An introduction to the SEP passive seismic dataset

Dave Nichols, Steve Cole and Lin Zhang

ABSTRACT

The passive seismic dataset acquired by SEP in fall 1988 provides a 3-D dataset with data that is unaliased in both x and y. The raw data contains some large spikes, traces with anomalous amplitudes and some monochromatic noise. These defects can be corrected and signals arriving from many different directions can be clearly seen. Some of the energy arrives at near vertical incidence as was hoped when the experiment was designed. This energy can be seen clearly on 2-D displays formed by projecting the 3-D data onto a 2-D plane and stacking.

INTRODUCTION

As described by Claerbout et al. (1988) the first goal of the SEP passive seismic experiment was to measure an emergent angle spectrum of the ambient wavefield. The dataset collected by SEP in September 1988 was collected on a grid which was sampled finely enough to allow conventional signal processing techniques to be applied in all three dimensions. The 13×13 grid had a group spacing of 125 feet, giving an array which was 1500 feet square. After conditioning the data to remove spikes and monochromatic noise and equalize trace amplitudes we can perform multichannel processing on the data to estimate the arrival direction of the various signals. We show some simple Fourier transform and beam forming processing of the data which reveals many distinct signals arriving at the array. Much of the energy arrive at slow surface velocities and is probably due to surface traveling waves generated by the nearby freeway and urban areas. There is also some energy arriving at high surface velocities. This is the steeply emerging energy we hoped to find. If the data is projected onto 2-D planes and stacked there are clearly coherent events arriving at angles close to the vertical.

ACQUISITION

In September 1988 the SEP personnel laid out a 1500 foot square array of receivers. The geophone groups were laid out to give a 13×13 grid, each group was connected to a seismic group recorder (SGR). Each group had 24 geophones laid out in a square at a spacing of 25ft.

The ambient wavefield was mostly recorded at night to minimize cultural noise. Nine records were recorded during the day to provide a comparison of day and night conditions and to attempt to record arrivals from blasts in a quarry 15 miles away. A total of 45 records were recorded, each record was 32 seconds long and was recorded at a 2ms sampling rate. During the night some of the SGR's ceased operation, the earliest records only have a few dead traces but by the end of the survey (the daytime records) about 20 percent of the SGRs had failed.

PRE-PROCESSING

Figure 1 shows 2 lines of raw field data from a record recorded at night and the same data after our pre-processing steps. The raw data is on the left and the pre-processed data is on the right. Only the first 1000 of 16000 samples are shown. On the raw data trace amplitudes are not balanced, some of the traces are dominated by high frequencies and there are large spikes present in the data. The lack of data on the bottom left plot is due to a large spike on the third trace that has caused the plot to be clipped at a very high value. The spikes are due to errors in transcription from the field tapes and are up to a factor of 10^4 higher than the rest of the data. Figure 2 shows average spectra for six records, the upper three were recorded at night and the lower three during the day. If the 60Hz spike from the nearby power lines is taken as a reference amplitude it can clearly be seen that there is a lot more low frequency energy on the daytime records.

Despike

A simple despike program was written to eliminate the spikes. The program finds the median absolute amplitude value within a window. It then calculates a trimmed mean dispersion for the absolute amplitudes within the window. A sample is identified as a spike if it falls more than a specified number of dispersions away from the median. A spike is replaced by the previous sample value.

The data was filtered using a value of seven dispersions as the cutoff for identifying spikes. This appeared to remove all the major spikes in the data and some sample values that were smaller but also anomalous.

