AZIMUTHAL VARIATION OF RADIATION OF SEISMIC ENERGY FROM CAST BLASTS

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As part of a series of seismic experiments designed to improve the understanding of the impact of mining blasts on verifying a Comprehensive Test Ban Treaty, a sixteen station network of three-component seismic sensors were deployed around a large cast shot in the Black Thunder Mine. The seismic stations were placed, where possible, at a range of 2.5 kilometers with a constant inter-station spacing of 22.5 degrees. All of the data were recorded with the seismometers oriented such that the radial component pointed to the middle point of the approximately 2 kilometer long shot. High quality data were recorded at each station. Data were scaled to a range of 2.5 kilometers and the sum of the absolute value of the vertical, radial, and transverse channels computed. These observations were used to construct radiation patterns of the seismic energy propagating from the cast shot. It is obvious that cast shots do not radiate seismic energy isotropically. Most of the vertical motion occurs behind the highwall while radial and transverse components of motion are enhanced in directions parallel to the highwall.

These findings have implications for local (0.1 to 15 kilometer range) and possibly for regional (100 to 2000 kilometer range) seismic observations of cast blasting. Locally, it could be argued that peak particle velocities could be scaled not only by range but also by azimuthal direction from the shot. This result implies that long term planning of pit orientation relative to sensitive structures could mitigate problems with vibration levels from future blasting operations. Regionally, the local radiation pattern may be important in determining the magnitude of large scale cast blasts. Improving the transparency of mining operations to international seismic monitoring systems may be possible with similar considerations.

MOTIVATION: The Geophysics Group at Los Alamos National Laboratory has been tasked with conducting research necessary to allow government agencies to verify that the protocols of the Comprehensive Test Ban Treaty (CTBT) are not being violated. Any test of an explosive nuclear device, in any environment, by any party is prohibited by the CTBT which was signed by President Clinton at the United Nations in September 1996. A more extensive background on the CTBT can be found in a companion paper by Stump and Pearson in this issue.

A cooperative series of experiments were conducted at the Thunder Basin Coal Company, Black Thunder Mine east of Wright, Wyoming in the active Powder River Basin coal field (Figure 1). During the initial planning phase of this work, mine personnel expressed interest in observing the variation of vibration intensity at various angles (azimuths) from large cast blasts. These effects, if documented, are also important to the community tasked with monitoring the CTBT. If large cast blasts radiate seismic energy preferentially in a given direction due to any combination of many local shooting characteristics, blasting personnel can use this information to mitigate vibration effects on local structures of interest. Likewise, the CTBT monitoring stations can use this information to more readily identify seismic events observed at ranges up to a few thousands of kilometers as mining blasts and improve the assessment of the seismic source size. As part of a comprehensive experiment to document the near source seismic character of large scale cast blasts (see companion paper by Martin etal, this issue), a group of seismic instruments were deployed to document the azimuthal variation of ground motion produced by a cast shot in the South pit of the Black Thunder Mine.

