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7.6 The seismic event on Novaya Zemlya 13 June 1995

Introduction

On 13 June 1995, the GSETT-3 IDC reported a small seismic event (m_b=3.4) near Novaya Zemlya, Russia. The estimated epicenter in the REB was 75.32°N, 54.85°E, placing the event approximately 100 km west of the islands, but the location error ellipse was rather large and an onshore location could not be excluded.

This event is of interest because of its proximity to the Russian nuclear test site, and also because the Novaya Zemlya region is a low-seismicity area as far as natural earthquakes are concerned. Thus, Marshall et al (1989) in their analysis of the 1 August 1986 Novaya Zemlya earthquake, noted that all previous teleseismically detected signals from this region appear to have been resulting from nuclear tests or post-test tectonic activity such as cavity collapses and aftershocks.

This paper presents a detailed analysis of the 13 June 1995 event, with comparisons to previously recorded events at Novaya Zemlya, including past nuclear explosions as well as the well-known New Year's eve event of 31 December 1992, which has previously been extensively analyzed (Ryall, 1993). In our analysis, we have benefited from access to additional data from stations on Russian territory provided through a cooperative agreement with the Kola Regional Seismological Centre, and we have thus been in a position to determine the epicenter and signal characteristics more accurately than was possible at the time the REB was generated.

Data

The 13 June 1995 event was recorded by several stations in Fennoscandia and NW Russia, as shown on Fig. 7.6.1. The most distant stations detecting the event were the arrays NORSAR/NORESS, Hagfors and FINESS, at a distance range of 17-20 degrees, but these stations all had relatively low SNR and no well-defined P-wave onset.

By far the best recordings were obtained at the four regional arrays in the distance range 7-10 degrees (Spitsbergen, ARCESS, Amderma and Apatity). Figs. 7.6.2-7.6.4 show filtered records (4-16 Hz) of one three-component sensor from the arrays Spitsbergen, ARCESS and Amderma, and it is seen that both the Pn and Sn phases are very strong in all three cases. In contrast, we have not been able to observe any Lg phase for this event at Spitsbergen or ARCESS, probably due to the Lg blockage associated with thick sedimentary layers below the Barents Sea as noted in numerous earlier studies. At Amderma, a low frequency Lg phase could be observed (see Fig. 7.6.5), but we have not made use of it in this study.

It should be noted that the ARCESS array experienced a clock problem at the time of this event, so that the absolute time associated with the ARCESS recordings is incorrect. For this reason, ARCESS data could not be retrieved by the IDC for the 13 June 1995 event. We were, however, able to extract the ARCESS data from the disk loop at NORSAR, and we can therefore use these data for waveform comparisons and also for epicentral distance estimation using the relative (Pn-Sn) arrival time difference.

Location of the 13 June 1995 event

For reasons previously explained, the IDC had only a small number of stations available to compute its epicenter solution (SPITS, FINESS, NORESS and HFS), and the large error ellipse of the REB location shown in Fig. 7.6.6 must be seen in this perspective. Using our additional data sources, we have been able to constrain the solution much better, and located the event with high confidence near the coast of the northern Novaya Zemlya islands (also shown in Fig. 7.6.6). In particular, the Amderma data have been essential in constraining the solution. While we did not use ARCESS data in our relocation (because of the timing problem), we note that the relative Pn-Sn times at ARCESS are quite consistent with the solution, and thus provide added confidence. Table 7.6.1 lists the arrival data used in the location calculation.

Fig. 7.6.6 shows, in addition to the 13 June 1995 event, also NORSAR's solution for the 31 December 1992 event, as well as the approximate geographical extent of the Novaya Zemlya nuclear testing grounds. As is well known, the 31 December 1992 event was quite close to the test site, and our error ellipse does not exclude a possible on-site location. We note that analysis of this event by other authors has given a smaller error ellipse in some cases (with no overlap with the test site). However, as appropriately noted by both Ryall (1993) and Israelson (1993), there are many unknown factors in the regional calibration for this area, and arrival times are difficult to compare between large and small events, due to the emergent onset of regional phases. It should also be noted that a key station like Spitsbergen has no recordings for known nuclear explosions that could be used for calibration purposes.

From Fig. 7.6.6, it is clear that the 13 June 1995 event is located well outside the nuclear testing grounds, at a distance of at least 100 km. However, it is close enough to the test site to make a waveform comparison with other Novaya Zemlya events interesting. In particular it would be of interest to see whether or not it might be possible to "screen out" such an event in an automatic screening procedure as envisaged in the CTBT negotiations. While we have not at this stage attempted to develop specific screening criteria, there are some obvious comparisons that could be applied to get an indication of how such a procedure might work. We will briefly address this issue in the following.

Waveform comparisons

We have compared the waveforms of the 13 June 1995 event to those of other seismic events at Novaya Zemlya, using the ARCESS array. The reason for focusing on ARCESS is that this is the only station for which we have high SNR recordings of both the 13 June 1995 event and of previous known nuclear explosions. Fig. 7.6.7 shows, as a representative example, ARCESS data from the C4 sensor filtered in a 4-8 Hz band for four events: 13 June 1995, 31 December 1992, 24 October 1990 and 4 December 1988 (the latter two being confirmed nuclear explosions).

From Fig. 7.6.7 we note first of all the large differences in SNR as indicated by the amplitude scaling in front of each trace. This is of course due to the differences in event size — the two confirmed nuclear explosions being 2-3 magnitude units larger than the other events. The P-to-S ratios are of particular interest. The S phase is relatively much stronger for the two smaller events, although there is some difference also between the two nuclear explosions.

