

Block EN07 (Eastern North 07)

GRAV-D Airborne Data Release User Manual

Applies to Data BETA Release, 9/2013

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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 **EN07** is located in the **E**astern Time Zone, in the **N**orth half (north of 40° latitude). This was the seventh (**07**) block of data completed in that region. Block EN07 is about 380 km by 460 km over coastal Maine, Quebec and New Brunswick, Canada. ([Figure 1](#)). The corner coordinates defining Block EN07 are listed in [Table 1](#).



Figure 1: Google Earth Image of the Location of Block EN07 (black rectangle).

Table 1: Latitude and Longitude Coordinates of Corner Points Defining Block EN07

Latitude (decimal degrees)	Longitude (decimal degrees)
43.972892941	-70.867697052
46.244082113	-65.737601599
49.147970032	-67.974335803
47.100298937	-73.287747779

2. Survey Design and Execution

Airborne gravity data in Block EN07 were collected during two surveys: ME12 (Maine 2012) and ME13 (Maine 2013). 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 EN07 all data lines are Northwest-Southeast and cross lines Southeast-Northwest. The block consists of 2 cross lines from ME12 and 49 data lines, 4 cross lines from ME13. 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. EN07101= block EN07’s line 101).

Table 2: Survey Overview

Conducting Organization	NOAA- National Geodetic Survey	
Survey Name	ME12	ME13
Airport Base of Operations	Bangor International (BGR) Bangor, ME FBO: Bangor Aviation Services	
Geographic Location	Maine, Canada	
Dates of Airborne Operations	Aug. 4 th , 2012	June 29 th – July 22 nd 2013

Table 3: Aircraft and Instrumentation

Aircraft	Hawker Beechcraft King Air (RC-12)
Engines, number and type	2, Turboprop
Gravity Instrumentation	Micro-g LaCoste (MGL) TAGS S-161 (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: 49 (ME13) Cross Lines: 2 (ME12) 4 (ME13) Repeat Lines: 2
Number of Crossovers	211

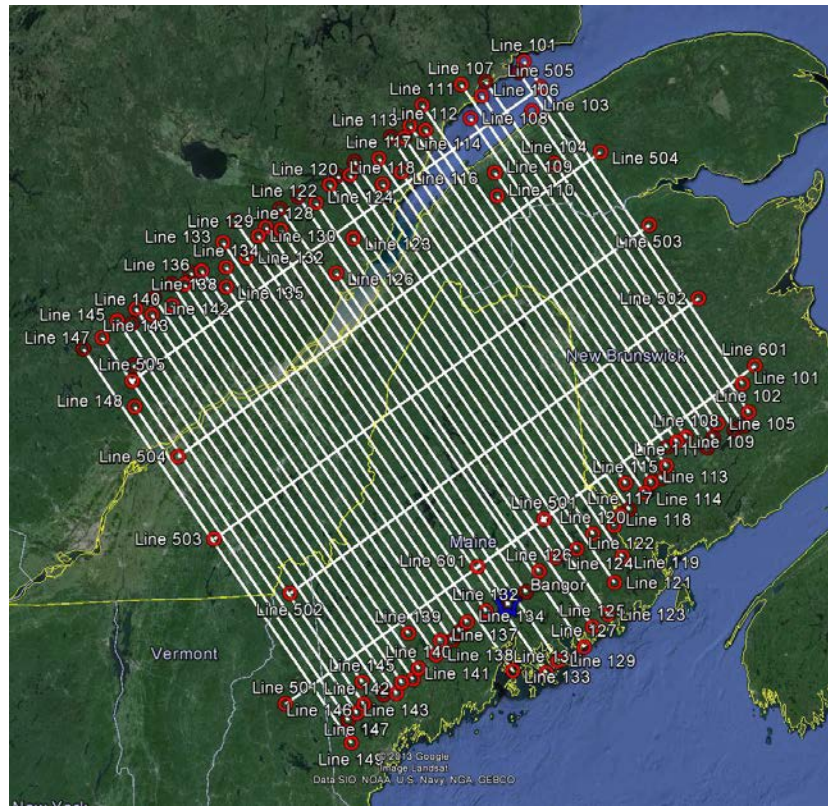


Figure 2: Data Coverage for EN07. Data lines start in the east at 101 and continue west to 149. Airport marked with a purple star.

