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I. CODA CONTENTS AND MULTIPATHING OF RAYLEIGH WAVES AT NORSAR

One of the most important problems in seismic discrimination today is how to improve the detectability of surface waves. As a contribution here a study has been completed (Bungum and Capon, 1974) in which the Rayleigh wave codas from 15 events recorded at NORSAR have been analyzed in detail with respect to power distribution in time, velocity and direction, for period of 20 and 40 sec. This has been done using the high-resolution (HR) frequency-wavenumber analysis method (Capon 1969).

A fairly extensive simulation experiment was first performed in order to learn more about the capabilities and the limitations of the HR-method when applied to this particular problem. One fundamental limiting factor is that the diameter of the array is slightly less than the wavelengths under analysis (at 40 sec period) and another problem is that we are analyzing transient signals and only 200 sec of data at a time. When the problem of detecting one signal in the presence of another is considered, the simulations (using both artificial and real data) showed that one of the most important parameters is the amount of overlap in time between the two waves. This is clearly demonstrated in Fig. I1, where different arrival times are used on otherwise identical signals. It should be noted that when the two wavetrains overlap completely, no resolution is possible regardless of method employed.

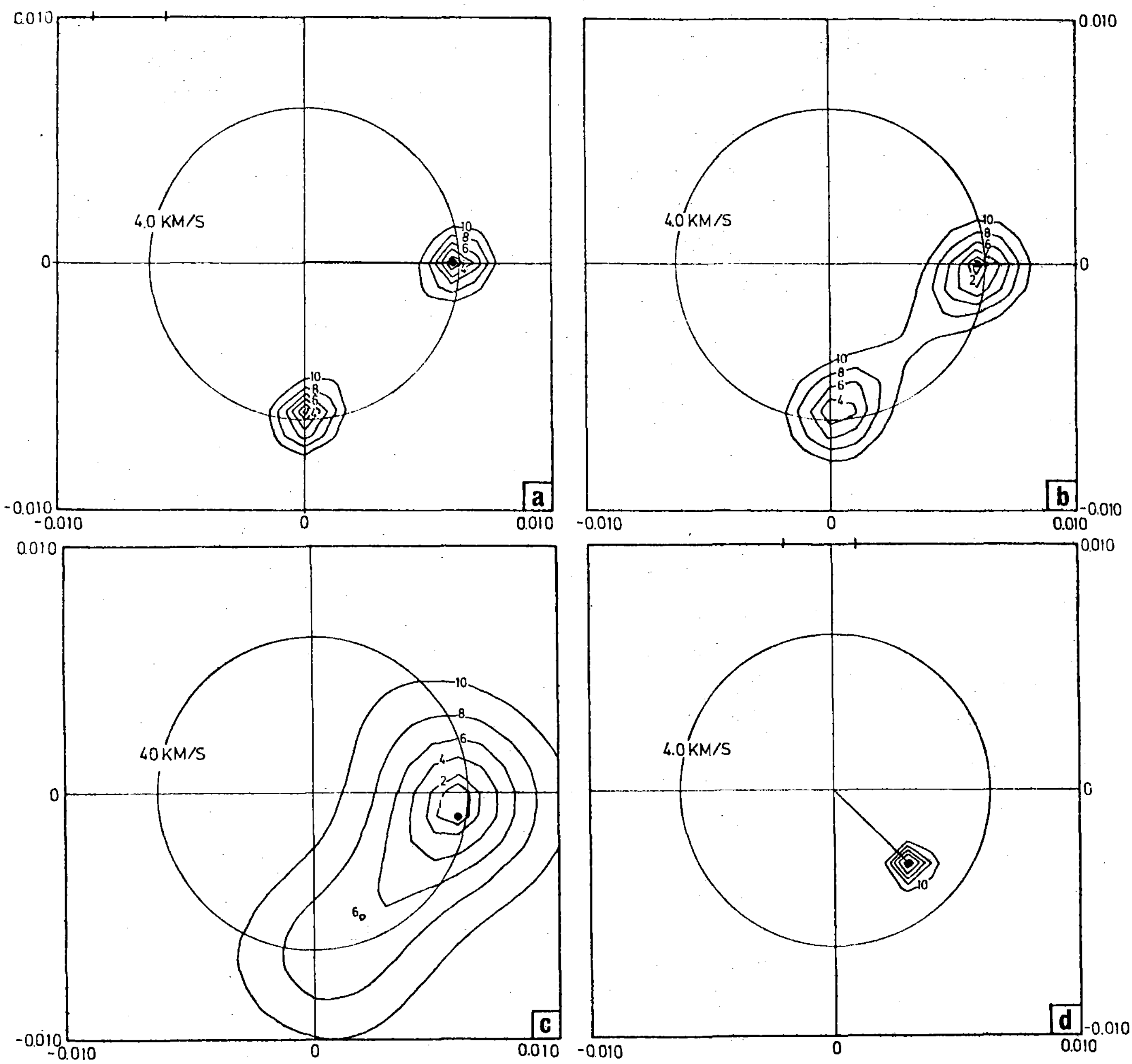

Fig. I1 Wavenumber spectra for simulation data using the HR-method on the sum of two sine waves 90° apart, both with velocity 4.0 km/sec. The four cases represent (a) no overlap in time between two waves, (b) 25% overlap, (c) 50% overlap, and (d) full overlap. Each spectrum is estimated from two 100 sec blocks of data.

