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The 16 August 1997 Novaya Zemlya Seismic Event As Viewed From GSN Stations KEV and KBS

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Abstract

Using current and historic seismic records from Global Seismic Network stations KEV and KBS, we find that S-minus-P arrival time comparisons between nuclear explosions and the 16 August 1997 seismic event ($m_b \approx 3.6$) from near Novaya Zemlya clearly indicate that (relative to KEV) the 16 August event occurred at least 80 km east of the Russian test site. Including S-minus-P arrival times from KBS constrains the location to beneath the Kara Sea and in good agreement with previously reported locations, over 100 km southeast of the test site. From an analysis of P_n/S_n waveform ratios at frequencies above 4 Hz, we find that the 16 August event falls within the population of regional earthquakes and is distinctly separated from Novaya Zemlya and other northern Eurasian nuclear explosion populations. Thus, given its location and waveform characteristics, we conclude the 16 August event was an earthquake. The 16 August event was not detected at teleseismic distances, and thus, this event provides a good example of the regional detection, location, and identification efforts that will be required to monitor the Comprehensive Test Ban Treaty below $m_b \approx 4$.

Introduction

On August 16, 1997 at near 02:11 GMT a seismic event from near the Russian island of Novaya Zemlya was detected at the Prototype Internation Data Center (PIDC). The PIDC used two array stations in Scandinavia (NORES and FINES) and one three-component seismic station in Russia (NRI) to detect the event, and then called up two additional auxiliary arrays (HFS and SPITS) and one three-component station (ARU) to locate the event off the eastern coast of the southern island of Novaya Zemlya beneath the Kara Sea (Figure 1). Seismology research organizations in Norway, Finland, and the United States all estimated locations similar to the PIDC location. Table 1 summarizes each organization's location, magnitude, and origin time estimate.

Seismic events from on or near Novaya Zemlya are carefully examined as the north end of the southern island is the Russian nuclear test site (NZTS in Figure 1). Furthermore, natural seismic events from this region are known to be rare, at least for events greater than about m_b 4.0. At magnitudes above this level, most events can be detected and located by using teleseismic records (seismic stations over 2500 km from the event). The 16 August event was too small to be detected or otherwise analyzed using teleseismic records. Hence, it was the first unidentified regional seismic event (recorded only at distances of less than about 2500 km) to be detected and located near a known nuclear test site since the United States and Russia signed the Comprehensive Test Ban Treaty (CTBT) in 1996. In many ways, this event represents what may become the routine CTBT monitoring situation, detecting, locating, and identifying a small seismic event using only regional data.

Soon after the event was reported by the PIDC we collected and analyzed current and historic seismic data recorded at stations KEV in northern Finland and KBS on Spitsbergen (Figure 1). We chose these stations because they have been operated for many years as USGS digital seismic stations, and because archived records from these stations are readily available via the Internet from the IRIS Data Management Center (DMC). Our first objective was to confirm that the 16 August event did not occur at or near the test site. Our second objective was to determine if P-to-S amplitude ratios could be used to class the 16 August event as an earthquake or as an explosion.

Focusing efforts on station KEV, we find that S-minus-P arrival times for explosions and for the 16 August event clearly indicate that (relative to KEV) the 16 August event occurred at least 80 km east of the test site. Including S-minus-P arrival times from KBS constrains the location to beneath the Kara Sea and in good agreement with the locations summarized in Table 1. From an analysis of P_n/S_n waveform ratios at frequencies above 4 Hz, we find that the 16 August event falls within the population of regional earthquakes and is distinctly separated from Novaya Zemlya and other northern Eurasian nuclear explosion populations.

Although the explosions all have magnitudes (m_b) above 4.5, and thus can not be directly compared to the smaller earthquakes, we believe that the separation between the two populations is great enough to conclude that the 16 August event is not an explosion source. Thus, given its location and waveform characteristics, we conclude the 16 August event was an earthquake. Below we report details of our study and offer some comments regarding preparation for CTBT monitoring.

S-minus-P Times

As a quick check on location, we compared S-minus-P arrival times for NZTS explosions and the 16 August event. Using observations from a common station, if the S-minus-P time for the 16 August event is different from the S-minus-P times for NZTS explosions, then we can safely conclude that the 16 August event did not occur at or near the test site. We are not estimating an absolute location for the 16 August event, and thus this technique is independent of an assumed velocity model. We make the assumptions that the NZTS explosions did indeed occur at the test site and P velocity is roughly 1.73 times S velocity (Poisson's Ratio is near 0.25).

Unfortunately, finding historic data (waveforms or bulletins) from previous Novaya Zemlya events that can be compared to the 16 August event is difficult. The last known Novaya Zemlya nuclear test occurred on 24 October, 1990 (Ringdal, 1997). Therefore, we looked for stations that began operation by at least mid-1990 and also recorded the 16 August event. The arrays in southern Norway and Sweden have operated since the 1970's (Figure 1) and recorded the 16 August event. However, these arrays are over 2000 km from NZTS, and at these distances and for magnitudes below about m_b 4.0, S is attenuated to background noise levels and can not be picked (Baumgardt, 1993). The array ARCES in northern Norway has operated since 1987 and has recorded NZTS explosions, but it was not operating on 16 August, 1997. The array SPITS on Spitsbergen Island recorded the 16 August event with clear P_n and S_n arrivals (Figure 2). However, SPITS has operated only since 1992 and has therefore never recorded a known nuclear explosion from NZTS.

Station KEV in northern Finland (Figure 1) is close to ARCES and has operated as a Digital World Wide Standard Seismic Network (DWWSSN) station and later as a Global Seismic Network (GSN) station since late 1981 (Federation of Digital Seismic Networks Station Book, 1994). KEV has recorded several NZTS nuclear explosions and also recorded the 16 August event. Station KBS on Spitsbergen Island operated in the mid-1980's as a DWWSSN station and was operating as a broadband, three-component GSN station on 16 August 1997. KEV is about 1125 km from the 16 August event and KBS is about 1375 km from the event. When bandpass-filtered between 3 and 8 Hz, P_n and S_n arrivals from the

August 16 event can be seen clearly at KEV and can also be seen, but somewhat less clearly, at KBS (Figure 3).

We picked P_n and S_n arrivals for both stations (Figure 3) and then obtained P_n and S_n arrival times from International Seismological Centre (ISC) Bulletins for NZTS nuclear explosions from the 1980's and 1990 (Table 2). For KEV we also obtained P_n and S_n times from the ISC Bulletin for the 1 August 1986 Kara Sea earthquake (Marshall, 1986). Figures 4 and 5, graphical displays of the ISC data in Table 2, show that, relative to KEV and KBS, S-minus-P times form the 16 August event are about 8 seconds greater than NZTS S-minus-P times. Eight seconds of S-minus-P time corresponds to at least 80 km of distance. Hence, the 16 August event occurred east-southeast of NZTS, well out into the Kara Sea and in agreement with the locations reported in Table 1.

For KEV, explosion S-minus-P times from the ISC bulletins range between about 98 and 104 seconds, increasing from the early 1980's through 1990 (Figure 4). In 1987 KEV was upgraded from a vertical-component, short-period station to a three-component, broadband station. To investigate this rather large range in reported times, we retrieved all available NZTS explosion waveforms for KEV from the IRIS DMC (Figure 6). After correcting all waveforms for instrument response, we picked P_n and S_n arrivals for 6 explosions and found a consistent S-minus-P time of near $100 \pm 1 s$ (Figure 7). We picked S_n where amplitudes first start to emerge from the decaying P coda, and when horizontal components were available (from 1987 to the present) we picked S_n from transverse records (Figure 8). Whoever picked and reported these times to the ISC, apparently read S_n on the broadband records where frequencies change to longer periods, about 4 seconds after S_n amplitudes begin to increase out of the P coda.

Using the 1990 NZTS explosion, we calibrated S-minus-P time at KEV (100 s) to distance (1046 km). From this calibration information and S-minus-P times from the 16 August event read at KEV ($\approx$ 108 s) and KBS ($\approx$ 131 s), we find that P_n and S_n arrival times at these stations are consistent with the location of the 16 August event reported by the PIDC (Figure 9). As described in the Introduction above, the PIDC did not use readings from KEV or KBS to locate the event. Hence, relative to NZTS, and considering the consistency with the PIDC location, the 16 August event clearly occurred even farther southeast and out into the Kara Sea than the 1 August 1986 earthquake (Figure 9).

Event Identification From Waveforms

The lack of natural seismicity near Novaya Zemlya and the relatively large sizes of historic NZTS explosions (generally above m_b 5.5) make event identification studies for this region difficult. We found that KEV has the most complete publicly available record of digital waveforms of nuclear explosions and earthquakes from northwestern Eurasia and the adjacent Arctic region. The more southern Scandinavian stations have operated for more years than KEV, but for the small earthquakes and explosions ($m_b < 4.0$) that are available for analysis, S_n is attenuated to background noise levels and can not be measured at distances greater than about 1500 km. We selected nuclear weapon tests from NZTS, Peaceful Nuclear Explosions (PNE's) from northern Eurasia, earthquakes from northern Eurasia, and earthquakes from northwest and northeast of Novaya Zemlya (Table 3 and Figure 1) for discrimination analysis. We used the USGS PDE catalog and the PIDC REB to select reference events. Most earthquakes are from south and southeast of Spitsbergen as the PIDC has been locating events with magnitudes between 3 and 4 from this region since 1995. We intentionally avoided events that are directly associated with the mid-Atlantic Ridge. Digital records of the 1 August 1986 Novaya Zemlya earthquake (Marshall, 1989) are not available at KEV. Of the three other unidentified events known to have occurred on or near Novaya Zemlya in 1992, 1995, and 1996 (Figure 9), only the m_b 2.4 event of 13 January 1996 was recorded at KEV. The 13 January event did not have signal that exceeded noise levels at KEV, and we did not use it in our study.

