Kinematic Positioning with DGPS: Expanding Frontiers in Aerogeophysics

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INTRODUCTION

In 1995, the National Research Council published a report on "Airborne Geophysics and Precise Positioning" (National Research Council, 1995) Much of the material presented here is summarized from that report, although this discussion focuses on the differential GPS applications exclusively.

Airborne geophysics has long been used for regional studies of remote and inaccessible areas. Recent developments in precise positioning of aircraft with the Global Positioning System (GPS) have greatly expanded the range of previously intractable science problems which now can be addressed with airborne techniques (i.e. Brozena et al, 1992). Differential GPS techniques for modern aerogeophysical studies include both real-time navigation of the aircraft and post-mission recovery of the precise positions for data reduction. Major science problems which have been addressed recently with aerogeophysics include deciphering the dynamics of the world's major ice sheets, imaging surface displacements due to earthquakes and decoding the structure of the continental lithosphere. Airborne studies often recover higher resolution data than can be retrieved with satellite technology. Subsequently the aircraft based approach fills a unique niche where land and ship based operations are expensive, difficult or even impossible (Figures 1 and 2).

Broad spectrum instrumented aircraft have demonstrated the capacity both to pursue process-oriented science questions and to survey unexplored regions. An example of an application of such airborne technology is identification of active volcanism beneath the West Antarctic ice sheet (Blankenship et al, 1992). The presence of this volcano has important ramifications for the stability and dynamic processes which govern the ice sheet (Figure 3). This feature was undetected before the application of high resolution airborne surveys, despite the imaging of this area by satellites and the traversing of this region by surface vehicles. Expanding high resolution airborne technology to recover even shorter wavelength signals will have important applications in the resource and environmental industries. Accurate navigation and precision position are critical to the recovery of these shorter wavelengths.

Aerogeophysics today are being used for several major research strategies, for long wavelength reconnaissance studies of unknown areas high resolution studies of detailed processes and for precise monitoring studies. Differential GPS continues to play a major role in the development of all these research strategies. The precise positioning and accurate navigation permit the acquisition of high resolution systematic data sets especially in inaccessible areas such as regions characterized by rugged terrain, dense vegetation or surface hazards which can range from political instabilities to glacial crevasses.

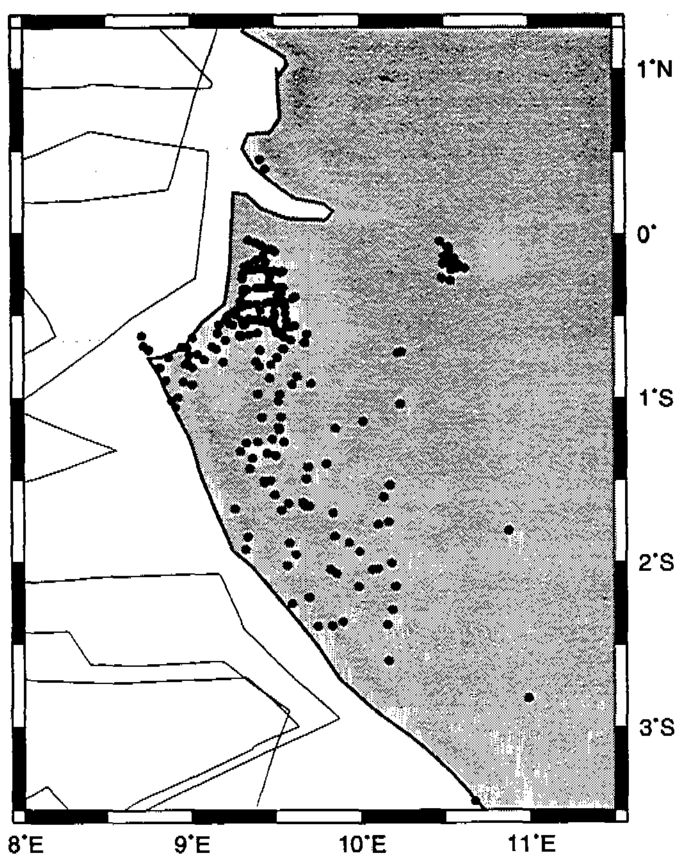

FIGURE 1 Land gravity measurements (dots) and marine gravity surveys (lines) of coastal Gabon. The land measurements were made principally on roads close to major cities. (Data from Watts et al., 1985).

