Modern land recording systems: How do they weigh up?

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As hydrocarbons are becoming more difficult to find and to produce, operators who utilize relevant advanced technology have a clear advantage. What is not always clear is which advanced technology is relevant or applicable in a given situation. If we look at developments in land 3D seismic surveying over the last few years, we see a dramatic increase in the capabilities of the equipment being used and also innovative methods of its usage. We have seen significant increases in the trace densities of surveys and the recording intervals have been decreasing accordingly, but at what trace interval do we cease using geophone arrays and start using point receivers? Should these receivers be vertical component (1-C) sensors or multicomponent (3-C)? Should we use capacitance-based MEMS sensors or induction-based moving-coil geophones? Finally, advances in electronic systems now permit recording data without the use of telemetry cables—either by transmitting the data back to the recording truck by radio for quality control purposes and immediate storage on tape or discs or by storing it locally at the receiver for later recovery. Are there circumstances where there is a significant benefit from the utilization of a cable-less system as opposed to one with cables? This paper will discuss some geophysical and operational factors related to these questions.
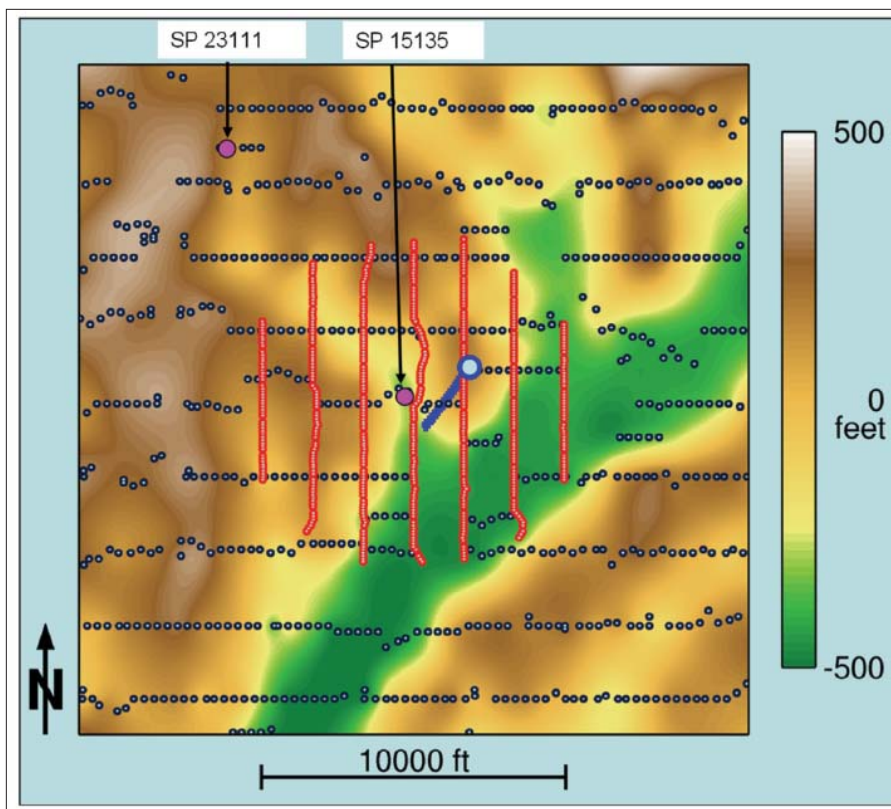
Geophysical considerations (data quality)

The signal-to-noise ratio is how most geophysicists evaluate the quality of a seismic survey. When considering the use of point receivers instead of geophone arrays, it is very important to remember that there is both a numerator (signal) and a denominator (noise). It is important to understand the characteristics of the signals that we wish to preserve and the noises that we wish to attenuate. Is the desired signal from a relatively strong, shallow reflector that we can expect to record with high frequencies and broad bandwidth, or is it from a deep formation with a weak reflection coefficient and correspondingly lower energy? If the latter, can we expect a single point sensor to give us the same signal strength as a well-planted array of 12 or more geophones?

