Block CS04 (Central South 04)

GRAV-D Airborne Data Release User Manual

Applies to Data Release BETA #2, 8/2014

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Version Notes

08/2014 BETA #2: Datum updated. Data in the first v.1 release (3/2013) were processed in ITRF00. Data in this version (BETA #2) were reprocessed using ITRF08.

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 **CS04** is located in the **C**entral Time Zone, in the **S**outh half (south of 40° latitude). This was the fourth (**04**) block of data completed in that region. Block CS04 is in the Gulf of Mexico, covering coastal areas of Texas and ocean areas from 100 to 220 km offshore (Figure 1). The corner coordinates defining Block CS04 are listed in Table 1.

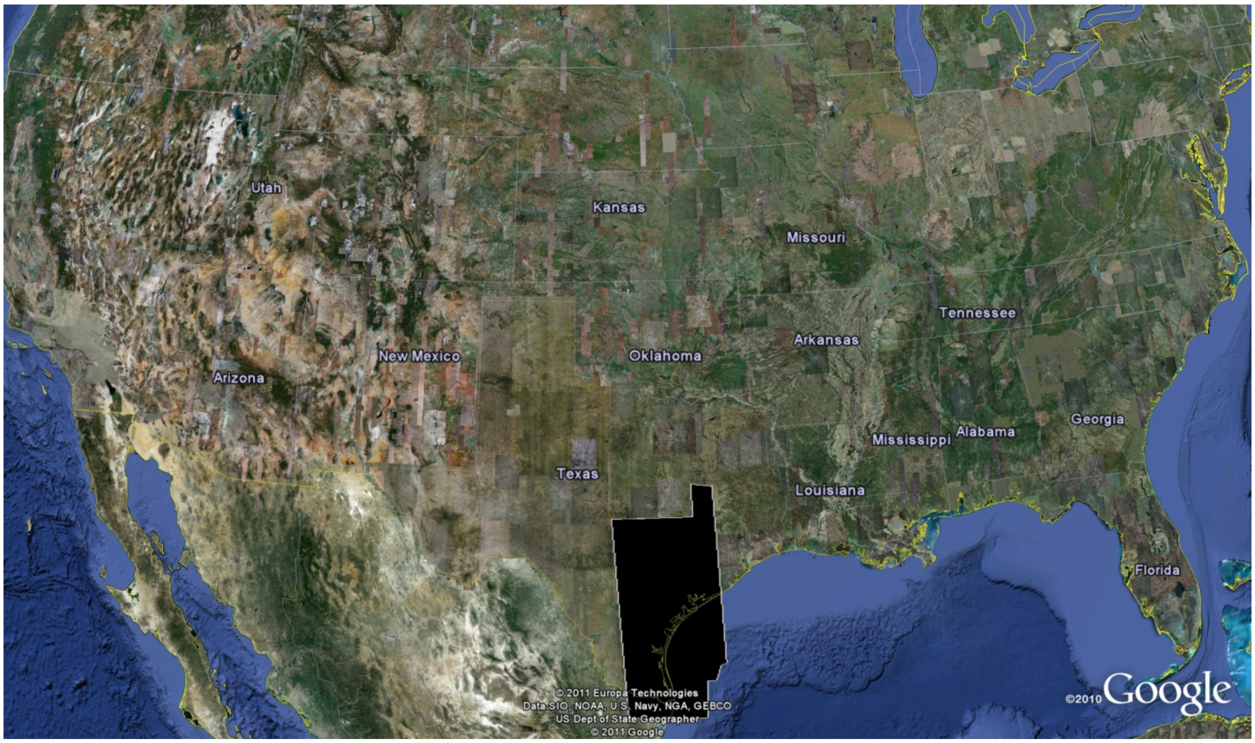


Figure 1: Google Earth Image of the Location of Block CS04 (black polygon) with respect to the Continental United States.

