Block CS09 (Central South 09)

GRAV-D Airborne Data Release User Manual

Applies to Data Release BETA #1, 03/2019

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Version Notes

03/2019 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 **CS09** is located in the **C**entral Time Zone, in the **S**outh half (south of 63° latitude). This was the ninth (**09**) block of data completed in that region. Block CS09 is 550 km by 385 km, covering parts of Oklahoma, and Texas (Figure 1). The corner coordinates defining Block CS09 are listed in Table 1.

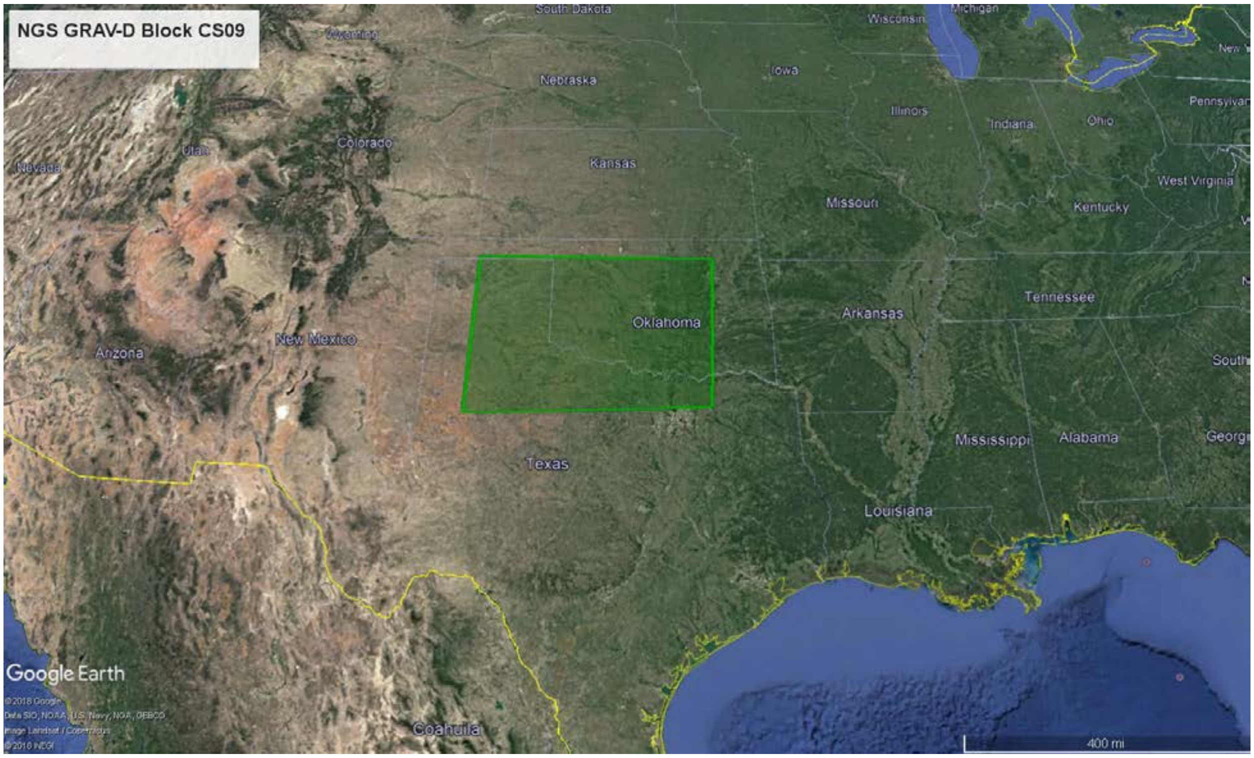

Figure 1: Google Earth Image of the Location of Block CS09

Table 1: Latitude and Longitude Coordinates of Corner Points Defining Block CS09

Latitude (decimal degrees)	Longitude (decimal degrees)
36.533735149	-95.851383362
36.562487849	-101.919455114
33.009568184	-101.952423081
33.160258912	-96.064072148

2. Survey Design and Execution

Airborne gravity data in Block CS09 were collected during 7 surveys: TX16-2 (Texas 2016, second occupation), TX16-3 (Texas 2016, third occupation), TX17-1 (Texas 2017, first occupation), OK18-1 (Oklahoma 2018, first occupation), OK18-3 (Oklahoma 2018, third occupation), TX18-1 (Texas 2018, first occupation), and OK18-4 (Oklahoma 2018, fourth occupation). Data lines from OK18-1 where flown at about 15,500 ft. Data lines from OK18-3, OK18-4, and TX17-1 where flown at about 20,000 ft. Data lines from TX16-2 and TX16-3, and TX18-1 where flown at about 21,000 ft. CS09 was surveyed with two different aircraft and three relative gravimeters. 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 CS09, data lines are east/west and cross lines are north/south. The block consists of 18 data lines and 2 cross lines from TX16-2, 14 data lines from TX16-3, 2 data lines and 5 cross lines from TX17-1, 1 data line from OK18-1, 2 data lines from OK18-3, 8 data lines from TX18-1, and 4 data lines from OK18-4. Five data lines, CS09102, CS09141, CS09142, CS09143, and CS09144 were flown twice with good data collected both times. The usual line numbering scheme used by GRAV-D (see "General User Manual") was used for this survey. In the data file, line numbers are preceded by the block name (i.e. CS09101= block CS09's line 101).

