

# Block ES06 (Eastern South 06)

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*GRAV-D Airborne Data Release User Manual*

*Applies to Data Release BETA #1, 5/2018*

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## Version Notes

**5/2018 BETA #1:** First release

## 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 **ES06** is located in the **E**astern Time Zone, in the **S**outh half (south of 40° latitude). This was the sixth (**06**) block of data completed in that region. Block ES06 is 240 km by 230 km, covering parts of Alabama, Florida, and Georgia including coastal Florida ([Figure 1](#)). The corner coordinates defining Block ES06 are listed in [Table 1](#).

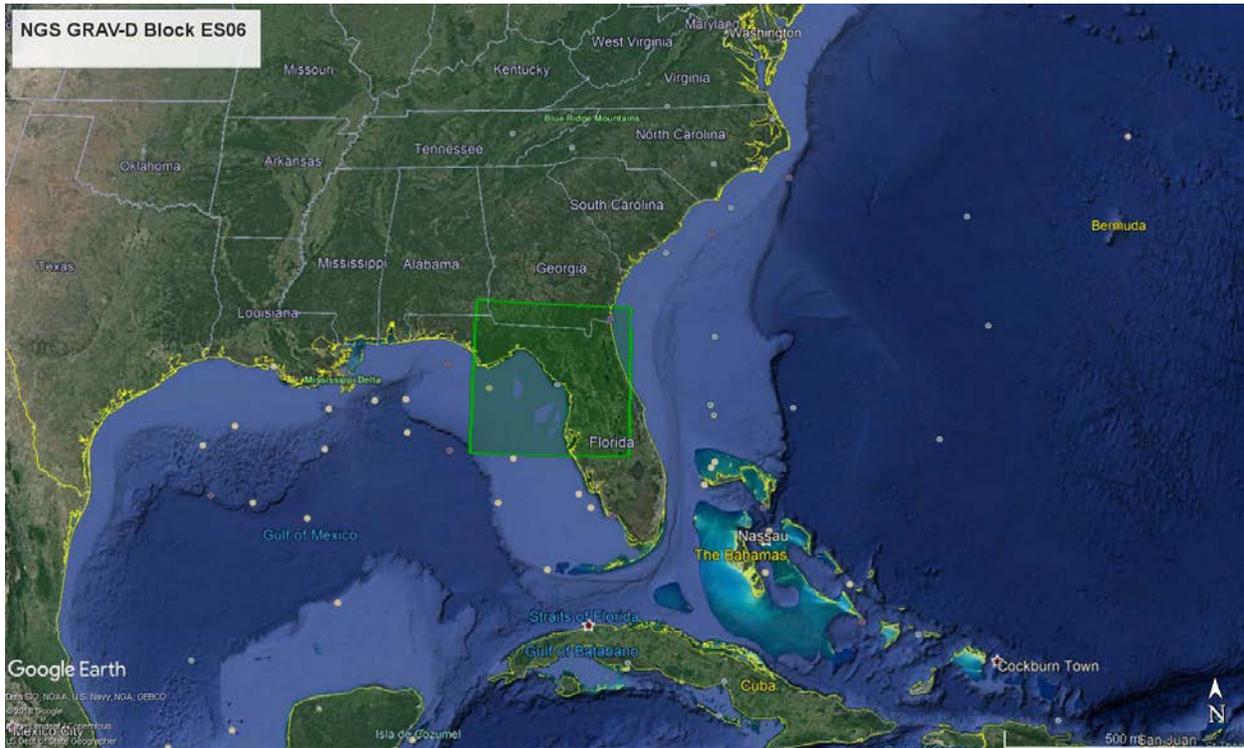


Figure 1: Google Earth Image of the Location of Block ES06

Table 1: Latitude and Longitude Coordinates of Corner Points Defining Block ES06

Latitude (decimal degrees)	Longitude (decimal degrees)
31.379810173	-85.451390430
27.452188520	-85.528963859
27.304881337	-81.023126349
31.078915813	-80.836219732

## 2. Survey Design and Execution

Airborne gravity data in Block ES06 were collected during two surveys: FL15-2 (Florida 2015, second occupation) and FL16-1 (2016, first occupation). Data lines from FL15-2 and FL16-1 were flown at approximately 20,000 ft. ES06 was surveyed with one aircraft and one relative gravimeter. 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 ES06, data lines are East-West and cross lines are North-South. The block consists of 29 data lines and 4 cross lines from FL15-2 and 23 data lines and 2 cross lines from FL16-1. Four data lines were flown twice and labeled as: ES06112/ES06212, ES06134/ES06234, ES06135/ES06235, and ES06142/ES06242. Also, cross line 503 is pieced together as ES06503/ES06603, but does not count as a reflight line set since there is very little overlap. 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. ES06101= block ES06’s line 101).

