Block TS01 (Atlantic South 02)

GRAV-D Airborne Data Release User Manual

Applies to Data Release BETA, 10/2012

Edited by Monica A. Youngman and Carly A. Weil

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. 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."

Contents

Figure List

Table List

1. Block Description

GRAV-D Block **TS01** is located in the **A**tlantic Time Zone, in the **S**outh half (south of 40° latitude). This was the first (**01**) block of data completed in that region. Block TS01 is 360 km by 420 km in the Caribbean, covering Puerto Rico and ocean areas from 80 to 270 km offshore (Figure 1). The corner coordinates defining Block TS01 are listed in Table 1.

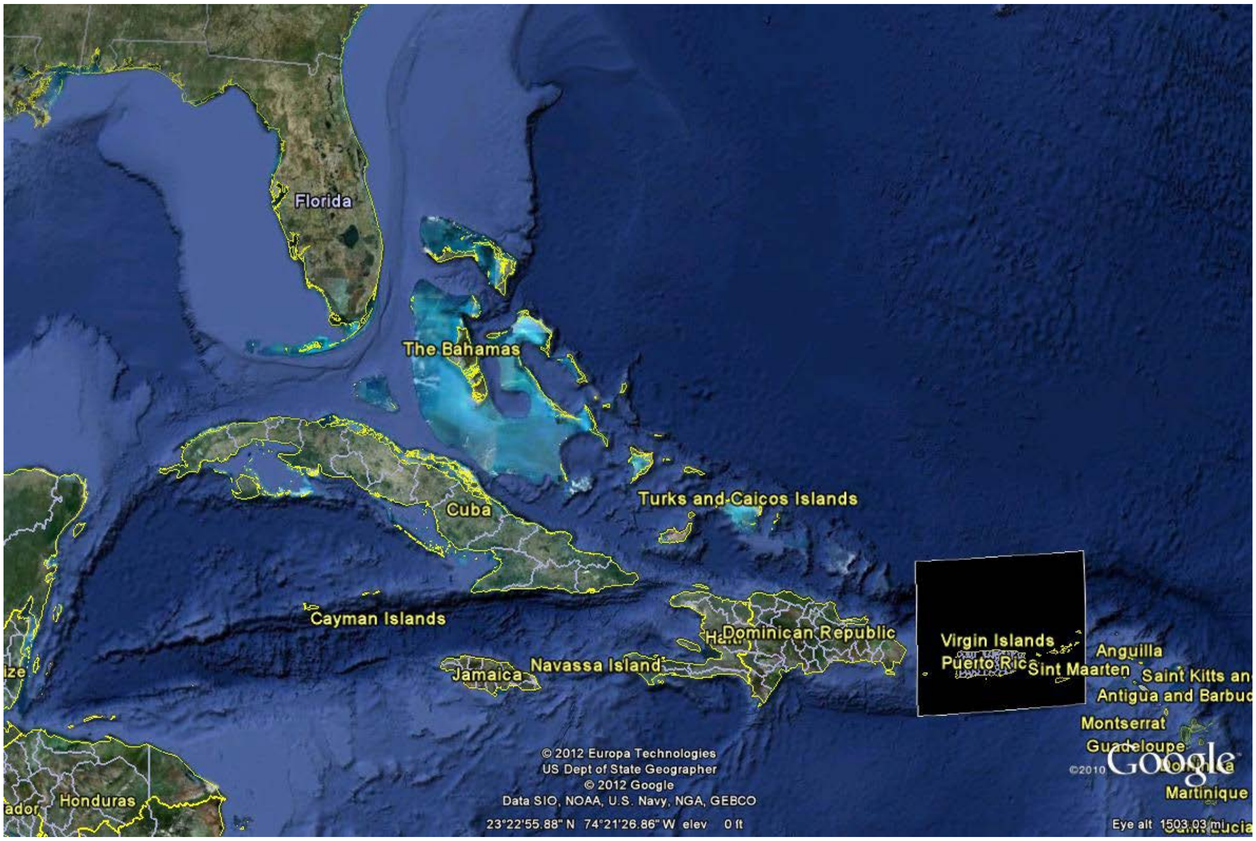


Figure 1: Google Earth Image of the Location of Block TS01 (black rectangle).