Table 1: Latitude and Longitude Coordinates of Corner Points Defining Block CS04

Latitude (decimal degrees)	Longitude (decimal degrees)
31.560211547	-95.804978155
31.639002464	-96.472478696
30.783217408	-96.430303233
30.780858447	-98.903778306
25.493791205	-98.489166608
25.428090145	-96.185160184
26.419007401	-96.146967817
26.424131447	-95.886832700
26.822912293	-95.728177896
26.883971741	-95.565977789

2. Survey Design and Execution

All airborne gravity data in Block CS04 were collected during the TX09 (Texas 2009) survey. The official NGS product from this survey includes flights done at 35,000 ft. Supplementary data includes cross lines and transit (target of opportunity) flights, which 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.

The survey was designed with 31 North-South data lines and 12 East-West cross lines. The lines are mostly located over coastal Texas, extending inland to the Llano/Hill Country region. Data line spacing is 10 km and cross line spacing is 40 km.

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. CS04101= block CS04’s line 101).

Table 2: Survey Overview

Conducting Organization	NOAA- National Geodetic Survey
Survey Name	TX09
Airport Base of Operations	Austin Intl (AUS) Austin, TX FBO: Signature Flight Services
Geographic Location	Gulf of Mexico, Texas, United Mexican States
Survey Size	300 km x 600 km
Dates of Airborne Operations	February 26, 2009 – May 15, 2009

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 Ashtech Z-Surveyors Applanix POS AV 510 (GPS + IMU)

Table 4: Survey Design and Execution

Line Spacing	Data Lines: 10 km Cross Lines: 40 km
Type of Layout	Regular data lines & regular cross lines
Nominal Survey Altitude	35,000 ft
Nominal Aircraft Ground Speed	280 knots
Number of Lines Released	Data Lines: 31 Cross Lines: 12 Repeat Lines: 0
Potential Number of Crossovers	321