In Fig. 7.6.8, which shows the same sensor filtered in a high-frequency band (8-16 Hz), the difference in P/S ratio between the two nuclear and the two unknown events is even more pronounced. However, it is premature to draw any firm conclusions about the source type from these observations. First of all, the inherent variability in P/S ratio for the same source type is unknown, and the significance of the observed differences in these ratios is therefore not possible to assess. Moreover, source scaling may be a factor in explaining this difference.

We also note from these two figures that the P/S ratios of the 13 June 1995 and the 31 December 1992 events are quite similar in both frequency bands. (The P-S time difference is slightly larger for 13 June 1995 because of a greater station-to-event distance.) Again, however, we cannot confidently state that these two events are of the same source type, but the short period data shown are certainly consistent with such a hypothesis.

Magnitudes

In view of the different P/S ratios shown earlier for the four events, their relative magnitudes, as estimated from ARCESS data, would show a different pattern if we use P-phases or S-phases (or S coda phases) for magnitude estimation purposes. We have chosen to use the P-phase in this study and Fig. 7.6.9 shows the P-beam in the 2-4 Hz filter band at ARCESS for the 4 events discussed above. The resulting magnitude (m_b) values are listed in Table 7.6.2, and our result for the 13 June 1995 event (m_b=3.54) is quite consistent with the IDC estimate.

Our reason for selecting the 2-4 Hz band is that this band is close to the frequencies used at teleseismic distances for m_b computation. In fact, small-aperture arrays in shield areas (such as NORESS) usually have their best teleseismic SNR in this filter band or a band close to it. We note, however, that for events at regional distances, it might sometimes be necessary to choose a higher filter passband, especially for small events with little or no "low frequency" signal energy. This would, because of source-scaling effects, cause a shift towards relatively higher magnitudes for smaller events, when comparing them to larger events with the same filter.

To illustrate this point, we again use the same four P-traces at ARCESS. In Fig. 7.6.10, the P-wave data have been filtered in the 8-16 Hz band, which is one of the best bands for P-detection at ARCESS for Novaya Zemlya events. We have used a single sensor (D4) in order to avoid beamforming loss at these high frequencies. The relative scaling between the largest and smallest of the 4 events has been reduced from 2.92 magnitude units (2-4 Hz band) to 2.37 (8-16 Hz band). Thus the relative shift is about 0.5 m_b units, as is also reflected in the relative m_b values listed in Table 7.6.2. This confirms that calculation of magnitudes at regional distances is a difficult problem, where the frequency range of the recording signal must be given special consideration, and probably compensated for by some empirical formula.

Finally, we have looked at the surface waves for the events analyzed in this paper. Once more, the ARCESS array is the most useful reference system. Figs. 7.6.11 and 7.6.12 show narrow-band filtered broadband recordings (0.04-0.06 Hz or 17-25 seconds) for the ARCESS center sensor for the two events 24 October 1990 and 13 June 1995. The surface waves for the first event are clearly seen, and the M_s is estimated to 3.5 using Marshall and Basham's (1972) formula. The surface waves of the 13 June 1995 event are marginal, but appear to just exceed the background noise. The corresponding M_s for this event would be 2.4, using the same formula.

While the M_s:m_b is an effective discriminant at teleseismic distances, its performance in the regional range is not generally proven (recall that the distance from ARCESS to the two events is 10-11 degrees). The values for 13 June 1995 (m_b=3.5, M_s=2.4) would seem to place this event in an intermediate category between the "expected" earthquake population and explosion population, but an appropriate reference data base is not available for this region. It should also be noted that these single-station magnitudes (in particular the M_s value) have a fair amount of uncertainty. Thus, the M_s:m_b data cannot conclusively be used to identify the 13 June 1995 event, but a reasonable screening criterion based on M_s:m_b would probably point out this event as a candidate for more extensive analysis.

Conclusions

The 13 June 1995 event provides an interesting case study for the Novaya Zemlya region. It highlights the fact that even for this well-calibrated region, where numerous well-recorded underground nuclear explosions have been conducted, it is a difficult process to reliably classify a seismic event of approximate m_b 3 1/2. It is also shown that supplementary data from a national network can provide useful constraints on event location, especially if the azimuthal coverage of the monitoring network is inadequate. It is clear from this study that more research is needed on regional travel-time calibration, regional signal characteristics and application of M_s:m_b at regional distances. In applying the latter criterion, it would be particularly useful to estimate an upper confidence limit on M_s for events with marginal or non-detected surface waves.

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References

Marshall, P.D. & P.W. Basham (1972): Discrimination between earthquakes and underground explosions employing an improve M_s scale. *Geophys. J.R. astr. Soc.*, 28, 431-458.

Marshall, P.D., R.C. Stewart & R.C. Lilwall (1989): The seismic disturbance on 1986 August 1 near Novaya Zemlya: a source of concern? *Geophys. J.*, 98, 565-573.

Israelsson, H. (1993): Estimates of the epicenter uncertainty for a small Novaya Zemlya event Dec 31 1992, Sci. Rep. No. 1, Center for Seismic Studies.

Ryall, A. (1993): The Novaya Zemlya event of 31 December 1992 and seismic identification issues. ARPA Rep., 15th Seismic Research Symposium, 8-10 Sep 1993, Vail, Colorado.

