

# Block EN02 (Eastern North 02)

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*GRAV-D Airborne Data Release User Manual*

*Applies to Data Release BETA, 4/2013*

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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 **EN02** is located in the **E**astern Time Zone, in the **N**orth half (south of 40° latitude). This was the second (**02**) block of data completed in that region. Block EN02 is 270 km by 500 km in the Great Lakes, covering coastal areas of New York, Pennsylvania, Ohio, Michigan, and Ontario as well as Lake Erie ([Figure 1](#)). The corner coordinates defining Block EN02 are listed in [Table 1](#).

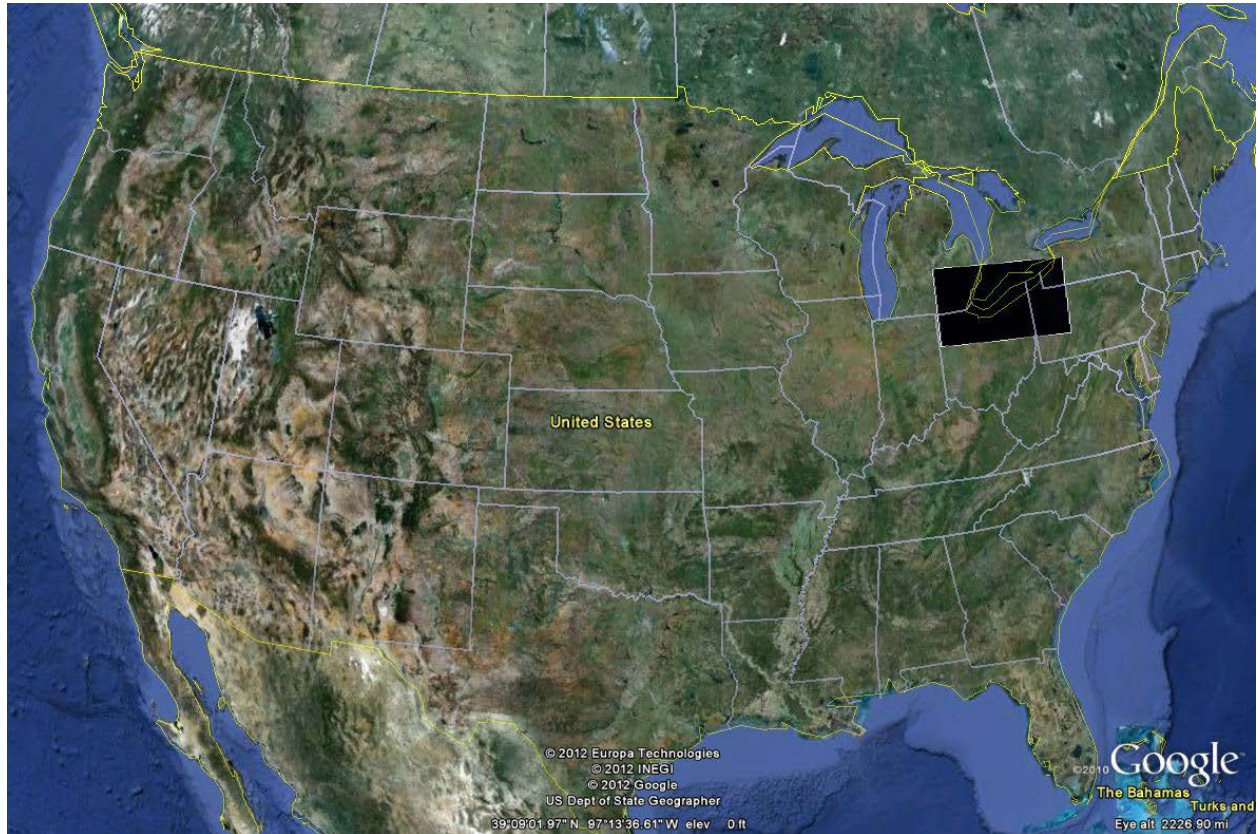


Figure 1: Google Earth Image of the Location of Block EN02 (black rectangle).

