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SINGLE-STATION LOCATIONS OF SEISMIC EVENTS

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ABSTRACT

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This report describes the progress being made in event location using a single 3-component station. In this study locations are obtained using a backazimuth determined by the particle motion of Pn and a distance determined by differential travel times between Pn, Pg, and Lg relative to a master event of known location.

The data set used consists of the seismic signals from 11 nuclear events at the Nevada Test Site (NTS) and recorded at the four Lawrence Livermore National Laboratory (LLNL) seismic stations: Elko, Kanab, Landers, and Mina. The stations range from 230 km to 400 km away from the events. The local magnitude (M_L) of the events range from 3.7 to 5.6 with the small events barely visible over the microseisms. All calculations and observations are made after the events have been filtered between 0.3 and 6 Hz.

The results of this analysis show that backazimuth can be determined to within $\pm 5^\circ$ of the true backazimuth, about 90% of the time, after systematic variations are taken out. These systematic variations are small for some stations like Elko but large (15° to 20°) for Mina. Little time was spent to optimize the backazimuth calculation except to determine the parameters that gave a consistent result, so further improvement is likely with more work. The distance calculation is subject to several errors, as is the backazimuth calculation, and the resulting location is usually within 20 km of the actual epicenter and many times within 10 km.

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INTRODUCTION

Seismologists have been locating seismic events for many years utilizing a number of different methods (cf. Buland, 1976). Typically, the times of the first arrivals are read at 4 or more stations and are combined with a velocity model to determine the location using Geiger's method. In some cases, later arrivals are also used, but this approach is not widespread due to the difficulty of identifying the later arrivals.

Recently more emphasis has been placed on combining measurements made on vertical and horizontal data. This allows the full 3-dimensional particle motion of the seismic wave train to be calculated. Three component particle motion analysis aids in the identification of secondary phases in the wave train and determination of the direction of approach and incident angle of each phase. Each seismic phase has a characteristic particle motion whose orientation is related to the direction the wave is traveling. If the assumption is made that the earth is laterally homogeneous (thereby eliminating the possibility of lateral refractions and scattering) knowledge of the direction a seismic wave is traveling can be used to infer the direction to the source. Knowing the direction to the source and using a velocity model for the earth in that direction, the distance to the source can be determined by measuring the travel-time differences of various seismic phases. The epicenter of the source can then be determined by using the direction and distance information. Thus, by only using one station with 3 components of data the source can be located.

The seismic phase that is the simplest to understand and the least contaminated by signal generated noise is the first arrival P phase. Its particle motion is in the vertical plane containing the source and the receiver. The projection of this motion on a horizontal plane can be used to determine the direction of approach of the wave unless the P wave arrives at the station with nearly vertical incidence. This often occurs for teleseismic P waves, for deep-focus events near the station, or when there is a low velocity layer at the surface. The P phase must also have good signal-to-noise characteristics so its particle motion is not masked by the particle motion due to the background noise. Other problems may be caused by lateral inhomogeneities in the earth which allow lateral refractions or scattered energy to contaminate the P phase and, in some cases, give a systematic rotation to its particle motion.

Other phases in the seismic wave train can be used to determine the direction to the source but each one has its own inherent problems when used to determine the direction the wave is traveling. The data presented in this report are based upon the first arrival Pn phase which is critically refracted from the crust-mantle boundary. The back azimuth calculation is done using the Pn phase and the distance calculation is done using arrival time differences between Pn, Pg and Lg.

THE DATA

The data used in this study come from 11 explosions ranging in local magnitude (M_L) from 3.7 to 5.6. The explosions were detonated at the

Nevada Test Site in the Yucca Valley and Pahute Mesa test areas. Figure 1 shows the location of the events at the Nevada Test Site and Table 1 gives the names, dates, locations, and magnitudes of the events. The three-component data from these events were recorded at the four LLNL stations located near Mina, Nevada; Kanab, Utah; Landers, California; and Elko, Nevada. Figure 2 shows the locations of the stations relative to the Nevada Test Site and Table 2 gives the station locations. It should be noted that for the events considered the four LLNL stations had horizontal seismometers oriented radially and tangentially to a point at the Nevada Test Site (37.2N, 116.1W). Columns four and five in Table 2 give the positive direction of the horizontal components where zero is North and positive angles are clockwise from North. Further information about the LLNL stations can be found in Denny (1977).

