Acquisition and Processing Helicopter Aeromagnetic Survey NE Tusas Mountains, New Mexico

Performed for:

United States Geological Survey

Performed by:

EDCON-PRJ, Inc.

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October 2010

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Introduction:

During the period October 1 to October 8, 2010 a helicopter aeromagnetic survey was performed by EDCON-PRJ over an area in northern New Mexico. The project required seven field days to complete. Three thousand five hundred and seventy-five line-km of data were acquired and processed by EDCON-PRJ. Data were acquired on a 200-m by 1,500-m grid. The survey area location is shown in Figure 1. Data were acquired on a calculated drape surface at a nominal height of 100 meters above ground level. A Pico Envirotec AGIS-XP helicopter-magnetometer system with a GeoMetrics towed-bird cesium-vapor magnetometer was used. Navigation and positioning were accomplished using Global Positioning System equipment and methods. A Bell Jet Ranger 206B helicopter, registration number N20620, was used.

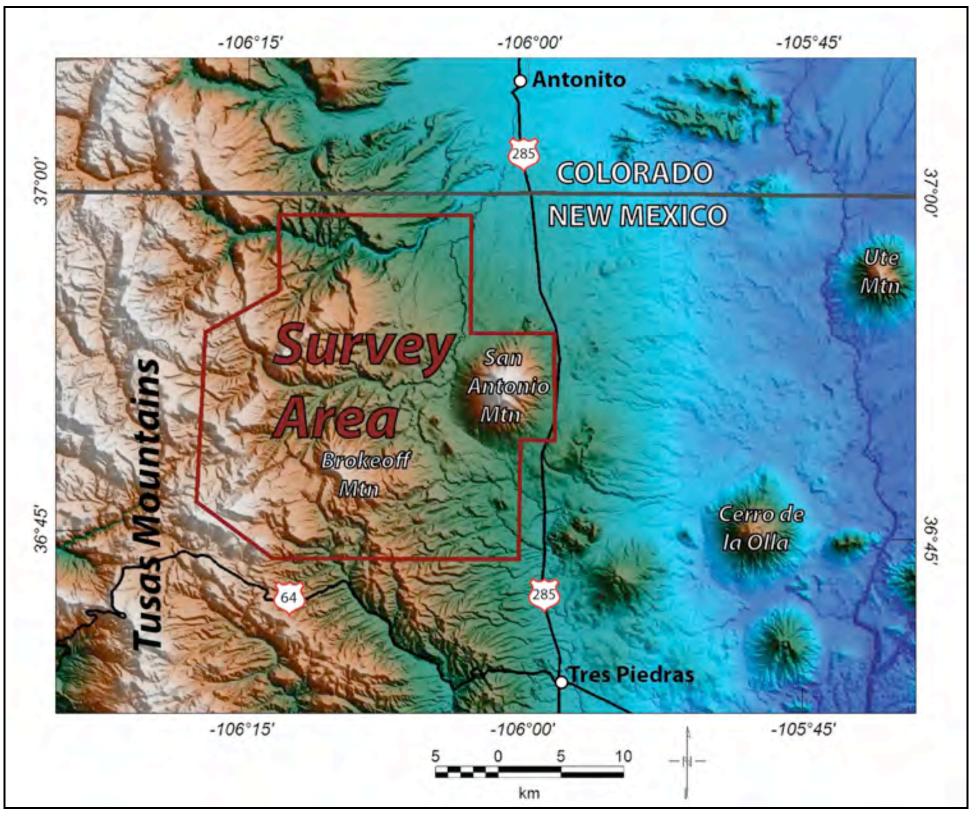

Figure 1: Survey area (USGS map)

Flight Grid:

The survey was flown on a 200-meter spaced east-west survey lines with 1,500-meter north-south tie lines. The completed survey program is shown in the map in Figure 2.

Federal Aviation Administration regulations do not allow flights over populated area with a sling load, such as the survey magnetometer. As a result of this regulation, there is one area on the east flank of San Antonio Peak, over a small sub-division, where the survey grid could not be followed within specifications. A small gap in data coverage exists as shown in the flight path map in Figure 3.