Table 7.6.1: NORSAR's epicentral solution for the 13 June 1995 event at Novaya Zemlya. The depth has been constrained to zero.

Novaya Zemlya, Russia

Date	Time	Latitude Smajor	Longitude Sminor	Az	Depth	Magl
1995/06/13	19:22:40.8	75.17 23.0	56.74 11.1	53	0.0 f	mb 3.4

Sta	Dist (deg)	Phase	Date	Time	TRes	Azim	Def
AMD	5.6	Pn	1995/06/13	19:24:02.4	0.3		T
AMD	5.6	Sn	1995/06/13	19:25:04.0	-1.3		T
SPITS	9.5	Pn	1995/06/13	19:24:54.9	-0.2	98.3	T
SPITS	9.5	Sn	1995/06/13	19:26:38.7	0.0	85.4	T
APA	10.5	Pn	1995/06/13	19:25:10.0	1.2		T
APA	10.5	Sn	1995/06/13	19:27:03.1	0.3		T
FINES	17.0	P	1995/06/13	19:26:38.4	-1.6	30.9	T
NORES	21.3	P	1995/06/13	19:27:27.9	2.1	31.5	T
HFS	21.3	P	1995/06/13	19:27:24.0	-1.7	35.9	T

Table 7.6.2: Magnitudes (m_b and M_s) measured at ARCESS for the four events discussed in the text. The m_b values (2-4 Hz) have been normalized using m_b=5.6 of the 24 October 1990 event as a reference, and the relative effect of choosing two higher frequency bands is also shown.

	ARCESS m_b	Relative m_b		ARCESS M_s
	2-4 Hz	4-8 Hz	8-16 Hz	(20 s)
4 Dec 1988	5.67	+0.07	+0.04	-
24 Oct 1990 (reference)	5.60	0	0	3.5
31 Dec 1992	2.75	+0.39	+0.59	-
13 Jun 1995	3.54	+0.24	+0.28	2.4

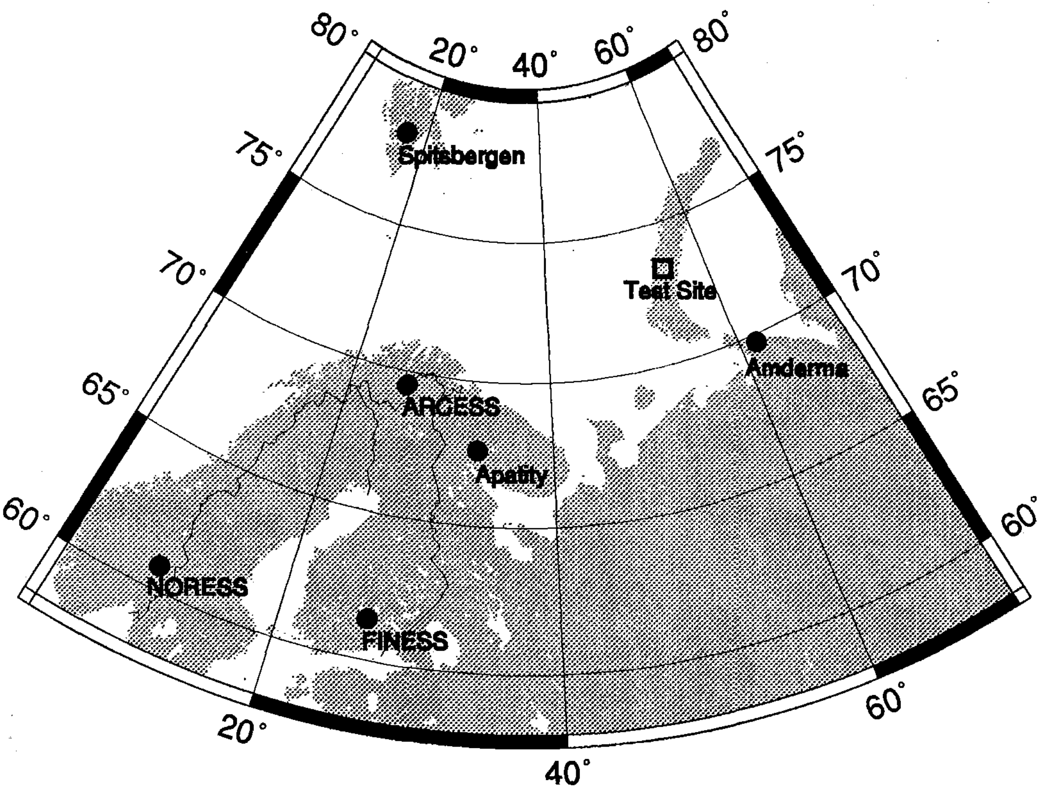

Fig. 7.6.1. Map showing the location of regional seismic arrays in Northern Europe. The location of the Novaya Zemlya nuclear test site is also shown.

