Receiver comparison for a non-repeatable earthquake source on the Hussar 2011 low-frequency seismic experiment

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Summary

CREWES, in conjunction with Husky Energy, Geokinetics, INOVA and Nanometrics, conducted a low-frequency 2D seismic experiment near Hussar, Alberta, in September of 2011. The purpose of the experiment was to study acquisition of low-frequency data in order to test inversion methods. Sources included three different Vibroseis units, and dynamite. Receivers on the ground were ION-sensor SM-7 10 Hz 3C geophones at 10 m station spacing, VectorSeis 3-C accelerometers at 10 m spacing, Sunfull 4.5 Hz 1C geophones at 20 m spacing, a partial line of SM-24 10 Hz high-sensitivity geophones at 20 m spacing, and Nanometrics compact broadband seismometers at 200 m spacing. The total receiver line length was 4.5 kilometers. On the last day of acquisition, a magnitude 6.3 earthquake occurred offshore Vancouver Island, British Columbia, Canada, approximately 1050 kilometers from the test line. The predominant frequency of earthquake arrivals was about 0.4 Hz, which is well out of the frequency range of 4.5 and 10 Hz geophones. However, the earthquake was recorded by all sensors that were part of the low-frequency experiment, and after correcting the data for geophone response, it is clear that data less than 1 Hz can be recorded on these geophones, for a sufficiently energetic source.

Introduction

Low-frequency seismic data is affected by receiver response to ground motion, low-cut filters in recording systems, and Vibroseis correlation. The 4.5 Hz and 10 Hz geophones have a flat response to velocity above 4.5 and 10 Hz respectively. Below that cut-off frequency data amplitude and phase are attenuated by the geophone response. VectorSeis accelerometers have a flat response to acceleration for all frequencies, but are affected by 1/f noise. Nanometrics compact seismometers have a flat response to velocity from 120 s (0.008 Hz) to 100 Hz (Nanometrics, 2011). Therefore, we regard the seismometer data to be the truth for our receiver comparisons. Geophone data were recorded on two INOVA (ARAM) Aries recorders, both of which had the standard low-cut filter turned off. VectorSeis data were recorded by an INOVA Scorpion recorder, which purportedly had a low-cut filter in place that could not be turned off. Each seismometer had it's own Nanometrics Taurus recorder, with no low-cut filter. The earthquake waves arrived during acquisition with a 24 second 1-100 Hz low-dwell sweep. Correlation with this sweep would attenuate frequencies below 1 Hz. We will be comparing single-fold uncorrelated data for this study, with the exception of the VectorSeis data, which were vertically stacked in the field.

Seismometer data

Figure 1 shows the vertical component of the seismometer data after normalization. The east and north components are similar. Red lines delineate the start time of the first sweep of two per vibe point, and a black line shows the time of the earthquake (Natural Resources Canada, 2011). The observer in the Scorpion recorder required that VP 209 be repeated due to noise on the line during the first try (Figures 1 and 2). The repeated VP 209 was not recorded by either of the Aries systems. Vibe points 210-217 were not acquired due to a highway crossing. Primary waves can be seen about halfway between VP 218 and 209 times, and secondary waves arrive just before VP 209 time. At VP 208 time, background noise has clearly not returned to the levels seen at VP 218 time.

Other sensors

Figure 2 shows uncorrelated shot gathers for VPs 218, 209 and 208 for the vertical component of all VectorSeis accelerometers on the line. Vibe engine noise and sweep, and pump-jack noise can be seen on the left side of each source gather. Noise from pumps at two additional well locations can be seen to the right. Three things became immediately apparent: 1) We recorded data of less than 1 Hz on all of the sensors that were deployed for the low-frequency experiment, regardless of recording system low-cut filters (if present) or geophone response to the velocity of low-frequency ground motion (Figure 3, middle), 2) As expected from known geophone and accelerometer characteristics, the low-frequency earthquake arrivals are least prominent on the 10 Hz geophone data, better on the 4.5 Hz geophones, and best on the accelerometer data (Figure 3). 3) The earthquake arrivals have an apparent velocity across the seismic line of about 4500 m/s (ie. 4.5 km of seismic line in about one second).