Because the available earthquakes are quite small, we did not attempt to measure surface waves and therefore did not do an $m_b{:}M_S$ analysis. Figures 3, 6, and 8 show that the only prominent phases on the regional seismograms are P_n and S_n. Furthermore, for many of the small earthquakes recorded at distances of more than 1000 km, P_n and S_n do not emerge from background noise until filtering at frequencies above 3 Hz. Hence, our discrimination efforts are focused only on high-frequency (f > 3 Hz) P_n/S_n amplitude ratios. Figure 10 shows a panel of various event types used in our analysis that are filtered between 6 and 8 Hz. The nuclear explosions (top two waveforms) are deficient in S_n energy relative to the earthquakes and 16 August event.

For each waveform, we picked P_n and S_n onsets and then measured rms amplitude within time windows determined by the phase onsets, phase window velocities (8.25 - 7.7 km s^{-1} for P_n and 4.65 - 4.3 km s^{-1} for S_n, and event-station distance. We formed P_n/S_n ratios in the $\log_{10}$ domain for all events that had P_n and S_n amplitudes that were at least twice the pre-event noise level. To account for different attenuation and spreading factors between P_n and S_n, we estimated a linear fit to the ratio-distance trend using only the earthquake ratios, and then removed the trend from all ratios (earthquakes, explosions, and the 16 August event). After removing the distance trend, we form the corrected ratio-versus-magnitude discrimination plot. We made all measurements on vertical component records after correcting for instrument response. Figures 11, 12, and 13, show results for the 4-6, 5-7, and 6-8 Hz bands.

Event-station distances range between about 400 and 2100 km for this data set. The ratio-distance trend for all bands is pronounced, and removing the trend increases separation between the explosion and earthquake populations. As frequency increases, separation also increases between the explosion and earthquake population. At 4-6 Hz the 16 August event is at the top of the earthquake population, but it is below the explosion population. Above 5 Hz the 16 August event remains near the top of the earthquake population, and the two populations remain separated.

The discrimination plots indicate that the 16 August event has an earthquake source. The smallest explosion in this data set has an m_b of 4.5 and the largest earthquake in the the data set has an m_b of 4.5. Thus, the populations just overlap in magnitude. More overlap at low magnitudes would be helpful, but because the explosion ratios do not appear to be decreasing with event size, we do not expect explosions in the m_b 3.5 to 4.3 range to overlap with the small earthquakes that we have evaluated. Furthermore, the P_n/S_n ratio of the 16 August event decreases with increasing frequency (Figures 11, 12, and 13). If the 16 August event were an explosion, we would expect it's P_n/S_n ratio to increase with frequency.

Discussion and Conclusions

We have evaluated the location of the 16 August event relative to explosions that are known to have occurred at NZTS using data from GSN stations KEV and KBS. We conclude that the event occurred at least 100 southeast of the test site, beneath the Kara Sea and in good agreement with locations estimated by other organizations. We have also done a discrimination analysis using KEV data, comparing P_n/S_n ratios of earthquakes, nuclear explosions, and the 16 August event. At frequencies above 4 Hz, the 16 August event falls within the earthquake population and is separated from the explosion population. Taking the location and discrimination results together, we conclude that the 16 August event was an earthquake.

Several important points regarding the monitoring of the CTBT can be drawn from our study. First, for this event, the International Monitoring System (IMS) worked as it is supposed to. The PIDC detected and reliably located the 16 August event just as the International Data Center will be expected to do when it becomes operational. This was especially encouraging given that the event was detected only at regional distances and the array ARCES was not operating. Second, although the event was detected and located, event identification methods that are applicable at regional distances and specifically tuned to this region were not yet in routine use. Given that many small events ($m_b < 4.0$) will be examined under the CTBT, and will therefore only be detected at regional distances, there is clearly a need for continued "regionalization" efforts to prepare for treaty monitoring. Third, the modern arrays, which are part of the CTBT International Monitoring System (IMS), played an important role in detection and location of the 16 August, but the long-established stations (such as KEV) are important for event identification and relative location studies, as these stations have recorded test site explosions and other seismic events over the years. Many modern arrays and stations may never record a nuclear explosion. Hence, because events of future interest may be small and recorded at only a few stations, all available data will be called upon to identify events. Therefore, regionalization efforts should include as many stations as possible and not be limited to IMS stations.

The 16 August event is the fourth seismic event from on or near Novaya Zemlya to be detected, located, and reported by treaty monitoring organizations since 1992, the same year that SPITS began operation (Figures 1 and 9). We anticipate that a similar number of earthquakes in the m_b 2.5 - 3.5 range will be detected and located in this region over the next 5 years. To expand regionalization efforts for Novaya Zemlya, we suggest using the 16 August event as an earthquake to be compared against other recent small seismic events from the area. The August 16 event can be used as an earthquake at SPITS, and the KEV record can be used as an earthquake at ARCES to help confirm these previous small events as earthquakes and begin to build a sample Novaya Zemlya earthquake population as recorded by the arrays.

A chemical explosion at NZTS in the m_b 3.7 - 4.2 range would be an immense help to the regionalization effort. However, given the weak S_n produced by explosions in this region, and given that S_n attenuation is greater than P_n attenutation, a calibration explosion should not be much less than m_b 4.0. High-frequency S_n from such a small explosion could fall below noise levels and, thus, could not be directly incorporated into discrimination studies for stations KEV, ARCES, SPITS, and KBS.

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References

Federation of Digital Seismograph Networks Station Book, IRIS Data Management System, Seattle, WA, 1994.

Marshall, P.D, R.C. Stewart, and R.C. Lilwall, The seismic disturbance on 1986 August 1 near Novaya Zemlya: a source of concern?, *Geophysical J.*, **98**, 565-573, 1988.

Ringdal, F., Study of low-magnitude events near the Novaya Zemlya nuclear test site, *Bull. Seism. Soc. Am.*, **87**, in press, 1997.

Wessel, P. and W. H. F. Smith (1991). Free software helps map and display data, *EOS Trans. AGU*, **72**, 441.

Figure Captions

Figure 1. Regional map of northern Europe and northwest Asia showing seismicity, seismic arrays, and seismic stations. Dates next to station labels indicate time periods over which digital data is available. We analyzed data recorded at stations KEV and KBS. The black stars near the NZTS label indicate the Russian test site. We used events denoted by large gray circles, stars, and the diamond (16 August event) in our discrimination analysis. Labels next to event symbols indicate origin time and magnitude. Small black circles denote seismic events from the years 1982-1997 that are reported in USGS PDE catalogs, but are not used in this study.

Figure 2. Sample waveforms of the 16 August event recorded at SPITS. Records have been bandpass filtered between 3 and 8 Hz. "A" marks the P_n arrival and "B" marks the S_n arrival.

Figure 3. Sample waveforms of the 16 August event recorded at KEV and KBS. Records have been bandpass filtered between 3 and 8 Hz. The records are instrument-corrected and are displayed as velocity in m/s.

Figure 4. S-minus-P time as a function of seismic event. Black squares represent NZTS nuclear explosions, the gray square represents the Novaya Zemlya earthquake of 1986, and the white square represents the August 16 event. Times were obtained from ISC Bulletins, except for the August 16 event, which we read from KEV records. In 1987 KEV was upgraded from a short-period, vertical-component station to a broadband, three-component station.

Figure 5. S-minus-P time as a function of seismic event. Black square represents a NZTS nuclear explosions from 1987, the gray square represents the Novaya Zemlya earthquake of 1986, and the white square represents the August 16 event. Times were obtained from ISC Bulletins, except for the August 16 event, which we read from KBS records.

Figure 6. Comparison of NZTS explosion waveforms and the 16 August event waveforms. All records are instrument-corrected and are displayed as velocity in m/s. Note that the difference in S-minus-P time between NZTS and the 16 August event is about 8 sec.

Figure 7. S-minus-P time as a function of seismic event. Black squares represent NZTS nuclear explosions and the white square represents the August 16 event. All times were read directly from from KEV records for this study. The S-minus-P time for NZTS explosions is $100 \pm 1\,s$, while the S-minus-P time for the 16 August event is 108 s. Thus, the 16 August event could not have occurred near NZTS, regardless of velocity model assumptions. Note that a higher bandpass filter was applied to the 16 August event.

Figure 8. A detailed view of P_n and S_n picks of the 1990 NZTS explosion and the 16 August event as recorded at KEV. We picked S_n on the transverse component where waveform amplitude begins to emerge from the P coda.

