

Block EN04 (Eastern North 04)

GRAV-D Airborne Data Release User Manual

Applies to Data Release BETA, 3/2013

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Introduction to GRAV-D and Data User Manuals

NOAA's National Geodetic Survey (NGS) launched the Gravity for the Redefinition of the American Vertical Datum (GRAV-D) program in 2007. This program is designed to replace the current national vertical datum (NAVD 88) with a datum based upon a gravimetric geoid by 2022. To produce the geoid with 1-2 cm accuracy (where possible), an airborne campaign has been launched to measure the gravity field over all of the US and its holdings.

A more comprehensive description of the GRAV-D project is available in the "GRAV-D General Airborne Gravity Data User Manual." The version of that manual that applies to this release is manual v. 2.X. That manual also describes general details of the nominal airborne field operations, data post-processing software specifics, data naming schemes and distribution, data formats, and how to calculate other commonly-used gravity values from the released data. This manual relates details for this block of data that are in addition to the General User Manual.

GRAV-D uses some specific terminology (e.g. "block" for a geographic area with enough flown data and tie lines to provide error statistics, and "survey" for an occupation by the field team of a particular airport, at a particular time, and with a particular aircraft and instrument suite). For a full list of terminology, refer to the Glossary in the Appendices of the "GRAV-D General Airborne Gravity Data User Manual."

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1. Block Description

GRAV-D Block **EN04** is located in the **E**astern Time Zone, in the **N**orth half (north of 40° latitude). This was the forth (**04**) block of data completed in that region. Block EN04 is 300 km by 470 km over Michigan and Lake Huron ([Figure 1](#)). The corner coordinates defining Block EN04 are listed in [Table 1](#).

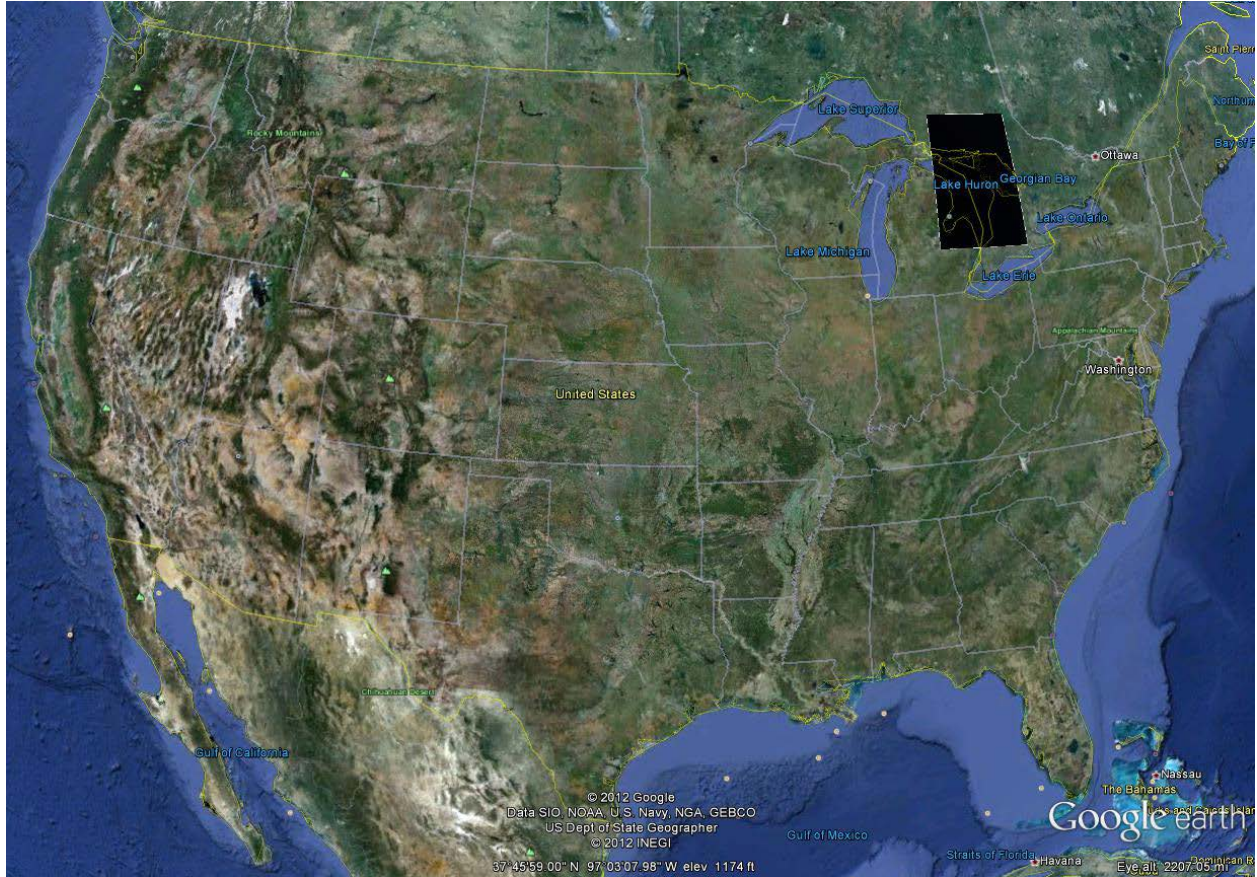


Figure 1: Google Earth Image of the Location of Block EN04 (black rectangle).

