurring during September and October.

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**Table 6.3.1. NORSAR’s locations of seismic events in the Barents Sea 12 Aug 2000**

| Date | Time (GMT) | Latitude (N) | Longitude (E) | Richter magnitude |
|---|---|---|---|---|
| 12.08.2000 | 07.28.27.0 | 69.70 | 36.80 | 1.50 |
| 12.08.2000 | 07.30.41.7 | 69.57 | 37.64 | 3.50 |

**Table 6.3.2:**

| | | |
|---|---|---|
| Location of the Kursk accident | 69.62 | 37.58 |

**Table 6.3.3. NORSAR's locations of seismic events in the Barents Sea Sep-Oct 2000**

| Date | Time (GMT) | Latitude (N) | Longitude (E) | Richter magnitude |
|---|---|---|---|---|
| 22.09.2000 | 17.25.17.8 | 69.59 | 37.08 | 2.15 |
| 23.09.2000 | 06.01.08.0 | 69.58 | 37.01 | 2.26 |
| 23.09.2000 | 12.08.28.0 | 69.44 | 36.88 | 2.08 |
| 23.09.2000 | 12.10.22.0 | 69.59 | 37.48 | 2.16 |
| 24.09.2000 | 06.02.57.0 | 69.41 | 36.87 | 2.23 |
| 24.09.2000 | 08.50.37.9 | 69.74 | 37.00 | 1.94 |
| 27.09.2000 | 04.58.55.0 | 69.70 | 37.90 | 1.89 |
| 27.09.2000 | 05.00.54.8 | 69.73 | 37.79 | 1.96 |
| 27.09.2000 | 05.27.31.9 | 69.69 | 37.32 | 1.88 |
| 27.09.2000 | 05.54.46.3 | 69.75 | 37.13 | 1.95 |
| 27.09.2000 | 17.55.41.2 | 69.68 | 37.27 | 2.24 |
| 12.10.2000 | 06.41.24.2 | 69.74 | 37.23 | 2.14 |
| 12.10.2000 | 16.05.22.4 | 69.78 | 36.89 | 2.16 |
| 12.10.2000 | 16.07.34.5 | 69.64 | 37.14 | 2.08 |
| 13.10.2000 | 12.00.07.4 | 69.61 | 37.23 | 2.22 |
| 14.10.2000 | 04.31.00.2 | 69.58 | 37.29 | 2.21 |
| 14.10.2000 | 04.32.50.9 | 69.56 | 37.00 | 2.20 |
| 14.10.2000 | 04.36.29.8 | 69.64 | 36.97 | 2.16 |
| 17.10.2000 | 02.34.41.8 | 69.75 | 37.43 | 2.15 |
| 17.10.2000 | 02.35.23.2 | 69.61 | 37.82 | 2.10 |
| 17.10.2000 | 02.36.15.4 | 69.67 | 37.27 | 2.10 |
| 17.10.2000 | 02.38.32.4 | 69.64 | 37.24 | 2.06 |
| 17.10.2000 | 07.05.05.7 | 69.56 | 37.34 | 2.17 |
| 17.10.2000 | 07.05.54.8 | 69.68 | 36.95 | 2.20 |
| 17.10.2000 | 19.38.30.1 | 69.66 | 37.15 | 2.24 |
| 17.10.2000 | 19.39.28.3 | 69.59 | 37.01 | 2.20 |
| 18.10.2000 | 06.16.38.1 | 69.84 | 37.03 | 2.05 |

**Table 6.3.3. NORSAR's locations of seismic events in the Barents Sea Sep-Oct 2000**

| Date | Time (GMT) | Latitude (N) | Longitude (E) | Richter magnitude |
|---|---|---|---|---|
| 18.10.2000 | 06.17.25.6 | 69.74 | 37.11 | 2.04 |
| 18.10.2000 | 06.18.29.7 | 69.80 | 37.04 | 2.00 |
| 18.10.2000 | 09.35.20.8 | 69.74 | 37.45 | 2.14 |
| 18.10.2000 | 09.36.23.6 | 69.67 | 37.25 | 2.18 |
| 18.10.2000 | 09.54.45.2 | 69.70 | 37.61 | 2.03 |
| 18.10.2000 | 10.20.31.6 | 69.55 | 37.43 | 2.22 |
| 18.10.2000 | 10.22.12.0 | 69.63 | 37.17 | 2.03 |
| 18.10.2000 | 10.31.28.5 | 69.64 | 37.21 | 2.03 |
| 18.10.2000 | 10.34.20.1 | 69.68 | 37.07 | 2.00 |
| 19.10.2000 | 12.59.43.0 | 69.46 | 36.93 | 2.08 |