2.1 GPS/IMU Instrumentation

The Hawker Beechcraft King Air (RC-12) had one GPS antennas 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 (ME12) or two (ME13) 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 of the King Air. 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 Hawker Beechcraft King Air (RC-12)

Instrument/Location	X (m)	Y (m)	Z (m)
Aircraft Center of Gravity	0.000	0.420	0.500
Aircraft GPS Antenna	-1.059	0.439	-1.122
NovAtel SPAN-SE IMU	0.027	0.001	0.500

Table 6: Lever Arm Measurements FROM the SPAN TO the GPS Antenna, for this Installation on the Hawker Beechcraft King Air (RC-12)

Instrument/Location	X (m)	Y (m)	Z (m)
GPS Antenna	-0.255	1.113	0.718

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) During 20,000 ft Data Collection

Airport	Type	Receiver	Flight Available	2013 Day of Year Available
BGR (ME12)	Kinematic	NovAtel (0008)	F19	217
		NovAtel (SPAN)	F19	217
	Static	Ashtech 5564	F19	217
		Ashtech East	F19	217
		Ashtech Mid	F19	217
BGR (ME13)	Kinematic	NovAtel (0008)	F01-F29	180-181,186-188,190-193,196-199,202-203
		NovAtel (SPAN)	F01-F29	180-181,186-188,190-193,196-199,202-203
	Static	Ashtech 3613	F01-F13,F15-F29	180-181,186-188,190-193,196-199,202-203
		Ashtech Hela	F01-F29	180-181,186-188,190-193,196-199,202-203

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 0.009 m and the average vertical position accuracy is 0.008 m.

3.1.2 Ground Gravity Tie

Updated absolute gravity measurements were performed by NGS with a Micro-g LaCoste A-10 gravimeter in spring of 2012. 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 Bangor, ME the location is designated as KBGR TAGS (44.8062719°N, -- 68.8127949°W) and it has an absolute gravity value of 980576.79747 ± 0.008 mGal.

3.1.3 Gravity Filtering

For block EN07, flights were accomplished in 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. 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 EN07, the result of the crossover analysis is shown in [Table 9](#) and in [Figure 3](#).

Table 8: Gravity Crossover Error Analysis for the EN07 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	6,571	211	2.27	2.27	-0.23	1.61

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.

