Block ES07 (Eastern South 07)

GRAV-D Airborne Data Release User Manual

Applies to Data BETA1 Release, 12/2019

BETA 1 edited by Jeffery A Johnson

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

Introduction to GRAV-D and Data User Manuals 1

Figure List 3

Table List 3

1. Block Description 4

2. Survey Design and Execution 5

  2.1 GPS/IMU Instrumentation 7

  2.2 Gravity Instrumentation 8

3. GPS and Gravity Data Processing 9

  3.1 Whole-Survey Applicable Details 9

    3.1.1 GPS 9

    3.1.2 Ground Gravity Tie 9

    3.1.3 Gravity Filtering 10

  3.2 Whole-Block Applicable Details 10

    3.2.1 Gravity Error Analysis 10

  3.3 Flight- and Line-Specific Details 13

    3.3.1 GPS processing- by flight 13

    3.3.2 Gravity processing- by line 13

4. Data Usage Guidelines 19

  4.1 Suggested Data Handling 19

  4.2 Documentation 19

  4.3 How to Cite These Data 19

5. References 20

Figure List

Figure 1: Google Earth Image of the Location of Block ES07. 4
Figure 2: Data Coverage for ES07. 7
Figure 3: Crossover Residuals, Histogram, and Statistics for Block ES07. 11
Figure 4: Full-field gravity at altitude (mean removed) for Block ES07. 17
Figure 5: Gravity disturbance for Block ES07 with respect to the GRS80 ellipsoid. 18

Table List

Table 1: Latitude and Longitude Coordinates of Corner Points Defining Block ES07 4
Table 3: Survey Overview 5
Table 4: Aircraft and Instrumentation 6
Table 5: Survey Design and Execution 6
Table 6: Lever Arm Measurements (IMU TO TAGS) 8
Table 7: Lever Arm Measurements (IMU TO the GPS Antenna) 8
Table 8: GPS High Rate Data Availability (1 Hz or higher) 9
Table 9: Gravity Ties at the height of the TAGS Gravimeter on the airplane 10
Table 10: Gravity Crossover Error Analysis 10
Table 11: Quality of Cross Lines Used in Crossover Analysis 12
Table 12: Average Data Line Correlation 12
Table 13: Reflown Line Correlations 12
Table 14: GPS+IMU and GPS-only Kinematic Processing Results 13
Table 15: Gravity Processing Results 14
Table 16: Bias from EGM08 by Line 15

1. Block Description

GRAV-D Block **ES07** is located in the **E**astern Time Zone, in the **S**outh half (south of 40° latitude). This was the seventh (**07**) block of data completed in that region. Block ES07 is about 700 km by 340 km over the east coast, including Georgia, and South Carolina extending into the Atlantic Ocean (Figure 1). The corner coordinates defining Block ES07 are listed in Table 1.