Table 1: Latitude and Longitude Coordinates of Corner Points Defining Block TS01

Latitude (decimal degrees)	Longitude (decimal degrees)
20.43714183760905	-68.0883182838888
17.19057953935588	-68.06358395265403
17.14384307319382	-64.15424879564571
20.42388914684049	-64.16131962696679

2. Survey Design and Execution

Airborne gravity data in Block TS01 were collected during one survey: PV09 (Puerto Rico 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 TS01 all data lines are North-South and cross lines East-West. The block consists of 42 data lines, 10 cross lines from PV09. 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. TS01101= block TS01's line 101).

Table 2: Survey Overview

Conducting Organization	NOAA- National Geodetic Survey
Survey Name	PV09
Airport Base of Operations	Cyril E. King Airport (STT) St. Thomas, VI FBO: Alliance Aviation Rafael Hernandez Airport (BQN) Borinquen, PR FBO: Western Aviation Jet Center
Geographic Location	Puerto Rico
Dates of Airborne Operations	Jan. 10 – Jan. 28th, 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 FG-5 102 (absolute) MGL G-157, and G-81 (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: 41 Cross Lines: 10 Repeat Lines: 0
Number of Crossovers	390

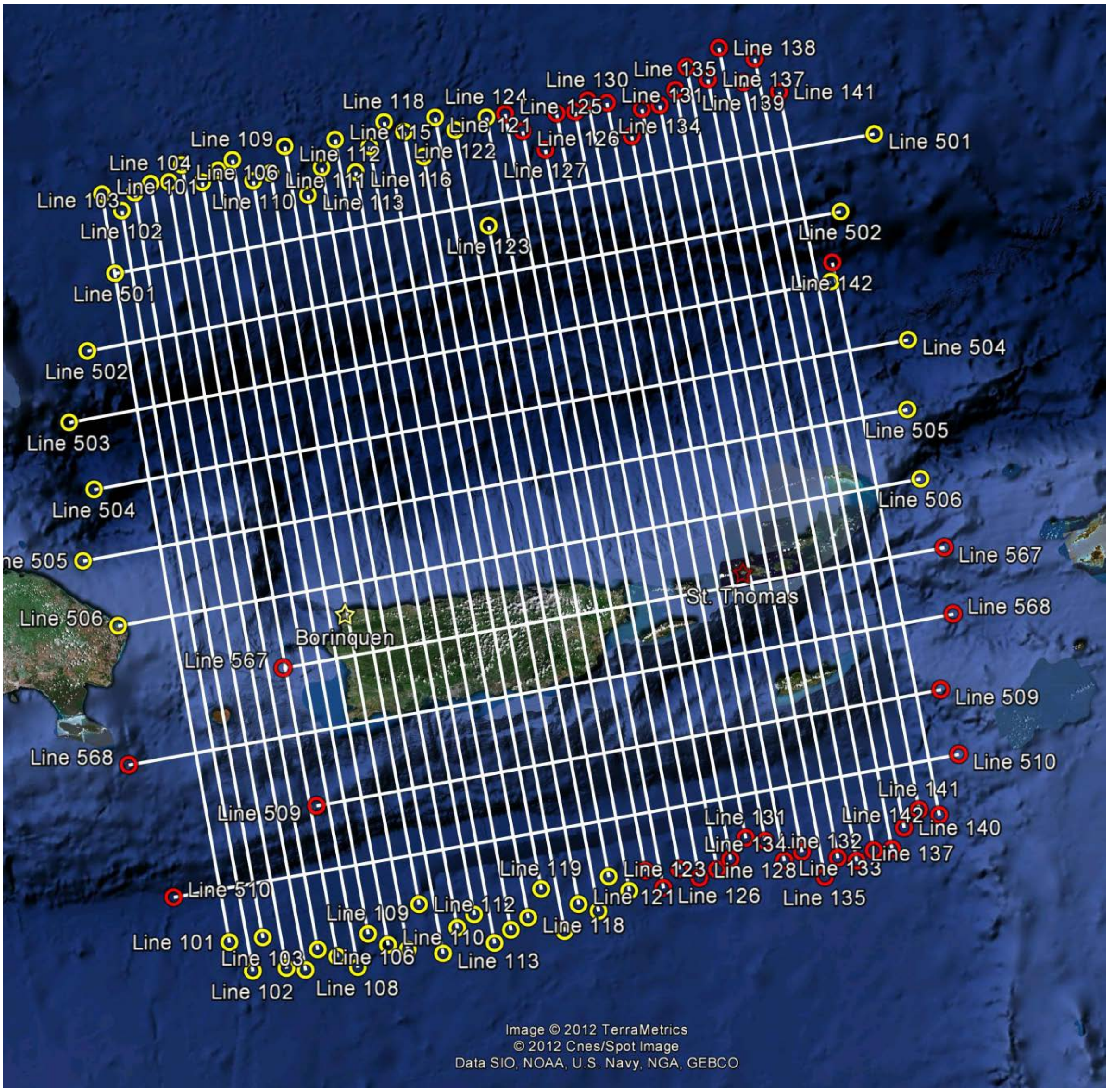


Figure 2: Data Coverage for TS01. Data lines start in the west at 101 to 124 (PV09, yellow from Rafael Hernandez Airport) and 125 to 142 (PV09, red from Cyril E. King Airport). Airports marked with red star.

2.1 GPS/IMU Instrumentation

The NOAA Cessna Citation II had two GPS antennas available for scientific measurements and only the the front one was used during the survey. Two geodetic-quality GPS receivers shared the antenna: NovAtel DL-4 Plus (included as part of the TAGS gravimeter timing unit) and a Trimble (inside the Applanix POS AV 510 system). For some flights an additional NovAtel DL-4 Plus was running. 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)	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)