Table 2: Survey Overview

Survey	Conducting Organization	Airport Base of Operations	Geographic Location	Survey Dates
TX16-2	NOAA-National Geodetic Survey	Rick Husband Amarillo International Airport (AMA) Amarillo, TX FBO: TAC Air	Colorado, Kansas, New Mexico, Oklahoma, and Texas	Oct 11 - Nov 13, 2016
TX16-3	NOAA-National Geodetic Survey	Lubbock Preston Smith International Airport (LBB) Lubbock, TX FBO: Lubbock Aero	Oklahoma and Texas	Oct 3 - Oct 30, 2016
TX17-1	NOAA-National Geodetic Survey	Rick Husband Amarillo International Airport (AMA) Amarillo, TX FBO: TAC Air	Colorado, Kansas, New Mexico, Oklahoma, Texas	Jan 21 - Mar 2, 2017
OK18-1	NOAA-National Geodetic Survey	Tulsa International Airport (TUL) Tulsa, OK FBO: Atlantic Aviation	Kansas, and Oklahoma	Jul 31 - Sep 3, 2018
OK18-3	NOAA-National Geodetic Survey	Tulsa International Airport (TUL) Tulsa, OK FBO: Atlantic Aviation	Kansas, Oklahoma, and Texas	Feb17-Mar 18, 2018

Survey	Conducting Organization	Airport Base of Operations	Geographic Location	Survey Dates
TX18-1	NOAA-National Geodetic Survey	Rick Husband Amarillo International Airport (AMA) Amarillo, TX FBO: TAC Air	Oklahoma and Texas	Sep 19 - Oct 1, 2018
OK18-4	NOAA-National Geodetic Survey	Tulsa International Airport (TUL) Tulsa, OK FBO: Atlantic Aviation	Arkansas, Kansas, Missouri, Oklahoma, Texas	Oct 9 - Nov 14, 2018

Table 3: Aircraft and Instrumentation

Survey	Aircraft	Engines: Number, and Type	Gravity Instrumentation	GPS Instrumentation
TX16-2	BLM Pilatus	1, Turboprop	Micro-g LaCoste (MGL) TAGS S-137	NovAtel DL-V3 or DL-4 Plus NovAtel SPAN-SE with Honeywell µIRS (GPS + IMU)
TX16-3	Dynamic Aviation King Air	2, Turboprop	Micro-g LaCoste (MGL) TAGS S-161	NovAtel DL-V3 or DL-4 Plus NovAtel SPAN-SE with Honeywell µIRS (GPS + IMU)
TX17-1	BLM Pilatus	1, Turboprop	Micro-g LaCoste (MGL) TAGS S-137	NovAtel DL-V3 or DL-4 Plus NovAtel SPAN-SE with Honeywell µIRS (GPS + IMU)
OK18-1	BLM Pilatus	1, Turboprop	Micro-g LaCoste (MGL) S-211	NovAtel DL-V3 or DL-4 Plus NovAtel PP7 with Honeywell µIRS (GPS + IMU)
OK18-3	BLM Pilatus	1, Turboprop	Micro-g LaCoste (MGL) S-211	NovAtel DL-V3 or DL-4 Plus NovAtel PP7 with Honeywell µIRS (GPS + IMU)
TX18-1	BLM Pilatus	1, Turboprop	Micro-g LaCoste (MGL) S-211	NovAtel DL-V3 or DL-4 Plus NovAtel PP7 with Honeywell µIRS (GPS + IMU)
OK18-4	BLM Pilatus	1, Turboprop	Micro-g LaCoste (MGL) S-211	NovAtel DL-V3 or DL-4 Plus NovAtel PP7 with Honeywell µIRS (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: 1 (OK18-1), 2 (OK17-3), 4(OK18-4), 18 (TX16-2), 14 (TX16-3), 2 (TX17-1), 8 (TX18-1) Cross Lines: 2 (TX16-2), 5 (TX17-1) Repeat Lines: 5 lines
Number of Crossovers	336