*Table 2: Survey Overview*

Coducting Organization	NOAA- National Geodetic Survey/Fugro EarthData Systems	
Survey Name	FL15-2	FL16-1
Airport Base of Operations	New Smyrna Beach Municipal Airport (EVB) New Smyrna, FL FBO: Atlantic Aviation	New Smyrna Beach Municipal Airport (EVB) New Smyrna, FL FBO: Atlantic Aviation
Geographic Location	Alabama, Georgia, Florida, and Coastal Florida	
Dates of Airborne Operations	Dec 11 - Mar 23, 2016	Oct 26 - Nov 23, 2016

*Table 3: Aircraft and Instrumentation*

Aircraft (Surveys)	Fugro Cessna Conquest (N93HC)
Engines, number and type	2, Turboprop
Gravity Instrumentation	Micro-g LaCoste (MGL) TAGS S-160 (relative) MGL A-10 (absolute) LaCoste and Romberg D-43 and G-6 (relative)
GPS Instrumentation	NovAtel DL-V3 or DL-4 Plus NovAtel SPAN-SE with Honeywell $\mu$ IRS (GPS + IMU)

Table 4: Survey Design and Execution

Line Spacing	Data Lines: 10 km Cross Lines: ~80 km
Type of Layout	Regular data lines & regular cross lines
Nominal Survey Altitude	20,000 ft.
Nominal Aircraft Ground Speed	250 knots
Number of Lines Released	Data Lines: 29 (FL15-2), 23 (FL16-1) Cross Lines: 4 (FL15-2), 2 (FL16-1) Repeat Lines: 4 data line flown twice, 1 cross line with two parts (not considered reflight)
Number of Crossovers	257