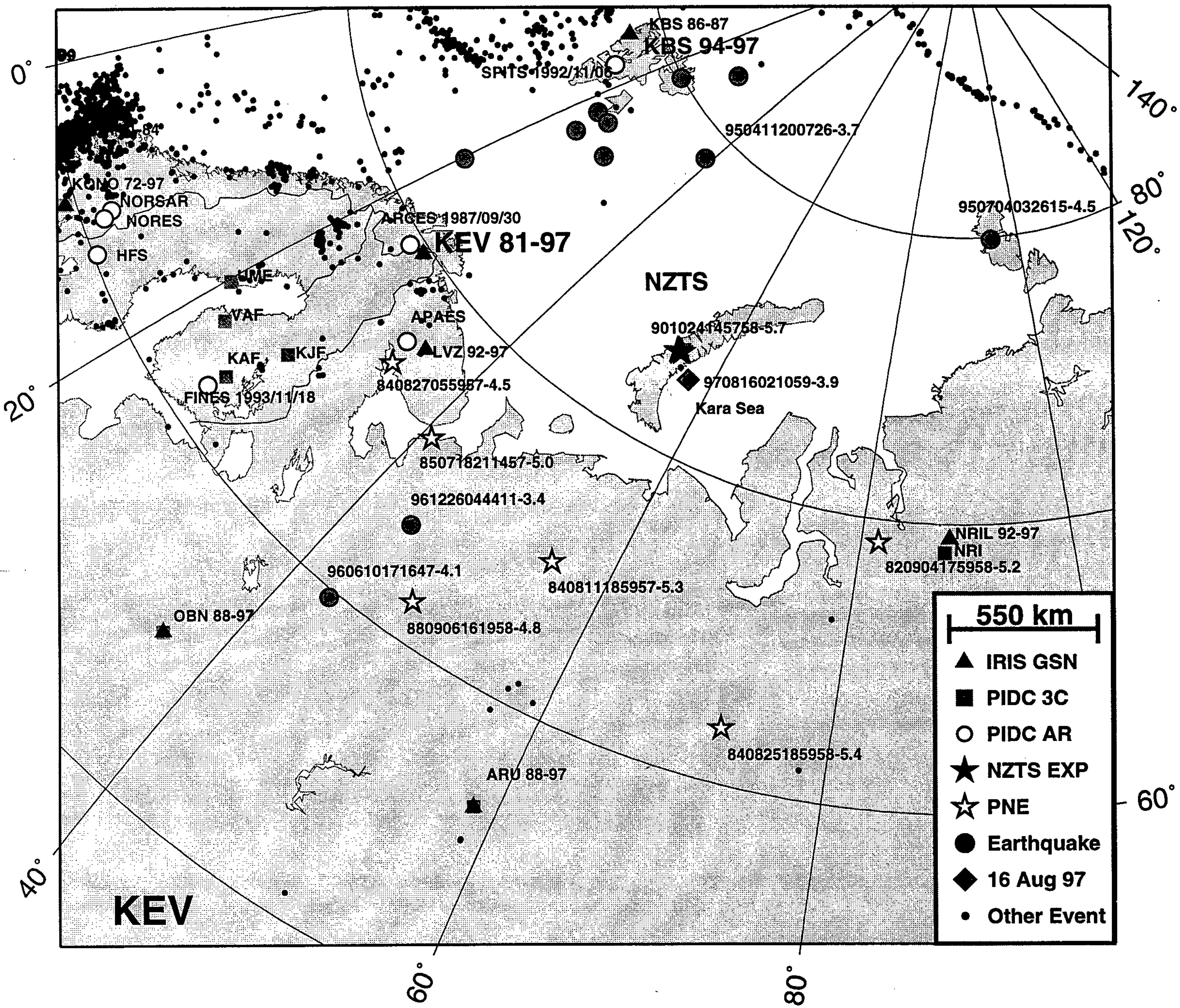
Figure 9. Seismic events from on or near Novaya Zemlya. We used the S-minus-P time from the 1990 NZTS explosion (black arc) to convert S-minus-P times from the 16 August event (as picked at KEV and KBS, see Figures 3, 6, and 8) into distance. The gray arcs associated with KEV and KBS nearly intersect the PIDC location, which was obtained independently of stations KEV and KBS.

Figure 10. Vertical-component waveforms of regional events recorded at KEV. These events are representative of the data we used in our discrimination analysis. The locations of these events and all events used in our discrimination analysis are shown on Figure 1. Note that the P_n/S_n ratios of the explosions are about 3:1 while the P_n/S_n ratios of the other events are between 1:1 and 0.5:1.

Figure 11. Discrimination analysis for the 4-6 Hz band at KEV. Top left shows uncorrected ratios-versus-m_b, top right shows distance trend found using only earthquake ratios, and bottom left is the distance-corrected ratio-versus-m_b discrimination plot. The label "Mahal" refers to Mahalonobis Distance, Δ, a measure of separation between earthquake and explosion populations and the scatter within each population:. $\Delta^2 = \frac{(\bar{v}_x - \bar{v}_q)^2}{\sigma_x^2 + \sigma_q^2}$, where $\bar{v}$'s and σ's refer to variances and means of the earthquake and explosion ratios.

Figure 12. Discrimination analysis for the 5-7 Hz band at KEV. See Figure 11 for a description.

Figure 13. Discrimination analysis for the 6-8 Hz band at KEV. See Figure 11 for a description.