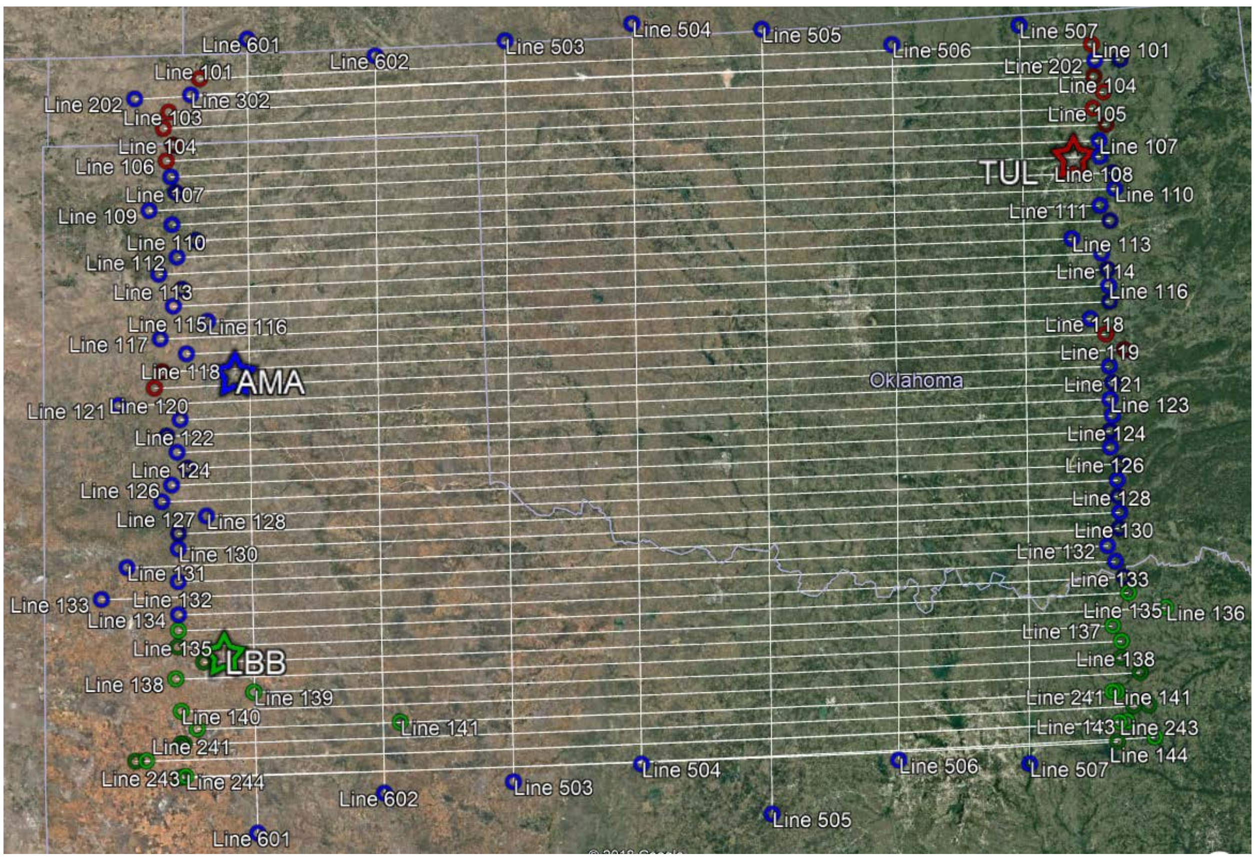

Figure 2: Data Coverage for CS09. Data lines range from 101 to 144. Rick Husband Amarillo International Airport (AMA) and lines flown from there are marked with blue. Tulsa International Airport (TUL) and lines flown from there are marked with Red. Lubbock Preston Smith International Airport (LBB) and lines flown from there are marked in green.

2.1 GPS/IMU Instrumentation

The aircraft 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 or PP7 (included as part of the Inertial Navigation System). The remote recevers on TAGS S-161 and S-137 surveys had a data rate of 1 Hz, and the remote receivers on TAGS S-211 surveys had a data rate of 20 Hz. The NovAtel SPAN-SE/PP7 system included a Honeywell 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 variety of different GPS receivers operated at either 20 Hz or 1 Hz to act as base stations. See Table 6 and Table 12 for information regarding 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 BLM Pilatus PC12 and the Dynamic Aviation King Air. The TAGS S-161 and TAGS S-137 record data at 1 Hz and have a Novatel timing unit mounted on the gravimeter. S-161 and S-137 also record a separate environmental file at about 1 Hz (Micro-g LaCoste, 2010). The TAGS S-211 records data at 20 Hz and has a NovAtel timing unit mounted on the gravimeter. The gravimeter includes environmental information in the same file as the gravity data at 20 Hz (Micro-g LaCoste, 2015).

