Block AN05 (Alaska North 05)

GRAV-D Airborne Data Release User Manual

Applies to Data Release BETA, 11/2013

Edited by Monica A. Youngman,Carly A. Weil, and Theresa M. Damiani

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."

Contents

Introduction to GRAV-D and Data User Manuals 1
Figure List 3
Table List 3
1. Block Description 4
2. Survey Design and Execution 5
2.1 GPS/IMU Instrumentation 7
2.2 Gravity Instrumentation 7
3. GPS and Gravity Data Processing 8
3.1 Whole-Survey Applicable Details 8
3.1.1 GPS 8
3.1.2 Ground Gravity Tie 8
3.1.3 Gravity Filtering 8
3.2 Whole-Block Applicable Details 9
3.2.1 Gravity Error Analysis 9
3.3 Flight- and Line-Specific Details 11
3.3.1 GPS processing- by flight 11
3.3.2 Gravity processing- by line 12
4. Data Usage Guidelines 17
4.1 Suggested Data Handling 17
4.2 Documentation 17
4.3 How to Cite These Data 18
5. References 18

Figure List

Figure 1: Google Earth Image of the Location of Block AN05 (black rectangle). 4
Figure 2: Data Coverage for AN05. Data lines start in the east at 101 and continue west to 148. Airport marked with red star. 6
Figure 3: Crossover Residuals, Histogram, and Statistics for Block AN05. 10
Figure 4: Full-field gravity at altitude (mean removed) for Block AN05. This is the data in the gravity release ".txt" file and includes the effects of differing altitudes along flight lines. 16
Figure 5: Free-air gravity disturbance for Block AN05 with respect to the WGS-84 ellipsoid. ..17

Table List

Table 1: Latitude and Longitude Coordinates of Corner Points Defining Block AN05 4
Table 2: Survey Overview 5
Table 3: Aircraft and Instrumentation 5
Table 4: Survey Design and Execution 5
Table 5: Lever Arm Measurements FROM the Center of the Gravimeter's Sensor TO the Other Instruments, for this Installation on the NOAA WP-3D 7
Table 6: GPS High Rate Data Availability (1 Hz or higher) During 20,000 ft Data Collection... 8
Table 7: Gravity Crossover Error Analysis for the AN05 block 9
Table 8: Quality of Cross Lines Used in Crossover Analysis.....11
Table 9: Average Data Line Correlation.....11
Table 10: GPS+IMU and GPS-only Kinematic Processing Results.....12
Table 11: Gravity Processing Results.....13
Table 12: Bias from EGM08 by Line 14

1. Block Description

GRAV-D Block **AN05** is located in the **A**laska Time Zone, in the **N**orth half (north of 63° latitude). This was the fifth (**05**) block of data completed in that region. Block AN05 is approximately 560 km by 480 km, covering coastal areas of Alaska and ocean areas from 140 to 200 km offshore (Figure 1). The corner coordinates defining Block AN05 are listed in Table 1.

Figure 1: Google Earth Image of the Location of Block AN05 (black rectangle).

Table 1: Latitude and Longitude Coordinates of Corner Points Defining Block AN05

Latitude (decimal degrees)	Longitude (decimal degrees)
66.516573607	-148.141981896
72.253644904	-151.339391327
71.786831934	-164.891890159
66.132840233	-158.513337867

2. Survey Design and Execution

Airborne gravity data in Block AN05 were collected during AK11 (Alaska 2011). All data and cross flights were done at 20,000 ft with the same aircraft and instrument suite. 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 AN05 all data lines are North-South and cross lines East-West. The block consists of 48 data lines, 6 cross lines. 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. AN05101= block AN05's line 101).

Table 2: Survey Overview

Conducting Organization	NOAA- National Geodetic Survey
Survey Name	AK11
Airport Base of Operations	Fort Wainwright Airport (FBK) Fairbanks, AK FBO: Fort Wainwright
Geographic Location	Northern Alaska
Dates of Airborne Operations	Apr. 5th – May 18th, 2011

Table 3: Aircraft and Instrumentation

Aircraft	NOAA43 WP-3D Orion
Engines, number and type	4, Turboprop
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	20,000 ft
Nominal Aircraft Ground Speed	270 knots
Number of Lines Released	Data Lines: 48 Cross Lines: 6 Repeat Lines: 0
Number of Crossovers	240

Figure 2: Data Coverage for AN05. Data lines start in the east at 101 and continue west to 148. Airport marked with red star.

