High resolution AIRGrav surveys: Advances in hydrocarbon exploration, mineral exploration and geodetic applications

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Summary:
Sander Geophysics has now operated its AIRGrav airborne gravity system for over ten years. More than 2,500,000 lkm of AIRGrav surveys have been flown, predominantly for hydrocarbon exploration. Recent advances in SGL's gravity data processing, involving advanced analysis of system dynamics and improved filtering, help to further reduce system noise and allow for the generation of high quality, low noise gravity data through a wider range of survey conditions than was previously possible.

In the past year, a number of AIRGrav projects with innovative survey design parameters have been successfully completed. Mineral exploration projects have been flown using a helicopter at extremely slow acquisition speed (30 knots) combined with tight (50 m) line spacing to produce data sets with higher resolution and higher accuracy. On the other end of the spectrum, the AIRGrav system produced excellent results when installed in a NASA DC 8 flown from 500 to 11,000 m altitude at 300 knots, covering approximately 9,000 km in 12 hour flights, with differential GPS baselines as long as 3,000 km. New data processing techniques have allowed the extraction of the horizontal gravity components of the airborne gravity data in addition to the traditionally used scalar gravity measurement.

Introduction:

Airborne gravity data has been collected since the late 1950s (Thompson & LaCoste, 1960). In the late 1990s the improvements in GPS processing and a new gravity instrument, the AIRGrav system (Argyle et al., 2000) resulted in a significant reduction in airborne gravity noise levels. Standard processing techniques have proven successful at extracting gravity data from the very dynamic aircraft environment where accelerations can reach 1 m/s^{2,} equivalent to 100,000 mGal. High precision differential GPS processing techniques and a robust gravimeter system resulted in final processed gravity grids with noise estimates of 0.1 to 0.3 mGal with a resolution of 2 kilometres. In this paper, five short case studies will be presented to illustrate improvements to the AIRGrav data accuracy and resolution resulting from modifications to standard processing techniques and acquisition parameters.

Method:

The AIRGrav system uses three orthogonal accelerometers, mounted on a three-axis, gyroscopically stabilized platform in conjunction with a specialized data acquisition system to monitor and record the data and parameters measuring gravimeter performance. In this paper, standard airborne gravity data processing refers to the subtraction of the vertical accelerations of the aircraft measured using high quality differentially corrected GPS data from the vertical accelerations measured by the gravimeter, followed by the application of standard corrections to remove the effects of the rotation of the earth, the movement of the platform over the globe, and terrain effects (Sander et al., 2004). A processing procedure, which we will call enhanced data processing involving advanced analysis and improved filtering, has been added to the data processing stream.

Case Study #1 – Hydrocarbon exploration project

An airborne survey for hydrocarbon exploration was flown using the AIRGrav system installed in one of SGL's Cessna Grand Caravans. The survey consisted of north-south oriented survey lines spaced at 500 m, with orthogonal control lines spaced at 2,500 m. A smooth drape surface was flown with a target clearance of 150 m above ground level. The survey was flown at a nominal ground speed of 105 knots (194 km/hr), which is equivalent to 54 m/s. Data from this project was processed using the standard technique described above as well as with the additional enhanced processing and the resulting data sets are compared.

On this project, a repeat test line was flown before and after each flight. An average test line was computed by combining the data from each test line filtered using a 56 second line filter, to create an “air truth” value for the test line in the manner described by Elieff and Ferguson, (2008) and the RMS error for each individual test line was calculated. These calculations were repeated for data processed both in the standard and enhanced methods. The line data processed using the enhanced method shows better repeatability for all test lines. The average standard deviation for the test lines processed using standard processing is 1.26 mGal, but 1.08 mGal for the test lines processed using the enhanced method.