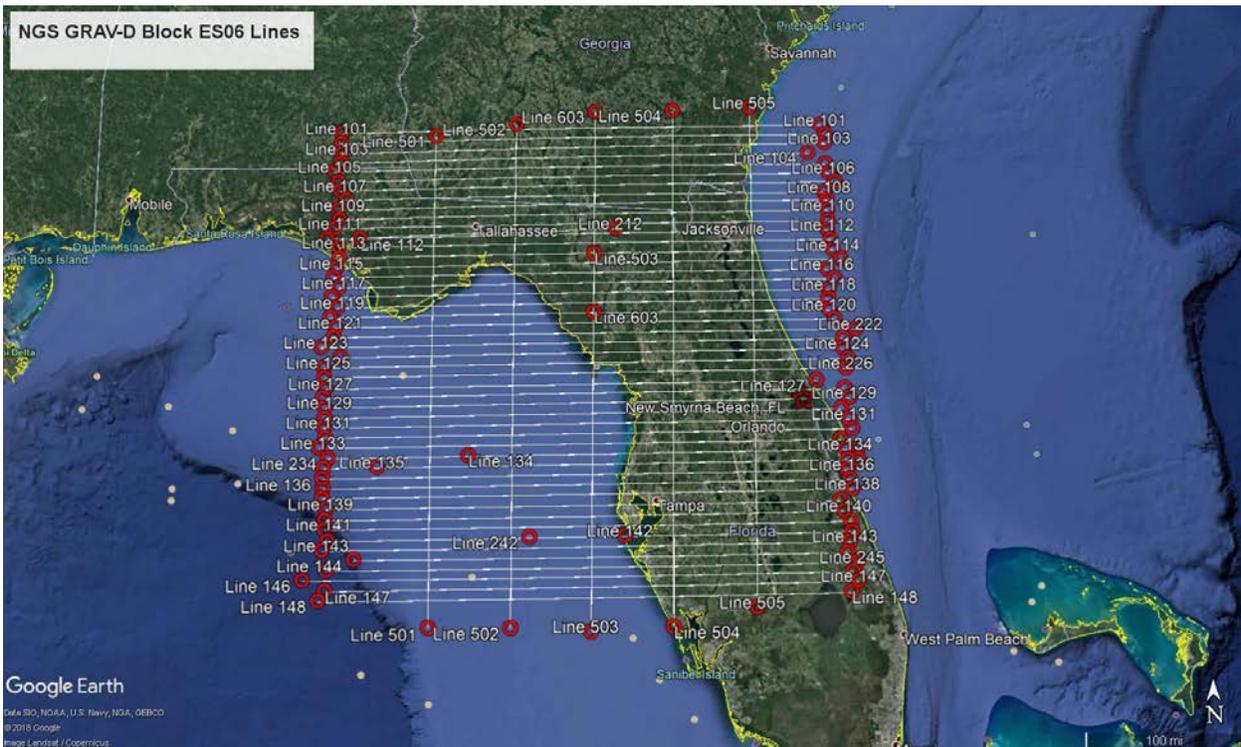


Figure 2: Data Coverage for ES06. Data lines range from 101 to 148. New Smyrna Beach Municipal Airport (EVB) is marked with a red star.

## 2.1 GPS/IMU Instrumentation

The Fugro Cessna Conquest had one GPS antenna available for scientific measurements. Two geodetic-quality GPS receivers shared the antenna: either a NovAtel DL-V3 or NovAtel DL-4 Plus (included as part of the TAGS gravimeter timing unit) and a NovAtel SPAN-SE. The NovAtels' had a data rate of 1 Hz. The NovAtel SPAN-SE system included a Litton (LN-200) 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-Extreme antenna/receivers for FL15-2 and FL16-1 recording at 1 Hz 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 Cessna Conquest. The TAGS records data at 1 Hz 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 TAGS was mounted to the seat tracks in the center of the fuselage of the aircraft. 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 right, Y positive toward the nose, and Z positive up.)

Table 5: Lever Arm Measurements FROM the SPAN TO the Other Instruments

Instrument/Location (N43U)	X (m)	Y (m)	Z (m)
Gravimeter (TAGS 160)	0.016	0.010	-0.476
Aircraft GPS Antenna	0.127	-1.390	0.408

## 3. GPS and Gravity Data Processing

### 3.1 Whole-Survey Applicable Details

#### 3.1.1 GPS

Table 6: GPS High Rate Data Availability (1 Hz or higher)

Airport	Type	Receiver	Flight Available	Day of Year Available (UTC)
FL15-2 EVB	Kinematic	NovAtel (SPAN)	f06-f10, f14-f16, f18-f21, f24-27, f30	18-21, 25, 26, 33, 34, 37, 43- 46, 66-68, 71, 84
	Static	Ashtech EVB1	f06-f10, f14-f16, f18-f21, f24-27, f30	18-21, 25, 26, 33, 34, 37, 43- 46, 66-68, 71, 84
		Ashtech EVB2	f06-f10, f14-f16, f18-f21, f24-27, f30	18-21, 25, 26, 33, 34, 37, 43- 46, 66-68, 71, 84
FL16-1 EVB	Kinematic	NovAtel (SPAN)	f02-f10	303-309, 311, 323, 328
	Static	Ashtech EVB1	f02-f10	303-309, 311, 323, 328
		Ashtech EVB2	f02-f10	303-309, 311, 323, 328

Data were processed using GRS80 and ITRF08. After post-processing the GPS-only kinematic data (before processing with coupled IMU), average position accuracy for the data block is calculated. 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  $\pm 0.050$  m and the average vertical position accuracy is  $\pm 0.081$  m (95% confidence interval).

### 3.1.2 Ground Gravity Tie

Absolute gravity measurements were performed by NGS with a Micro-g LaCoste A-10 gravimeter in January 2015 (EVB). 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. [Table 7](#) is a summary of the point ID, location and gravity tie from each of the airports.