Is the noise primarily random ambient noise (wind, rain, etc.), or is it coherent source-generated (e.g., ground roll), scattered source-generated, or perhaps a combination of all three? Although random noise may be attenuated very well by the use of higher-trace density surveys, geophone arrays may still offer an advantage in areas with very high random noise levels. However, for ground roll, we cannot deploy geophones arrays that are sufficiently long to attenuate the noise wavelengths without also suffering significant signal attenuation,
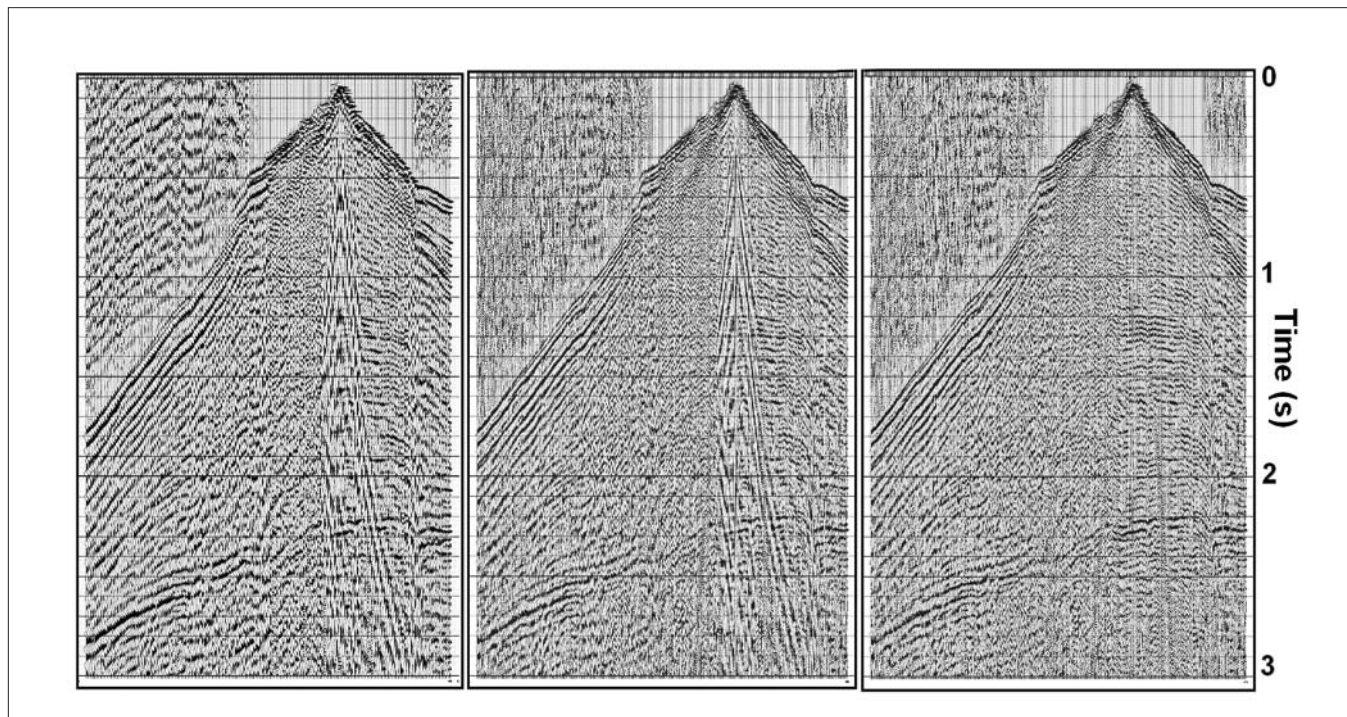
Figure 1. *Shot record with 12 vertical geophones per group (left); single-sensor vertical component DSU MEMS before polarization filters (center) and after such filtering (right). Polarization filters use the data from the horizontal components to attenuate noise on the vertical component. Other methods (not shown here) are used to attenuate noise on 1-C data. Comparing the data from the geophone groups to the single-sensor MEMS, it is evident that the single-sensor data are noisier but also contain more signal especially in the high frequencies.*

Figure 2. Location map of the receiver spread (in a circle) and two shots, one at the center of the spread and one outside.

the three geophones, together with the operational difficulties of leveling and aligning them (Lansley et al., 1998) and channel-capacity limitations of the old recording systems, result in costly data acquisition; hence, the use of multicomponent surveys has been limited. In recent year, the introduction of digital MEMS sensors and very high channel-count recording systems has eliminated the weight and leveling problems. Yet we still do not see widespread recording of 3-C surveys, except in a few areas. Why? If we again consider the question of arrays versus point receivers, it is necessary to understand that, due to the digital nature of their electronics, MEMS sensors cannot be connected in arrays to perform electrical summation in the same way as analog sensors. Therefore, in order to record 3-C data with MEMS, we are automatically recording with a point receiver or single sensors.