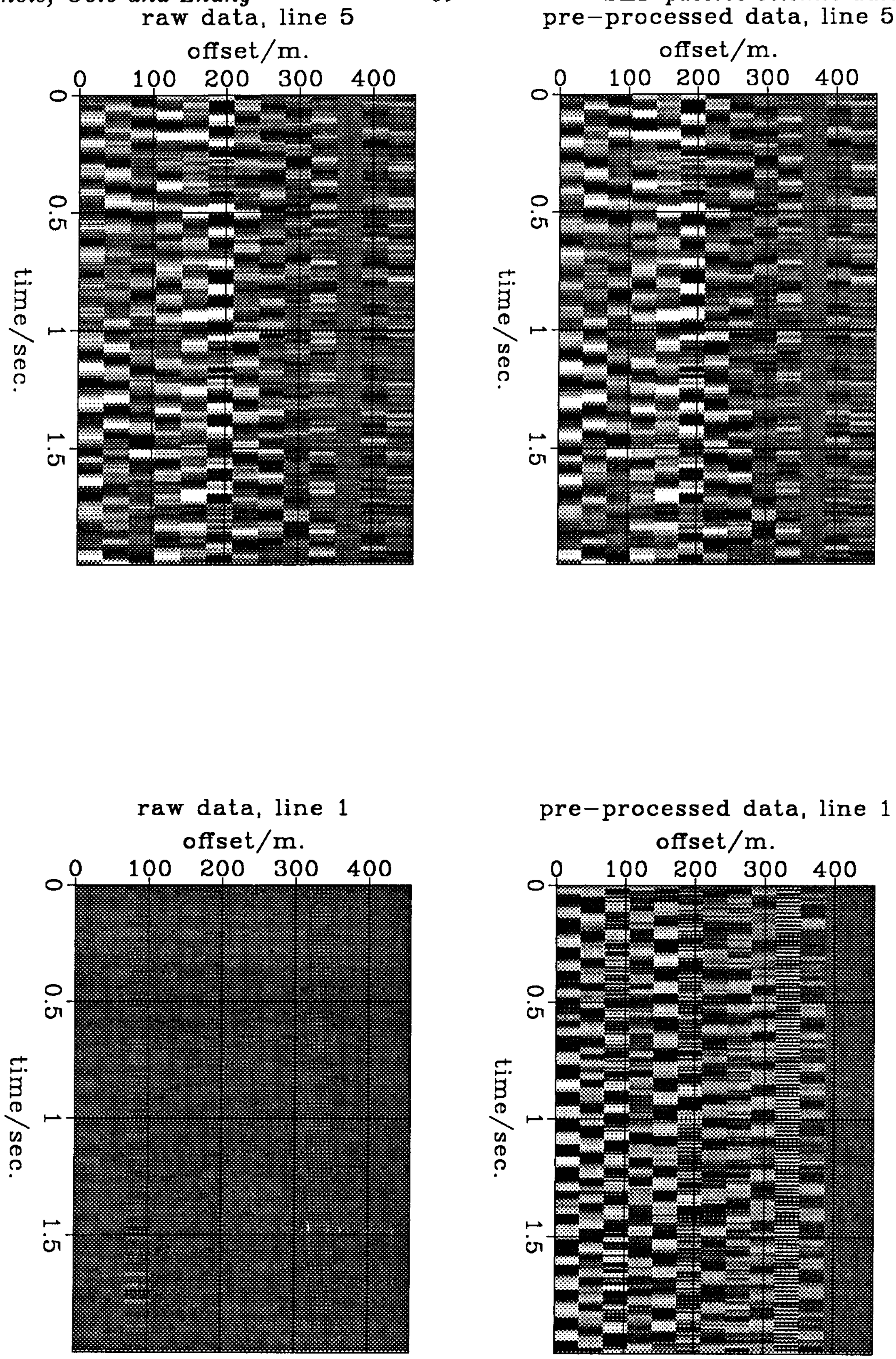

FIG. 1. A portion of raw field data and the pre-processed data from two of the 13 lines.

