

# Block EN09 (Eastern North 09)

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*GRAV-D Airborne Data Release User Manual*

*Applies to Data BETA #2 Release, 2/2016*

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## Version Notes

**2/2016 BETA #2:** GPS processing method updated. Data in the first BETA release (8/2013) were processed using differential positioning. Data in this version (BETA #2) were reprocessed using Precise Point Positioning.

## 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 **EN09** is located in the **E**astern Time Zone, in the **N**orth half (north of 40° latitude). This was the ninth (**09**) block of data completed in that region. Block EN09 is about 400 km by 300 km over the northeastern coast, including Massachusetts, Connecticut, Rhode Island, New Hampshire, and New York ([Figure 1](#)). The corner coordinates defining Block EN09 are listed in [Table 1](#).



Figure 1: Google Earth Image of the Location of Block EN09 (black rectangle).

Table 1: Latitude and Longitude Coordinates of Corner Points Defining Block EN09

Latitude (decimal degrees)	Longitude (decimal degrees)
38.617812742	-71.9982632910
39.968305946	-69.0026264082
43.364653590	-70.5738985968
42.030381264	-73.7250441267

## 2. Survey Design and Execution

Airborne gravity data in Block EN09 were collected during one survey: NH12 (New Hampshire 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 EN09 all data lines are Northwest-Southeast and cross lines Southeast-Northwest. The block consists of 30 data lines, 6 cross lines. 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. EN09101= block EN09’s line 101).

*Table 2: Survey Overview*

Conducting Organization	NOAA- National Geodetic Survey
Survey Name	NH12
Airport Base of Operations	Portsmouth International (PSM) Portsmouth, NH FBO: Port City Air
Geographic Location	Massachusetts, Rhode Island, Connecticut, New Hampshire, New York
Dates of Airborne Operations	Aug. 17 <sup>th</sup> – Sept. 14 <sup>th</sup> 2012

*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-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: ~40 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: 30 (NH12) Cross Lines: 6 (NH12) Repeat Lines: 4 (123 & 223, 124 & 224, 126 & 226, 101 & 301)
Number of Crossovers	106

