Block CS01 (Central South 01)

GRAV-D Airborne Data Release User Manual

Applies to Data Release #1, 08/2011

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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 2021. 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 U.S. 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. 1.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 **CS01** is located in the **C**entral Time Zone, in the **S**outh half (south of 40° latitude). This was the first (**01**) block of data completed in that region. Block CS01 is in the Gulf of Mexico, covering coastal areas of the Alabama/Florida state border to ~350 km (215 miles) offshore (Figure 1: Google Earth Image of the Location of Block CS01 (black rectangle) with respect to the Continental United States.). The corner coordinates defining Block CS01 are listed in Table 1.

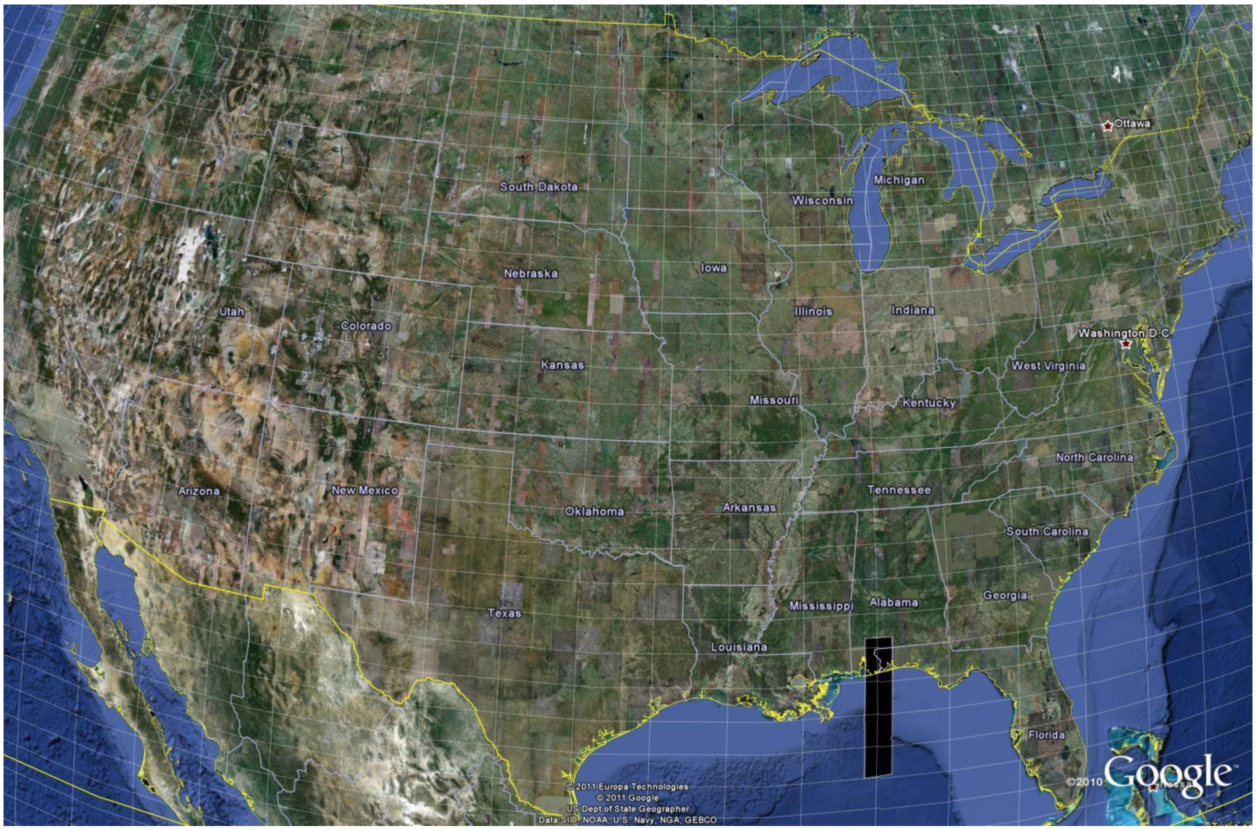

Figure 1: Google Earth Image of the Location of Block CS01 (black rectangle) with respect to the Continental United States.

Table 1: Latitude and Longitude Coordinates of Corner Points Defining Block CS01

Latitude (decimal degrees)	Longitude (decimal degrees)
27.084022234	-87.958450135
27.148610674	-86.991447083
31.327020618	-86.984881422
31.340498956	-87.949864497

2. Survey Design and Execution

All airborne gravity data in Block CS01 were collected during the AL08 (Alabama 2008) survey. This survey was the first flown for GRAV-D and was designed as a proof-of-concept survey. The official NGS product from this survey includes only flights done at 20,000 ft. Supplementary, experimental data were collected during the survey at 5,500 ft and 35,000 ft and may be made available in separate, future releases. Table 2, Table 3, and Table 4 give a synopsis of survey layout and execution for the 20,000 ft data. Figure 2 shows the data coverage, plotted in Google Earth.