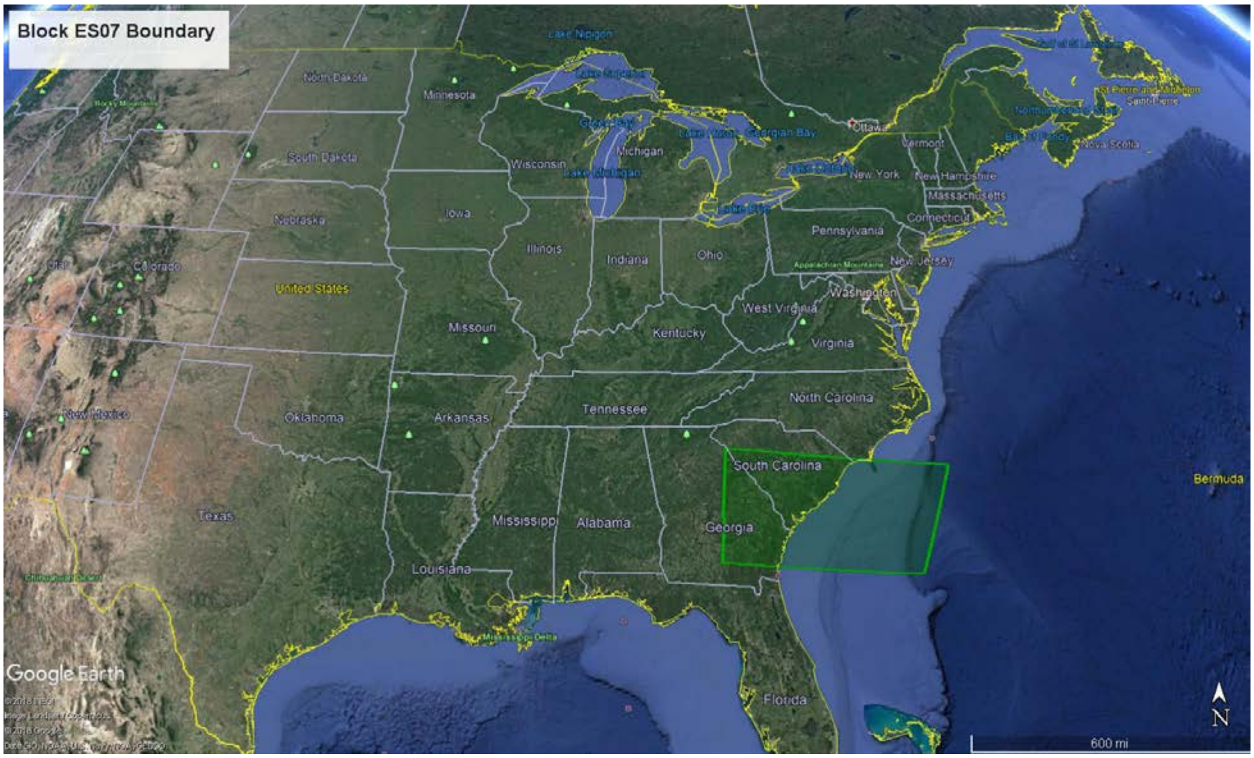

Figure 1: Google Earth Image of the Location of Block ES07.

Table 1: Latitude and Longitude Coordinates of Corner Points Defining Block ES07

Latitude (decimal degrees)	Longitude (decimal degrees)
34.382979996	-82.861160029
31.231612862	-83.177849454
30.679872768	-76.739232022
33.636187069	-75.240781093

2. Survey Design and Execution

Airborne gravity data in Block ES07 were collected during four surveys: GA17-1 (Georgia 2017, first occupation), GA18-1 (Georgia 2018, first occupation), FL18-1 (Florida 2018, first occupation), and MS19-1 (Mississippi 2019, first occupation). For all four surveys, data and cross line flights were flown at about 21,000 ft. Three different aircraft and three different airborne gravimeters were used to collect ES07 data. Table 3, Table 4, and Table 5 give a synopsis of survey layout and execution for the data. Figure 2 shows a map of the data coverage.

In ES07 all data lines are East-West and cross lines are North-South. The block consists of 10 data lines and 2 cross lines from GA17-1; 5 data lines from GA18-1; 19 data lines and 6 cross lines from FL18-1, and 1 data line from MS19-1. Three data lines, ES07110, ES07119, and ES07123 were flown twice with good data collected for part of the line both times. 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. ES07101= block ES07’s line 101).

Table 2: Survey Overview

Survey	Conducting Organization	Airport Base of Operations	Geographic Location	Survey Dates
GA17-1	NOAA- National Geodetic Survey	Middle Georgia Regional Airport (MCN) Macon, GA FBO: Lowe Aviation Co.	Mid-Atlantic	September 28 - December 15, 2017
GA18-1	NOAA- National Geodetic Survey	Middle Georgia Regional Airport (MCN) Macon, GA FBO: Lowe Aviation Co.	Mid-Atlantic	February 28 - April 6, 2018
FL18-1	NOAA- National Geodetic Survey	Lakeland Linder International Airport (LAL) Lakeland, FL FBO: NOAA Aircraft Operations Center	Mid-Atlantic	February 11 - February 24, 2018
MS19-1	NOAA- National Geodetic Survey	Golden Triangle Regional Airport (GTR) Columbus, MS FBO: Avflight	Mid-Atlantic	October 2 – December 6, 2019