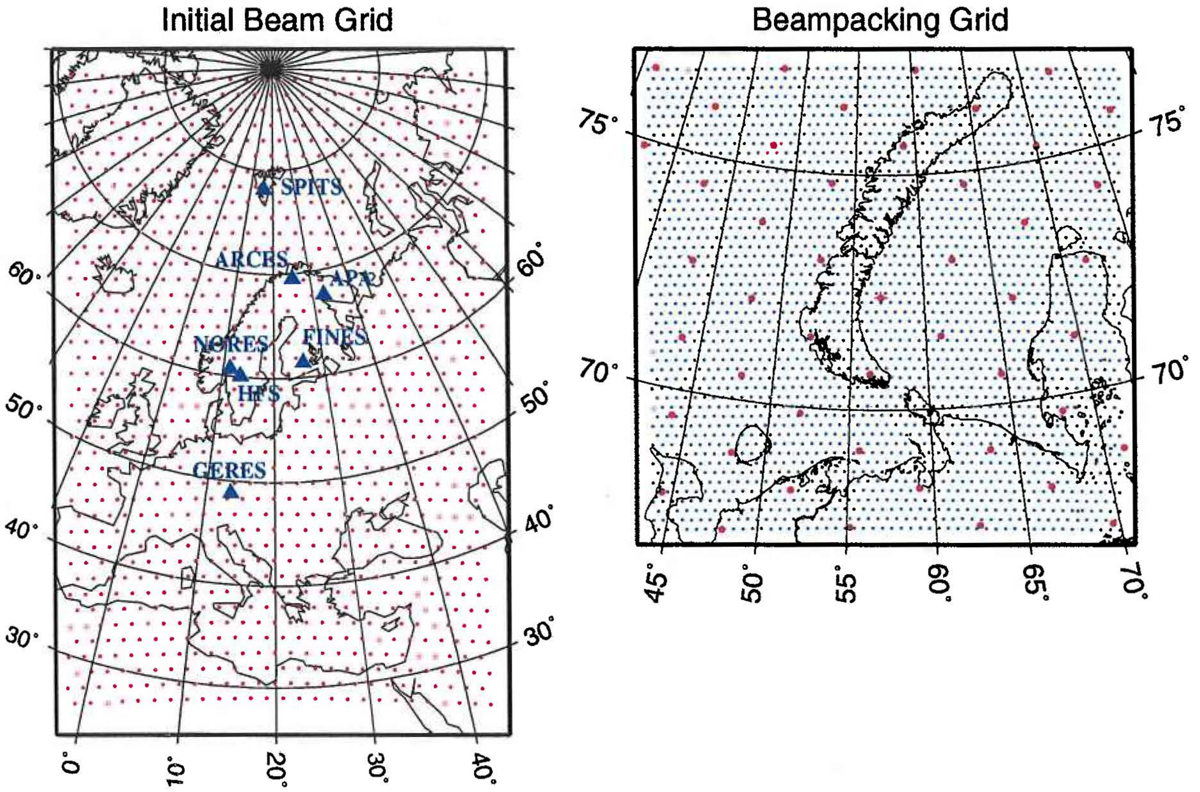



*Fig. 6.3.1. Map showing the location of the seismic arrays used by NORSAR for the automatic multi-array phase association and location algorithm (Generalized Beamforming - GBF). The initial grid system used as aiming points is indicated on the left part of the figure. The right part shows a denser grid (in this example covering the Novaya Zemlya region) which is used in a second pass of the algorithm to refine the location estimates.*