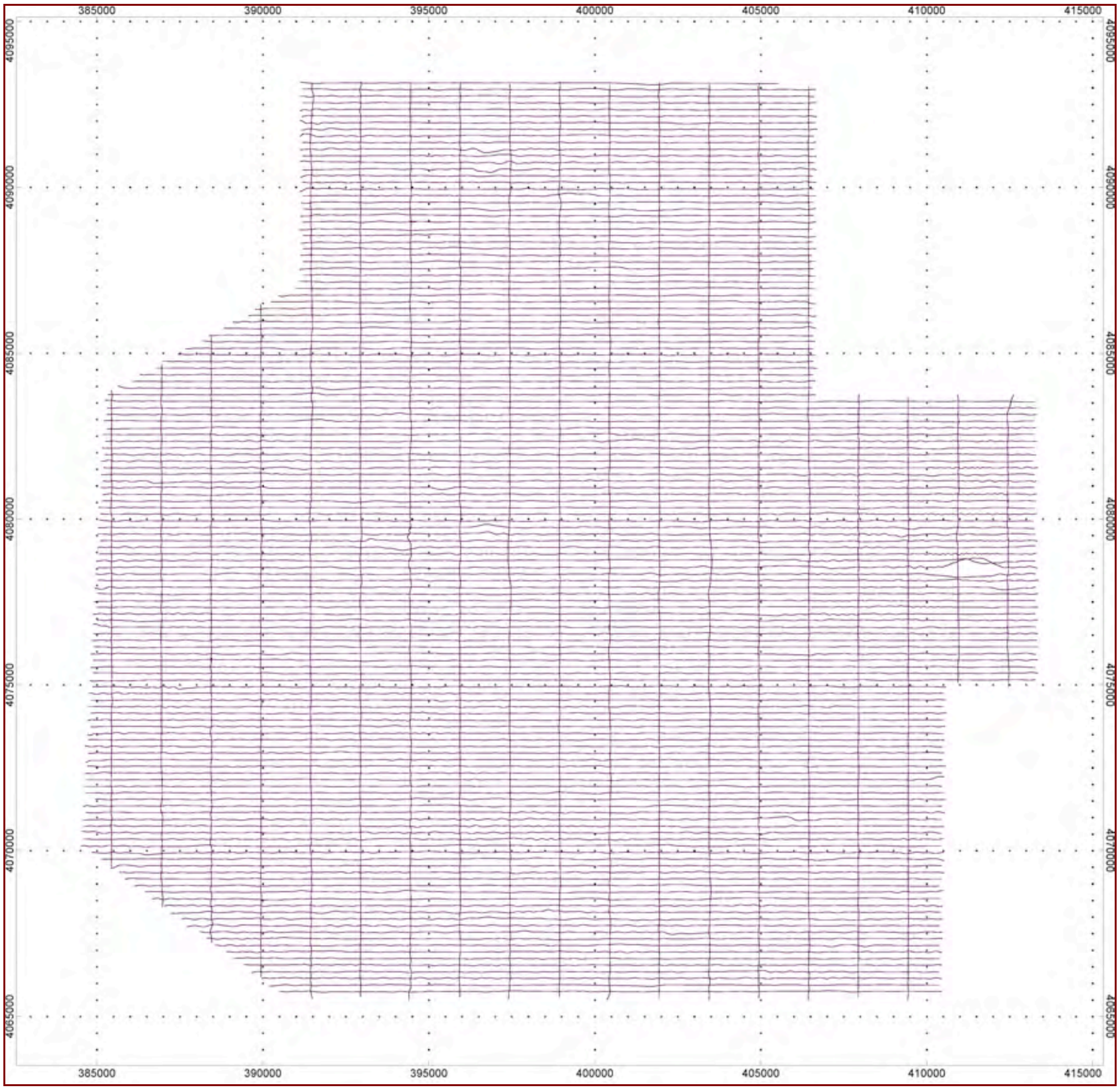

Figure 2: Completed survey program

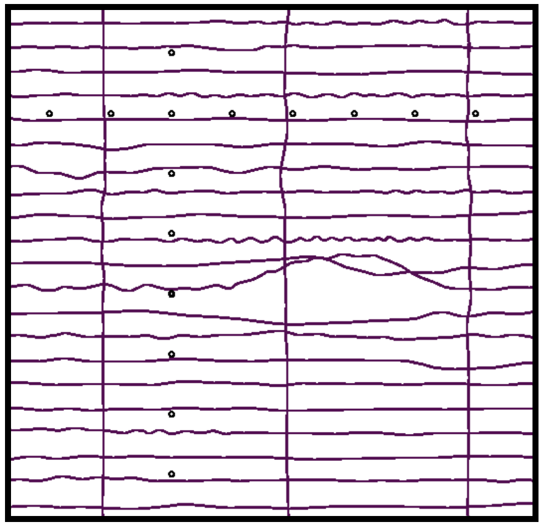

Figure 3: Out of specification flight lines

Flight Elevation:

The survey was flown on a calculated drape surface nominally 100-meters above the terrain. The drape surface was calculated based on the digital elevation model (DEM) of the survey area and the flight characteristics of the survey helicopter. For this survey, the maximum slope of the drape surface was 15 degrees. The pilot is presented a display that shows the helicopter position above or below the drape surface, Figure 8. Using this information the pilot flies the helicopter on the surface. For this survey the specification is that the helicopter would be flown with +/- 20 meters of the calculated drape surface (10 percent of the line spacing). Generally the pilot was capable of flying with +/- 10 meters of the surface.

Survey Equipment:

The following survey equipment and personnel were used for this project.

Helicopter:

A Bell Jet Ranger 206B, serial number 3369, registration number N20620 was used for this project. The helicopter was chartered from El Aero Services, Elko, Nevada. The helicopter was flown by pilot Ted McBride. El Aero provided a fuel truck and crew trailer for the survey. The helicopter was based in the field for the duration of the project. The helicopter and fuel truck are shown in Figure 6.

Airborne Geophysical Equipment:

- Pico Envirotec AGIS-XP Airborne Geophysical Information System s/n 0910021set to sample magnetic data at 10 Hz
- WAAS-enabled Hemisphere R-220 GPS s/n 0917-9136-0015 with Antcom dual-frequency GPS antenna set to log GPS data at 1 Hz
- WAAS-enabled Hemisphere R-102 GPS s/n 0818-7033-0078 was used for helicopter navigation and 10-Hz data logging.
- Pilot navigation display unit and operator iTech display unit
- FreeFlight radar altimeter and display, s/n 8472331 and s/n 8263174 ()
- GeoMetrics cesium magnetometer s/n C-2087 and interface s/n 823206
- Fiberglass magnetometer bird and 30-m tow cable
- Two flight path recovery, KCI Communications "Black Box" SBX-3100 units with CMOS cameras, self-contained GPS and data logging

Ground-based Geophysical Equipment:

A GeoMetrics G-858 Base Station Magnetometer was used and set to log base station magnetic data at 1 Hz, as shown in Figure 11. The base station magnetometer clock was synchronized to UTC time using a hand-held Garmin 76CSx GPS receiver. The base station magnetometer was operated at two different sites during the survey (location and elevation are from the hand-held Garmin GPS):

Base Magnetometer Station 1 (October 2-5, 2010):
Latitude: 36° 47.887' North,
Longitude: 105° 59.902' West,
Elevation: 2,574 m

Base Magnetometer Station 2 (October 6-7, 2010):
Latitude: 36° 54.941' North,
Longitude: 105° 59.292' West,
Elevation: 2,525 m

Global Positioning System Surveying:

The survey positions and elevations are from a WAAS-enabled Hemisphere R-220 dual-frequency high-precision GPS receiver and a WAAS-enabled Hemisphere R-120 single-frequency high-precision GPS receiver. The R-220 GPS antenna was located on the magnetometer survey bird. The R-120 GPS antenna was mounted on a plate attached to the pitot tube on the nose of the survey helicopter. The R-220 GPS data, acquired at 1 Hz, were used for magnetic data processing. The R-120 GPS data, acquired at 10 Hz, were used for helicopter navigation. The system did not allow for the secondary (R-220) GPS data at 10 Hz. The R-220 data was interpolated to 10 Hz for data processing.