Table 3: Aircraft and Instrumentation

Survey	Aircraft	Engines: Number, and Type	Gravity Instrumentation	GPS Instrumentation
GA17-1 (MCN)	King Air 200T (N43U)	2, Turboprop	Micro-g LaCoste (MGL) TAGS S-137 (relative) MGL A-10 25 (absolute) MGL D-43, G-6 (relative)	NovAtel DL-4 Plus NovAtel SPAN-SE (GPS + IMU)
GA18-1 (MCN)	King Air 200T (N43U)	2, Turboprop	Micro-g LaCoste (MGL) TAGS S-161 and S-211 (relative) MGL A-10 25 (absolute) MGL D-43, G-6 (relative)	NovAtel DL-4 Plus NovAtel SPAN-SE (GPS + IMU)
FL18-1 (LAL)	Gulfstream IV-SP (G-IV N49RF)	2, Jet	Micro-g LaCoste (MGL) TAGS S-161 (relative) MGL A-10 25 (absolute) MGL D-43, G-6 (relative)	NovAtel DL-4 Plus NovAtel SPAN-SE (GPS + IMU)
GA18-1 (GTR)	King Air 200T (N54F)	2, Turboprop	Micro-g LaCoste (MGL) TAGS S-137 (relative) MGL A-10 25 (absolute) MGL D-43, G-6 (relative)	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	21,000 ft.
Nominal Aircraft Ground Speed	250 knots (King Air), 370 knots (G-IV)
Number of Lines Released	Data Lines: 35 Cross Lines: 8 Repeat Lines: 3
Number of Crossovers	274

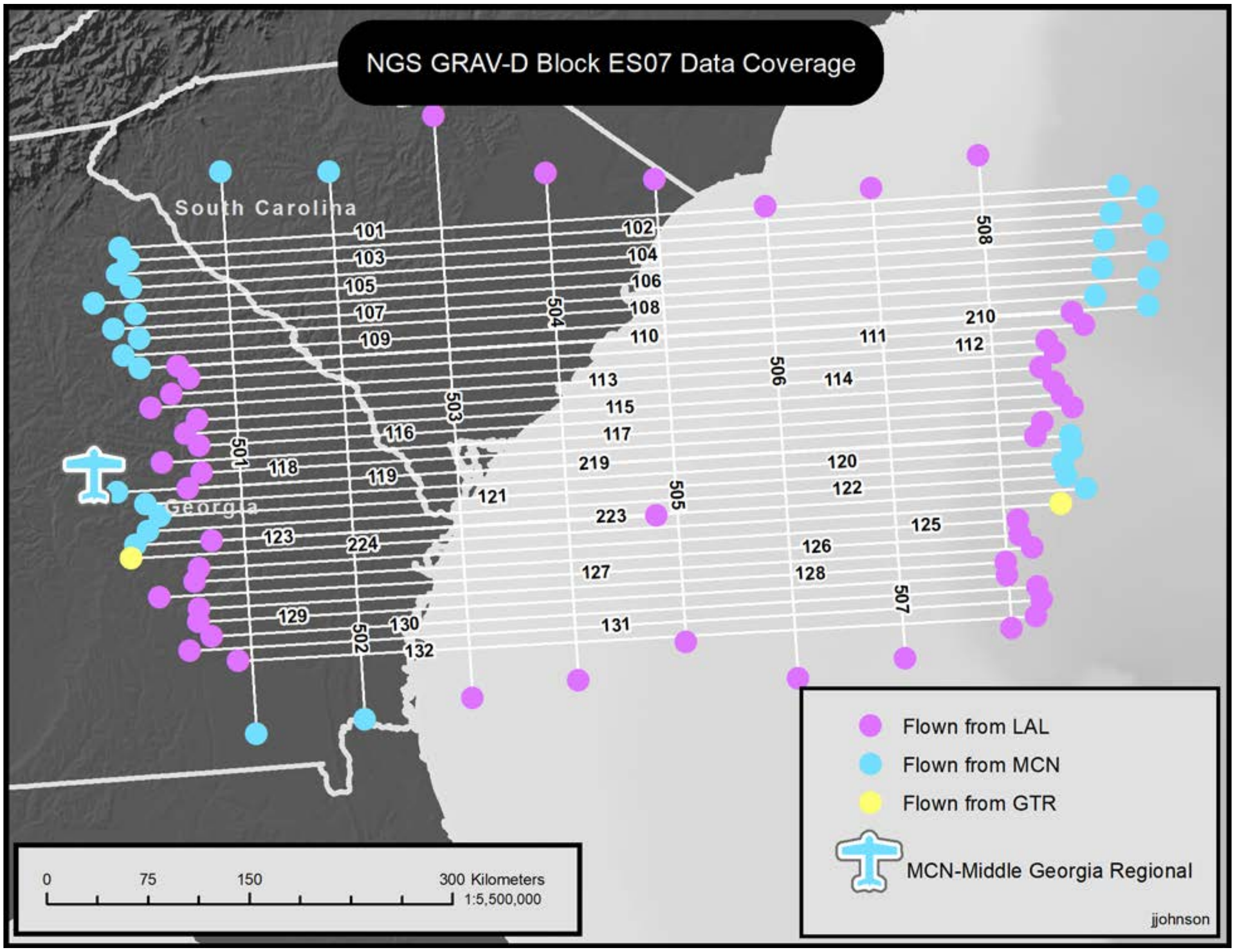

Figure 2: Data Coverage for ES07. Data lines start in the north at 101 and continue south to 132. Lines marked with a purple dot are flown from Lakeland Linder International Airport (LAL). Lines marked with a blue dot are flown from Middle Georgia Regional Airport (MCN). Lines marked with a yellow dot are flown from Golden Triangle Regional Airport (GTR). Due to map scale limitations, MCN and GTR are not shown on the map.