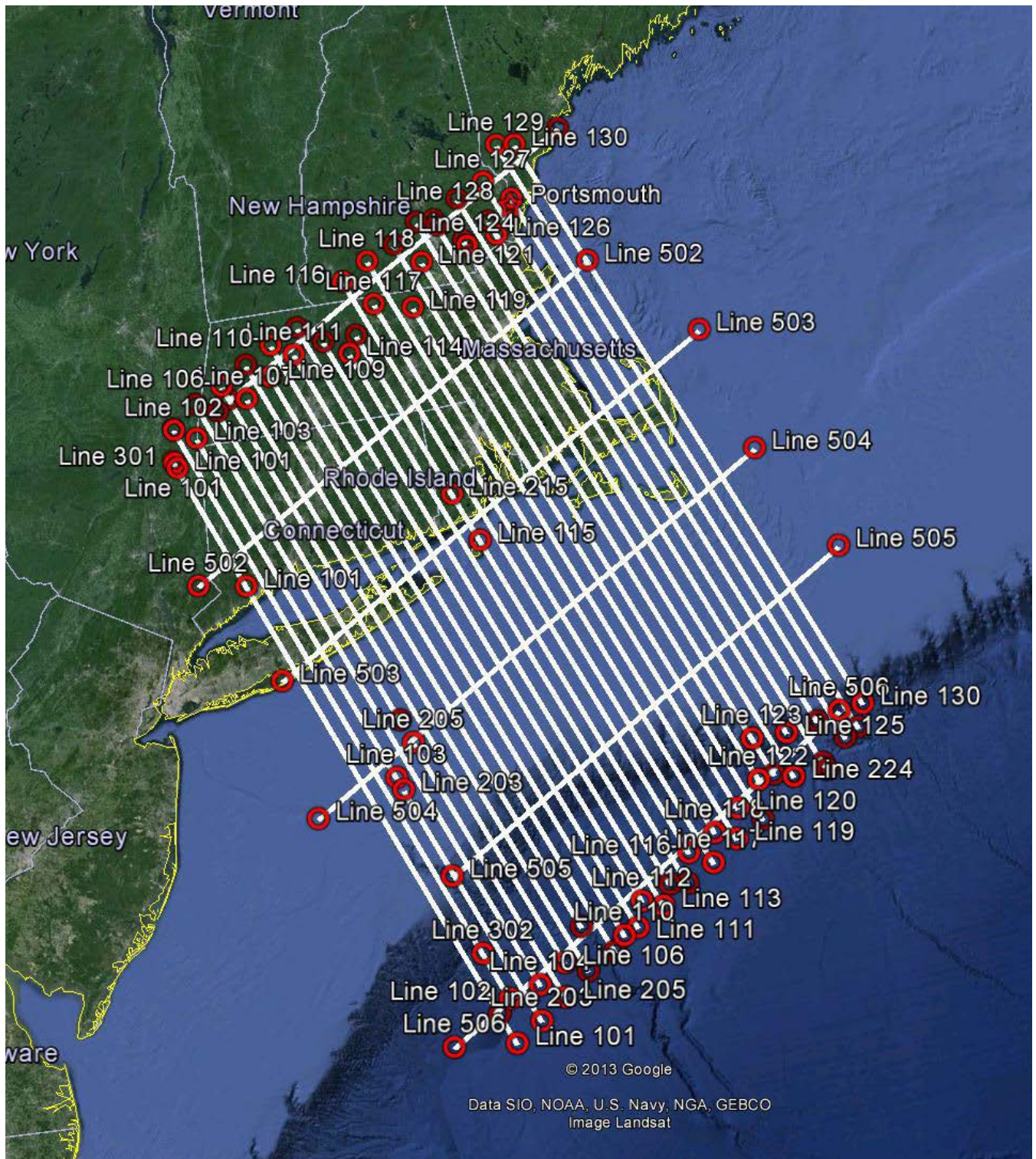


Figure 2: Data Coverage for EN9. Data lines start in the west at 101 and continue east to 130. Airports marked with red star.

## 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  $\mu$ 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 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	2012 Day of Year Available
PSM	Kinematic	NovAtel (0008)	F04,F06-F14,F16-F21,F23-F26	235-237,239-240,242-243,247,252,256-258
		NovAtel (SPAN)	F04,F06-F14,F16-F21,F23-F26	235-237,239-240,242-243,247,252,256-258
	Static	Ashtech North	F04,F06-F14,F16-F21,F23-F26	235-237,239-240,242-243,247,252,256-258
		Ashtech South	F04,F06-F14,F16-F21,F23-F26	235-237,239-240,242-243,247,252,256-258
		Ashtech West	F04,F06-F14,F16-F21,F23-F26	235-237,239-240,242-243,247,252,256-258

Table 8: NGS GPS Base Station Position(s)

Airport	Base Name	Antenna Type	Latitude (dec deg)	Longitude (dec deg)	Ellipsoidal Height (m)
PSM	Ashtech North	ASH701975.01A	43.06903591	-70.80691114	-7.161
	Ashtech South	ASH701975.01A	43.06880461	-70.80672287	-7.013
	Ashtech West	ASH701975.01A	43.06886426	-70.80762713	-7.107

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 0.007 m and the average vertical position accuracy is 0.009 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 Portsmouth, NH the location is designated as KPSM TAGS (43.0712306694°N , -70.8092318917°W) and it has an absolute gravity value of 980450.00321 ± 0.0077 mGal.

#### 3.1.3 Gravity Filtering

For block EN09, 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. 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 EN09, the result of the crossover analysis is shown in [Table 9](#) and in [Figure 3](#).

*Table 9: Gravity Crossover Error Analysis for the EN09 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	6,412	186	1.81	1.80	0.25	1.28

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.

