Advances in gravity survey resolution

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Major technological advances have been made in the last few years in gravity resolution for many acquisition systems currently available for exploration. These advances have resulted from better instrumentation, better use of DGPS, and better processing methods. This in turn led to a renaissance in the use of gravity in modern multidisciplined, cost-effective oil and mineral exploration. The aim of this article is to show how gravity resolution has improved with time rather than how improved resolution is being used to investigate and map subsurface density structures.

Resolution is the ability to separate two features that are very close together. For gravity, this can be expressed in terms of the accuracy of the measuring system (in mGal) at the shortest resolvable signal wavelength (km). Current practice defines gravity wavelength as the half sine wave distance (1/2 wavelength) and this definition is used here. Because gravity measurements are generally collected along profile lines, a survey's spatial resolution largely depends on profile line spacing.

Resolution for conventional land and/or seabed gravity surveys (static surveys), using high-performance gravity meters, is simply a function of the spatial coverage of observation points and microseismic activity (gravity meters are similar in design to seismometers). However, resolution for shipborne and airborne surveys (dynamic surveys) is influenced by a range of noise components induced by uncertainty and variability of speed, position, sea state, and air turbulence. Thus, resolution claims are compared to the "best possible" obtained under ideal survey conditions. Resolution of marine gravity surveys degrades significantly with worsening sea state. In airborne surveys, flying straight and level with no turbulence (ideal conditions) is generally not achieved. On the other hand, recent improvements in airborne gravity resolution have revealed the inadequacy of the ground static measurements used to quantify this resolution.

Figure 1 is the time-trend plot of resolution for the range of systems currently used by the oil industry. Static measurements have been discussed above. Other commonly available techniques are satellite-derived gravity, shipborne and airborne gravity, and gravity gradiometry.

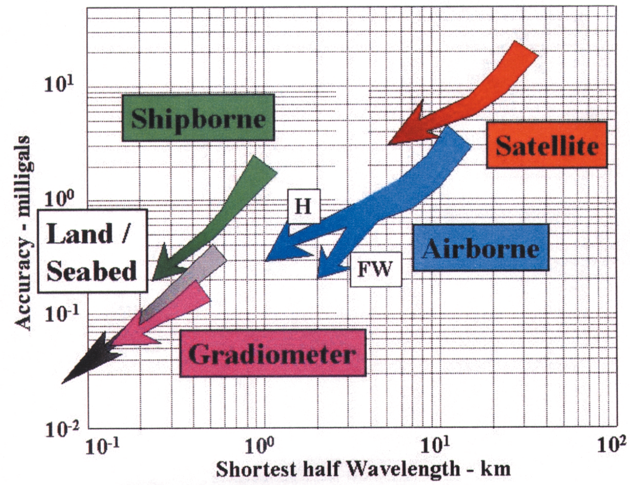

Figure 1. Time-trend log-log plot of gravity "best possible" resolution of survey systems (arrow points represent current claims). FW = fixed wing. H = helicopter.

Satellite gravity. Satellite-derived gravity relies on satellite radar altimetry mapping of the marine geoid surface and then transformation, essentially by determination of the vertical gradient, to free air gravity (*TLE*, August 2001). The trend of resolution with time has primarily been controlled by improvements in spatial coverage and better picking of radar reflections. This has improved resolution from 20 mGal @ 25 km in the mid-1980s to about 5 mGal @ 12 km in the mid-1990s to ~3 mGal @ 5 km today. Swath radar mapping may be a way to achieve even higher resolution.

Shipborne gravity. The breakthrough in shipborne gravity resolution in the mid-to-late 1980s is credited to Edcon which used GPS to monitor Eötvös effects and upgraded the LaCoste & Romberg (L & R) S-meter to the SAGE meter, which could make the 1-s sampling necessary to track the Eötvös effect. Prior to this, in the 1970s, 1-minute and then 10-s sampling were the norm and resolution varied from 2 mGal @ 1km to 0.5 mGal @ 0.5 km (the latter for stand-alone surveys in calm weather). After the introduction of the SAGE meter in the mid- to late 1980s, resolution dramatically improved to 0.2 mGal @ 0.25 km. Since then, the slump in oil prices has reduced the principal contractors to two (Fugro-LCT and AEI) and only minor resolution improvements have been achieved since.

Airborne gravity. Since the mid-1990s, there has been considerable effort to convert dynamic gravity R & D research in airborne gravity into high-resolution commercial systems. These new systems are likely to dictate future trends in potential field acquisition. Airborne gravity can be traced back to early tests in the 1970s; Carson Services introduced helicopter-mounted gravity systems in 1977 (claimed resolution was ~1 mGal @ 5-8 km) and then fixed-wing systems in the mid-1980s. Carson was the unrivaled champion of airborne gravity until the mid- to late 1990s. Mastering DGPS, upgrading the Carson system, and introduction of rival acquisition systems by Edcon, Fugro, and Sander (to name but three) resulted in resolution claims of 0.3 mGal @ 1 km for helicopter-mounted systems traveling at ~50 knots and 0.2-1 mGal @ 2 km for fixed-wing systems traveling at ~100 knots (*TLE*, October and November 2000).

Sander's AIRGrav, the newest of these systems, uses accelerometers instead of the L & R devices used by the other contractors. The AIRGrav system uses the same principles as an inertial navigation system with gyros but with no attempt to null the horizontal accelerations. The accelerometers have lower noise (factor of 2-3) and higher resolution because they do not have the nonlinearity of the L & R system; as a result, variations in vertical acceleration can be more accurately tracked and removed during processing. A unique feature of the AIRGrav system is that it is unaffected by air turbulence, which makes survey costs lower and allows the system to be drape flown.

Gravity gradiometry. Gravity gradiometers are essentially Lockheed Martin instruments that can measure 3-D gravity gradients and tensors. Accuracy claims based on Gulf of Mexico surface ship measurements by Bell Geospace put the system at 0.5 Eötvös (0.5 mGal/km). The modified airborne system, developed by BHP and flown by Sander Geophysics, generated impressive vertical gravity gradient data (*TLE*, 2000).

Conclusions. We conclude with some lessons learned about best practices. Resolution will generally be below that shown in Figure 1 due to nonideal survey conditions. Thus, monitoring resolution (i.e., checking resolution claims to see if a survey remains within specifications) is a challenge for an oil company.

For marine gravity surveys undertaken as part of 2-D or 3-D seismic surveys, one would appear limited to monitoring the occasional repeat lines and adjacent line comparisons and evaluating crossover levels. Best practice suggests that gravity/navigation/bathymetry should be continuously recorded throughout the survey. By so doing, data coverage can increase 100% and a significant number of crosslines can be generated at no extra cost. Standalone surveys (marine and airborne) have greater opportunities to follow best practice procedures. For airborne surveys, this would be to fly the same test line at the start and end of each flight during a survey. The test line could be compared to ground-based measurements if available. Such a procedure gives comfort that the gravity system and processing are producing consistent results from flight to flight that are within specification.

Finally, because an airborne survey generally costs well in excess of $0.5 million, it is not unreasonable to have independent acquisition quality control. Using different contractors for acquisition and processing generally improves survey acquisition standards and reporting of resolution to the client.

Improvements in resolution over the last 20 years have been dramatic and we confidently look forward to further improvements in resolution, accuracy, and consistency in the next few years. TLE

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