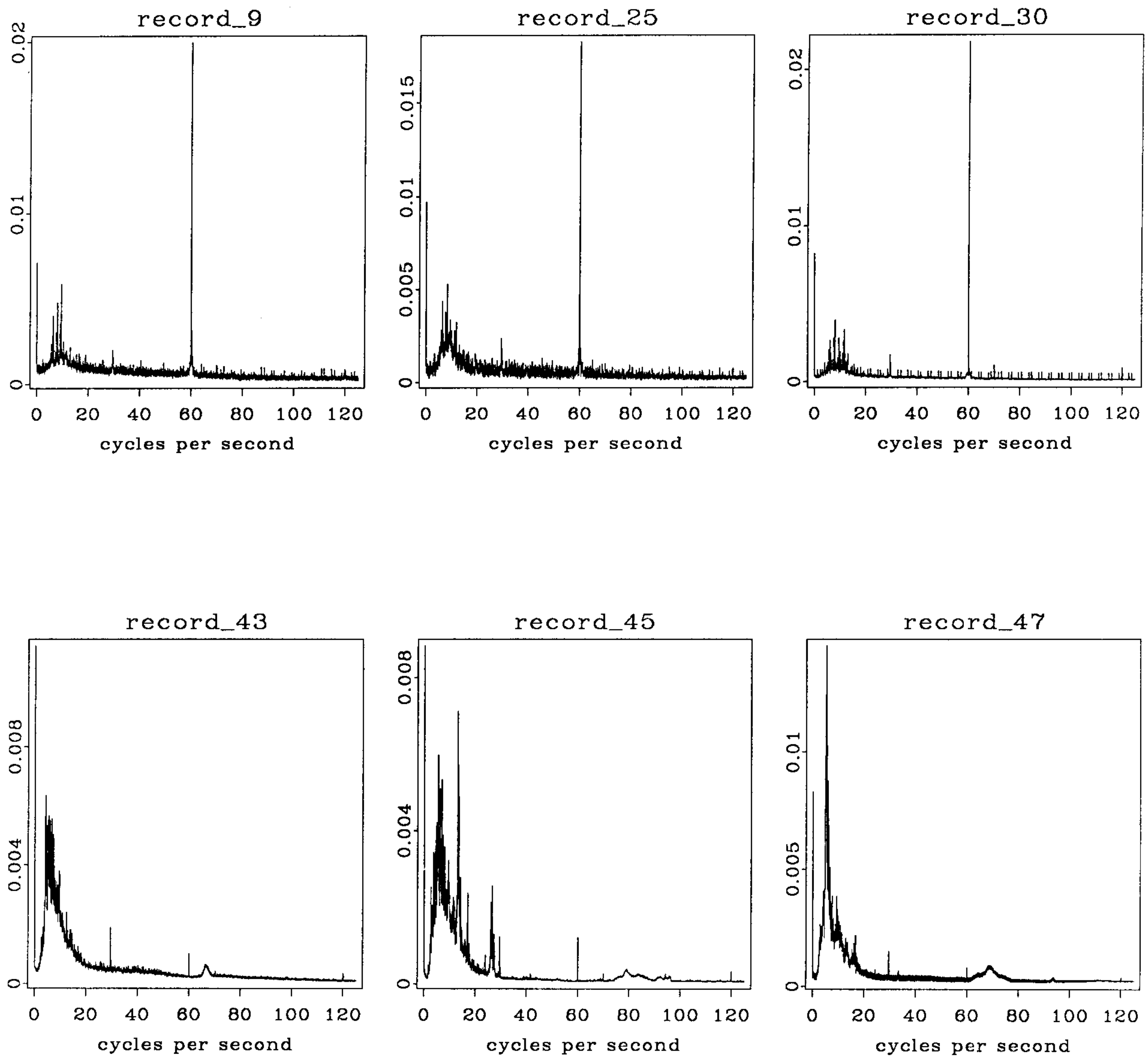

FIG. 2. Average spectra of raw field data for six records. The upper three were recorded at night, the lower three during the day.