Table 1: Latitude and Longitude Coordinates of Corner Points Defining Block EN02

Latitude (decimal degrees)	Longitude (decimal degrees)
43.137125595	-84.561306661
40.729746705	-84.733312241
40.479584195	-78.832439861
42.885366747	-78.479669593

## 2. Survey Design and Execution

Airborne gravity data in Block EN02 were collected during two surveys: NY11 (New York 2011) and IN11 (Indiana 2011). 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 EN02 all data lines are East-West and cross lines Northwest-Southeast. The block consists of 18 data lines, 2 cross lines from NY11 and 11 data lines, 3 cross lines from IN11. 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. EN02101= block EN02’s line 101).

*Table 2: Survey Overview*

Conducting Organization	NOAA- National Geodetic Survey	
Survey Name	NY11	IN11
Airport Base of Operations	Buffalo Niagara Intl (BUF) Buffalo, NY FBO: Western Aviation Jet Center	Fort Wayne Intl (FWA) Ft. Wayne, IN FBO: Atlantic Aviation
Geographic Location	Lake Erie, New York, Pennsylvania, Ohio, Michigan, Ontario	
Dates of Airborne Operations	Aug. 8 – Sept. 2, 2011	Sept. 21 – Nov. 21 <sup>st</sup> , 2011

*Table 3: Aircraft and Instrumentation*

Aircraft	Hawker Beechcraft King Air E90A (NY11)	Alaska Fire Service (BLM) Pilatus PC-12 (IN11)
Engines, number and type	2, Turboprop	1, Turboprop
Gravity Instrumentation	Micro-g LaCoste (MGL) TAGS S-137 (relative) MGL FG-5 102 (absolute) MGL D-43 (relative)	
GPS Instrumentation	NovAtel DL-4 Plus Applanix POS AV 510 (GPS + IMU) NovAtel SPAN-SE (GPS + IMU)	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 & diagonal cross lines
Nominal Survey Altitude	20,000 ft
Nominal Aircraft Ground Speed	220 knots
Number of Lines Released	Data Lines: 18 (NY11), 11 (IN11) Cross Lines: 2 (NY11), 3 (IN11) Repeat Lines: 0
Number of Crossovers	67





The IMU was mounted on top of the TAGS and in the center of the frame. Lever arm measurements were done for both aircraft, Table 5 and Table 6 for the King Air E90A and Table 7 and Table 8 for the Pilatus PC-12. [Table 5](#) and Table 7 list 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 and Table 8](#) list 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 Dynamic Aviation King Air E90A*

<b>Instrument/Location</b>	<b>X (m)</b>	<b>Y (m)</b>	<b>Z (m)</b>
Aircraft Center of Gravity	0.000	0.219	0.413
Aircraft GPS Antenna	-1.582	0.219	-1.063
Applanix POS AV 510 IMU	0.130	0.015	-0.500

*Table 6: Lever Arm Measurements FROM the SPAN TO the GPS Antenna, for this Installation on the Dynamic Aviation King Air E90A*

<b>Instrument/Location</b>	<b>X (m)</b>	<b>Y (m)</b>	<b>Z (m)</b>
GPS Antenna	-.204	-1.582	0.513

*Table 7: Lever Arm Measurements FROM the Center of the Gravimeter's Sensor TO the Other Instruments, for this Installation on the Pilatus PC-12*

<b>Instrument/Location</b>	<b>X (m)</b>	<b>Y (m)</b>	<b>Z (m)</b>
Aircraft Center of Gravity	0.270	0.000	0.397
Aircraft GPS Antenna	-0.631	-0.012	-1.223
Applanix POS AV 510 IMU	0.000	0.000	-0.495

*Table 8: Lever Arm Measurements FROM the SPAN TO the GPS Antenna, for this Installation on the Pilatus PC-12*

<b>Instrument/Location</b>	<b>X (m)</b>	<b>Y (m)</b>	<b>Z (m)</b>
GPS Antenna	-.008	0.669	0.615