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 IMU 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 IMU TO the Other Instruments

Instrument/Location	X (m)	Y (m)	Z (m)
S-211 Gravimeter	-0.001	-0.002	-0.453
S-161 Gravimeter	-0.016	0.021	-0.503
S-137 Gravimeter	-0.011	0.036	-0.514
GNSS antenna on Dynamic Aviation King Air (S-161)	-0.133	0.389	0.538
GNSS antenna on BLM Pilatus PC-12 (S-137)	0.006	0.674	0.608
GNSS antenna on BLM Pilatus PC-12 (S-211)	0.01	0.56	0.732

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)
OK18-1 TUL	Kinematic	NovAtel SPAN	f03	30
OK18-1 TUL	Static	NovAtel PP6 (44)	f03	30
OK18-1 TUL	Static	NovAtel DLV3	f03	30
OK18-3 TUL	Kinematic	NovAtel SPAN	f03	67, 68
OK18-3 TUL	Static	NovAtel DLV3	f03	67, 68
OK18-4 TUL	Kinematic	NovAtel PP7	f06	294
OK18-4 TUL	Static	NovAtel DLV3	f06	294
TX16-2 AMA	Kinematic	NovAtel	f01, f03, f05, f09, f12, f13, f16, f18, f22	285, 289, 290, 293, 299, 300, 302-304, 314-316, 318
TX16-2 AMA	Static	NovAtel PP6 (47)	f01, f03, f05, f09, f12, f13, f16, f22	285, 289, 290, 293, 299, 300, 302-304, 314-315, 318
TX16-2 AMA	Static	NovAtel PP6 (49)	f01, f03, f05, f09, f12, f13, f16, f18, f22	285, 289, 290, 293, 299, 300, 302-304, 314-316, 318
TX16-3 LBB	Kinematic	NovAtel SPAN	f01-f04, f06-f08	291-293, 296, 297, 302-304
TX16-3 LBB	Static	NovAtel PP6 (44)	f01-f04, f06-f08	291-293, 296, 297, 302-304
TX16-3 LBB	Static	Ashtech (South)	f03, f04, f06, f07	296, 297, 302, 303
TX17-1 AMA	Kinematic	NovAtel SPAN	f01, f03, f05-f07	21, 22, 28, 29, 32, 33, 37
TX17-1 AMA	Static	NovAtel PP7 (47)	f05-f07	32, 33, 37
TX17-1 AMA	Static	NovAtel PP7 (49)	f01, f03, f05-f07	21, 22, 28, 29, 32, 33, 37
TX18-1 AMA	Kinematic	NovAtel PP7	f01, f04-f06	270, 271, 273-275
TX18-1 AMA	Static	NovAtel DLV3	f01, f04-f06	270, 271, 273-275

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 ±0.027 m and the average vertical position accuracy is ±0.045 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 on February 2012 (LBB, called KLBB TAGS), March 2014 (AMA, called KAMA TAGS), and December 2017 (TUL, called KTUL TAGS). The A-10 was set up at the exact location of the aircraft. The positions were determed from the GPS data 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/ Airplane	Point ID	Latitude	Longitude	Tie height above mark (cm)	Gravity Tie (mGal)
TUL/ BLM Pilatus	KTUL TAGS	36.19331658°N	-95.89405207°W	163.7	979762.692 ± 0.008
AMA/ BLM Pilatus	KAMA TAGS	35.21689382°N	-101.7085789°W	163.7	979406.461 ± 0.006
LBB/ BLM Pilatus	KLBB TAGS	33.64448003°N	-101.8364365°W	163.7	979307.855 ± 0.012
LBB/ Dynamic Aviation King Air (N43U)	KLBB TAGS	33.64448003°N	-101.8364365°W	162.5	979307.858 ± 0.011

3.1.3 Gravity Filtering

For block CS09, flights were accomplished in seven 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 confocal ellipsoid normal gravity free-air correction method 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 CS09, 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	6096	6440	336	1.53	1.53	0.10	1.08

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.