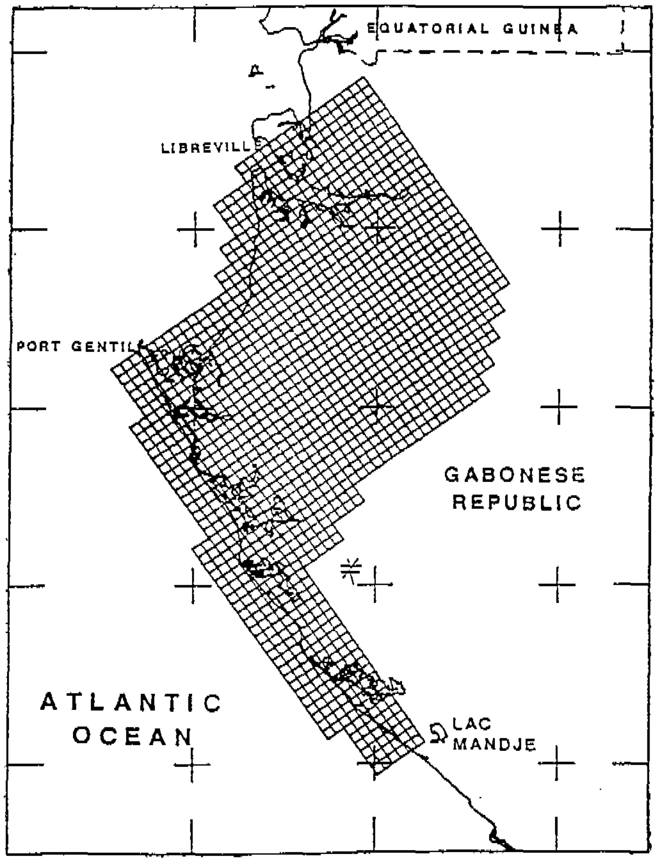

FIGURE 2 Airborne gravity survey (lines) flown over Gabon in 6 x 6 km grid. The sampling strategy is not limited by access to roads. (Figure courtesy of W. Gumert, Carson Geophysical).

SCIENTIFIC MOTIVATION

The scientific motivation for enhanced use of DGPS technology in aerogeophysics is driven by a broad constituency from researchers interested in global change to mineral companies attempting to identify new major prospects to environmental scientists constraining the extent of contamination from a safe, remote distance. Aerogeophysics provides unique access to regions and results in systematic data sets otherwise impossible to acquire.

Interdisciplinary earth science problems can be addressed with research strategies which integrate aerogeophysics and differential GPS. An example of a global change issue addressed with aerogeophysics is ice sheet mass balance where real time differential techniques are necessary to accurately locate the experiment and precise positioning in three dimensions is critical to the analysis of the ice surface. Erosion processes and landform evolution can also be studied with an accurately navigated aerogeophysical platform used to trace region changes in topography. Similarly aerogeophysics can be used to trace emerging hot spots in hydrologic studies by enabling the simultaneous acquisition of geologic imaging and measurements of developing salt water intrusions (Babu et al, 1991).

Natural hazards, an emerging priority at both the national and international science communities, can be studied with aerogeophysics combined with DGPS. Specific examples include recovering eruption volumes using precise topographic mapping tools (Garvin, 1993) and recovering the regional distribution of motion from an earthquake using repeat airborne SAR interferometry (Massonnet et al, 1993).

Commercial motivations for high resolution aerogeophysics emerge from both the mineral and petroleum industries. The mineral industry uses high resolution aeromagnetics extensively to trace geologic structures in order to identify potential ore bodies. Petroleum explorationist use aerogeophysics, both gravity and magnetics, to examine structure beneath thick salt sheets which cannot be imaged with seismic techniques, to identify faults which bound sedimentary basins and to image oil bearing sedimentary sequences. Airborne gravity gradiometry is an emerging priority target of these industries. (Boddard et al, 1991 and Bell et al, 1995).

Aerogeophysics with precise GPS support can also be used for site characterization. Site characterization is of use for nuclear verification when used to monitor small changes in surface topography associated with an underground explosion (Houser, 1970). For environmental site characterization, aerogeophysics can be used to identify disturbed soil (Doll et al, 1993 and Phillips, 1993), often indicative of contaminated sites, as well as outlines of buried containers (Figures 4 and 5).