### 3. GPS and Gravity Data Processing

#### 3.1 Whole-Survey Applicable Details

##### 3.1.1 GPS

Table 9: GPS High Rate Data Availability (1 Hz or higher)

Airport	Type	Receiver	Flight Available	2009 Day of Year Available
BUF	Kinematic	NovAtel (0009)	F11,F18-F27	229,237-238,241-247
		SPAN	F11,F18-F27	229,237-238,241-247
		Trimble (mgps)	F11,F18-F27	229,237-238,241-247
	Static	Ashtech (Middle)	F11,F18-F27	229,237-238,241-247
		Ashtech (North)	F11,F18-F27	229,237-238,241-247
		Ashtech (South)	F11,F18-F27	229,237-238,241-247
FWA	Kinematic	NovAtel (0009)	F08,F15,F18,F24-F27	286,301,306,321-322
		SPAN	F08,F15,F18,F21-F22,F24-F27	286,301,306,309,321-322
		Trimble (mgps)	F08,F15,F18,F21-F22,F24-F27	286,301,306,309,321-322
	Static	Ashtech (3613)	F08,F15,F18,F24-F27	286,301,306,321-322
		Ashtech (3812)	F08,F15,F18 ,F24-F27	286,301,306,321-322
		Ashtech (3828)	F08,F15,F18,F21-F22,F24-F27	286,301,306,309,321-322

Table 10: NGS GPS Base Station Position(s)

Airport	Base Name	Antenna Type	Latitude (dec deg)	Longitude (dec deg)	Ellipsoidal Height (m)
BUF	Ashtech (Middle)	ASH701975.01A	42.944870424	-78.731476055	177.970
	Ashtech (North)	ASH701975.01A	42.945845154	-78.731926077	177.590
	Ashtech (South)	ASH701975.01A	42.945240336	-78.732952273	177.237
FWA	Ashtech (3613)	ASH701975.01A	40.990413641	-85.195805797	211.392
	Ashtech (3812)	ASH701975.01A	40.991443126	-85.195009809	210.762
	Ashtech (3828)	ASH701975.01A	40.989876820	-85.195391503	211.612

Data were processed using WGS84 and ITRF00. After post-processing the GPS-only kinematic data (before processing with coupled IMU), average position accuracy for the data block is calculated. 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 0.016 m. For flights from NY11, GPS+IMU solutions were calculated using the Applanix IMU. For flights from IN11, GPS+IMU solutions were calculated using the SPAN.



### 3.1.2 Ground Gravity Tie

Updated absolute gravity measurements were performed by NGS with a Micro-g LaCoste A-10 gravimeter in summer of 2011. At both airports 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 Buffalo, NY the location is designated as BUF TAGS (42.94732°N, -78.7357094°W) and it has an absolute gravity value  $980353.39503 \pm 0.0028$  mGal. In Fort Wayne, IN the location is designated as KFWA TAGS (40.98703°N, -85.1906201°W) and it has an absolute gravity value  $980187.2360 \pm 0.0029$  mGal.

### 3.1.3 Gravity Filtering

For block EN02, flights were accomplished two surveys 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 EN02, the result of the crossover analysis is shown in [Table 11](#) and in [Figure 3](#).

*Table 11: Gravity Crossover Error Analysis for the EN02 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	6,288	67	2.37	2.39	0.01	1.68

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 9](#). 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.