The survey was designed with 10 North-South data lines and two East-West cross lines. The lines are located mostly out over the water of the Gulf of Mexico, but include small portions of the Alabama and Florida coast. Data line spacing is 10 km.

Because of the unusual survey layout, at three altitudes, the usual line numbering scheme used by GRAV-D (see “General User Manual”) was modified for this survey. The line numbers listed below were used for this block’s 20,000 ft data. In the data file, line numbers are preceded by the block name (i.e. CS01201= block CS01’s line 201).
200s = Data Lines at 20,000 ft
600s = Cross Lines at 20,000 ft

Table 2: Survey Overview

Conducting Organization	NOAA- National Geodetic Survey
Survey Name	AL08
Airport Base of Operations	Montgomery Regional Airport (MGM) Montgomery, AL FBO: Montgomery Aviation
Geographic Location	Gulf of Mexico, AL/FL border
Survey Size	100 km x 500 km
Dates of Airborne Operations	January 20 – February 10, 2008

Table 3: Aircraft and Instrumentation

Aircraft	NOAA Cessna Citation II (N52RF)
Engines number and type	2, Jet
Gravity Instrumentation	Micro-g LaCoste (MGL) TAGS S-137 (relative) MGL A-10 (absolute)
GPS Instrumentation	NovAtel DL-4 Plus Applanix POS AV 510 (GPS + IMU)

Table 4: Survey Design and Execution

Line Spacing	Data Lines: 10 km Cross Lines: ~275 km
Type of Layout	Regular data lines & irregular tie lines
Nominal Survey Altitude	20,000 ft
Nominal Aircraft Ground Speed	280 knots
Number of Lines Completed	Data Lines: 10 Cross Lines: 2 Repeat Lines: 0
Potential Number of Crossovers	20