Collection of data from the above events occurred during the time when the LLNL Seismic system was being converted to a digital system. For this reason and because of telephone transmission problems some events were not recorded at all four of the stations. Table 3 shows the stations which recorded usable data for each event. This table also shows the distance from each station to each event and the actual back azimuth. These two parameters will be used to check the accuracy of the single-station location technique.

All of the data were digitized in real time at the stations before being transmitted over phone lines to the LLNL Seismic Research Center at Livermore, California. The digitization rate was 42 samples per second per component.

Figure 3 shows an example of the broadband three-component data from the event Nessel as recorded at Elko. Figure 4 shows just the Pn phase at Elko for all three components. Some of the events used in this study had Pn amplitudes much smaller than the microseisms so filtering was necessary. The filtering was done with an 11 point cosine taper in the frequency domain resulting in signals band limited between .3 and 6 hertz.

BACKAZIMUTH CALCULATION

The method used to determine particle motion on 3 components of data in this work is described in Montalbetti and Kanasewich (1970), and Flinn (1965). Basically, this method calculates a three-dimensional ellipsoid, fitting the particle motion over a finite time window. For the case of random noise, this ellipsoidal envelope would be spherical and for a pure longitudinal motion it would be a straight line (degenerate ellipsoid). For the usual case of a longitudinal wave plus a small noise component, the direction of the major axis of the ellipsoidal envelope is parallel to the propagation direction.

The ellipsoid is estimated by calculating a covariance matrix from the 3 components of data. The matrix is then rotated to its principle axes and the resulting eigenvalues represent the dimensions of the best-fitting ellipsoid in the directions given by the eigenvectors (relative to the original coordinate system).

In the case of a longitudinal wave such as Pn, one of the eigenvalues should be much larger than the others, indicating an elongate ellipsoid. The corresponding eigenvector can be used to determine the orientation of the ellipsoid in 3-D space. This orientation can be represented as an azimuth in the horizontal plane and an incident angle relative to the vertical axis. Since the Pn wave arrives at the station from below, the measured incident angle can be used to determine the unique direction the Pn wave is traveling. A rotation of 180 degrees from this direction gives the back azimuth, or direction pointing back to the source.

The above calculation is performed on overlapping time "windows" of the trace. The variables in these calculations are the number of points in each time window and the amount of overlap of each window. The window length chosen for this data set was 40 samples and the overlap was 75%.

DISTANCE CALCULATION

The distance from the station to the source was calculated using travel-time differentials between Pn-Pg and Pn-Lg. No absolute Pg or Lg arrival time pick was made, instead a master event technique was used. It was assumed that one of the large events had been recorded by enough stations to be located accurately or was located by some other means. From this information, Pn and approximate Pg and Lg velocities were calculated. For this study, event Nessel was taken to be the master event. Each other event is overlayed on the master and offsets are determined. It can be shown that if the time of Pg for an event is delta-time different from the master event

Pg time (after the Pn's have been aligned), then the distance to the event is $C \cdot \Delta t$ plus the distance to the master event. C is defined to be:

$$C = \frac{\text{velocity of Pn} \cdot \text{velocity of Pg}}{\text{velocity of Pn} - \text{velocity of Pg}}$$

Similar relations can be constructed for other phases but only Lg and Pg were considered distinct enough to be used in this study.

OBSERVATIONS

The values of the back azimuth for the Pn wave were determined by averaging the values of the back azimuth for six consecutive windows with centers starting at the Pn onset. Figure 5 shows the actual back azimuths plotted vs. the back azimuths calculated using the Pn particle motion. The calculated azimuths are usually greater than the actual ones by up to 22 degrees. Figure 6 shows the differences in detail with the error plotted against the actual values. A difference of zero means that the measured back azimuth is exactly the same as the actual back azimuth. The data from Elko gives back azimuths only a couple of degrees from the actual values, while Kanab and Landers show five-to-eight degree offsets. Mina shows the greatest errors ranging from 11 to 22 degrees.

The results of the distance calculation are shown in Figure 7. Here the error in estimation (the actual distance subtracted from the calculated distance) is plotted vs. the actual distances. The distance values are calculated from an average of the Pn-Pg and the Pn-Lg results.

Utilizing the spread in values for all the events recorded at a station an ellipse can be constructed to give a summary plot of where the single-station calculation located the events as a group (Figure 8). Note that events located from Elko data are close to their actual locations. Landers and Kanab data located the events 10 to 50 kilometers away and Mina shows even greater offset in its location.