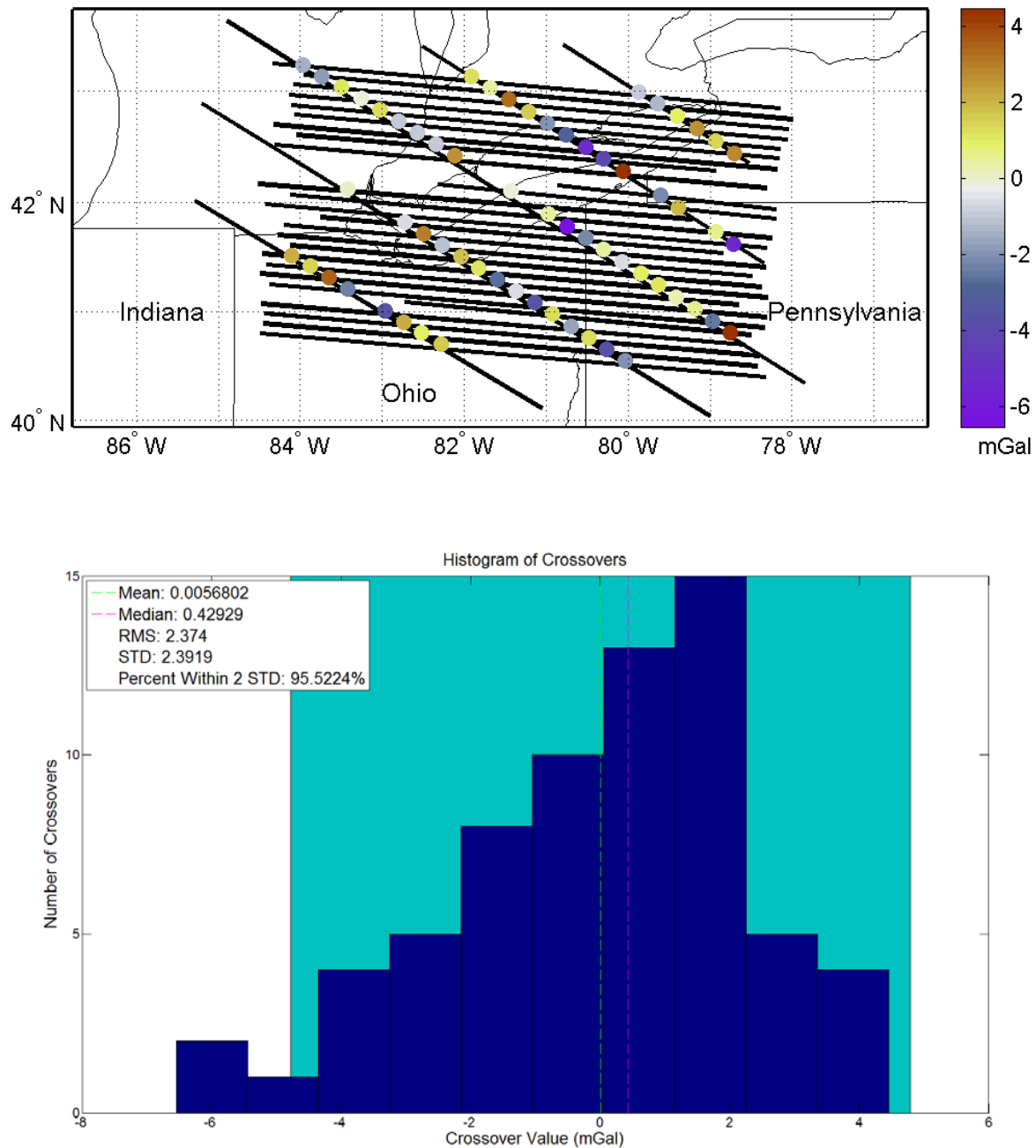


Figure 3: Crossover Residuals, Histogram, and Statistics for Block EN02. Color scale in mGals.

Table 12: 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	1.72	0.94
602	3.22	-0.65
603	2.13	-0.25
704	2.13	-0.25
705	2.41	1.19

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 13](#)). 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 13: Average Data Line Correlation

Number of Correlations	Average Data Line Correlation	Standard Deviation of Correlations
18	91.80%	11.84%

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 EN02, however, there were no reflight lines.