Data for this project were gridded and filtered using a range of low pass grid filters to evaluate the noise levels and the signal content. For this project, a detailed set of ground gravity data was available over part of the survey area. *Figures 1* and *2* show the area of overlap, which is approximately 30 km by 30 km in size, and is covered by 2,200 lkm of AIRGrav data, and 8,100 ground gravity points. The actual AIRGrav survey is much larger in size, but is not shown due to the client's request for confidentiality. Gridded ground gravity was compared to the grids created from the airborne data with different filter lengths as an additional evaluation step. For the standard processed data, a 1.25 km grid filter was applied to gravity grids generated from 20 second filtered line data. For enhanced processed gravity data, a 750 m grid filter was applied to gravity grids generated from 5 second filtered line data.

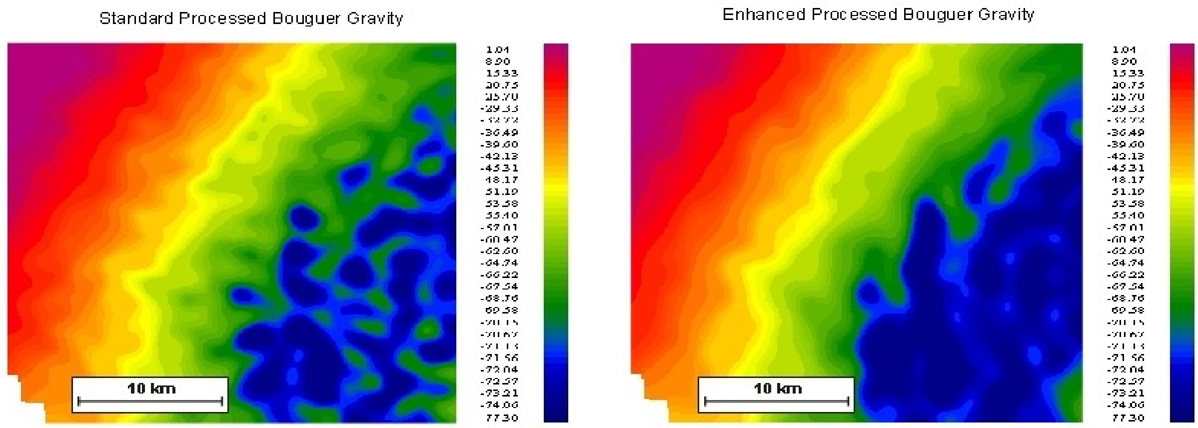

Figure 1: AIRGrav Bouguer Gravity Grids

A first vertical derivative of each gravity data set was calculated in order to remove the long wavelength regional field to emphasize the higher frequency anomalies which are closer to the grid filter length (*Figure 2*). The enhanced grid shows a stronger correlation with the ground gravity grid, in particular with the higher frequency features in the regions with the highest density ground gravity coverage.