Filter and subsample

The data was subsampled from its original 2ms sample rate to 4ms, after application of a 90Hz high cut filter. Notch filters were applied to remove the energy at D.C. and the power line noise at 60Hz.

Trace balancing

Each trace was gained so that all the traces had the same r.m.s. amplitude. This was done because the traces had very different amplitudes which did not appear to contain information. Some anomalous amplitudes are due to incorrect amplifier settings on the recording boxes, and some are probably due to poor geophone planting or heterogeneities in the near surface. The panels on the right of Figure 1 show the the effect of these pre-processing steps on the data.

ESTIMATION OF THE DIRECTION OF INCIDENT ENERGY

In Figure 1 and on other displays of the data recorded by our array, it is clear that there is some coherent energy present. A logical first step in treating this energy is to determine where it is coming from. Is the energy travelling along the surface or approaching from deep in the earth? Beam steering is a process that can tell us the distribution of energy as a function of arrival direction. Beam steering has been applied to a different passive dataset by Cole (1988).

In beam steering, the energy received by the array is analyzed as a function of apparent velocity and azimuth. Energy arriving from deep in the earth will have a very high apparent velocity because it arrives at all stations in the array at nearly the same time. Energy that is moving at relatively low apparent velocities is travelling on or near the surface, and in such cases the azimuth direction of the energy may give clues as to its source.

Figure 3 shows the result of performing beam steering on a record recorded during the day. The individual panels represent different azimuth angles. Within each panel, the power of the incident wavefield is displayed as a function of time within the record and of apparent velocity. There is a large amount of energy arriving at azimuths close to 90 degrees and with an apparent velocity of about 3500 meters/second. This direction corresponds to the nearby freeway. There is also clearly a large amount of steeply emergent energy present, indicated by high apparent velocity.

Figure 4 gives the same result for a record taken during the night. One can see that the incident wavefield has a different character during the night. The freeway noise has effectively disappeared. The most noticeable feature seems to be some steeply emergent energy.