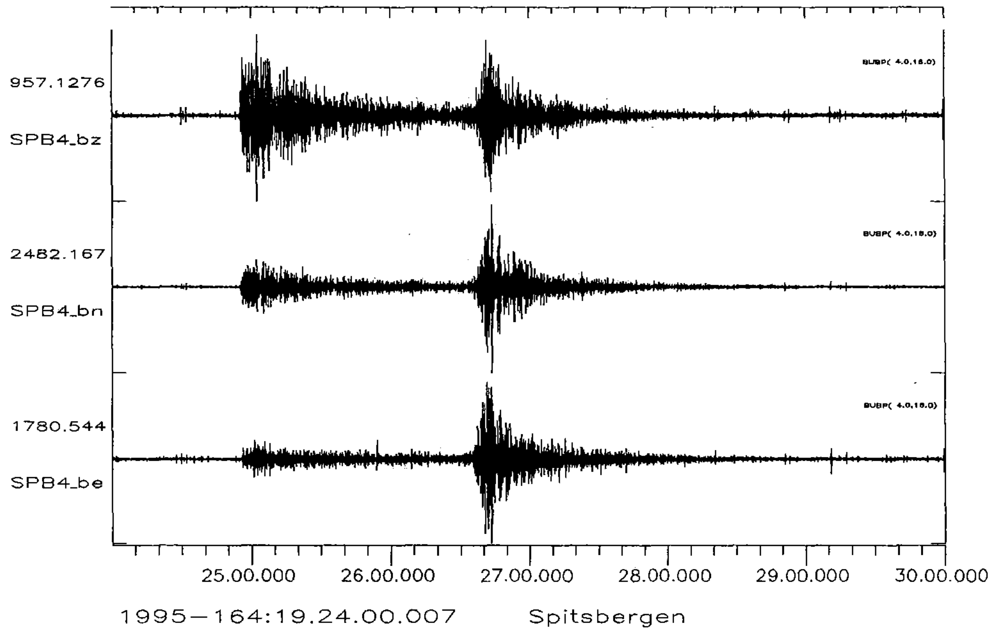

Fig. 7.6.2. Three-component recordings by the Spitsbergen array for the 13 June 1995 event at Novaya Zemlya. The data have been filtered in the 4-16 Hz band. Note the clear P and S phases.

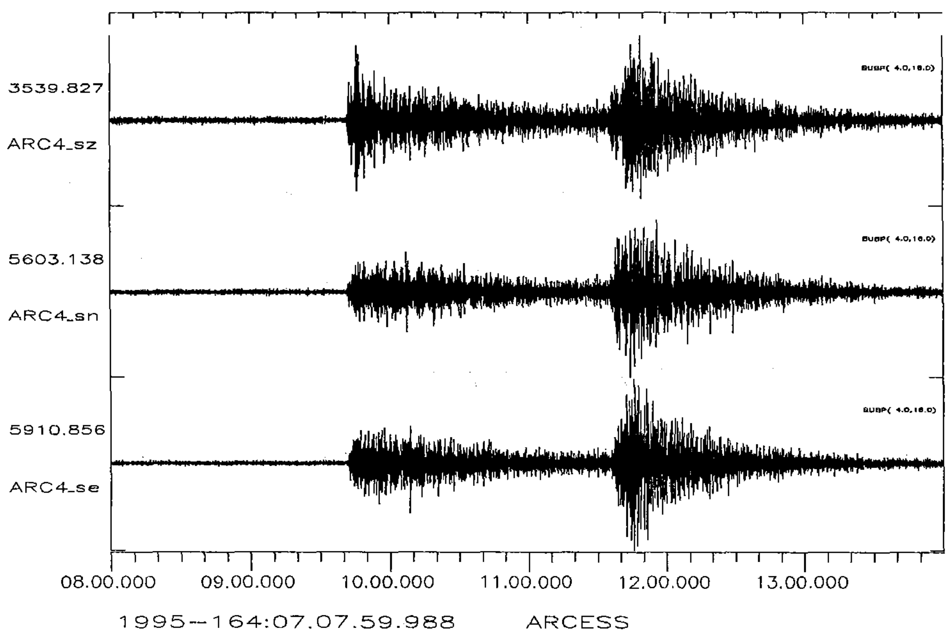

Fig. 7.6.3. Same as Fig. 7.6.2, but showing the three-component recordings at the ARCESS array. Note that the absolute time is incorrect (see text), but the waveform characteristics as well as the relative P-S time can be used in the analysis.

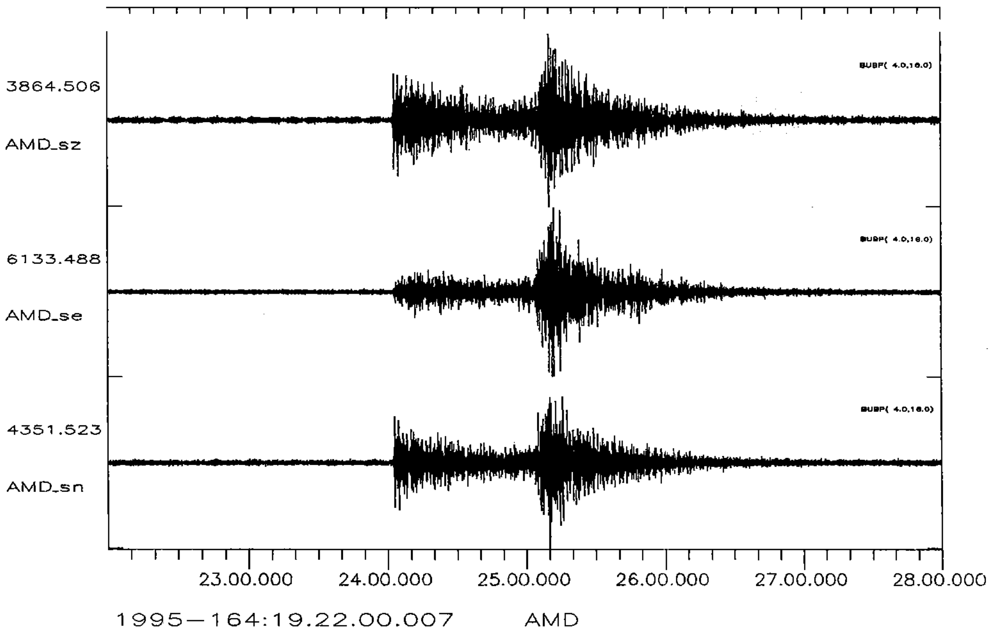

Fig. 7.6.4. Same as Fig. 7.6.2, but showing the three-component recordings at the Amderma array south of Novaya Zemlya.