Airport	Type	Receiver	Flight Available	2009 Day of Year Available
STT (PV09)	Kinematic	NovAtel (0013)	F01-13	10-14, 17-19
STT (PV09)	Kinematic	NovAtel (0016)	F01-04	10-11
STT (PV09)	Kinematic	Trimble (mgps)	F01-13	10-14, 17-19
STT (PV09)	Static	NovAtel (0016)	F05-13	12-14, 17-19
STT (PV09)	Static	NovAtel (0009)	F01-02	10
STT (PV09)	Static	Ashtech MAST	F01-13	10-14, 17-19
BQN (PV09	Kinematic	NovAtel (0013)	F14-26	21-22, 24-28
BQN (PV09	Kinematic	Trimble (mgps)	F14-21, F23, F25-26	21-22, 24-28
BQN (PV09	Static	NovAtel (0016)	F14-26	21-22, 24-28
BQN (PV09	Static	Ashtech MAST	F14-26	21-22, 24-28

Table 7: NGS GPS Base Station Position(s)

Airport	Base Name	Antenna Type	Latitude (dec deg)	Longitude (dec deg)	Ellipsoidal Height (m)
STT	NovAtel (0016)	NovAtel 702_2.02	18.3364734677	-64.965762858	-40.26825
STT	NovAtel (0009)	NovAtel 702_2.02	18.3364734677	-64.965762858	-40.26825
STT	Ashtech MAST	ASH701975.01A	18.3364912646	-64.9653526556	-40.2646
BQN	NovAtel (0016)	NovAtel 702_2.02	18.4997377536	-67.126223003	16.719
BQN	Ashtech MAST	ASH701975.01A	18.500073897	67.1263445631	15.9942

Data were processed using WGS84 and ITRF00. 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 0.023 m and the average vertical position accuracy is 0.016 m.

3.1.2 Ground Gravity Tie

Updated absolute gravity measurements were performed by NGS with a Micro-g LaCoste FG-5 gravimeter in winter of 2008/2009. Two relative surveys were performed in January 2009 to transfer the absolute gravity values to the aircraft parking spot at each airport. In Borniquin, PR the location is designated as BQN TAGS (18.49861°N, 67.12944°W) and it has an absolute gravity value of 978643.4720 ± 0.011 mGal. In St. Thomas, VI the location is designated as STT TAGS (18.339417°N, 64.9665833°W) and it has an absolute gravity value of 978666.5660 ± 0.008mGal.

