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7.3 Wavefield decomposition for three-component seismograms

Seismograms at regional ranges are built up from a complex mixture of seismic propagation phenomena involving multiple reflections and guided waves in the crust (e.g. the phases Pg, Lg) and waves returned from the uppermost mantle (Pn, Sn). In order to detect and locate events as well as to assess the nature of the seismic source and propagation path, it is necessary to be able to recognize and characterize different parts of the seismic wavefield. Both phased array techniques for single component sensors and vectorial analysis of 3-component recordings can provide estimates of the azimuth and slowness of seismic phases. Although it has been shown that the accuracy of the 3-component estimates of slowness and azimuth is generally lower than from an array, especially for S waves, a combination of these approaches provides a more powerful tool to estimate the propagation characteristics of different seismic phases at regional distances.

Most methods of using three-component data rely on polarization parameters as their main device for characterizing different features on a seismic wavetrain. Recently Jepsen and Kennett (1990) have shown how it is possible to extract estimates of the relative amplitudes of the three incident wavetypes (P, SV, SH) from three-component records under the assumption that the dominant arrival at any given time is a single plane wave described by its slowness and azimuth. This procedure depends on modelling the interaction of the wavefield with near-receiver structure. The main contribution, at hard rock sites such as NORESS and ARCESS, comes from the interaction of the wavefield with the free surface.

If the slowness and azimuth of the incoming wavefield are known, then the free surface effect on an incident plane wave is frequency independent, but may involve phase shifts. The extraction of the wavefield components requires the inversion of the matrix of interaction imposed by the free surface together with rotation in a horizontal plane. For a three-component station situated at an array such as ARCESS, beamforming over the vertical component sensors can be used to estimate the slowness and azimuth as a function of time. These array beam parameters may then be used to produce estimates of the P, SV and SH contributions to the wavefield as a function of time. This process is illustrated in Fig. 7.3.1 for the 3-component station C7 at the ARCESS array for an event close to the array. The array beam estimates were generated by using the broadband f-k procedure on a sliding 2 sec window.

This decomposition of the seismic wavefield by wavetype as a function of time not only has considerable benefits for the recognition of seismic phases, but also provides a domain in which the relative proportions of P, SV, and SH can be compared directly, because free-surface amplification effects have been removed. This information on the current proportions of different wavetypes summarizes much of the propagation processes between source and receiver and therefore can help to provide specific measures of wavefield character which can be beneficial in attempts to discriminate between different source types.

For an individual 3-component station, the estimation of apparent azimuth is usually more reliable than slowness. However, for regional phases, it proves quite effective to use the wavefield decomposition procedure with a number of fixed slownesses designed to enhance different features of the wavefield arriving at different times. A slowness of 0.12 sec/km gives very good resolution of the early P wave energy (see Fig. 7.3.2) while suppressing later SV energy. P is usually accompanied by a small S component which can be reduced by optimal estimates of slowness.

An S wave slowness of 0.22 (see Fig. 7.3.3) enables a clear identification of the SV contribution to Lg. Even though the wavefield decomposition procedure removes the phase shift from free surface reflection imposed on SV at large slownesses, there is commonly no close correspondence between the SV and SH components. Rg waves are evident by the presence of coupled P and S energy.

An interesting by-product of a high slowness decomposition is an amplification of the P arrivals occurring in the notional SV trace. This occurs without significant amplification of the background noise and can lead to a definite improvement in the signal-to-noise ratio. The SV trace for high slowness can therefore be investigated as a possible detector for the P onset.

The wavefield decomposition procedure depends on the specification of the near surface velocities, but fortunately in general the main results are not very sensitive to the values of the velocities. The exception is for slownesses close to the reciprocal of the surface P wave velocity (around 0.17 km/s at ARCESS) where the inverse of the free surface response is a rapidly varying function of slowness. Also an error of around 10° in azimuth can be tolerated, the main effect is on the SH component.

