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7.5 The Indian nuclear explosions of 11 and 13 May 1998

Introduction

This contribution describes observations made at our institution for the announced Indian nuclear explosions on 11 and 13 May this year. Some comparisons are also made with the PNE at the same site on 18 May 1974.

The nuclear explosion of 11 May 1998

The explosion (which were in fact announced as three separate explosions, but which apparently were conducted at the same time) took place near Pokhran on 11 May 1998, with origin time 10:13:44 GMT. Table 7.5.1 lists the basic parameters of the event as provided by various sources. The m_b magnitudes range from 5.0 to 5.3. The most accurate location is provided by the REB bulletin, which uses a world-wide network for location purposes. The solution by the NORSAR regional network after analyst processing and locating with HYPOSAT (Schweitzer, 1997) and using the IASP91 travel-time tables (Kennett and Engdahl, 1991), is also listed. The NORSAR array automatic solution is included in the table and the NORSAR automatic detection/event processor output is shown in Fig. 7.5.1.

Figs. 7.5.2 shows plots of the P-onset beams at each regional array. The trace plots of Fig. 7.5.2 are based on single channels for the seven arrays Apatity, ARCESS, FINESS, GERESS, Hagfors, NORESS, and Spitsbergen and the beam parameters velocity and back-azimuth are the results from the automatic processing. Table 7.5.2 summarizes these parameters for the seven regional arrays. The ARCESS and Spitsbergen arrays show outstanding signal-to-noise ratios (SNR). The velocity/azimuth estimates are within the expected uncertainty for all arrays.

We were also able to retrieve data from the station Nilore (NIL), Pakistan for this event. NIL, which is providing data through a satellite link installed and operated by NORSAR, is the closest digital broad-band station to the Indian test site. Fig. 7.5.3 shows all three components of the original broad-band STS-2 seismograms and the same data filtered in two different frequency bands: once band-pass filtered between 3. and 8. Hz and once low-pass filtered at 1 Hz and afterwards band-pass filtered between 0.04 and 0.08 Hz. Note the different P-to-S amplitude ratios for the different frequency bands. The SNR is quite high on all traces, and it is clear that the station NIL is by far the best IMS station for monitoring the Indian test site. Fig. 7.5.4 show the vertical component after reconstructing the ground movement from the STS-2 trace. Note the complex Pn onset with a relative long period first onset. Whether this Pn phase shows details of the three subevents of the explosion cannot be decided as long as the upper mantle and crustal structure between the test site near Pokhran and the station in Nilore is unknown.

Estimating M_s for the nuclear explosion of 11 May 1998

The only station with a surface wave that could be confidently detected was Nilore (NIL): The broad-band channel NIL-sz was low-pass filtered at 1 Hz and then band-pass filtered between 0.04 and 0.1 Hz (see Fig. 7.5.3, trace NIL-Z2). A maximum amplitude of 523.97 nm with a period of 11.95 s was measured at 10:18:20.8. The observed surface wave magnitude in a distance of 6.6 degrees is Ms = 3.31.

No M_s values were possible to calculate from stations in Fennoscandia and Europe. We carried out an intensive study to calculate such values, but without success. In the following we list estimated upper limits for M_s values from observations at arrays of different apertures and at several single stations. The time window in which surface waves for this event can be expected in Northern and Central Europe is influenced by the direct phases and surface waves from an earthquake North of Svalbard which occurred about 12 minutes after the Indian explosions (REB source parameters: 11 May 1998, 10:26:08.4, 84.86 N, 8.72 E, m_b 3.6). If this event is not taken into account, M_s measurements for the Indian nuclear test can easily be overestimated.