2.1 GPS/IMU Instrumentation

The NOAA43 WP-3D Orion had one GPS antenna available for scientific measurements. Three geodetic-quality GPS receivers shared the antenna: 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. A second IMU, the Micro IRS, was used during the survey inside a NovAtel SPAN inertial system.

On the ground, three Ashtech Z-Surveyor also recorded at 1 Hz served as GPS base stations throughout the survey. See Section 3.2.1 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 P-3 Orion near the center of gravity. 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).

The TAGS was mounted in the center of the fuselage. 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 WP-3D

Instrument/Location	X (m)	Y (m)	Z (m)
Aircraft Center of Gravity	0.00	0.43	0.00
Aircraft GPS Antenna	-3.77	0.43	-2.00
Micro IRS IMU	0.00	0.00	-0.54
Applanix POS AV 510 IMU	-0.13	0.00	-0.50

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) During 20,000 ft Data Collection

Airport	Type	Receiver	Flight Available	2009 Day of Year Available
FBK	Kinematic	NovAtel (0009)	F01-F15	98, 100-101, 107, 110, 111, 114-116, 119-121, 124-125
		Trimble (mgps)	F01-F12,F14-F15	98, 100-101, 107, 110, 111, 114-116, 119-122, 124-125
	Static	Ashtech North	F01-F15	98, 100-101, 107, 110, 111, 114-116, 119-122, 124-125
		Ashtech South	F01-F15	98, 100-101, 107, 110, 111, 114-116, 119-122, 124-125
		Ashtech User	F01-F15	98, 100-101, 107, 110, 111, 114-116, 119-122, 124-125

Data were processed using WGS84 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 0.022 m and the average vertical position accuracy is 0.020 m.

3.1.2 Ground Gravity Tie

Updated absolute gravity measurements were performed by NGS with a Micro-g LaCoste A-10 gravimeter in summer of 2011. At the airport, the A-10 was set up at the exact location of the aircraft. The positions were determed from the GPS collected during the gravity survey while the plane was parked. In Fairbanks, AK the location is designated as P3 TAGS (64.8396298333°N,-147.5970598333°W) and it has an absolute gravity value of 982228.5832 ± 0.01051 mGal at 312.42 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 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 AN05, the result of the crossover analysis is shown in Table 8 and in Figure 3.

Table 7: Gravity Crossover Error Analysis for the AN05 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	5,777	240	1.91	1.92	-0.10	1.35

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 AN05. 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)
508	1.62	-0.09
509	1.22	-0.28
510	2.23	0.55
511	2.08	-0.70
512	2.05	0.71
513	1.47	-1.02

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 9: Average Data Line Correlation

Number of Correlations	Average Data Line Correlation	Standard Deviation of Correlations
45	99.64%	0.34%

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 AN05, however, there were no reflown lines.

3.3 Flight- and Line-Specific Details

3.3.1 GPS processing- by flight

If SPAN data were available GPS data were processed in Inertial Explorer (IE) 8.5. If Applanix data were used then 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. 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 or 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 or IE. 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 10: GPS+IMU and GPS-only Kinematic Processing Results

Survey	Flight Num.	Rover GPS Unit	Solution Type	Elevation Mask (degrees)	Line Num.	NGS Quality Grade
AK11	01	Trimble	GPS+IMU	7.5	101	99.91
					102	100.00
					103	98.54
					104	99.93
	02	Trimble	GPS+IMU	7.5	117	96.14
					118	100.00
					119	100.00
					120	98.14
	03	Trimble	GPS+IMU	7.5	121	98.56
					122	99.84
					123	98.25
					124	95.89
	04	Trimble	GPS+IMU	7.5	125	94.96
					126	100.00
					127	95.37
					128	87.82
	05	Trimble	GPS+IMU	7.5	143	95.95
					144	99.75
	06	SPAN	GPS+IMU	5	141	100.00
					142	100.00
	07	SPAN	GPS+IMU	5	133	100.00
					134	100.00
					135	100.00
					136	100.00
	08	Trimble	GPS+IMU	5	233*	100.00
					234*	100.00
					235*	100.00
					236*	100.00
					137	97.73
					138	100.00
	09	SPAN	GPS+IMU	5	139	100.00
					140	100.00
	10	SPAN	GPS+IMU	5	105	100.00
					106	99.98