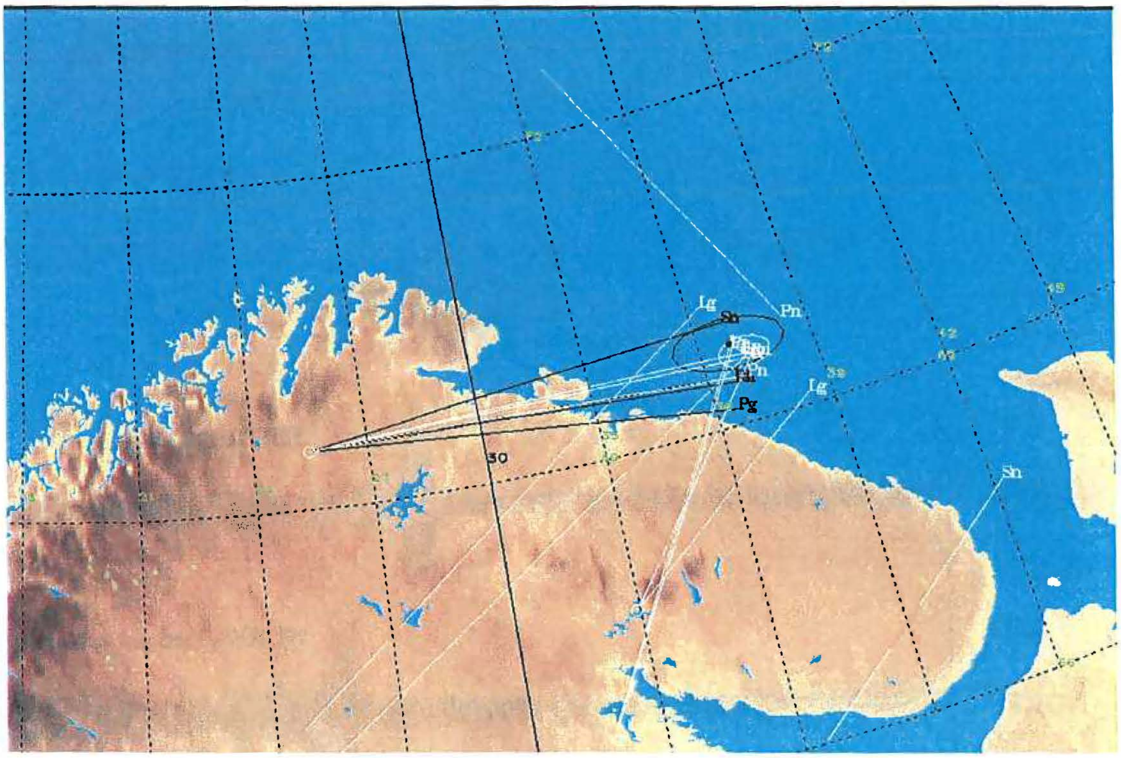



*Fig. 6.3.2. Estimated location of the two seismic events in the Barents Sea on 12 August 2000. The white ellipse shows the 90% confidence area for locating the largest event, while the black ellipse corresponds to the smallest event. Estimated azimuths of phases recorded at individual stations are also shown.*