Single sensors eliminate intra-array statics and the effects of differential NMO, and MEMS have a wider frequency band and do not have high-frequency spurious noise. Therefore, they provide better signal than geophone groups, with improved resolution and multicomponent data, and they also provide more random and coherent noise. This increased noise with single sensors must be compensated by increased data density and more sophisticated data processing. It is also apparent that getting the full value from analysis of shear waves is more difficult than actually acquiring multicomponent data (Mattocks et al., 2005; Roche et al., 2006). In order to deliver the same final data quality as is recorded with geophone arrays, surveys with single sensors typically require smaller station intervals. We have found that single-sensor intervals must be, at most, half of geophone group intervals. Figures 2-4 show one example of 3D data from the United States in which single sensors, with an interval of 110 ft, provided similar final data quality to groups of six geophones at 220 ft.

In this example, a small 3D survey was recorded with the following parameters. Receiver lines were oriented NS with a nominal line interval of 1650 ft. Production geophone arrays with six geophones per group were planted along the receiver lines at an interval of 220 ft. In the center of the survey area, an embedded test, consisting of 544 additional MEMS 3-C single sensors, was planted along seven of the receiver lines (red in Figure 2). These single sensors were spaced at an interval of 110 ft so that alternate receivers were aligned with the centers of the production geophone groups and the others were midway between. Sources were aligned primarily EW with a nominal line spacing of 2420 ft. The source-point interval was 330 ft and 1266 explosive shot points were drilled