3.1.3 Gravity Filtering

For block TS01, flights were accomplished in one 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 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

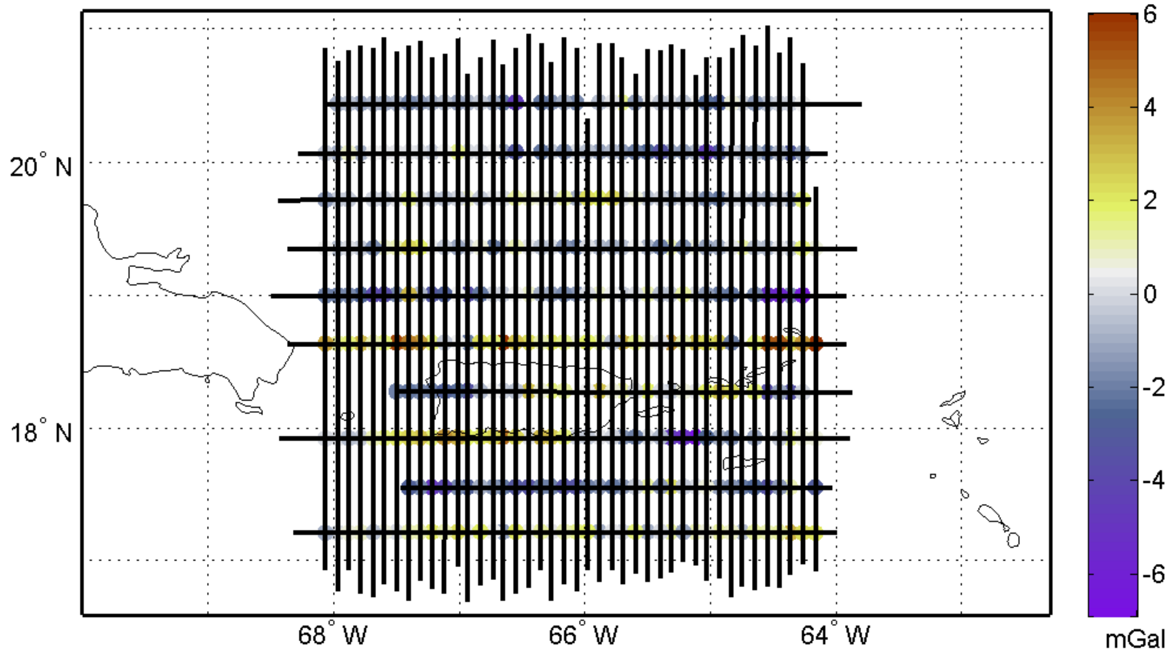
3.2.1 Gravity Error Analysis

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 TS01, the result of the crossover analysis is shown in Table 8 and in Figure 3.

Table 8: Gravity Crossover Error Analysis for the TS01 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	11,228	390	1.90	1.90	-0.15	1.34

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.



