Block ES03 (Eastern South 03)

GRAV-D Airborne Data Release User Manual

Applies to Data BETA Release, 5/2014

Edited by Monica A. Youngman and Carly A. Weil

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."

Contents

Figure List

Table List

1. Block Description

GRAV-D Block **ES03** is located in the **E**astern Time Zone, in the **S**outh half (south of 40° latitude). This was the third (**03**) block of data completed in that region. Block ES03 is about 550 km by 340 km over the east coast, including Pennsylvania, Maryland, Virginia, West Virginia, Delaware, and New Jersey (Figure 1). The corner coordinates defining Block ES03 are listed in Table 1.

Figure 1: Google Earth Image of the Location of Block ES03 (black rectangle).

Table 1: Latitude and Longitude Coordinates of Corner Points Defining Block ES03

Latitude (decimal degrees)	Longitude (decimal degrees)
40.484230778	-79.202797604
37.319592644	-79.535720028
36.815873125	-74.069381115
38.140246993	-73.071045298
38.969038539	-72.115344082
39.685536495	-71.991414484

2. Survey Design and Execution

Airborne gravity data in Block ES03 were collected during one survey: MD13 (Maryland 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 ES03 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. ES03101= block ES03's line 101).

Table 2: Survey Overview

Conducting Organization	NOAA- National Geodetic Survey
Survey Name	MD13
Airport Base of Operations	Hagerstown Regional Airport (KHGR) Hagerstown, MD FBO: Fugro EarthData
Geographic Location	Mid-Atlantic
Dates of Airborne Operations	October 4th-November 14th 2013

Table 3: Aircraft and Instrumentation

Aircraft	Cessna 441 Conquest II
Engines, number and type	2, Turboprop
Gravity Instrumentation	Micro-g LaCoste (MGL) TAGS S-160 (relative) MGL A-10 25 (absolute) MGL D-43, 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	17,500-20,000 ft
Nominal Aircraft Ground Speed	250 knots
Number of Lines Released	Data Lines: 40 Cross Lines: 8 Repeat Lines: 0
Number of Crossovers	258