particularly on shallow, high-frequency reflections. There are two solutions for attenuating coherent noise such as ground roll. One solution is to reduce the station interval to less than half a wavelength of the ground roll so that *f-k* filters can be used. This is very expensive, no matter what type of sensors are used. Ground-roll wavelengths can be less than 20 m and the implied 10-m station interval may be prohibitively expensive. In 3D we have to provide sampling in the crossline as well as in the inline direction. In 3D, ground roll can be sampled and attenuated by *f-k-k* filters only at great cost due to increased receiver and source effort. The other solution is polarization filters as described by a number of authors including de Meersman and Kendall (2005). Polarization filters use the data recorded on the horizontal components to attenuate ground roll on the vertical component and vice-versa. Figure 1 shows a data example from the Green River Basin, Wyoming (Ronen et al., 2005.) This comparison is between data recorded using linear arrays of 12 geophones and single 3-C digital sensors with half the receiver spacing. The single sensors are shown without and with polarization filtering. In this case there is a significant advantage to recording all three components of the ground motion to attenuate the ground roll. The data on the right clearly show a strong reduction in the amplitudes of the ground roll and much better signal continuity.
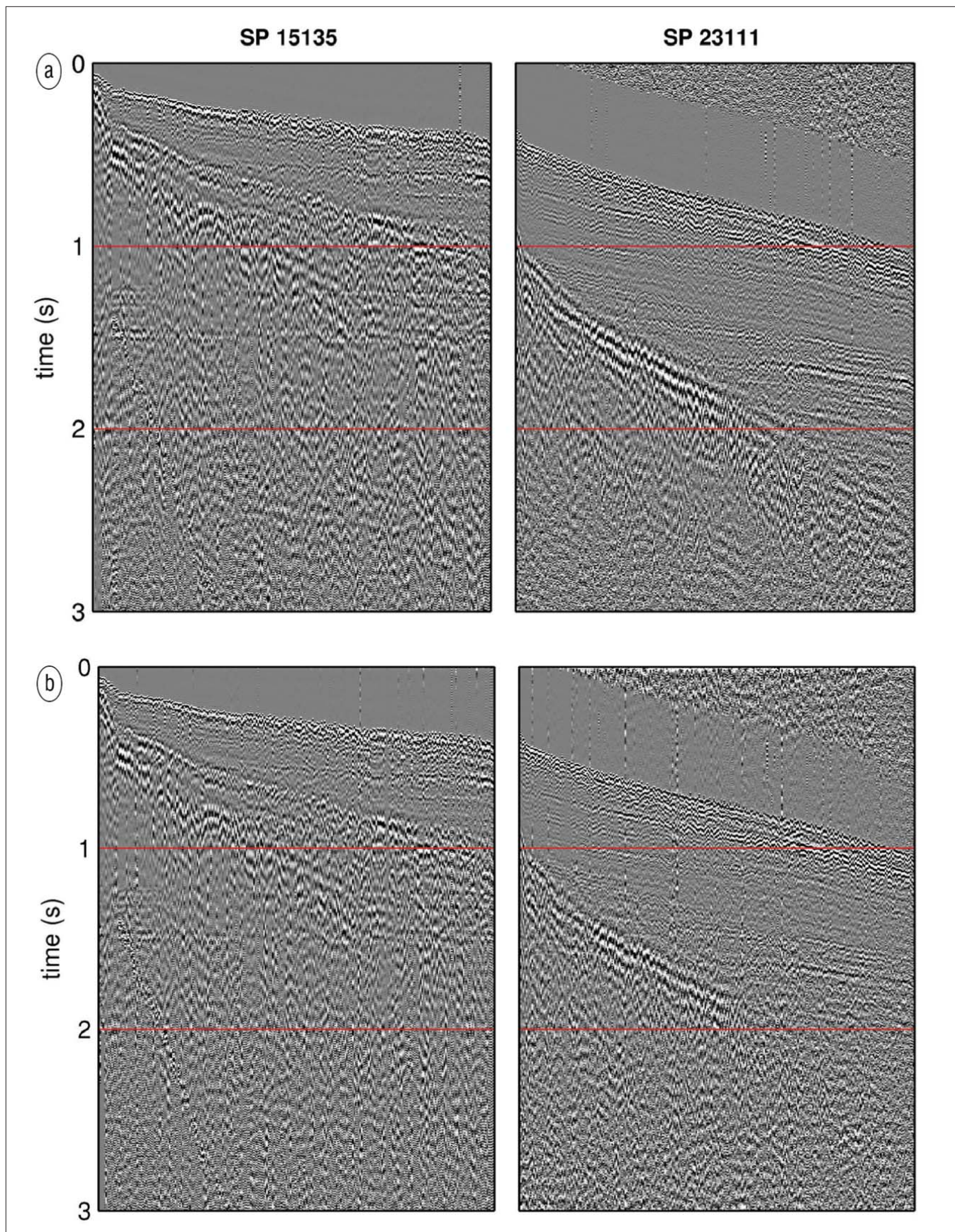
Multicomponent (3-C) recording has been conducted on land since the 1970s. For many years analog moving-coil geophones were used, either in arrays or individually, in conjunction with conventional data recording systems. The weight of