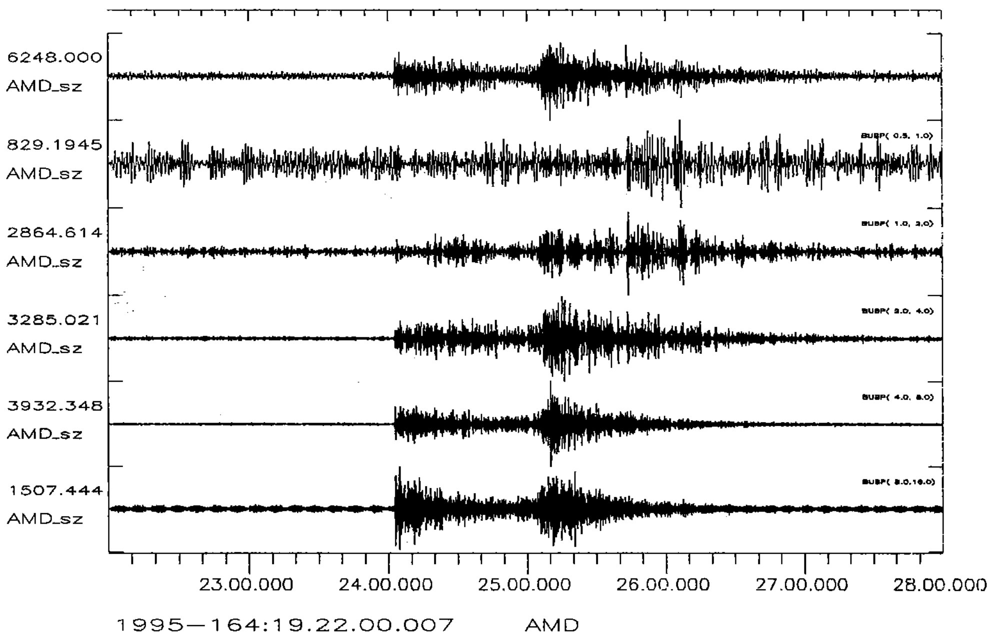

Fig. 7.6.5. Bandpass filtered recordings of the Amderma Center SPZ sensor, in the following bands (top to bottom): Unfiltered, 0.5-1 Hz, 1-2 Hz, 2-4 Hz, 4-8 Hz, 8-16 Hz. Note that the Lg phase is visible in the two lowest frequency filter bands.