2.1 GPS/IMU Instrumentation

The aircraft each 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. 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 GPS base stations recorded at 1 Hz or 20 Hz (for TAGS S-211 observations) 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 S-137 and S-161 records data at 1 Hz and has a NovAtel timing unit mounted on the gravimeter. These gravimeters also record an environmental file at 0.1 Hz. For more information on the instrument, refer to its user manual (Micro-g LaCoste, 2010). The TAGS S-211 records data at 20 Hz and has a NovAtel timing unit mounted on the gravimeter. S-211 records environmental data along with the raw gravity data at 20 Hz. (Micro-g LaCoste, 2015)

The IMU was mounted on top of the TAGS and in the center of the frame. Table 6 lists the lever arm measurements between the IMU and the TAGS (distances are measured along the body of the aircraft: X positive toward the right, Y positive toward the nose, and Z positive up). Table 7 lists the lever arm measurement between the IMU and the GPS antenna (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 IMUs Sensor TO the Center of the TAGS Sensor

Instrument/Location	X (m)	Y (m)	Z (m)
TAGS S-137	-0.011	0.036	-0.514
TAGS S-161	-0.016	0.021	-0.503
TAGS S-211	-0.001	-0.002	-0.453

Table 6: Lever Arm Measurements FROM the Center of the IMU's sensor TO the GPS Antenna

Instrument/Location	X (m)	Y (m)	Z (m)
GPS Antenna N43U (S-137)	-0.132	0.392	0.526
GPS Antenna N43U (S-161)	-0.133	0.389	0.538
GPS Antenna N43U (S-211)	-0.139	0.38	0.665
GPS Antenna N54F (S-137)	-0.122	0.441	0.524
GPS Antenna N49RF (S-161)	-0.051	0.406	1.016

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 (Survey)	Type	Receiver	Flight Available	2013-2014 Day of Year Available
MCN (GA17-1)	Kinematic	NovAtel (SPAN)	f01, f06, f07, f09, f10, f11	287, 295, 304, 315-316, 318
	Static	NovAtel (47)	f01, f06, f07, f09, f10, f11	287, 295, 304, 315-316, 318
		NovAtel (49)	f01, f06, f07, f09, f10, f11	287, 295, 304, 315-316, 318
MCN (GA18-1)	Kinematic	NovAtel (SPAN)	f03-f05	83, 84, 87, 88, 90, 91
	Static	NovAtel (47)	f03-f05	83, 84, 87, 88, 90, 91
		NovAtel (49)	f03-f05	83, 84, 87, 88, 90, 91
LAL (FL18-1)	Kinematic	NovAtel (SPAN)	f01-f08	46-48, 51-55
	Static	NovAtel (47)	f01-f08	46-48, 51-55
		NovAtel (49)	f01-f08	46-48, 51-55
GTR (MS19-1)	Kinematic	NovAtel (SPAN)	f17	320, 321
	Static	Trimble netR9 (East)	f17	320, 321
		Trimble netR9 (West)	f17	320, 321

Data were processed using GRS80 and IGS08. 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 0.048 m and the average vertical position accuracy is 0.084 m.

3.1.2 Ground Gravity Tie

Absolute gravity measurements at each airport were performed by NGS with a Micro-g LaCoste A-10 gravimeter. 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. See Table 9 for more information about each of the gravity ties.

Table 8: Gravity Ties at the height of the TAGS Gravimeter on the airplane

Airport/ Airplane	Point ID	Latitude	Longitude	Tie height above mark (cm)	Gravity Tie (mGal)
MCN/ King Air 200T	KMCN TAGS	32.70132275°N	83.64719052°W	162.5	979516.616 ± 0.008
LAL/ Gulfstream IV	KONT TAGS	27.99705840°N	81.99751341°W	246.7	979173.120 ± 0.008
GTR/King Air 200T	KGTR TAGS	32.453342419°N	88.588420031°W	162.5	979558.899 ± 0.008

3.1.3 Gravity Filtering

Newton v1.4 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 ES07, the result of the crossover analysis is shown in Table 10 and in Figure 3.