Table 1: Latitude and Longitude Coordinates of Corner Points Defining Block EN04

Latitude (decimal degrees)	Longitude (decimal degrees)
47.409793473	-83.719054061
43.094721425	-84.194351134
42.953694777	-80.165478434
47.230094922	-79.916335217

2. Survey Design and Execution

Airborne gravity data in Block EN04 were collected during one survey: MI12 (Michigan 2012). All data and cross flights were done at 20,000 ft with the same aircraft and instrument suite. Supplementary data from transit (target of opportunity) flights may be made available at a future date. [Table 2](#), [Table 3](#), and [Table 4](#) give a synopsis of survey layout and execution for the data. [Figure 2](#) shows the data coverage, plotted in Google Earth.

In the EN04 all data lines are North-South and cross lines East-West. The block consists of 34 data lines, 5 cross lines from MI12. The usual line numbering scheme used by GRAV-D (see “General User Manual”) was used for this survey. In the data file, line numbers are preceded by the block name (i.e. EN04101= block EN04’s line 101).

Table 2: Survey Overview

Conducting Organization	NOAA- National Geodetic Survey
Survey Name	MI12
Airport Base of Operations	Detroit Metropolitan Wayne County Airport (DTW) Romulus, MI FBO: Metro Flight Services
Geographic Location	Michigan, Lake Huron, Canada
Dates of Airborne Operations	August 16 th – September 28 th , 2012

Table 3: Aircraft and Instrumentation

Aircraft	NOAA Turbo Commander 1000 (N45RF)
Engines, number and type	2, Turboprop
Gravity Instrumentation	Micro-g LaCoste (MGL) TAGS S-137 (relative) MGL A-10 25 (absolute) MGL G-6 (relative)
GPS Instrumentation	NovAtel DL-4 Plus NovAtel SPAN-SE (GPS + IMU)

Table 4: Survey Design and Execution

Line Spacing	Data Lines: 10 km Cross Lines: ~80 km
Type of Layout	Regular data lines & regular cross lines
Nominal Survey Altitude	20,000 ft
Nominal Aircraft Ground Speed	~250 knots
Number of Lines Released	Data Lines: 34 Cross Lines: 5 Repeat Lines: 0
Number of Crossovers	138