German Regional Seismic Network (GRSN): the broad-band stations of the GRSN were analyzed as part of an huge array with an aperture of about 300 km. The vertical traces of the stations BFO, BRG, BSEG, BUG, CLZ, FUR, and MOX were used to calculate a theoretical beam (velocity 3.2 km/s; back-azimuth 94 degrees) after filtering (at first with a low-pass at 1 Hz and afterwards with a band-pass between 0.04 and 0.08 Hz) all data equally. An upper limit for M_s was estimated by measuring on the beam at 10:39:05.3 a maximum amplitude of 14.30 nm with a period of 12.96 s. For the reference station MOX (delta 50.8 degrees) we obtained $M_s \leq 3.18$.

Gräfenberg Array (GRF): This array has an aperture of about 100 x 40 km. The data were processed as for the GRSN stations and a theoretical beam (velocity 3.2 km/s, back-azimuth 93 degrees) was calculated for the reference station GRA1 (delta 51 degrees). The maximum amplitude was measured two times: at 10:35:22.5 (and at 10:40:53.0) with an amplitude of 11.52 (and of 16.15) nm and a period of 18.14 (and of 17.98) s. This gave an estimate for $M_s$of ≤ 2.94 (or 3.09).

NORSAR array: We can use the 7 broad-band channels of the NORSAR array to form a beam for an array with an aperture of about 50 km. As reference station NAO01 was used, with an epicentral distance of 52.6 degrees. The data were processed as explained above and a theoretical beam was calculated for a velocity of 3.2 km/s and a back-azimuth of 101.3 degrees. Whether this case we also measured the maximum amplitude two times: at 10:37:24.78 (and at 10:39:31.49) with an amplitude of 8.03 (and of 23.76) nm and a period of 13.31 (and of 21.50) s. This gave an estimate for M_s of ≤ 2.94 (or 3.20). The second measurement is clearly influenced by the surface waves of the Svalbard event.

For the following stations only one broad-band or long-period channel is available to measure long-period amplitudes and therefore no enhancement of the SNR due to beam forming could be applied:

Apatity array: The broad-band channel APZ9-bz was filtered as above and a maximum amplitude of 103.52 nm with a period of 20.83 s could be measured at 10:37:04.6. The M_s estimate for a distance of 46.8 degrees is: Ms ≤ 3.77.

GERESS array: The broad-band channel GEC2-hz was filtered as above and a maximum amplitude of 16.68 nm with a period of 11.36 s could be measured at 10:38:57.5. The M_s estimate for a distance of 49.4 degrees is: Ms ≤ 3.28.

ARCESS array: The long-period channel ARE0-lz was band pass filtered between 0.04 and 0.08 Hz. A maximum amplitude of 49.23 nm with a period of 19.97 s could be measured at 10:35:48.0. The M_s estimate for a distance of 50.3 degrees is: Ms ≤ 3.52. The maximum amplitude is clearly influenced by the event North of Svalbard!

Hagfors array: The long-period channel FSC2-lz was band pass filtered between 0.04 and 0.08 Hz. A maximum amplitude of 21.22 nm with a period of 15.63 s could be measured at 10:40:31.7. The M_s estimate for a distance of 51.2 degrees is: Ms ≤ 3.27.

The M_s 3.31 measured at the near-by station NIL is reasonably consistent with the upper limit measurements for this explosion at the European arrays and stations.

The nuclear explosion of 13 May 1998

This explosion (or two explosions, according to the Indian authorities), took place on 13 May 1998, with an announced origin time 06:51 GMT. No signals were detected by any of the IMS stations. We retrieved data from the NIL station for this event as well, and were not able to find any signal in a large time window around the expected onset time. The upper limit of detectability of this station is approximately mb=2.5, as seen by scaling the original signal with a SNR of 714 down towards the noise value. The upper limit for the M_s is, by the same algorithm, obtained by measuring the noise before the observed event. Using the same filters as above, the maximum noise amplitude is 55.29 nm for a period of 10.13 s (see the beginning of trace NIL-Z2 in Fig. 7.5.3). This would correspond with a noise $M_s = 2.41$.

Comparison with a previous event at the Indian test site

In the following we make a brief comparison between the first explosion dealt with above and the test conducted at the same test site on 18 May 1974.

