Block ES04 (Eastern South 04)

GRAV-D Airborne Data Release User Manual

Applies to Data BETA2 Release, 9/2019

BETA 1 edited by Monica A. Youngman and Carly A. Weil

BETA 2 updated/edited by Jeff Johnson

BETA 2 updated to include flights from surveys GA17-1 and FL18-1. Also, a wrong calibration for TAGS S-160 was fixed for survey NC13-1.

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 **ES04** is located in the **E**astern Time Zone, in the **S**outh half (south of 40° latitude). This was the fourth (**04**) block of data completed in that region. Block ES04 is about 600 km by 360 km over the east coast, including North Carolina, Virginia, and South Carolina (Figure 1). The corner coordinates defining Block ES04 are listed in Table 1.

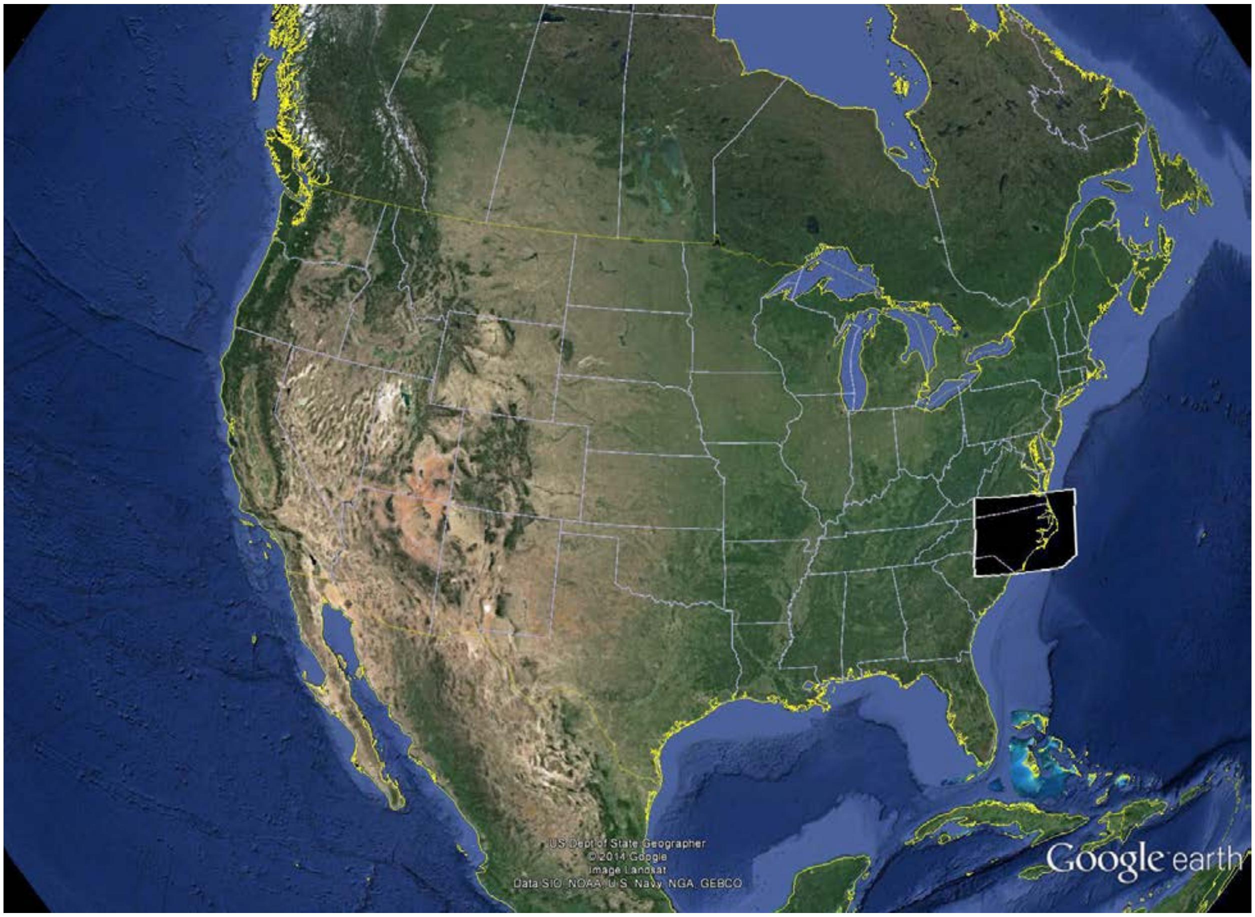

Figure 1: Google Earth Image of the Location of Block ES04.