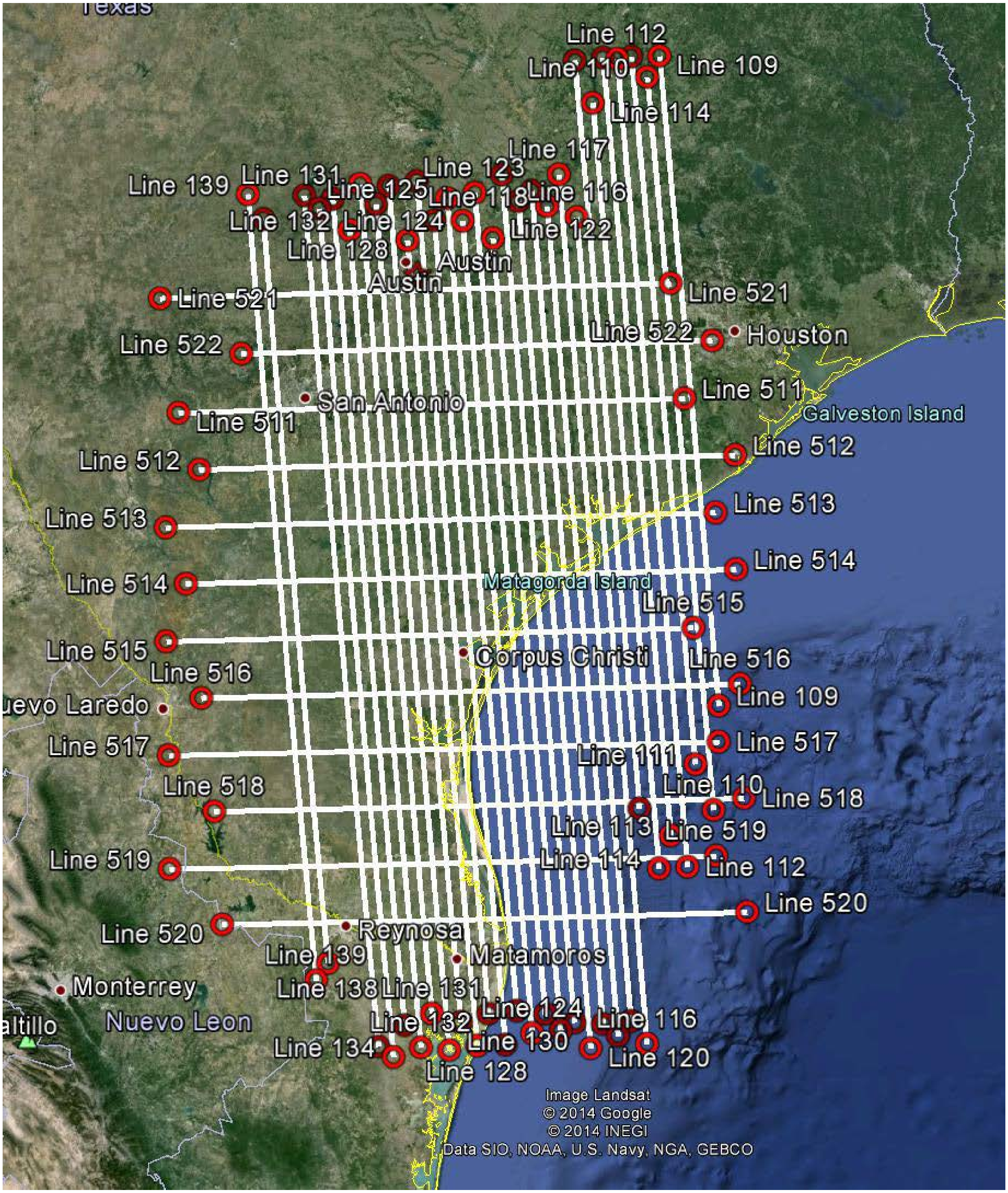


Figure 2: Data Coverage for this Block. Data lines start in the east at 109 and go west to 138. Airport marked with red star.

2.1 GPS/IMU Instrumentation

The NOAA Cessna Citation II had two GPS antennas available for scientific measurements and both were used at different times during the survey. Three geodetic-quality GPS receivers shared the antennas: two NovAtel DL-4 Plus (included as part of the TAGS gravimeter timing unit) and a Trimble (inside the Applanix POS AV 510 system). The NovAtels 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, one backup NovAtel DL-4 Plus (TAGS timing unit) recorded at 1 Hz and one Ashtech Z-Surveyor also recorded at 1 Hz served as GPS base stations throughout the survey. See Section 3.3.1 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 (Front)	3.81	-0.20	-0.88
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	2009 Day of Year Available
Kinematic	NovAtel (0013)	F09, F11,F13, F15, F19	69-70,111-112,128
	NovAtel (0016)	F23, F25, F29	130-131,134
	NovAtel (0009)	F10,F11,F13, F15, F19, F23, F25, F29	70, 111-112, 128,130-131,134
	Trimble (mgps)	F06, F13-F16,F18-F19,F22-F23,F25-F26	60,111-112, 114-128,130-132
Static	NovAtel (0013)	F23, F25	130-131
	NovAtel (0016)	F09, F11,F13, F15, F19	69-70,111-112,128
	Ashtech MAST*	F09-F11,F13-F16, F18-19, F23, F26	69-70,111-114, 128,130,132

* Data files labled as both MAST and CWF, although these are the same instrument in the same location at Austin.

Data were processed using WGS84 and ITRF08 with precise point positioning. 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 0.050 m and the average vertical position accuracy is 0.039 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 Signature Flight Services FBO, at the exact location that the aircraft was parked for the TX09 survey. That location is designated as AUS TAGS (30.183921110°N, 97.662056090°W) and its position coordinates were determined from the GPS collected during the gravity survey while the plane was parked. The AUS TAGS location has an absolute gravity value of 979273.7310 ± 0.008 mGal at 125 cm above the tarmac.