*Table 7: Gravity Ties at the height of the TAGS Gravimeter in the airplane.*

Airport	Point ID	Latitude	Longitude	Tie height above mark (cm)	Gravity Tie (mGal)
EVB	KEVB TAGS	29.05725°N	-80.94329°W	162.5	979259.222 $\pm$ 0.008

### 3.1.3 Gravity Filtering

For block ES06, flights were accomplished in three surveys and were filtered the same way. 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

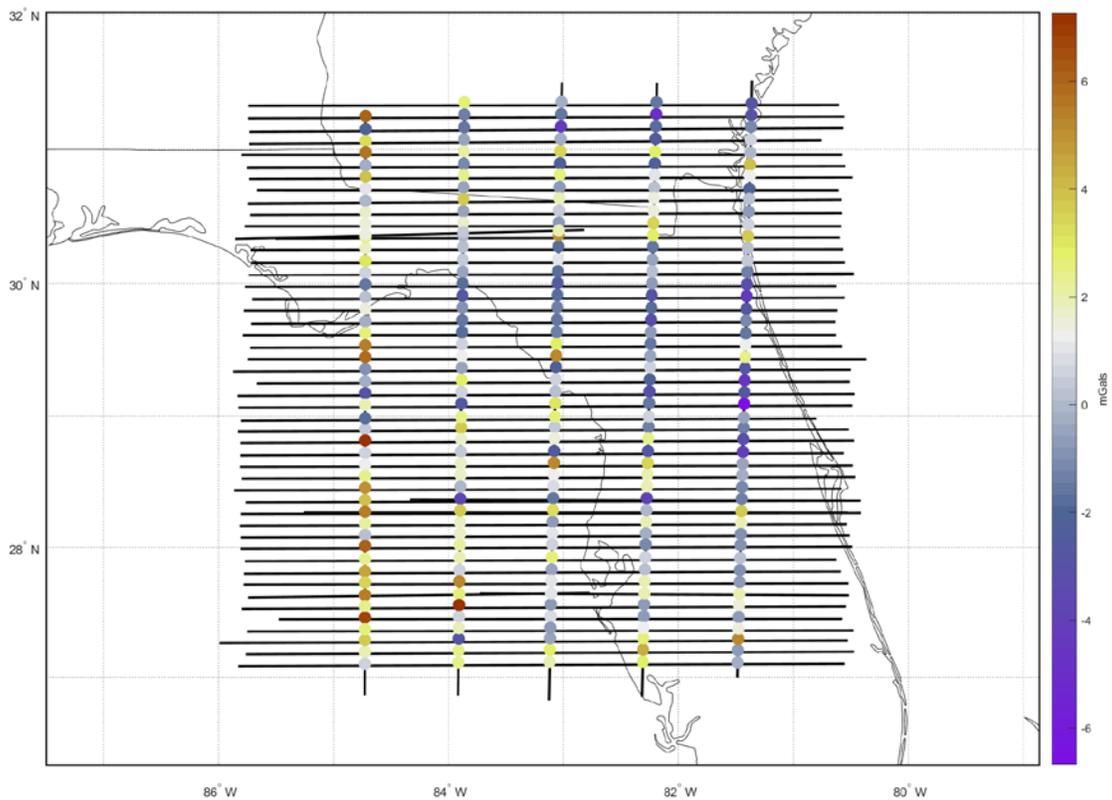
### 3.2.1 Gravity Error Analysis

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 ES06, 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)
20,000	6,096	6,405	257	2.46	2.40	0.58	1.74

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.