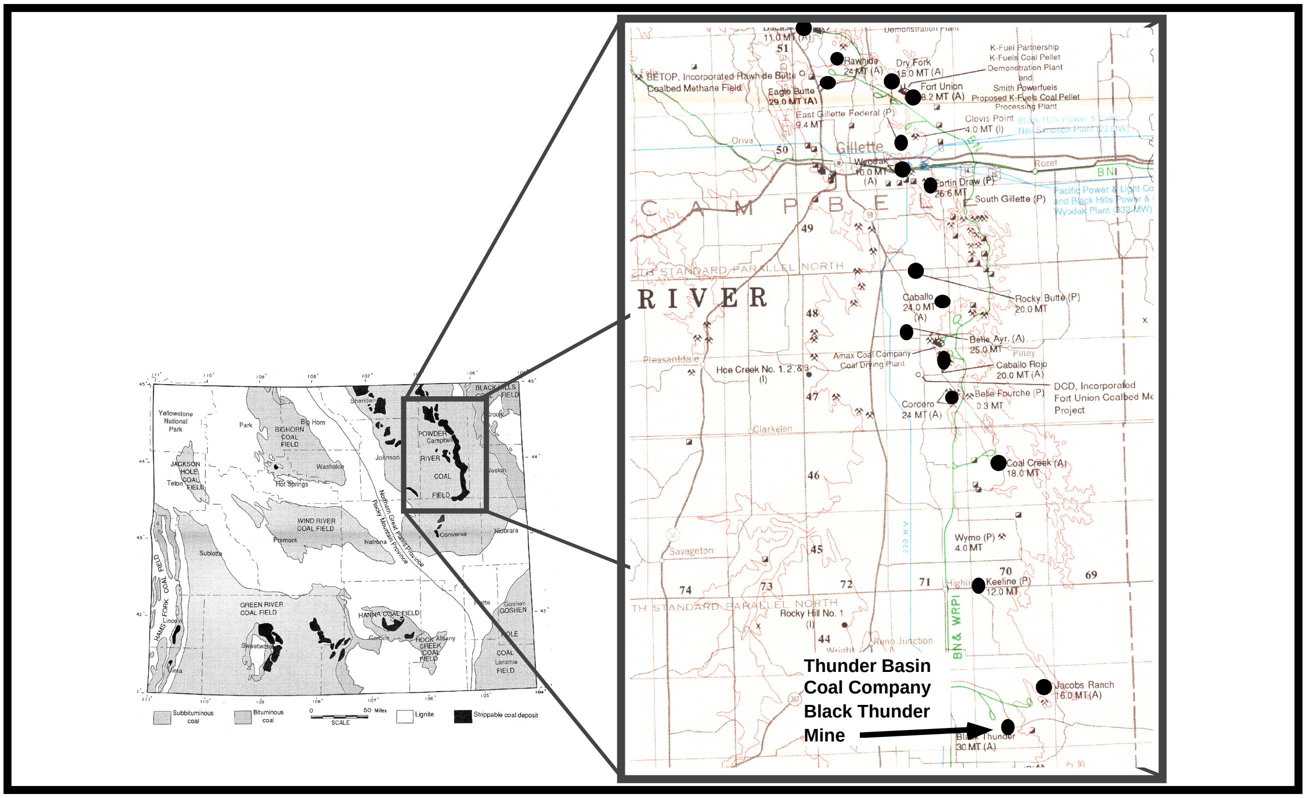

Figure 1. Location map of the Powder River Basin in the state of Wyoming. Coal production areas are shown in the state map on the left, and the Powder River Basin with mines producing more than 5 million tons of coal per year are expanded and highlighted in the map on the right. The Thunder Basin Coal Company Black Thunder Mine location is noted.

EXPERIMENTAL DESIGN: To document the azimuthal radiation pattern of a large cast blast, a sixteen station network of three-component seismic sensors were deployed around a large cast shot in the Black Thunder Mine. The seismic stations were placed, where possible, at a range of 2.5 kilometers with a constant inter-station spacing of 22.5 degrees. It was not possible to deploy stations A7, A8 and A9 at 2.5 kilometers due to grass harvesting activities. Figure 2 shows the deployment of the azimuthal seismic stations (A1 through A16), relative to the location of the cast blast.

Each of the azimuthal seismic stations was instrumented with a three-component Mark Products L4C-3D velocity gauge with a natural frequency of 1 hertz and a flat response in velocity to approximately 100 hertz. The seismometers were oriented such that the radial component pointed to the middle point of the cast blast. The calibrated voltage outputs of the seismometers were digitized using Refraction Technology model 72A-08 data loggers sampled at 500 samples per second with 21 bit digital resolution. Following digitization, the data are stored in static RAM and spooled to 1 gigabyte hard disks for archival.