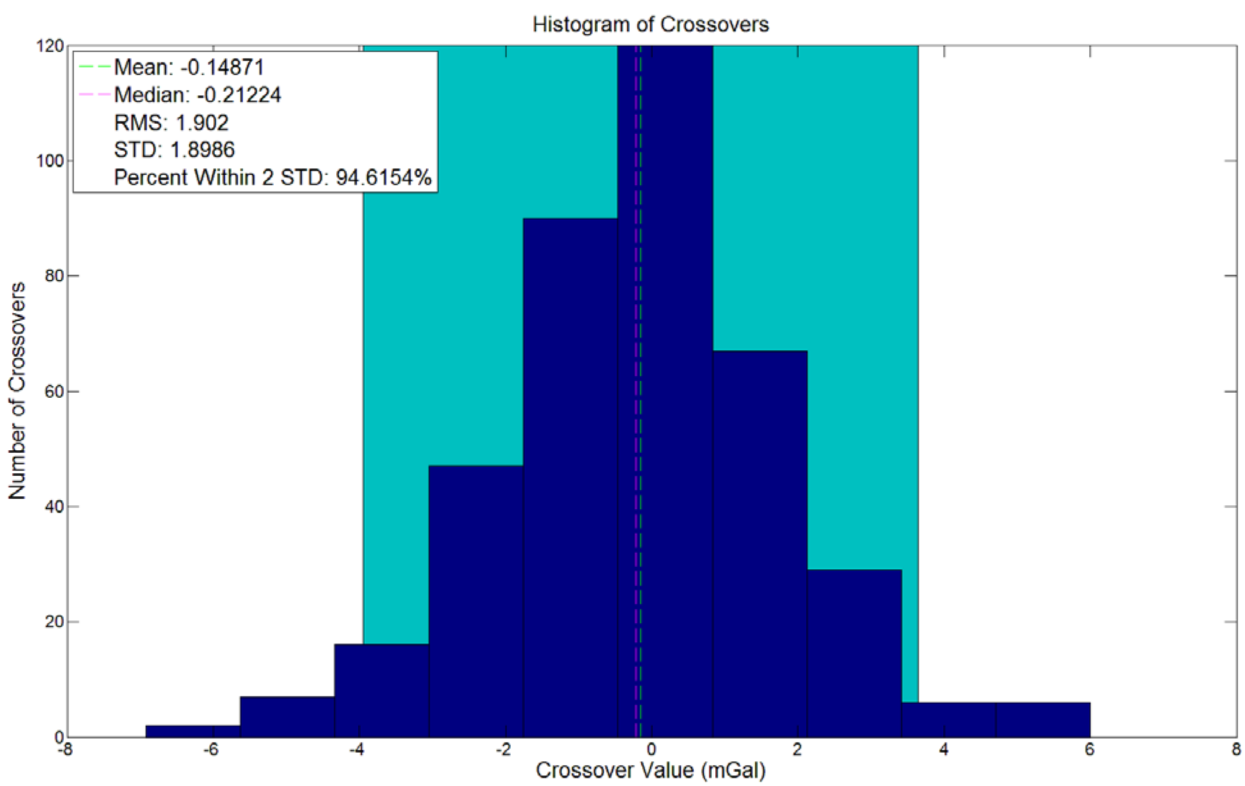


Figure 3: Crossover Residuals, Histogram, and Statistics for Block TS01. Color scale in mGals.

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	1.09	-0.86
502	1.28	-0.94
503	1.04	0.02
504	1.07	-0.15
505	1.93	-1.35
506	1.89	2.16
507	1.87	-0.10
508	2.41	0.36
509	1.55	-1.74
510	1.07	0.74

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
40	99.20%	1.88%

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 TS01, 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.7.80.2315 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 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 11: GPS+IMU and GPS-only Kinematic Processing Results

Survey	Flight Num.*	Base GPS Unit(s)	Rover GPS Unit	Solution Type	Elevation Mask (degrees)	Line Num.	NGS Quality Grade
PV09 STT	01	NovAtel	Trimble	GPS+IMU	10	142	96.64
						141	95.93
	02	NovAtel	Trimble	GPS+IMU	7	140	94.82
						139	94.33
	03	NovAtel	Trimble	GPS+IMU	11	138	83.97
						137	97.41
	04	Ashtech	Trimble	GPS+IMU	9	136	90.75
						135	95.54
	05	NovAtel	Trimble	GPS only	12	134	94.38
						133	74.22
	06	Ashtech	Trimble	GPS+IMU	11	131	64.97
						132	72.08
	07	Ashtech	Trimble	GPS+IMU	11	129	95.69
						130	94.55
	08	Ashtech	Trimble	GPS+IMU	13	127	87.37
						127	82.59
	09	Ashtech	Trimble	GPS+IMU	11	125	91.25
						126	93.83
	10	Ashtech	Trimble	GPS+IMU	9	510	93.53
						509	84.00
	11	Ashtech	Trimble	GPS only	9	508	92.51
						507	84.83
PV09 BQN	14	Ashtech	Trimble	GPS only	9	501	84.00
						503	96.31
	15	Ashtech	Trimble	GPS+IMU	9	123	98.00
						124	84.00
	16	NovAtel	Trimble	GPS+IMU	13	121	85.97