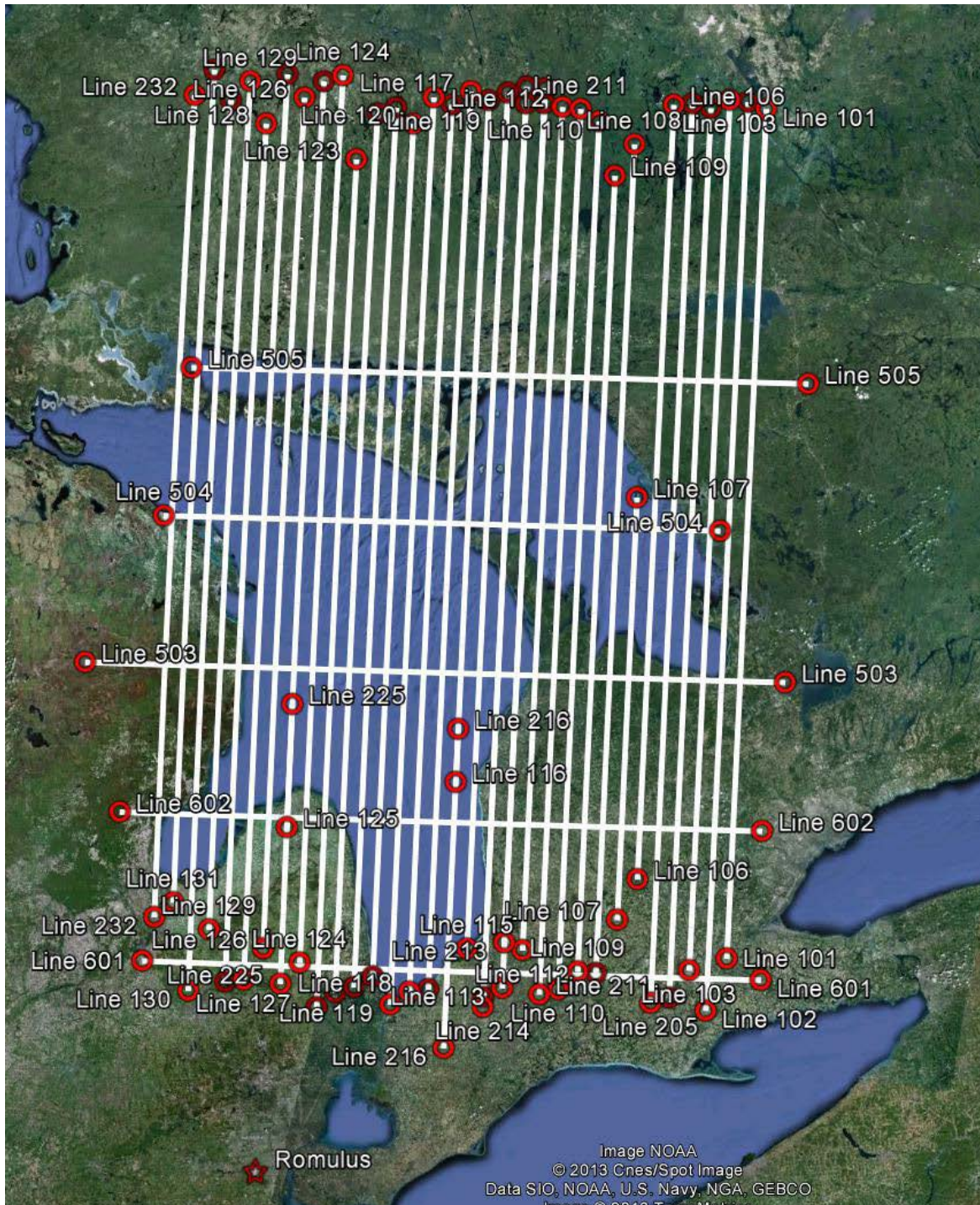


Figure 2: Data Coverage for EN04. Data lines start in the east at 101 and continue west to 232 (a reflight of 132). Airport marked with red star.

2.1 GPS/IMU Instrumentation

The NOAA Turbo Commander 1000 had one GPS antenna available for scientific measurements. Two geodetic-quality GPS receivers shared the antenna: NovAtel DL-4 Plus (included as part of the TAGS gravimeter timing unit) and a NovAtel (inside the SPAN-SE system). The NovAtels had a data rate of 1 Hz and the SPAN NovAtel of 20Hz. The NovAtel μ IMU system also contained an Inertial Measurement Unit (IMU) that recorded aircraft orientation information at 200 Hz during the flight, including pitch, roll, yaw, and heading.

On the ground, three Ashtech Z-Surveyors recorded at 1 Hz and served as GPS base stations throughout the survey. See Section [3.2.1](#) for a table of GPS data available for each flight and processing details.

2.2 Gravity Instrumentation

The Micro-g LaCoste TAGS (Turn-key Airborne Gravimetry System) was mounted in the cargo area. The TAGS records data at 1Hz and has a NovAtel timing unit mounted on the gravimeter. The gravimeter also records an environmental file at 0.1 Hz. For more information on the instrument, refer to its user manual (Micro-g LaCoste, 2010).

The IMU was mounted on top of the TAGS and in the center of the frame. [Table 5](#) lists the lever arm measurements between the TAGS and other instruments (distances are measured along the body of the aircraft: X positive toward the nose, Y positive toward the right, and Z positive down.) [Table 6](#) lists the lever arm measurement between the TAGS and the SPAN-SE (distances measured along the body of the aircraft: X positive toward the right, Y positive toward the nose, and Z positive up).

Table 5: Lever Arm Measurements FROM the Center of the Gravimeter's Sensor TO the Other Instruments, for this Installation on the NOAA Turbo Commander 1000

Instrument/Location	X (m)	Y (m)	Z (m)
Aircraft Center of Gravity	0.00	0.00	-0.56
Aircraft GPS Antenna	0.16	0.13	-1.25
NovAtel SPAN-SE IMU	0.025	0.00	-0.495

Table 6: Lever Arm Measurements FROM the SPAN TO the GPS Antenna, for this Installation on the NOAA Turbo Commander 1000

Instrument/Location	X (m)	Y (m)	Z (m)
GPS Antenna	0.092	0.143	0.616

3. GPS and Gravity Data Processing

3.1 Whole-Survey Applicable Details

3.1.1 GPS

Table 7: GPS High Rate Data Availability (1 Hz or higher)

Airport	Type	Receiver	Flight Available	2009 Day of Year Available
DTW (MI12)	Kinematic	NovAtel DV-4 Plus	F05-15	245-247, 249-250, 255-257
		SPAN	F05-26	245-247, 249-250, 255-257, 260-261, 263, 269-272
	Static	Ashtech North	F06-26	246-247, 249-250, 255-257, 260-261, 263, 269-272
		Ashtech South	F05-26	245-247, 249-250, 255-257, 260-261, 263, 269-272
		Ashtech West	F05-26	245-247, 249-250, 255-257, 260-261, 263, 269-272