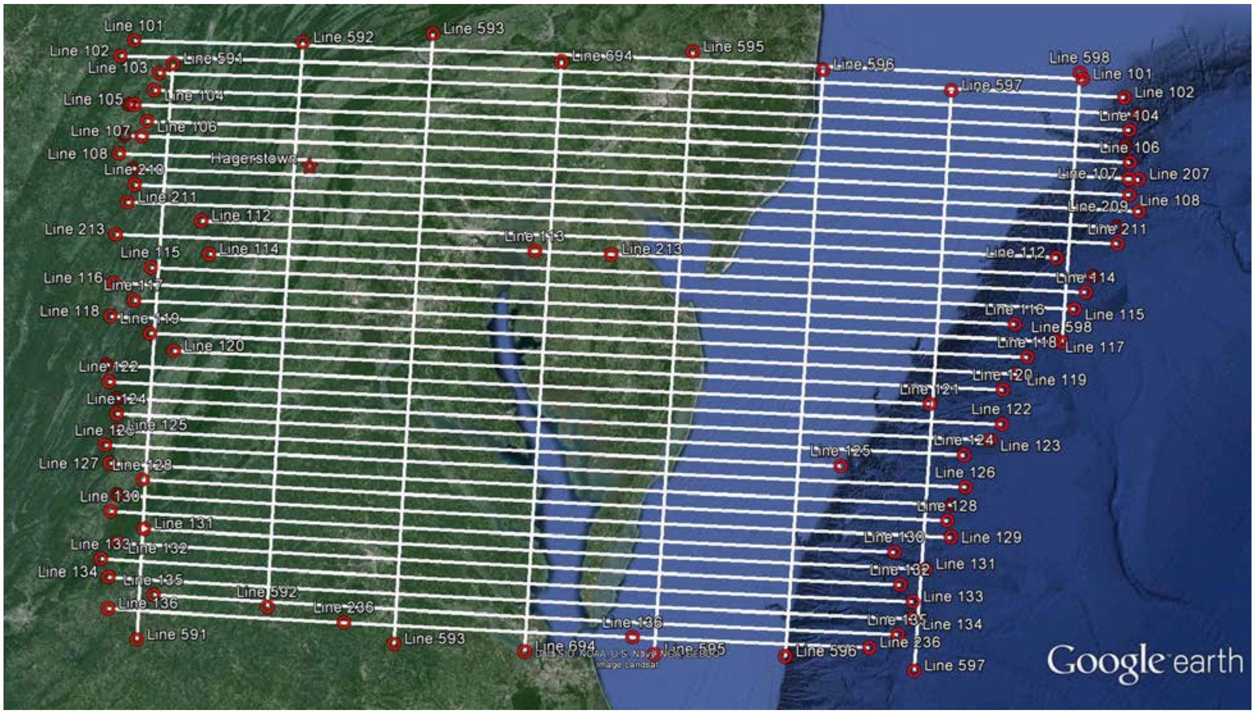


Figure 2: Data Coverage for ES03. Data lines start in the north at 101 and continue south to 136. Airports marked with red star.

2.1 GPS/IMU Instrumentation

The Cessna 441 Conquest II 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 µIMU 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, two 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

Instrument/Location	X (m)	Y (m)	Z (m)
NovAtel SPAN-SE IMU	-0.017	0.019	-0.433

Table 6: Lever Arm Measurements FROM the SPAN TO the GPS Antenna

Instrument/Location	X (m)	Y (m)	Z (m)
GPS Antenna	0.025	-0.75	0.481

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	2012 Day of Year Available
PSM	Kinematic	NovAtel (0002)	F01-F12, F18-F19, F27, F33-F36, F39, F40, F44, F46, F50-F51	277-281, 287, 293, 299-300, 302, 308, 318
		NovAtel (SPAN)	F01-F12, F18-F19, F27, F33-F36, F39, F40, F44, F46, F50-F51	277-281, 287, 293, 299-300, 302, 308, 318
	Static	Ashtech 3552	F01-F12, F18-F19, F27, F33-F36, F39, F40, F44, F46, F50-F51	277-281, 287, 293, 299-300, 302, 308, 318
		Ashtech Noth	F03, F08-F12, F18-F19, F27, F33-F36, F39, F40, F44, F46, F50-F51	277-281, 287, 293, 299-300, 302, 308, 318

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 0.012 m and the average vertical position accuracy is 0.010 m.

3.1.2 Ground Gravity Tie

Absolute gravity measurements were performed by NGS with a Micro-g LaCoste A-10 gravimeter in July 2013. At both airports the A-10 was set up at the exact location of the aircraft. The positions were determed from the GPS collected during the gravity survey while the plane was parked. In Hagerstown, MD the location is designated as KHGR TAGS (39.710960950°N , 77.735509875°W) and it has an absolute gravity value of 980032.9731 ± 0.0078 mGal at 146.6 cm above the tarmac.