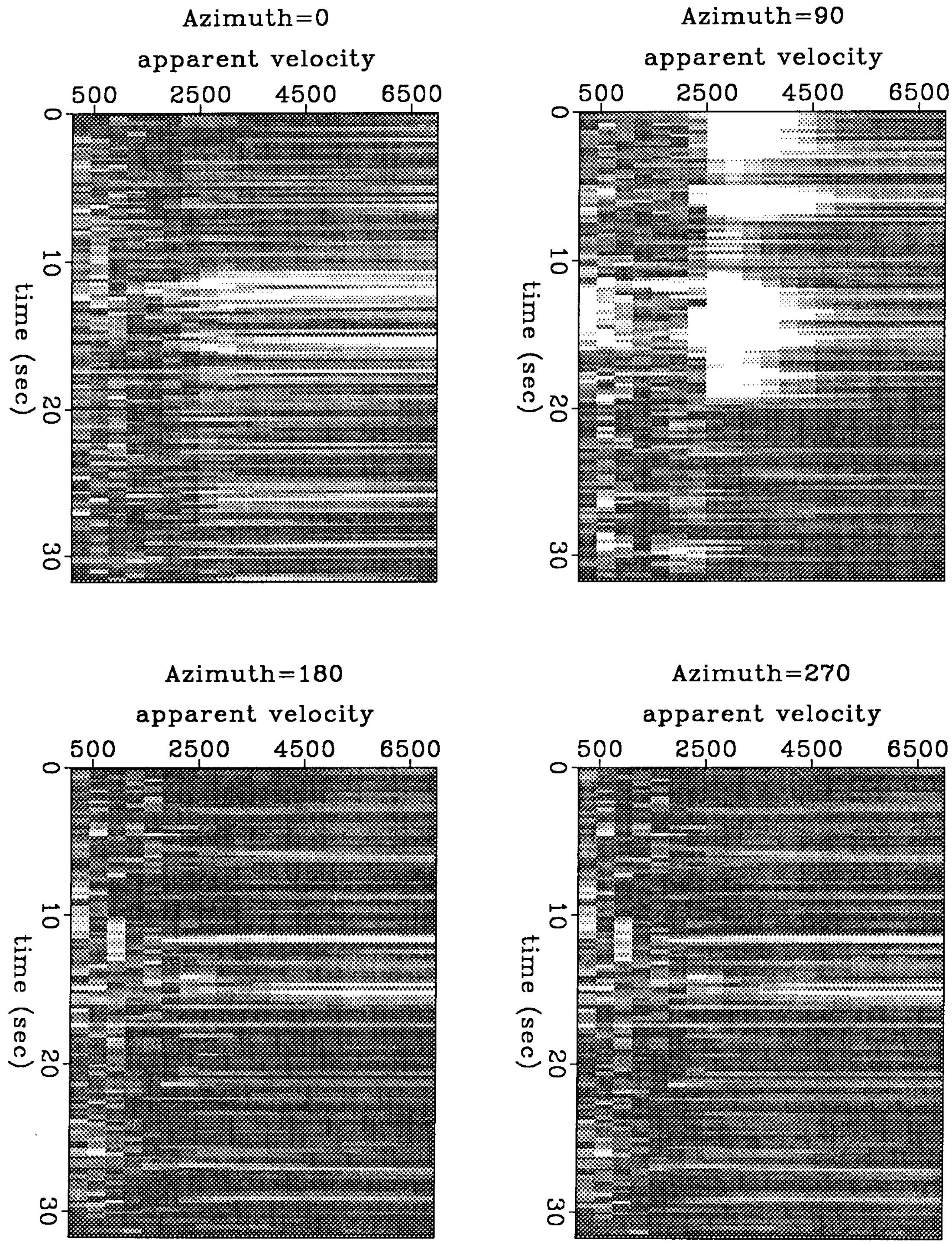

FIG. 3. Beam steering panels for four different azimuth directions for a daytime record. Power is displayed as a function of time and apparent velocity within each panel. The large amount of energy at an azimuth of 90 degrees is most likely due to surface noise from a nearby freeway.