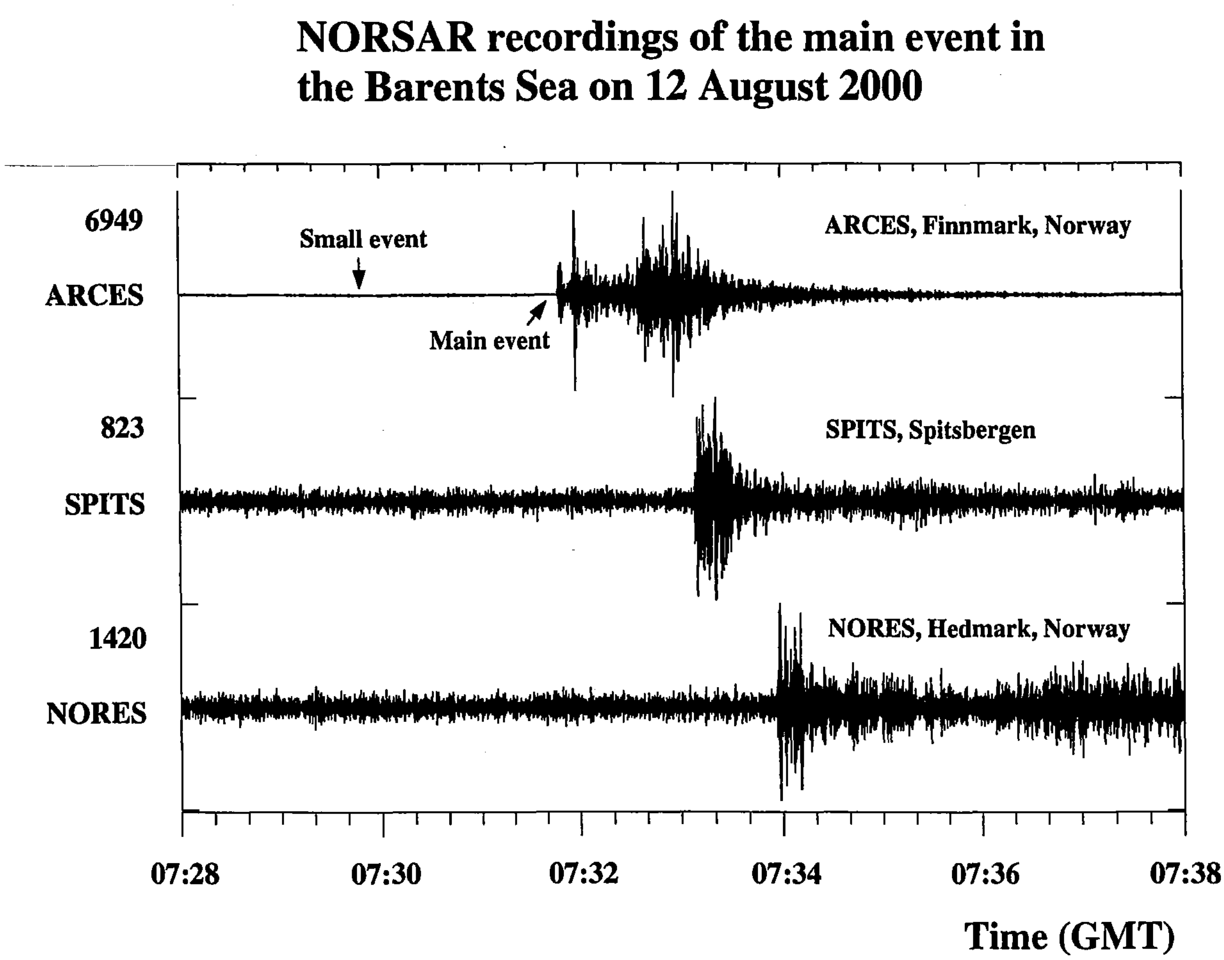



*Fig. 6.3.3. Recordings by Norwegian stations of the two events in the Barents Sea on 12 August 2000. The first event is to small to be discernible on the plot, although it was detected by the ARCES array (see Fig. 6.3.4)*