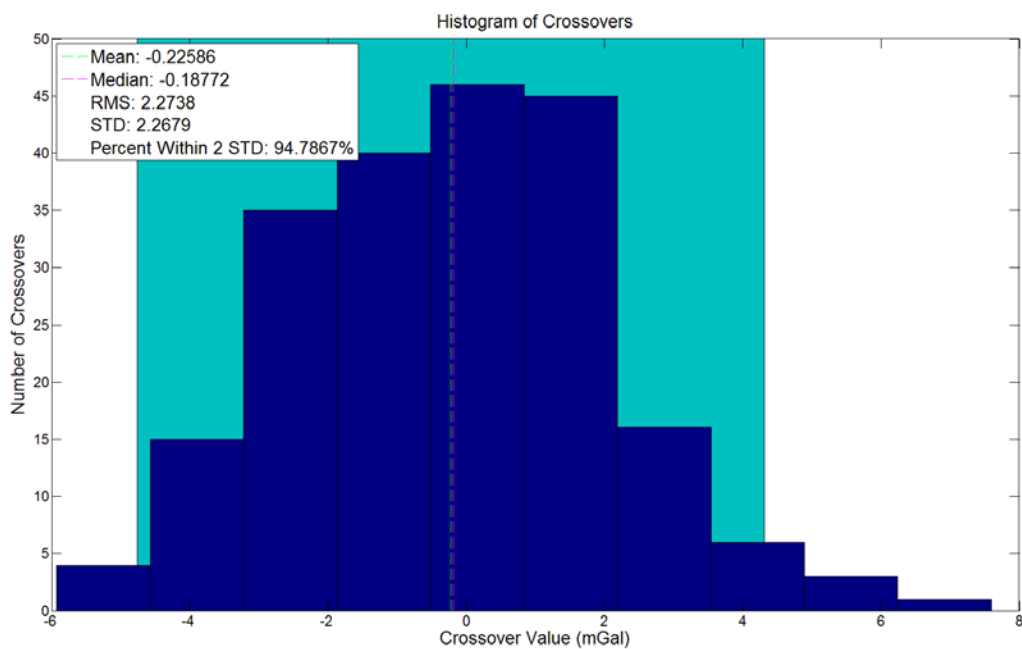
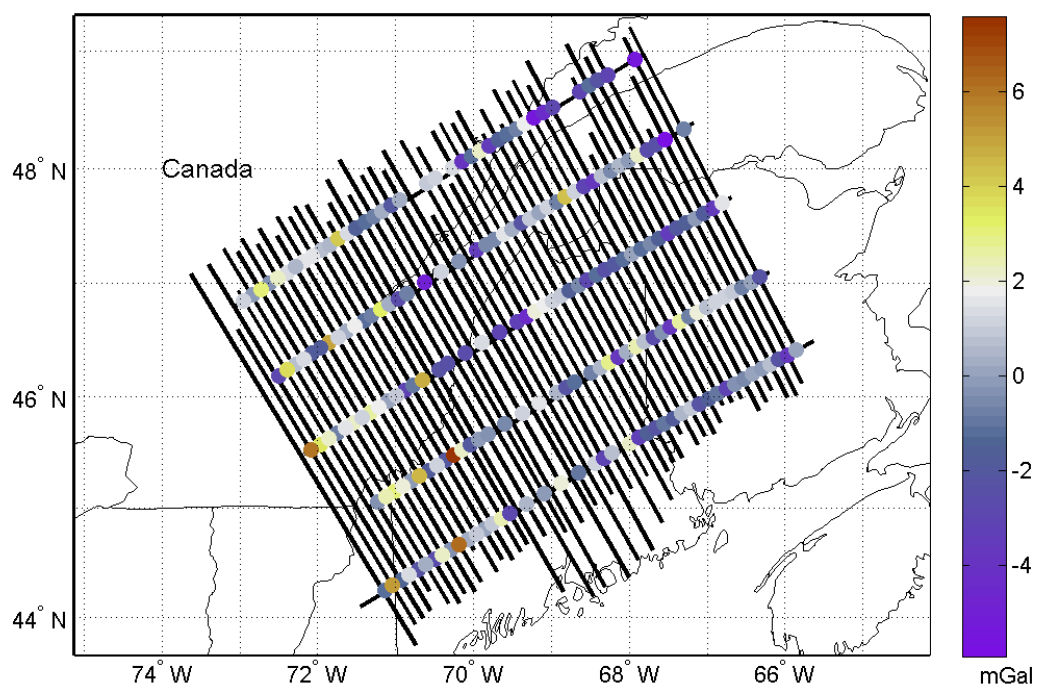


Figure 3: Crossover Residuals, Histogram, and Statistics for Block EN07. Color scale in mGals.

Table 9: Quality of Cross Lines Used in Crossover Analysis

Cross Line Number	Standard Deviation of Residuals Along Line (mGal)	Mean of Residuals Along Line (mGal)
501	2.33	0.42
601	1.73	-0.98
502	2.21	0.40
503	2.37	-0.35
504	2.32	-0.50
505	2.33	-0.32

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 10](#)). 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 10: Average Data Line Correlation

Number of Correlations	Average Data Line Correlation	Standard Deviation of Correlations
49	99.70%	0.22%

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.

3.3 Flight- and Line-Specific Details

3.3.1 GPS processing- by flight

GPS data were processed in Inertial Explorer (IE) 8.5. 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 11: GPS+IMU and GPS-only Kinematic Processing Results