Table 9: 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)
21,000	6,400	6,403	274	1.27	1.27	-0.11	0.90

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 11. 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.

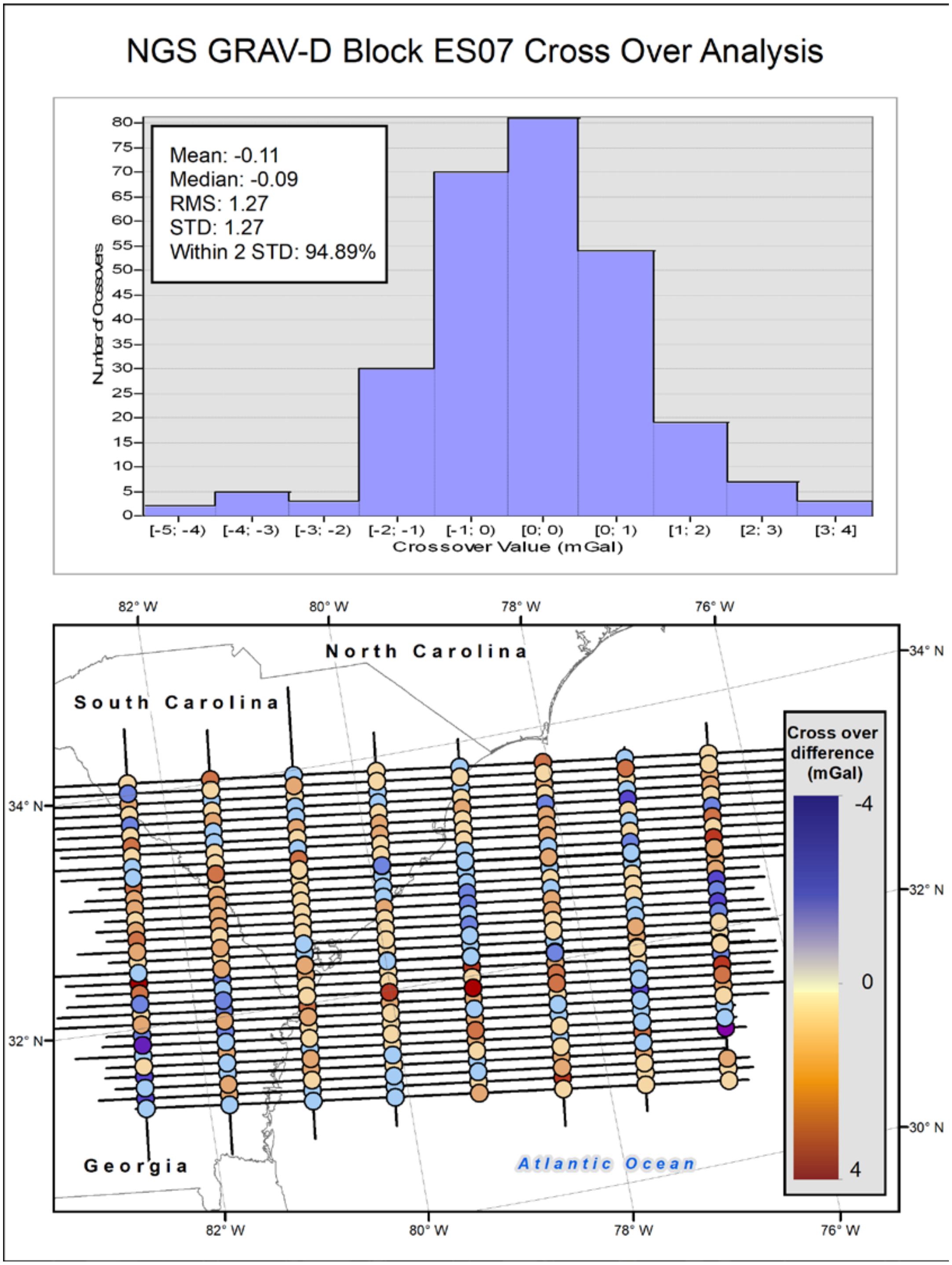

Figure 3: Crossover Residuals, Histogram, and Statistics for Block ES07. Color scale in mGals.