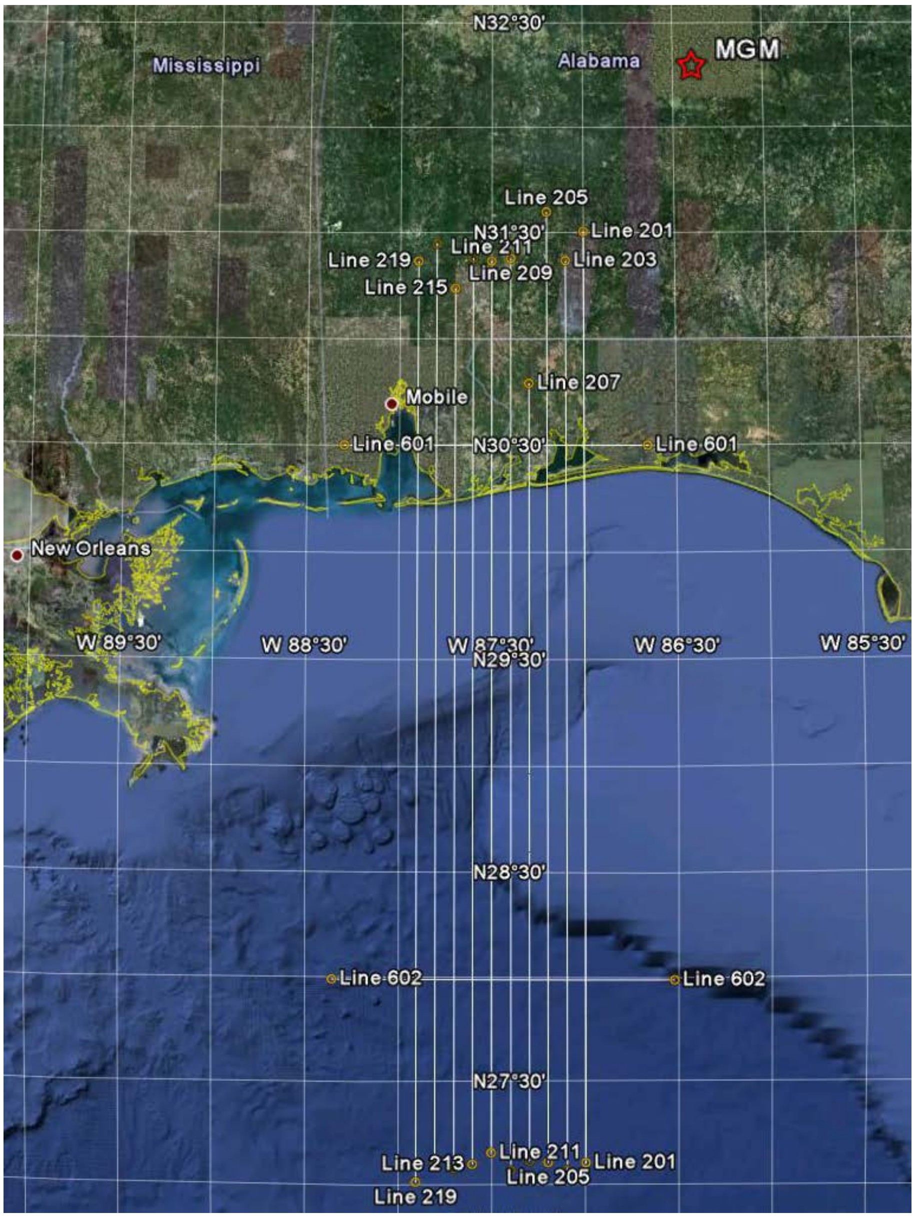

Figure 2: Data Coverage at 20,000 ft. Data lines start in the east at 201 and go west to 219. Cross lines are 601 in the north and 602 in the south. Airport marked with red star.

2.1 GPS/IMU Instrumentation

The NOAA Cessna Citation II had two GPS antennas available for scientific measurements, but only the rear antenna was used. Two geodetic-quality GPS receivers shared the antenna: a NovAtel DL-4 Plus (included as part of the TAGS gravimeter timing unit) and a Trimble (inside the Applanix POS AV 510 system). The NovAtel had a data rate of 1 Hz and the Trimble of 10Hz. The Applanix POS AV 510 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, a backup NovAtel DL-4 Plus (TAGS timing unit) recording at 1 Hz served as a GPS base station throughout the survey. The minimum elevation mask used for recording data on the base station NovAtel was set to 10 degrees, which limits the mask that can be used in post-processing to 10 degrees or higher. Additional 1 Hz rate data were collected from nearby Continuously Operating Reference Stations (CORS) for potential use in positioning and use as backup base stations. See Section 3.2.1 GPS processing- by flight 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 Citation. 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).

At the time, the TAGS was in its original, experimental rack and not approved by the FAA for mounting to seat tracks. An FAA-approved rack was later acquired by GRAV-D in 2010. Thus, for this survey the TAGS was mounted in the far back of the plane, in the center of the cargo area. 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 5: Lever Arm Measurements FROM the Center of the Gravimeter's Sensor TO the Other Instruments, for this Installation on the NOAA Cessna Citation II

Instrument/Location	X (m)	Y (m)	Z (m)
Aircraft Center of Gravity	0.85	0.00	0.40
Aircraft GPS Antenna (Rear)	2.87	-0.15	-0.91
Applanix POS AV 510 IMU	0.15	-0.10	-0.41

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)

Type	Receiver	Flight Available	2008 Day of Year Available
Kinematic	NovAtel (0013)	F19-F22, F24-F25	34-35, 39-41
	Trimble (mgps)	F19-F22, F24-F25	34-35, 39-41
Static	NovAtel (0016)	F19-F22, F24-F25	34-35, 39-41
	CORS AL60	F19-F22, F24-F25	34-42
	CORS AL90	F19-F22, F24-F25	34-42
	CORS CRST	F19-F22, F24-F25	34-42
	CORS GRIS	F19-F22, F24-F25	34-42
	CORS MSGA	F19-F22, F24-F25	34-42
	CORS MSPC	F19-F22, F24-F25	34-42
	CORS MSSC	F19-F22, F24-F25	34-42
	CORS PCLA	F19-F22, F24-F25	34-42

Table 7: NGS GPS Base Station Position(s)

Base Name	Antenna Type	Latitude (dec deg)	Longitude (dec deg)	Ellipsoidal Height (m)
NovAtel (0016)	NovAtel 702_2.02	32.304817040	-86.392594960	34.791

Data were processed using WGS84 and ITRF00. After post-processing the GPS-only kinematic data, 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 average to provide a survey-wide estimate of GPS position accuracy. For the data lines, the average horizontal position accuracy is 0.028 m and the average vertical position accuracy is 0.027 m.