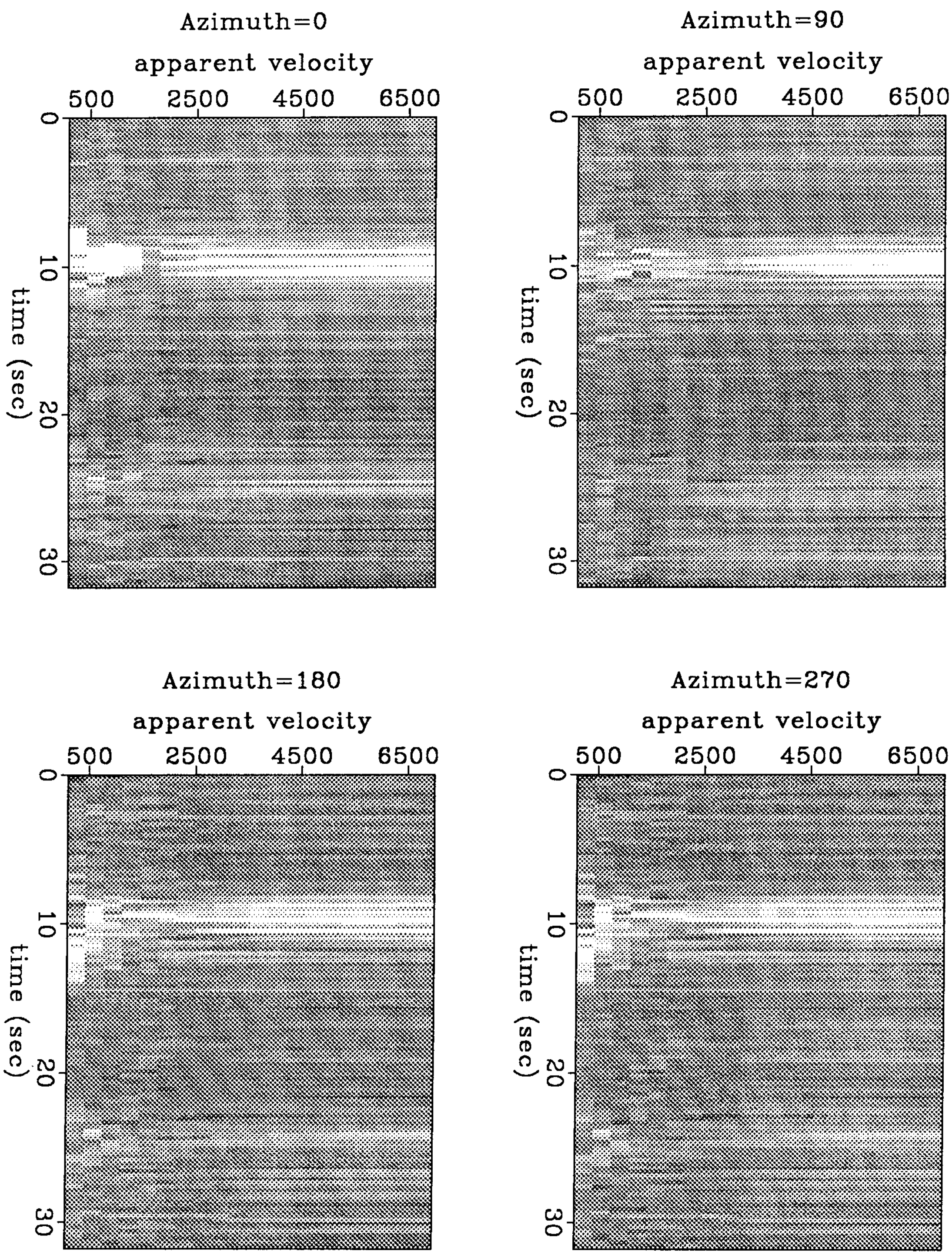

FIG. 4. Beam steering panels for four different azimuth directions for a nighttime record. Power is displayed as a function of time and apparent velocity within each panel. Daytime surface noise has disappeared. There is some indication of steeply emergent energy.

STACKING ONTO 2-D PLANES

Stacking is a simple and effective method to enhance the useful signal and eliminate noise. In a conventional reflection experiment we use data redundancy to enhance the reliability of the data. For our passive data we can point the array in a particular azimuth direction by stacking the data along the lines perpendicular to that aziumth direction. In these examples we choose the two diagonal directions as shown in Figure 5.

Let $P(it, ix, iy)$ be the recorded 3-D data. The equations for stacking are

$$P_1(it, ih) = \sum_{ix} P(it, ix, ih + ix)$$

$$P_2(it, ih) = \sum_{ix} P(it, ix, ih - ix + nx)$$

This operation has the following advantages and disadvantages:

- Advantages
  1. Reduce the effects of the dead traces.
  2. Increase the number of traces in a line.
  3. Partially cancel white noise.
  4. Partially eliminate the surface noise.
  5. Reduce the processing work.
- Disadvantages
  1. Two dimensional models can not fully represent 3-D wave propagation.
  2. The resolution of the azimuth direction is low.
  3. When stacking along the diagonals the stack fold is not uniform.

A portion of the stacked data is shown in Figure 6 and 7. The data in Figure 6 was recorded during the night when traffic is quiet. We can see several events coming up almost vertically. Of course, there is also a lot of noise. The dead traces are filled in so the section looks nice. Figure 7 shows the data recorded at day time when there are a lot of cars running nearby. We see a lot of surface noise which has low apparent velocity.