# Recordings of the two events in the Barents Sea on 12 August 2000 made in Finnmark, northern Norway

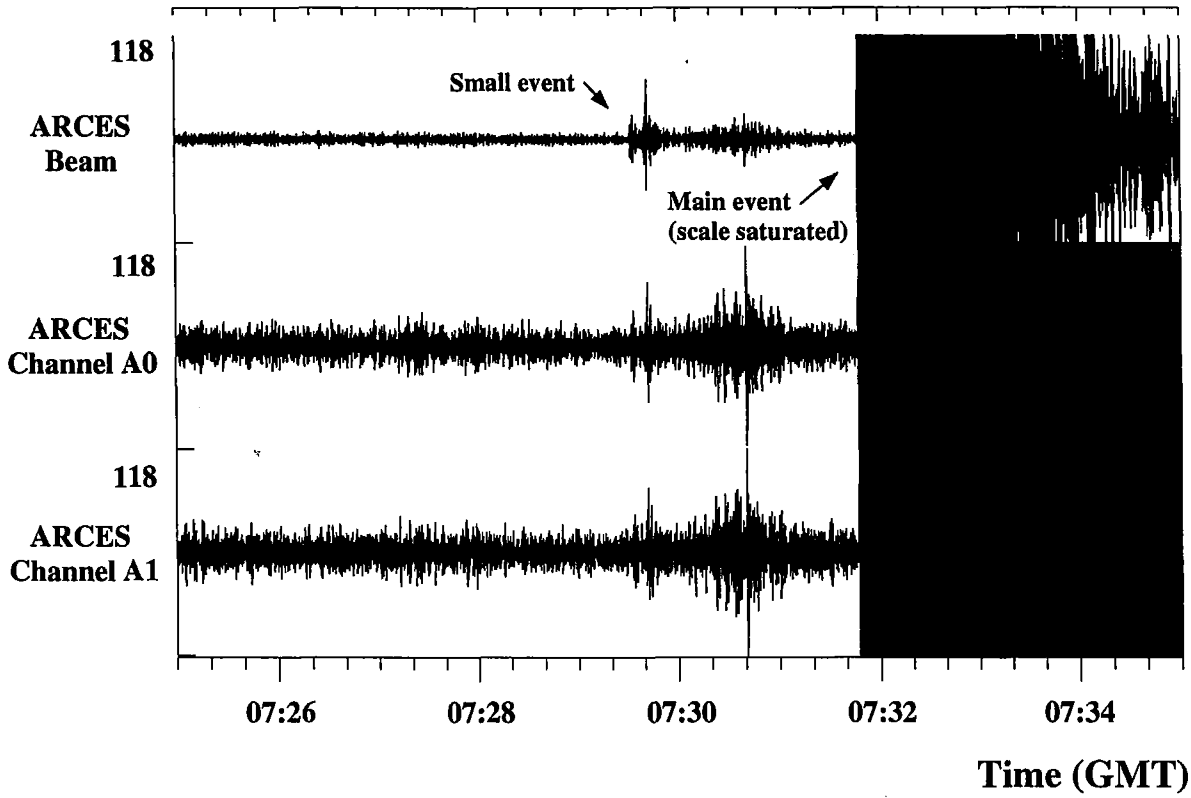



*Fig. 6.3.4. Recordings of the two events in the Barents Sea on 12 August 2000 made at the ARCES array in Finnmark, northern Norway. The plot is scaled to show the smallest event, resulting in the second (larger) event being off-scale.*