KBS 86-87
KBS 94-97
SPITS 1992/11/06
950411200726-3.7
950704032615-4.5
KONO 72-97
NORSAR
NORES
HFS
ARCES 1987/09/30
KEV 81-97
NZTS
UME
VAF
APAES
KAF
KJF
LVZ 92-97
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OBN 88-97
840825185958-5.4
ARU 88-97
KEV
550 km
IRIS GSN
PIDC 3C
PIDC AR
NZTS EXP
PNE
Earthquake
16 Aug 97
Other Event
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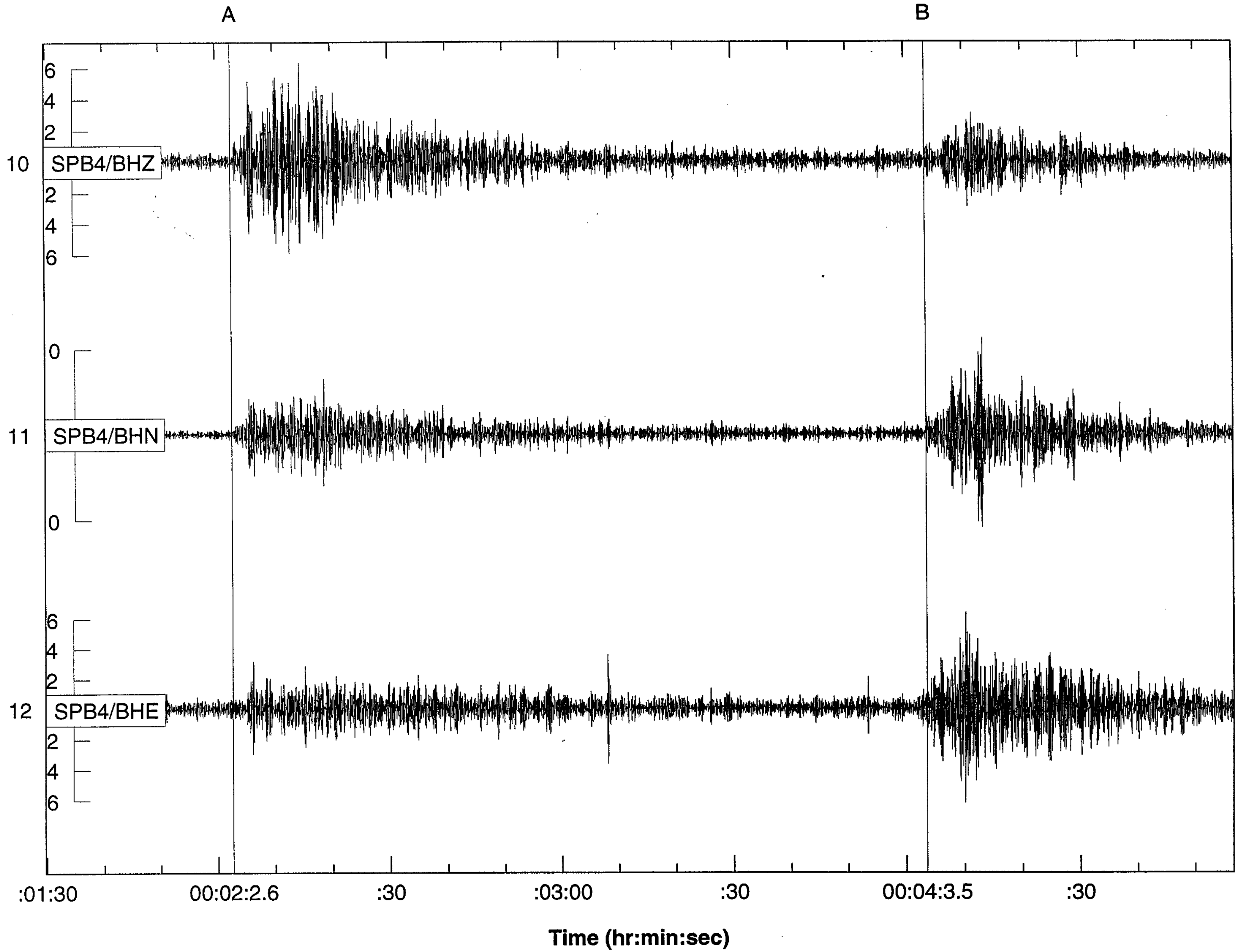
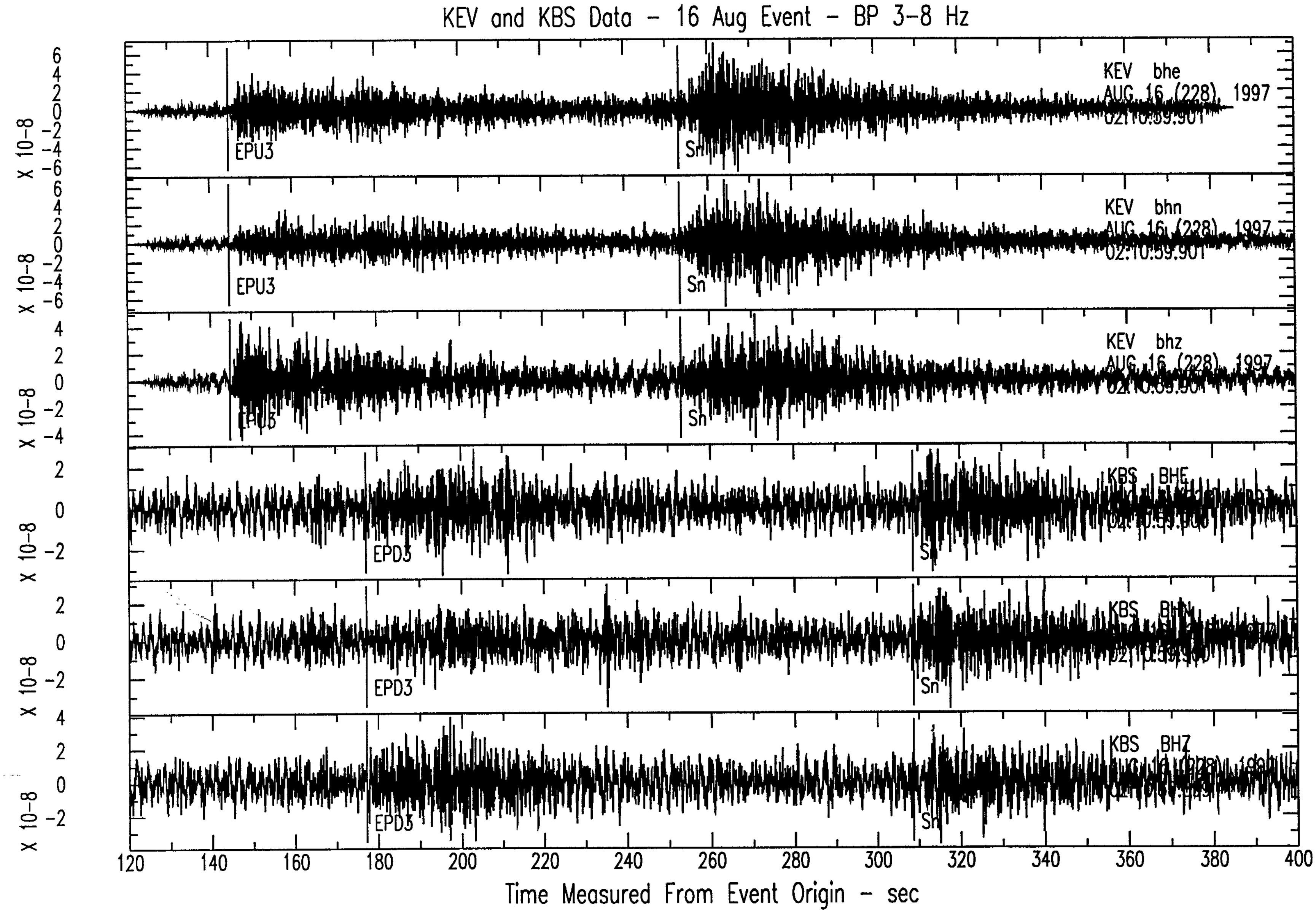
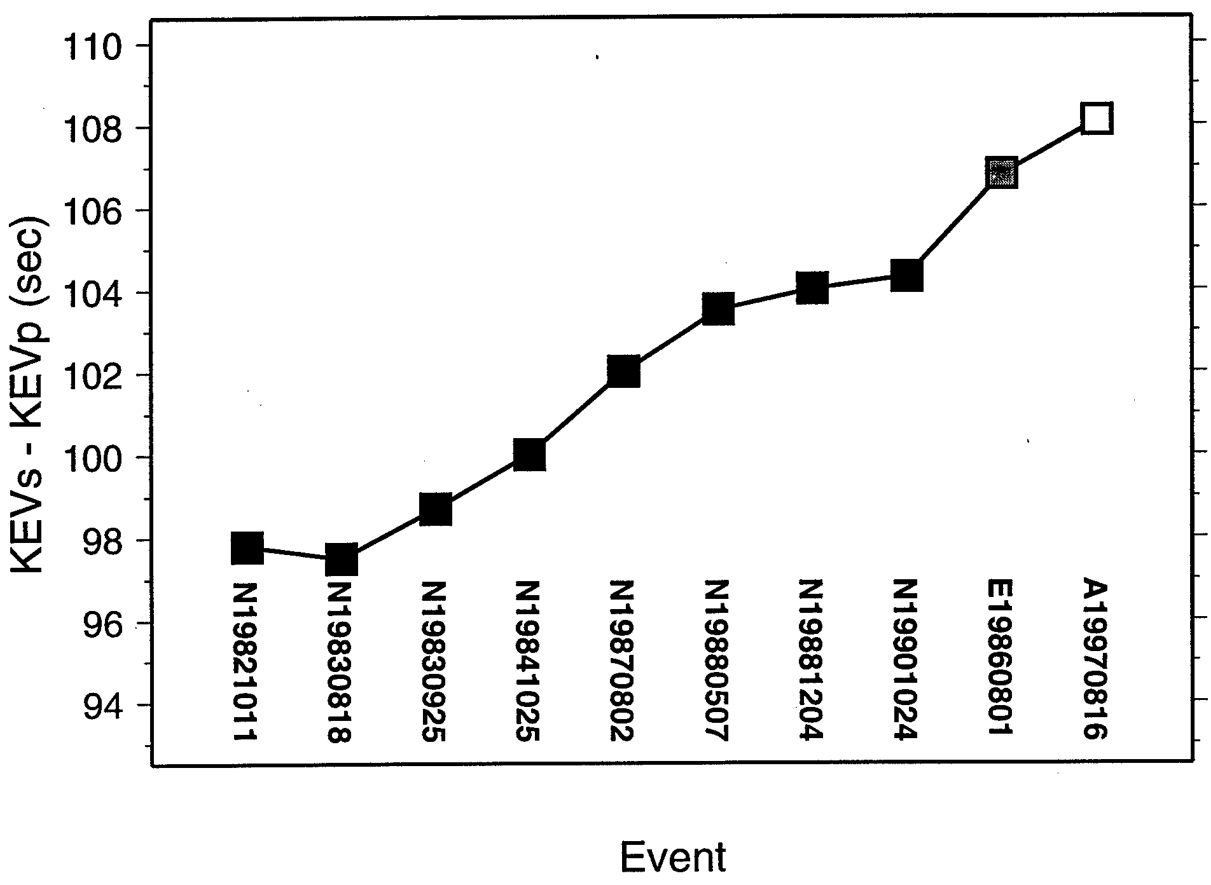
20°
40°
60°
80°
140°
120°



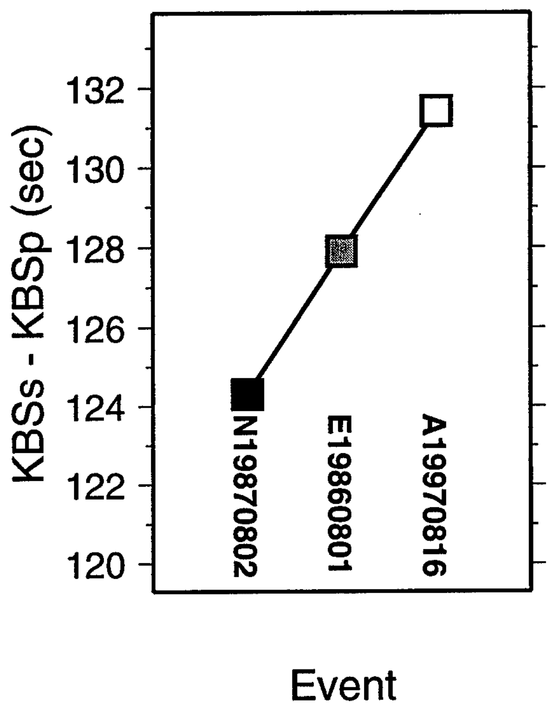
A
B
10
SPB4/BHZ
11
SPB4/BHN
12
SPB4/BHE
6
4
2
0
:01:30
00:02:2.6
:30
:03:00
:30
00:04:3.5
:30
Time (hr:min:sec)