Figure 3. *(a) Geophone groups data. (b) Single-sensor MEMS data. Two shot profiles with different offset ranges are shown for each data set. Bandpass filter (8-12-80-100) and 1000-ms AGC. The geophones in groups of six have an advantage in signal/noise as can be seen, for example, on the reflector at 1.2 and 1.5 s two-way traveltime.*
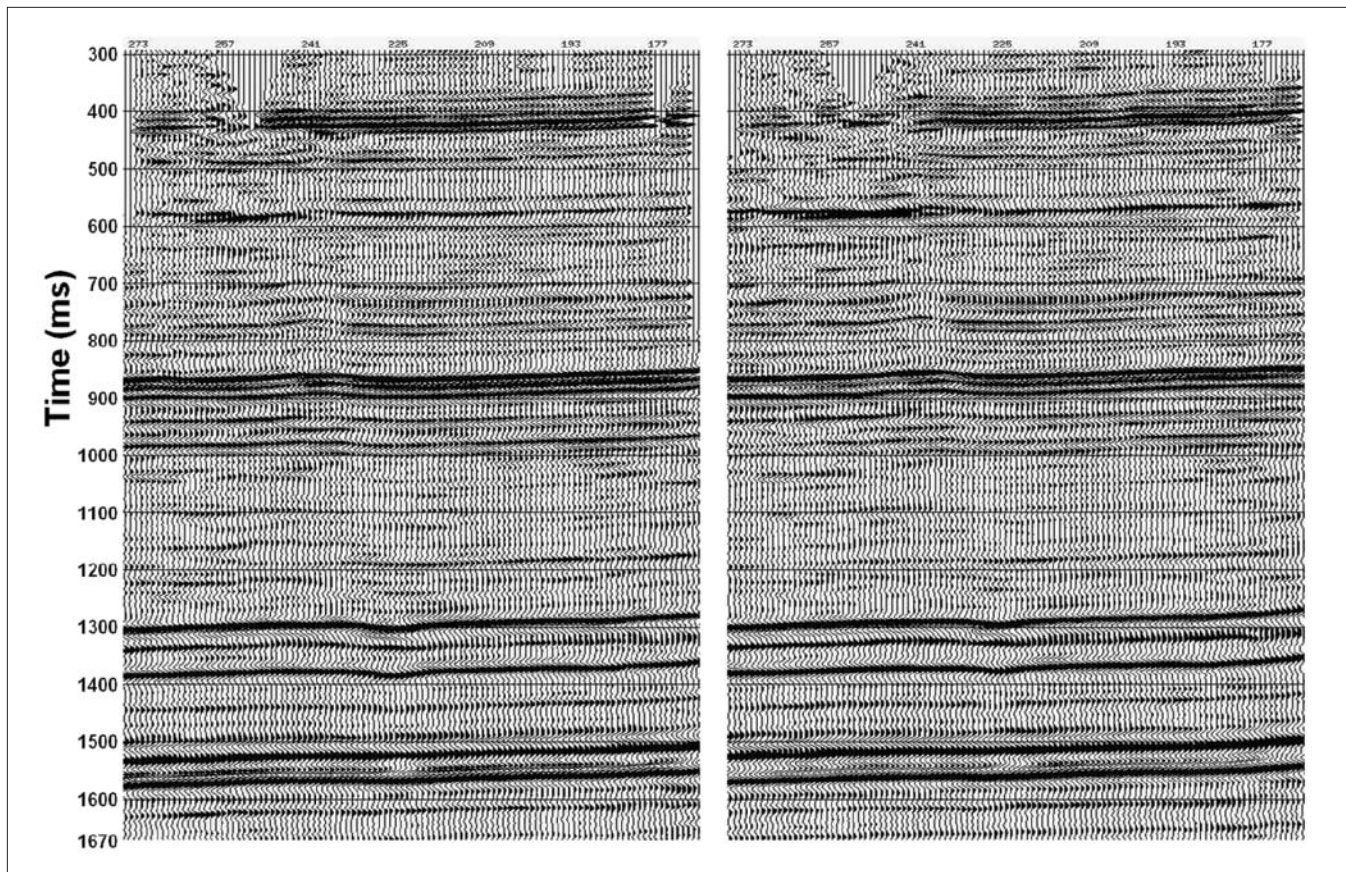
Figure 4. *Cross-sections from the conventional geophone groups data (left) and MEMS single-sensor data (right) after migration. The MEMS single-sensor data have been decimated after migration to the same bin size for display. It therefore has the signal/noise benefit of having been recorded with twice the data density. In areas of complex geology, the benefit of the finer spatial sampling would be more visible. The factor two in fold more or less compensated for the factor six in groups versus single sensors.*

and recorded simultaneously by both the production geophone arrays and the single sensors. This enables comparison of the different sensors to be made on single-fold shot records and migrated data.