Receiver comparisons

Geophone response can be modeled as a 2^{nd} order minimum-phase Butterworth filter (Bertram and Margrave, 2011). Inverting this filter to create a time-domain wavelet and applying to geophone data by convolution has been shown to successfully correct for geophone response to amplitude. Receiver gathers of sensors at, or closest to, seismometer stations were created. All traces were de-biased and normalized before the amplitude spectra were calculated. Figure 3 shows the first five Hertz of the averaged amplitude spectra for those gathers. Seismometer data is repeated in both columns. VectorSeis (acceleration) and integrated VectorSeis (velocity) data are repeated in both columns. The left column shows uncorrected geophone data, and the right column shows geophone data after applying the inverse filter. Improvements in the geophone amplitude spectra, defined as a closer visual match to the seismometer amplitude spectra, can be seen to almost zero Hertz for all geophones.

Conclusions

The earthquake provided the best low-frequency source we could have asked for during a low-frequency experiment. That it happened while our sensors were on the ground is very fortunate, as the last large earthquake on the west coast was about ten years ago. To our surprise, the less than 1 Hz earthquake arrivals were recorded on all of our sensors, and after inverse filtering to correct for geophone response at low-frequencies, the geophone data is surprisingly similar to the accelerometer and seismometer data. Inverse filtering of the 10 Hz and 4.5 Hz geophone data to correct for geophone response at low frequencies is shown to be succesfull, based on visual inspection, at enhancing data with frequencies of less than one Hertz.

Acknowledgements

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References

Bertram, M. B. and Margrave, G. F., 2011, Recovery of low frequency data from 10Hz geophones, CREWES Research Report, **22**.

Nanometrics, 2011,

http://www.nanometrics.ca/ckfinder/userfiles/files/NMX-TrilliumCompact-brochure.pdf, Accessed October 30, 2011.

Natural Resources Canada, 2011, http://earthquakescanada.nrcan.gc.ca/stndon/NEDB-BNDS/bull-eng.php, accessed October 31, 2011.

