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High-Altitude Aerogravity Survey for Improved Geoid Determination

V.A. Childers and S.A. Martinka
Marine Geosciences Division

Introduction: Shallow water (littoral) regions present unique challenges for Naval operations. Warfighter support in the littoral region is hampered by our inability to relate tide and ocean circulation models directly to nautical charts via an absolute vertical datum. Various water measurements of critical importance to the Navy (such as tide gauges, ocean bottom pressure/inverted echo sounders, satellite altimetry, and heights now easily measured by GPS) are made with respect to different vertical reference frames (tidal datums and ellipsoidal frames), and there is no mechanism for conversion from one frame to another.

An accurate geoid can provide the vertical reference required to relate the various vertical reference frames. The geoid is the surface of equal gravitational potential that most closely approximates mean sea level (in a motionless ocean) located with respect to the ellipsoidal (GPS) reference frame. Historically, the gravity field had not been sufficiently determined to produce a geoid accurate enough to relate the reference frames. Since 2003, however, the Gravity Recovery and Climate Experiment (GRACE) satellite has revolutionized our ability to construct geoids by accurately resolving the long-wavelength component of the global gravity field to wavelengths as short as 350-400 km. NRL has been combining GRACE data with short-wavelength terrestrial, marine, and airborne gravity to create a geoid for the Gulf of Mexico accurate to 5 cm (as compared with tide gauge data located by GPS surveys).

NRL's interest in accurate geoid determination dovetails closely with the mission of NOAA's National Geodetic Survey (NGS): to maintain and evolve a National Spatial Reference System based on the most accurate geoid possible for North America. NRL has recently partnered with NGS to conduct high-altitude airborne surveys at critical locations along the Gulf Coast. These surveys are designed to improve the geoid determination by filling in regions with little or no gravity data coverage, by identifying errors in existing land and marine data, and by resolving systematic errors in the 1988 North American Vertical Datum (NAVD88) orthometric reference frame.

High-Altitude Survey: In May 2005, NGS and NRL performed the first-ever high-altitude airborne gravity survey aboard the NOAA Cessna Citation jet (Fig. 1). The survey was conducted over southwestern peninsular Florida and the ocean just north of Cuba (Fig. 2) at an average altitude of 28,000 ft (~8,535 m) and speed of 260 kts (~480 km/h). The NRL Lacoste and Romberg gravimeter was installed on the aircraft along with Trimble GPS receivers. NASA-Goddard Space Flight Center also operated a LIDAR on the aircraft for imaging instantaneous ocean heights. The survey encroached on the beginning of the 2005 hurricane season in the Gulf of Mexico. Constant storm buildup dramatically limited the data recovery (red lines vs blue (planned) lines, Fig. 2(a)). The gridded gravity anomaly data from the survey are displayed in Fig. 2(b).

The NRL airborne gravimetry methodology has been optimized for low-altitude surveys (1,000-3,000 ft) aboard the Navy P-3 Orion aircraft. The P-3 is a large, 4-engine turbo-prop aircraft designed for submarine surveillance and is significantly larger than the Cessna Citation jet. The differences in aircraft dynamics and survey altitudes have posed significant challenges to successfully processing the aerogravity data. Corrections calculated as part of the gravity processing were adapted to accommodate the increased altitude. Most notably, the height correction (which corrects the predicted gravity value to the aircraft altitude) was modified from the simplification appropriate at low altitudes to the full expression that appropriately accounts for the mass of the atmosphere. As the measurement height goes up, the shorter wavelengths of the gravity field are increasingly attenuated, thus reducing the signal-to-noise ratio in these wavelengths. To compensate for this effect, we had to perform longer period low-pass filtering than expected.

Aircraft motion, as detected by inertial measurement units, differs noticeably between the two aircraft. The aircraft motion is a combination of the aircraft dynamics (a function of aircraft size and shape) and the differing atmospheric characteristics at the two altitudes. We compared the pitch, roll, and yaw of the Citation during two flights with P-3 measurements during a Gulf of Mexico survey in 2004. There is a pronounced difference in the roll characteristics of the two aircraft (Fig. 3). The horizontal accelerations of the aircraft contribute to driving the gravimeter's stabilized platform off-level. The off-level corrections we perform improve the result, but imperfectly. We expect that the peak in the roll power for the Citation could play a significant role in the increased error that seemed to remain in the filtered gravity anomaly.

Summary: The preliminary results suggest that there is a bias difference of 3-4 mGals between the terrestrial Florida gravity measurements and the offshore marine gravity data, although the data recovery was sparse. NRL and NGS will follow this survey with the second field season in January 2006 along the Gulf Coast.