Two shot records (locations shown in Figure 2) are compared in Figure 3. Figure 3a shows the data recorded by the production groups of six geophones and Figure 3b that from the single sensors. Both data sets are displayed with the same filter and 1000-ms AGC scaling. Since the MEMS sensors (Figure 3b) are recording acceleration and also have a much wider bandwidth than the geophones, these data have been integrated to velocity and match-filtered to simulate the low-frequency response of the geophones. The single-sensor MEMS data are decimated to the same trace spacing as the regular geophone groups for comparison purposes. Note that the reflections on the MEMS data compare very well with the geophone data after integration (from acceleration to velocity) and match-filtering to simulate the low-frequency response of the geophones. Also, more high-frequency noise is visible before the first breaks and on the deeper data.

Figure 4 is the comparison after 3D migration. The MEMS data were processed using all of the data all of the way through the data processing, but were decimated to the same trace interval after migration for comparison purposes. Overall, the signal-to-noise ratio is very comparable. There are some places where geophone groups look marginally bet-

ter than the single sensors and vice versa. In general, the geophone data are marginally better in the deep section and the MEMS data better at shallow depths. Since the single sensors were recorded with finer spatial sampling, this agrees quite well with what we expect. Note, however, that the single-sensor data were recorded with half the receiver interval (i.e., twice the trace density) of the geophone group data.

A few years ago, acquisition systems were limited by channel count and reducing the receiver interval and recording 3-C was not practical. Fortunately, channel counts are no longer an issue because modern systems have a capability of 100 000 channels in real time at a sampling rate of 2 ms. Of course, although the recording of the seismic data with most of the cable-less systems is in real time, the actual data recovery for transfer to data processing and long-term storage is not. In fact, data recovery and, hence, data processing may be delayed significantly depending upon weather and other operational issues.

The geophysical considerations relevant to comparing cable to cable-less systems are less obvious. The same receivers can be connected to either system. However, one big advantage of cable telemetry is improved field QC with better monitoring of noise levels and early detection of poor coupling.

Operational considerations (time and money)

The potential operational advantage of systems without ca-
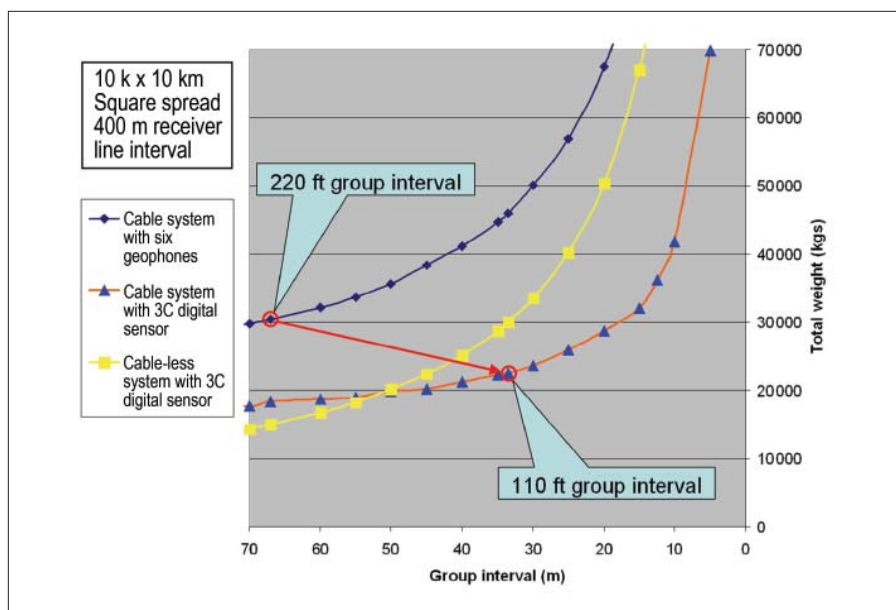
Figure 5. *Total ground equipment weight as a function of receiver interval for a 10 × 10-km recording spread with 400-m receiver line interval. All necessary equipment, including transverse data transmission cables, boxes and batteries, is incorporated.*
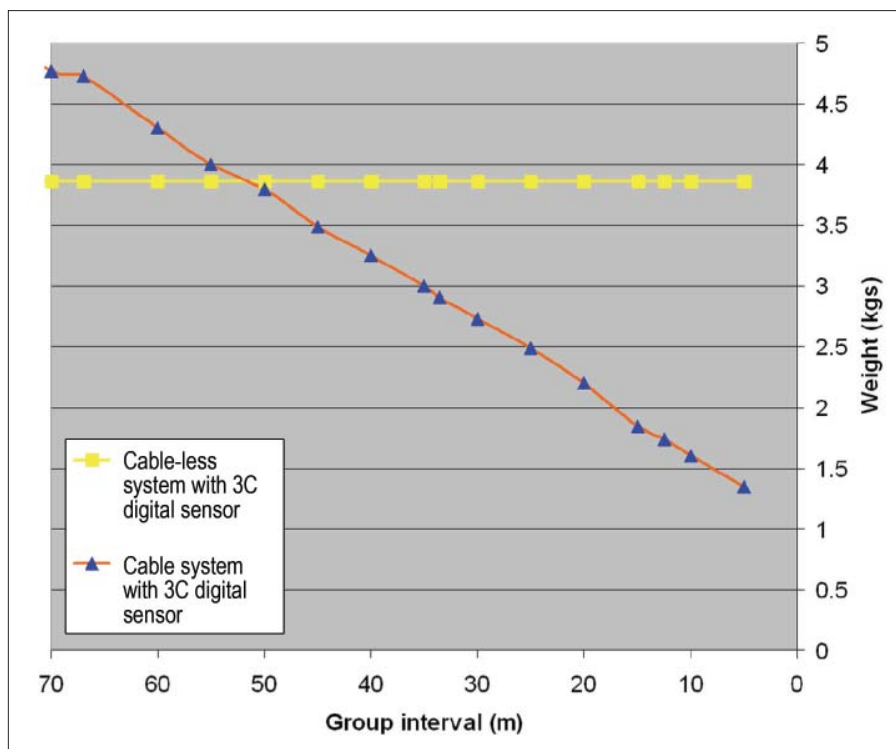
Figure 6. *Weight per receiver position, calculated from the total weight of all required ground equipment divided by the number of receiver positions.*