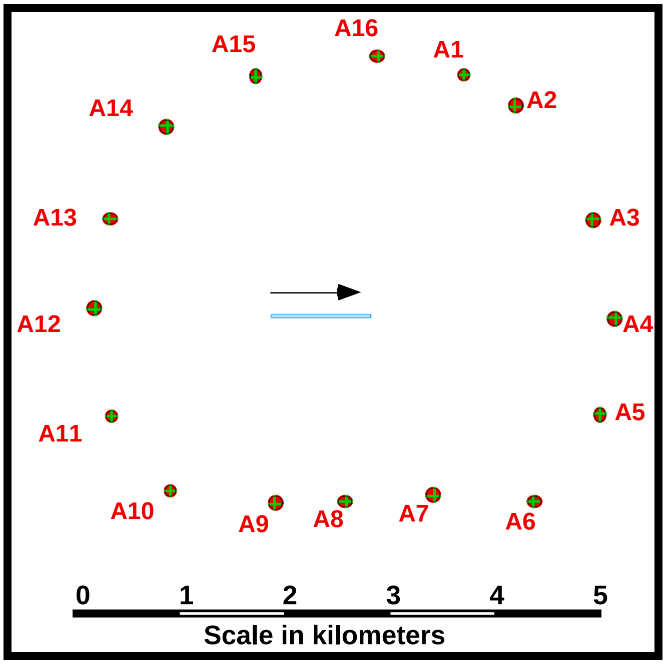

Figure 2. Design of the Cast Blast Azimuthal Radiation Pattern Experiment. The location and spatial extent, in true scale, of the South pit cast blast is shown. The arrow indicates the direction in which the shot was detonated.

The digital data were downloaded to a Sun UNIX workstation for final archival and processing. Calibration factors are applied to convert the digital voltage records to true ground motion. The data were then normalized to a constant range by applying a 1/r correction where r is the actual range of the station to the center of the cast blast.

DATA PROCESSING AND ANALYSIS: Different phases of seismic wavefields such as the compressional, shear, and surface wave components exhibit characteristically different frequency components. Compressional waves in general will have equal energy at all frequencies up to a frequency called the corner frequency. The corner frequency is controlled by the rise time and spatial extent of the explosive source. Shear wave components are similar to compressional wave components, however the corner frequency is always lower than that of the compressional wave due to a lower propagation velocity of shear waves relative to that of compressional waves. Surface wave components are dominated by lower frequency components than are compressional and shear wave components and are often the largest amplitude components of the wavefield.

A novel plotting technique is used to represent the data recorded by the azimuthal seismic array. Figure 3 is a detailed representation of the azimuthal data plots used in this report. These types of representations allow one to see the time aligned seismograms recorded at different stations distributed azimuthally around the shot. Time increases from the outer circle toward the inner part of the figure with 5 seconds between circles for a total time of 20 seconds. The radiation pattern is shown as a filled polygon in the center of the plot.