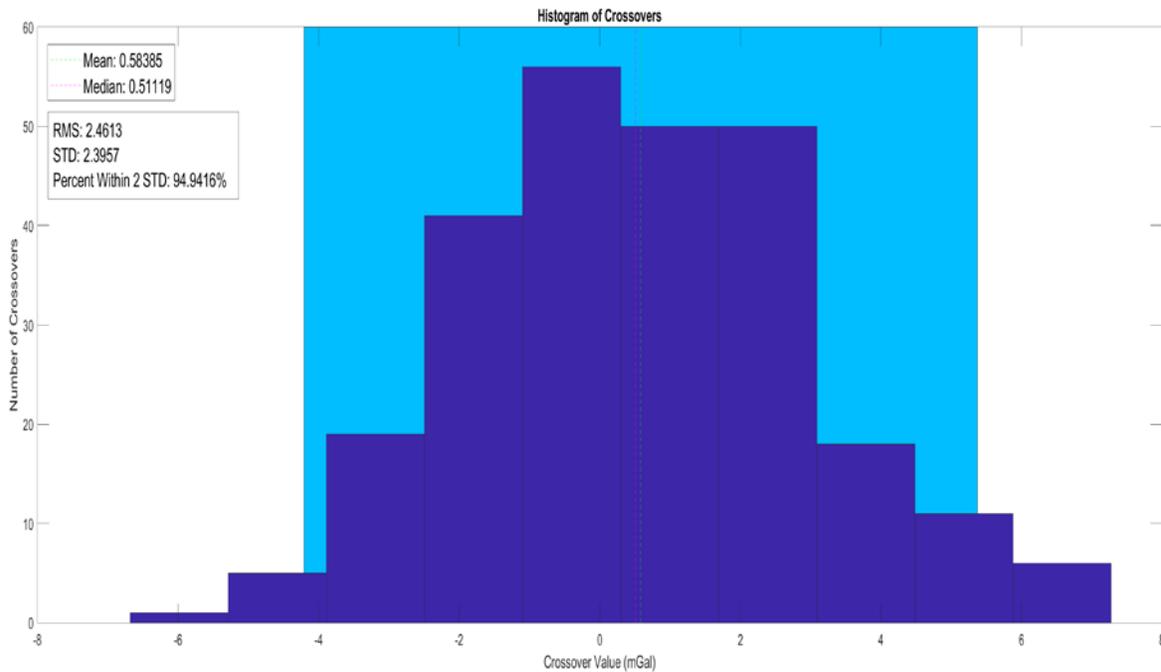


Figure 3: Crossover Residuals, Histogram, and Statistics for Block ES06

Table 9: Quality of Cross Lines Used in Crossover Analysis

Cross Line Number	Standard Deviation of Residuals Along Line (mGal)	Mean of Residuals Along Line (mGal)
501	2.47	2.30
502	2.08	0.81
503	1.88	0.83
603	2.30	-0.19
504	2.18	-0.06
505	2.27	-0.56

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
42	94.53%	5.77%

A fourth way of gauging data quality is by calculating the repeatability of the gravity signal along reflow lines of good quality. Reflight analysis can also help to pinpoint the lightest filtering that produces highly-correlated results. In ES06 4 data line were re-flown as ES06112/ES06212, ES06134/ES06234, ES06135/ES06235, and ES06142/ES06242. The correlations between these re-flown lines are found in ([Table 11](#)).

Table 11: Correlations between Reflow Lines

Survey	Line Track Number	Correlation
FL16-1	ES06112	97.85%
FL16-1	ES06212	
FL15-2	ES06134	97.79%
FL15-2	ES06234	
FL15-2	ES06135	98.79%
FL15-2	ES06235	
FL15-2	ES06142	98.49%
FL15-2	ES06242	

### 3.3 Flight- and Line-Specific Details

#### 3.3.1 GPS processing- by flight

GPS data were processed in Inertial Explorer (IE) v. 8.7. 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 both Inertial Explorer. 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.”

During survey FL15-2 there were numerous GPS data quality issues with the SPAN GPS receiver that may have been caused by a bad cable or some other electronic malfunction. In most cases a Differential solution using data from the gravimeter related receiver and base station EVB1 yielded the solution with the best quality control statistics. Occasionally, a different solution type yielded the best statistics. See [Table 12](#) for details on how each flight was processed.

### 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 12: GPS+IMU and GPS-only Kinematic Processing Results

Survey	Flight	Rover GPS Unit	Solution Type	Elevation Mask (deg)	Line Num.	NGS Quality Grade
FL15-2 EVB	6	DL-V4	GPS + IMU Differential	5	147	100
					148	100
	7	DL-V4	GPS + IMU Differential	5	146	100
	8	DL-V4	GPS + IMU Differential	5	144	100
					245	100
	9	DL-V4	GPS + IMU Differential	5	142	100
					143	100
	10	DL-V4	GPS + IMU Differential	5	140	100
					141	100
					242	100
	14	SPAN	GPS + IMU PPP	5	136	100
					237	100
	15	DL-V4	GPS + IMU PPP	7.5	134	100
					135	100
	16	DL-V4	GPS + IMU Differential	5	138	100
					139	100
	18	DL-V4	GPS + IMU Differential	5	234	100
					235	100
	19	DL-V4	GPS + IMU Differential	5	132	100
					133	100
20	DL-V4	GPS + IMU Differential	5	130	100	
				131	100	
21	DL-V4	GPS + IMU Differential	5	128	100	
				129	100	
24	DL-V4	GPS + IMU PPP	5	127	100	
25	DL-V4	GPS + IMU Differential	5	124	100	
				125	100	
26	DL-V4	GPS + IMU Differential	5	123	100	
				226	100	