Table 1: Latitude and Longitude Coordinates of Corner Points Defining Block ES04

Latitude (decimal degrees)	Longitude (decimal degrees)
34.192525321	-80.952348039
33.598616407	-74.900813466
33.846283006	-74.449681047
36.802227221	-73.897478631
37.407060306	-80.512823753

2. Survey Design and Execution

Airborne gravity data in Block ES04 were collected during four surveys: NC13-1 (North Carolina 2013, first occupation), NC14-1 (North Carolina 2014, first occupation), GA17-1 (Georgia 2017, first occupation), and FL18-1 (Florida 2018, first occupation). For surveys NC13-1 and NC14-1, data and cross line flights were flown at 17,500-18,000 ft. For surveys GA17-1 and FL18-1, data and cross line flights were flown at 20,500-21,000 ft. Four different aircraft and two different airborne gravimeters were used to collect ES04 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 ES04 all data lines are East-West and cross lines are North-South. The block consists of 30 data lines and 7 cross lines from NC13-1; 25 data lines and 4 cross lines from NC14-1; 2 data lines from GA17-1, and 4 data lines from FL18-1. Eleven data lines, PS01107, PS01108, PS01109, PS01116, PS01125, PS01126, PS01131, PS01133, PS01134, PS01141, and PS01142 were flown twice with good data collected for part of the line each time. 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. ES04101= block ES04's line 101). Because of aircraft and weather challenges this block had many reflights. Some reflown lines are complete reflights, and others are segments that together make up a complete data line. See Table 2 for the names of lines flown more than once and to check whether or not they are complete lines or only a portion/segment of a line.

Table 2: Data from lines flown more than once

Survey	Flight	Line	Complete or Segment
NC13-1	f23	ES04205	Segment
NC13-1	f23	ES04405	Segment
NC13-1	f14	ES04207	Segment
NC13-1	f25	ES04307	Segment
NC13-1	f23	ES04208	Complete
NC13-1	f25	ES04308	Complete
NC13-1	f15	ES04110	Segment
NC13-1	f27	ES04210	Segment
NC13-1	f22	ES04111	Segment
NC14-1	f05	ES04311	Segment
NC13-1	f22	ES04112	Almost Complete
NC14-1	f01	ES04312	Complete
NC13-1	f21	ES04113	Segment
NC13-1	f26	ES04213	Segment
NC13-1	f21	ES04114	Segment
NC14-1	f18	ES04414	Segment
NC13-1	f09	ES04116	Complete
NC14-1	f24	ES04216	Complete
NC13-1	f09	ES04117	Complete

Survey	Flight	Line	Complete or Segment
NC14-1	f24	ES04217	Complete
NC13-1	f24	ES04219	Segment
NC13-1	f26	ES04319	Segment
NC13-1	f24	ES04120	Almost Complete
NC13-1	f29	ES04220	Almost Complete
NC13-1	f29	ES04121	Almost Complete
NC14-1	f05	ES04221	Segment
NC14-1	f16	ES04125	Complete
NC14-1	f19	ES04225	Segment
NC13-1	f30	ES04132	Almost Complete
NC14-1	f15	ES04332	Segment
NC14-1	f26	ES04233	Complete
NC14-1	f29	ES04433	Segment
NC14-1	f06	ES04135	Segment
NC14-1	f28	ES04335	Segment
NC14-1	f20	ES04137	Complete
GA17-1	f12	ES04237	Complete
NC14-1	f23	ES04338	Complete
GA17-1	f12	ES04438	Complete
NC13-1	f01	ES04591	Segment
NC13-1	f27	ES04791	Segment
NC13-1	f03	ES04594	Segment
NC13-1	f28	ES04894	Segment
NC13-1	f27	ES04595	Segment
NC13-1	f11	ES04895	Complete

Table 3: Survey Overview

Survey	Conducting Organization	Airport Base of Operations	Geographic Location	Survey Dates
NC13-1	NOAA- National Geodetic Survey Fugro Earth Data, Inc.	Smith Reynolds Airport (INT) Winston-Salem, NC FBO: Landmark Aviation	Mid-Atlantic	November 18, 2013- March 11, 2014
NC14-1	NOAA- National Geodetic Survey Fugro Earth Data, Inc.	Smith Reynolds Airport (INT) Winston-Salem, NC FBO: Landmark Aviation	Mid-Atlantic	June 9-August 19, 2014
GA17-1	NOAA- National Geodetic Survey	Middle Georgia Regional Airport (MCN) Macon, GA FBO: Lowe Aviation Co.	Mid-Atlantic	September 28 - December 15, 2017

Survey	Conducting Organization	Airport Base of Operations	Geographic Location	Survey Dates
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

Table 4: Aircraft and Instrumentation

Survey	Aircraft	Engines: Number, and Type	Gravity Instrumentation	GPS Instrumentation
NC13-1 (INT)	Cessna 441 Conquest II	2, Turboprop	Micro-g LaCoste (MGL) TAGS S-160 (relative) MGL A-10 25 (absolute) MGL D-43, G-6 (relative)	NovAtel DL-4 Plus NovAtel SPAN-SE (GPS + IMU)
NC14-1 (INT)	Hawker Beechcraft King Air E90A	2, Turboprop	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)
GA17-1 (MCN)	Hawker Beechcraft King Air 200T	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)
FL18-1 (LAL)	Gulfstream IV-SP	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)

Table 5: 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	17,500-21,000 ft.
Nominal Aircraft Ground Speed	250 knots
Number of Lines Released	Data Lines: 61 Cross Lines: 11 Repeat Lines: 7
Number of Crossovers	432