CONCLUSION AND RECOMMENDATIONS

In conclusion, one can say that single station location techniques are feasible, especially if a calibration event from the same area is available. However, if a calibration event is not available, errors in the back azimuth calculation can be off by as much as 20 degrees or more. The errors in estimation could be caused either by the structure between the source and the receiver or possibly a misalignment of the horizontal components. Continuation of this work indicates that the directional error produced by the particle motion at Mina varies with azimuth of the source (Dave Harris, personal communication). This would indicate that the error is caused by path effects between Mina and NTS.

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FIGURE CAPTIONS

1. Map of the Nevada Test Site showing the locations of the events used in this report.
2. Location of LLNL seismic stations relative to NTS.
3. Broadband seismic data for NTS event Nessel recorded at Elko.
4. Pn phase for NTS event Nessel at Elko.
5. Actual back azimuths vs. observed back azimuths from each of the stations to the event location.
6. Actual back azimuths vs the error in the azimuth calculation for each event-station pair.
7. Actual distance vs. the error in the distance calculation for each event-station pair.
8. Map showing error ellipses for each LLNL seismic station using NTS events. Each ellipse represents the location for the population of events if only the station perpendicular to the major axis of the ellipse was used to locate the events.

TABLE 1

LOCATION AND MAGNITUDE OF EVENTS

<u>EVENT</u>	<u>DATE</u>	<u>LATITUDE</u>	<u>LONGITUDE</u>	<u>MAGNITUDE (M)</u>
KLOSTER	02/15/79	37.1520 N	116.0718 W	4.6
CHESS	06/20/79	37.1076 N	116.0151 W	5.0
FAJY	6/28/79	37.1432 N	116.0875 W	4.8
BURZET	08/03/79	37.0840 N	116.0699 W	4.8
OFFSHORE	08/03/79	37.0147 N	116.0080 W	5.0
NE SSEL	08/29/79	37.1212 N	116.0666 W	5.6
HEARTS	09/06/79	37.0881 N	116.0528 W	5.5
PERA	09/08/79	37.15550 N	116.0382 W	3.7
SHEEPSEHAD	09/26/79	37.2291 N	116.3641 W	5.4
BACKGAMMON	11/29/79	36.9940 N	116.0241 W	4.0
AZUL	12/14/79	37.1379 N	116.06307 W	4.6

TABLE 2

LOCATION OF LLNL NETWORK STATIONS

<u>NAME</u>	<u>LATITUDE</u>	<u>LONGITUDE</u>	<u>RADIAL</u> <u>DIRECTION</u>	<u>TANGENTIAL</u> <u>DIRECTION</u>
	(deg.)	(deg.)	(deg. from N clock)	
ELKO	40.745 N	115.239 W	10.5	
KANAB	37.017 N	112.822 W	95.0	
LANDERS	34.390 N	116.412 W	185.2	
MINA	38.432 N	116.154 W	307.7	

TABLE 3
DISTANCE AND BACKAZIMUTH FROM STATION TO SOURCE

									Sheeps	Back		
	Kloster	Chess	Fajy	Burzet	Offshore	Nessel	Hearts	Pera	Head	Gammon		Azul
	BACK AZIMUTH IN DEGREES FROM NORTH											
ELK	190.5	189.7	191.0	190.3	189.3	190.4	190.1	190.1	194.4	189.5	190.3	
KNB	X	X	X	272.4	270.9	273.3	272.6	274.0	275.3	270.4	273.7	
LAC	X	6.7	5.4	5.8	7.0	5.8	6.1	6.1	0.8	6.9	5.8	
MNU	X	X	127.5	X	X	127.7	128.2	126.6	129.7	129.7	127.2	

DISTANCE IN KILOMETERS

ELK	405.3	409.4	406.5	412.7	419.4	404.6	412.0	404.5	402.3	422.3	406.5
KNB	X	X	X	289.0	283.5	288.7	287.4	286.3	315.6	284.6	288.2
LAC	X	303.7	306.9	300.5	293.5	304.6	301.1	308.7	315.1	290.7	306.8
MNV	X	X	231.5	X	X	234.5	237.8	234.1	266.5	247.1	233.7

Figure 2. Locations at Lawrence Livermore National Laboratory broadband seismograph stations used in this study.

Figure 3. Broadband velocity seismograms of the Nessel explosion recorded at Elko. The vertical, radial, and transverse components of motion are so identified. Several arrivals of seismic phases are marked on the vertical component record.

Fig. 4

ACTUAL VS OBSERVED BACKAZIMUTHS FROM DSS TO NTS

Fig. 5

Fig. 6

Fig. 7

Fig. 8