TYPE OF OBSERVATIONS

Several type of aerogeophysical measurements can be used to address these scientific motivations. The suite of aerogeophysical measurements which require high resolution differential GPS include: gravity field measurements, gravity gradiometry, electromagnetic measurements, measurements of the earth's magnetic field, precise topography recovery via direct range measurements, recovery of precise topography from Synthetic Aperture Radar (SAR) and ice penetrating radar.

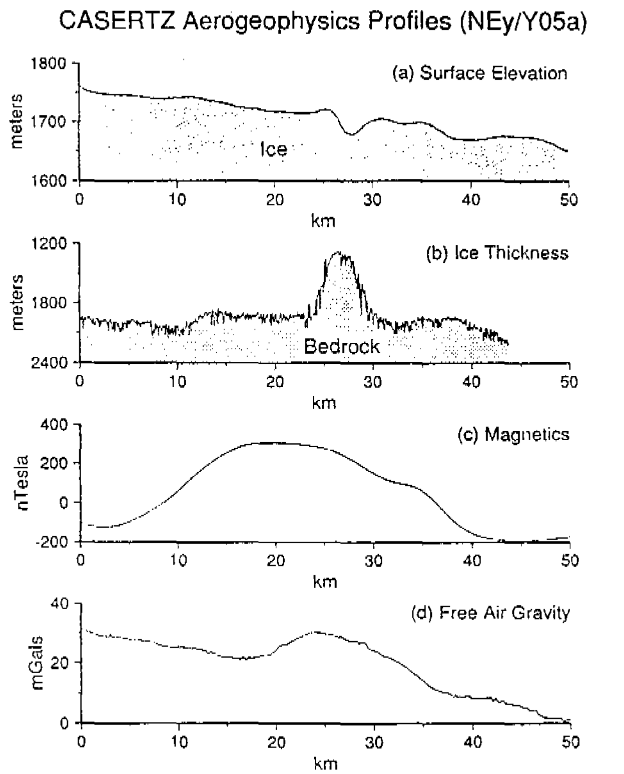

FIGURE 3 Evidence for active volcanism beneath the West Antarctic Ice Sheet from precise surface altimetry measurements and other airborne geophysical observations. The measurements were made as part of a major study of the stability mechanisms of the West Antarctic ice sheet and were collected along a north-south profile. (a) Surface elevations from a GPS-positioned laser altimeter reveals an anomalous depression in the ice surface located at 28 km. (b) Depth to bedrock (Ice thickness) from ice penetrating radar observations. The prominent feature at 26.5 km is centered in a shallow rimmed caldera. (c) Total magnetic field observations reveal a large anomaly between 0 and 40 km that is strongly correlated with the caldera and central edifice. (d) Free air gravity anomaly of 7 mGal is associated with the central edifice at 24 km. (Figure modified from Blankenship et al., 1993).

GENERAL DGPS USES: NAVIGATION AND POSITIONING

Two primary uses of differential GPS are employed for high resolution aerogeophysical applications today including navigation and precise positioning. The navigation application ensures that the fundamental measurements acquired during an experiment are acquired in the proper location. The second application is for precise positioning which requires the post processing of the carrier phase GPS data from the aircraft and the fixed base station. For aerogeophysical DGPS navigation the differential correction is broadcast to the aircraft in real time at a high data rate. In remote areas a dedicated broadcast system may be required. In North America it may be possible to make use of the government or commercially broadcast corrections. For the precise positioning for high resolution aerogeophysics, the aircraft position must be recovered to better than 50 cm in post-mission processing. This positioning is recovered by post-mission reduction of the carrier phase data acquired from a fixed base station and a GPS system mounted aboard the aircraft. This data must be recorded at 1 Hz data rate at both the dual frequency receivers. Installing and maintaining sufficient ground GPS receivers can be a significant logistical impact on an aerogeophysical project.