Table 8: NGS GPS Base Station Position(s)

Airport	Base Name	Antenna Type	Latitude (dec deg)	Longitude (dec deg)	Ellipsoidal Height (m)
DTW	Ashtech North	ASH701975.01A	42.227112576	-83.330690632	158.234
	Ashtech South	ASH701975.01A	42.226404833	-83.330513587	158.267
	Ashtech West	ASH701975.01A	42.226635903	-83.331062867	158.557

Data were processed using WGS84 and ITRF08. Average position accuracy for the data block is calculated from the final GPS position solution. Position standard deviation is estimated by the GPS processing programs for each flight and those numbers are averaged to provide a survey-wide estimate of GPS position accuracy. For the data lines, the average horizontal position accuracy is 0.018 m and the average vertical position accuracy is 0.021 m.

3.1.2 Ground Gravity Tie

An absolute gravity measurement was performed by NGS with a Micro-g LaCoste A-10 gravimeter in the spring of 2012. The A-10 was set up at the exact location of the aircraft. The positions were determined from the GPS collected during the gravity survey while the plane was parked. In Romulus, MI the location is designated as KDTW TAGS (42.227513242°N, -83.328743650°W) and it has an absolute gravity value of 980305.8883 ± 0.0078 mGal.

3.1.3 Gravity Filtering

For block EN04, flights were accomplished in one survey and were filtered the same way. Newton v1.2 uses a time-domain Gaussian filter that is applied three times to the data during final filtering. The Gaussian filter chosen for this survey has a 6-sigma of 120s, i.e. a 2-sigma of only 40s. Applying the filter three times provides superior noise reduction compared to a single application of the filter. Although the triple application provides better noise reduction, the filter is tailored to best preserve the amplitudes of the long wavelength signal, while allowing some

short wavelength noise to remain in the final product. Also, a pre-filter was applied to the GPS solution for input into the offlevel correction. For suggestions on data handling, including on further noise suppression, see Section [4.1 Suggested Data Handling](#).

3.2 Whole-Block Applicable Details

3.2.1 Gravity Error Analysis

Crossover error analysis was done by identifying the crossing points of the data lines and cross lines and then applying the standard free-air correction to bring all points to the average altitude of the block. There was an unidentified bias in all flight lines, so an additional correction was applied before the crossover analysis to adjust each line's median airborne gravity value to the median gravity value of EGM08 along the line. The bias-corrected difference between the cross line gravity value and data line gravity value is the residual. The square root of the RMS of the residuals yields the total RMS error. For EN04, the result of the crossover analysis is shown in [Table 9](#) and in [Figure 3](#).

Table 9: Gravity Crossover Error Analysis for the EN04 block

Nominal Altitude (ft)	Nominal Altitude (m)	Altitude for Analysis (m)	Number of Crossovers	RMS Of Residuals (mGal)	Std. Dev. Of Residuals (mGal)	Mean Crossover Difference (mgal)	RMS Error (mGal)
20,000	6,096	6,419	138	2.46	2.46	-0.20	1.74

One assumption of crossover analysis is that the quality of the cross lines are high and that the crossover difference reflects only the error in the data lines. This is not necessarily the case. This means that the crossover statistics do not accurately reflect the quality of the data lines, due to the errors in the cross lines. One way to quantify this problem is by reporting the standard deviation and mean of the crossover residuals for each cross line, as in [Table 10](#). The higher the standard deviation of the residuals, the more likely that the cross line was noisy. Also, a non-zero mean could indicate a cross-line bias with respect to the data lines (unlikely here because of the bias correction applied), which would produce false crossover statistics that indicate poor data line quality.