3.1.2 Ground Gravity Tie

An updated absolute gravity measurement was performed by NGS with a Micro-g LaCoste A-10 gravimeter in spring of 2011. The A-10 was set up at the Montgomery Aviation FBO, at the exact location that the aircraft was parked for the AL08 survey. That location is designated as MGM TAGS (32.30536036°N, 86.39322381°W) and its position coordinates were determined from the GPS collected during the gravity survey while the plane was parked. The MGM TAGS location has an absolute gravity value of 979494.51272 ± 0.008 mGal at 125 cm above the tarmac.

3.1.3 Gravity Filtering

For block CS01, all flights were accomplished during the same survey and were filtered the same way. Newton v1.2 uses a time-domain Gaussian filter that is applied three times to the data during final filtering. The Gaussian filter chosen for this survey has a 6-sigma of 120s, i.e. a 2-sigma of only 40 s. 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.

3.1.1 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. The 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 CS01, the result of the crossover analysis is shown in Table 8 and in Figure 3.

Table 8: Gravity Crossover Error Analysis for the CS01 block

Nominal Altitude (ft)	Nominal Altitude (m)	Altitude for Analysis (m)	Number of Crossovers	RMS Of Residuals (mGal)	Std. Dev. Of Residuals (mGal)	Mean Crossover Difference (mgal)	RMS Error (mGal)
20,000	6,096	6,320	20	3.14	3.21	-0.23	1.77

One assumption of crossover analysis is that the quality of the cross lines is high and that the crossover difference reflects only the error in the data lines. This is not necessarily the case. For block CS01, the cross lines were noticeably noisier than the data 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, which would produce false crossover statistics that indicate poor data line quality.

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)
601	2.26	-2.63
602	1.98	2.17

Another way to evaluate the quality of gravity data is to calculate the correlation of the gravity values along two adjacent 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 does not 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.

