Block CS03 (Central South 03)

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 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 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 **CS03** is located in the **C**entral Time Zone, in the **S**outh half (south of 40° latitude). This was the third (**03**) block of data completed in that region. Block CS03 is 215 km by 490 km in the Gulf of Mexico, covering coastal areas of Texas and Louisiana and ocean areas from 200 to 300 km offshore (Figure 1). The corner coordinates defining Block CS03 are listed in Table 1.

Figure 1: Google Earth Image of the Location of Block CS03 (black rectangle).

Table 1: Latitude and Longitude Coordinates of Corner Points Defining Block CS03

Latitude (decimal degrees)	Longitude (decimal degrees)
31.293673174	-93.497949405
31.574559864	-95.822334637
26.884204765	-95.549706982
27.024624439	-93.356151209

2. Survey Design and Execution

Airborne gravity data in Block CS03 were collected during two surveys: TX09 (Texas 2009) and LA09 (Louisana 2009). All data and cross flights were done at 35,000 ft with the same aircraft and instrument suite. 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 the CS03 all data lines are North-South and cross lines East-West. The block consists of 8 data lines and 9 cross lines from TX09 and 13 data lines from LA09. 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. CS03101= block CS03's line 101).

Table 2: Survey Overview (LA09/TX09)

Conducting Organization	NOAA- National Geodetic Survey	
Survey Name	LA09	TX09
Airport Base of Operations	Chennault (CWF) Lake Charles, LA FBO: MillionAir	1. Chennault (CWF) Lake Charles, LA FBO: MillionAir 2. Austin Intl (AUS) Austin, TX FBO: Signature
Geographic Location	Texas, Louisiana, Gulf of Mexico	
Dates of Airborne Operations	Feb. 3 – Feb. 26th, 2009	1. Feb. 26 – Mar. 1st, 2009 2. March 9th, 2009

Table 3: Aircraft and Instrumentation

Aircraft	NOAA Cessna Citation II (N52RF) (LA09 & TX09)
Engines, number and type	2, Jet
Gravity Instrumentation	Micro-g LaCoste (MGL) TAGS S-137 (relative) MGL FG-5 102 (absolute) MGL G-157, G-81, and D-43 (relative)
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: ~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: 8 (TX09), 13 (LA09) Cross Lines: 9 (TX09) Repeat Lines: 0
Number of Crossovers	197

Figure 2: Data Coverage for CS03. Data lines start in the east at 145 to 157 (LA09, green from Lake Charles, LA Chennault Airport) and continue west at 101 to 108 (TX09, blue from Austin, TX and red from Lake Charles, LA Chennault Airport). Airports 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 (Rear)	2.87	-0.15	-0.91
Aircraft GPS Antenna (Front)	3.81	-0.20	-0.88
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)

Airport	Type	Receiver	Flight Available	2009 Day of Year Available
CWF	Kinematic	NovAtel (0013)	F08, F11-F13 (LA09) F02, F04, F06 (TX09)	38-39, 41, 57 (LA09) 58-60 (TX09)
		Trimble (mgps)	F06, F08-F10, F12-F13 (LA09) F01, F03, F05 (TX09)	37-39, 41, 57 (LA09) 58-60 (TX09)
	Static	NovAtel (0016)	F08-F09, F11-F13 (LA09) F02, F04, F06 (TX09)	38-39, 41, 57 (LA09) 58-60(TX09)
		Ashtech CWF	F06, F08, F10-F11 (LA09) F01, F03, F05-F06 (TX09)	37-39 (LA09) 58-60(TX09)
AUS	Kinematic	NovAtel (0013)	F07-F08 (TX09)	68 (TX09)
		NovAtel (0009)	F08 (TX09)	68 (TX09)
	Static	NovAtel (0016)	F08 (TX09)	68 (TX09)
		Ashtech MAST*	F07-F08 (TX09)	68 (TX09)

*Data files from Austin were originally labled as CWF, but to differentiate are now labeled MAST

Data were processed using WGS84 and ITRF08 with precise point positioning. 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 survey-wide estimate of GPS position accuracy. For the data lines, the average horizontal position accuracy is 0.052 m and the average vertical position accuracy is 0.040 m.

CORS data is available at a 1 second data rate for a number of stations within the survey area. This data was not used in processing but is available upon request.

3.1.2 Ground Gravity Tie

Updated absolute gravity measurements were performed by NGS with a Micro-g LaCoste A-10 gravimeter in spring of 2011. At both airports the A-10 was set up at the exact location of the aircraft and the gravity value was reported at 125 cm above the tarmac. The positions were determed from the GPS collected during the gravity survey while the plane was parked. In Austin, TX the location is designated as AUS TAGS (30.183921110°N, 97.662056090°W) and it has an absolute gravity value of 979273.7310 ± 0.008 mGal. In Lake Charles, LA the location is designated as CWF TAGS (30.214532709°N, -93.150988548°W) and it has an absolute gravity value of 979316.5777 ± 0.008 mGal.