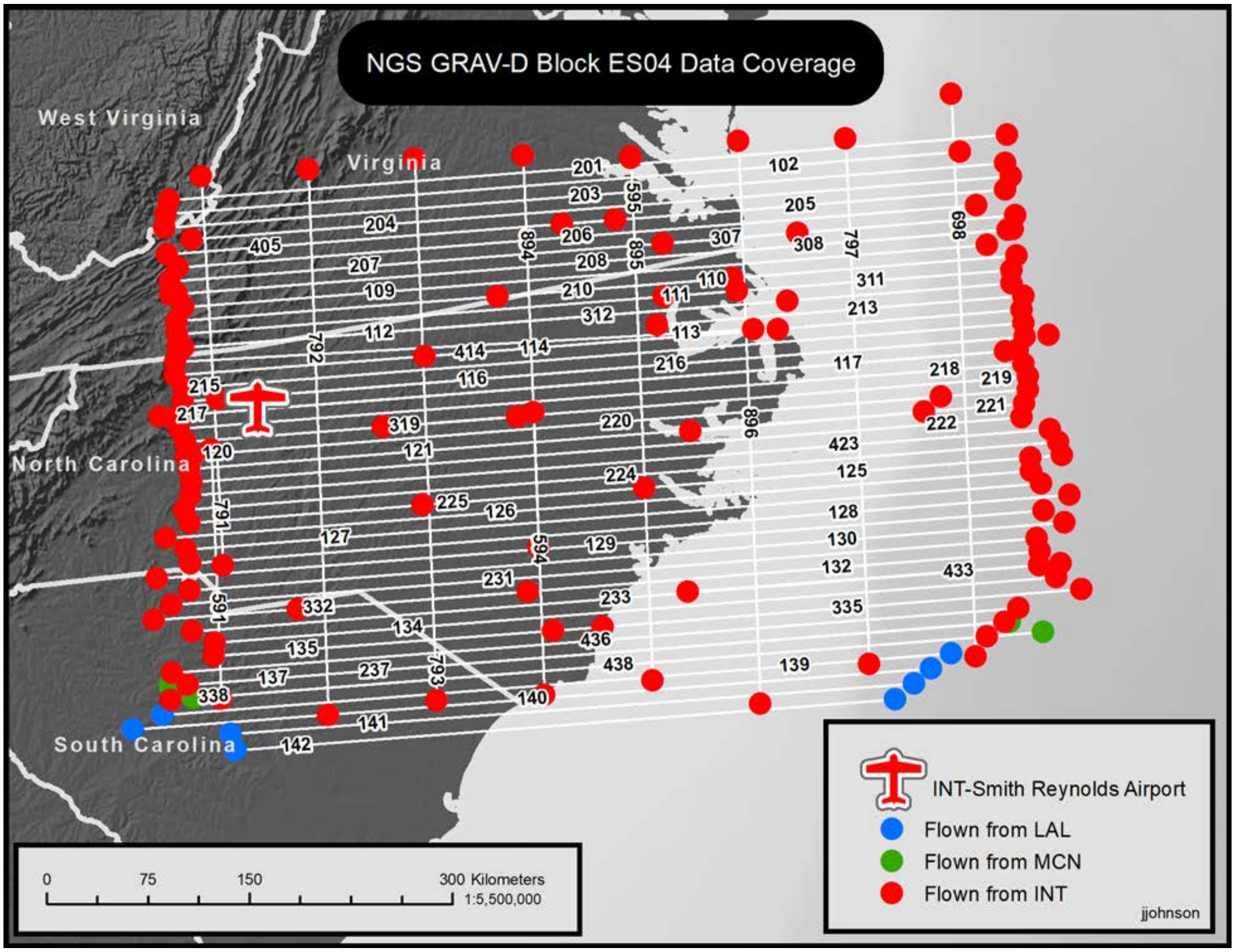

Figure 2: Data Coverage for ES04. Data lines start in the north at 101 and continue south to 142. Lines marked with a red dot are flown from Smith Reynolds Airport (INT). Lines marked with a green dot are flown from Middle Georgia Regional Airport (MCN). Lines marked with a blue dot are flown from Lakeland Linder International Airport (LAL). Due to map scale limitations, MCN and LAL 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 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 GPS base stations recorded at 1 Hz 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 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 6: 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-160 and S-161 for NC13-1 and NC14-1	-0.017	0.019	-0.433
TAGS S-137 for GA17-1	-0.011	0.036	-0.514
TAGS S-161 for FL18-1	-0.016	0.021	-0.503

Table 7: 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 (Conquest II)	-0.025	-0.75	0.481
GPS Antenna (King Air E90A)	-0.135	-0.34	0.606
GPS Antenna (King Air 200T)	-0.132	0.392	0.526
GPS Antenna (Gulfstream IV)	-0.051	0.406	1.016

3. GPS and Gravity Data Processing

3.1 Whole-Survey Applicable Details

3.1.1 GPS

Table 8: GPS High Rate Data Availability (1 Hz or higher)