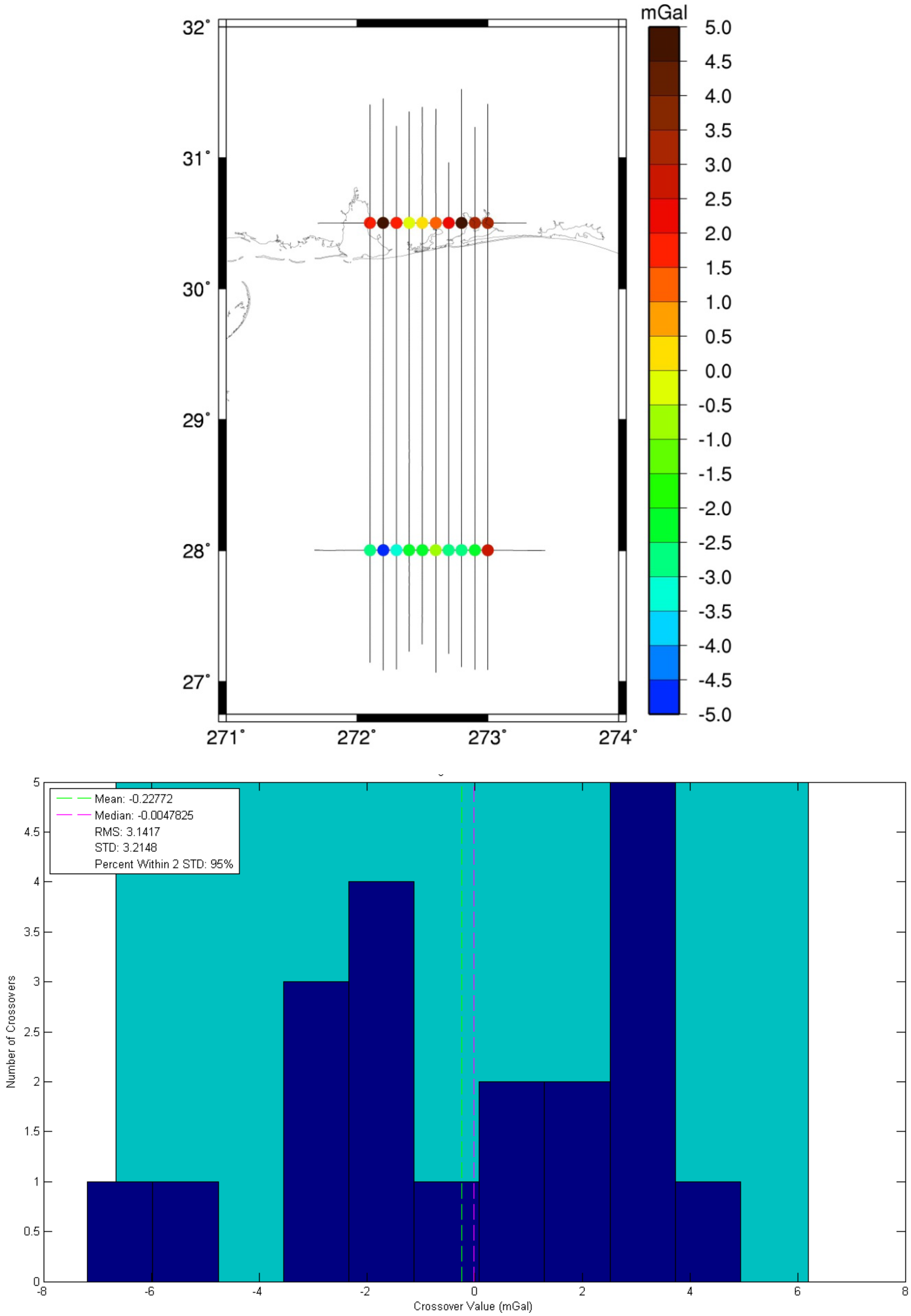

Figure 3: Crossover Residuals, Histogram, and Statistics for Block CS01.

Table 10: Average Data Line Correlation at Each Altitude

Nominal Altitude (ft)	Number of Correlations	Average Data Line Correlation	Standard Deviation of Correlations
20,000	9	99.92%	0.04%

A third 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. In CS01, there were no reflown lines at 20,000 ft. However, in the experimental data at 35,000 ft, lines 101 and 103 were reflown (named lines 401 and 403 on that second flight) because of low quality data on line 101. However, 103 and 403 are both of acceptable quality and can be compared to yield statistics about data repeatability. The filter length used on the 20,000 ft data produces a very high correlation in the reflown tracks, of almost 99%.

Table 11: Statistics from Reflown Data Lines of Acceptable Quality

Filter Length(s)	RMS Error (mGal)	Cross correlation
120	4.88	98.95%

A final way of estimating data quality is by comparing the full-field gravity results from block CS01 with the global gravity model EGM08's full-field gravity over the same area, at the same altitude. By subtracting the airborne from the EGM08 data (out to degree and order 2190), we produce a residual and statistics on that comparison (Figure 4).

3.2 Flight- and Line-Specific Details

3.2.1 GPS processing- by flight

GPS data were processed in GrafNav v.7.80.2315 for GPS-only position solutions and in POSPac v.4.4 for GPS+IMU position solutions. Positions were always obtained as GPS+IMU loosely-coupled solutions if the IMU data were collected. 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 POSPac 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 GrafNav and POSPac. 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."