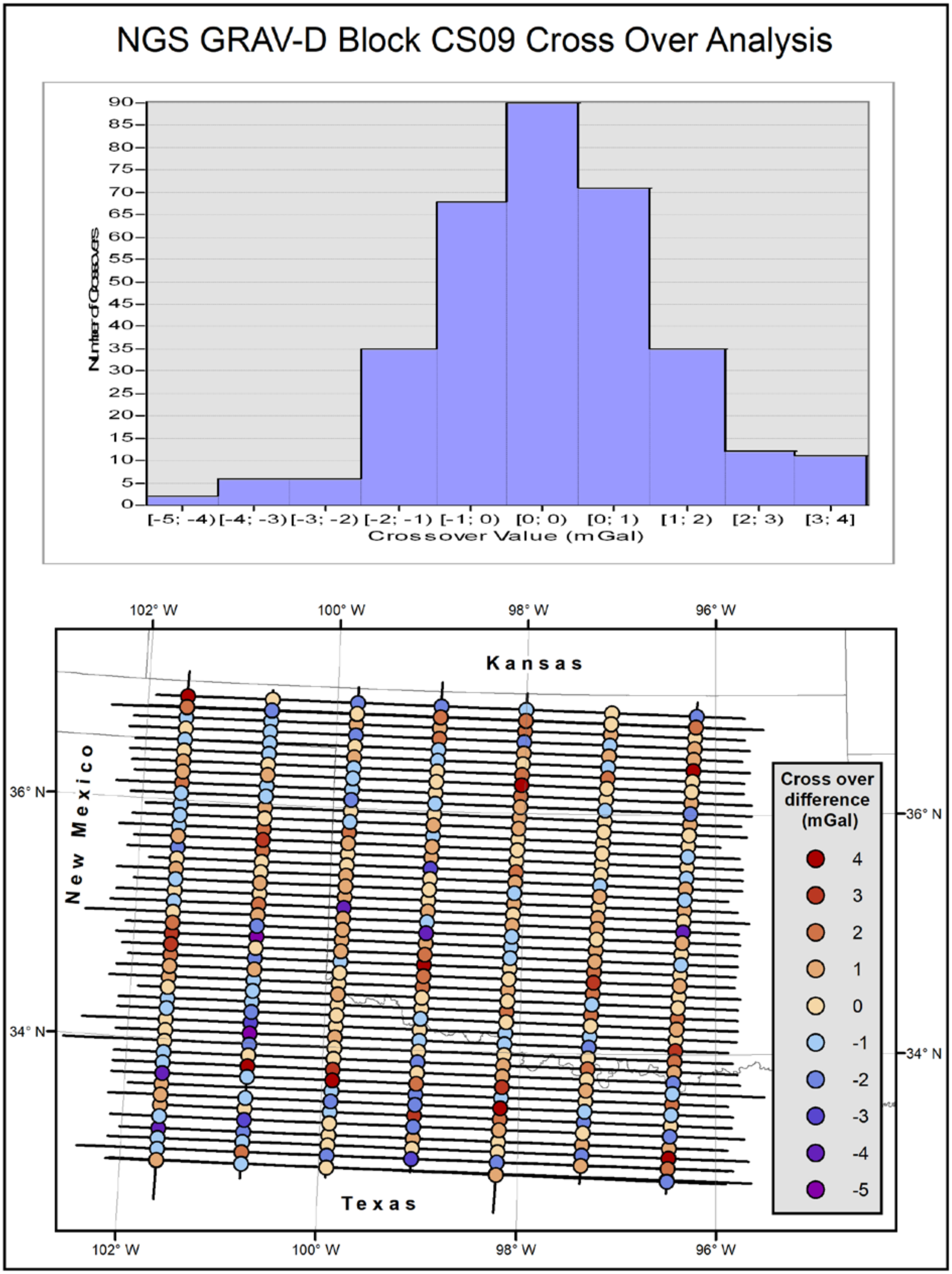

Figure 3: Crossover Residuals, Histogram, and Statistics for Block CS09

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)
CS09601	1.64	0.22
CS09602	1.78	-0.45
CS09503	1.30	-0.15
CS09504	1.69	0.04
CS09505	1.45	0.56
CS09506	1.14	0.23
CS09507	1.55	0.26

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
60	99.14%	3.86%

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 CS09, 5 data lines were re-flown as CS09202/CS09302, CS09141/CS09242, CS09142/CS09242, CS09143/CS09243, and CS09144/CS09244. Table 11 shows the correlation between these two sets of repeat lines.

Table 11: Repeat Line Correlations

Repeat Lines	Correlation
CS09202 CS09302	99.59%
CS09141 CS09241	99.27%
CS09142 CS09242	99.51%
CS09143 CS09243	99.58%
CS09144 CS09244	99.58%

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.”