The Federal Aviation Administration Wide Area Augmentation System (WAAS) is a system of earth stations and satellites that improves the tracking accuracy of the GPS navigation system. The earth stations track the GPS satellites and send correction signals to the WAAS satellites which then transmit them to WAAS-enabled GPS receivers. The FAA WAAS specification require position accuracy of 7.6 meters. Numerous tests of actual performance measurements of the system at specific locations have shown it typically provides 1.0 meter horizontally and 1.5 vertical accuracy.

For this survey a comparison of the R-220 and R-120 GPS data was made over a two-hour period with both GPS receivers connected to the GPS antenna on the survey bird and the survey bird stationary on the ground. The statistics for the two receivers during this test are:

GPS Receiver	Observations	Mean Value(elevation)	SD	
R-220 (Survey Bird GPS)	7580	2525.829	0.292	1- Hz data
R-120 (Helicopter Nav GPS)	75800	2525.423	0.316	10-Hz data
GPS Receiver	Observations	Mean Value(Easting)	SD	
R-220 (Survey Bird GPS)	7580	411942.692	0.146	1- Hz data
R-120 (Helicopter Nav GPS)	75800	411942.639	0.207	10-Hz data
GPS Receiver	Observations	Mean Value(Northing)	SD	
R-220 (Survey Bird GPS)	7580	4086033.658	0.132	1- Hz data
R-120 (Helicopter Nav GPS)	75800	4086033.621	0.127	10-Hz data

The above shows both receivers provided similar sub-meter results with sub-half-meter Standard Deviations.

Radar Altimeter:

A FreeFlightTRA-3000 radar altimeter with a FreeFlight TRS 40 display was used. The radar altimeter antenna was mounted on the bottom of the survey bird. The display was mounted on the pilot glare shield. The analogue output of the radar altimeter was recorded a 10-Hz on the AGIS system with the published calibration. The system has the following manufacture-quoted specifications:

Altitude Range: 40 to 2500 ft.
Antenna(s): Dual; ±20° pitch, ±30° roll
Transmitter Power: 20 mW typical, 10 mW minimum
Frequency: 100 MHz sweep, within 4.2 to 4.4 GHz
Analogue output calibration: 2.5mv/ft
Altitude Accuracy:
- 40 to 100 ft. ±5 ft.
- 100 to 500 ft. ±5%
- 500 to 2500 ft. ±7%

The radar altimeter displayed erratic operation during the first two survey flights on October 2, with radar drop-outs and noisy data. After the first flight, the display was changed, after the second flight the antenna was changed. For the remainder of the survey the radar worked normally. The lines that experienced loss of radar data were repeated.

Flight-path Recovery Cameras:

Two KCI Communications SBX-3100 “Smart Black Box” units with CMOS cameras, self-contained GPS and data logging were used. The cameras were mounted on the belly of the helicopter. The units were powered by 12-volt batteries. The SBX-3100 is designed as a vehicle-mounted “smart black box” which records images in a TCI Communications binary format at a rate of 5 Hz. The images are GPS location and time tagged using the self-contained GPS unit in each SBX-3100. The GPS antennas were mounted on the inside of the left-seat helicopter overhead bubble window. Data were recorded on SD memory cards. Each file contains up to one hour of date and has the file extension of “.vdd”. The cards were downloaded following each flight and archived on a external computer storage device. The flight-path photos may be viewed using the provided software and exported in jpg format.

The photo viewing software is “PCViewer DriveRecorder 3CH\PCViewer.exe”. The software provides a screen as shown in Figure 4. A sample jpg file from the display software is shown in Figure 5. The GPS camera locations are on the WGS84 datum.