						122	85.54
	17	Ashtech	Trimble	GPS+IMU	12	119	94.33
						120	85.29
	18	NovAtel	Trimble	GPS+IMU	10	118	95.94
						117	84.96
	19	Ashtech	Trimble	GPS+IMU	10	116	88.65
						115	82.02
						114	88.51
	20	NovAtel	Trimble	GPS+IMU	10	113	98.63
						112	99.18
						111	95.54
	21	Ashtech	Trimble	GPS+IMU	10	108	96.32
						109	86.13
						110	93.39
	22	NovAtel	Trimble	GPS+IMU	9	105	95.00
						106	97.37
						107	89.83
	23	Ashtech	Trimble	GPS+IMU	10	103	94.18
						104	78.81
	24	Ashtech	NovAtel	GPS only	12	101	84.00
						102	95.92
	25	Ashtech	Trimble	GPS+IMU	11	505	94.24
						506	84.00
	26	Ashtech	Trimble	GPS+IMU	10	502	83.99
						504	94.71

**Flights 12 and 13 were used to test low altitude flights and are not part of the released data*

Table 12: Gravity Processing Results

Survey	Flight Num.	Line Num.	Times of Deleted Data Sections (s)	Comments
PV09 STT	01	141	57907-58138	
		142	52795-53086, 53442-53767	
	02	139		
		140		
	03	137		
		138	50509-50877	
	04	135		
		136	69271-70330	
	05	133		
		134		
	06	131		
		132		
	07	129		
		130		
	08	127		
		128		

	09	125		
		126		
	10	509		
		510		
	11	507		
		508		
PV09 BQN	14	501		
		503		
	15	123		
		124		
	16	121		
		122	76159-76484	
	17	119		
		120		
	18	117		
		118	69491-69977	
	19	114		
		115		
		116		
	20	111		
		112		
		113		
	21	108		
		109		
		110		
	22	105		
		106		
		107		
	23	103		
		104	56467-56809	
	24	101		
		102		
	25	505		
		506		
	26	502		
		504		

Table 13: Bias from EGM08 by Line

Survey	Flight Num.	Line Num.	Bias from EGM08 (mGals)
PV09 STT	1	142	-1.91
		141	-1.64
	2	140	-1.93
		139	-2.22
	3	138	-1.90
		137	-1.58
	4	136	-1.91

		135	-1.88
	5	134	-2.38
		133	-2.20
	6	131	-2.51
		132	-2.95
	7	129	-2.29
		130	-2.89
	8	127	-2.52
		128	-2.73
	9	125	-2.41
		126	-2.77
	10	510	-1.29
		509	-4.71
	11	508	-0.69
		507	-3.90
PV09 BQN	14	501	-3.92
		503	-0.72
	15	123	-2.87
		124	-3.01
	16	121	-2.71
		122	-2.61
	17	119	-2.86
		120	-3.16
	18	118	-3.02
		117	-2.63
	19	116	-3.00
		115	-2.62
		114	-2.57
	20	113	-2.26
		112	-2.20
		111	-2.31
	21	108	-3.01
		109	-2.88
		110	-2.41
	22	105	-2.12
		106	-2.10
		107	-2.60
	23	103	-1.87
		104	-2.11
	24	101	-1.28
		102	-1.18
	25	505	-3.77
		506	-1.31
	26	502	-3.85
		504	-0.60