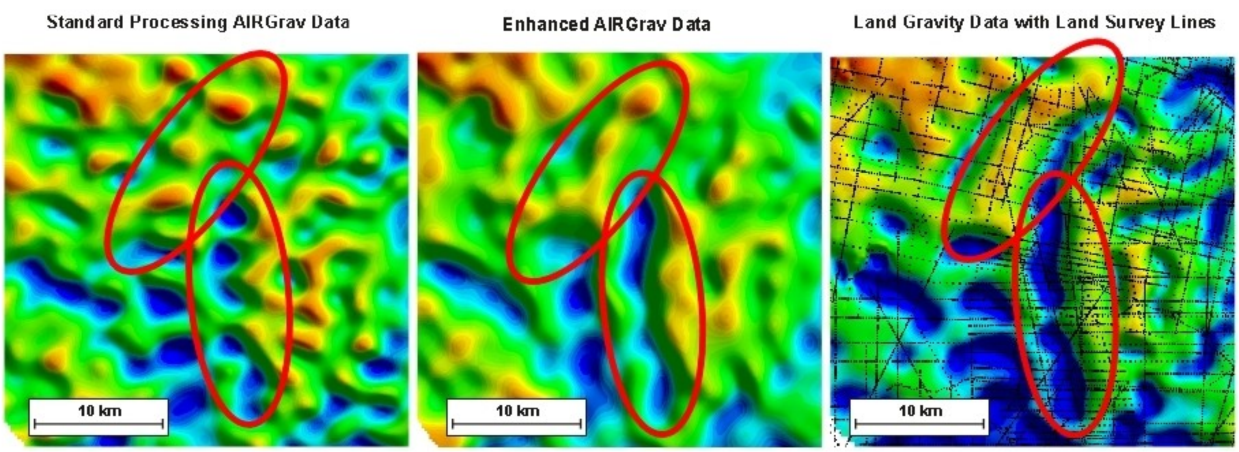

Figure 2: First vertical derivative of AIRGrav and land gravity data

Case Study #2 – Using horizontal gravity components for geodetic applications

A 550 kilometre long continuous test line was flown from 20 kilometres south-east of Ottawa, Canada to the eastern shore of Lake Huron with the AIRGrav system installed in a Cessna Grand Caravan. The test successfully determined that the horizontal gravity components can be measured with high repeatability using the AIRGrav system and the measured horizontal components agree well with geoid models of the highest order available when terrain effects are removed.

Case Study #3 – Mineral exploration project

Airborne gravity data has traditionally been used to define regional scale geology for which standard acquisition parameters using a fixed wing aircraft were adequate. However for mineral exploration, a higher resolution data set is preferable. Recently, the AIRGrav system was installed in a helicopter and six small survey blocks were flown at an extremely slow acquisition speed (30 knots or 56 km/hr) with tight (50 m) line spacing. Scanning laser data were concurrently acquired in order to create a high resolution 1 m grid cell size digital terrain model.

This configuration coupled with the enhanced processing technique resulted in a gravity data set that met the requirements of this mineral exploration project with an accuracy of 0.4 mGal at a 300 m resolution. The accuracy was calculated using the even-odd grid comparison method (Sander et al., 2002). *Figure 3* shows the gravity data superimposed on the derived terrain model for a small region of the survey.

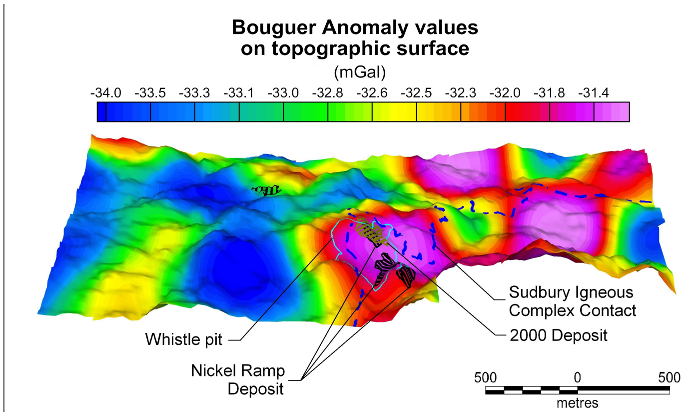

Figure 3: Mineral Exploration Project (300 m resolution gravity data)

Case Study #4 – Scientific Research Project

The AIRGrav system was chosen for scientific use after comparison test flights in which data was simultaneously acquired using a CMG GT-1A gravimeter and the AIRGrav system (Studinger et al., 2008). This led to the 2008-2009 AGAP project where the AIRGrav system was flown in a Twin Otter from a field camp on the Antarctic ice sheet. The data collected is being used to better understand the geologic origin and tectonic evolution of the Gamburtsev Subglacial Mountains buried below more than 3 km of ice (*Figure 4*). The multi-year multi-parameter IceBridge project involves using an AIRGrav system during flights over the Antarctic with a NASA DC-8, and Greenland and the Arctic with a NASA DC-8 and P-3, in the spring season of each hemisphere. During the 2009 Antarctica phase, the DC-8 was flown from 500 m to 11,000 m altitude at 300 knots, covering up to 9,000 km per flight in 12 hour flights, with differential GPS baselines as long as 3,000 km. The airborne gravity data is being used to constrain the water depth of subglacial cavities beneath several floating glaciers and ice shelves to support realistic computer modeling of ocean circulation beneath the ice shelves.