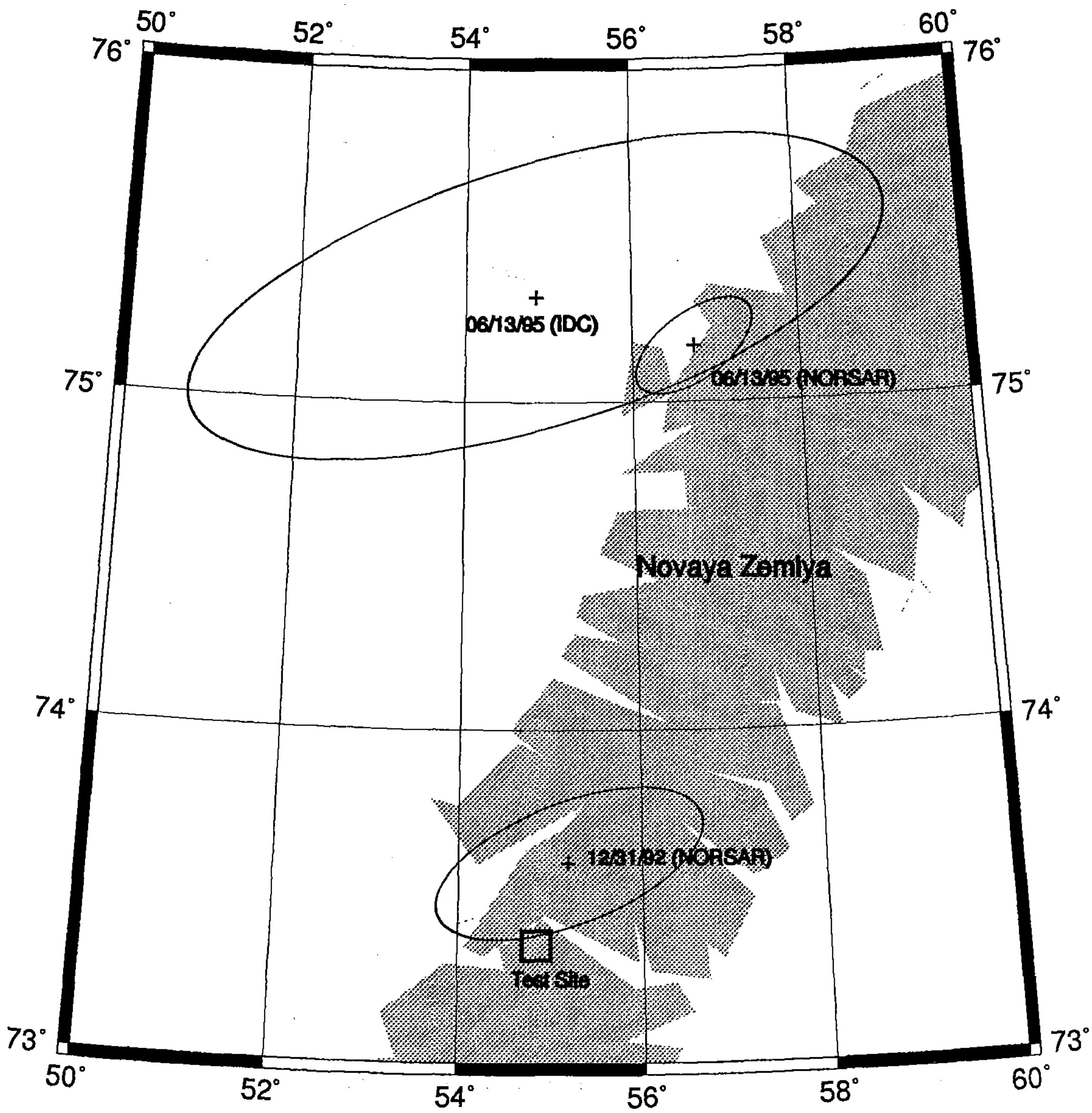

Fig. 7.6.6. Estimated locations and error ellipses by the IDC and NORSAR (this study) for the 13 June 1995 event. The event on 31 December 1992 is shown for comparison (NORSAR solution). The approximate extent of the Novaya Zemlya test site is indicated.

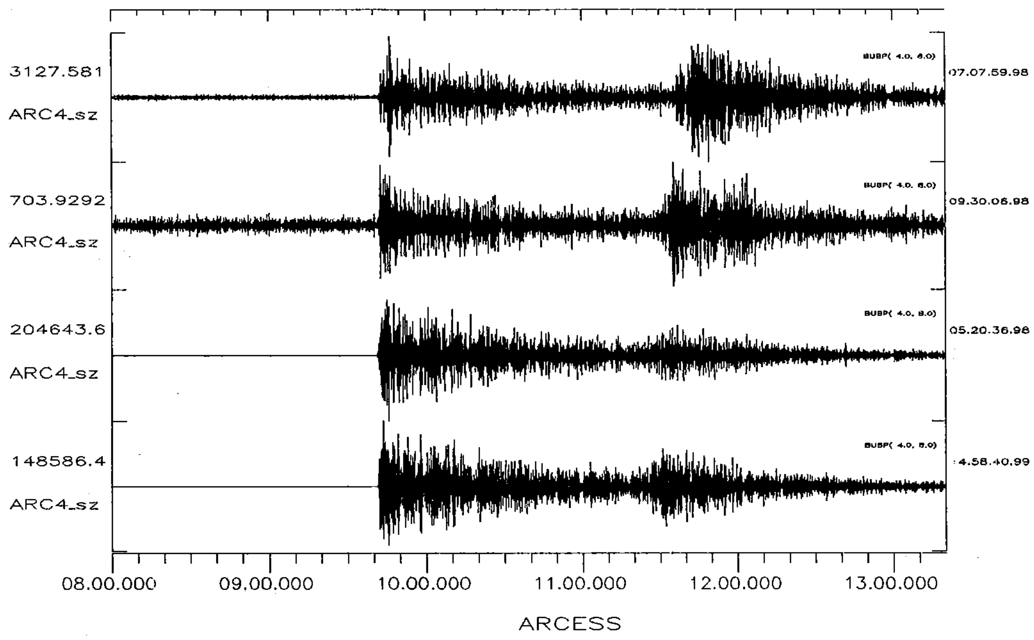

Fig. 7.6.7. Bandpass filtered records (4-8 Hz) of the ARCESS C4 sensor for 4 Novaya Zemlya events: From top: 13 June 1995, 31 December 1992, 4 December 1988 and 24 October 1990. Note the variation in P/S ratio.