bles is in areas with limited access or on surveys where the receiver station interval is large. Cable-based systems have operational advantages where cables can be deployed, receiver station intervals are small and they also have the geophysical advantage of improved field QC.

The most important factors that govern the operational and recording efficiency are: equipment weight, power consumption of the ground electronics, battery and power man-

agement, and source/spread management.

As discussed earlier, when using point receivers, the trace density is typically doubled in order to provide a similar signal-to-random-noise ratio as would be achieved when using arrays of six geophones. Therefore, when considering equipment weight, this factor needs to be comprehended. Figure 5 shows the approximate weight relationship between three different recording scenarios: a cable system with arrays of six geophones, a cable system with 3-C digital point receivers, and a cable-less system also using 3-C digital point receivers. The total weights shown are for a 10 × 10-km square spread with 400-m receiver line interval plotted against receiver station interval. (For these weight comparisons, the choice of cable and the actual cable length between takeouts are very important. The cable used in these graphs is that recommended by Sercel for 3-C single sensor deployment with a weight of 47 kg/km.) The length of cable between takeouts is equal to the group interval plus 5 m for group intervals of 20 m and larger and group interval plus 3 m for intervals less than 20 m. For the cable system shown, the weight of all ground equipment necessary for data recording is included: transverse cables, crossline telemetry boxes, batteries, etc. There is a significant weight advantage to using the digital 3-C sensors, even when the recording group interval is halved as shown on the graph. This is due to the large difference in weight between a string of six geophones (3.3 kg, not including digitizer) and the weight of one of the equivalent two 3-C digital sensors (2 × 0.5 kg including digitizer). What is also apparent is that, for large group intervals (coarse spatial sampling), there may be a slight weight advantage for the system without cables. However, as the industry moves to higher and higher trace densities and finer spatial sampling, the weight advantage moves in favor of the cable system. If we compare systems with 3-C digital sensors, the crossover between cable and cable-less systems is at approximately 50 m (or ~165 ft.)

Figure 6 shows an alternative view of the same information where the weight per 3-C digital sensor station is plotted against the group interval. Here the advantage of a cabled

system is clearly apparent as the receiver station interval is reduced. Since different cable-less systems have different capabilities (e.g., 1-C versus 3-C, analog sensors versus digital MEMS) and different power consumption, it is difficult to make direct comparisons. However, understanding the power consumption and the corresponding battery requirements for each type and make of receiver station will provide a good estimate of the weight per receiver position. Comparison with the weight of a cable system, such as shown in Figure 6, will then provide a better understanding of the relative merits of one system versus another in any given situation.