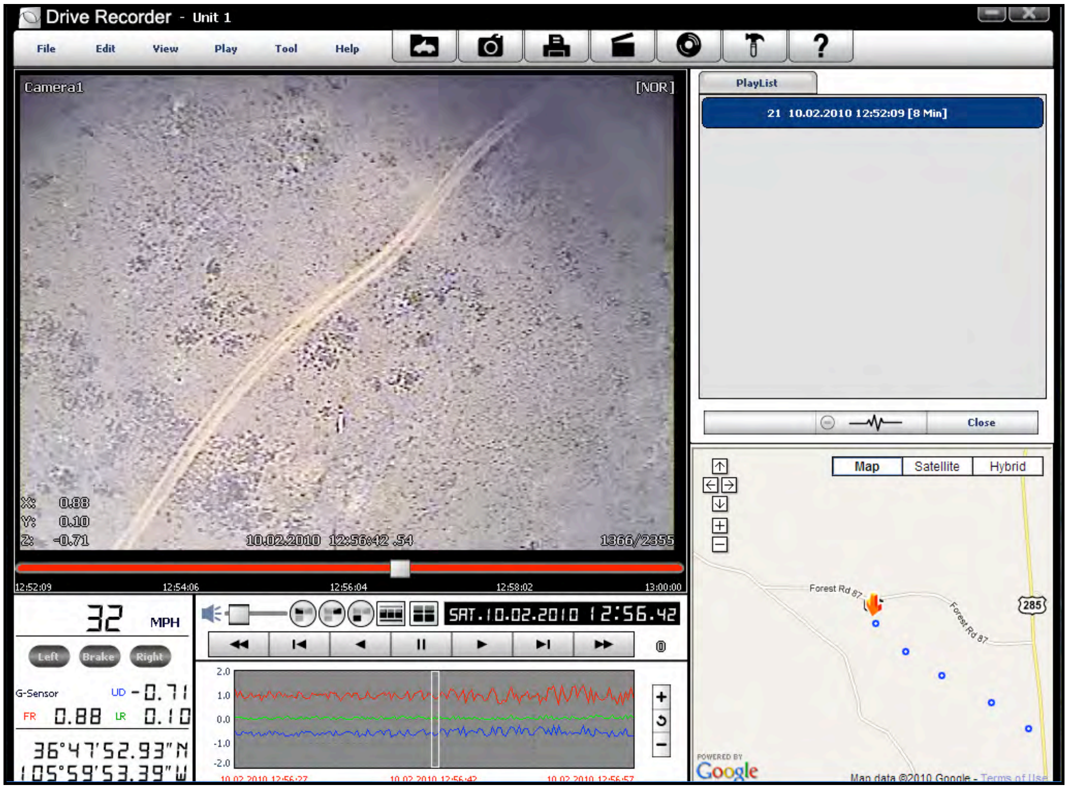

Figure 4: Flight-path recovery camera software display

Figure 5: Sample jpg file from flight-path recovery camera software

Personnel and Base of Operations:

These data were acquired by John Seibert and Mike Hobbs of EDCON-PRJ. The helicopter was chartered from El Aero Services, Elko Nevada and piloted by Ted McBride. The fuel truck was driven by Brian Coleman.

Flight operations were based at the El Aero fuel truck / trailer site approximately 30 miles north of Taos, New Mexico. Seibert and Hobbs based from the Taos Best Western motel.

Preliminary data analysis was performed in the field. The field-checked data were posted on the secure EDCON-PRJ ftp site for additional analysis and processing. Final data processing and analysis were performed by EDCON-PRJ in Denver, Colorado.

Survey Flight Operations:

Survey Operations were conducted from October 1 through October 7, 2010. A total of 50 helicopter survey flight hours were utilized, as follows: 11.5 ferry flight hours from and return to Elko Nevada and 38.5 survey flight hours. Twenty-six survey flights were flown plus two radar calibration and lag check flights.

Weather:

The weather during the survey was generally good. Some afternoon thunderstorms and lightening were experienced. During thunderstorm and lightning, survey operations were suspended. The thunderstorms were generally localized and would dissipate within a few hours allowing survey operations to proceed.

Survey Operations:

Daily survey operations and raw data files are listed below:

Date 2010	Helicopter Hours	Activity / Raw Data File Name
29-Sept	0	Seibert and equipment travel to Elko, Nevada
30-Sept	0.8	Install and test Heli-mag system at El Aero Helicopters, Elko, Nevada
1-Oct	6.2	Ferry Helicopter N20620 Elko, Nevada to Taos, New Mexico Hobbs drives from Denver to Taos Coleman drives fuel truck with camp trailer from Elko to Taos
2-Oct	6.4	Survey flight 1, data file B0100216.P25 depart 10:20 local Survey flight 2, data file B0100218.P57 depart 12:55 local Survey flight 3, data file B0100221.P26 depart 15:20 local
3-Oct	5.4	Survey flight 4, data file B0100314.P52 depart 8:45 local Survey flight 5, data file B0100316.P58 depart 10:55 local Survey flight 6, data file B0100319.P12 depart 13:10 local Operations suspended due to lightening at 15:00 local time
4-Oct	8.7	Survey flight 7, data file B0100413.P36 depart 07:30 local Survey flight 8, data file B0100415.P22 depart 09:15 local Survey flight 9, data file B0100416.P50 depart 10:45 local Survey flight 10, data file B0100419.P13 depart 13:05 local Survey flight 11, data file B0100420.P44, depart 14:40 local Survey flight 12, data file B0100422.P18, depart 16:15 local
5-Oct	7.1	Survey flight 13, data file B0100514.P02, depart 08:00 local Survey flight 14, data file B0100515.P42, depart 09:40 local Survey flight 15, data file B0100517.P22, depart 11:19 local Survey flight 16, data file B0100518.P26, depart 12:24 local Survey flight 17, data file B0100519.P43, depart 13:41 local Land 14:32 due to thunderstorms and lightening Lag test flight 18, data file B0100521.P42, depart 15:40 local Second lag test data file B0100521.P59 Survey flight 19, data file B0100522.P08 depart 16:00 Land 17:15, rain
6-Oct	9.7	Survey flight 20, data file B0100613.P43, depart 07:35 local Survey flight 21, data file B0100615.P25, depart 09:19 local Survey flight 22, data file B0100617.P10, depart 11:08 local Land in meadow and wait-out a thunderstorm Survey flight 23, data file B0100618.P23, depart 12:20 local Survey flight 24, data file B0100619.P37, depart 13:35 local Survey flight 25, data file B0100621.P13, depart 15:12 local Survey flight 26, data file B0100622.P24, depart 16:22 local Survey flight 27, data file B0100623.P48, depart 17:47 local Land 18:35, survey data acquisition completed
7-Oct	0.4	Radar calibration flight 28, data file B0100716.P13, depart 09:30 Land 10:31 Demobilize survey equipment in the field
7-Oct	5.3	Helicopter ferry to Elko, Nevada

Equipment Photographs:

Figure 6: Survey helicopter and fuel truck

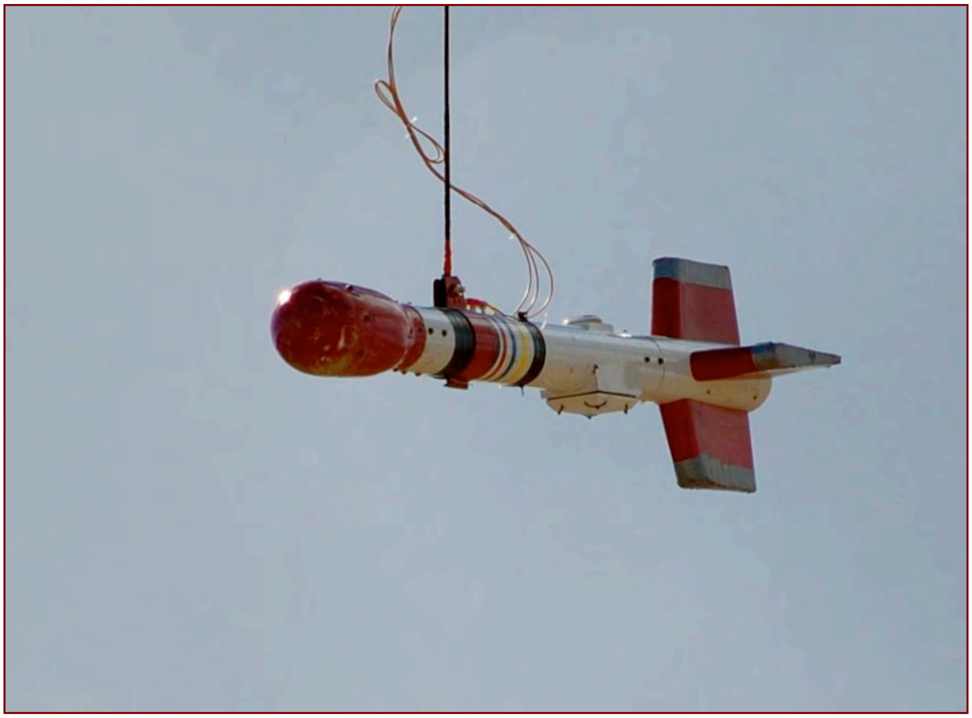

Figure 7: Survey bird with GPS and radar altimeter antennas

The GeoMetrics G-823 magnetometer sensor is mounted in the nose of the magnetometer bird, shown in Figure 7, and aligned to the proper orientation based on the magnetic inclination and declination of the magnetic field at the survey area. The GeoMetrics interface is mounted in the rear of the magnetometer bird. Power to the magnetometer and the Larmor Frequency from the magnetometer travel along a coax cable inside the magnetometer tow cable. The Larmor Frequency is converted to the magnetic field reading by the electronics in the helicopter and recorded at a 10Hz sample interval. The GPS antenna is mounted on the top of the bird and the radar altimeter antenna is mounted on bottom of the bird just in front of the stabilization fins. Three low-loss RG-400 coax cables feed magnetometer, GPS and radar altimeter up the tow cable.

Figure 8: Pilot graphic display

The Pilot Graphic Display, shown in Figure 8, provides the pilot with navigation information to allow the helicopter to be flown along each pre-determined survey flight line. The display shows the aircraft's position along each survey line and the position left or right of the survey lines. This information is displayed both graphically and digitally. The display shows the aircraft elevation relative to the digital terrain model as an aid to flying the planned controlled drape survey.

The survey equipment operator monitors and controls the AGIS system using the AGIS touch screen control display shown in Figure 9.

The AGIS electronics and GPS receivers were placed on the rear seat of the helicopter and secured with cargo straps, as shown in Figure 10. The system was powered from the auxiliary helicopter power outlet, except the cameras which were powered by individual 12 volt batteries.

Figure 9: AGIS control display

Figure 10: AGIS and GPS receivers on helicopter back seat

Figure 11: GeoMetrics G-858 base station magnetometer

The GeoMetrics G-858 base station magnetometer was set up at the start of each survey day. The base station clock was synchronized to UTC time using a hand-held Garmin GPS receiver. The G-858 recorded diurnal changes in the Earth's magnetic field and provided information about any excessive magnetic storm activity during the survey. For this survey, the diurnal magnetic activity was acceptably quiet and no survey lines needed to be re-acquired due to excessive diurnal or magnetic storm activity.

Data Processing Procedures:

The data were processed and mapped using the following steps:

Field Data Processing:

Following each flight, the binary field "B" files were converted to ASCII files and loaded into GeoSoft on a flight-by-flight basis. The base station magnetometer files were downloaded and loaded into GeoSoft. The base station magnetometer data were downloaded from the G-858 base station magnetometer and evaluated. Field plots were evaluated to insure survey coverage. Preliminary, unadjusted maps were generated and provided to the client along with daily operations reports. Once checked and verified for data accuracy and completeness, the data were uploaded to the EDCON-PRJ ftp site.

Mapping Parameters:

The GPS vertical and horizontal coordinate outputs were recorded as latitude, longitude, x, y and ellipsoid height using the WGS84 geographic coordinate system. Mapping parameters for processed digital and mapped data are the following:

Projection:	UTM
UTM Zone:	13
Datum:	NAD27 (WGS84 values are also provided)
Vertical Datum:	WGS84 ellipsoid

System Latency:

The magnetometer and radar each have potential latency or lag. The lag is the difference between the logged position for a given parameter and the actual position. Magnetometer lag is determined by flying over a high-frequency magnetic anomaly in opposite directions, determining the system-logged position for that anomaly. Radar altimeter lag is determined using the same technique over a sharp topographic feature.

Possible lag is also evaluated by viewing mapped magnetic and radar data. With adjacent survey lines running in opposite directions, lag manifests itself as scalloping or herringboning of the mapped data.

For this date set, it was determined that there is a 1-second magnetometer data lag and a 3-second radar altimeter data lag.