	27	DL-V4	GPS + IMU PPP	5	503	100
					504	100
					505	100
	30	DL-V4	GPS + IMU Differential	5	603	100
FL16-1 EVB	2	SPAN	GPS + IMU PPP	5	121	100
					222	100
	3	SPAN	GPS + IMU PPP	5	117	100
					118	100
					119	100
					120	100
	4	SPAN	GPS + IMU PPP	5	113	100
					114	100
					115	100
					116	100
	5	SPAN	GPS + IMU PPP	5	112	100
	6	SPAN	GPS + IMU PPP	5	102	100
					103	100
	7	SPAN	GPS + IMU PPP	5	101	100
					501	100
	8	SPAN	GPS + IMU PPP	5	108	100
					109	100
					110	100
					111	100
	9	SPAN	GPS + IMU PPP	5	104	100
212					100	
502					100	
10	SPAN	GPS + IMU PPP	5	105	100	
				106	100	
				107	100	

Table 13: Gravity Processing Results

Survey	Flight Num.	Line Num.	Time of Deleted Data	Comments
FL15-2 EVB	10	140	2016-01-26 01:06:46 - 2016-01-26 01:08:53	Bump Removed

Table 14: Bias from EGM08 by Line

Survey	Flight Num.	Line	EGM08 mean
FL15-2 EVB	6	147	3.39
		148	3.72
	7	146	4.46
	8	144	4.2
		245	3.19
	9	142	2.01
		143	2.25
	10	140	3.41
		141	3.29
		242	3.05
	14	136	4.58
		237	3.7
	15	134	4.7
		135	2.38
	16	138	3.16
		139	2.77
	18	234	4.75
		235	2.34
	19	132	3.61
		133	3.05
	20	130	4.33
		131	2.82
	21	128	3.61
		129	3.19
	24	127	3.32
	25	124	4.19
		125	3.22
	26	123	3.85
226		4.32	
27	503	4.61	
	504	4.26	
	505	3.74	
30	603	4.97	
FL16-1 EVB	2	121	3.3
		222	2.13
	3	117	6.39
		118	4.47
		119	5.4

	120	4.04
4	113	6.32
	114	4.65
	115	5.75
	116	5.26
5	112	3.4
6	102	6.57
	103	5.77
7	101	5.61
	501	6.67
8	108	4.75
	109	3.67
	110	4.35
	111	3.42
9	104	5.18
	212	5.46
	502	4.99
10	105	3.08
	106	4.57
	107	3.5