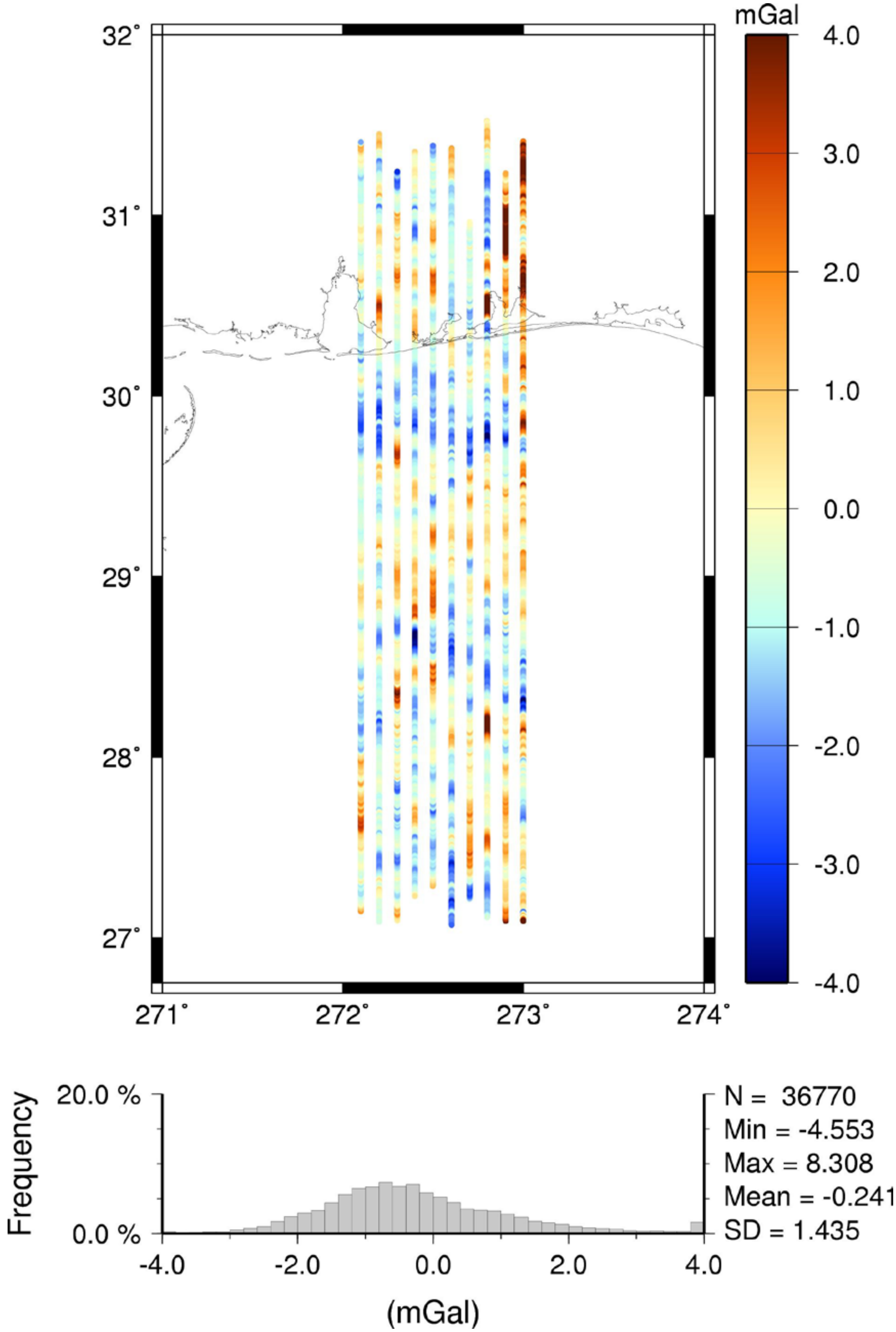

Figure 4: Block CS01 residuals for the GRAV-D full-field gravity minus EGM08 out to N=2190.

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

Flight Num.	Base GPS Unit(s)	Rover GPS Unit	Solution Type	Elevation Mask (degrees)	Comments	Line Num.	NGS Quality Grade
19	AL60	NovAtel	GPS+IMU	11	NovAtel base not working	201	80.20
						203	75.69
20	NovAtel	NovAtel	GPS+IMU	10	None	205	76.67
						207	68.47
21	NovAtel	NovAtel	GPS+IMU	13	None	209	69.79
						211	81.37
22	NovAtel	NovAtel	GPS+IMU	10	None	213	70.41
						215	58.94
24	NovAtel	NovAtel	GPS+IMU	10	None	217	83.07
						219	74.76
25	NovAtel	NovAtel	GPS+IMU	10.5	None	602	70.00
						601	60.00

3.2.2 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 5), although other gravity products such as free-air anomalies or free-air disturbances (Figure 6) can be easily calculated by following directions in Section 4 of the "GRAV-D General Airborne Gravity Data User Manual".

Table 13: Gravity Processing Results

Flight Number	Altitude (ft)	Line Number	Times of Deleted Data Sections (s)	Comments
19	20,000	201	None	None
		203	None	None
20	20,000	205	None	None
		207	None	None
21	20,000	209	None	None
		211	None	None
22	20,000	213	None	None
		215	None	None
24	20,000	217	None	None
		219	None	None
25	20,000	602	None	None
		601	None	None