The 11 May 1998 and the test conducted at the same test site on 18 May 1974 have very similar magnitudes and wave forms. This similarity is illustrated in Fig. 7.5.5, which shows the NORSAR P-wave recordings for both events. The data were band-pass filtered between 1. and 3. Hz and all traces were aligned visually and sorted by the NORSAR sites. The upper trace shows always data from the 11 May 1998 test and the lower trace the data from the 18 May 1974 explosion, respectively.

Because we can assume different source functions for the two events, the pulse-form similarity at each NORSAR site is an indication that these observed pulses are mostly formed by path effects rather than by the test devices. The main conclusion from this similarity is that the two tests took place at a very close distance.

The similarity of the recordings, taken 24 years apart, also demonstrate that the NORSAR instrumentation has remained stable, and confirms that even after the recent refurbishment of the seismometers and digitizers the recordings can be successfully used for comparisons with historical archives.

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References

Kennett, B.L.N. & Engdahl, E.R., 1991. Travel times for global earthquake location and phase identification, Geophys. J. Int. 105, 429 - 466.

Schweitzer, J. 1997. HYPOSAT - a new routine to locate seismic events. In: NORSAR Semiannual Tech. Summ. 1 April - 30 September 1997, NORSAR Sci. Rep. 1-97/98, Kjeller, Norway, 94-102.

Reference	Origin time	Latitude	Longitude	m_b
REB	10:13:44.2	27.07	71.76	5.0
NORSAR array (automatic)	10:13:44.02	25.22	70.49	5.1
NORSAR- regional arrays	10:13:44.97	27.08	71.45	
PDE-Q	10:13:41.78	27.09	71.91	5.3

Table 7.5.1:.Location estimates by various systems of the 11 May 1998 nuclear explosion. One of the estimates (NORSAR array solution) was made automatically. The solution NORSAR-regional arrays was calculated with P observations at Apatity, ARCESS, FINESS, GERESS, Hagfors, NORESS and SPITS and PcP observations at FINESS, GERESS and Hagfors (inverted were re-measured values of onset time, azimuth and slowness for all phases).

Array	Onset time	STA/ LTA	Velocity	Res	Azimuth	Res
Apatity	131:10.22.15.1	44.3	14.8	0.6	124.5	-6.3
ARCESS	131:10.22.41.0	193.6	15.3	0.7	123.8	1.0
FINESS	131:10.22.07.4	89.2	15.2	1.1	121.3	4.2
GERESS	131:10.22.34.8	40.3	15.5	0.2	97.2	3.2
Hagfors	131:10.22.47.3	48.9	19.7	4.9	124.6	21.3
NORESS	131:10.22.55.3	33.2	14.8	-.2	107.5	5.7
NORSAR	131:10.22.57.4	47.1	15.2	0.2	104.3	3.0
SPITS	131:10.23.30.0	207.90	12.7	-2.9	112.0	-6.6

Table 7.5.2. Automatic detection list for the Indian nuclear explosion on 11 May 1998. The columns show array name, automatic EP-SigPro onset time, maximum signal-to-noise ratio (STA/LTA), apparent velocity (km/s), residual in km/s, back-azimuth in degrees, and back-azimuth residual. All residuals are relative to predictions using IASP91 tables and PDE-Q location.