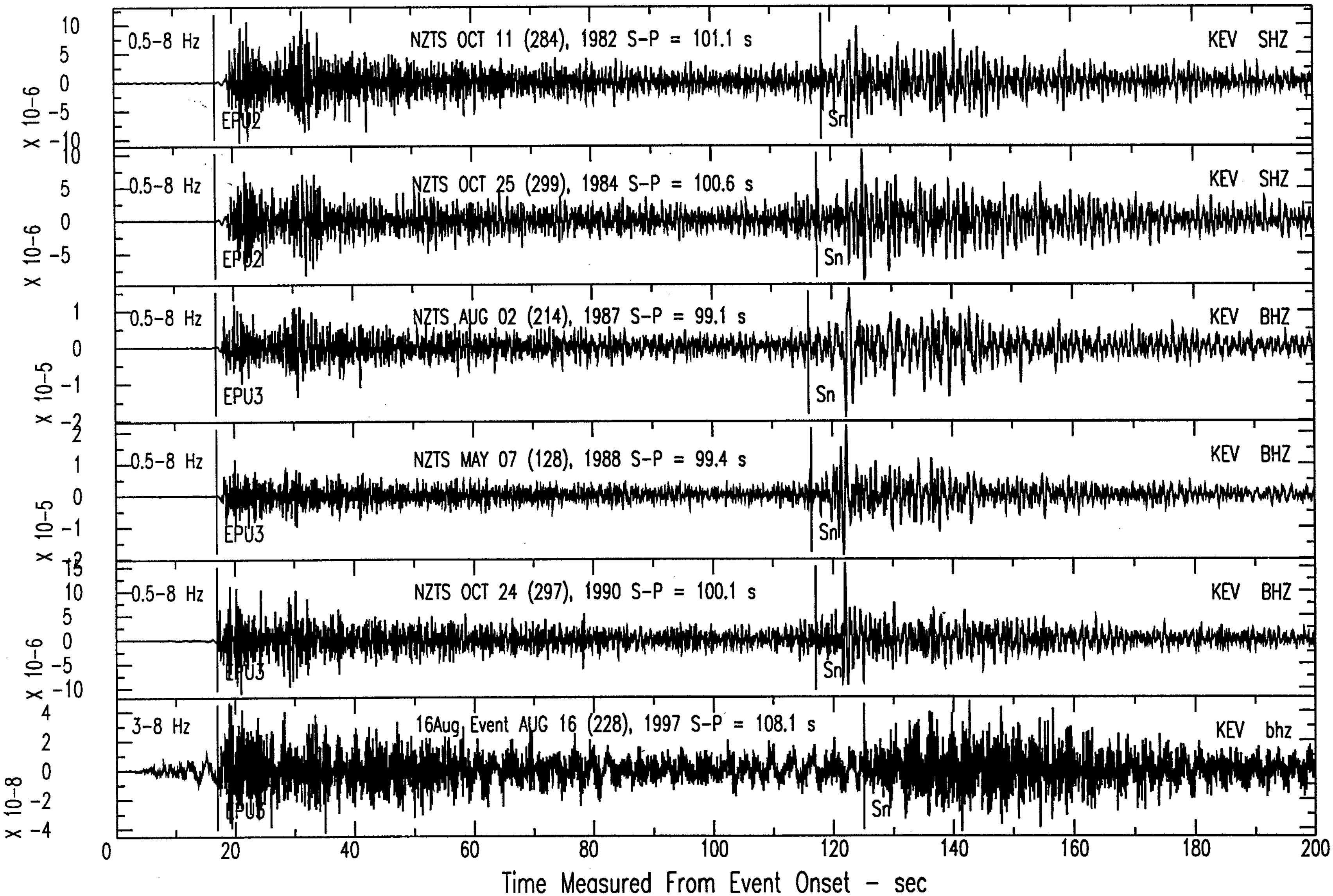

KEV and KBS Data - 16 Aug Event - BP 3-8 Hz
KEV bhe
AUG 16 (228) 1997
02:10:59.901
KEV bhn
AUG 16 (228) 1997
02:10:59.901
KEV bhz
AUG 16 (228) 1997
KBS BHE
KBS BHN
KBS BHZ
EPU3
Sn
EPD3
X 10-8
Time Measured From Event Origin - sec

KEV S - P times (ISC)

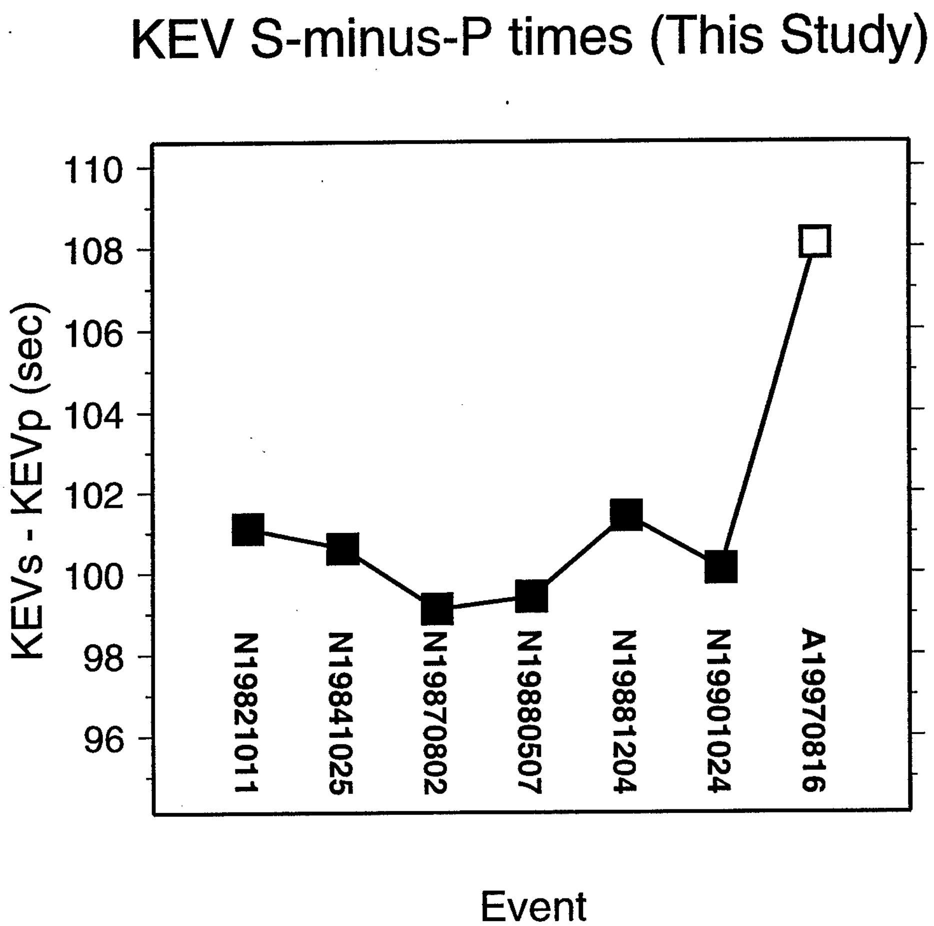


KBS S-minus-P times (ISC)





0.5-8 Hz
NZTS OCT 11 (284), 1982 S-P = 101.1 s
KEV SHZ
EPU2
Sn
0.5-8 Hz
NZTS OCT 25 (299), 1984 S-P = 100.6 s
KEV SHZ
Sn
0.5-8 Hz
NZTS AUG 02 (214), 1987 S-P = 99.1 s
KEV BHZ
EPU3
Sn
0.5-8 Hz
NZTS MAY 07 (128), 1988 S-P = 99.4 s
KEV BHZ
EPU3
Sn
0.5-8 Hz
NZTS OCT 24 (297), 1990 S-P = 100.1 s
KEV BHZ
Sn
3-8 Hz
16Aug Event AUG 16 (228), 1997 S-P = 108.1 s
KEV bhz
Sn
X 10-6
X 10-6
X 10-5
X 10-5
X 10-6
X 10-8
Time Measured From Event Onset - sec