3.1.3 Gravity Filtering

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

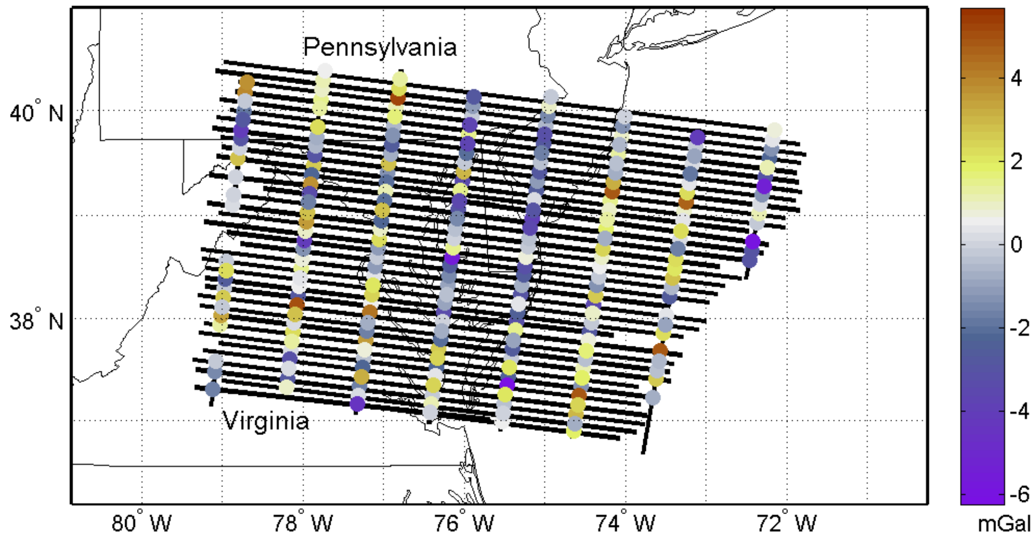
3.2.1 Gravity Error Analysis

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 ES03, the result of the crossover analysis is shown in Table 8 and in Figure 3.

Table 8: Gravity Crossover Error Analysis

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)
17,500	5,334	5,523	258	2.20	2.20	-0.13	1.56

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.



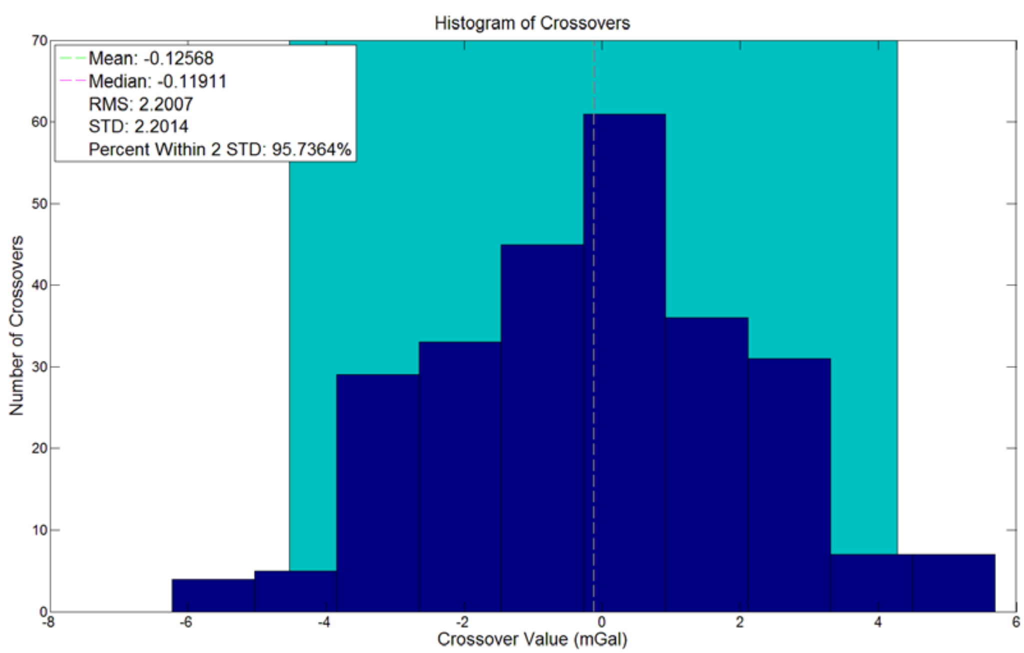


Figure 3: Crossover Residuals, Histogram, and Statistics for Block ES03. Color scale in mGals.