CONCLUSIONS

The dataset recorded by SEP contains the steeply arriving energy that we had hoped to see. Because of the care taken to ensure that the data was unaliased we can apply standard multi-channel processing techniques to the data. Although the

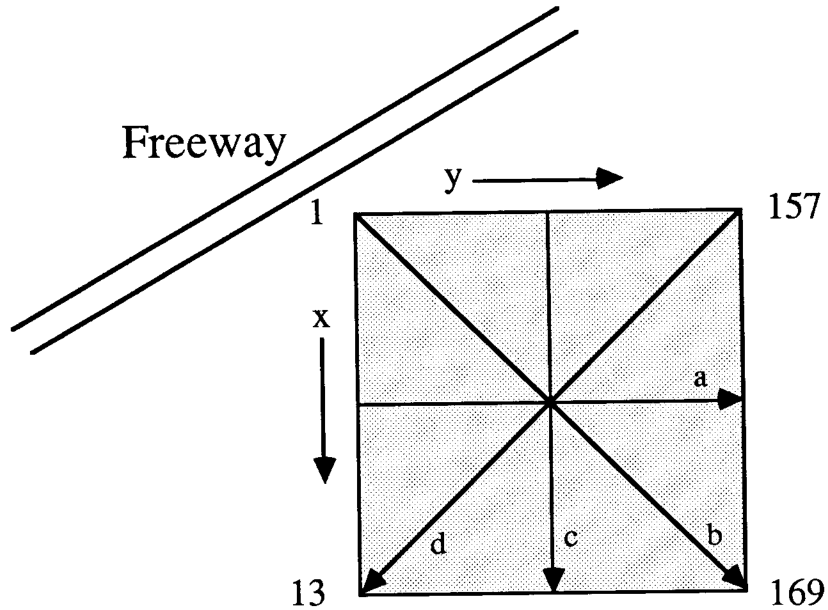

FIG. 5. Geometry of the stacking. The numbers at the corners are the SGR station numbers.