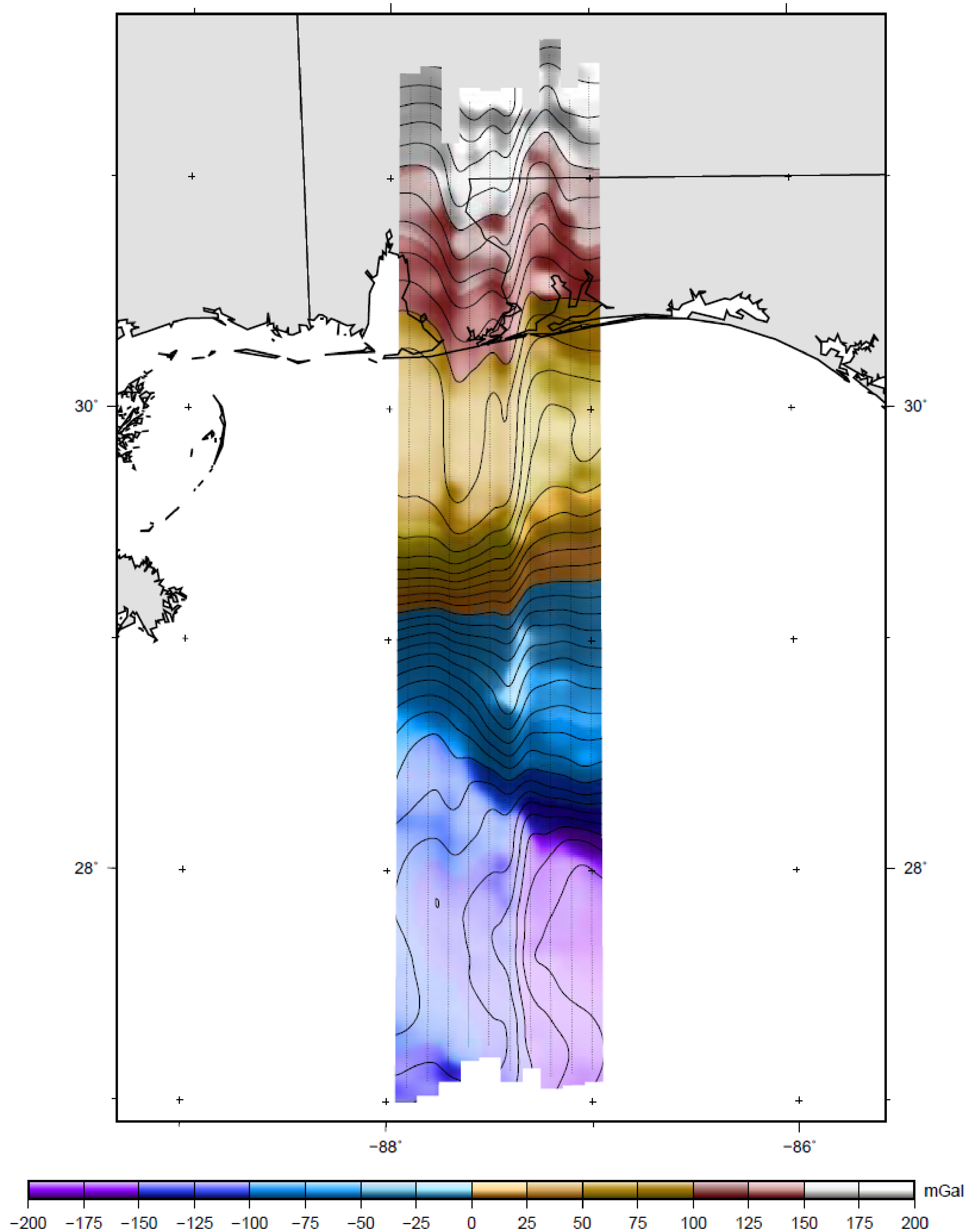

Figure 5: Full-field gravity at altitude (mean removed) for Block CS01. This is the data in the gravity release ".txt" file and includes the effects of differing altitudes along flight lines.