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)
591	2.18	-0.01
592	2.20	0.41
593	2.11	0.37
694	2.04	-0.88
595	1.85	-1.36
596	1.82	0.74
597	2.04	0.56
598	2.81	-1.14

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
33	97.30%	2.28%

A fourth way of gauging data quality is by calculating the repeatability of the gravity signal along reflown 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
MD13	01	SPAN	GPS+IMU	7.5	136	100.00
					593	73.73
	02	SPAN	GPS+IMU	7.5	135	100.00
					236	100.00
					591	100.00
					592	100.00
	03	SPAN	GPS+IMU	7.5	127	83.35
					128	100.00
	04	SPAN	GPS+IMU	7.5	133	100.00
					134	100.00
	05	SPAN	GPS+IMU	5	132	100.00
	06	SPAN	GPS+IMU	5	123	100.00
					124	98.61
	07	SPAN	GPS+IMU	7.5	115	100.00
					116	100.00
	08	SPAN	GPS+IMU	5	130	100.00
					131	100.00
	09	SPAN	GPS+IMU	7.5	126	100.00
					129	100.00
	10	SPAN	GPS+IMU	5	117	99.36
					118	100.00
	11	SPAN	GPS+IMU	5	119	100.00
					120	100.00
	12	SPAN	GPS+IMU	7.5	101	100.00
					125	76.37
					598	100.00
	18	SPAN	GPS+IMU	5	102	100.00
					103	100.00
	19	SPAN	GPS only	5	121	100.00
					122	92.41
	27	SPAN	GPS+IMU	5	595	100.00
					694	85.14

	33	SPAN	GPS only	12	107	99.81
					108	100.00
	34	SPAN	GPS+IMU	7.5	105	100.00
					106	100.00
	35	SPAN	GPS+IMU	7.5	596	100.00
					597	88.26
	36	SPAN	GPS+IMU	7.5	113	100.00
					114	100.00
	39	SPAN	GPS+IMU	5	104	100.00
	40	SPAN	GPS+IMU	7.5	213	100.00
	44	SPAN	GPS+IMU	7.5	205	100.00
					207	76.05
	46	SPAN	GPS+IMU	7.5	112	100.00
	50	SPAN	GPS+IMU	9	209	100.00
					210	100.00
	51	SPAN	GPS+IMU	15	211	76.95

Table 12: Gravity Processing Results

Survey	Flight Num.	Line Num.	Times of Deleted Data Section(s)	Comments
MD13	14	101		
		102		
		103		
		591		
		592		
	15	104		
		105		
		593		
	16	106		
		107		
		108		
		694		
	17	115		
		116		
	20	109		
		110		
	22	113		
		114		
	23	122		
		123		
	24	124		
		125	131667-132009	Spike Removed
	25	117		
		118		
	26	126		
		127		
	29	120		
	37	128		
		221		
	38	230		
		231		
	39	233		
	41	228		
		595		
		596		
		697		
	47	129		
	48	211		
		212		
	49	219		
		229		

Table 13: Bias from EGM08 by Line

Survey	Flight Num.	Line Num.	Bias from EGM08
MD13	14	101	-0.99
		102	1.48
		103	-0.03
		591	1.06
		592	0.54
	15	104	1.87
		105	4.32
		593	2.74
	16	106	-0.96
		107	1.60
		108	-0.54
		694	0.40
	17	115	-1.29
		116	0.68
	20	109	-0.50
		110	1.40
	22	113	1.88
		114	0.51
	23	122	0.03
		123	4.55
	24	124	0.53
		125	0.93
	25	117	1.44
		118	0.02
	26	126	1.28
		127	2.10
	29	120	2.98
	37	128	0.96
		221	-0.18
	38	230	0.44
		231	0.23
	39	233	0.55
	41	228	-0.01
		595	-0.37
		596	-0.54
		697	0.74
	47	129	0.49
	48	211	0.71
		212	1.90
	49	219	2.82
		229	0.49