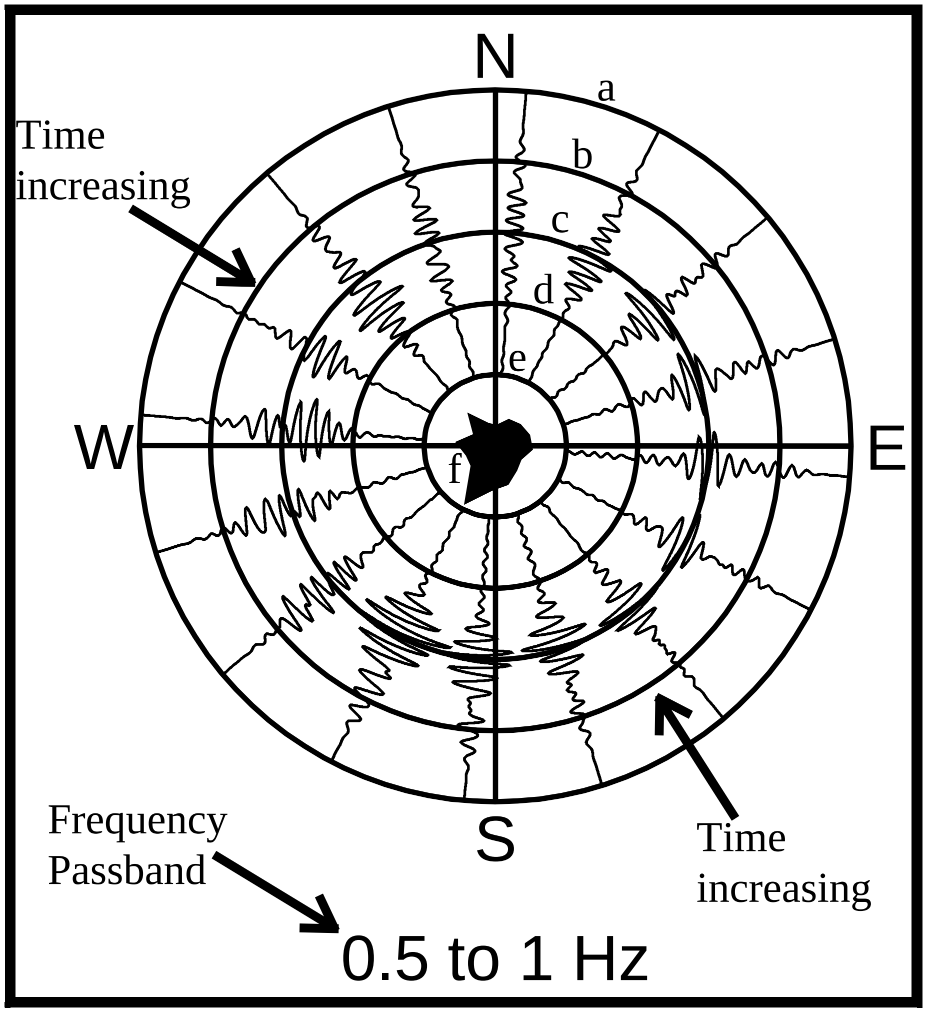

Figure 3. Detailed description of azimuthal seismic data plots. Circles labeled a, b, c, d and e represent times in seconds 0, 5, 10, 15, and 20 respectively. Time increases from the outer circle toward the center. The radiation pattern labeled f is computed by summing the absolute value of the bandpass filtered waveforms shown. Cardinal compass directions are indicated along the outside of the figure. The filter frequency band parameters are shown at the bottom of each subfigure in the following figures.

One technique useful for isolating the different components of the wavefield is bandpass filtering of the data. Bandpass filters of 0.5 to 1, 1 to 2, 2 to 4, and 4 to 8 hertz were applied to all components of the range corrected azmithual station data. Figures 4, 5 and 6 show the four bandpass filtered data sets of the vertical, radial, and transverse components of ground motion. The seismic data are plotted along radial lines corresponding to the azimuth of the station from the center of the cast blast with time increasing from the outer part of the figure toward the center. The seismic radiation pattern of the cast blast source is calculated by summing the absolute value of each sample of the digital waveform. This value is then plotted as a filled polygon in the middle of each azmithual bandpass component of the figures.