Radar Altimeter Calibration:

For this survey the FreeFlight radar altimeter calibration was determined by flying a series of flights at different elevations over a flat surface of known elevation and comparing the radar altimeter elevation with the GPS elevation. The use of the radar on the magnetometer bird required considerably longer than usual coax cable between the radar altimeter antenna and the display. Due to the use of long coax cable, the calibration was attenuated by about 15 percent and produced a lag in the recording of the radar of three seconds.

Magnetic Data:

Digital magnetic data from the airborne acquisition systems were received by ftp.

Data Editing was performed using the following steps:

- Profile plots of the magnetic data for each line were inspected for noisy or missing data.
- The data quality was considered good, and no filters were applied.
- No deculturing of the data was performed.

I.G.R.F.:

The International Geomagnetic Reference Field (IGRF 2010), updated to the dates of the survey, was calculated and applied to the data set. The IGRF was applied at the end of the processing stream.

Diurnal Correction:

The base magnetometer data were inspected and compared with the observed magnetic data trace. The observed diurnal data were hi-cut filtered to remove noise and subtracted from the observed magnetic data.

Leveling:

Mis-ties at line intersections were calculated and adjusted to minimize mis-tie errors. Initial leveling adjustments were completed using a DC level adjustment to compensate for long wavelength diurnal effects. The average intersection mis-tie before DC adjustment was 38.03 nT; after DC adjustment, the average mis-tie was 27.46 nT. After final leveling the average mis-tie was 0.3 nT. Micro-leveling was used to produce the final leveled.

Micro-leveling:

Even after standard leveling is applied to magnetic data (e.g., DC least squares adjustment using mis-ties between profile and tie lines), some corrugation is usually evident in the grid made from the data. This corrugation is due to small mismatches between adjacent lines arising from residual heading errors, small differences in flight elevation, and horizontal positioning errors.

The corrugation can be removed from the grid by splitting the gridded data into matching low-pass and high-pass components, applying tuned strike suppression filters along the profile and tie line directions to the high-pass component, and reassembling the result with the low-pass component. This destroys short-wavelength geological anomalies oriented along the flight and tie line directions, but these are unrecoverable anyway in the presence of corrugation. Variations of this procedure are standard in the industry, and are known generally as decorrugation.

The remaining problem is to transfer this correction back to the profile data. Simply extracting the profiles from the gridded data yields a result which lacks the short-wavelength content of the original data; the idea is to retain the shorter wavelength components in the profile data, while using the longer wavelength components of the data extracted from the decorrugated grid.

The procedure used is as follows. The spectrum of the difference between the profile data and the extracted profiles is analyzed to design a low-pass filter that reflects the long-wavelength part of the difference, and the filter is applied to the difference. The low-pass difference is then subtracted from the profile data, which is equivalent to replacing the long-wavelength component of the profile data with that of the profile extracted from the grid. This is a variation of the procedure known as micro-leveling.

The differences between the profile data before and after micro-leveling are quite small, generally less than 1 nT except for DC shifts. However, the final data now interpolates to a grid which is essentially free of corrugation.

Deliverables:

The following are the deliverable products of this project:

Grids:

21016_TMI.GXF: Total Magnetic Intensity map in GeoSoft GXF Format.
21026_RADAR.GXF: Radar Altimeter Grid In GeoSoft GXF Format.
21026_TOPO.GXF: calculated Topography Grid In GeoSoft GXF Format.

Line Data:

21026_TUSAS.XYZ: Line data in GeoSoft XYZ format shown below.
Tusas.iO: GeoSoft import template.

Report:

21027_REPORT.PDT: This report in pdf format.

Columns	Format	Description	Units
1-8	I8	Line Name	Alpha
9-17	F9.1	Flight Direction	Degrees
18-29	F12.5	Latitude (NAD27)	Decimal degrees
30-41	F12.5	Latitude (NAD27)	Decimal degrees
42-52	F10.2	UTM X (WGS 84)	Meters (zone 13)
53-63	F10.2	UTM Y (WGS 84)	Meters (zone 13)
64-74	F10.2	UTM X (NAD27)	Meters (zone 13)
75-85	F10.2	UTM Y (NAD27)	Meters (zone 13)
86-94	F9.0	Fiducial	Tenth of seconds
95-104	A10	Year/Julian Day	YYYY/DDD
105-117	A13	UTC Time	HH:MM:SS.SS
118-125	F8.1	GPS Ellipsoid Elevation Helicopter	Meters
126-133	F8.1	Drape Surface	Meters
134-141	F8.1	GPS Ellipsoid Elevation Bird	Meters
142-149	F8.1	Radar Altimeter Bird	Meters
150-157	F8.1	Calculated Topography	Meters
158-167	F10.2	Diurnal Magnetics	nT
168-177	F10.2	Raw Magnetics	nT
178-187	F10.2	Diurnally-corrected Magnetics	nT
188-197	F10.2	DC-Leveled Diurnally-corrected Magnetics	nT
198-207	F10.2	Micro-leveled Diurnally-corrected Magnetics	nT
208-217	F10.2	Final IGRF-corrected Magnetics	nT
218-227	F10.2	IGRF correction	nT

Grids:

Copies of the grids provided are shown in Figure 12, Figure 13 and Figure 14.