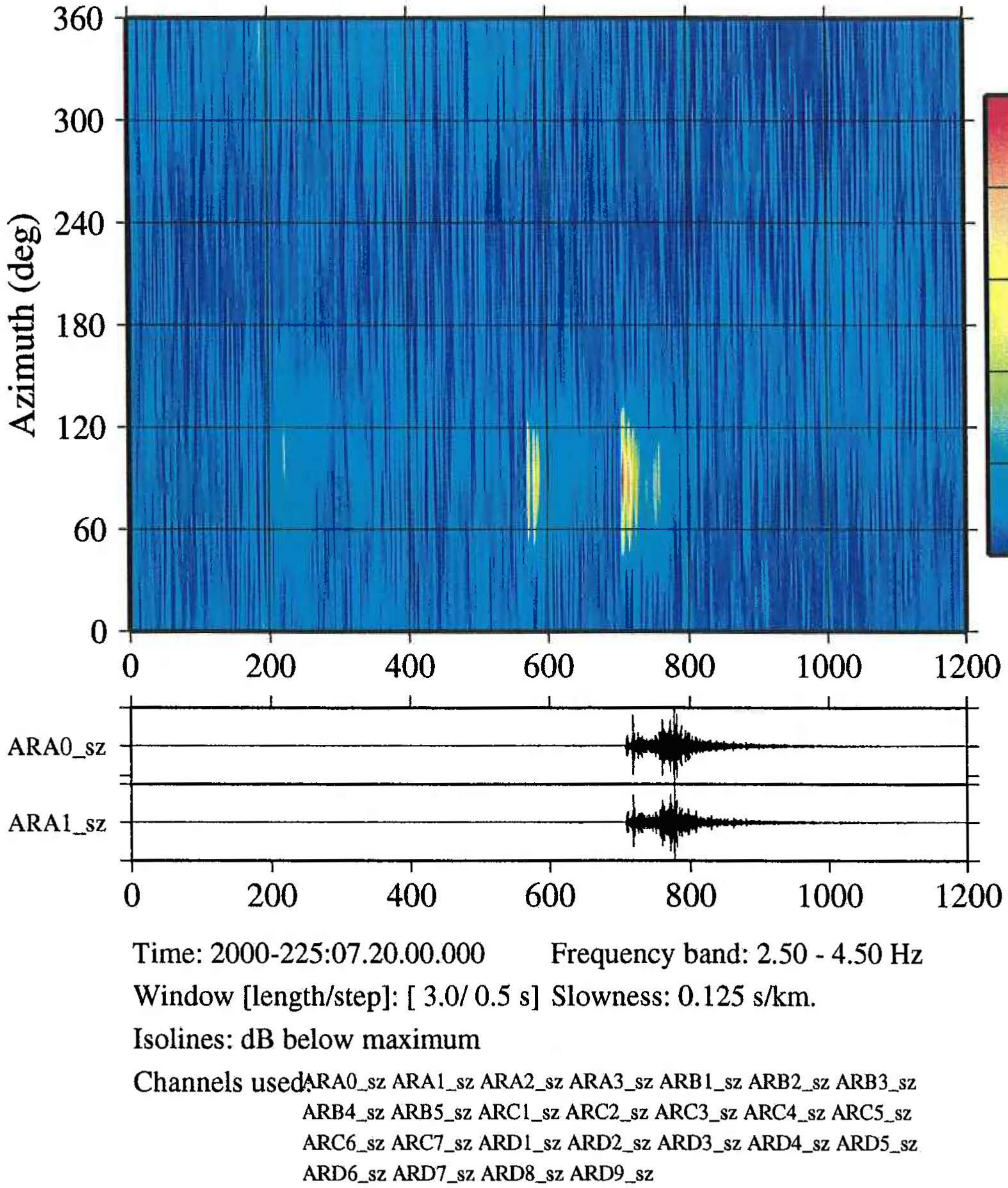
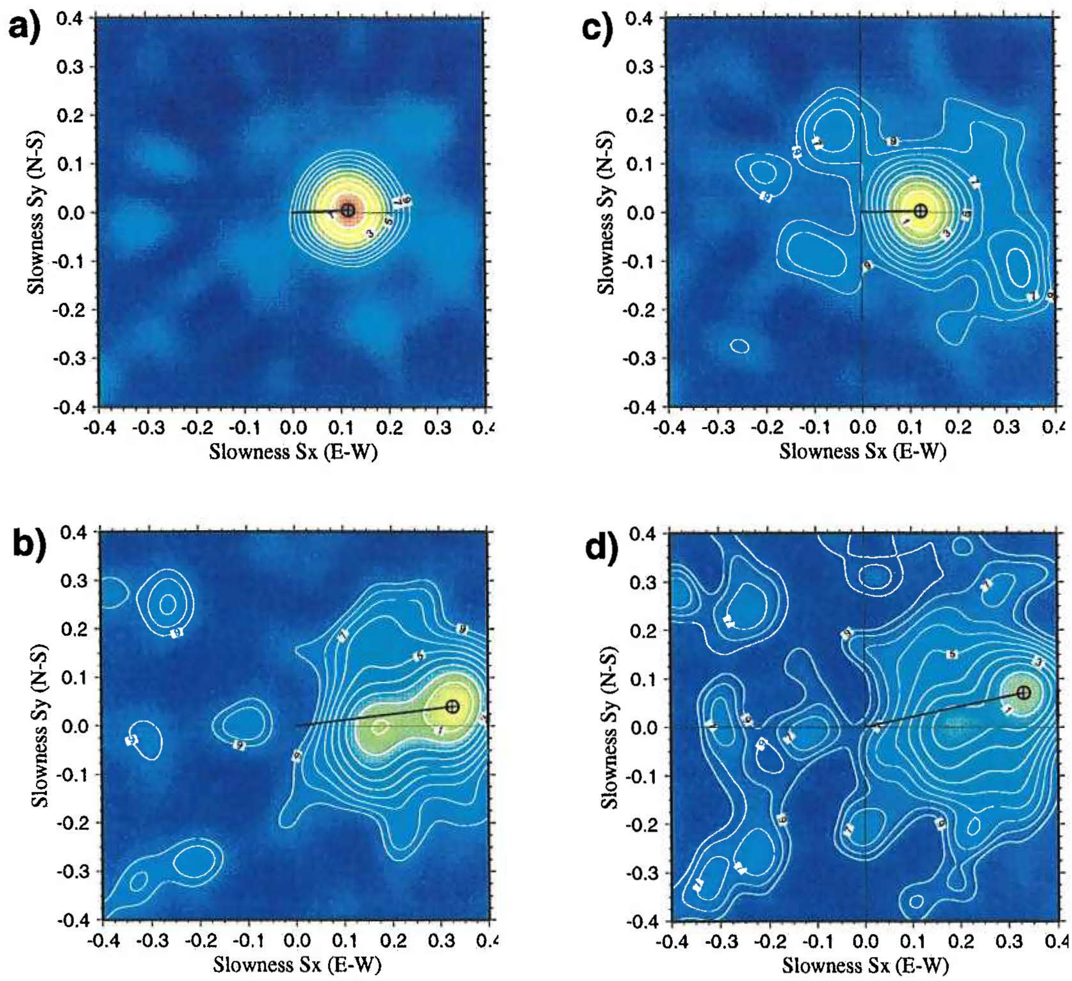