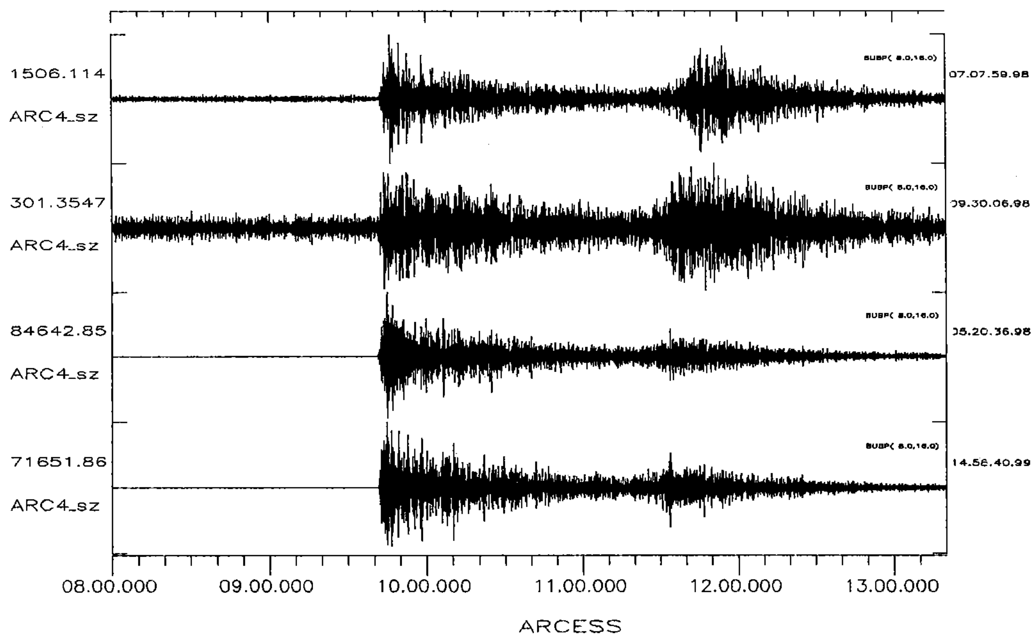

Fig. 7.6.8. Same as Fig. 7.6.7, but for the 8-16 Hz filter band.

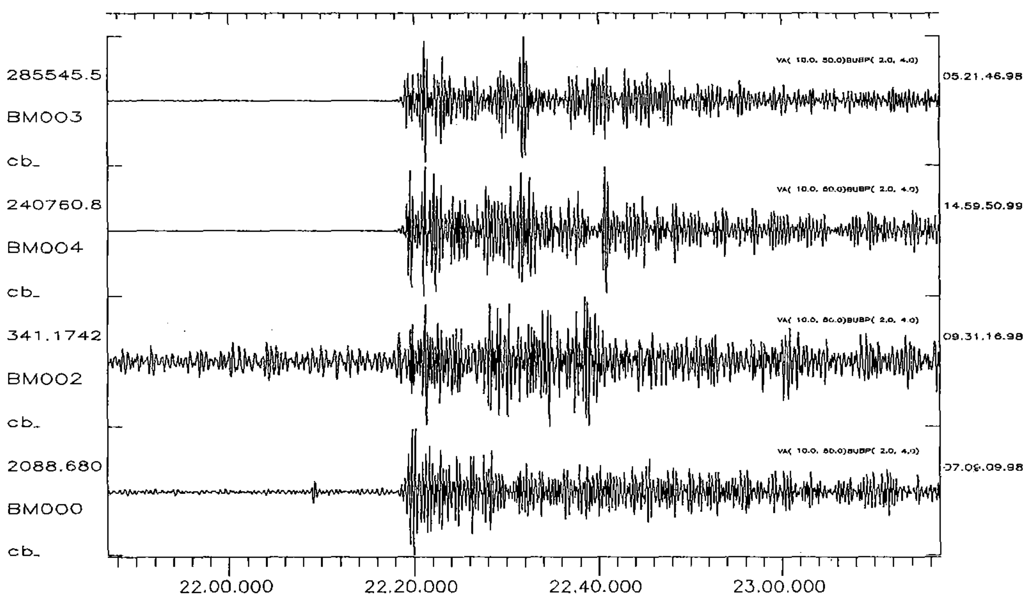

Fig. 7.6.9. P-waves (ARCESS array beam) for four Novaya Zemlya events. From top to bottom: 4 Dec 88, 24 Oct 90, 31 Dec 92 and 13 Jun 95. The data have been filtered in the 2-4 Hz band, and the maximum amplitudes are given to the left of each trace. Note that the complexity of the waveforms makes it difficult to compare onset times.

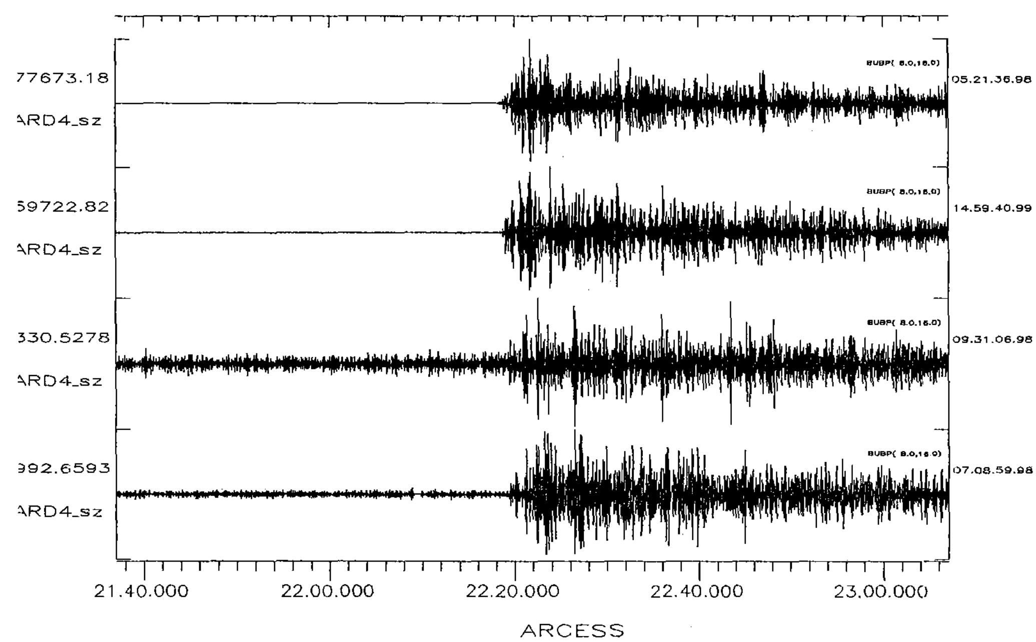

Fig. 7.6.10. Same as Fig. 7.6.9, but for a single sensor (D4) in a high frequency passband (8-16 Hz). Note that the amplitudes of the large and small events show less difference than in Fig. 7.6.9.