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	1.65	-0.14
502	1.08	-0.01
503	0.81	0.13
504	0.95	-0.25
505	1.44	-0.18
506	1.10	0.13
507	1.10	-0.47
508	1.78	-0.09

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 12) 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
40	99.22%	0.29%

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. Table 13 shows the correlation of lines flown twice with a significant amount of overlap.

Table 12: Reflown Line Correlations

Line	Correlation
ES07110	99.90%
ES07210	
ES07119	99.85%
ES07219	
ES07123	99.59%
ES07223	

3.3 Flight- and Line-Specific Details

3.3.1 GPS processing- by flight

GPS data were processed in Inertial Explorer (IE) 8.50-8.70. 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 v1.4 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 13: GPS+IMU and GPS-only Kinematic Processing Results

Survey	Flight	Rover GPS Unit	Solution Type	Elevation Mask (deg)	Line Num.	NGS Qualtiy Grade
FL18-1	f01	SPAN	GPS + IMU	5	127	100
FL18-1	f01	SPAN	GPS + IMU	5	131	100
FL18-1	f01	SPAN	GPS + IMU	5	132	100
FL18-1	f02	SPAN	GPS + IMU	7.5	125	100
FL18-1	f02	SPAN	GPS + IMU	7.5	126	100
FL18-1	f02	SPAN	GPS + IMU	7.5	129	100
FL18-1	f02	SPAN	GPS + IMU	7.5	130	100
FL18-1	f03	SPAN	GPS + IMU	5	123	100
FL18-1	f03	SPAN	GPS + IMU	5	128	100
FL18-1	f04	SPAN	GPS + IMU	5	111	100
FL18-1	f04	SPAN	GPS + IMU	5	210	100
FL18-1	f05	SPAN	GPS + IMU	5	112	100
FL18-1	f05	SPAN	GPS + IMU	5	113	100
FL18-1	f05	SPAN	GPS + IMU	5	118	100
FL18-1	f05	SPAN	GPS + IMU	5	119	100
FL18-1	f06	SPAN	GPS + IMU	7.5	114	100

Survey	Flight	Rover GPS Unit	Solution Type	Elevation Mask (deg)	Line Num.	NGS Qualtiy Grade
FL18-1	f06	SPAN	GPS + IMU	7.5	115	100
FL18-1	f07	SPAN	GPS + IMU	5	503	100
FL18-1	f07	SPAN	GPS + IMU	5	504	100
FL18-1	f07	SPAN	GPS + IMU	5	505	100
FL18-1	f07	SPAN	GPS + IMU	5	506	100
FL18-1	f07	SPAN	GPS + IMU	5	507	100
FL18-1	f07	SPAN	GPS + IMU	5	508	100
FL18-1	f08	SPAN	GPS + IMU	7.5	116	100
FL18-1	f08	SPAN	GPS + IMU	7.5	117	100
GA17-1	f01	SPAN	GPS + IMU	5	103	100
GA17-1	f01	SPAN	GPS + IMU	5	104	100
GA17-1	f06	SPAN	GPS + IMU	7.5	501	100
GA17-1	f06	SPAN	GPS + IMU	7.5	502	100
GA17-1	f07	SPAN	GPS + IMU	7.5	101	100
GA17-1	f07	SPAN	GPS + IMU	7.5	102	100
GA17-1	f09	SPAN	GPS + IMU	7.5	105	100
GA17-1	f09	SPAN	GPS + IMU	7.5	106	100
GA17-1	f10	SPAN	GPS + IMU	5	107	100
GA17-1	f10	SPAN	GPS + IMU	5	108	100
GA17-1	f11	SPAN	GPS + IMU	5	109	100
GA17-1	f11	SPAN	GPS + IMU	5	110	100
GA18-1	f03	SPAN	GPS + IMU	5	223	100
GA18-1	f04	SPAN	GPS + IMU	7.5	120	100
GA18-1	f04	SPAN	GPS + IMU	7.5	219	100
GA18-1	f05	SPAN	GPS + IMU	5	121	100
GA18-1	f05	SPAN	GPS + IMU	5	122	100
MS19-1	f17	SPAN	GPS + IMU	5	224	100

Table 14: Gravity Processing Results

Survey	Flight Num.	Line Num.	Time of Deleted Data	Comments
GA18-1	f04	219	2018-03-29 02:09:54- 2018-03-29 02:12:35	Bump removed