### 3.3 Flight- and Line-Specific Details

#### 3.3.1 GPS processing- by flight

For flights from NY11 using the Applanix IMU, GPS data were processed in POSPac v.4.4 for GPS+IMU position solutions or in GrafNav v.7.80.2315 for GPS-only position solutions. For flights from IN11 using the SPAN, 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 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 14: GPS+IMU and GPS-only Kinematic Processing Results

Survey	Flight Num.	Base GPS Unit(s)	Rover GPS Unit	Solution Type	Elevation Mask (degrees)	Line Num.	NGS Quality Grade
NY11 BUF	11	Middle	Trimble	GPS+IMU	10	103	100.00
						104	100.00
	18	Middle	Trimble	GPS+IMU	8	101	100.00
						102	100.00
	19	Middle	Trimble	GPS+IMU	8	105	96.78
						106	100.00
	20	Middle	Trimble	GPS+IMU	8	601*	89.06
						602*	94.15
	21	Middle	Trimble	GPS+IMU	8	107	100.00
						108	100.00
	22	Middle	Trimble	GPS+IMU	8	109	100.00
	23	Middle	Trimble	GPS+IMU	8	111	90.42
						112	94.82
	24	Middle	Trimble	GPS+IMU	8	113	97.14
						114	100.00
IN11 FWA	25	Middle	Trimble	GPS+IMU	8	115	96.03
	26	Middle	Trimble	GPS+IMU	8	117	93.09
						216*	99.48
	27	Middle	Trimble	GPS+IMU	8	118	99.48
						119	97.77
	08	3613	SPAN	GPS+IMU	8	603*	100.00
	15	3812	SPAN	GPS+IMU	8	220*	100.00
	18	3812	SPAN	GPS+IMU	8	226*	100.00
	21	3828	SPAN	GPS+IMU	8	320*	100.00
						321*	100.00
	22	3828	SPAN	GPS+IMU	12	222*	100.00
						223*	100.00
	24	3613	SPAN	GPS+IMU	8	228*	100.00
	25	3828	SPAN	GPS+IMU	8	224*	100.00
						225*	100.00
	26	3828	SPAN	GPS+IMU	10	326*	100.00
						327*	100.00
	27	3828	SPAN	GPS+IMU	8	704*	100.00
						705*	100.00

\*Lines were originally flown earlier in the surveys and were reflown due to poor data quality.

Table 15: Gravity Processing Results

Survey	Flight Num.	Line Num.	Times of Deleted Data Sections (s)	Comments
NY11 BUF	11	103	None	
		104	None	
	18	101	None	
		102	None	
	19	105	None	
		106	None	
	20	601	None	
		602	None	
	21	107	86574-86800	Spike Removed
		108	None	
	22	109	None	
	23	111	None	
		112	None	
	24	113	83396-83874	Spike Removed
		114	87182-87460, 88886-89540	Spikes Removed
	25	115	101014-102197	Spike Removed
	26	117	25763-26220	Spike Removed
		216	None	
	27	118	None	
		119	None	
IN11 FWA	08	603	None	
	15	220	None	
	18	226	None	
	21	320	None	
		321	None	
	22	222	None	
		223	None	
	24	228	None	
	25	224	None	
		225	None	
	26	326	None	
		327	None	
	27	704	None	
		705	None	

Table 16: Bias from EGM08 by Line

Survey	Flight Num.	Line Num.	Bias from EGM08 (mGals)
NY11 BUF	11	103	-2.14
		104	-0.74
	18	101	0.37
		102	-1.18
	19	105	1.24
		106	-0.42
	20	601	0.66
		602	0.00
	21	107	1.58
		108	0.70
	22	109	-4.05
	23	111	0.00
		112	-0.75
	24	113	0.22
		114	-1.57
	25	115	4.37
	26	117	-1.95
		216	1.04
	27	118	0.99
		119	-0.66
IN11 FWA	08	603	-0.02
	15	220	-1.18
	18	226	-0.98
	21	320	0.33
		321	1.32
	22	222	-0.31
		223	2.71
	24	228	1.80
	25	224	-0.76
		225	2.19
	26	326	-1.48
		327	1.01
	27	704	0.07
		705	2.37