3.1.3 Gravity Filtering

Newton v1.2 uses a time-domain Gaussian filter that is applied three times to the data during final filtering. The Gaussian filter chosen for this survey has a 6-sigma of 120s, i.e. a 2-sigma of only 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.

3.2 Whole-Block Applicable Details

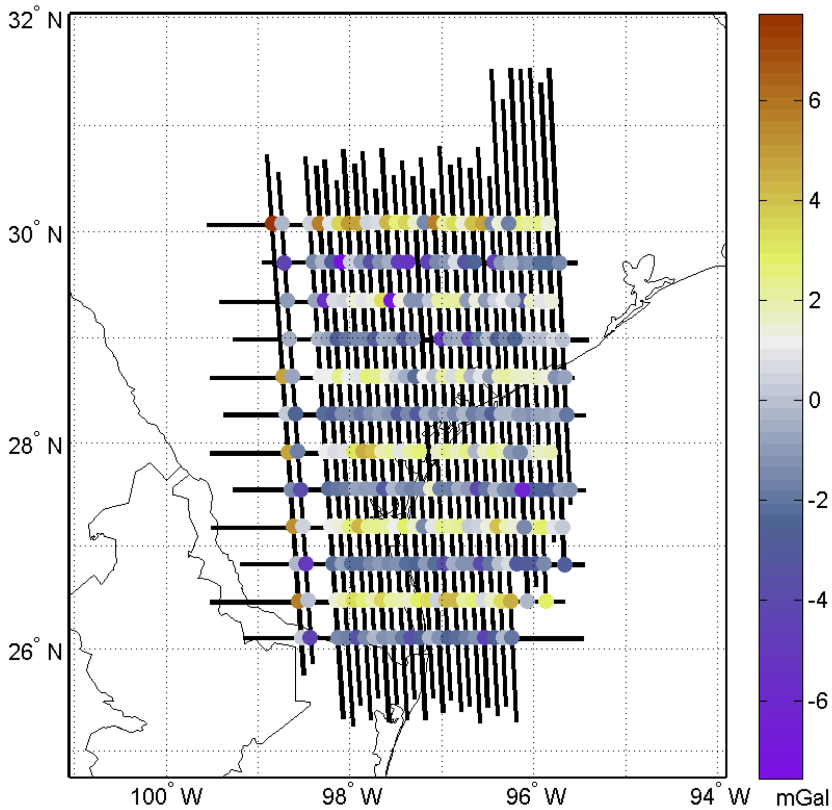
3.2.1 Gravity Error Analysis

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 CS04, the result of the crossover analysis is shown in Table 7 and in Figure 3.

Table 7: Gravity Crossover Error Analysis for the CS04 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)
35,000	10,668	11,126	321	2.37	2.37	-0.09	1.68

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. Due to a prevailing, strong E-W wind pattern, the cross lines for CS04 are much noisier than the data lines. 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 8. 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.