Table 15: Bias from EGM08 by Line

Survey	Flight Num.	Line	EGM08 mean
FL18-1	f01	127	0.5
FL18-1	f01	131	-0.1
FL18-1	f01	132	-0.12
FL18-1	f02	125	0.84
FL18-1	f02	126	1.17
FL18-1	f02	129	-0.25
FL18-1	f02	130	-0.4
FL18-1	f03	123	-1.04
FL18-1	f03	128	1.25
FL18-1	f04	111	0.66
FL18-1	f04	210	1.01
FL18-1	f05	112	0.82
FL18-1	f05	113	0.89
FL18-1	f05	118	0.01
FL18-1	f05	119	-0.28
FL18-1	f06	114	1.27
FL18-1	f06	115	0.84
FL18-1	f07	503	-0.47
FL18-1	f07	504	-0.01
FL18-1	f07	505	-0.68
FL18-1	f07	506	-0.04
FL18-1	f07	507	0.35
FL18-1	f07	508	0.2
FL18-1	f08	116	-0.17
FL18-1	f08	117	0.94
GA17-1	f01	103	-1.55
GA17-1	f01	104	0.48
GA17-1	f06	501	-0.51
GA17-1	f06	502	-0.43
GA17-1	f07	101	-0.04
GA17-1	f07	102	1.25
GA17-1	f09	105	-0.5
GA17-1	f09	106	1.86
GA17-1	f10	107	-0.36
GA17-1	f10	108	1.99
GA17-1	f11	109	-1.26
GA17-1	f11	110	1.43
GA18-1	f03	223	-1.3

Survey	Flight Num.	Line	EGM08 mean
GA18-1	f04	120	1.14
GA18-1	f04	219	0.09
GA18-1	f05	121	-0.53
GA18-1	f05	122	1.11
MS19-1	f17	224	-2.49