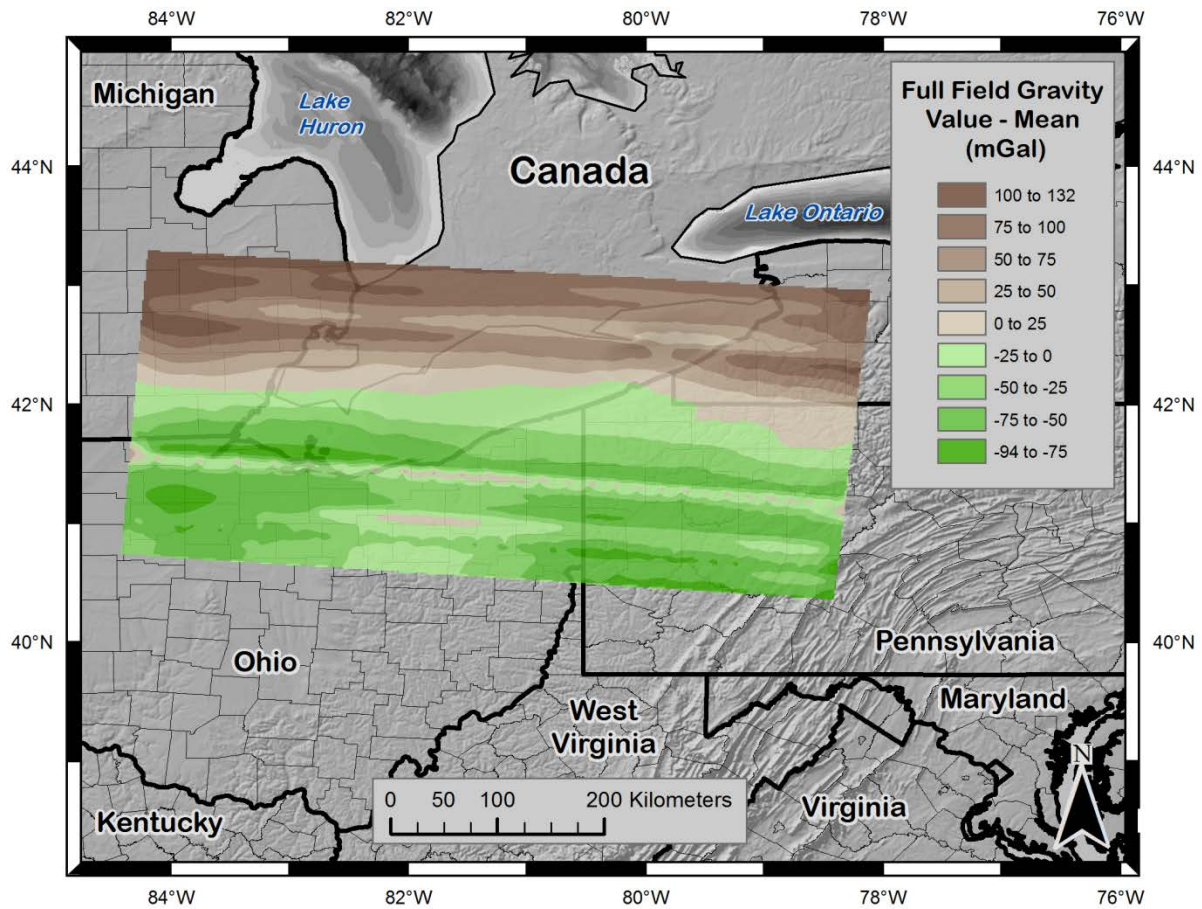


Figure 4: Full-field gravity at altitude (mean removed) for Block EN02. This is the data in the gravity release ".txt" file and includes the effects of differing altitudes along flight lines.