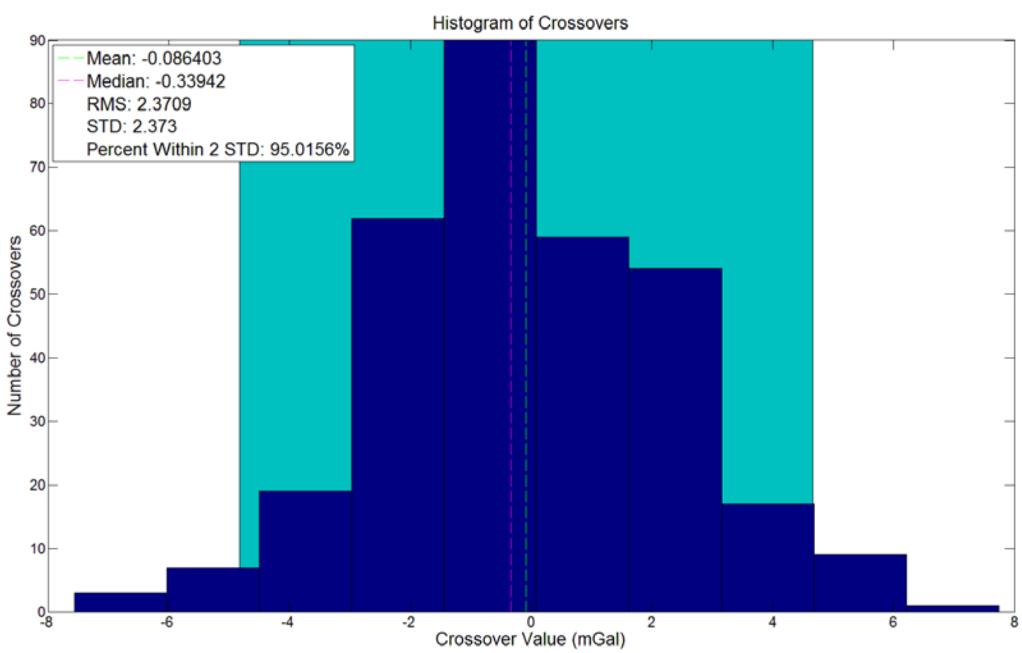


Figure 3: Crossover Residuals, Histogram, and Statistics for Block CS04. Color scale in mGals.

Table 8: Quality of Cross Lines Used in Crossover Analysis

Cross Line Number	Standard Deviation of Residuals Along Line (mGal)	Mean of Residuals Along Line (mGal)
511	2.28	0.05
512	1.37	-1.34
513	1.43	1.00
514	0.88	-1.34
515	1.59	1.64
516	1.42	-1.76
517	1.48	1.73
518	1.28	-1.88
519	1.48	2.46
520	1.29	-1.88
521	2.34	2.44
522	1.97	-2.27

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 9) 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 9: Average Data Line Correlation

Number of Correlations	Average Data Line Correlation	Standard Deviation of Correlations
27	99.93%	0.13%

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. In CS04, however, there were no reflown lines.

3.3 Flight- and Line-Specific Details

3.3.1 GPS processing- by flight

GPS data were processed in POSPac v.4.4 for GPS+IMU position solutions or in GrafNav v.8.50.2923 for GPS-only 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.”

3.3.2 Gravity processing- by line

All gravity processing was done with NGS’ Newton v1.2 software. For a description of the package, refer to the “GRAV-D General Airborne Gravity Data User Manual.” The final gravity data file contains full-field gravity at altitude (Figure 4), although other gravity products such as free-air anomalies or free-air disturbances (Figure 5) can be easily calculated by following directions in Section 4 of the “GRAV-D General Airborne Gravity Data User Manual.”

Table 10: GPS+IMU and GPS-only Kinematic Processing Results

Flight Num.	Rover GPS Unit	Aircraft Antenna Used	Solution Type	Elevation Mask (degrees)	Line Num.	NGS Quality Grade
08	NovAtel 0009	Rear	GPS only	5	109	100.00
09	NovAtel 0013	Front	GPS only	5	110	100.00
					111	100.00
10	NovAtel 0009	Rear	GPS only	5	114	100.00
					115	100.00
11	NovAtel 0009	Rear	GPS only	5	112	100.00
					113	85.03
12	NovAtel 0009	Front	GPS only	5	511	100.00
					512	100.00
13	Trimble	Front	GPS+IMU	5	116	100.00
					117	100.00
14	Trimble	Front	GPS+IMU	5	118	100.00
					119	100.00
15	Trimble	Front	GPS+IMU	5	120	99.46
					121	100.00
16	NovAtel 0013	Front	GPS+IMU	5	122	100.00
					123	100.00
17	Trimble	Front	GPS+IMU	5	124	100.00
					125	100.00
18	Trimble	Front	GPS+IMU	5	126	100.00
					127	100.00
19	NovAtel 0009	Rear	GPS only	5	128	100.00
					129	100.00
20	Trimble	Front	GPS+IMU	5	513	100.00
					514	100.00
21	Trimble	Front	GPS+IMU	5	515	100.00
					516	100.00
22	Trimble	Front	GPS+IMU	5	130	100.00
					131	100.00
23	Trimble	Front	GPS+IMU	5	132	100.00
					133	100.00
24	Trimble	Front	GPS+IMU	5	521	100.00
					522	100.00
25	NovAtel 0009	Rear	GPS only	5	138	100.00
					139	65.04
26	Trimble	Front	GPS+IMU	5	134	100.00
					135	100.00
28	Trimble	Front	GPS+IMU	5	519	100.00
					520	100.00
30	Trimble	Front	GPS+IMU	5	517	100.00
					518	100.00