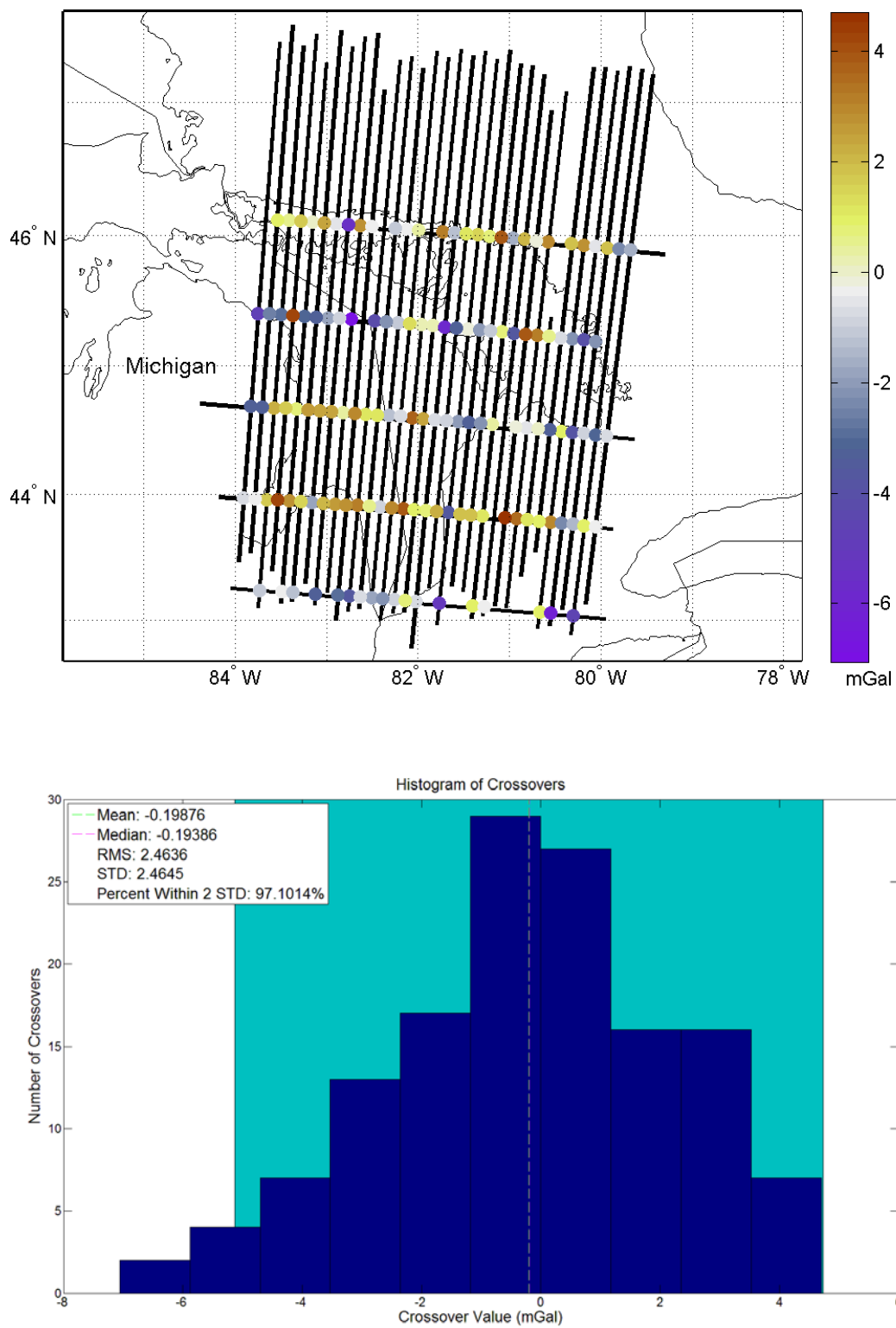


Figure 3: Crossover Residuals, Histogram, and Statistics for Block EN04. Color scale in mGals.

Table 10: Quality of Cross Lines Used in Crossover Analysis

Cross Line Number	Standard Deviation of Residuals Along Line (mGal)	Mean of Residuals Along Line (mGal)
601	2.11	-1.81
602	1.96	1.26
503	2.16	-0.17
504	2.69	-1.55
505	2.02	0.54

Another way to evaluate the quality of gravity data is to calculate the correlation of the gravity values along two adjacent data lines. Average correlation and statistics on the spread of correlations can yield information about the quality of the data lines ([Table 11](#)). This technique works well as a measure of data quality in areas with little lateral variability in the gravity field (such as the Gulf of Mexico). But the technique doesn't work well when the correlations are not expected to be high, such as in areas with large changes in topography and/or density from data line to data line. Line correlations were calculated for adjacent lines and then averaged to give an overall quality measurement. Correlations > 80% mean the lines are very highly correlated, 70% - 80% mean the lines are highly correlated, 50% - 70% mean the lines are more correlated than not, and <50% are more uncorrelated than correlated.

Table 11: Average Data Line Correlation

Number of Correlations	Average Data Line Correlation	Standard Deviation of Correlations
24	99.92%	0.11%

A fourth way of gauging data quality is by calculating the repeatability of the gravity signal along reflight lines of good quality. Reflight analysis can also help to pinpoint the lightest filtering that produces highly-correlated results. In EN04, however, there were no reflight lines.

3.3 Flight- and Line-Specific Details

3.3.1 GPS processing- by flight

GPS data were processed in Inertial Explorer (IE) 8.4. A lever arm correction (to move the position solution from that of the GPS antenna to that of the center of the gravimeter) was applied within the IE software and included in the GPS+IMU solution. In the case of the GPS-only solution, no IMU data were available and a translation-only, vertical lever arm correction was instead applied by the Newton gravity code to translate the GPS-only positions to the center of the gravimeter.

NGS has developed an independent method of measuring the quality of GPS position solutions based on information available from IE. For the GPS-only part of the position solution, the quality analysis takes into account the following: whether a fixed or float solution was achieved, the magnitude of the combined separation between forward and reverse solutions (a measure of precision), and the estimated position accuracy. For details on the calculation, please refer to the "GRAV-D General Airborne Gravity Data User Manual."