Another problem in the calculation of wavenumber spectra is that errors are introduced due to the grid quantization in wavenumber space. The distribution of azimuth errors introduced in this way is given in Fig. I2, where it can be seen that the errors are in the range ±5 degrees. Similar quantization errors are introduced in the velocity measurements, and it has been found, based on certain assumptions about expected phase velocities, that this leads to an accepted velocity range of 3.5-4.2 km/sec for 40 sec period waves, and 3.4-4.0 for 20 sec.

For all the 15 events, which have a relatively uniform geographical distribution, the power vs. time has been calculated. The average of this is presented in Fig. I3, which shows that the power drops off faster at 40 sec than at 20 sec. For this reason, the amount of interference should be less at 40 sec. However, this is compensated for by the fact that the resolving power of the array is better at 20 sec.

Besides the estimate of power, the analysis has also given phase velocity and azimuth for successive non-overlapping 200 sec blocks of data. This gives a picture of the multipath propagation, and it has lead to proposals for ray paths for some of the events. An example is given in Fig. I4, which shows that severe multipathing is taking place, especially for 20 sec period. This event is relatively typical for what we see, at 40 sec there is usually a well-defined main group arriving along or close to the great circle path, while at 20 sec the energy is typically dispersed over an angle of 40-60 degrees, with no clear onset.

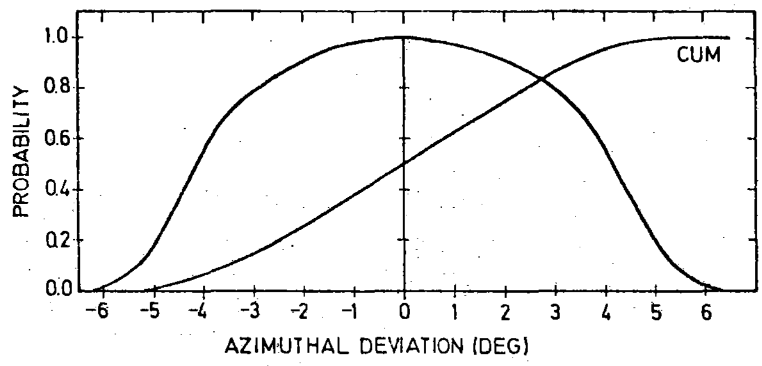

Fig. I2 Normalized incremental and cumulative distributions of azimuthal quantization errors using a wavenumber grid with increments of 0.001 c/km to measure a wave with a velocity distribution centering on 3.85 km/sec and a period of 40 sec.

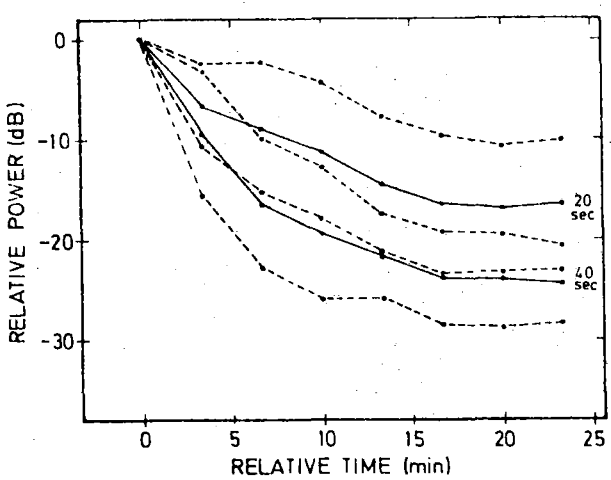

Fig. I3 The average of the coda power distributions for 15 events at periods of 40 and 20 sec. The standard deviations are indicated by dotted lines.