Table 11: Gravity Processing Results

Flight Num.	Line Num.	Times of Data Deleted	Comments
08	109		
09	110		
	111		
10	114		
	115		
11	112		
	113		
12	511		
	512		
13	116		
	117	66607-67033	Spike Removed
14	118		
	119		
15	120		
	121		
16	122		
	123	60315-60637	Spike Removed
17	124	73880-74067, 74411-74624, 75199-75452	Spikes Removed
	125		
18	126		
	127		
19	128		
	129		
20	513		
	514		
21	515		
	516		
22	130		
	131		
23	132		
	133		
24	521		
	522		
25	138		
	139	85754-86507	Spike Removed
26	134		
	135		
28	519		
	520		
30	517		
	518		

Table 12: Bias from EGM08 by Line

Flight Num.	Line Num.	Bias from EGM08 (mGals)
08	109	-1.01
09	110	-1.19
	111	-1.07
10	114	-0.17
	115	-0.76
11	112	-1.16
	113	-0.15
12	511	0.33
	512	-2.27
13	116	-1.23
	117	-2.24
14	118	-1.96
	119	-0.39
15	120	-2.81
	121	-2.78
16	122	-3.18
	123	-1.82
17	124	-1.70
	125	-1.52
18	126	-1.20
	127	-0.85
19	128	-1.82
	129	-1.41
20	513	0.06
	514	-3.09
21	515	-0.31
	516	-3.05
22	130	-1.81
	131	-1.83
23	132	-1.39
	133	-0.73
24	521	1.62
	522	-2.58
25	138	-1.44
	139	-0.23
26	134	-0.98
	135	-0.44
28	519	0.27
	520	-3.69
30	517	0.21
	518	-3.88