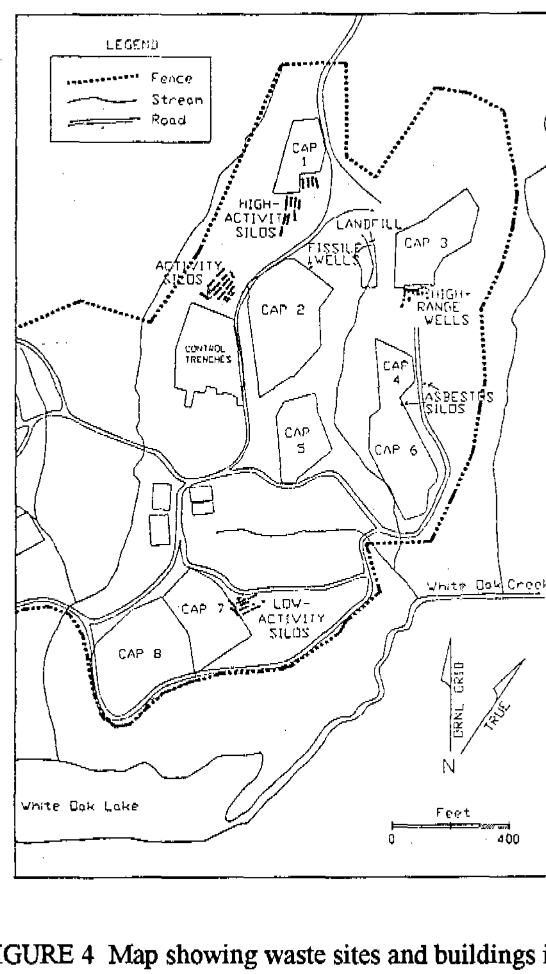

FIGURE 4 Map showing waste sites and buildings in the survey area, Oak Ridge National Laboratory. (Figure modified from Doll et al., 1993).

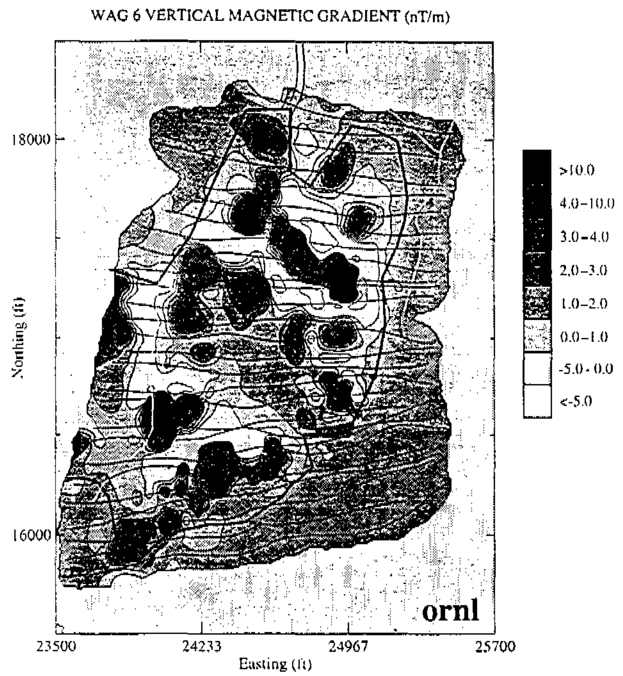

FIGURE 5 Short-wavelength magnetic anomalies (vertical component) measured from a GPS-navigated helicopter are associated with high- and low- activity silos, surface pipes (labeled "high range wells"), high- and low-activity materials disposal trenches (capped areas 1, 2, 4, 7, and Control Trenches), biological disposal trenches (capped areas 5 and 8), and asbestos disposal trenches (capped area 6). (Figure modified from Doll et al., 1993).

DGPS REQUIREMENTS

The aerogeophysical requirements for DGPS include use of dual frequency receivers recording carrier phase data at a high data rate (1 Hz). Ancillary data which can be useful include base magnetometer measurements to identify periods of high ionospheric activity. Orbits are required for the positioning applications but not for the real time navigation.

OUTSTANDING COORDINATION ISSUES

Differential GPS is being increasingly integrated into high resolution aerogeophysical applications. For optimal usage, several coordination issues need to be addressed. First, an increased awareness of Federal and commercial DGPS systems must to be integrated into both commercial and academic aerogeophysical planning. The increased awareness will have the impact the quality of the navigation used for aerogeophysical surveys. The awareness of available continuously operating GPS site may have result in reduced costs to the commercial and academic applications.

Outstanding issues in kinematic GPS is the robustness of algorithms for reduction of the GPS data for precise positions. Efforts to enhance these algorithms will provide improved resolution and scientific results.

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