KEV S-minus-P times (This Study)
110
108
106
104
102
100
98
96
KEVs - KEVp (sec)
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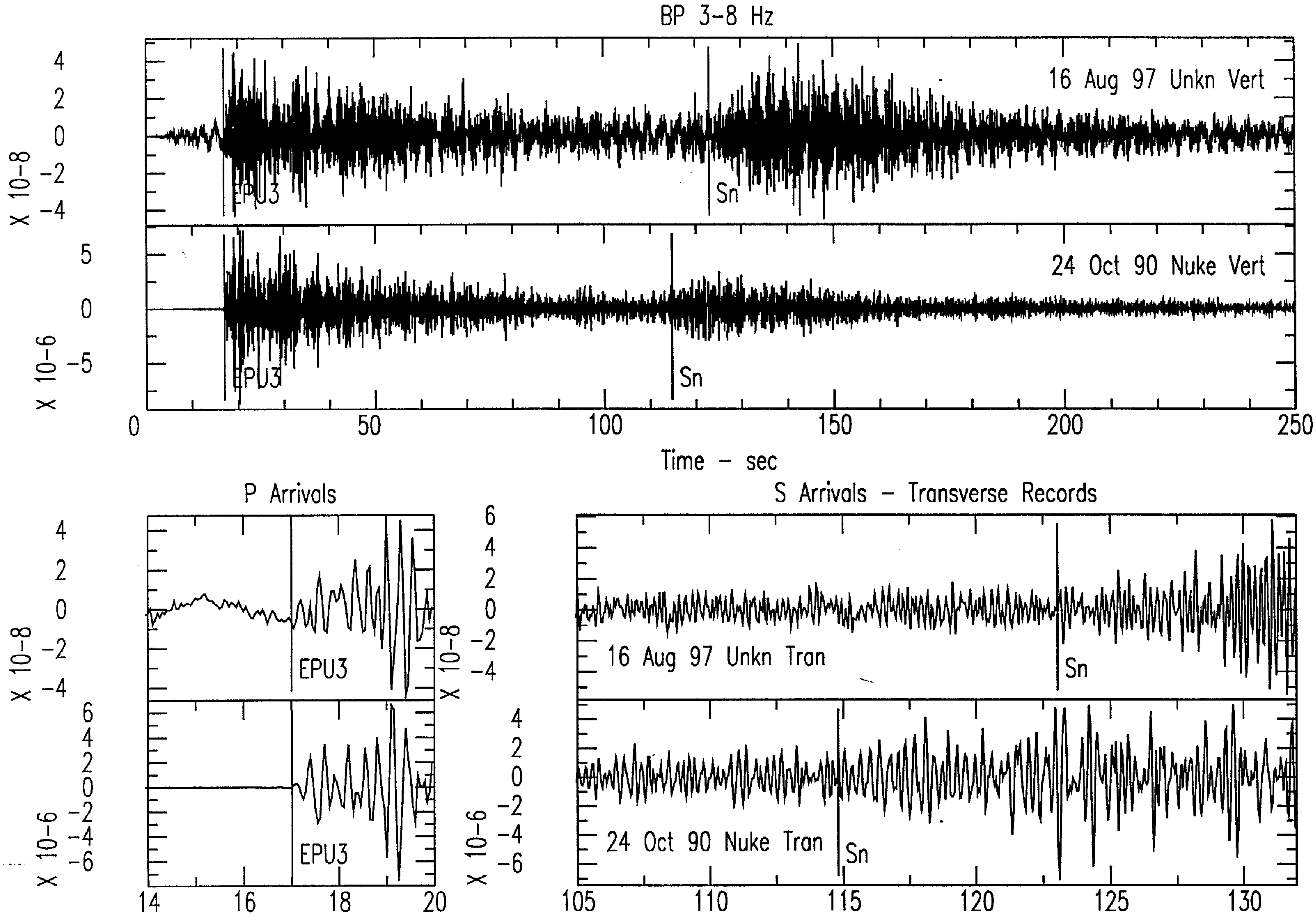
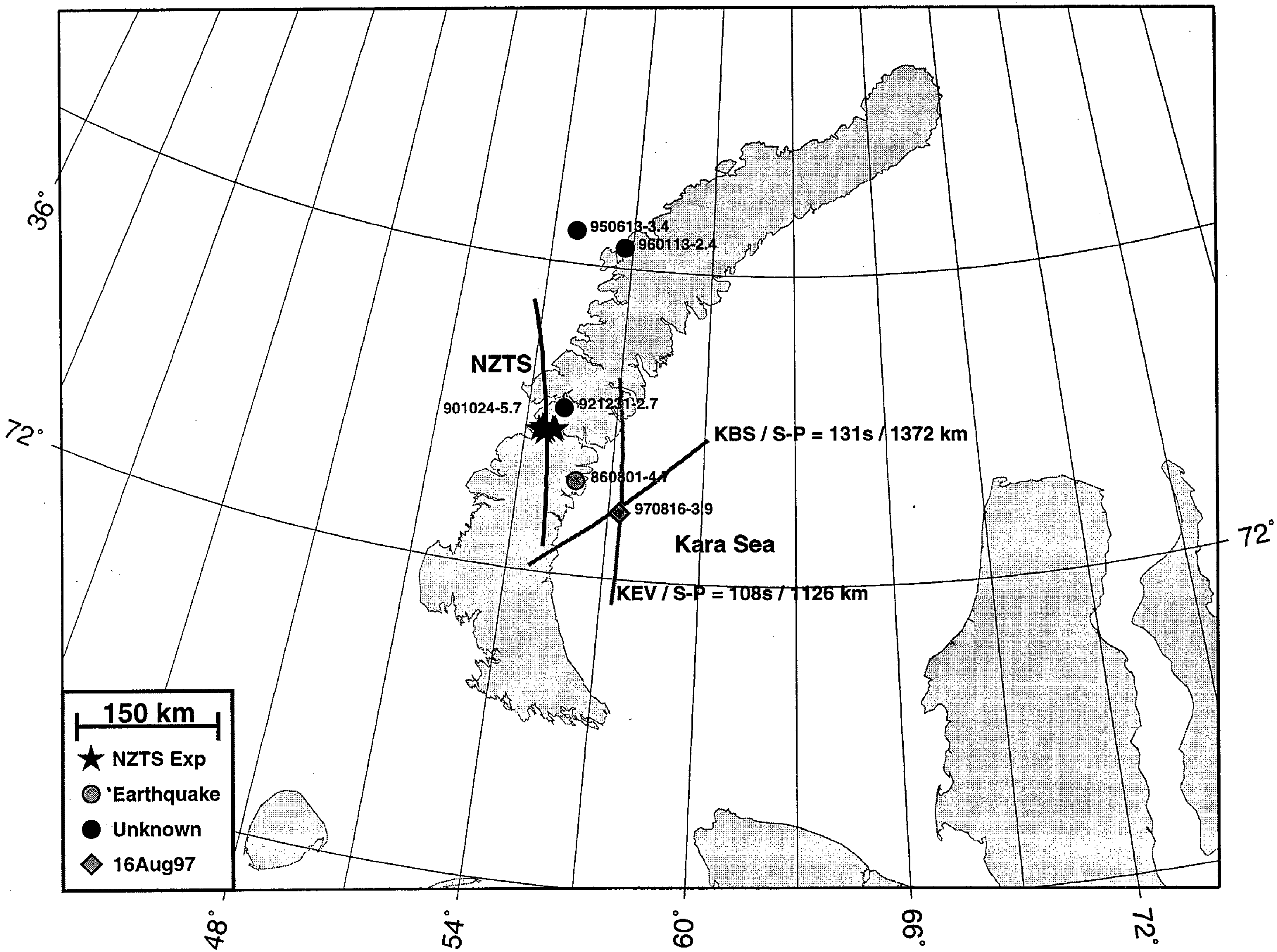
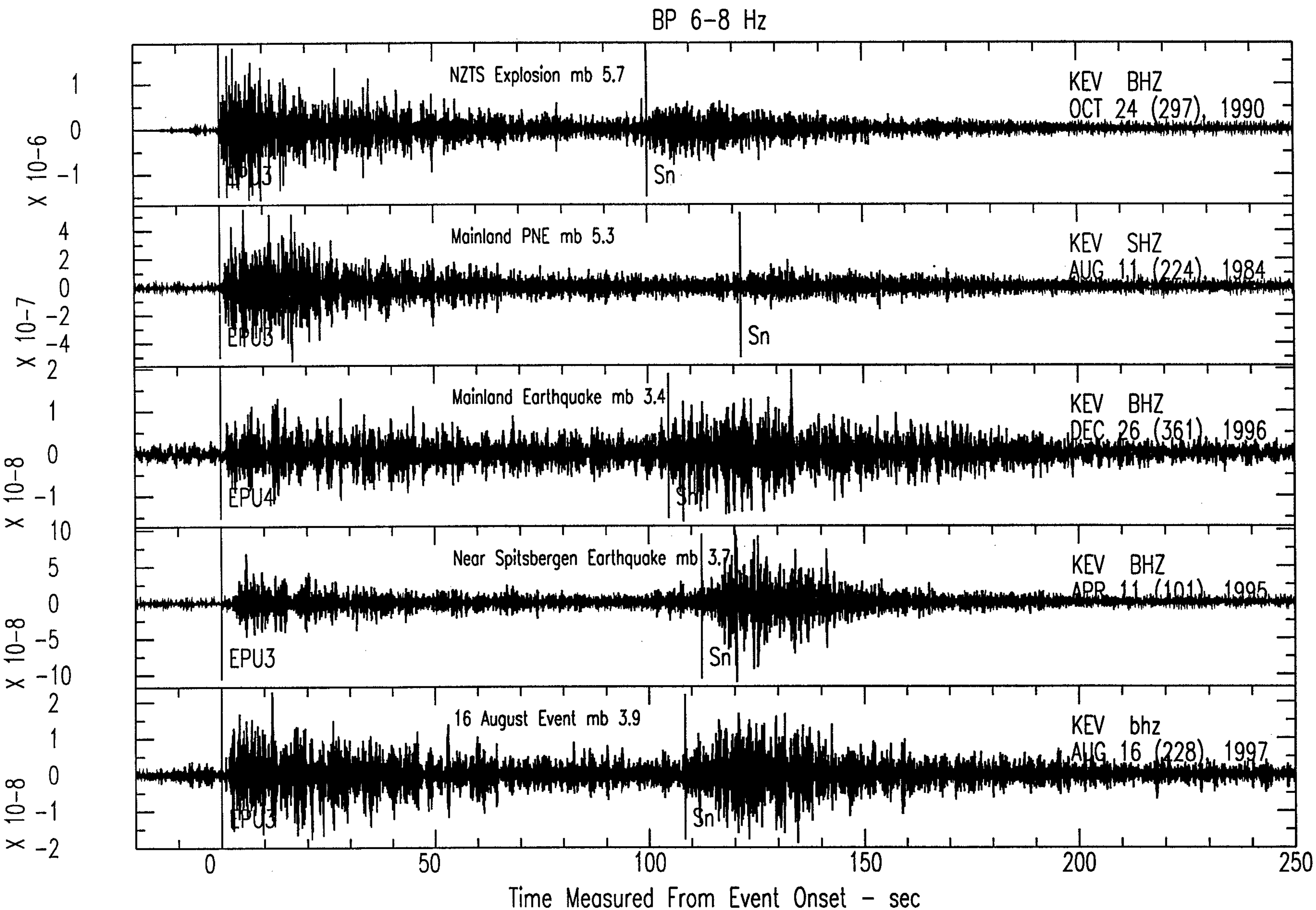
Event