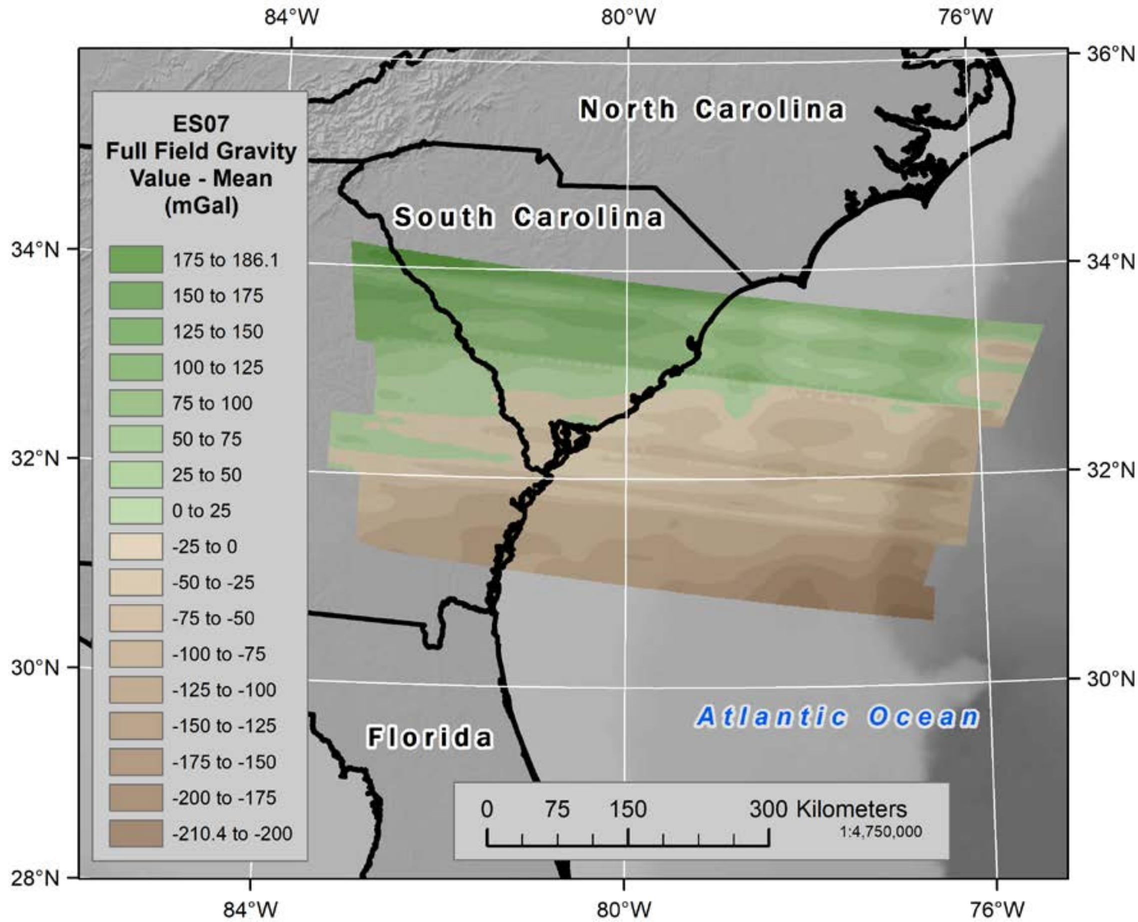

Figure 4: Full-field gravity at altitude (mean removed) for Block ES07. This is the data in the gravity release ".txt" file and includes the effects of differing altitudes along flight lines.

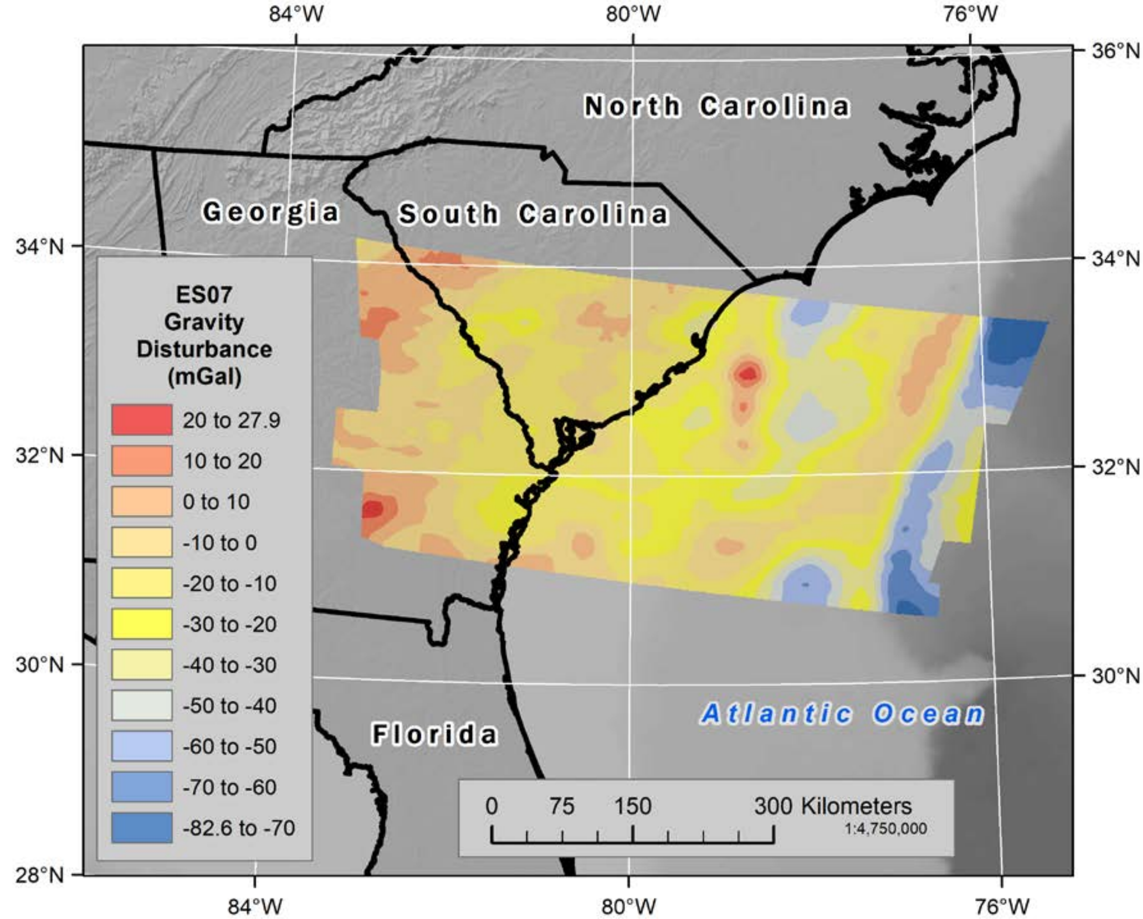

Figure 5: Gravity disturbance for Block ES07 with respect to the GRS80 ellipsoid.

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 E. Dahlberg, Theresa M. Damiani, Jeff Kanney, Jeffery A Johnson, Chris Villarreal, and Derek van Westrum.

To reference the ES07 data file, reference the webpage:
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