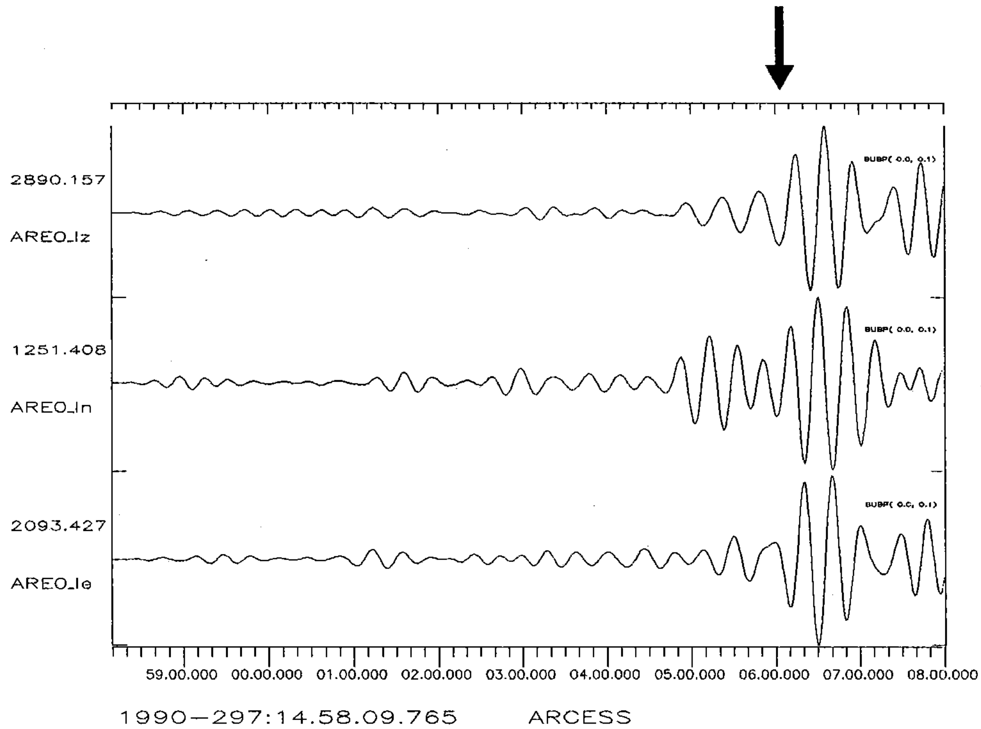

Fig. 7.6.11. Three-component long period ARCESS data for the 24 October 1990 nuclear explosion filtered in a 17-25 sec band. The arrival of the 20-second energy is indicated with an arrow.

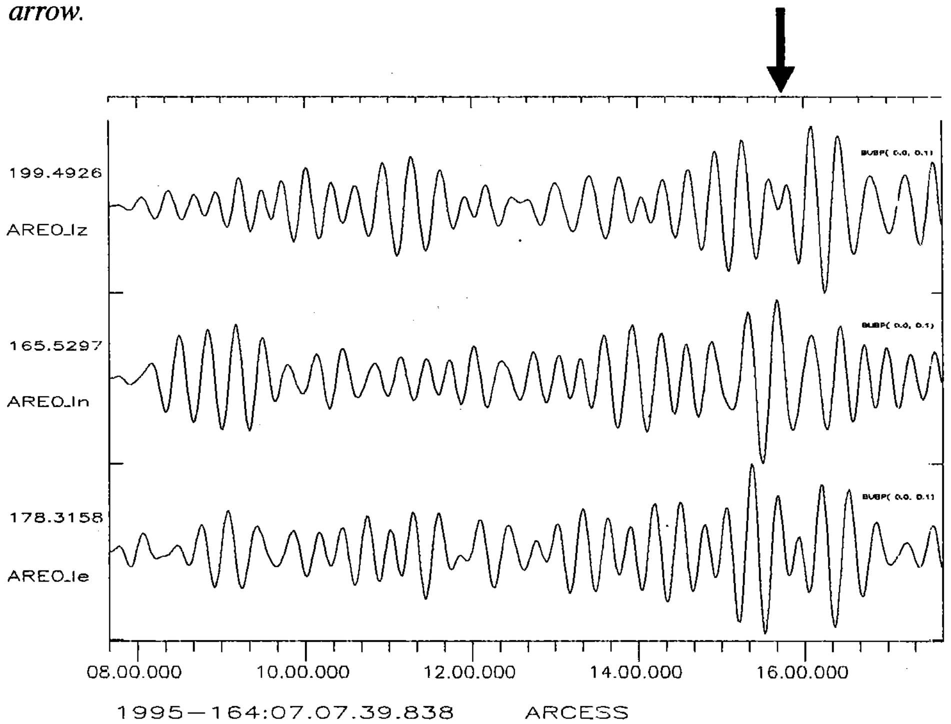

Fig. 7.6.12. Three-component long period ARCESS data for the 13 June 1995 event filtered in a 17-25 sec band. The arrow marks the expected arrival of 20-second energy. Note that the Rayleigh wave is marginal, but probably can be observed on these recordings.