Airport	Type	Receiver	Flight Available	2013-2014 Day of Year Available
INT (NC13-1)	Kinematic	NovAtel (0002)	F01, F03, F06, F11, F13-F16, F18-F19, F21-F30	322-324, 335-337, 354, 12-13, 59-61, 65, 57, 69-70
		NovAtel (SPAN)	F01, F03, F06, F11, F13-F16, F18-F19, F21-F30	322-324, 335-337, 354, 12-13, 59-61, 65, 57, 69-70
	Static	Ashtech 3552	F01, F03, F06, F11, F13-F16, F18-F19, F21-F30	322-324, 335-337, 354, 12-13, 59-61, 65, 57, 69-70
		Ashtech Noth	F01, F03, F06, F11, F13-F16, F18-F19, F21-F30	322-324, 335-337, 354, 12-13, 59-61, 65, 57, 69-70
INT (NC14-1)	Kinematic	NovAtel (0002)	F01, F03, F05, F09, F13, F15-F16, F18-F29	160, 164, 166, 175, 183, 186-187, 194-195, 199, 208, 211, 219-220, 226-228, 230-231
		NovAtel (SPAN)	F01, F03, F05, F09, F13, F15-F16, F18-F29	160, 164, 166, 175, 183, 186-187, 194-195, 199, 208, 211, 219-220, 226-228, 230-231
	Static	Ashtech 3552	F01, F05, F09, F13, F15-F16, F20-F29	160, 166, 175, 183, 186-187, 199, 208, 211, 219-220, 226-228, 230-231
		Ashtech Noth	F01, F05, F09, F13, F15-F16, F18-F29	160, 166, 175, 183, 186-187, 194-195, 199, 208, 211, 219-220, 226-228, 230-231
MCN (GA17-1)	Kinematic	NovAtel (SPAN)	F12	321
	Static	NovAtel (47)	F12	321
		NovAtel (49)	F12	321
LAL (FL18-1)	Kinematic	NovAtel (SPAN)	F04, F06	51, 53
	Static	NovAtel (47)	F04, F06	51, 53
		NovAtel (49)	F04, F06	51, 53

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 surveywide 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 0.068 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 9: 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)
INT/Cessna II	KINT TAGS	36.14863548°N	80.22470149°W	146.6	979703.177 ± 0.007
INT/King Air 90E	KINT TAGS	36.14863548°N	80.22470149°W	152.5	979703.159 ± 0.007
MCN/ King Air 200T	KPSP 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

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 ES04, the result of the crossover analysis is shown in Table 10 and in Figure 3.

Table 10: 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)
20,000	6096	5,515	432	2.08	2.08	0.05	1.47

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.