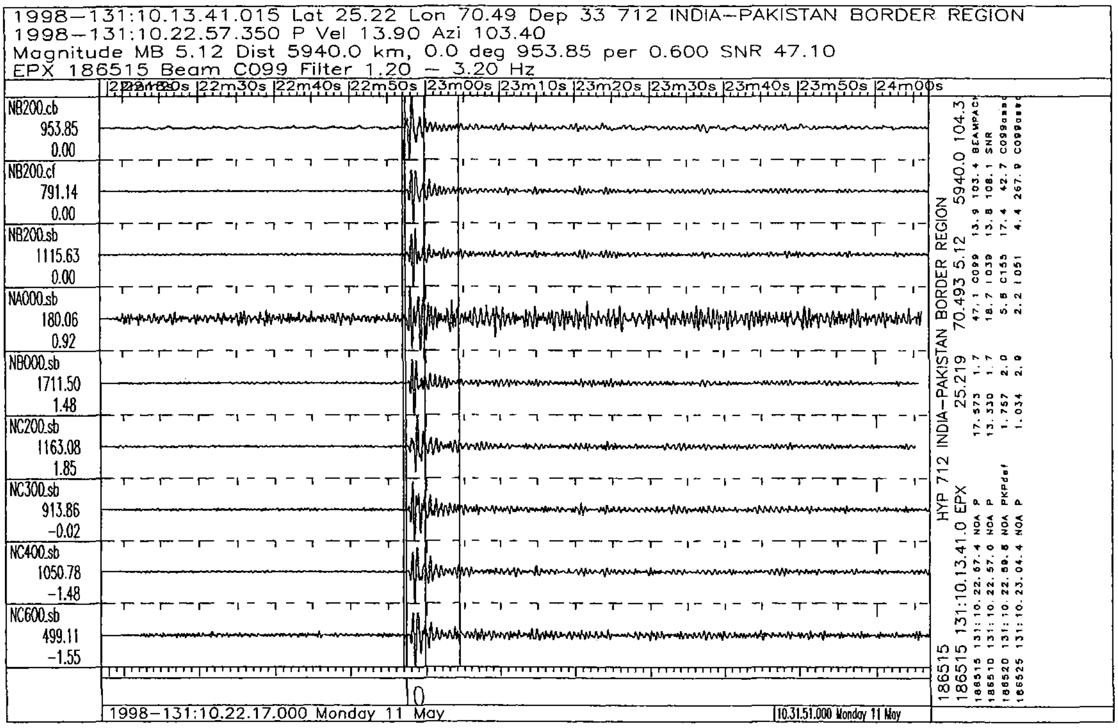

Fig. 7.5.1. Plot of the automatic NORSAR detection/event processor output for the Indian nuclear explosion on 11 May 1998.