3.3.2 Gravity processing- by line

All gravity processing was done with NGS' Newton v1.2 software. For a description of the package, refer to the "GRAV-D General Airborne Gravity Data User Manual." The final gravity data file contains full-field gravity at altitude ([Figure 4](#)), although other gravity products such as free-air anomalies or free-air disturbances ([Figure 5](#)) can be easily calculated by following directions in Section 4 of the "GRAV-D General Airborne Gravity Data User Manual".

Table 12: GPS+IMU and GPS-only Kinematic Processing Results

Survey	Flight Num.	Base GPS Unit	Rover GPS Unit	Solution Type	Elevation Mask (degrees)	Line Num.	NGS Quality Grade
	05	West	SPAN	GPS+IMU	8	131	98.41
						232*	80.51
	06	West	SPAN	GPS+IMU	8	129	100.00
						130	83.12
	07	West	SPAN	GPS+IMU	8	601	100.00
						602	100.00
	08	North	SPAN	GPS+IMU	8	115	100.00
						116	100.00
	10	West	SPAN	GPS+IMU	8	112	100.00
	11	West	SPAN	GPS+IMU	8	109	100.00
						110	100.00
	12	North	SPAN	GPS+IMU	8	107	99.98
						108	100.00
	13	West	SPAN	GPS+IMU	8	101	100.00
						102	100.00
	14	West	SPAN	GPS+IMU	8	103	100.00
						104	100.00
	15	West	SPAN	GPS+IMU	8	106	100.00
	16	West	SPAN	GPS+IMU	9	127	94.32
						128	100.00
	17	West	SPAN	GPS+IMU	8	125	100.00
						126	100.00
	18	West	SPAN	GPS+IMU	8	504	90.28
	19	West	SPAN	GPS+IMU	10	213*	100.00
						214*	100.00
	20	West	SPAN	GPS+IMU	9	123	50.00
						124	50.00
	21	West	SPAN	GPS+IMU	8	121	100.00
						122	100.00
	22	North	SPAN	GPS+IMU	8	119	100.00
						120	100.00
	23	North	SPAN	GPS+IMU	10	117	100.00
						118	100.00
	24	West	SPAN	GPS+IMU	8	205*	96.31
						211*	100.00
	25	West	SPAN	GPS+IMU	8	216	83.37
						225	100.00
						503	85.51
	26	West	SPAN	GPS+IMU	8	505	100.00

*Lines 232, 213, 214, 205, and 211 were originally flown during Flight 04, 09, and 10 respectively, but due to poor data quality the lines were re flown.

Table 13: Gravity Processing Results

Survey	Flight Num.	Line Num.	Times of Deleted Data Sections (s)	Comments
	05	131	None	None
		232	None	None
	06	129	None	None
		130	None	None
	07	601	None	None
		602	None	None
	08	115	None	None
		116	None	None
	10	112	70308-70609	Spike Removed
	11	109	None	None
		110	89095-89903	Spike Removed
	12	107	None	None
		108	None	None
	13	101	80720-81037	Spike Removed
		102	None	None
	14	103	None	None
		104	None	None
	15	105	None	None
		106	None	None
	16	127	None	None
		128	None	None
	17	125	None	None
		126	None	None
	18	504	None	None
	19	213	None	None
		214	None	None
	20	123	58220-58591	Spike Removed
		124	None	None
	21	121	77960-78222	Spike Removed
		122	80074-80780	Spike Removed
	22	119	None	None
		120	None	None
	23	117	None	None
		118	98350-98550	Spike Removed
	24	205	None	None
		211	None	None
	25	216	None	None
		225	None	None
		503	None	None
	26	505	None	None

Table 14: Bias from EGM08 by Line

Survey	Flight Num.	Line Num.	Bias from EGM08 (mGals)
	05	131	-0.17
		232	-0.10
	06	129	-0.70
		130	-0.29
	07	601	-1.24
		602	0.38
	08	115	0.69
		116	0.43
	10	112	2.04
	11	109	0.04
		110	0.78
	12	107	-0.50
		108	0.43
	13	101	0.73
		102	0.87
	14	103	-0.47
		104	-0.04
	15	105	-0.16
		106	0.70
	16	127	-0.31
		128	0.32
	17	125	0.41
		126	0.16
	18	504	-1.34
	19	213	0.82
		214	0.36
	20	123	-0.24
		124	0.35
	21	121	0.35
		122	0.05
	22	119	-0.13
		120	0.78
	23	117	-1.45
		118	-1.07
	24	205	-0.18
		211	0.42
	25	216	-0.42
		225	-0.53
		503	1.0
	26	505	0.89