Survey	Flight Num.	Rover GPS Unit	Solution Type	Elevation Mask (degrees)	Line Num.	NGS Quality Grade
ME12	19	SPAN	GPS+IMU	5	501	100.00
					601	100.00
ME13	1	SPAN	GPS+IMU	5	101	100.00
					102	100.00
	2	SPAN	GPS+IMU	7.5	502	100.00
	3	SPAN	GPS+IMU	7.5	503	100.00
	4	SPAN	GPS+IMU	5	103	100.00
					104	100.00
	5	SPAN	GPS+IMU	7.5	105	100.00
					106	83.34
	6	SPAN	GPS+IMU	5	107	100.00
					108	100.00
	7	SPAN	GPS+IMU	7.5	109	100.00
					110	100.00
	8	SPAN	GPS+IMU	5	505	100.00
	9	SPAN	GPS+IMU	7.5	504	100.00
	10	SPAN	GPS+IMU	7.5	111	100.00
					112	100.00
	11	SPAN	GPS+IMU	7.5	209*	100.00
					210*	100.00
	12	SPAN	GPS+IMU	5	113	100.00
					114	100.00
	13	SPAN	GPS+IMU	7.5	115	100.00
					116	100.00
	14	SPAN	GPS+IMU	5	117	100.00
					118	100.00
	15	SPAN	GPS+IMU	7.5	119	100.00
					120	100.00
	16	SPAN	GPS+IMU	7.5	121	100.00
					122	100.00
	17	SPAN	GPS+IMU	7.5	123	100.00
					124	100.00
	18	SPAN	GPS+IMU	7.5	125	100.00
					126	100.00
	19	SPAN	GPS+IMU	7.5	127	100.00
					128	100.00
	20	SPAN	GPS+IMU	7.5	129	100.00

					130	100.00
	21	SPAN	GPS+IMU	5	148	100.00
					149	100.00
	22	SPAN	GPS+IMU	5	131	100.00
					132	100.00
	23	SPAN	GPS+IMU	5	133	100.00
					134	100.00
	24	SPAN	GPS+IMU	5	146	100.00
					147	100.00
	25	SPAN	GPS+IMU	7.5	144	100.00
					145	100.00
	26	SPAN	GPS+IMU	5	142	100.00
					143	100.00
	27	SPAN	GPS+IMU	5	140	100.00
					141	100.00
	28	SPAN	GPS+IMU	7.5	138	100.00
					139	100.00
	29	SPAN	GPS+IMU	7.5	135	100.00
					136	100.00
					137	100.00

**Lines 209 and 210 were originally flown during Flight 07 and reflight for quality evaluation purposes.*

Table 12: Gravity Processing Results

Survey	Flight Num.	Line Num.	Times of Deleted Data Sections (s)	Comments
ME12	19	501		
		601		
ME13	1	101	53590-53840	Spike Removed
		102	57627-57982	Spike Removed
	2	502		
	3	503		
	4	103		
		104		
	5	105		
		106		
	6	107	45986-46338	Spike Removed
		108		
	7	109		
		110		
	8	505		
	9	504		
	10	111		
		112		
	11	209		
		210		
	12	113		

		114		
	13	115	90413-90710	Spike Removed
		116		
	14	117		
		118		
	15	119		
		120		
	16	121		
		122		
	17	123		
		124		
	18	125		
		126		
	19	127		
		128		
	20	129		
		130		
	21	148		
		149		
	22	131		
		132		
	23	133		
		134	66010-66389	Spike Removed
	24	146		
		147		
	25	144		
		145		
	26	142		
		143		
	27	140		
		141		
	28	138		
		139		
	29	135		
		136		
		137		

Table 13: Bias from EGM08 by Line

Survey	Flight Num.	Line Num.	Bias From EGM08
ME12	19	501	-0.44
		601	-1.47
ME13	1	101	0.55
		102	-0.02
	2	502	-1.64
	3	503	-1.11
	4	103	-0.08
		104	-1.72

	5	105	-0.18
		106	-2.17
	6	107	-0.23
		108	-1.25
	7	109	-0.22
		110	-1.21
	8	505	-2.26
	9	504	-1.66
	10	111	-0.02
		112	-0.50
	11	209	-0.61
		210	-1.74
	12	113	-0.81
		114	-2.16
	13	115	-1.59
		116	-2.98
	14	117	-0.83
		118	-1.72
	15	119	-1.17
		120	-2.17
	16	121	-0.82
		122	-1.86
	17	123	-0.35
		124	-1.43
	18	125	-0.65
		126	-2.03
	19	127	-1.13
		128	-2.91
	20	129	0.83
		130	-1.46
	21	148	-1.91
		149	-0.66
	22	131	-1.03
		132	-1.25
	23	133	0.34
		134	-1.36
	24	146	-1.70
		147	-0.51
	25	144	-1.28
		145	-0.46
	26	142	-2.23
		143	-0.33
	27	140	-3.87
		141	-1.66
	28	138	-1.46
		139	-0.35
	29	135	-3.09
		136	-1.30
		137	-0.08