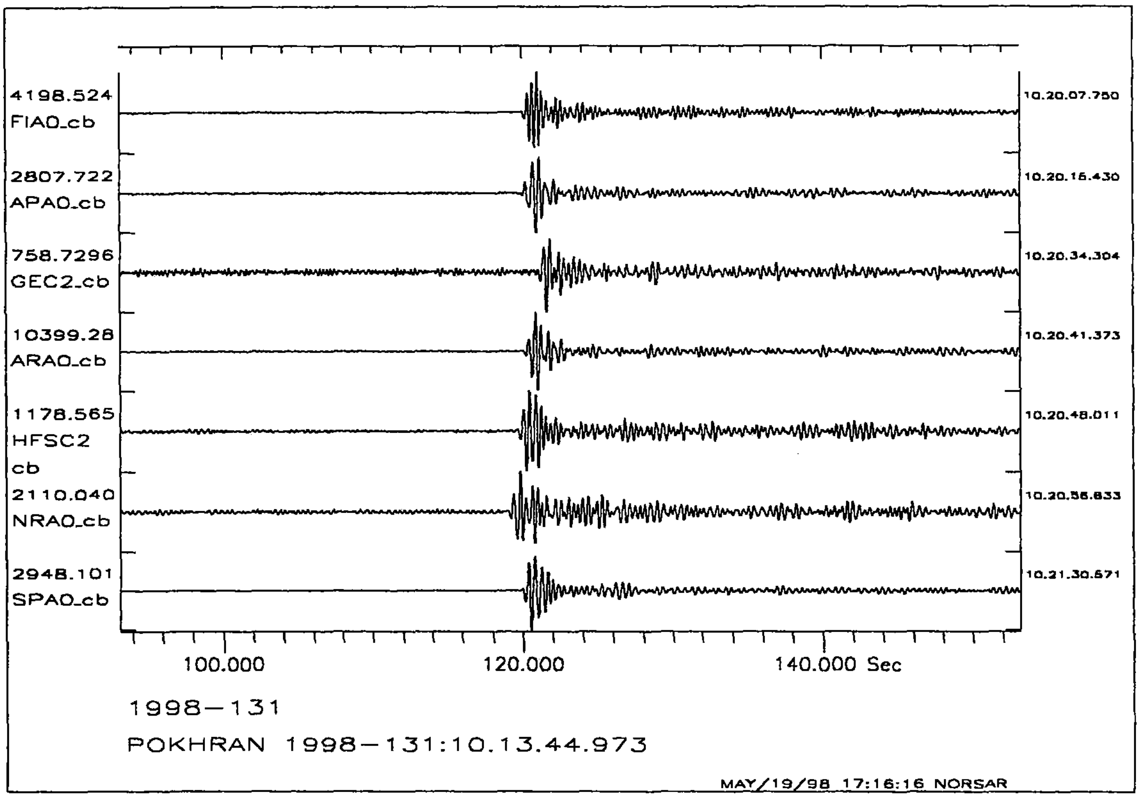

Fig. 7.5.2. Plot of the automatic beams at the regional arrays for the 11 May 1998 explosion at the Indian test site Pokhran. The traces are sorted by epicentral distance from top to bottom and shifted by the theoretical travel times from the IASP91 tables using the NORSAR regional array solution (see Table 7.5.2). Corrections for ellipticity of the Earth and station elevation were not taken in account for this plot but were accounted for the location program.