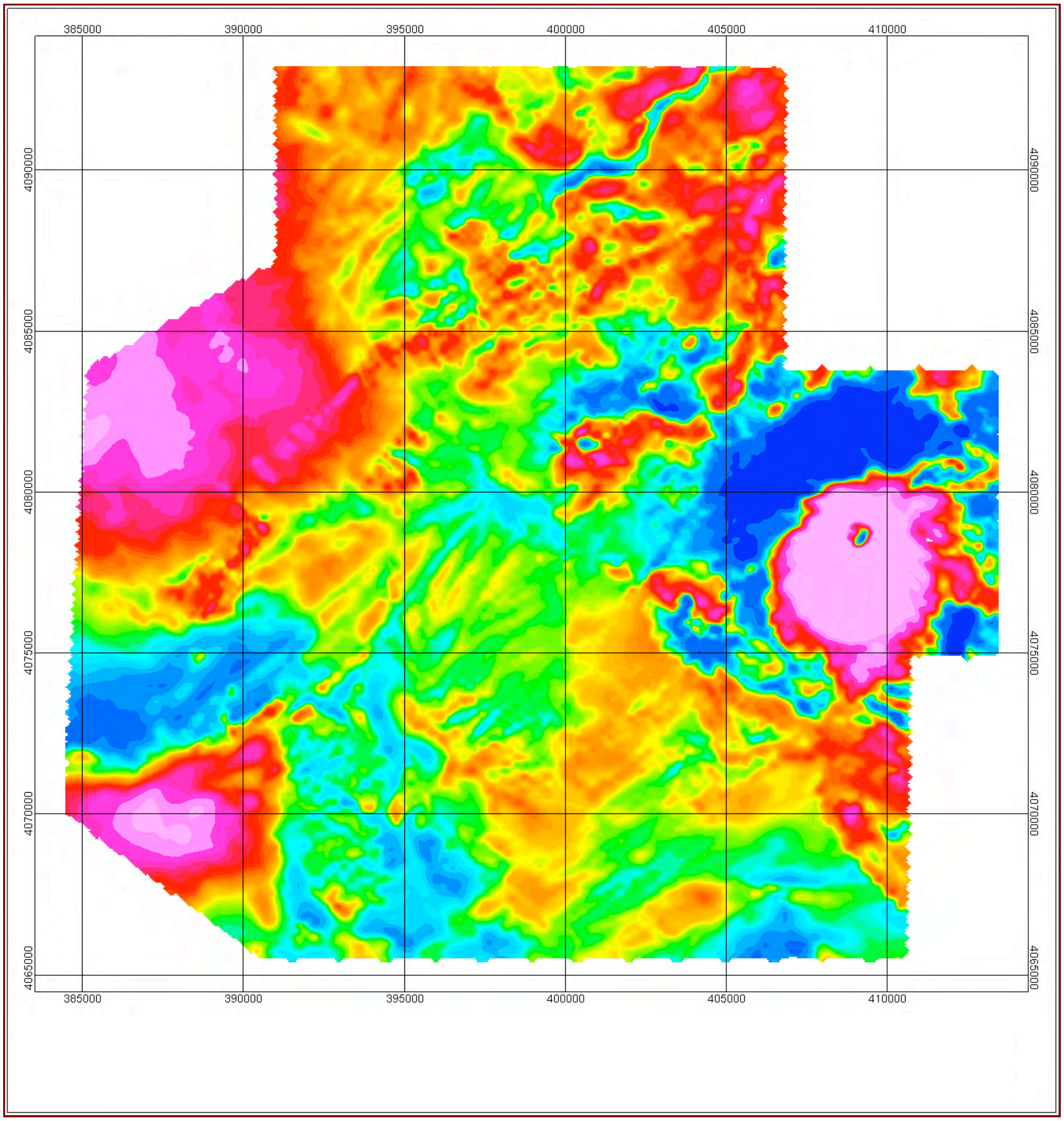

Figure 12: Total Magnetic Intensity grid (21016_TMI.GXF)