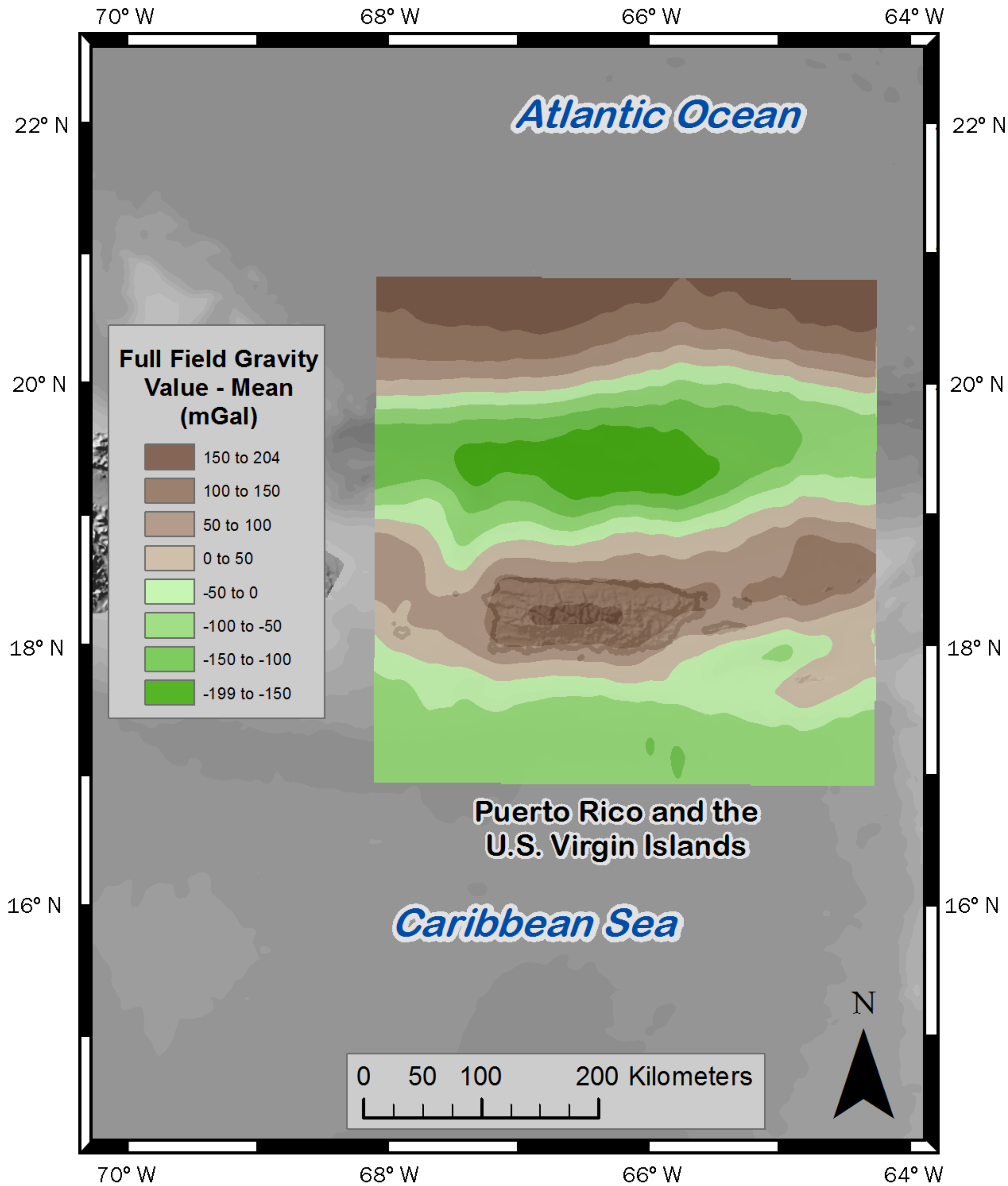


Figure 4: Full-field gravity at altitude (mean removed) for Block TS01. This is the data in the gravity release ".txt" file and includes the effects of differing altitudes along flight lines.