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FIGURE 1
The NOAA Cessna Citation aircraft used for the Florida survey.

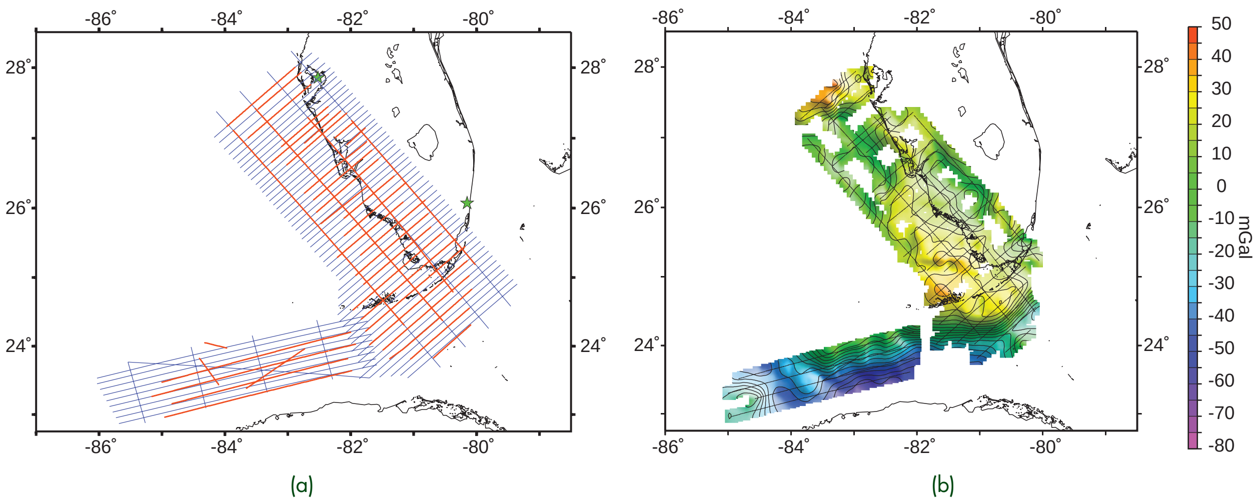

FIGURE 2
(a) The actual lines flown (in red) are shown with the planned survey lines (blue). The low data recovery was caused by the poor weather. (b) The gridded free-air gravity anomaly, with the tracks identified by black lines. The contour interval is 5 mGal.

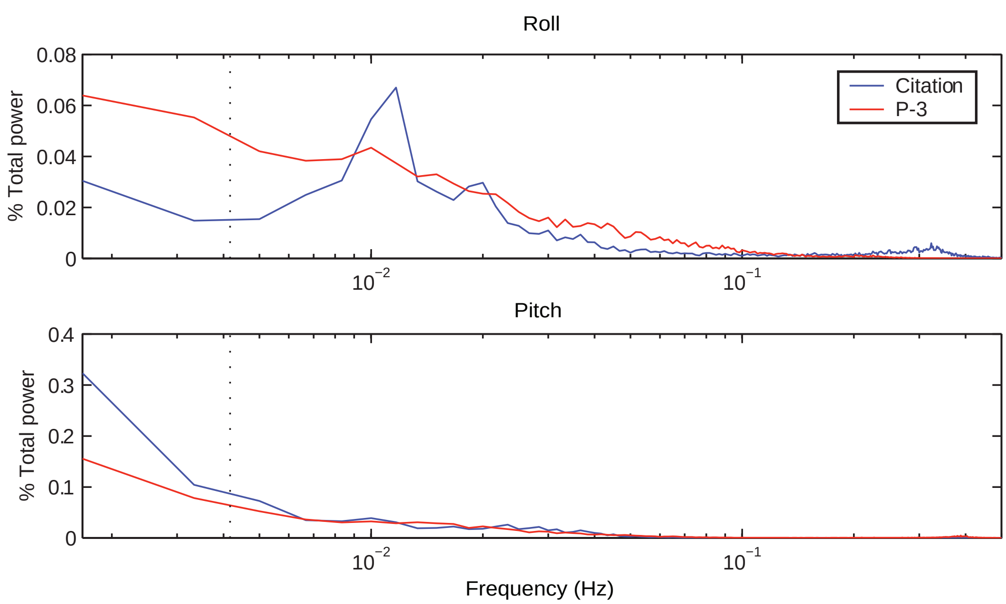

FIGURE 3
Comparison of Citation and P-3 aircraft motion. Normalized power spectra from inertial attitude data from data tracks from two flights for the Citation (blue) and the P-3 (red) were ensemble averaged using 10-min windows. Note the peak in the roll power in the Citation motion at a 1.42-min period.