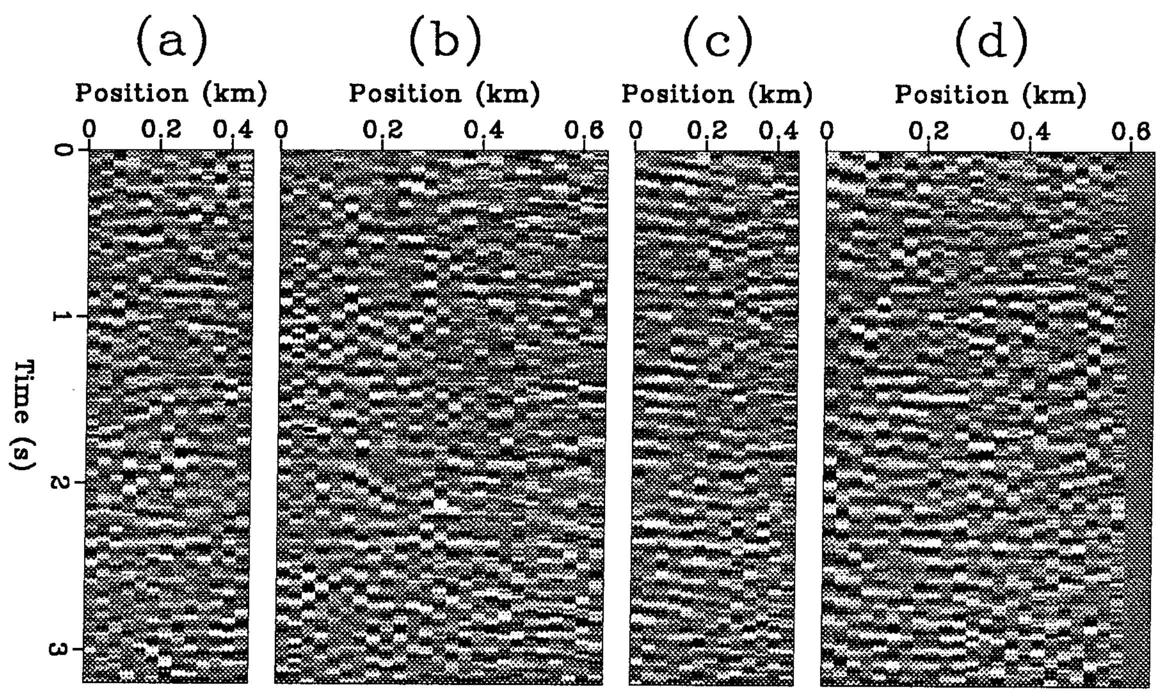

FIG. 6. Stacked data recorded at night, the letters a-d refer to the lines in Figure 5.

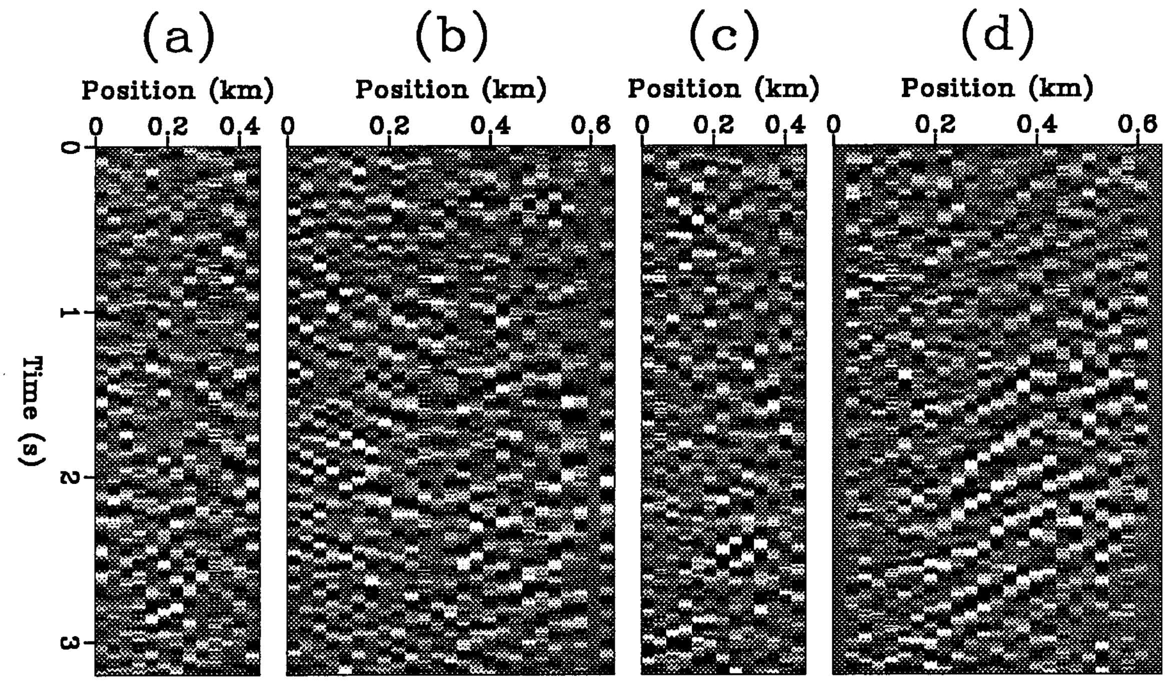

FIG. 7. Stacked data recorded during the day, the letters a-d refer to the lines in Figure 5.

data was contaminated by spikes and mono-frequency noise simple, single-channel processing techniques were able to remove these problems.

REFERENCES

Claerbout, J., Cole, S., Nichols, D., and Zhang, L., 1988, Why a big 2-D array to record microseisms?: SEP–**59**, 1-10.

Cole, S., 1988, Examination of a passive seismic dataset using beam steering: SEP–**57**, 417-426.