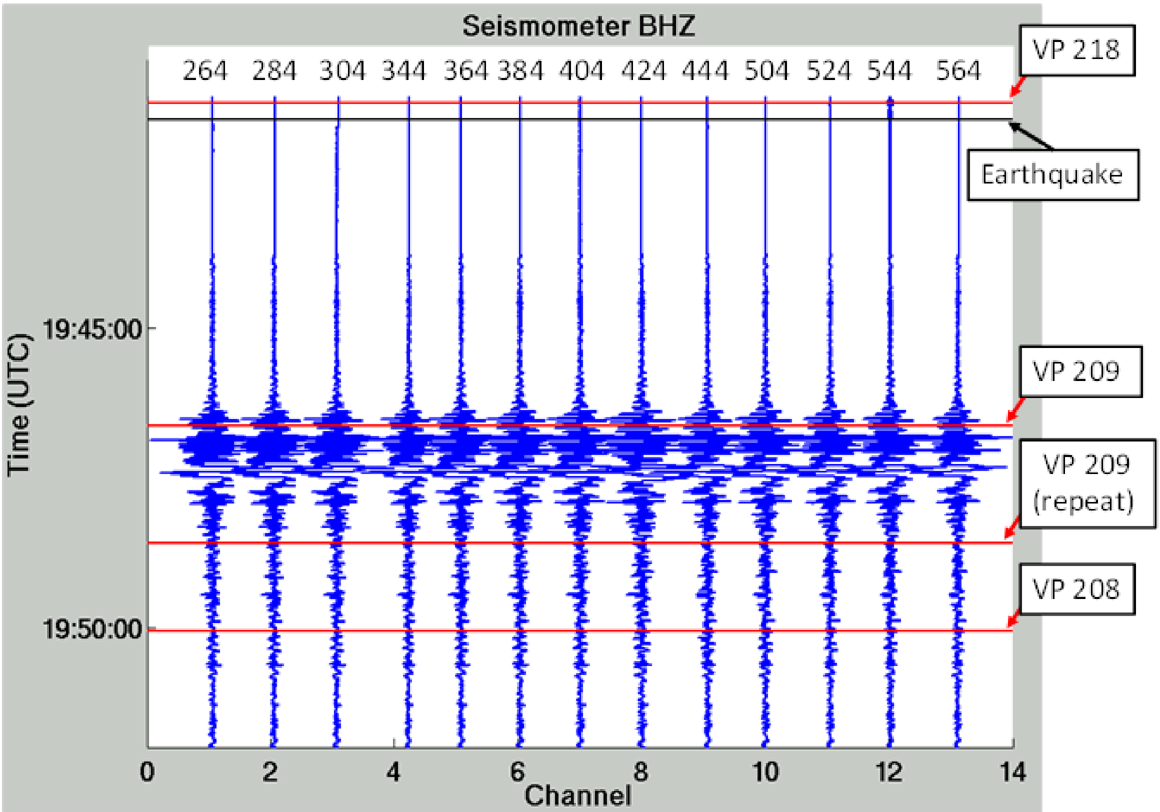

Figure 1: Vertical component of uncorrelated data from seismometers. Trace length is 11.5 minutes. The time of the first sweep (of two sweeps per vibe point) is shown as a red line. The time of the earthquake is shown as a black line.

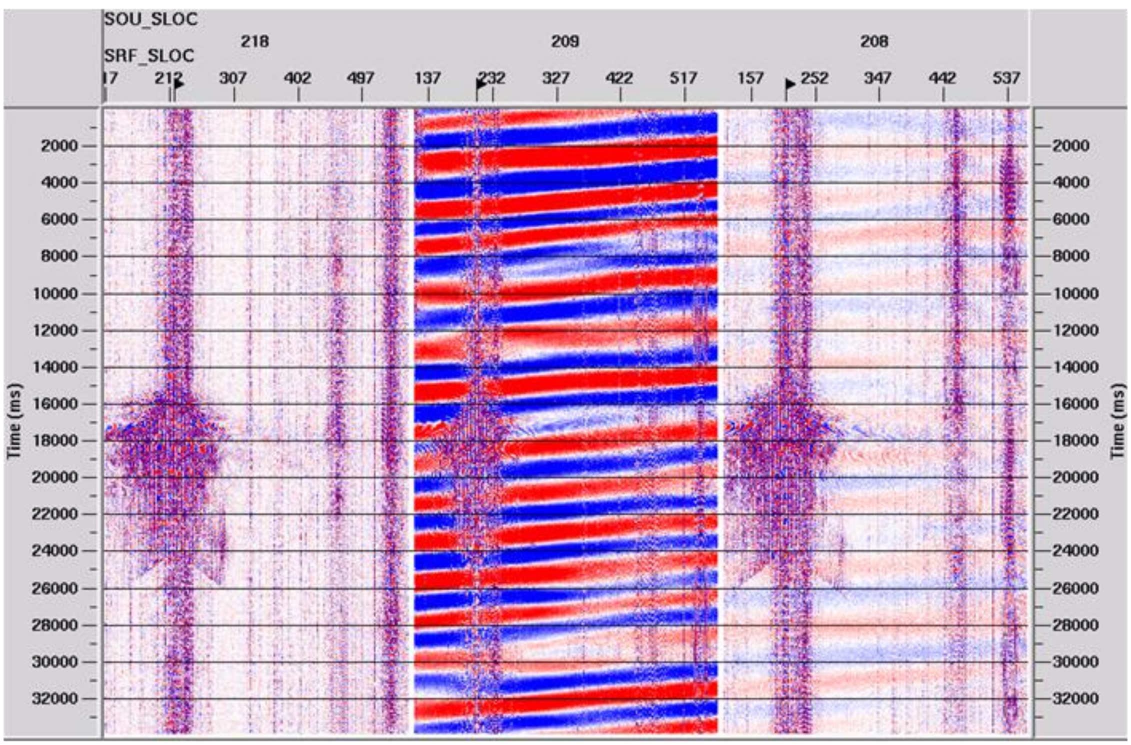

Figure 2: Uncorrelated data from the vertical component of VectorSeis accelerometers for VP 218 (left), VP 209 (middle), and VP 208 (right). Each source gather is 4.5 km wide. Trace length is 34 seconds, vertical fold is two. The Vancouver Island earthquake epicenter is ~1050 km to the right.