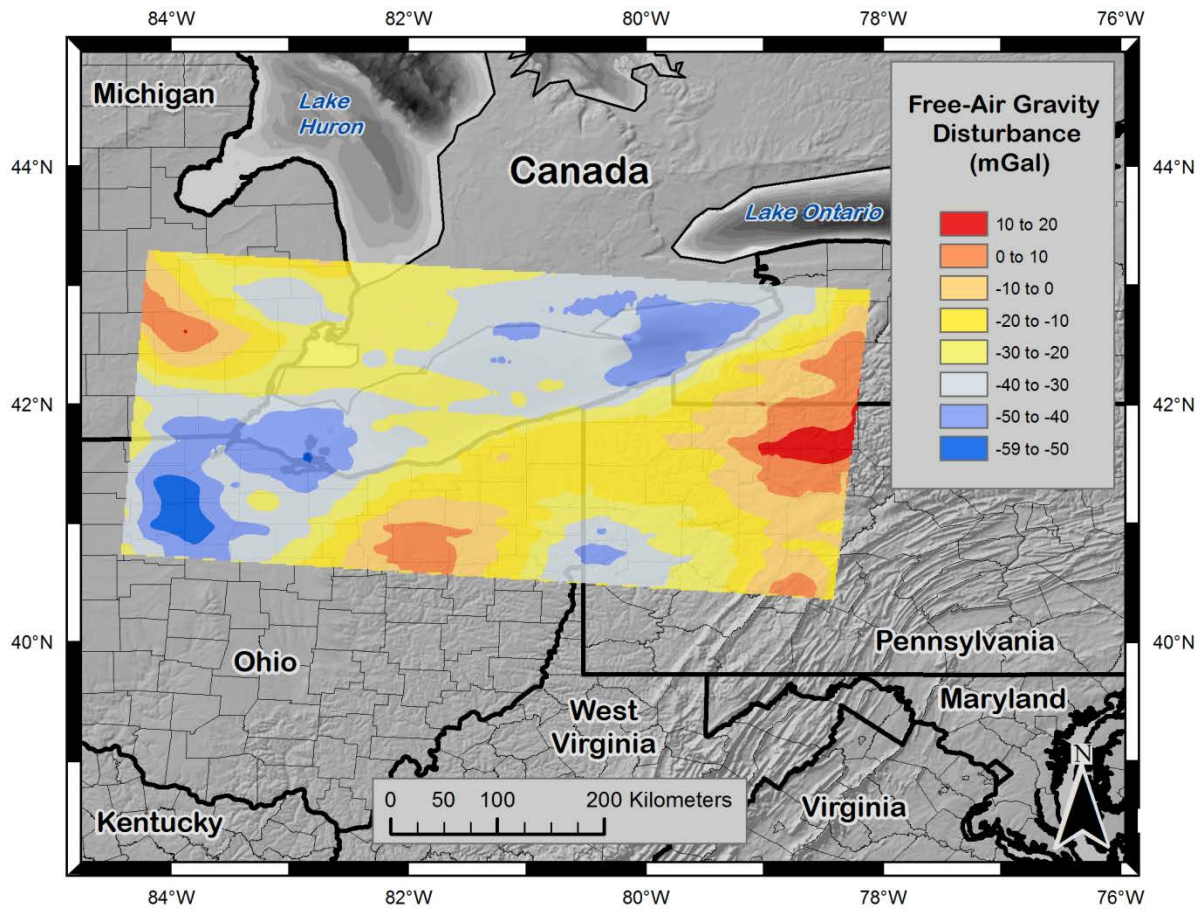


Figure 5: Free-air gravity disturbance for Block EN02 with respect to the WGS-84 ellipsoid.

## 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 EN02 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 EN02". Available *DATE*. Online at: [http://www.ngs.noaa.gov/GRAV-D/data\\_EN02.shtml](http://www.ngs.noaa.gov/GRAV-D/data_EN02.shtml)

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

GRAV-D Science Team (2013). "Block EN02 (Eastern South 02); GRAV-D Airborne Gravity Data User Manual." Monica Youngman and Carly Weil, ed. Version BETA. Available *DATE*. Online at: [http://www.ngs.noaa.gov/GRAV-D/data\\_EN02.shtml](http://www.ngs.noaa.gov/GRAV-D/data_EN02.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\\_products.shtml](http://www.ngs.noaa.gov/GRAV-D/data_products.shtml)

## 5. References

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