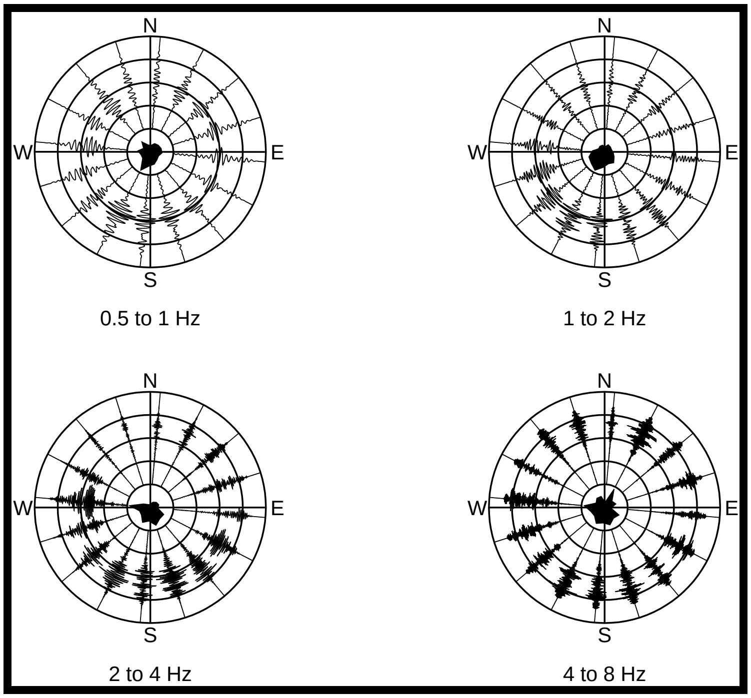

Figure 4. Vertical component azimuthal radiation patterns and seismic data corrected for range effects. Individual subplots represent different frequency passbands and are labeled accordingly.

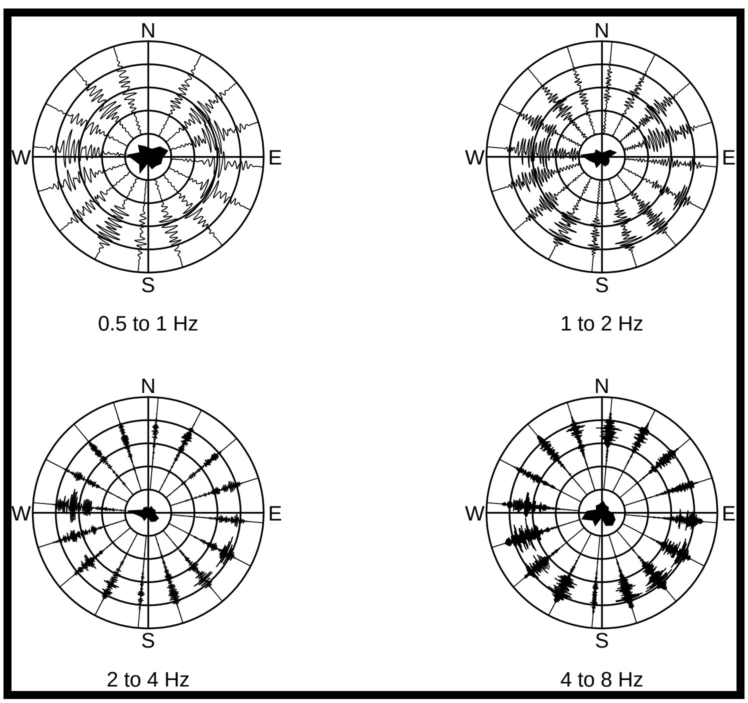

Figure 5. Radial component azimuthal radiation patterns and seismic data corrected for range effects. Individual subplots represent different frequency passbands and are labeled accordingly.

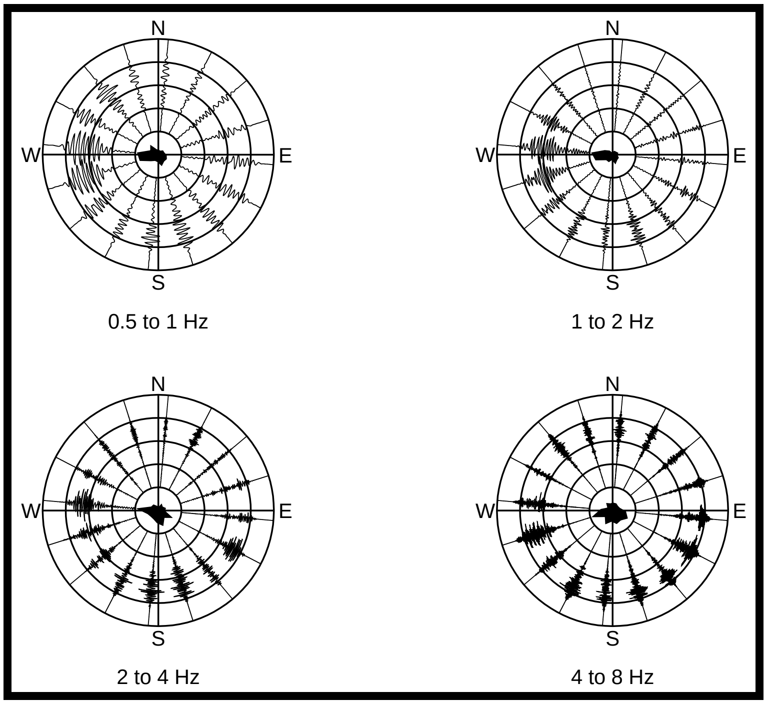

Figure 6. Transverse component azimuthal radiation patterns and seismic data corrected for range effects. Individual subplots represent different frequency passbands and are labeled accordingly.