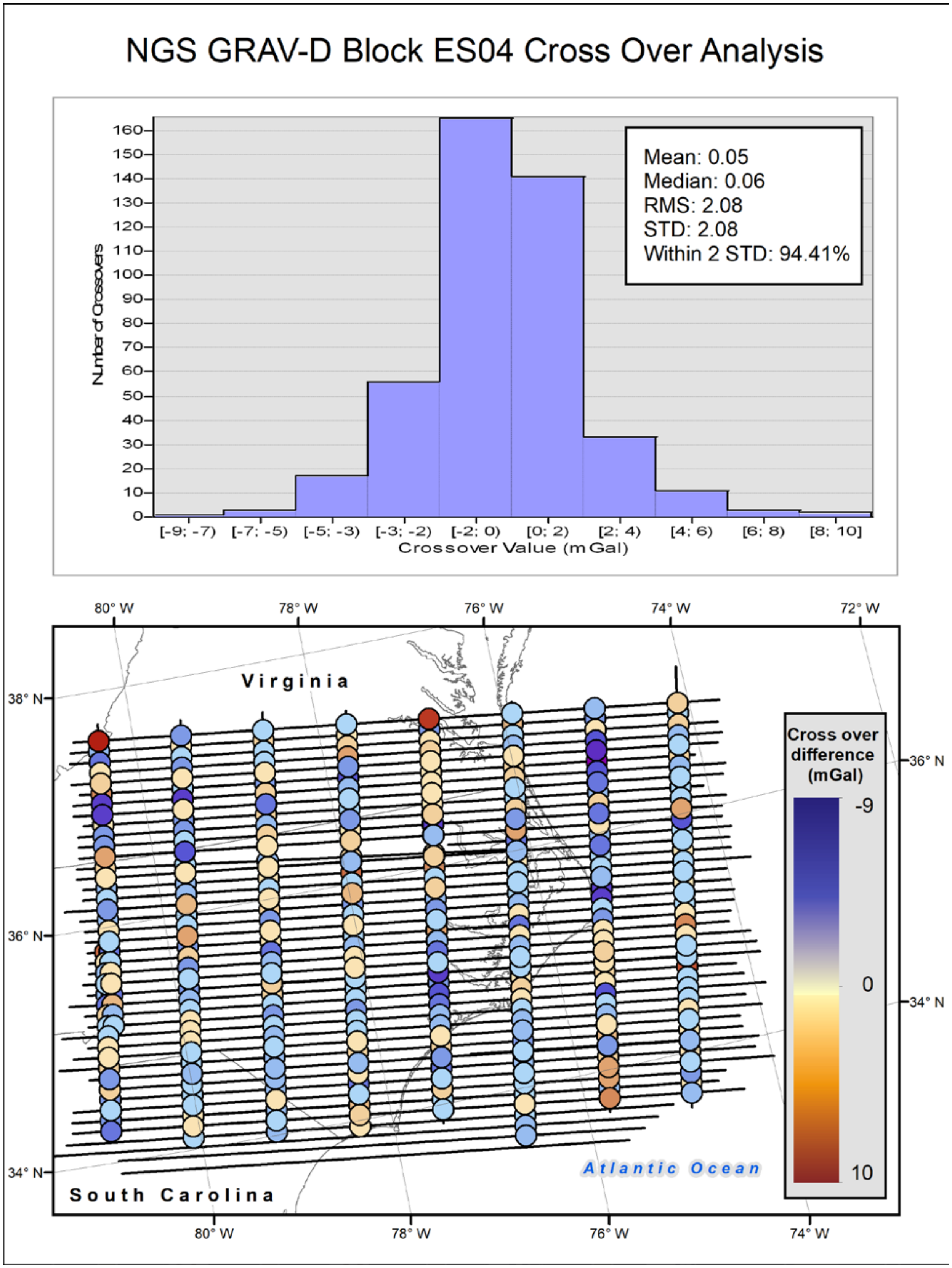

Figure 3: Crossover Residuals, Histogram, and Statistics for Block ES04. Color scale in mGals.

Table 11: 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	2.25	-0.22
791	2.91	0.15
792	1.72	-0.13
793	1.61	0.02
594	1.58	0.84
894	1.95	0.36
595	1.77	0.27
895	2.49	-0.02
896	1.39	0.01
797	2.82	-0.56
698	1.99	0.27

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 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 12: Average Data Line Correlation

Number of Correlations	Average Data Line Correlation	Standard Deviation of Correlations
42	97.67%	7.09%

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 13: Reflown Line Correlations

<table>
<tr><th>Line</th><th>Correlation</th></tr>
<tr><td>ES04208</td><td rowspan="2">99.80%</td></tr>
<tr><td>ES04308</td></tr>
<tr><td>ES04112</td><td rowspan="2">99.38%</td></tr>
<tr><td>ES04312</td></tr>
<tr><td>ES04116</td><td rowspan="2">99.88%</td></tr>
<tr><td>ES04216</td></tr>
</table>

Line	Correlation
ES04117	99.86
ES04217	
ES04120	99.72
ES04220	
ES04137	99.96%
ES04237	
ES04338	99.97%
ES04438	

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 14: 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	f04	SPAN	GPS+IMU	5	139	100
FL18-1	f04	SPAN	GPS+IMU	5	140	100
FL18-1	f06	SPAN	GPS+IMU	7.5	141	100
FL18-1	f06	SPAN	GPS+IMU	7.5	142	100
GA17-1	f12	SPAN	GPS+IMU	7.5	237	100
GA17-1	f12	SPAN	GPS+IMU	7.5	438	100

Survey	Flight	Rover GPS Unit	Solution Type	Elevation Mask (deg)	Line Num.	NGS Qualtiy Grade
NC13-1	f01	SPAN	GPS+IMU	5	591	100
NC13-1	f03	SPAN	GPS+IMU	7.5	594	100
NC13-1	f06	SPAN	GPS+IMU	5	135	100
NC13-1	f09	SPAN	GPS+IMU	5	116	100
NC13-1	f09	SPAN	GPS+IMU	5	117	100
NC13-1	f11	SPAN	GPS+IMU	7.5	102	100
NC13-1	f11	SPAN	GPS+IMU	7.5	201	100
NC13-1	f13	SPAN	GPS+IMU	7.5	109	100
NC13-1	f14	SPAN	GPS+IMU	5	206	100
NC13-1	f14	SPAN	GPS+IMU	5	207	100
NC13-1	f15	SPAN	GPS+IMU	7.5	110	100
NC13-1	f16	SPAN	GPS+IMU	5	203	100
NC13-1	f16	SPAN	GPS+IMU	5	204	100
NC13-1	f18	SPAN	GPS+IMU	5	792	100
NC13-1	f18	SPAN	GPS+IMU	5	793	100
NC13-1	f19	SPAN	GPS+IMU	5	215	100
NC13-1	f19	SPAN	GPS+IMU	5	218	100
NC13-1	f21	SPAN	GPS+IMU	7.5	113	100
NC13-1	f21	SPAN	GPS+IMU	7.5	114	100
NC13-1	f22	SPAN	GPS+IMU	5	111	100
NC13-1	f22	SPAN	GPS+IMU	5	112	100
NC13-1	f23	SPAN	GPS+IMU	7.5	205	100
NC13-1	f23	SPAN	GPS+IMU	7.5	208	100
NC13-1	f24	SPAN	GPS+IMU	5	120	100
NC13-1	f24	SPAN	GPS+IMU	5	219	100
NC13-1	f25	SPAN	GPS+IMU	7.5	307	100
NC13-1	f25	SPAN	GPS+IMU	7.5	308	100
NC13-1	f25	SPAN	GPS+IMU	7.5	405	100
NC13-1	f26	SPAN	GPS+IMU	7.5	213	100
NC13-1	f26	SPAN	GPS+IMU	7.5	319	100
NC13-1	f27	SPAN	GPS+IMU	5	210	100
NC13-1	f27	SPAN	GPS+IMU	5	595	100
NC13-1	f27	SPAN	GPS+IMU	5	791	100
NC13-1	f28	SPAN	GPS+IMU	7.5	894	100
NC13-1	f29	SPAN	GPS+IMU	7.5	121	100
NC13-1	f29	SPAN	GPS+IMU	7.5	220	100
NC13-1	f30	SPAN	GPS+IMU	7.5	132	100
NC14-1	f01	SPAN	GPS+IMU	5	312	100
NC14-1	f05	SPAN	GPS+IMU	5	221	100