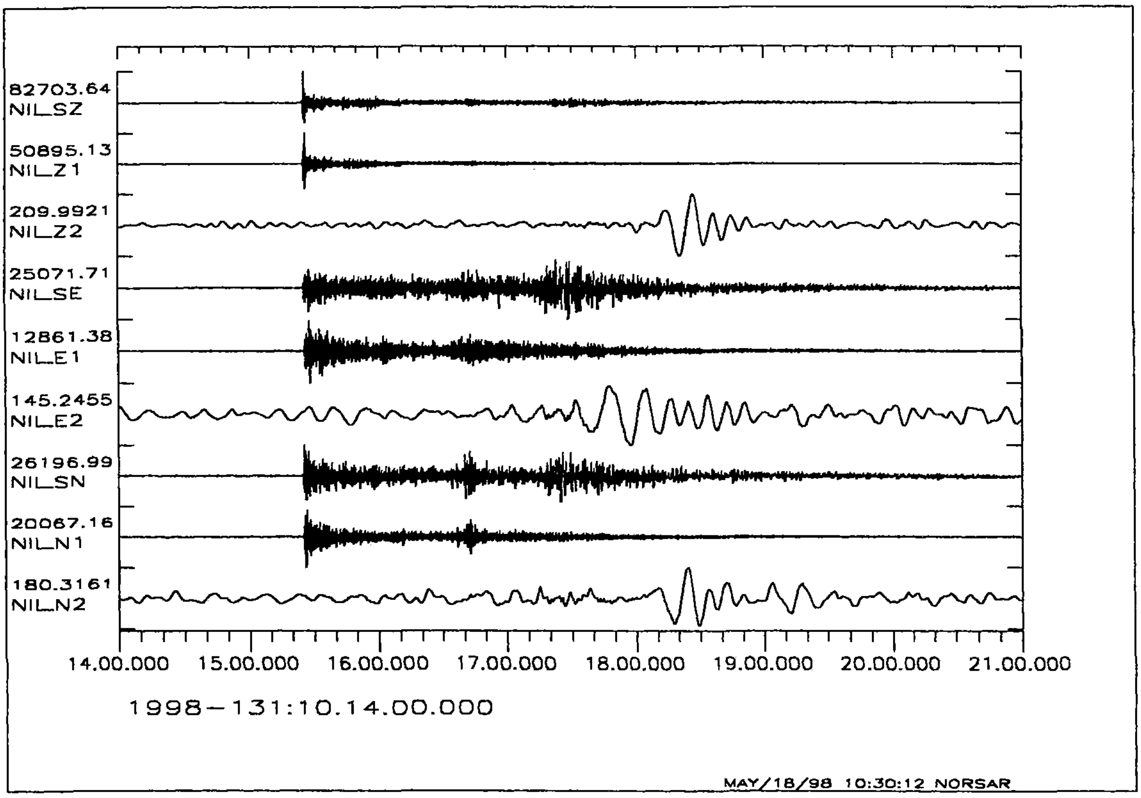

Fig. 7.5.3. The observations of the Indian nuclear explosion on 11 May 1998 at station NIL. Shown are the original broad-band data (traces SZ, SE, and SN), the 3. - 8. Hz band-pass filtered data (traces Z1, E1, and N1) and the 1 Hz low-pass and afterwards 0.04 - 0.1 Hz band-pass filtered data (traces Z2, E2, and N2). All seismograms were normalized by the given amplitudes (in counts).

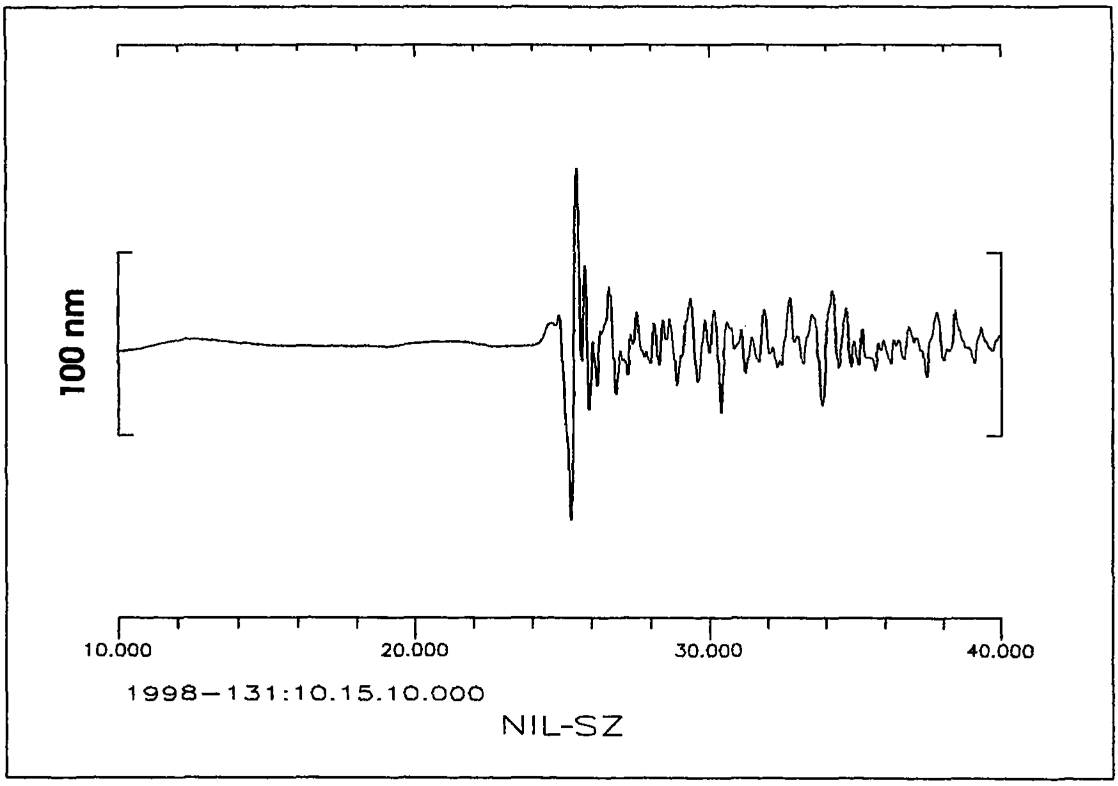

Fig. 7.5.4. Restitution of the ground movement from the STS-2 vertical component at NIL of the Indian nuclear test on 11 May 1998. The peak-to-peak amplitude of the Pn signal is 192.16 nm with a dominant period of 0.413 s. The length of the amplitude bar shown at the left scales corresponds to 100nm.