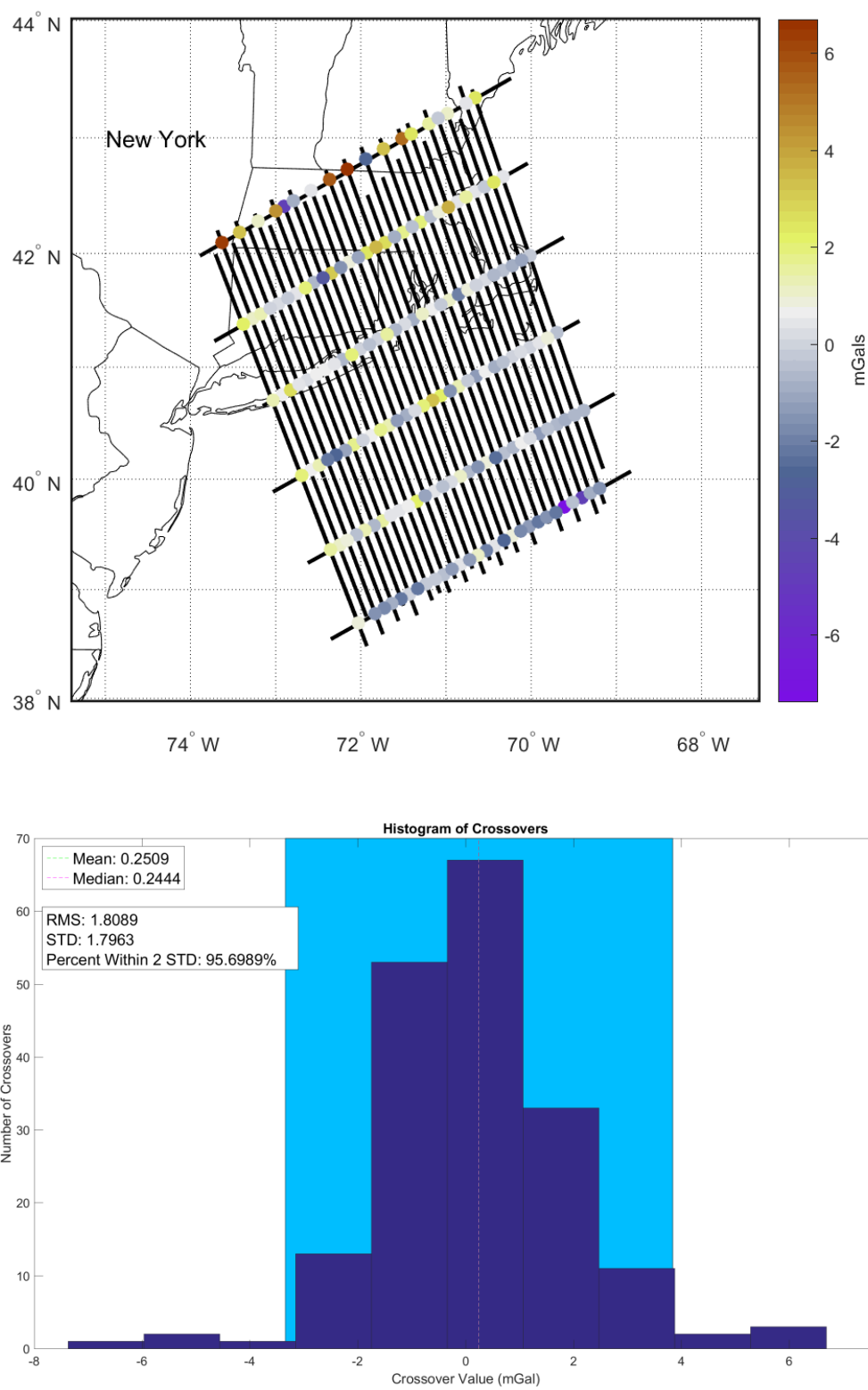


Figure 3: Crossover Residuals, Histogram, and Statistics for Block EN09. Color scale in mGals.