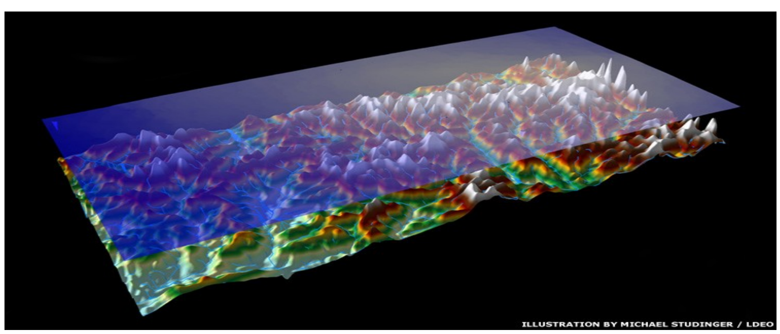

Figure 4: A simple illustration of the Gamburtsevs inferred from just gravity data. (Studinger, 2009)

Case Study #5 – Marine AIRGrav

The AIRGrav system was installed in a utility trailer which was installed on the deck of a 17 m dive boat in Kingston, Ontario. A small survey was performed over two days in Lake Ontario to test the performance of the AIRGrav system on a seaborne project in a moderately high sea state with 2 m wave height. A total of 470 km of line data was acquired in a grid pattern with 200 m line spacing. *Figure 5* shows the resultant gravity grid as well as the magnetic data which were acquired concurrently. The gravity grid has an accuracy of 0.21 mGal and a resolution of 300 m.

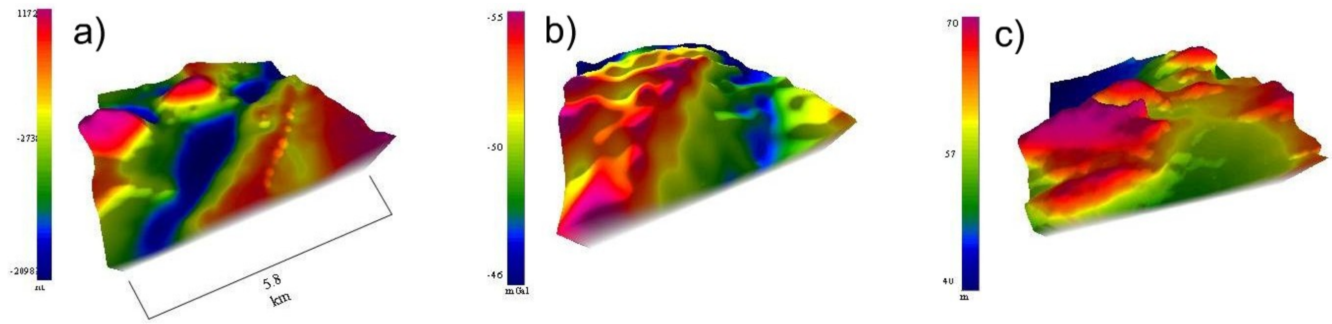

Figure 5: Marine AIRGrav Survey a) Total Magnetic Intensity, b) Free Air Gravity, c) Bathymetry

Conclusions:

Recent advances in SGL's gravity data processing have allowed the generation of higher quality, lower noise gravity data. In addition, the new processing techniques have allowed the extraction of the horizontal gravity components of the airborne gravity data which are useful for geodetic applications. Innovative survey design parameters have been used to acquire data for varied specialised projects including mineral exploration and to define the terrain below large depths of glacial ice. The AIRGrav system was also successfully tested in a marine configuration.

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