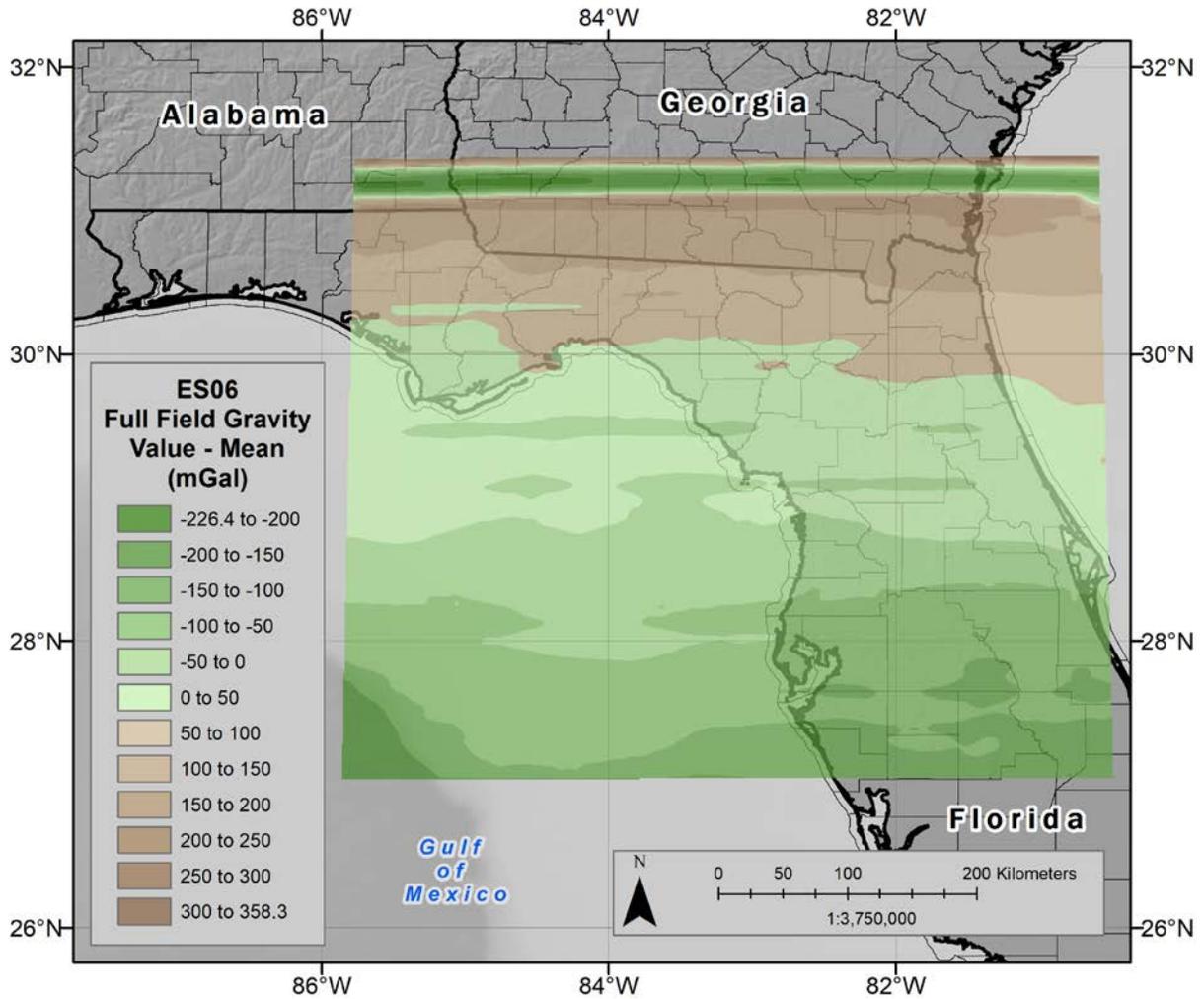


Figure 4: Full-field gravity at altitude (mean removed) for Block ES06. This is the data in the gravity release “.txt” file and includes the effects of differing altitudes along flight lines.