Survey	Flight	Rover GPS Unit	Solution Type	Elevation Mask (deg)	Line Num.	NGS Qualtiy Grade
NC14-1	f05	SPAN	GPS+IMU	5	311	100
NC14-1	f11	SPAN	GPS+IMU	5	895	100
NC14-1	f12	SPAN	GPS+IMU	5	797	100
NC14-1	f13	SPAN	GPS+IMU	5	222	100
NC14-1	f15	SPAN	GPS+IMU	7.5	332	100
NC14-1	f16	SPAN	GPS+IMU	5	125	100
NC14-1	f16	SPAN	GPS+IMU	5	126	100
NC14-1	f18	SPAN	GPS+IMU	7.5	414	100
NC14-1	f18	SPAN	GPS+IMU	7.5	423	100
NC14-1	f19	SPAN	GPS+IMU	7.5	225	100
NC14-1	f20	SPAN	GPS+IMU	5	137	100
NC14-1	f21	SPAN	GPS+IMU	7.5	436	100
NC14-1	f22	SPAN	GPS+IMU	7.5	127	100
NC14-1	f22	SPAN	GPS+IMU	7.5	224	100
NC14-1	f23	SPAN	GPS+IMU	5	338	100
NC14-1	f23	SPAN	GPS+IMU	5	896	100
NC14-1	f24	SPAN	GPS+IMU	7.5	216	100
NC14-1	f24	SPAN	GPS+IMU	7.5	217	100
NC14-1	f25	SPAN	GPS+IMU	5	128	100
NC14-1	f25	SPAN	GPS+IMU	5	129	100
NC14-1	f26	SPAN	GPS+IMU	5	134	100
NC14-1	f26	SPAN	GPS+IMU	5	233	100
NC14-1	f27	SPAN	GPS+IMU	5	130	100
NC14-1	f27	SPAN	GPS+IMU	5	231	100
NC14-1	f28	SPAN	GPS+IMU	7.5	335	100
NC14-1	f28	SPAN	GPS+IMU	7.5	698	100
NC14-1	f29	SPAN	GPS+IMU	7.5	433	100

Table 15: Gravity Processing Results

Survey	Flight Num.	Line Num.	Time of Deleted Data	Comments
NC13-1	f21	113	2014-02-28 16:07:34-2014-02-28 16:09:55	Bump Removed
NC13-1	f24	120	2014-03-02 14:39:58-2014-03-02 14:42:52	Bump Removed
NC14-1	f15	332	2014-07-05 06:35:33-2014-07-05 06:38:08	Bump Removed
NC14-1	f15	332	2014-07-05 07:00:00-2014-07-05 07:02:42	Bump Removed

Survey	Flight Num.	Line Num.	Time of Deleted Data	Comments
NC14-1	f25	129	2014-08-14 05:55:39-2014-08-14 05:59:25	Bump Removed
NC14-1	f26	233	2014-08-15 08:29:16-2014-08-15 08:32:17	Bump Removed

Table 16: Bias from EGM08 by Line

Survey	Flight Num.	Line	EGM08 mean
FL18-1	f04	139	-0.3
FL18-1	f04	140	-0.25
FL18-1	f06	141	-0.24
FL18-1	f06	142	-0.28
GA17-1	f12	237	-1.69
GA17-1	f12	438	0.64
NC13-1	f01	591	5.49
NC13-1	f03	594	6.69
NC13-1	f06	135	5.62
NC13-1	f09	116	2.74
NC13-1	f09	117	3.64
NC13-1	f11	102	6.47
NC13-1	f11	201	4.55
NC13-1	f13	109	4.7
NC13-1	f14	206	2.55
NC13-1	f14	207	3.42
NC13-1	f15	110	3.86
NC13-1	f16	203	4.04
NC13-1	f16	204	4.32
NC13-1	f18	792	4.49
NC13-1	f18	793	4.46
NC13-1	f19	215	3.28
NC13-1	f19	218	4.27
NC13-1	f21	113	3.95
NC13-1	f21	114	4.46
NC13-1	f22	111	3.81
NC13-1	f22	112	4.21
NC13-1	f23	205	4.65
NC13-1	f23	208	5.02
NC13-1	f24	120	4.55
NC13-1	f24	219	4.31
NC13-1	f25	307	4.42
NC13-1	f25	308	4.25