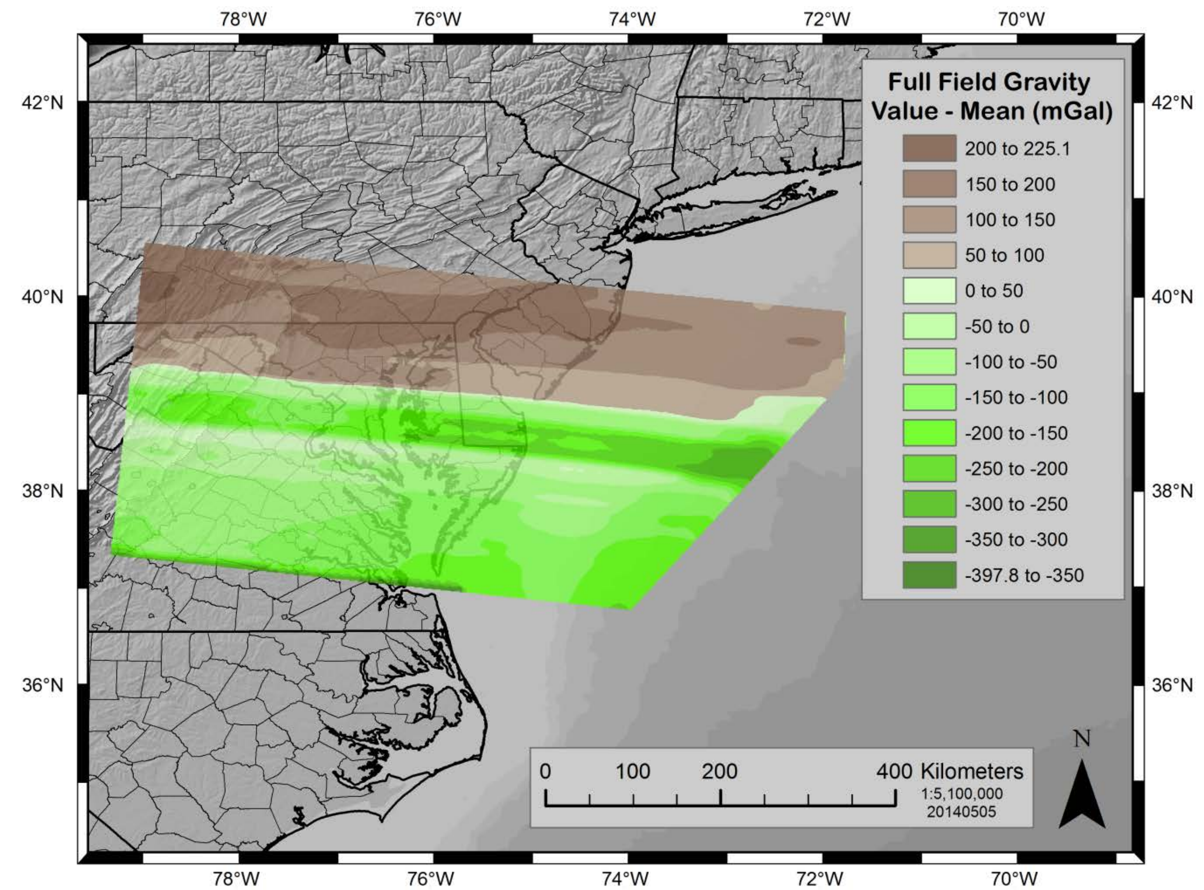


Figure 4: Full-field gravity at altitude (mean removed) for Block ES03. This is the data in the gravity release ".txt" file and includes the effects of differing altitudes along flight lines.