Although slowness and azimuth estimates from the array are most stable for a particular frequency band (typically 3–5 Hz), the f-k estimates can be applied quite successfully to unfiltered data or to particular filtered components.

Further examination of this class of 3-component analysis procedures will involve the implementation and testing of the classification schemes of Jepsen and Kennett (1990). Such schemes categorize the stability, rectilinearity, planarity, etc. of the wavefield and use a set of rules for classifying a particular wavetype (i.e. elliptical P and S, rectilinear P and S, rectilinear SH, Rayleigh, etc.).

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References

Jepsen, D.C. and B.L.N. Kennett (1990): Three-component array analysis of regional seismograms. Manuscript accepted for publication in *Bull. Seism. Soc. Am.*.

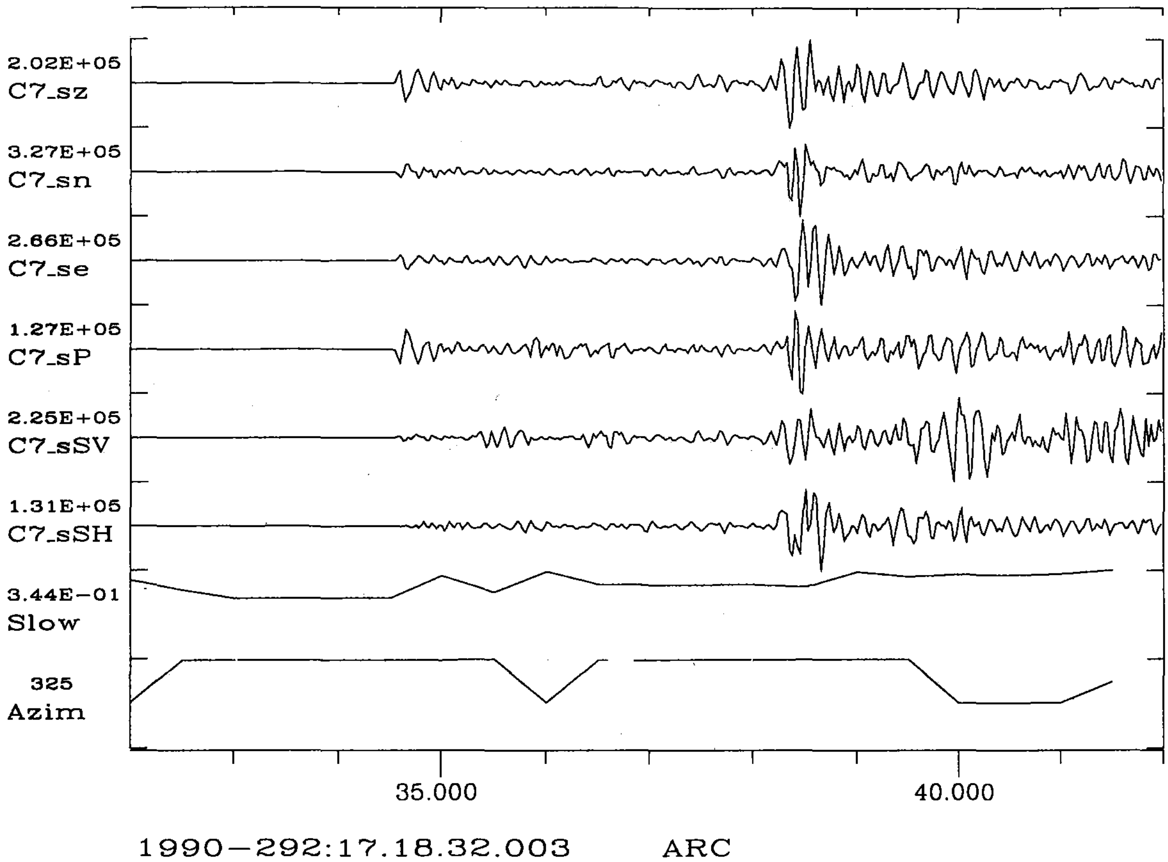

Fig. 7.3.1. This figure illustrates the decomposition of a three component seismogram into the relative components of P, SV and SH. The top three traces are the original three-component time series, the next three traces are for P, SV, and SH respectively, and the bottom two traces show the values, as a function of time, of slowness and azimuth used in computing the P, SV, and SH contributions. The slowness and azimuth were computed from a 2 second sliding window using the entire array of vertical sensors and a broad band f-k analysis.