Survey	Flight Num.	Line	EGM08 mean
NC13-1	f25	405	4.59
NC13-1	f26	213	3.9
NC13-1	f26	319	3.71
NC13-1	f27	210	3.98
NC13-1	f27	595	3.15
NC13-1	f27	791	4.54
NC13-1	f28	894	4.29
NC13-1	f29	121	4.81
NC13-1	f29	220	5.58
NC13-1	f30	132	3.52
NC14-1	f01	312	-0.33
NC14-1	f05	221	1.38
NC14-1	f05	311	-3.85
NC14-1	f11	895	-3.94
NC14-1	f12	797	-6.25
NC14-1	f13	222	0.49
NC14-1	f15	332	-1.37
NC14-1	f16	125	1.39
NC14-1	f16	126	-0.77
NC14-1	f18	414	0.72
NC14-1	f18	423	1.36
NC14-1	f19	225	0.92
NC14-1	f20	137	0.99
NC14-1	f21	436	0.84
NC14-1	f22	127	0.87
NC14-1	f22	224	1.33
NC14-1	f23	338	0.83
NC14-1	f23	896	1.6
NC14-1	f24	216	1.76
NC14-1	f24	217	1.43
NC14-1	f25	128	1.41
NC14-1	f25	129	1.33
NC14-1	f26	134	1.1
NC14-1	f26	233	1.44
NC14-1	f27	130	1
NC14-1	f27	231	0.6
NC14-1	f28	335	1.16
NC14-1	f28	698	1.02
NC14-1	f29	433	2.68

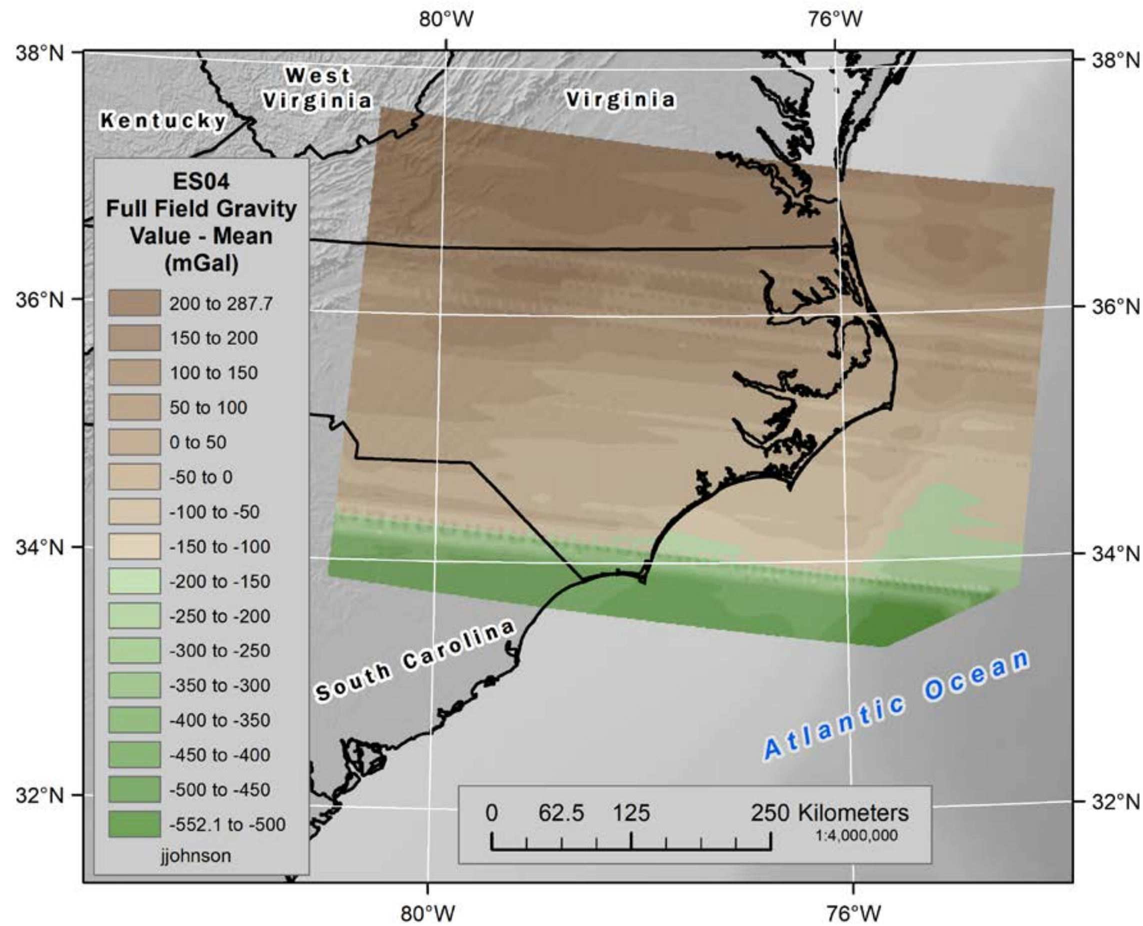

Figure 4: Full-field gravity at altitude (mean removed) for Block ES04. This is the data in the gravity release ".txt" file and includes the effects of differing altitudes along flight lines.