BP 3-8 Hz
16 Aug 97 Unkn Vert
24 Oct 90 Nuke Vert
EPU3
Sn
X 10-8
X 10-6
Time - sec
P Arrivals
S Arrivals - Transverse Records
16 Aug 97 Unkn Tran
24 Oct 90 Nuke Tran

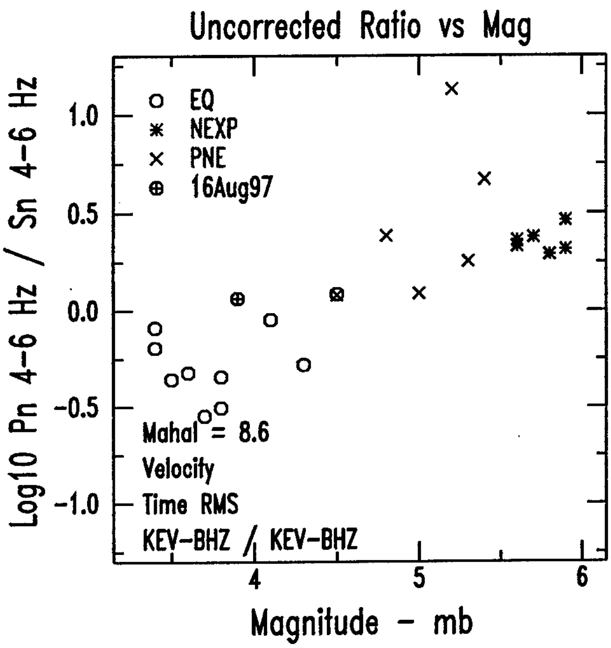
4

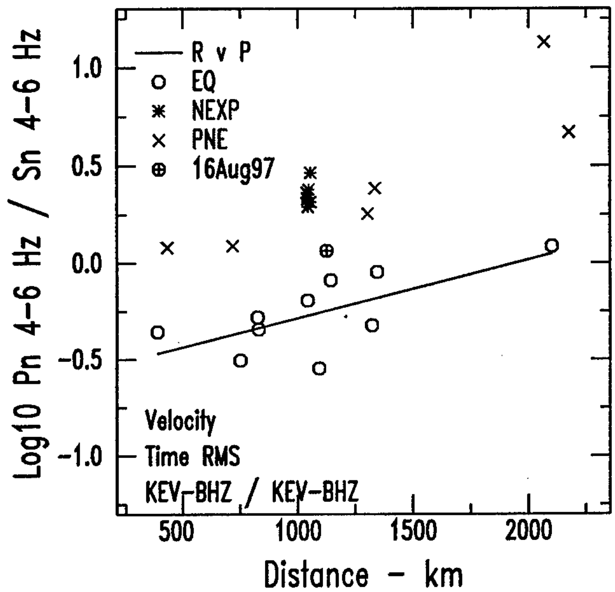


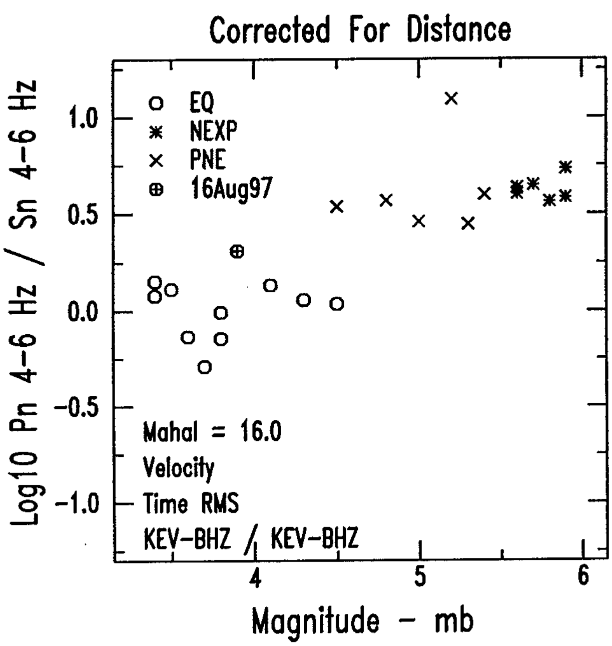
36°
72°
72°
48°
54°
60°
66°
72°
NZTS
901024-5.7
921231-2.7
950613-3.4
960113-2.4
860801-4.1
970816-3.9
KBS / S-P = 131s / 1372 km
KEV / S-P = 108s / 1126 km
Kara Sea
150 km
NZTS Exp
Earthquake
Unknown
16Aug97



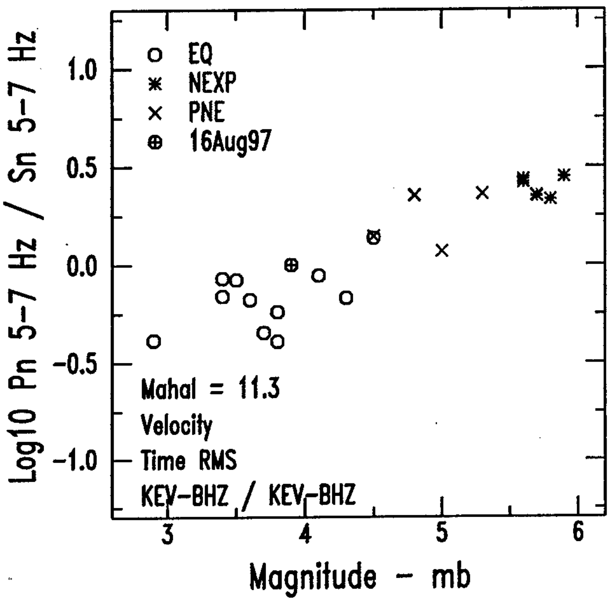
BP 6-8 Hz
NZTS Explosion mb 5.7
KEV BHZ
OCT 24 (297), 1990
EPU3
Sn
Mainland PNE mb 5.3
KEV SHZ
AUG 11 (224), 1984
EPU3
Sn
Mainland Earthquake mb 3.4
KEV BHZ
DEC 26 (361), 1996
EPU4
Sn
Near Spitsbergen Earthquake mb 3.7
KEV BHZ
APR 11 (101), 1995
EPU3
Sn
16 August Event mb 3.9
KEV bhz
AUG 16 (228), 1997
EPU3
Sn
X 10-6
X 10-7
X 10-8
X 10-8
X 10-8
0
50
100
150
200
250
Time Measured From Event Onset - sec

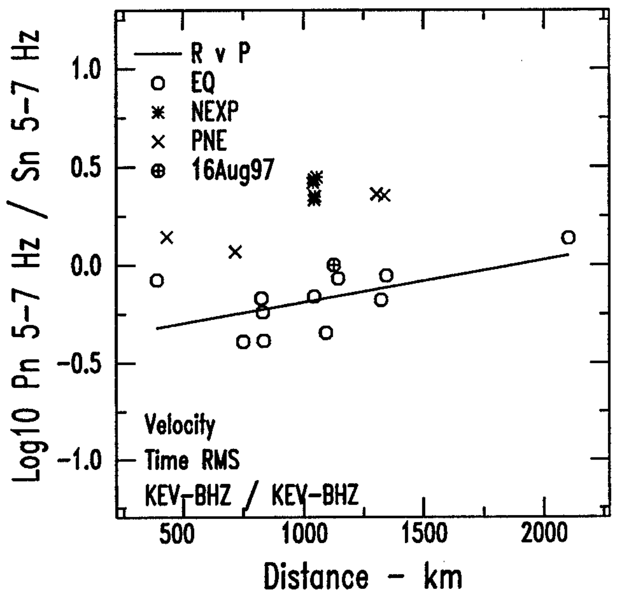

Uncorrected Ratio vs Mag
EQ
NEXP
PNE
16Aug97
Mahal = 8.6
Velocity
Time RMS
KEV-BHZ / KEV-BHZ
Log10 Pn 4-6 Hz / Sn 4-6 Hz
1.0
0.5
0.0
-0.5
-1.0
4
5
6
Magnitude - mb


R v P
EQ
NEXP
PNE
16Aug97
Velocity
Time RMS
KEV-BHZ / KEV-BHZ
Log10 Pn 4-6 Hz / Sn 4-6 Hz
1.0
0.5
0.0
-0.5
-1.0
500
1000
1500
2000
Distance - km

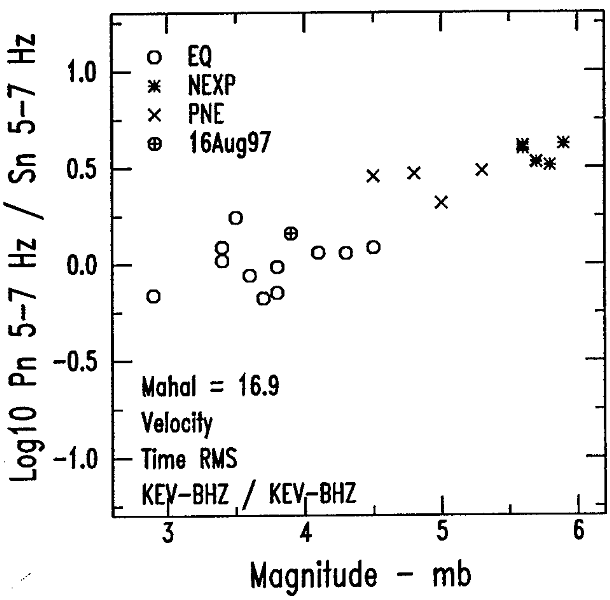

Corrected For Distance
EQ
NEXP
PNE
16Aug97
Mahal = 16.0
Velocity
Time RMS
KEV-BHZ / KEV-BHZ
Log10 Pn 4-6 Hz / Sn 4-6 Hz
1.0
0.5
0.0
-0.5
-1.0
4
5
6
Magnitude - mb