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)
501	2.99	2.06
502	1.56	0.81
503	0.97	0.26
504	1.37	0.27
505	1.03	-0.01
506	1.69	-1.27

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
30	99.86%	0.20%

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 12: 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
NH12	04	South	SPAN	GPS+IMU	7.5	130	100.00
	06	South	SPAN	GPS+IMU	7.5	501	100.00
						502	100.00
	07	South	SPAN	GPS+IMU	5	127	100.00
						128	100.00
	08	North	SPAN	GPS+IMU	7.5	125	100.00
						126	100.00
	09	North	SPAN	GPS only	7.5	123	100.00
						124	100.00
	10	South	SPAN	GPS+IMU	7.5	121	100.00
						122	100.00
	11	West	SPAN	GPS+IMU	7.5	119	100.00
						120	100.00
	12	West	SPAN	GPS+IMU	5	117	100.00
						118	100.00
	13	West	SPAN	GPS+IMU	7.5	115	100.00
						116	100.00
	14	South	SPAN	GPS+IMU	5	113	100.00
						114	100.00
	16	West	SPAN	GPS+IMU	5	223*	100.00
						224*	100.00
	17	West	SPAN	GPS+IMU	7.5	111	100.00
						112	100.00
	18	South	SPAN	GPS+IMU	7.5	503	100.00
						504	100.00
	19	North	SPAN	GPS+IMU	7.5	129	100.00
						226*	100.00
	20	West	SPAN	GPS+IMU	5	109	100.00
						110	100.00
	21	West	DLV3	GPS only	5	101	97.74
						102	100.00
	22	West	SPAN	GPS+IMU	5	505	100.00
						506	100.00
	23	North	SPAN	GPS+IMU	7.5	107	100.00
						108	100.00
	24	South	SPAN	GPS+IMU	5	105	100.00
						106	100.00
	25	West	SPAN	GPS+IMU	7.5	103	100.00
						104	100.00
	26	North	SPAN	GPS+IMU	5	301*	100.00

\*Lines 223,224, 226, and 301 were originally flown during Flight 09, 08 and 21 respectively and repeated due to lack of IMU data. Since both lines are of good quality, they have all been released and are available for comparison. Only the original lines were used in the crossovers.

Table 13: Gravity Processing Results

Survey	Flight Num.	Line Num.	Times of Deleted Data Section(s)	Comments
NH12	04	130	None	
	06	501	None	
		502	None	
	07	127	None	
		128	None	
	08	125	None	
		126	None	
	09	123	None	
		124	None	
	10	121	None	
		122	None	
	11	119	None	
		120	None	
	12	117	None	
		118	None	
	13	115	None	
		116	None	
	14	113	None	
		114	None	
	16	223	None	
		224	None	
	17	111	None	
		112	None	
	18	503	None	
		504	None	
	19	129	None	
		226	None	
	20	109	None	
		110	None	
	21	101	None	
		102	None	
	22	505	None	
		506	None	
	23	107	None	
		108	None	
	24	105	None	
		106	None	
	25	103	None	
		104	None	
	26	301	None	

Table 14: Bias from EGM08 by Line

Survey	Flight Num.	Line Num.	Bias from EGM08
NH12	04	130	0.23
	06	501	2.15
		502	0.57
	07	127	0.04
		128	-0.10
	08	125	0.49
		126	-0.08
	09	123	-0.40
		124	-0.06
	10	121	-0.69
		122	0.44
	11	119	-1.32
		120	0.62
	12	117	-0.78
		118	1.11
	13	115	-1.15
		116	-2.29
	14	113	-0.24
		114	-0.68
	16	223	-0.43
		224	-0.31
	17	111	-0.92
		112	1.14
	18	503	-0.31
		504	0.74
	19	129	0.50
		226	-0.57
	20	109	0.13
		110	0.37
	21	101	-0.29
		102	-0.46
	22	505	-0.28
		506	0.58
	23	107	-1.26
		108	-0.25
	24	105	-0.11
		106	0.38
	25	103	-0.66
		104	0.31
	26	301	-0.73