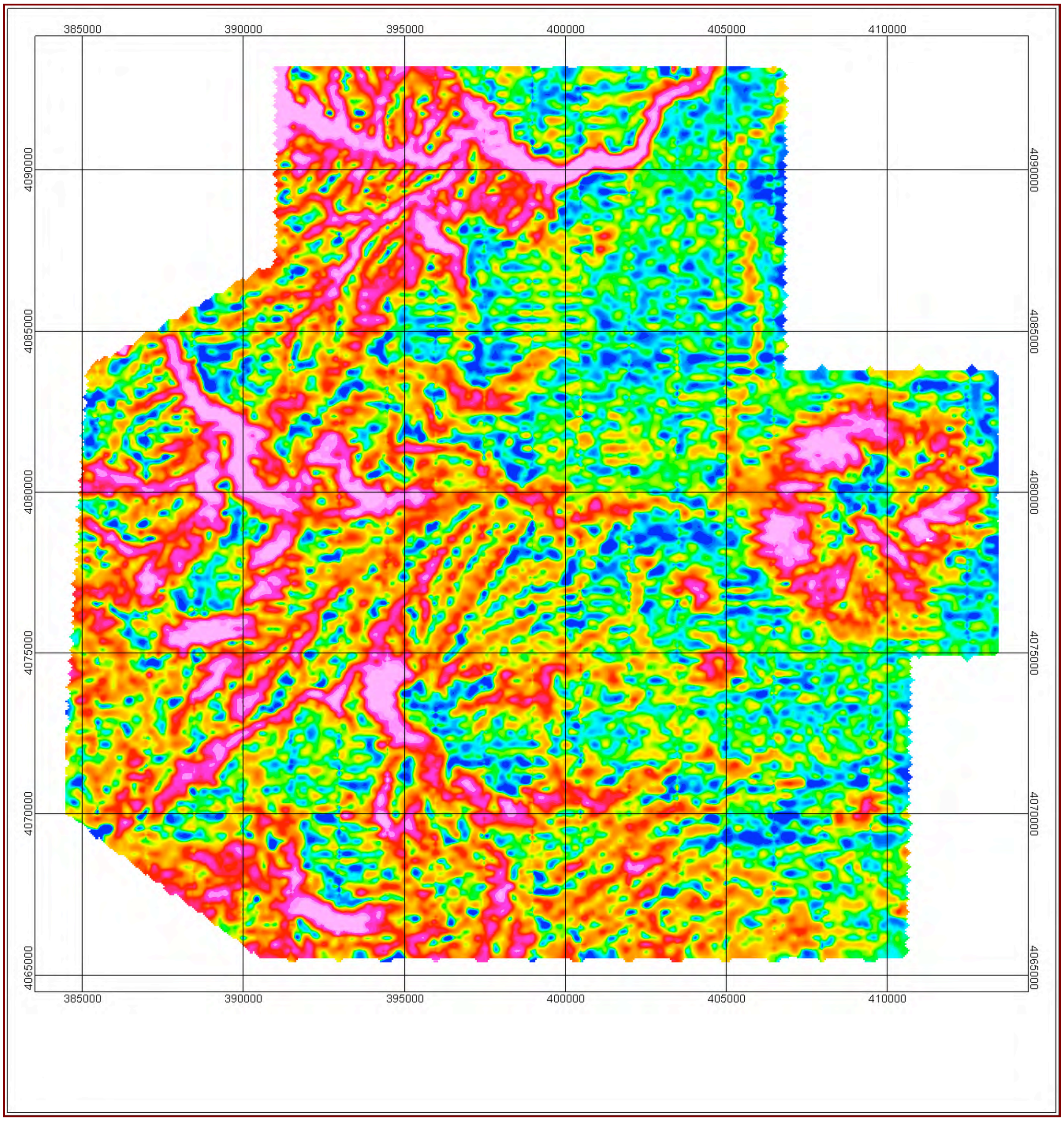

Figure 13: Radar Altimeter (21026_RADAR.GXF)

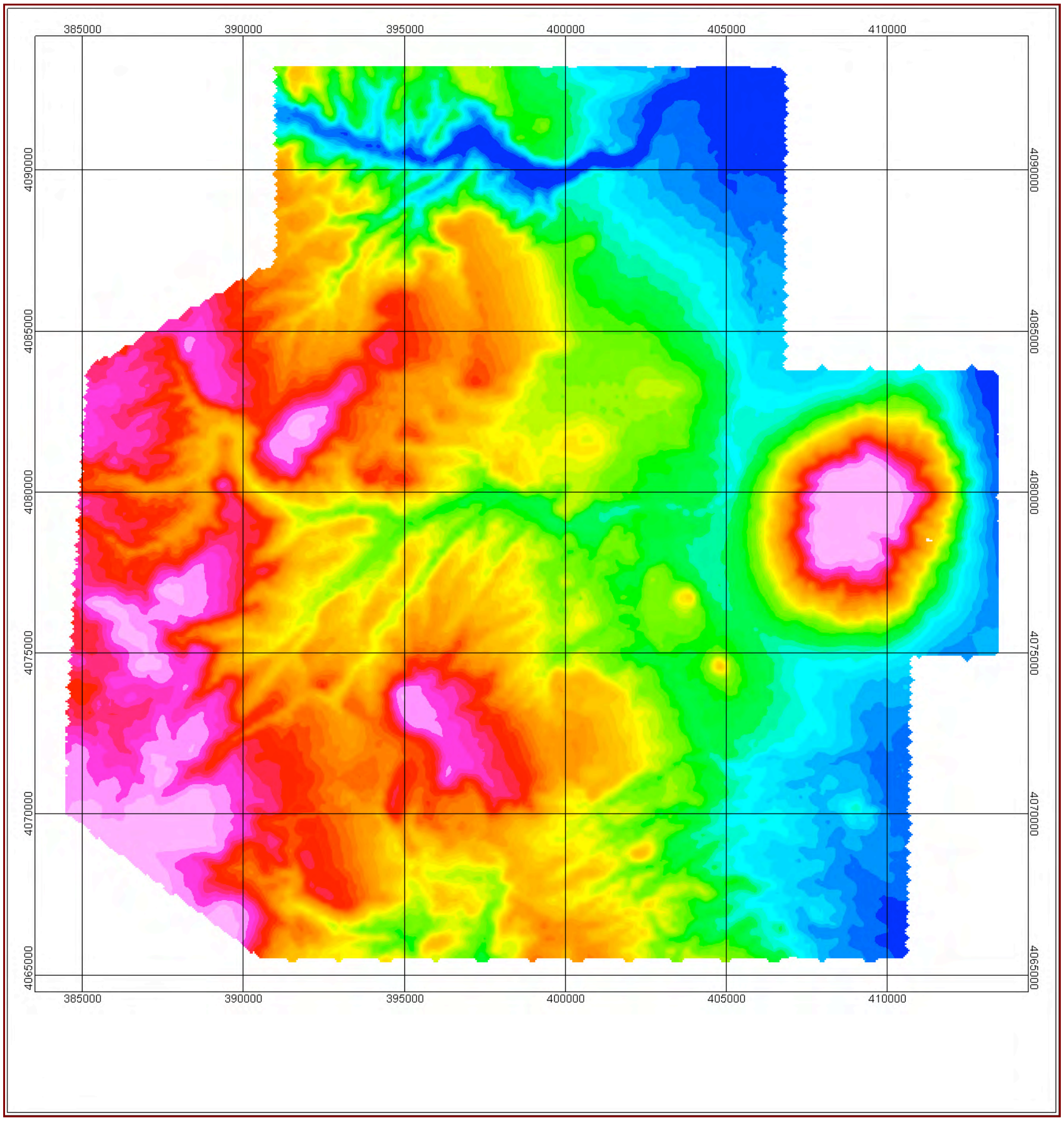

Figure 14: Calculated Topo from radar and GPS data (21026_TOPO.GXF)

Summary:

This survey was completed with minimal delays or problems. The only equipment problem was the radar altimeter. After the faulty radar antenna was replaced no further radar data drops were experienced. The pilot was able to fly the planned grid and controlled drape surface very precisely and no out-of-specification lines needed to be re-flown. The field-base data Quality Control and Quality Assurance procedures worked well and the data were processed and delivered within the specified time period.

This project was completed under EDCON-PRJ job number 21026.

Sincerely,

EDCON-PRJ, Inc.

John E. Seibert

Nick Anderson