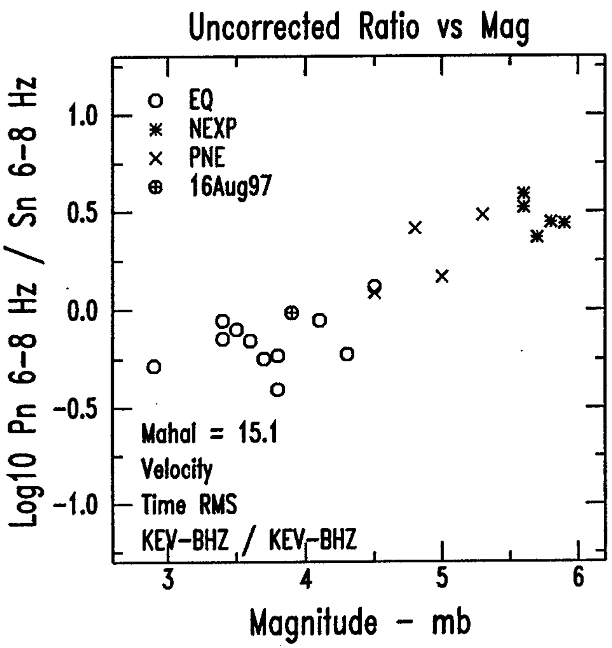
Uncorrected Ratio vs Mag

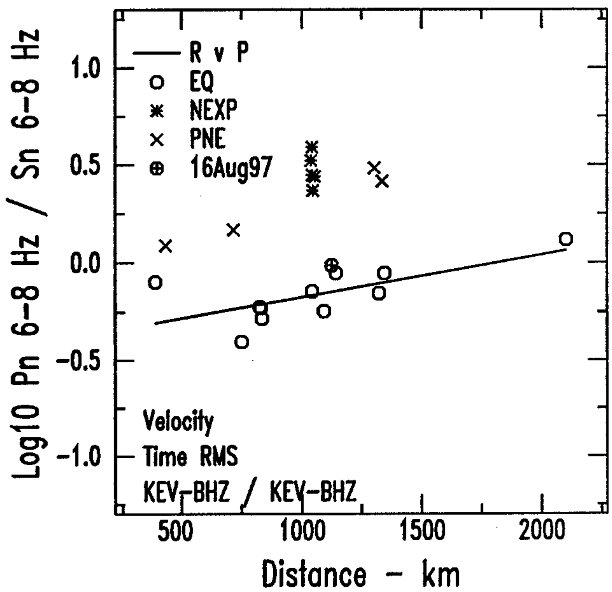




Corrected For Distance




Uncorrected Ratio vs Mag
Log10 Pn 6-8 Hz / Sn 6-8 Hz
EQ
NEXP
PNE
16Aug97
Mahal = 15.1
Velocity
Time RMS
KEV-BHZ / KEV-BHZ
Magnitude - mb


Log10 Pn 6-8 Hz / Sn 6-8 Hz
R v P
EQ
NEXP
PNE
16Aug97
Velocity
Time RMS
KEV-BHZ / KEV-BHZ
Distance - km

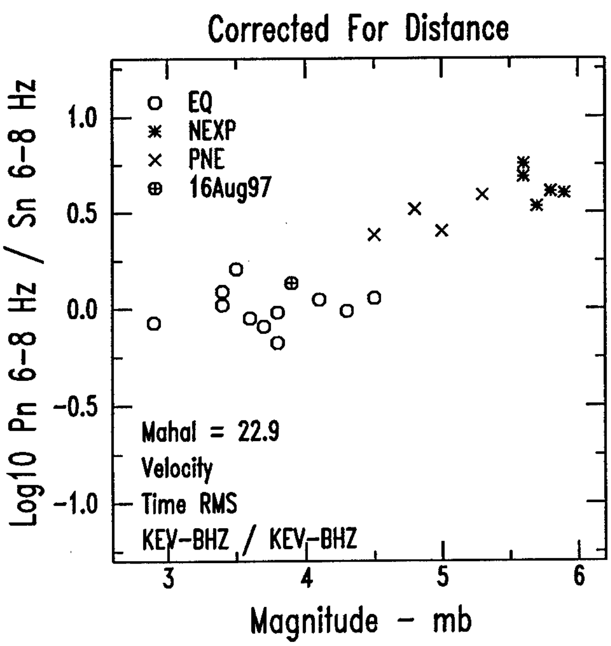

Corrected For Distance
Log10 Pn 6-8 Hz / Sn 6-8 Hz
EQ
NEXP
PNE
16Aug97
Mahal = 22.9
Velocity
Time RMS
KEV-BHZ / KEV-BHZ
Magnitude - mb

Table 1

Location Information For 16 August 1997 Event					
Origin Time	*Lat (°N)*	*Lon (°E)*	*Depth (km)*	*Mag*	*Organization*
19970816 021059.9	72.6484	57.3517	0	3.9 mb	PIDC
19970816 021101.8	72.57	57.72	10	3.8 ML	FIN NDC
19970816 021100.4	73	57		3.6 ML	NORSAR
19970816 021059.77	72.835	57.225	10	3.2 ML	USGS

Note: NORSAR reports no depth. All other depths were fixed by the analyst.

Location Information For 1990 Novaya Zemlya Explosion					
Origin Time	*Lat (°N)*	*Lon (°E)*	*Depth (km)*	*Mag*	*Organization*
19901024 145758.1	73.361	54.707	0	5.7 mb	USGS

Table 2

KEV P and S Arrival Times							
Event	*Type*	*ISC Bulletin*			*This Study*		
		P_n	S_n	*S-P*	P_n	P_n	*S-P*
19821011	NZTS Exp	071714.2	071852	97.8	071712.9	071854.0	101.1
19830818	NZTS Exp	161215.5	161353	97.5			
19830925	NZTS Exp	131213.3	131352	98.7			
19841025	NZTS Exp	063215.0	063355	100.0	063213.8	063354.4	100.6
19870802	NZTS Exp	020216.0	020358	102.0	020215.6	020354.7	99.1
19880507	NZTS Exp	225213.5	225357	103.5	225213.7	225353.1	99.4
19881204	NZTS Exp	052211.0	052355	104.0	052210.1	052351.5	101.4
19901024	NZTS Exp	150014.6	150159.9	104.3	150015.3	150155.4	100.1
19860801	Earthquake	135858.2	140045.0	106.8			
19970816	16 August				021325.1	021513.2	108.1

KBS P and S Arrival Times							
Event	Type	*ISC Bulletin*			*This Study*		
		P_n	S_n	*S-P*	P_n	P_n	*S-P*
19821011	NZTS Exp	071739.9					
19830925	NZTS Exp	131239.1					
19841025	NZTS Exp	063239.6					
19870802	NZTS Exp	020241.2	020445.5	124.3			
19880507	NZTS Exp	225243.2					
19901024	NZTS Exp	150039.9					
19860801	Earthquake	135924.2	140132.1	127.9			
19970816	16 August				021357.1	021608.5	131.4

Table 3

Events Used For Discrimination Anaysis At KEV						
Event	*Type*	m_b	*Dist (km)*	*Lat (°N)*	*Lon (°E)*	*Source*
820904175958	PNE	5.2	2068	69.206	81.647	USGS
821011071458	NEXP	5.6	1042	73.392	54.559	USGS
840811185957	PNE	5.3	1304	65.025	55.187	USGS
840825185958	PNE	5.4	2177	61.876	72.092	USGS
840827055957	PNE	4.5	432	66.770	33.680	USGS
841025062957	NEXP	5.9	1054	73.370	54.955	USGS
850718211457	PNE	5.0	717	65.970	40.863	USGS
870802015959	NEXP	5.8	1043	73.339	54.626	USGS
880507224958	NEXP	5.6	1038	73.364	54.445	USGS
880906161958	PNE	4.8	1336	61.331	47.955	USGS
881204051953*	NEXP	5.9	1055	73.387	54.998	USGS
901024145758	NEXP	5.7	1046	73.361	54.707	USGS
950304182903	Quake	3.6	1323	81.600	28.990	USGS
950411200726	Quake	3.7	1093	79.050	39.000	PIDC
950704032615	Quake	4.5	2102	79.930	94.920	USGS
950829221214	Quake	4.3	825	77.040	22.500	PIDC
960610171647	Quake	4.1	1345	59.740	43.110	PIDC
961008045413	Quake	3.8	830	77.160	24.670	PIDC
961027235515	Quake	3.4	1143	79.960	23.430	PIDC
961226044411	Quake	3.4	1043	63.350	44.310	PIDC
970114003652	Quake	3.8	751	76.460	28.840	PIDC
970502073116	Quake	3.5	389	72.465	20.195	PIDC
970816021059	16 Aug	3.9	1125	72.648	57.352	PIDC

*Event 881204051953 was not used in discrimination analysis for bands above 6 Hz because of high-frequency noise spikes on the record.

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