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 Qualtiy Grade
OK18-1	f03	SPAN	GPS + IMU	7.5	101	100
OK18-3	f03	SPAN	GPS + IMU	5	119	100
OK18-3	f03	SPAN	GPS + IMU	5	120	100
OK18-4	f06	PP7	GPS + IMU	5	103	100
OK18-4	f06	PP7	GPS + IMU	5	104	100
OK18-4	f06	PP7	GPS + IMU	5	105	100
OK18-4	f06	PP7	GPS + IMU	5	106	100
TX16-2	f01	SPAN	GPS + IMU	7.5	115	100
TX16-2	f01	SPAN	GPS + IMU	7.5	116	100
TX16-2	f03	SPAN	GPS + IMU	7.5	131	100
TX16-2	f03	SPAN	GPS + IMU	7.5	132	100
TX16-2	f04	SPAN	GPS + IMU	7.5	133	100
TX16-2	f04	SPAN	GPS + IMU	7.5	134	100
TX16-2	f05	SPAN	GPS + IMU	5	129	100

Survey	Flight	Rover GPS Unit	Solution Type	Elevation Mask (deg)	Line Num.	NGS Qualtiy Grade
TX16-2	f05	SPAN	GPS + IMU	5	130	100
TX16-2	f09	SPAN	GPS + IMU	5	127	100
TX16-2	f09	SPAN	GPS + IMU	5	128	100
TX16-2	f12	SPAN	GPS + IMU	7.5	125	100
TX16-2	f12	SPAN	GPS + IMU	7.5	126	100
TX16-2	f13	SPAN	GPS + IMU	5	123	100
TX16-2	f13	SPAN	GPS + IMU	5	124	100
TX16-2	f16	SPAN	GPS + IMU	5	117	100
TX16-2	f16	SPAN	GPS + IMU	5	118	100
TX16-2	f18	SPAN	GPS + IMU	5	121	100
TX16-2	f18	SPAN	GPS + IMU	5	122	100
TX16-2	f22	SPAN	GPS + IMU	7.5	601	100
TX16-2	f22	SPAN	GPS + IMU	7.5	602	100
TX16-3	f01	SPAN	GPS + IMU	5	143	100
TX16-3	f01	SPAN	GPS + IMU	5	144	100
TX16-3	f02	DLV	GPS only	5	141	100
TX16-3	f02	DLV	GPS only	5	142	100
TX16-3	f03	SPAN	GPS + IMU	5	241	100
TX16-3	f03	SPAN	GPS + IMU	5	242	100
TX16-3	f04	SPAN	GPS + IMU	5	243	100
TX16-3	f04	SPAN	GPS + IMU	5	244	100
TX16-3	f06	SPAN	GPS + IMU	5	139	100
TX16-3	f06	SPAN	GPS + IMU	5	140	100
TX16-3	f07	SPAN	GPS + IMU	5	137	100
TX16-3	f07	SPAN	GPS + IMU	5	138	100
TX16-3	f08	SPAN	GPS + IMU	5	135	100
TX16-3	f08	SPAN	GPS + IMU	5	136	100
TX17-1	f03	SPAN	GPS + IMU	5	113	100
TX17-1	f03	SPAN	GPS + IMU	5	114	100
TX17-1	f05	SPAN	GPS + IMU	5	503	100
TX17-1	f05	SPAN	GPS + IMU	5	504	100
TX17-1	f06	SPAN	GPS + IMU	5	507	100
TX17-1	f07	SPAN	GPS + IMU	7.5	505	100
TX17-1	f07	SPAN	GPS + IMU	7.5	506	100
TX18-1	f01	PP7	GPS + IMU	5	111	100
TX18-1	f01	PP7	GPS + IMU	5	112	100
TX18-1	f04	PP7	GPS + IMU	5	109	100
TX18-1	f04	PP7	GPS + IMU	5	110	100

Survey	Flight	Rover GPS Unit	Solution Type	Elevation Mask (deg)	Line Num.	NGS Qualtiy Grade
TX18-1	f05	PP7	GPS + IMU	5	107	100
TX18-1	f05	PP7	GPS + IMU	5	108	100
TX18-1	f06	PP7	GPS + IMU	5	202	100
TX18-1	f06	PP7	GPS + IMU	5	302	100

Table 13: Gravity Processing Results

Survey	Flight Num.	Line Num.	Time of Deleted Data	Comments
OK18-1	f03	101	2018-01-30 18:26:18-2018-01-30 18:29:55	Bump removed
TX16-2	f18	122	2016-11-11 01:56:31-2016-11-11 01:58:12	Bump removed
TX16-3	f07	137	2016-10-29 01:05:18-2016-10-29 01:08:56	Bump removed

Table 14: Bias from EGM08 by Line

Survey	Flight Num.	Line	EGM08 mean
OK18-1	f03	101	1.94
OK18-3	f03	119	1.31
OK18-3	f03	120	2.76
OK18-4	f06	103	1.05
OK18-4	f06	104	2.07
OK18-4	f06	105	0.59
OK18-4	f06	106	0.54
TX16-2	f01	115	-0.84
TX16-2	f01	116	2.04
TX16-2	f03	131	-1.77
TX16-2	f03	132	1.13
TX16-2	f04	133	-2.68
TX16-2	f04	134	0.4
TX16-2	f05	129	-2.22
TX16-2	f05	130	0.09
TX16-2	f09	127	-1.22
TX16-2	f09	128	1.82
TX16-2	f12	125	-1.38
TX16-2	f12	126	0.66