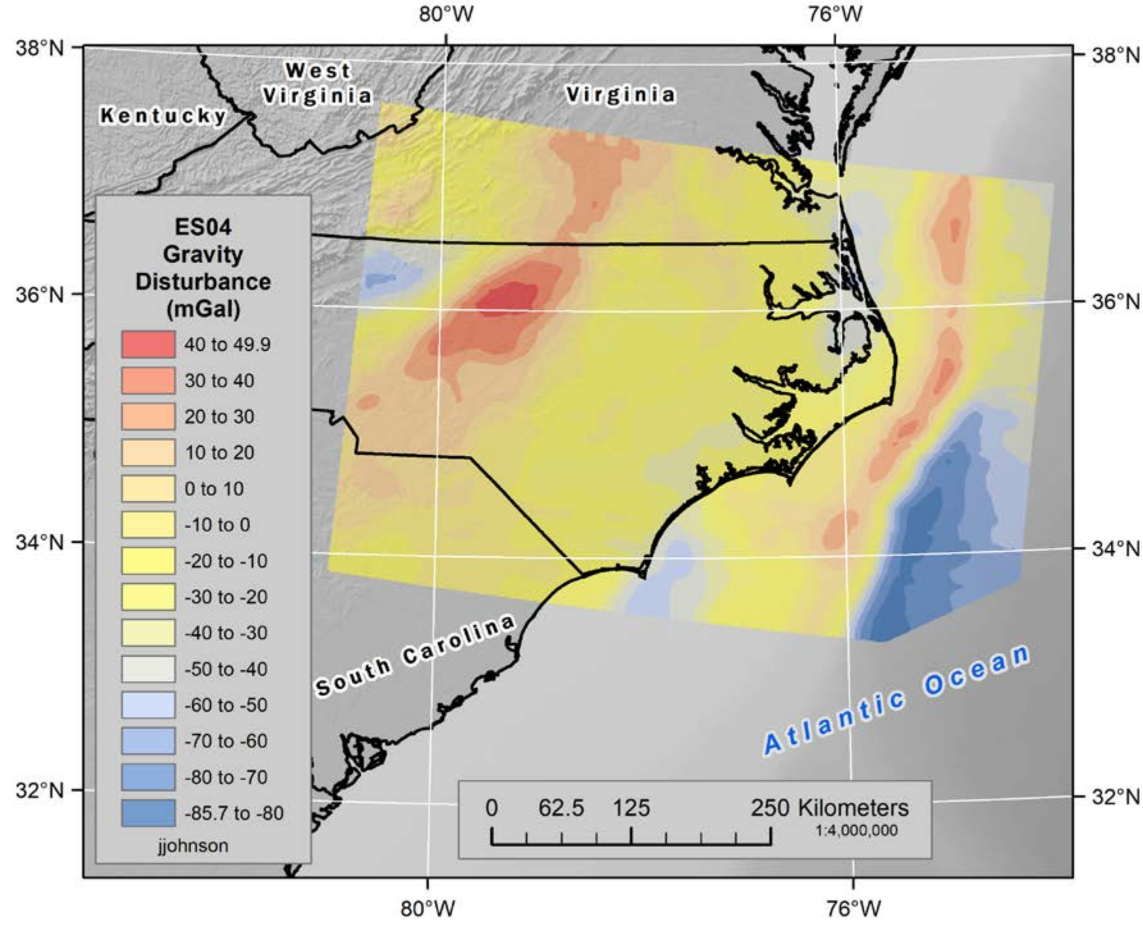

Figure 5: Gravity disturbance for Block ES04 with respect to the GRS80 ellipsoid.

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, Sandra A. Martinka Preaux, Chris Villarreal, Derek van Westrum, Carly A. Weil, Tim G. Wilkins, and Monica A. Youngman.

To reference the ES04 data file, reference the webpage:
GRAV-D Team (2019). "Gravity for the Redefinition of the American Vertical Datum (GRAV-D) Project, Airborne Gravity Data; Block ES04". Available *DATE*. Online at: http://www.ngs.noaa.gov/GRAV-D/data_ES04.shtml

To reference the block and survey details, reference the block user manual:
GRAV-D Team (2019). "Block ES04 (Eastern South 04); GRAV-D Airborne Gravity Data User Manual." Monica Youngman, Carly Weil, and Jeff Johnson, ed. Version BETA. Available *DATE*. Online at: http://www.ngs.noaa.gov/GRAV-D/data_ES04.shtml

To reference the general GRAV-D project operations, reference the General User Manual:
GRAV-D Team (2017). "GRAV-D General Airborne Gravity Data User Manual." Theresa Damiani, Monica Youngman, and Jeff Johnson, ed. Version 2.1 Available *DATE*. Online at: http://www.ngs.noaa.gov/GRAV-D/data_ES04.shtml

5. References

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