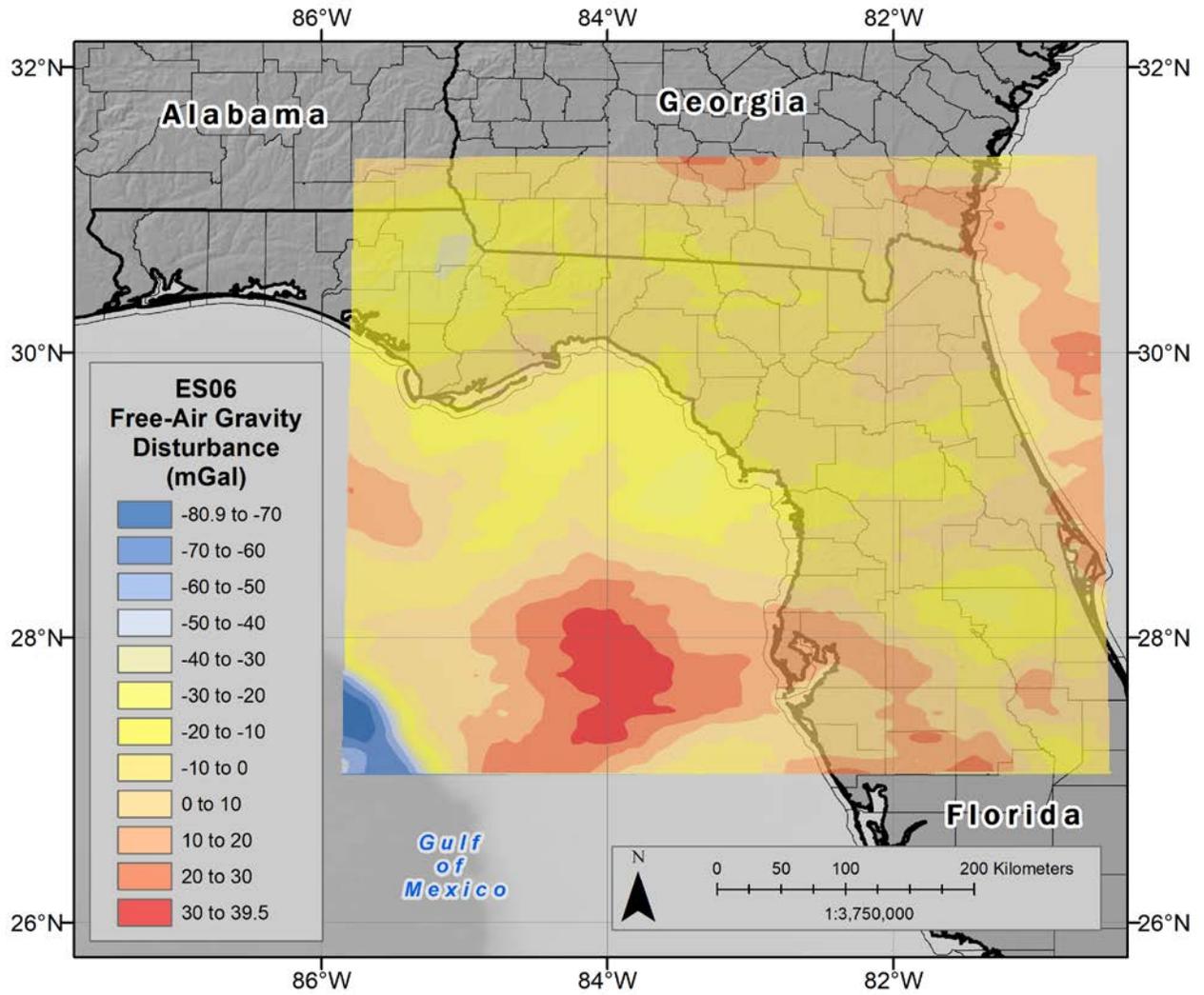


Figure 5: Free-air gravity disturbance for Block ES06 with respect to the GRS80 ellipsoid

## 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 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: Kevin Ahlgren, Vicki A. Childers, Justin Dahlberg, Theresa M. Damiani, Jeff Kanney, Jeffery A. Johnson, Chris Villarreal, Derek van Westrum, and Monica A. Youngman.

To reference the ES06 data file, reference the webpage:

GRAV-D Science Team (2018). "Gravity for the Redefinition of the American Vertical Datum (GRAV-D) Project, Airborne Gravity Data; Block ES06". Available *DATE*. Online at: [http://www.ngs.noaa.gov/GRAV-D/data\\_ES06.shtml](http://www.ngs.noaa.gov/GRAV-D/data_ES06.shtml)

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

GRAV-D Science Team (2018). "Block ES06 (Eastern South 06); GRAV-D Airborne Gravity Data User Manual." Monica A. Youngman and Jeffery A. Johnson, ed. Version BETA. Available *DATE*. Online at: [http://www.ngs.noaa.gov/GRAV-D/data\\_ES06.shtml](http://www.ngs.noaa.gov/GRAV-D/data_ES06.shtml)

To reference the general GRAV-D project operations, reference the General User Manual:

GRAV-D Science Team (2017). "GRAV-D General Airborne Gravity Data User Manual." Theresa Damiani, Monica Youngman, and Jeffery Johnson, ed. Version 2.1. Available *DATE*. Online at: [http://www.ngs.noaa.gov/GRAV-D/data\\_products.shtml](http://www.ngs.noaa.gov/GRAV-D/data_products.shtml)

## 5. References

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