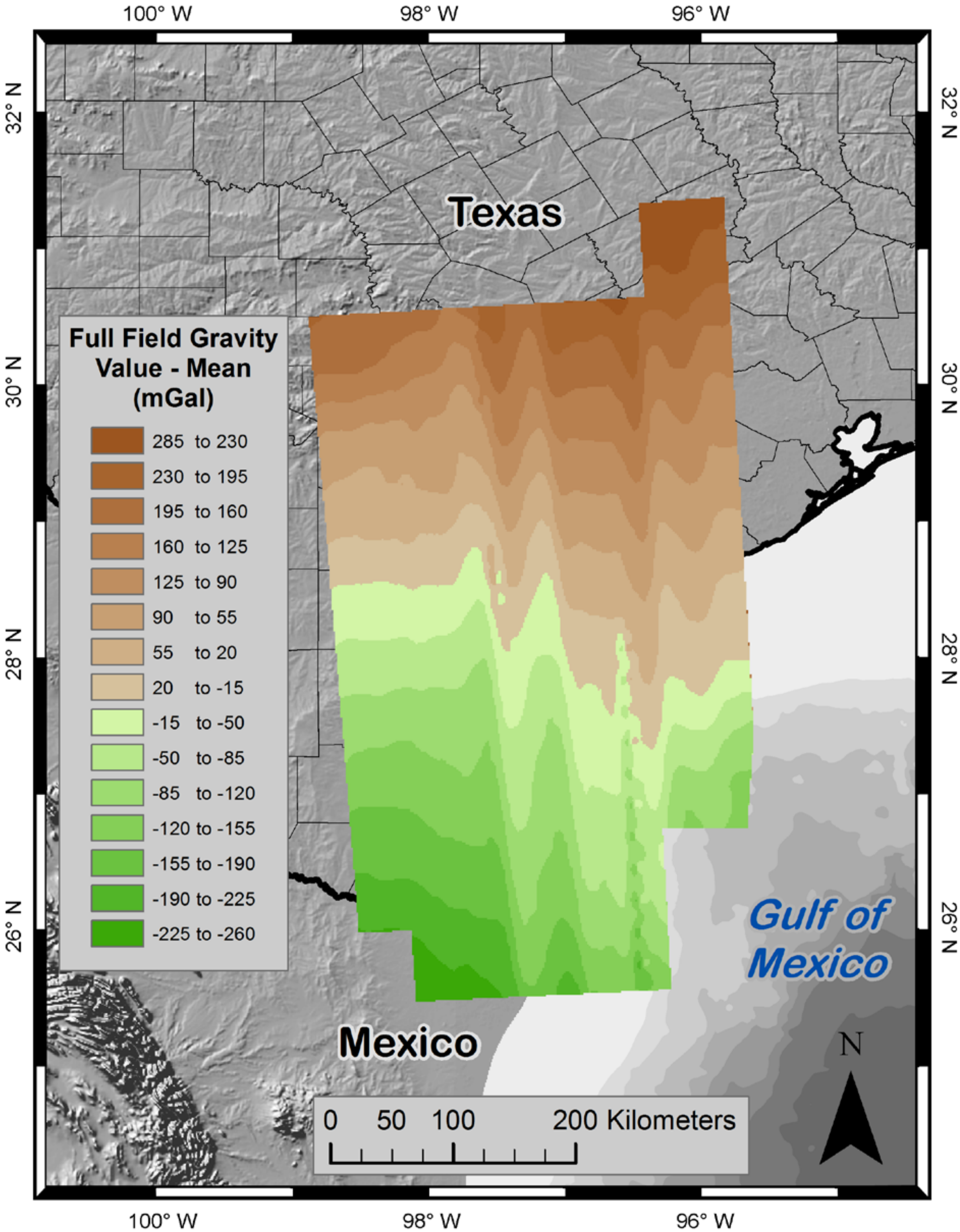


Figure 4: Full-field gravity at altitude (mean removed) for Block CS04. This is the data in the gravity release ".txt" file and includes the effects of differing altitudes along flight lines.