Survey	Flight Num.	Line	EGM08 mean
TX16-2	f13	123	-0.36
TX16-2	f13	124	1.98
TX16-2	f16	117	-1.45
TX16-2	f16	118	1.2
TX16-2	f18	121	-0.52
TX16-2	f18	122	2.71
TX16-2	f22	601	-0.01
TX16-2	f22	602	0.56
TX16-3	f01	143	-0.39
TX16-3	f01	144	1.19
TX16-3	f02	141	0.1
TX16-3	f02	142	0.8
TX16-3	f03	241	0.78
TX16-3	f03	242	3.11
TX16-3	f04	243	1.18
TX16-3	f04	244	2.35
TX16-3	f06	139	-0.46
TX16-3	f06	140	0.97
TX16-3	f07	137	-0.28
TX16-3	f07	138	0.26
TX16-3	f08	135	-1.46
TX16-3	f08	136	0.39
TX17-1	f03	113	-1.25
TX17-1	f03	114	0.55
TX17-1	f05	503	0.08
TX17-1	f05	504	0.1
TX17-1	f06	507	-0.18
TX17-1	f07	505	-0.73
TX17-1	f07	506	-1.34
TX18-1	f01	111	0.44
TX18-1	f01	112	1.7
TX18-1	f04	109	0.24
TX18-1	f04	110	1.88
TX18-1	f05	107	0.01
TX18-1	f05	108	2.91
TX18-1	f06	202	0.13
TX18-1	f06	302	1.81

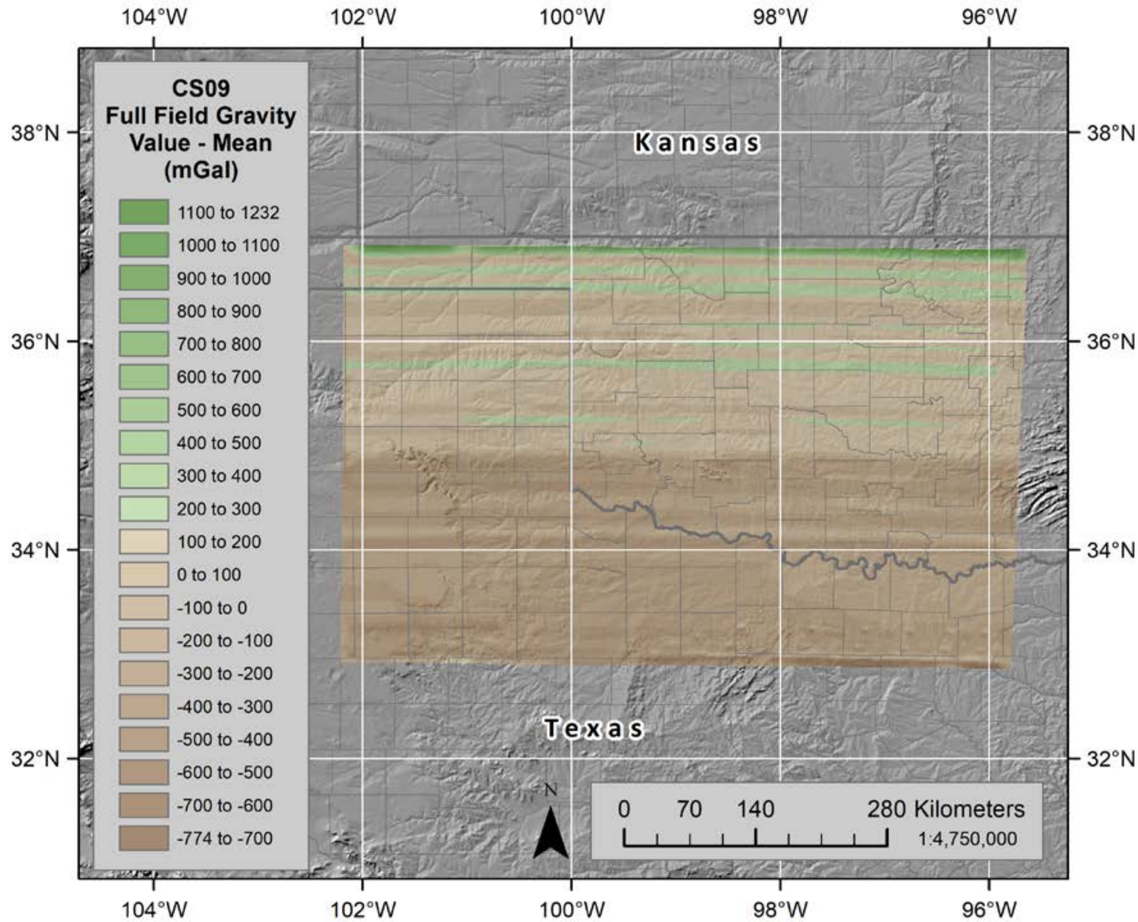

Figure 4: Full-field gravity at altitude (mean removed) for Block CS09. This is the data in the gravity release ".txt" file and includes the effects of differing altitudes along flight lines.