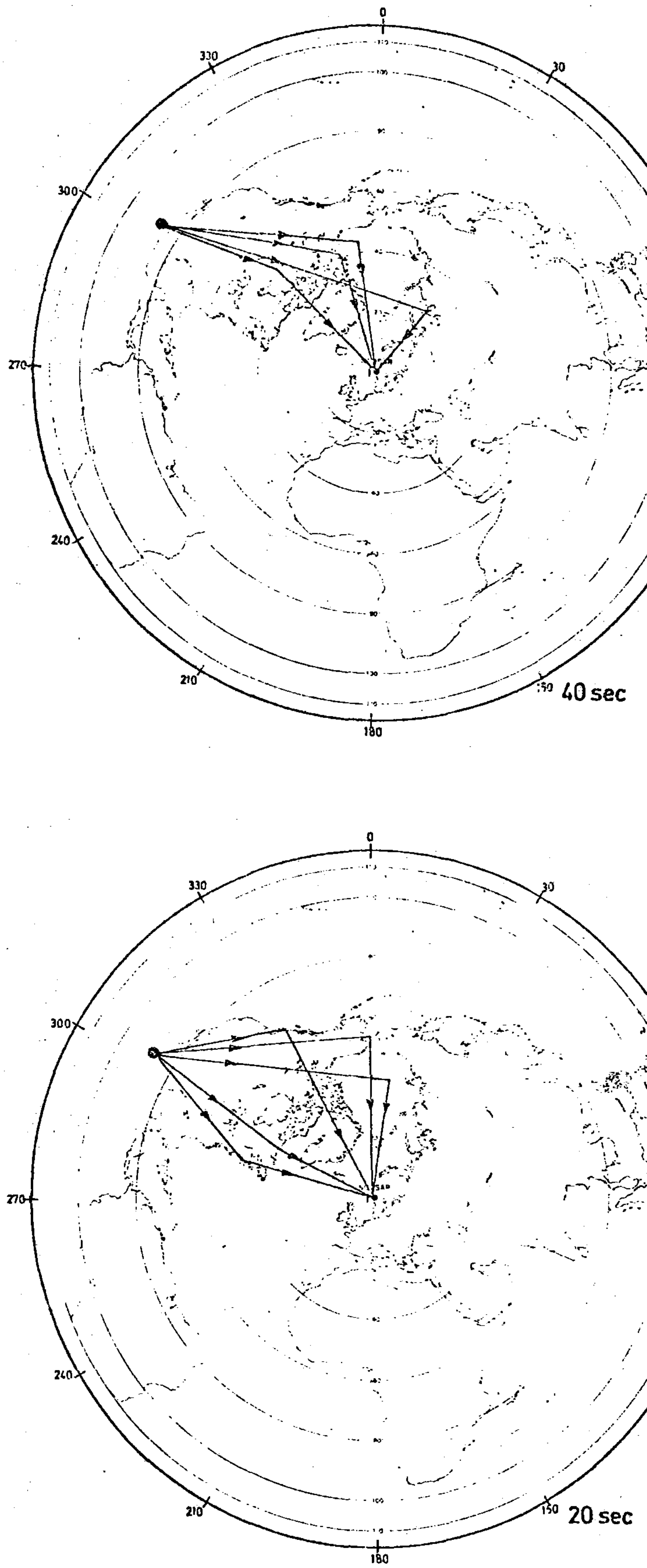

Fig. I4 Ray path solution for an event from California for period of 40 and 20 sec.

These observations do have some implications which should be stressed specifically. First of all, the multipathing complicates the detection problem a great deal. This is because the distribution of energy both in time and frequency-wavenumber space becomes very complex and therefore difficult to recognize and identify, and also because it greatly adds to the confusion when two events are appearing simultaneously. Next, the effect of this multipathing on Rayleigh wave magnitude determinations can also be serious, pointing towards the preference of an algorithm using information from a wider band both in time and frequency. Besides this, the multipathing also strongly affects the precision with which one can measure group velocities, which traditionally are based on the assumption of wave propagation along great circle paths.

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Bungum, H., and J. Capon: Analysis of coda and multipath propagation of Rayleigh waves at NORSAR, NORSAR Scientific Report 3-73/74, NTNF/NORSAR, Kjeller, Norway, In press, 1974.

Capon, J.: High-resolution frequency-wavenumber spectrum analysis, Proc IEEE, Vol 57, 1408-1418, 1969.