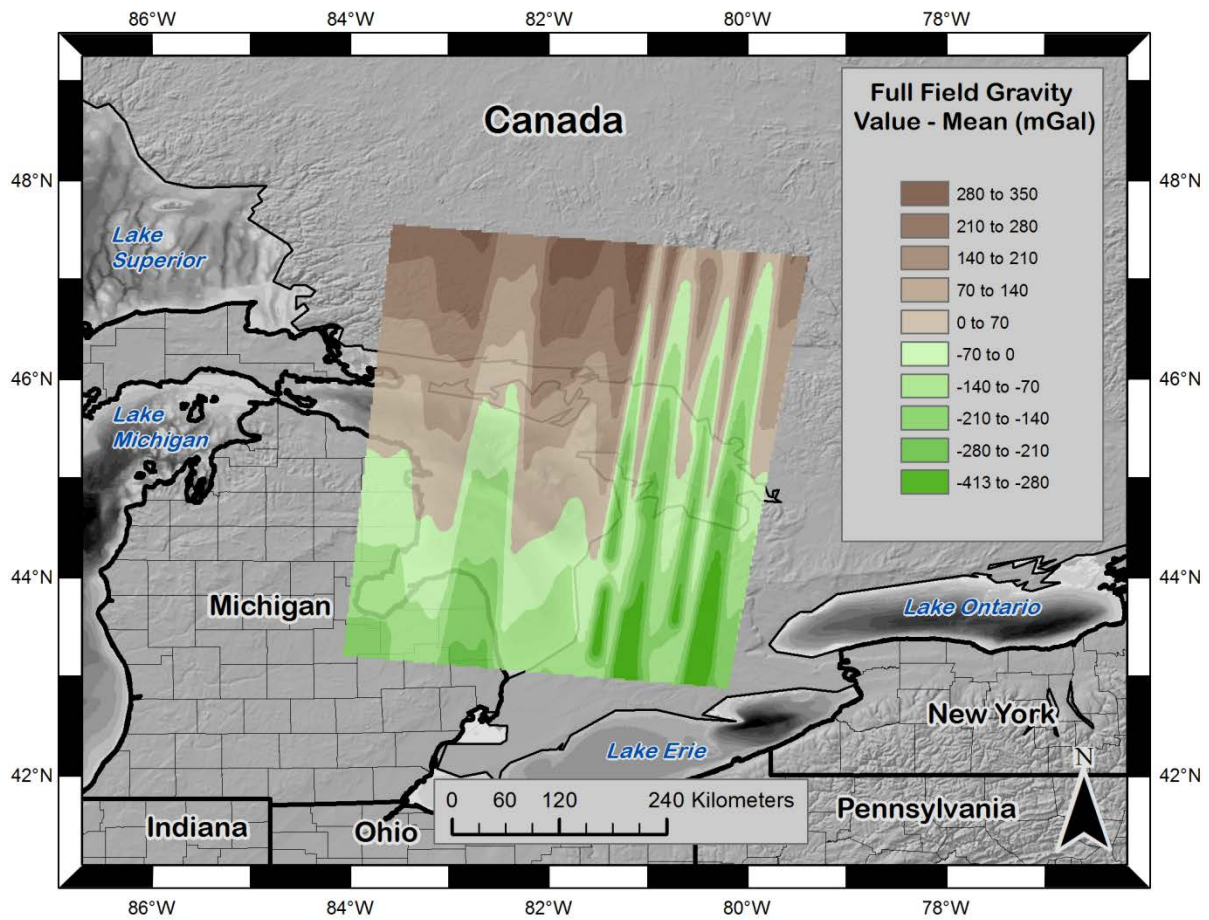


Figure 4: Full-field gravity at altitude (mean removed) for Block EN04. This is the data in the gravity release ".txt" file and includes the effects of differing altitudes along flight lines.