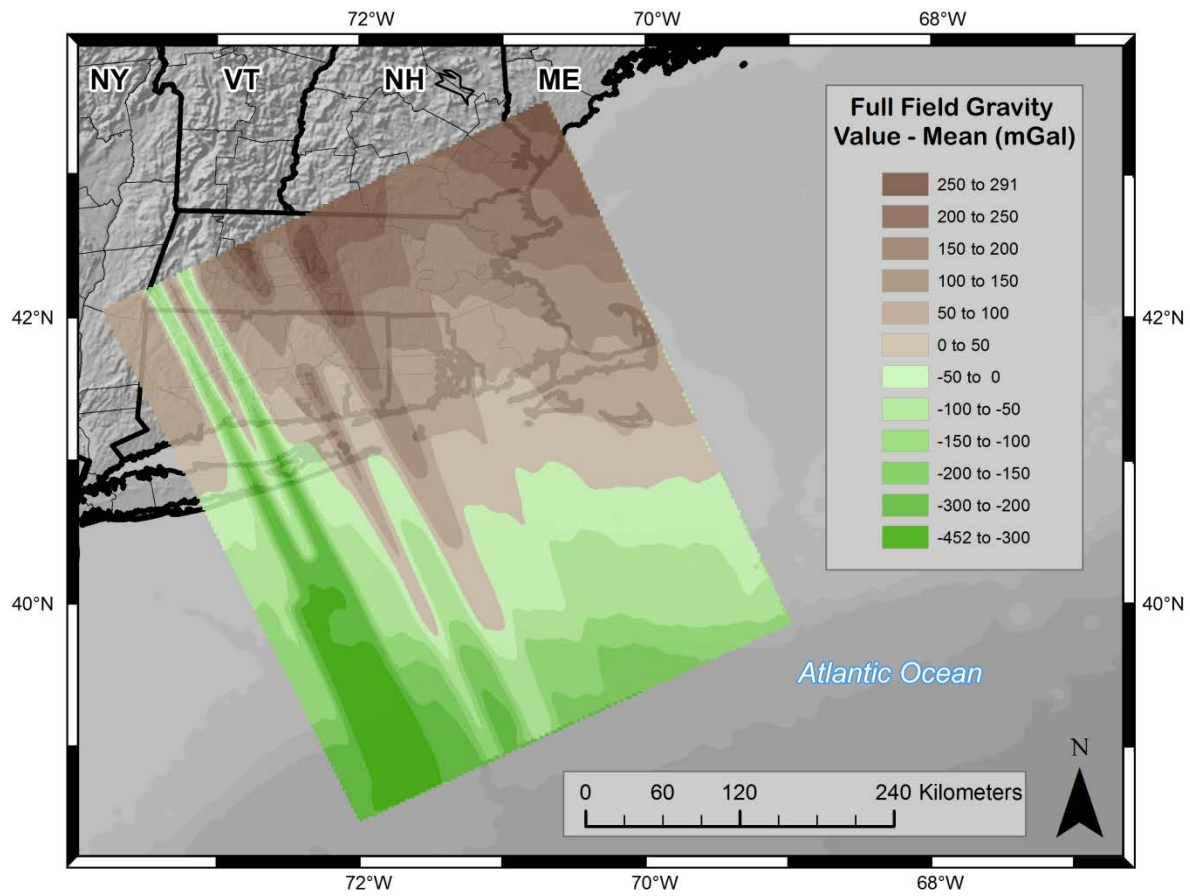


Figure 4: Full-field gravity at altitude (mean removed) for Block EN09. This is the data in the gravity release “.txt” file and includes the effects of differing altitudes along flight lines.