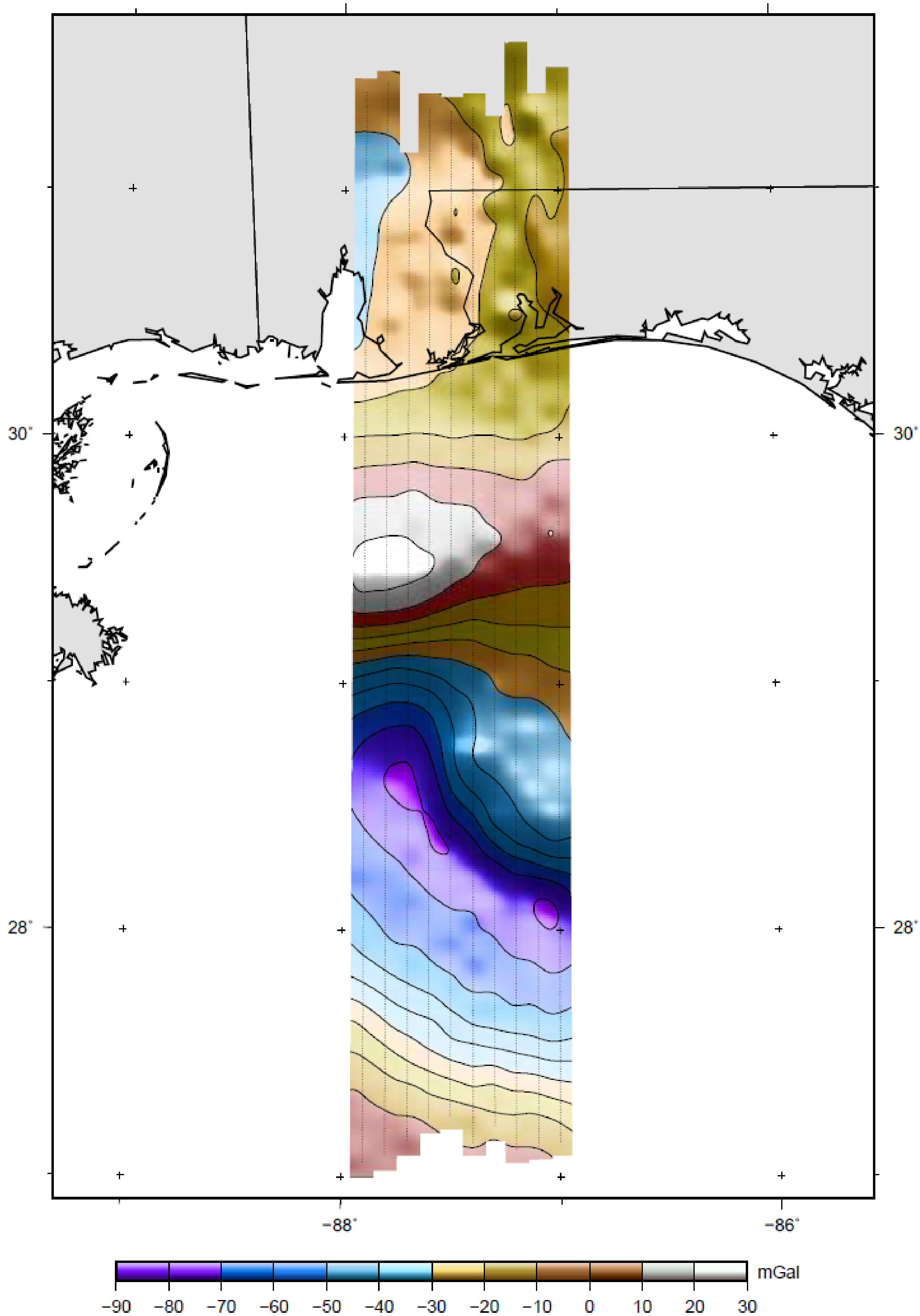

Figure 6: Free-air gravity disturbance for Block CS01 with respect to the WGS-84 ellipsoid.

4. Data Usage Guidelines

4.1 Suggested Data Handling

This data product was purposefully filtered to preserve the amplitude of the long-wavelength gravity signal. As a trade-off, the filter allows some short wavelength noise to remain in the product. Prior to use for geophysical purposes, the data should be run through a frequency-domain low-pass filter to remove that excess short wavelength noise. For geodetic purposes, higher frequencies can be damped during inclusion into a spherical harmonic model. In any case where downward continuation will be done with this data, the high frequency noise should first be filtered out, damped, or otherwise dealt with so that the downward continuation does not amplify the noise.

4.2 Documentation

The survey block User Manual, the general GRAV-D User Manual, and metadata for the block should all be downloaded with the data and kept in the same directory. The contents of the manuals are critical to correctly understanding the quality of the data and using the data properly.

4.3 How to Cite These Data

The following citations should be used in all presentations or publications that reference the GRAV-D work. Please replace the *DATE* tag in the following references with the date you downloaded the data or reports from the NGS website.

The GRAV-D Science Team, in alphabetical order, are: Vicki A. Childers, Theresa M. Damiani, Sandra A. Martinka Preaux, and Carly A. Weil.

To reference the CS01 data file, reference the webpage:
GRAV-D Science Team (2011). "Gravity for the Redefinition of the American Vertical Datum (GRAV-D) Project, Airborne Gravity Data; Block CS01". Available *DATE*. Online at: http://www.ngs.noaa.gov/GRAV-D/data_cs01.shtml

To reference the block and survey details, reference the block user manual:
GRAV-D Science Team (2011). "Block CS01 (Central South 01); GRAV-D Airborne Gravity Data User Manual." Theresa M. Damiani, ed., Version 1. Available *DATE*. Online at: http://www.ngs.noaa.gov/GRAV-D/data_cs01.shtml

To reference the general GRAV-D project operations, reference the General User Manual:
GRAV-D Science Team (2011). "GRAV-D General Airborne Gravity Data User Manual." Theresa M. Damiani, ed., Version 1. Available *DATE*. Online at: http://www.ngs.noaa.gov/GRAV-D/data_cs01.shtml

5. References

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