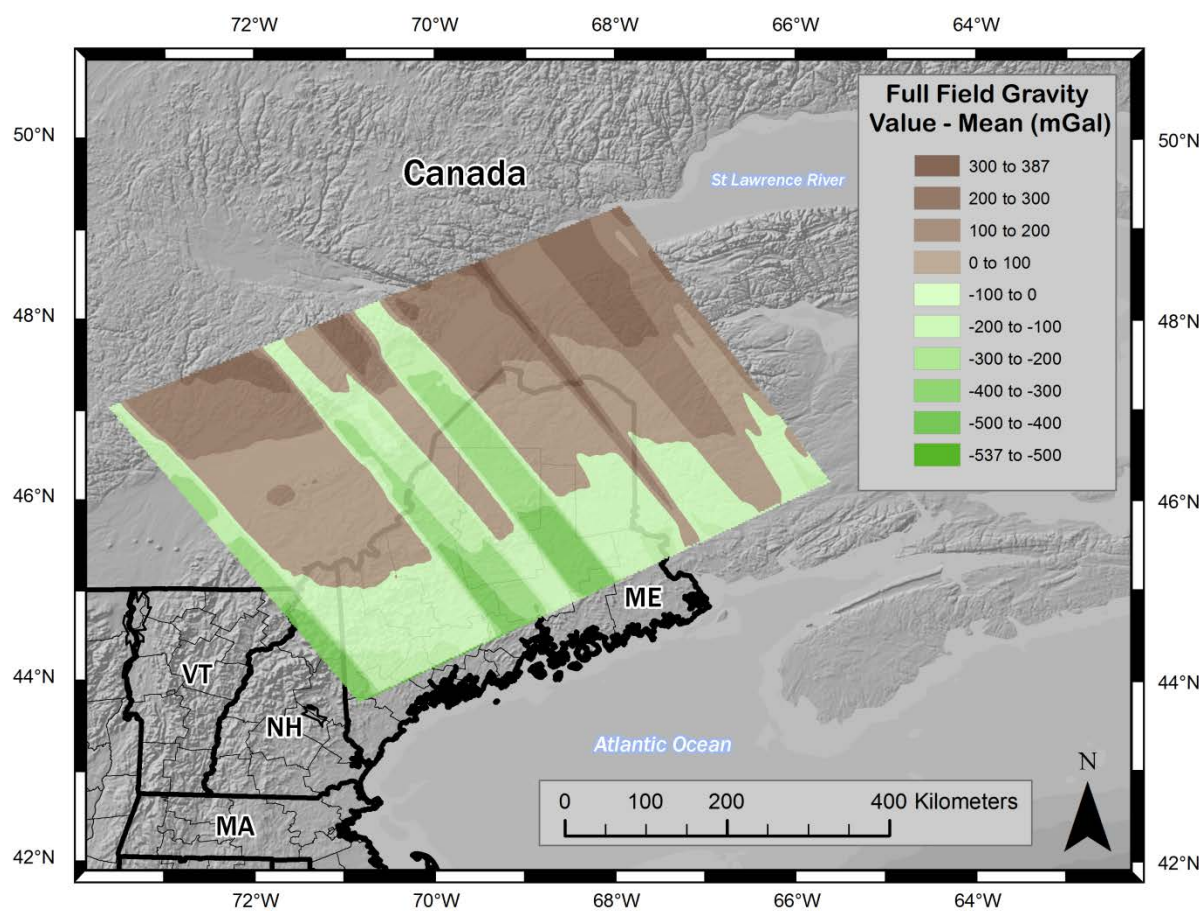


Figure 4: Full-field gravity at altitude (mean removed) for Block EN07. This is the data in the gravity release “.txt” file and includes the effects of differing altitudes along flight lines.