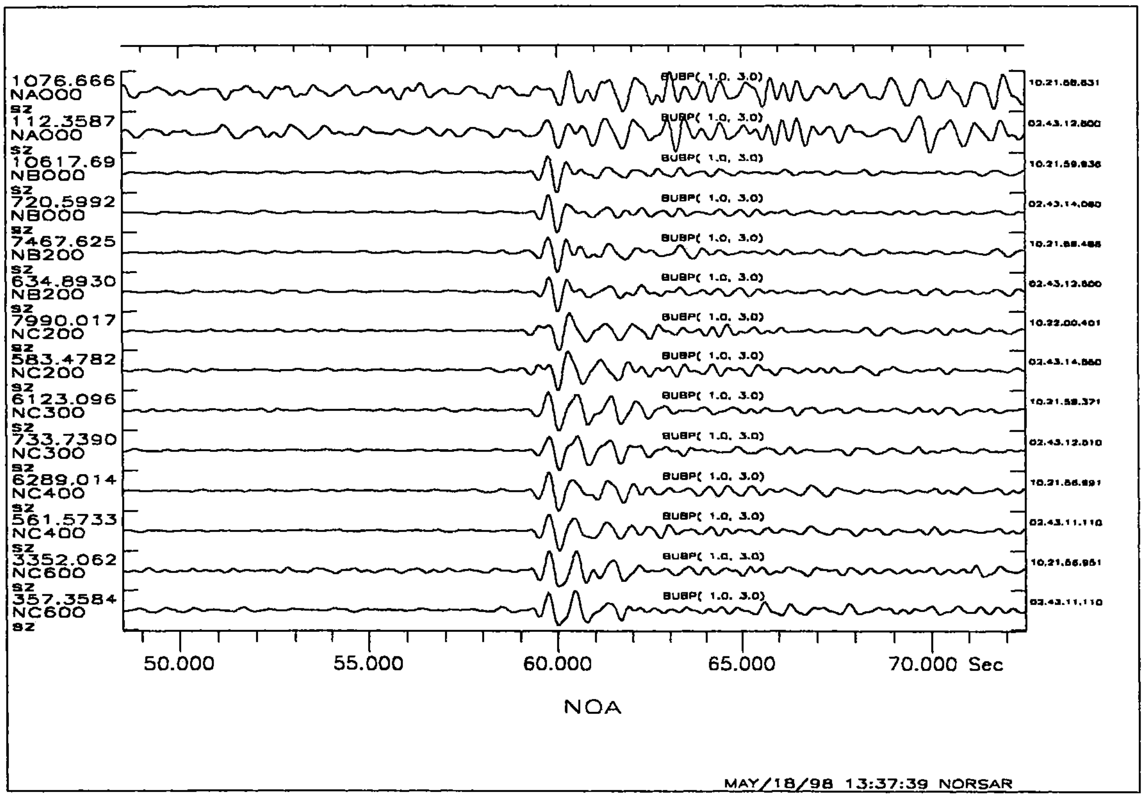

Fig. 7.5.5. Observations of the 18 May 1974 and of the 11 May 1998 explosions at the Indian nuclear test site. Shown are pairwise seismograms at single sites of NORSAR. The upper trace shows always the 11 May 1998 and the lower trace the 18 May 1974 explosion. All data were 1. - 3. Hz band-pass filtered, the traces were normalized with the given maximum amplitudes (in counts), and the traces were aligned visually to a common onset time.