Review of the seismic data and the radiation patterns in Figures 4, 5, and 6 shows that cast blasts do not radiate seismic energy equally in all directions. The vertical components exhibit the most isotropic (i.e. equal radiation in all directions) radiation pattern, however, stations located in the unmined area behind the highwall show enhanced amplitudes in each of the passbands. Each of the horizontal components (radial and transverse) exhibit strongly anisotropic (i.e. unequal radiation as a function of direction) radiation patterns. Both the radial and transverse component radiation patterns exhibit high amplitudes in a direction parallel to sub-parallel to the direction of the highwall.

CONCLUSIONS and IMPLICATIONS: It is apparent that cast blasts do not radiate seismic energy equally in all directions. Low frequency, 0.5 to 4 hertz, components of the wave-field exhibit strong vertical motions in a direction behind and perpendicular to the highwall and enhanced horizontal ground motions in both directions parallel to the high-wall. The higher frequency components show weaker dependence on the pit geometry. The higher frequency vertical component tends toward isotropic (equal in all directions) radiation while the horizontal components show weakly preferential radiation in directions parallel to the highwall.

Figure 7 is a compilation of the vertical, radial, and transverse motion radiation patterns from figures 4, 5, and 6. They are arranged with the three components of motion from left to right with the different frequency bands increasing down the page. Vertical motions are denoted by a gray shaded outer circle, while radial and transverse motions are indicated by gray shaded arrows to give a sense of the motion field represented. These radiation patterns have implications for both the cast blasting operator and possibly the CTBT monitoring community.

The most obvious correlation of the data and the radiation patterns with the cast blast is the pit orientation. The largest amplitudes are observed on the horizontal components off both ends of the shot, parallel to the highwall. A strong asymmetry is seen in the lower frequency passbands (0.5 to 1 and 1 to 2 hertz) on the transverse component in the direction of the shot initiation point. This component should be dominated by shear energy produced by the casting process and may be reflecting the shear displacement of the overburden.

Close to the cast blast source, it is apparent that the orientation of the pit can be utilized to minimize ground vibrations. Drill and blast programs designed such that the highwall is progressing away from neighbors or regulated structures would minimize both vertical and horizontal ground motions in the direction away from highwall progression. Conversely, if sensitive structures are located in the direction parallel to the highwall and on the initiation end of the shot, they will experience the maximum amount of ground vibrations from a cast blast. While is not always possible or desirable to change the orientation of the highwall, vibration concerns could lead to consideration of such drastic measures. The radiation patterns tend to become more isotropic at higher frequencies as is evident in Figure 7. This is likely due to the scattering effect of local geological features which have their greatest influence at the higher frequencies. If vibration problems exist at higher frequencies, the effect of the radiation pattern will have less of a bearing on minimizing these problems.

These near source radiation patterns also lead to consideration of regulatory limits of ground vibration. Given that cast blasts radiate seismic energy at different intensities for given directions, it seems that some consideration should be given to a directional scaled range measurement for cast blasting.

CTBT monitoring stations at regional (500 to 10000 kilometers) distances may be able to use the fact that cast blasting does not radiate seismic energy equally in all directions to identify that a cast blast has occurred and does not warrant further scrutiny. The observations presented here have led to further deployments of portable seismic stations at greater distances to determine whether or not the near source radiation pattern is still discernible at greater ranges.