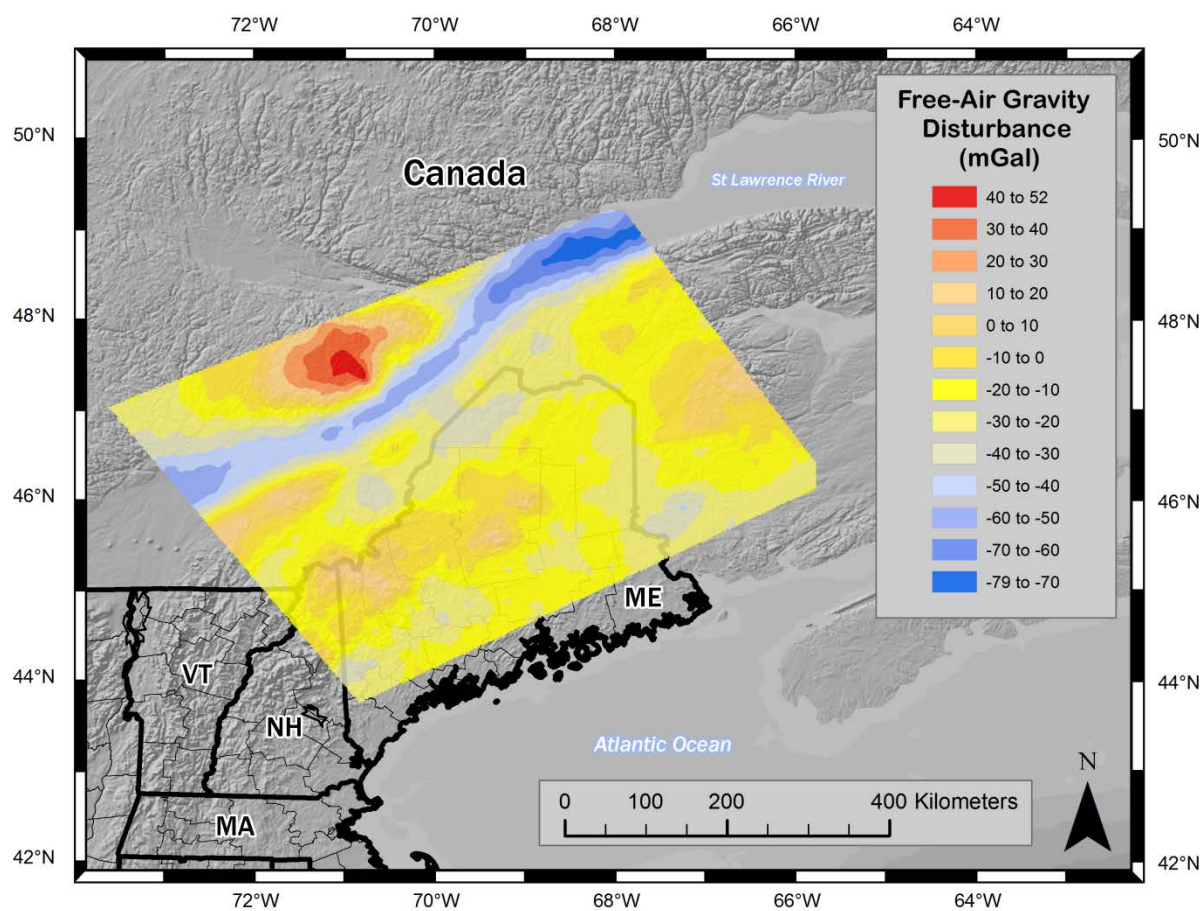


Figure 5: Free-air gravity disturbance for Block EN07 with respect to the WGS-84 ellipsoid.

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 EN07 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 EN07". Available *DATE*. Online at: http://www.ngs.noaa.gov/GRAV-D/data_EN07.shtml

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

GRAV-D Science Team (2013). "Block EN07 (Eastern North 07); GRAV-D Airborne Gravity Data User Manual." Monica Youngman and Carly Weil. Version BETA. Available *DATE*. Online at: http://www.ngs.noaa.gov/GRAV-D/data_EN07.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, ed. Version 2. Available *DATE*. Online at: http://www.ngs.noaa.gov/GRAV-D/data_EN07.shtml

5. References

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