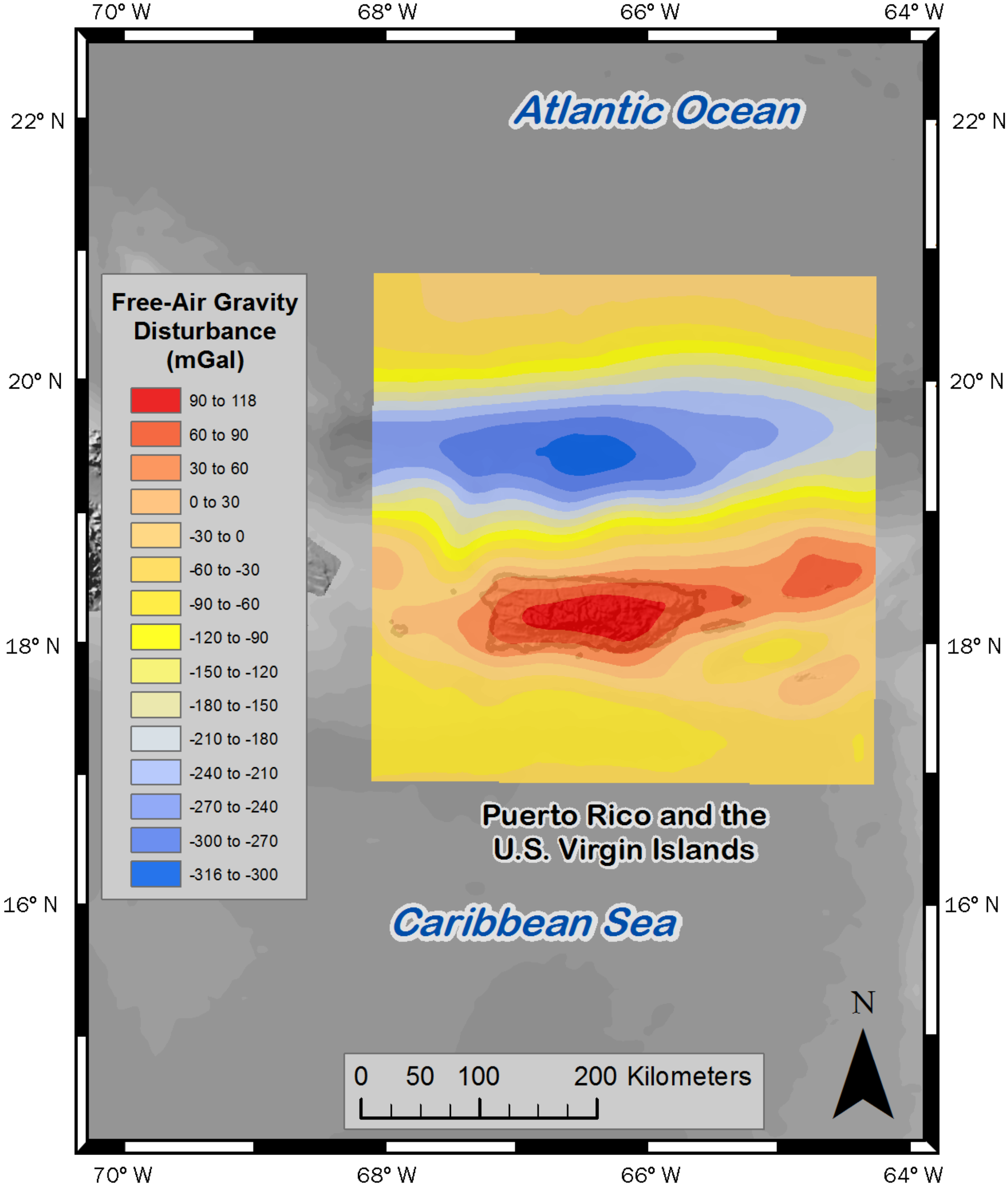


Figure 5: Free-air gravity disturbance for Block TS01 with respect to the WGS-84 ellipsoid.

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, Carly A. Weil, and Monica A. Youngman.

To reference the TS01 data file, reference the webpage:
GRAV-D Science Team (2012). "Gravity for the Redefinition of the American Vertical Datum (GRAV-D) Project, Airborne Gravity Data; Block TS01". Available *DATE*. Online at: http://www.ngs.noaa.gov/GRAV-D/data_TS01.shtml

To reference the block and survey details, reference the block user manual:
GRAV-D Science Team (2012). "Block TS01 (Atlantic South 01); GRAV-D Airborne Gravity Data User Manual." Monica Youngman and Carly Weil, ed. Version 1. Available *DATE*. Online at: http://www.ngs.noaa.gov/GRAV-D/data_TS01.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 Damiani, ed. Version 1. Available *DATE*. Online at: http://www.ngs.noaa.gov/GRAV-D/data_TS01.shtml

5. References

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