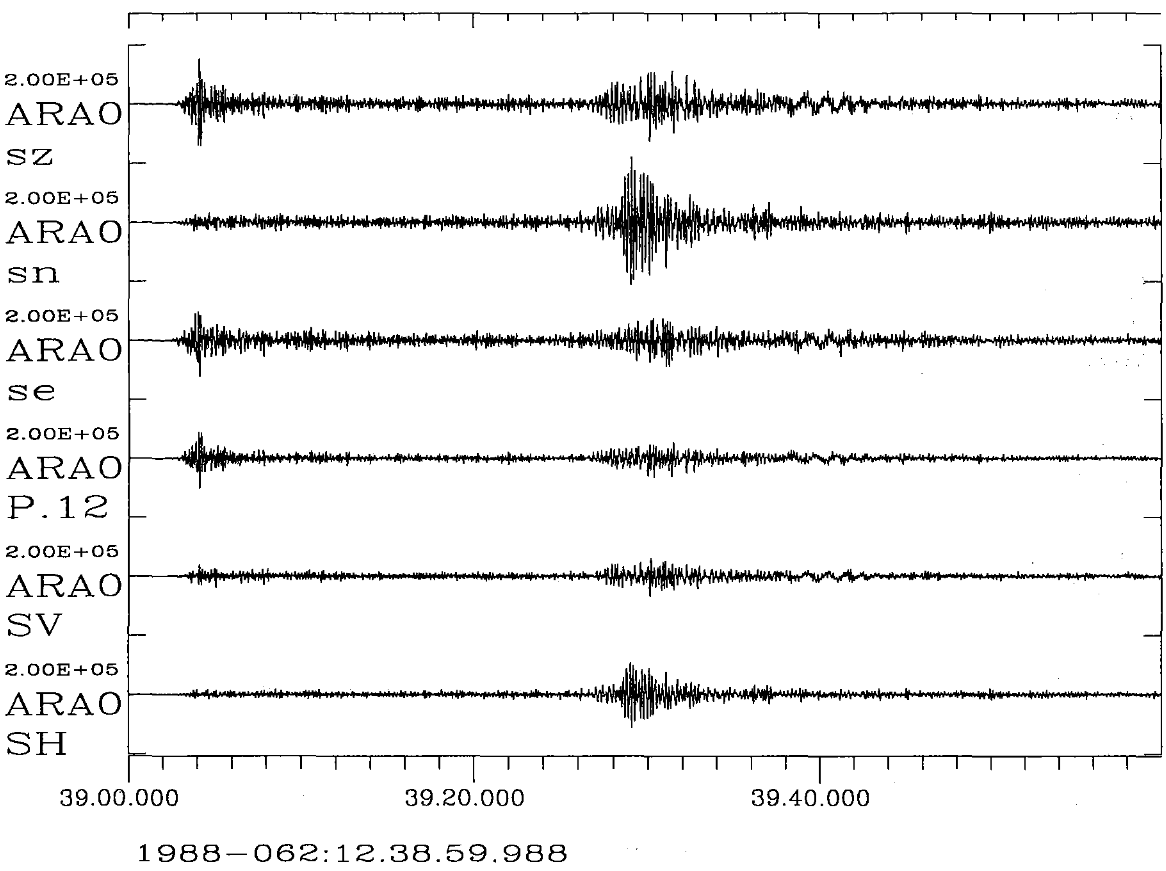

Fig. 7.3.2. This figure illustrates the decomposition of a three component seismogram into the relative components of P, SV and SH with a fixed slowness of .12 sec/km and azimuth of 92. The top three traces are the original three-component time series and the bottom three traces are for P, SV, and SH respectively.