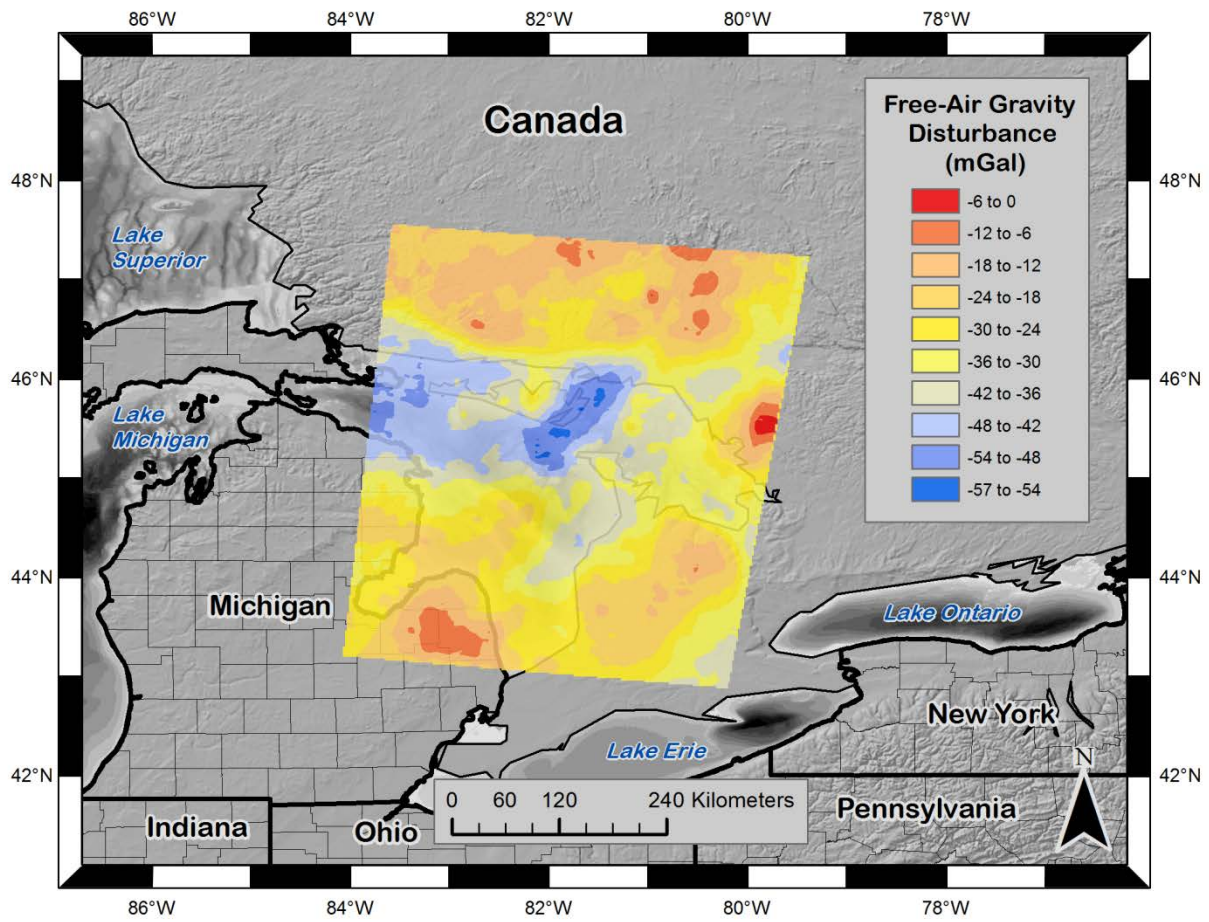


Figure 5: Free-air gravity disturbance for Block EN04 with respect to the WGS-84 ellipsoid.

4. Data Usage Guidelines

4.1 Suggested Data Handling

This data product was purposefully filtered to preserve the amplitude of the long-wavelength gravity signal. As a trade-off, the filter allows some short wavelength noise to remain in the product. Prior to use for geophysical purposes, the data should be run through a frequency-domain low-pass filter to remove that excess short wavelength noise. For geodetic purposes, higher frequencies can be damped during inclusion into a spherical harmonic model. In any case where downward continuation will be done with this data, the high frequency noise should first be filtered out, damped, or otherwise dealt with so that the downward continuation does not amplify the noise.

4.2 Documentation

The survey block User Manual, the general GRAV-D User Manual, and metadata for the block should all be downloaded with the data and kept in the same directory. The contents of the manuals are critical to correctly understanding the quality of the data and using the data properly.

4.3 How to Cite These Data

The following citations should be used in all presentations or publications that reference the GRAV-D work. Please replace the *DATE* tag in the following references with the date you downloaded the data or reports from the NGS website.

The GRAV-D Science Team, in alphabetical order, are: Vicki A. Childers, Theresa M. Damiani, Sandra A. Martinka Preaux, Carly A. Weil, and Monica A. Youngman.

To reference the EN04 data file, reference the webpage:

GRAV-D Science Team (2013). "Gravity for the Redefinition of the American Vertical Datum (GRAV-D) Project, Airborne Gravity Data; Block EN04". Available *DATE*. Online at: http://www.ngs.noaa.gov/GRAV-D/data_EN04.shtml

To reference the block and survey details, reference the block user manual:

GRAV-D Science Team (2013). "Block EN04 (Eastern North 04); GRAV-D Airborne Gravity Data User Manual." Monica Youngman and Carly Weil, ed. Version 1. Available *DATE*. Online at: http://www.ngs.noaa.gov/GRAV-D/data_EN04.shtml

To reference the general GRAV-D project operations, reference the General User Manual:

GRAV-D Science Team (2013). "GRAV-D General Airborne Gravity Data User Manual." Theresa Damiani and Monica Youngman, ed. Version 2. Available *DATE*. Online at: http://www.ngs.noaa.gov/GRAV-D/data_EN04.shtml

5. References

Micro-g LaCoste, 2010. "TAGS Turnkey Airborne Gravity System AIR III Hardware & Operations Manual."