*Fig. 6.3.5. Plot of estimated wave azimuth at ARCES as a function of time during 20 minutes surrounding the events on 12 August.*




*Figu. 6.3.6. Frequency-wavenumber (f-k) plots of the Pn and Sn phases at ARCES for the two events on 12 August 2000. The labels a) and b) correspond to the Pn and Sn phases for the large event, whereas c) and d) correspond to the small event. Note the similarity of the two cases. In particular, both events show the same difference between apparent P-azimuth and apparent S-azimuth.*

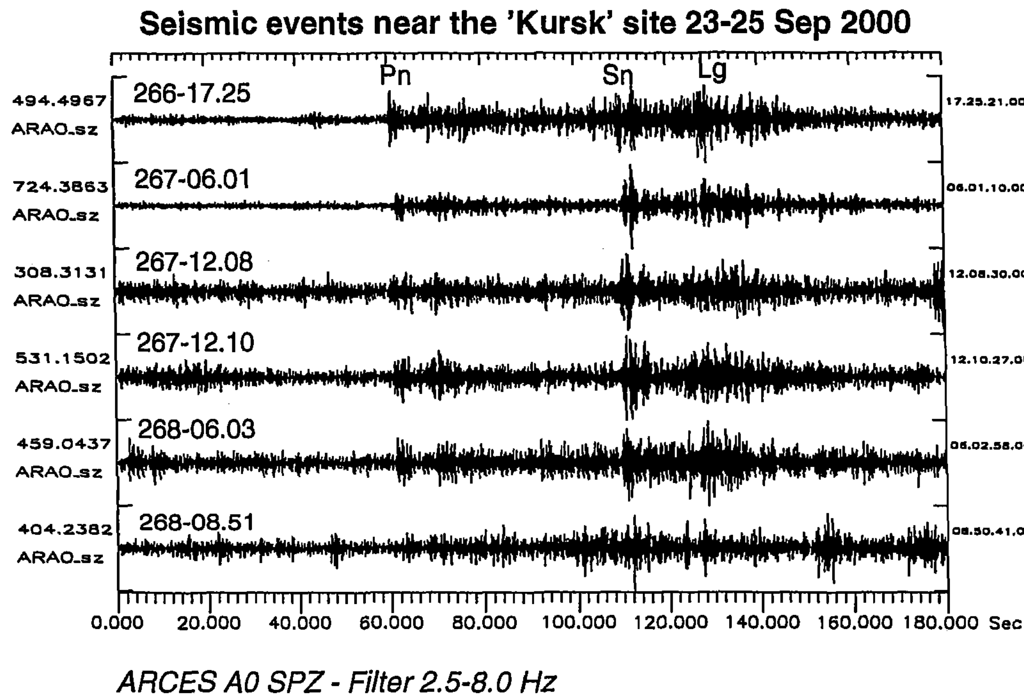



*Fig. 6.3.7. Waveforms for the first 6 events in Table 6.3.3, as recorded on the center seismometer of the ARCES array in Finnmark, northern Norway. The data have been filtered in the band 2.5-8 Hz.*