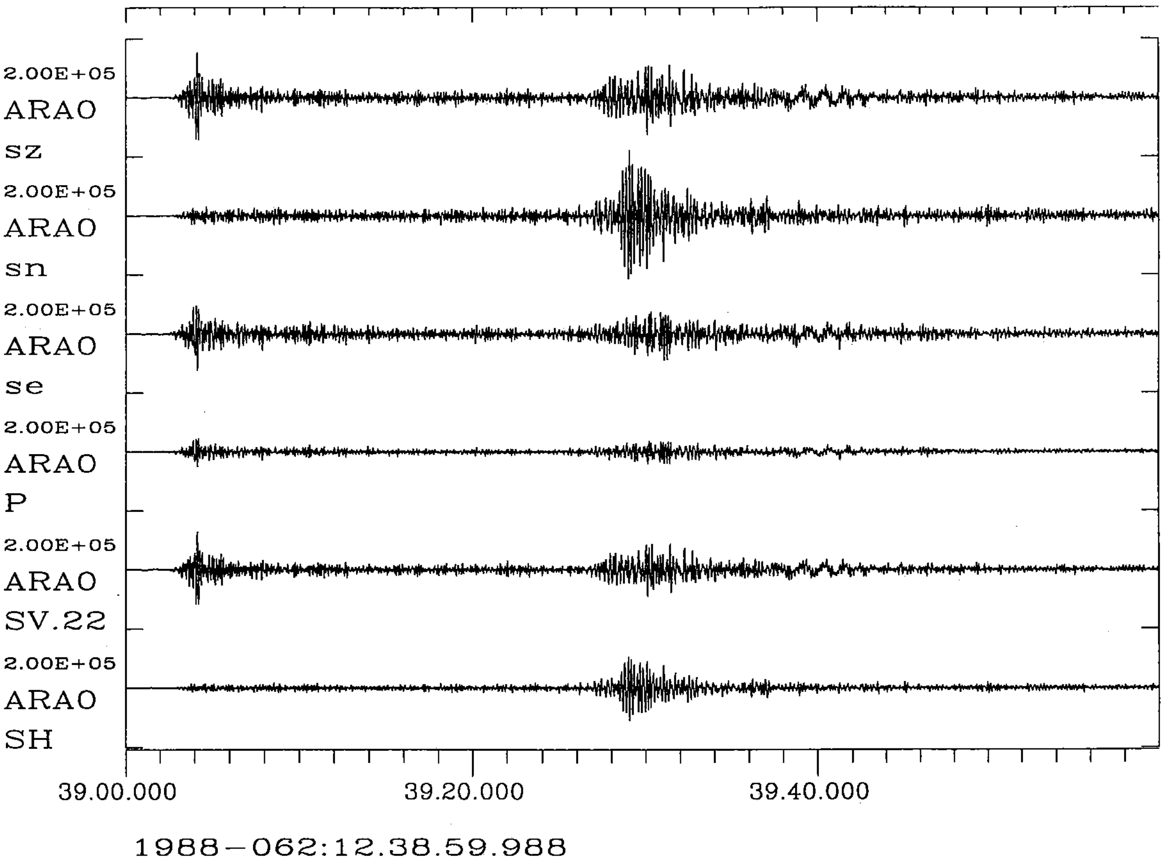

Fig. 7.3.3. This figure illustrates the decomposition of a three component seismogram into the relative components of P, SV and SH with a fixed slowness of .22 sec/km and azimuth of 92. The top three traces are the original three-component time series and the bottom three traces are for P, SV, and SH respectively.