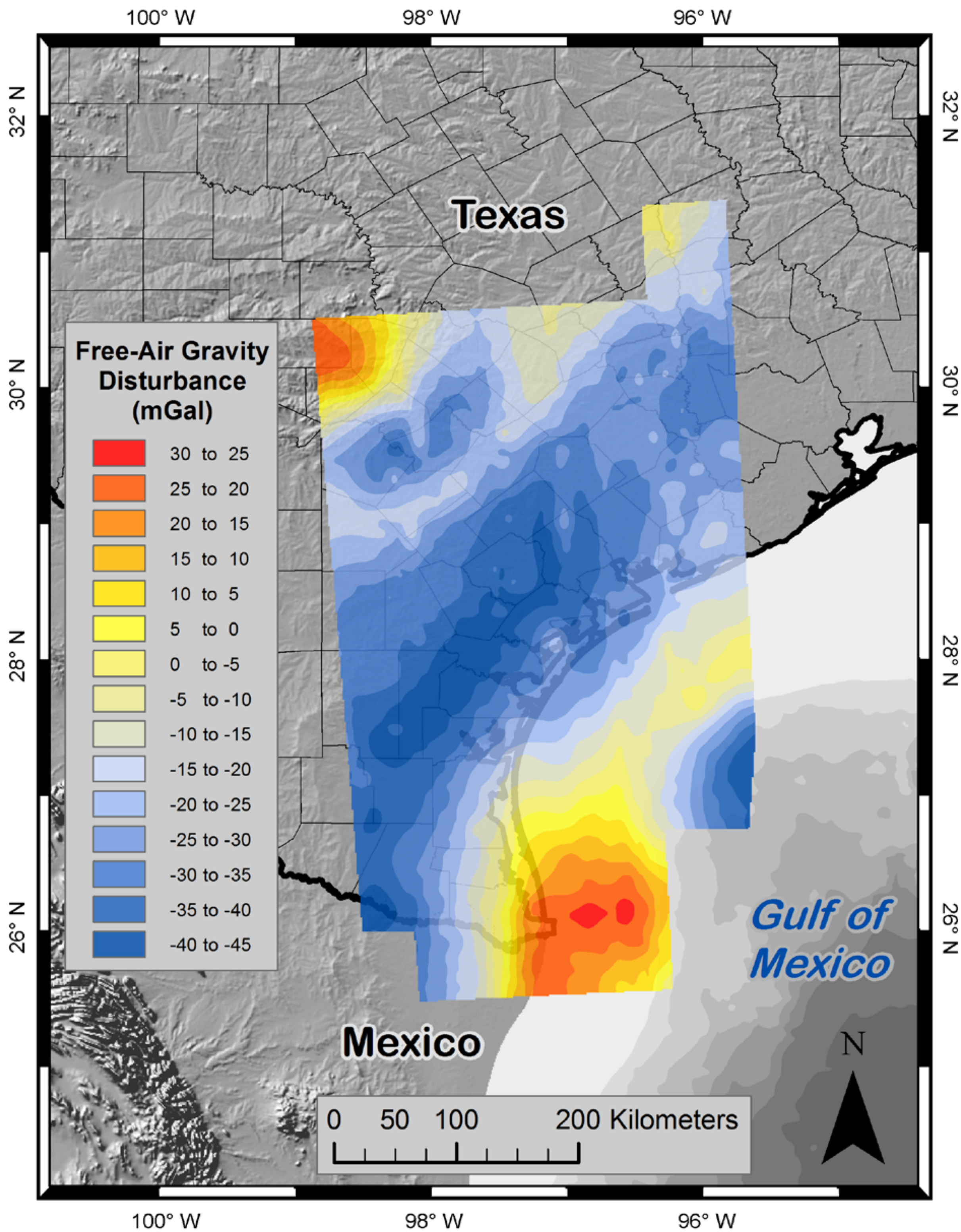


Figure 5: Free-air gravity disturbance for Block CS04 with respect to the WGS-84 ellipsoid.

4. Data Usage Guidelines

4.1 Suggested Data Handling

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

4.2 Documentation

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

4.3 How to Cite These Data

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

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

To reference the CS04 data file, reference the webpage:
GRAV-D Team (2014). "Gravity for the Redefinition of the American Vertical Datum (GRAV-D) Project, Airborne Gravity Data; Block CS04". Available *DATE*. Online at:
http://www.ngs.noaa.gov/GRAV-D/data_CS04.shtml

To reference the block and survey details, reference the block user manual:
GRAV-D Team (2014). "Block CS04 (Central South 04); GRAV-D Airborne Gravity Data User Manual." Monica Youngman and Carly Weil, ed. Version BETA #2. Available *DATE*. Online at:
http://www.ngs.noaa.gov/GRAV-D/data_CS04.shtml

To reference the general GRAV-D project operations, reference the General User Manual:
GRAV-D Team (2013). "GRAV-D General Airborne Gravity Data User Manual." Theresa Damiani and Monica Youngman, ed. Version 2. Available *DATE*. Online at:
http://www.ngs.noaa.gov/GRAV-D/data_products.shtmll

5. References

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