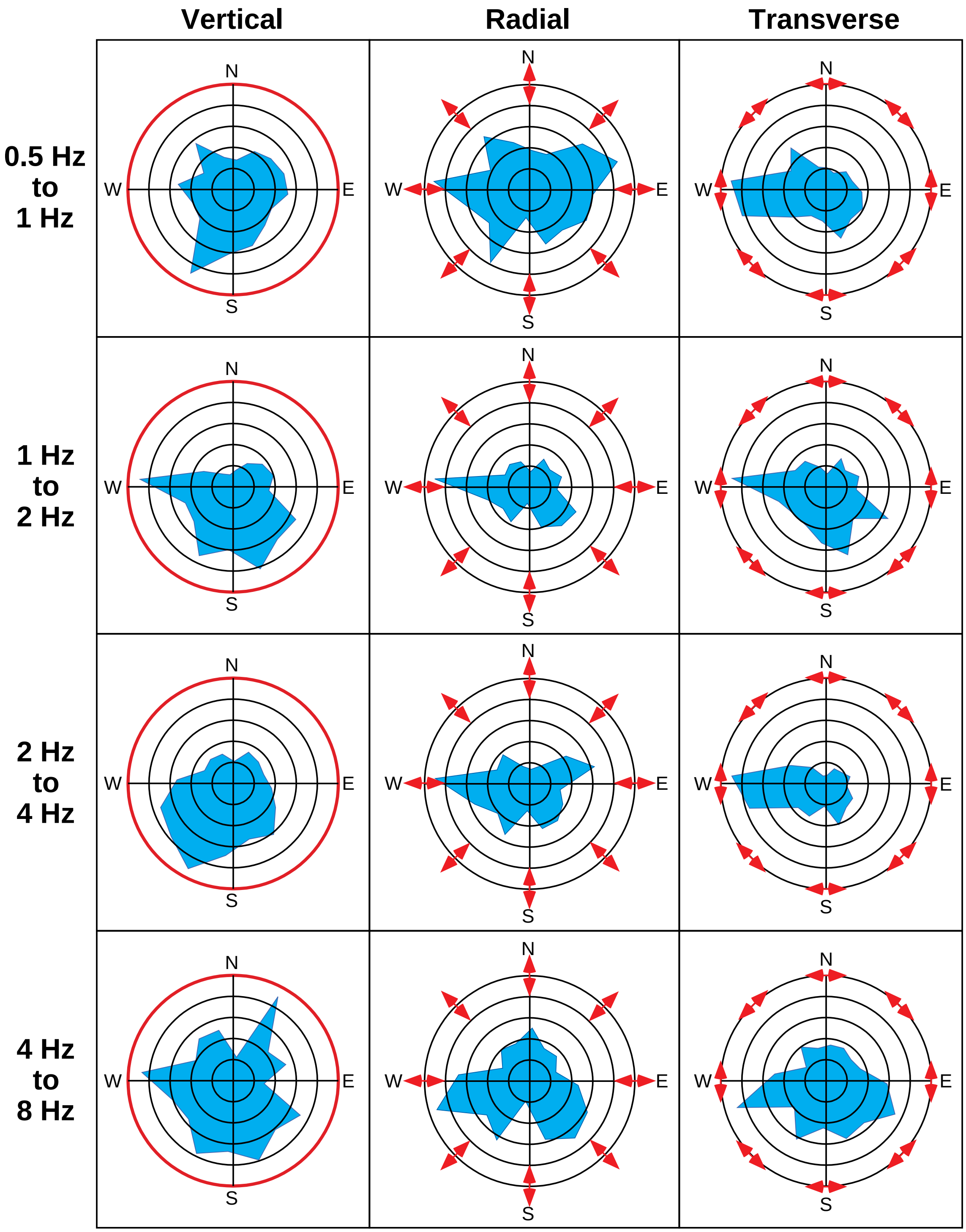

Figure 7. A compilation of radiation patterns shown in figures 4, 5, and 6. The vertical, radial, and transverse components of motion are arranged from left to right and the different frequency bands are arranged in increasing order down the page. Vertical motion is represented by a gray shaded outer circle in the radiation patterns while radial and transverse motions are represented by arrows depicting the direction of motion represented in the radiation patterns.