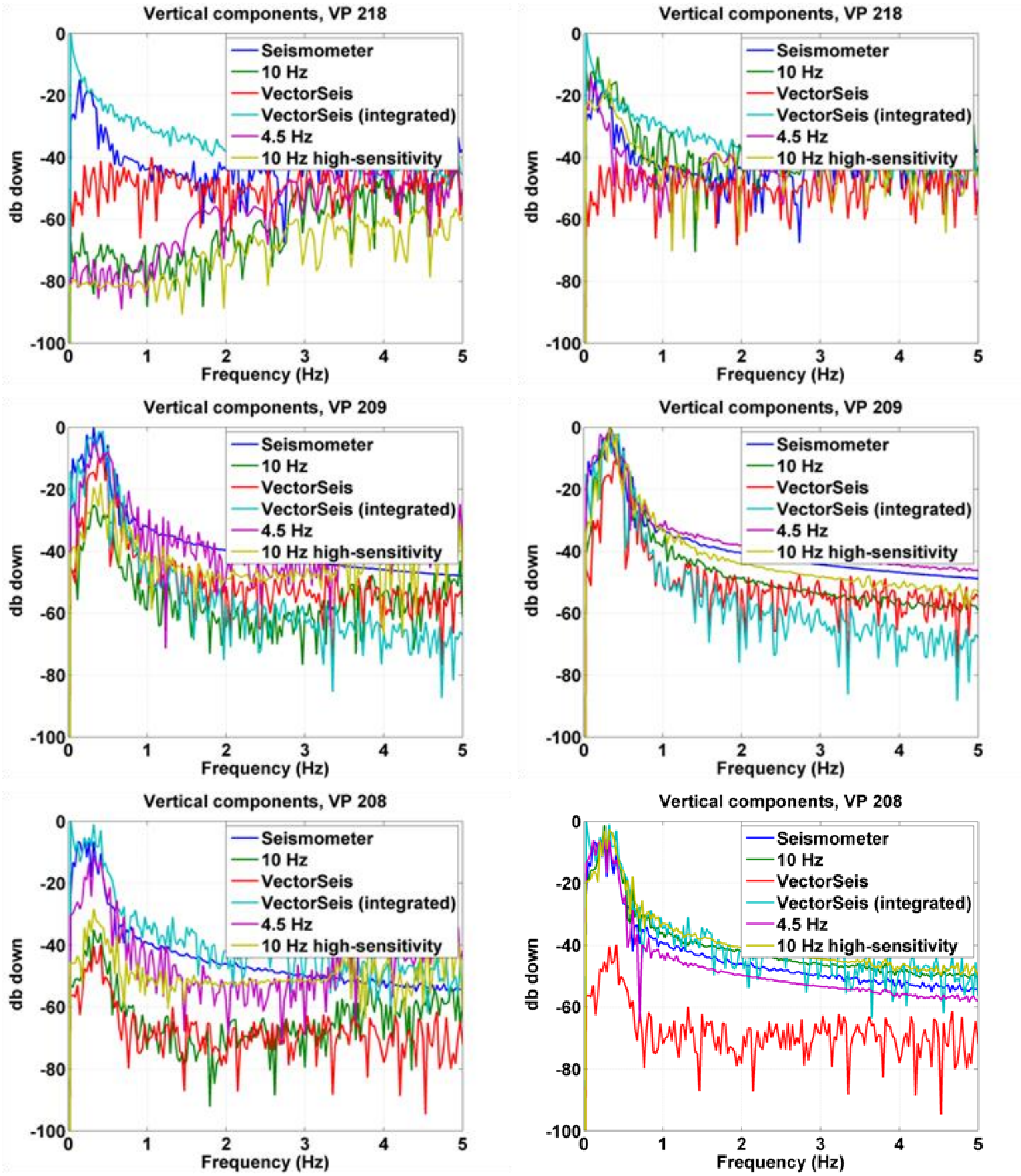

Figure 3: The first five Hertz of amplitude spectra for uncorrelated data from VP 218 (top; before earthquake arrivals), VP 209 (middle) and VP 208 (bottom), before correcting for geophone response (left column) and after correcting for geophone response (right).