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 CS03, the result of the crossover analysis is shown in Table 7 and in **Error! Reference source not found.**.

Table 7: Gravity Crossover Error Analysis for the CS03 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	11,031	197	1.46	1.44	0.25	1.03

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 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 CS03. 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)
501	1.04	0.19
502	0.93	1.15
503	0.98	-1.62
504	0.85	0.25
505	0.85	1.76
506	1.14	-0.90
507	0.78	0.97
508	1.43	0.88
509	1.08	-0.92
510	0.93	0.86

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
17	99.93%	0.12%

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 CS03, 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.8.5.4320 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

Survey	Flight Num.	Rover GPS Unit	Aircraft Antenna Used	Solution Type	Elevation Mask (degrees)	Line Num.	NGS Quality Grade
LA09 CWF	06	Trimble	Rear	GPS+IMU	5	145	100.00
						146	100.00
	08	Trimble	Rear	GPS+IMU	5	147	100.00
						148	100.00
	09	Trimble	Rear	GPS+IMU	5	150	100.00
	10	Trimble	Rear	GPS+IMU	5	153	100.00
						154	100.00
	11	NovAtel	Rear	GPS only	5	151	100.00
						152	100.00
	12	Trimble	Rear	GPS+IMU	5	155	100.00
						156	100.00
	13	Trimble	Front	GPS+IMU	5	249*	100.00
						157	100.00
TX09 CWF	01	Trimble	Front	GPS+IMU	5	101	100.00
						102	100.00
	02	Trimble	Front	GPS+IMU	5	508	100.00
						509	100.00
						510	100.00
	03	Trimble	Front	GPS+IMU	5	505	100.00
						506	100.00
						507	100.00
	04	NovAtel (0013)	Front	GPS+IMU	5	501	100.00
						503	100.00
						504	100.00
	05	Trimble	Front	GPS+IMU	5	103	100.00
						104	100.00
	06	Trimble	Front	GPS+IMU	5	105	100.00
TX09 AUS	07	NovAtel (0009)	Front	GPS only	5	106	100.00
						107	100.00
	08	NovAtel (0009)	Rear	GPS only	5	108	100.00

**Line 149 was originally flown during Flight 09 but due to poor data quality the line was relfown.*

Table 11: Gravity Processing Results

Survey	Flight Num.	Line Num.	Times of Deleted Data Sections (s)	Comments
LA09 CWF	06	145	None	
		146	None	
	08	147	None	
		148	None	
	09	150	None	
	10	153	None	
		154	None	
	11	151	None	
		152	None	
	12	155	None	
		156	None	
	13	249	None	
		157	None	
TX09 CWF	01	101	None	
		102	None	
	02	508	None	
		509	None	
		510	None	
	03	505	None	
		506	None	
		507	None	
	04	501	None	
		503	None	
		504	None	
	05	103	None	
		104	None	
	06	105	None	
TX09 AUS	07	106	None	
		107	None	
	08	108	None	

Table 12: Bias from EGM08 by Line

Survey	Flight Num.	Line Num.	Bias from EGM08 (mGals)
LA09 CWF	06	145	-1.44
		146	-1.50
	08	147	-1.82
		148	-1.86
	09	150	-2.23
	10	153	-1.40
		154	-1.88
	11	151	-0.46
		152	-1.13
	12	155	-1.09
		156	-1.18
	13	249	-2.13
		157	-1.18
TX09 CWF	01	101	-2.15
		102	-2.04
	02	508	0.05
		509	-2.52
		510	-1.01
	03	505	-0.09
		506	-2.80
		507	0.41
	04	501	-2.27
		503	-2.36
		504	-0.27
	05	103	-1.29
		104	-1.20
	06	105	-1.25
TX09 AUS	07	106	-1.13
		107	-1.11
	08	108	-0.67

Figure 4: Full-field gravity at altitude (mean removed) for Block CS03. 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 CS03 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 CS03 data file, reference the webpage:
GRAV-D Science Team (2014). “Gravity for the Redefinition of the American Vertical Datum (GRAV-D) Project, Airborne Gravity Data; Block CS03”. Available *DATE*. Online at: http://www.ngs.noaa.gov/GRAV-D/data_CS03.shtml

To reference the block and survey details, reference the block user manual:
GRAV-D Team (2014). “Block CS03 (Central South 03); GRAV-D Airborne Gravity Data User Manual.” Theresa Damiani, Monica Youngman, and Carly Weil, ed. Version 1. Available *DATE*. Online at: http://www.ngs.noaa.gov/GRAV-D/data_CS03.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.”