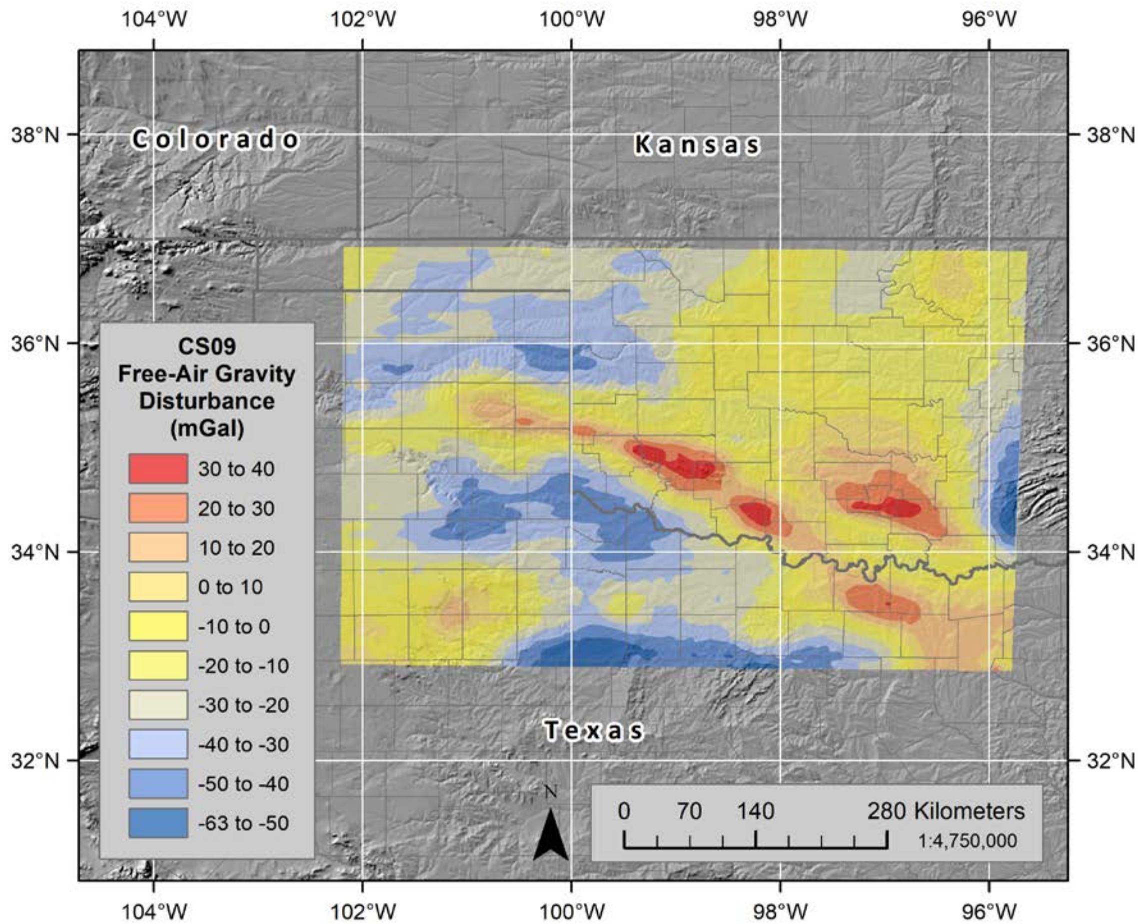

Figure 5: Gravity disturbance for Block CS09 with respect to the GRS80 ellipsoid. Calculated with the confocal ellipsoid method of calculating normal gravity.

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

To reference the CS09 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 CS09". Available *DATE*. Online at: http://www.ngs.noaa.gov/GRAV-D/data_CS09.shtml

To reference the block and survey details, reference the block user manual:
GRAV-D Science Team (2018). "Block CS09 (Central South 09); GRAV-D Airborne Gravity Data User Manual." Jeffery A. Johnson, ed. Version BETA. Available *DATE*. Online at: http://www.ngs.noaa.gov/GRAV-D/data_CS09.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

5. References

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

Micro-g LaCoste, 2015. “TAGS-6 Turnkey Airborne Gravity System 6 AIR User’s Manual.”