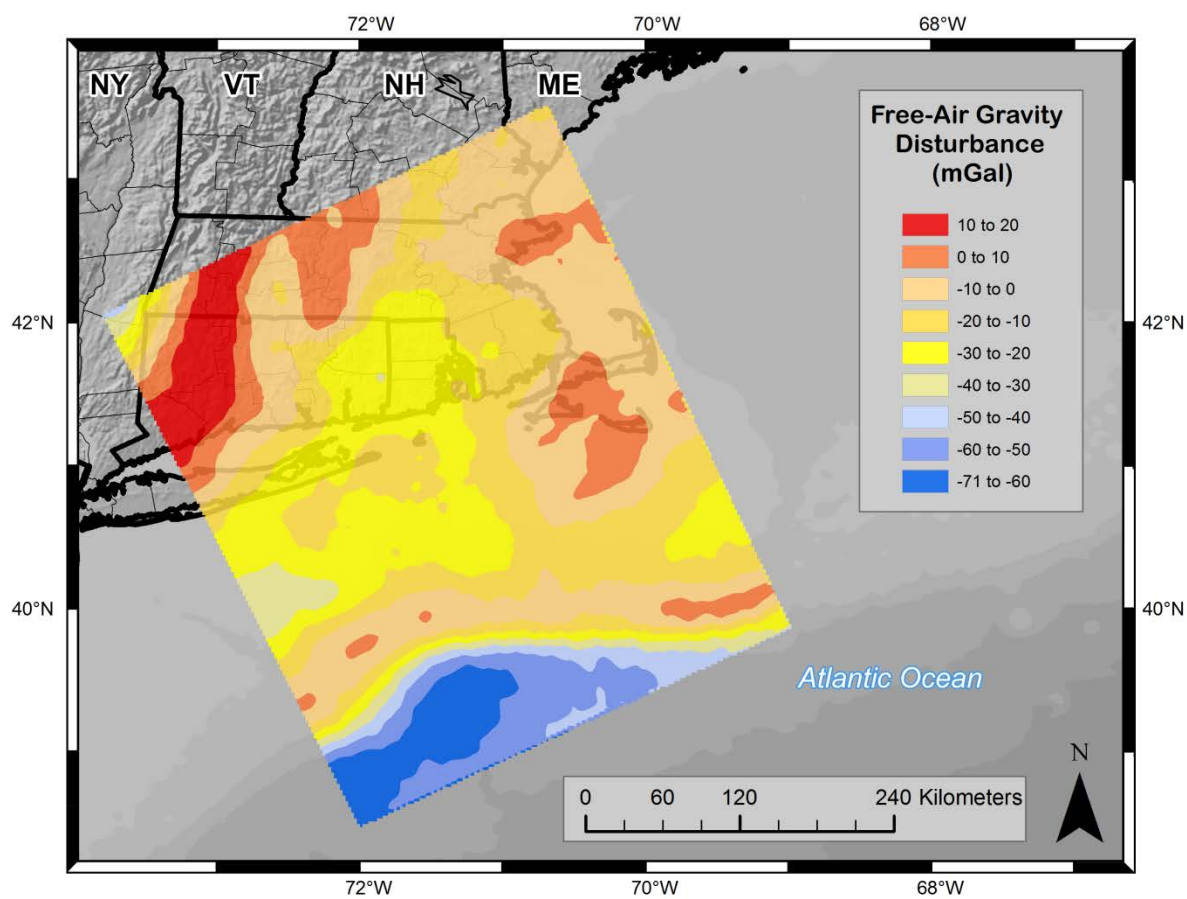


Figure 5: Free-air gravity disturbance for Block EN09 with respect to the WGS-84 ellipsoid.

## 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 EN09 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 EN09". Available *DATE*. Online at: [http://www.ngs.noaa.gov/GRAV-D/data\\_EN09.shtml](http://www.ngs.noaa.gov/GRAV-D/data_EN09.shtml)

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

GRAV-D Science Team (2013). "Block EN09 (Eastern North 09); 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\\_EN09.shtml](http://www.ngs.noaa.gov/GRAV-D/data_EN09.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\\_EN09.shtml](http://www.ngs.noaa.gov/GRAV-D/data_EN09.shtml)

## 5. References

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