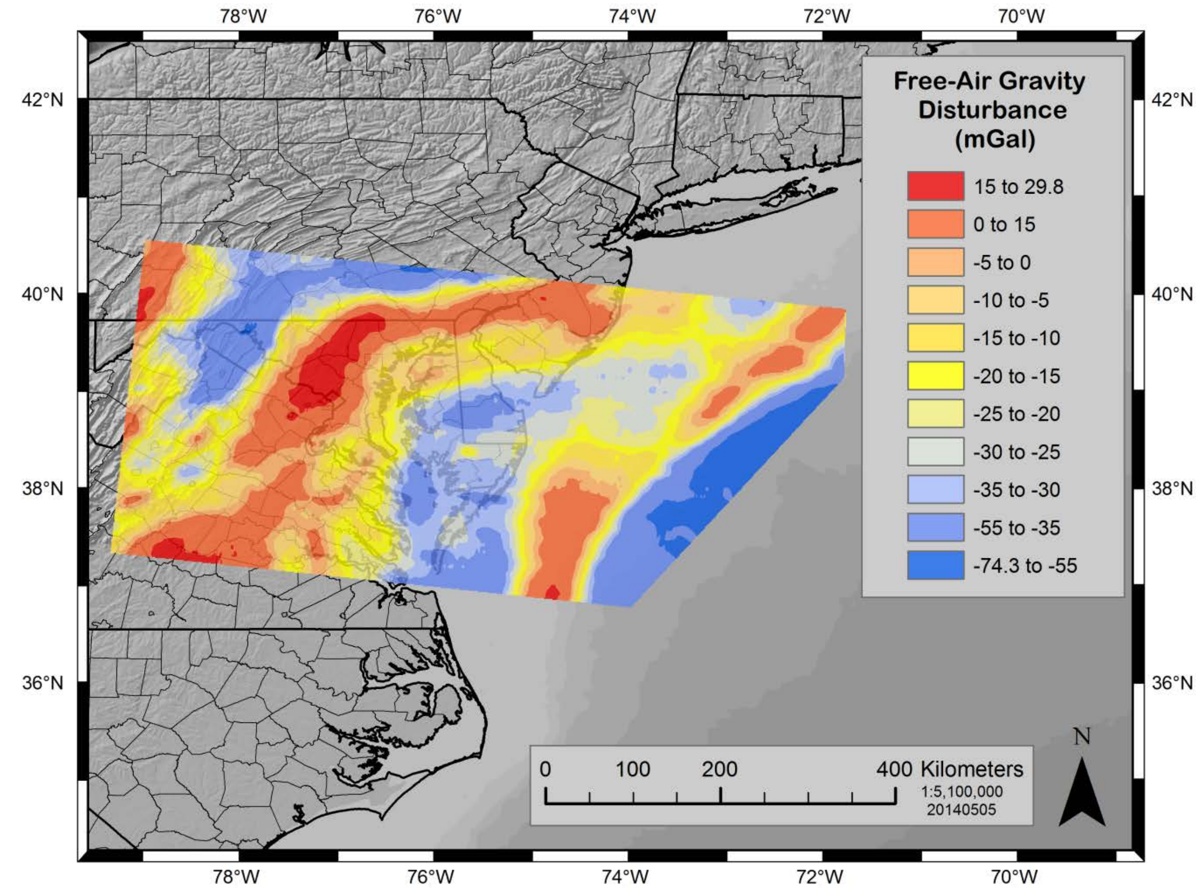


Figure 5: Free-air gravity disturbance for Block ES03 with respect to the WGS-84 ellipsoid.

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 Team, in alphabetical order, are: Vicki A. Childers, Justin Dahlberg, Theresa M. Damiani, Sandra A. Martinka Preaux, Carly A. Weil, Tim Wilkins, and Monica A. Youngman.

To reference the ES03 data file, reference the webpage:
GRAV-D Science Team (2014). "Gravity for the Redefinition of the American Vertical Datum (GRAV-D) Project, Airborne Gravity Data; Block ES03". Available *DATE*. Online at: http://www.ngs.noaa.gov/GRAV-D/data_ES03.shtml

To reference the block and survey details, reference the block user manual:
GRAV-D Team (2014). "Block ES03 (Eastern South 03); 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_ES03.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_ES03.shtml

5. References

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