Power consumption and battery management are obviously related and the lower the power consumption of the ground electronics the better. Although some battery types may have very good power-to-weight ratios, initial and replacement cost may be significantly higher. Low temperatures also affect battery life and some types (e.g., lithium-ion) may not be very well suited to such environments. When we consider the number of batteries deployed within an active recording spread, with the cable-less system we have at least as many batteries as receiver points, which today may range from 5000 to 50 000. For battery charging and management, an additional 50% is often necessary to ensure an adequate supply of fully charged batteries. With a cable system, the number of batteries per line is typically divided by 30-40, which becomes much more manageable. Although each individual battery may be heavier, the type can be selected to be appropriate for the operating environment and the management and recharging is much easier. Another issue that is of concern for land surveys is whether the seismic source is explosives or vibrators. For explosive surveys, the recording time can be minimized by the use of several shooters and careful management of the operations. Hence the battery life can be optimized and may allow the deployed battery to remain in the field until the station is picked up and rolled to the next location. However, for vibrator recording the operations are normally continuous and therefore require the recording system to be active continuously. This increased recording time means that most cable-less systems do not have adequate battery life and will require battery replacement during the time that the units are deployed at one receiver location. If we consider a recording spread with 10 000 or more active receiver locations, that is a very large number of batteries to recharge and replace.

Modern high channel-count recording systems incorporate very efficient source and receiver spread management tools that enable source-controlled shooting to be effectively implemented. These, together with the real-time verification of data quality, can ensure that these high-density multicomponent surveys meet the desired objectives.

Conclusions

High-quality, high-density, multicomponent 3D surveys are being acquired very cost-effectively using single sensors. The receiver station interval (hence trace density) needs to be adjusted to compensate for the increased random noise that will be recorded with single sensors. We have found that two 3-C

digital MEMS sensors are typically required to replace an array of six geophones. In areas with weak reflection strength or poor signal-to-noise ratio, where arrays with more than six geophones are frequently used, the number of single sensors may need to be increased even more to ensure that adequate signal strength is being recorded. Despite this improved spatial sampling, there is still a considerable reduction in the weight of the ground equipment being deployed with a corresponding improvement in operational efficiency. When compared with the historical average recording production over several prior recording seasons in the same area, statistics from a number of large, Canadian, single-sensor surveys with more than 170 500-receiver locations showed an increase of better than 40% in the layout and pickup of the recording equipment. A remarkable increase of more than 45% in the number of shots recorded per day was also observed.

In areas with difficult access and/or high population densities, such as cities, there will be a benefit in using cable-less systems. For low trace density, coarsely sampled 3D surveys with large receiver-station intervals, there will also be a slight weight advantage in recording without cables. However, as the spatial sampling becomes smaller and the trace density greater, significant operational and recording efficiency benefits are gained using cables. Uncommitted systems that offer the flexibility to use either cables, or cable-less technology, or a combination of both within the recording spread will permit recording optimization under all conditions.

Suggested reading. "Multicomponent 3D seismic pilot study in the Orinoco heavy oil belt" by Lansley et al. (SEG 1998 *Expanded Abstracts*). "A complex SVD-polarization filter for ground-roll attenuation on multicomponent data" by de Meersman and Kendall (EAGE 2005 *Extended Abstracts*). "Multicomponent seismic in rough terrain: an example from Wyoming Green River basin" by Ronen et al. (SEG 2005 *Expanded Abstracts*). More general reading on some of the additional benefits of 3-C recording may be found in "Prediction of shale plugs between wells in heavy oil sands using seismic attributes" by Gray et al. (*Natural Resources Research*, 2006); "Converted-wave azimuthal anisotropy in a carbonate foreland basin" by Mattocks et al. (SEG 2005 *Expanded Abstracts*) and "Delineating reservoir sands using PP and PS seismic data" by Roche et al. (EAGE 2006 *Extended Abstracts*). **TLE**