					107	100.00
					108	100.00
	11	SPAN	GPS+IMU	5	109	100.00
					110	100.00
					111	100.00
					112	100.00
	12	SPAN	GPS+IMU	5	113	100.00
					114	99.50
					115	99.94
					116	100.00
	13	SPAN	GPS only	5	145	100.00
					146	100.00
					147	97.06
					148	100.00
	14	SPAN	GPS+IMU	5	508	100.00
					509	100.00
					510	100.00
					511	98.37
	15	SPAN	GPS+IMU	5	512	100.00
					513	100.00

**Lines 233, 234, 235, and 236 were originally meant to be reflights, but due to the aircraft autopilot the lines do not match so both lines were kept to have more complete data coverage.*

Table 11: Gravity Processing Results

Survey	Flight Num.	Line Num.	Times of Deleted Data Sections (s)	Comments
AK11	01	101		
		102		
		103		
		104		
	02	117		
		118		
		119		
		120		
	03	121		
		122		
		123		
		124		
	04	125		
		126		
		127	78458-7877	Spike Removed
		128		
	05	143		
		144		
	06	141		

		142		
	07	133		
		134	73611-73959	Spike Removed
		135		
		136	84540-85128	Spike Removed
	08	233		
		234		
		235		
		236		
		137		
		138		
	09	139	79896-80209	Spike Removed
		140	85002-85355	Spike Removed
	10	105	70115-70546	Spike Removed
		106	74176-74680	Spike Removed
		107	79423-79766	Spike Removed
		108	83938-84124	Spike Removed
	11	109	68389-68691	Spike Removed
		110		
		111		
		112		
	12	113	69175-69480	Spike Removed
		114		
		115		
		116		
	13	145		
		146	75070-75470	Spike Removed
		147	79624-79850	Spike Removed
		148	82817-83026	Spike Removed
	14	508		
		509	76808-77403	Spike Removed
		510		
		511	85488-85879	Spike Removed
	15	512	71870-72214	Spike Removed
		513	67605-67970	Spike Removed

Table 12: Bias from EGM08 by Line

Survey	Flight Num.	Line Num.	Bias from EGM08
AK11	01	101	0.01
		102	-0.30
		103	-0.46
		104	-0.49
	02	117	-0.91
		118	-0.81
		119	-0.08
		120	3.38

	03	121	1.58
		122	3.39
		123	-0.13
		124	-0.14
	04	125	-0.31
		126	-0.41
		127	-0.33
		128	-1.52
	05	143	0.13
		144	-0.40
	06	141	2.16
		142	2.46
	07	133	-0.60
		134	-0.69
		135	-0.25
		136	0.39
	08	233	-0.04
		234	0.97
		235	1.24
		236	0.96
		137	0.61
		138	0.36
	09	139	0.36
		140	0.44
	10	105	-0.46
		106	-0.48
		107	-0.55
		108	0.02
	11	109	0.09
		110	-0.22
		111	0.25
		112	-0.06
	12	113	0.02
		114	0.10
		115	0.08
		116	-0.28
	13	145	0.69
		146	0.30
		147	0.62
		148	0.53
	14	508	0.52
		509	-0.38
		510	0.46
		511	0.49
	15	512	1.09
		513	-1.10

Figure 4: Full-field gravity at altitude (mean removed) for Block AN05. 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 AN05 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 AN05 data file, reference the webpage:
GRAV-D Science Team (2013). "Gravity for the Redefinition of the American Vertical Datum (GRAV-D) Project, Airborne Gravity Data; Block AN05". Available *DATE*. Online at: http://www.ngs.noaa.gov/GRAV-D/data_AN05.shtml

To reference the block and survey details, reference the block user manual:
GRAV-D Science Team (2013). "Block AN05 (Alaska North 05); GRAV-D Airborne Gravity Data User Manual." Monica Youngman, Carly Weil, and Theresa Damiani ed. Version BETA. Available *DATE*. Online at: http://www.ngs.noaa.gov/GRAV-D/data_AN05.shtml

To reference the general GRAV-D project operations, reference the General User Manual:
GRAV-D Science 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.shtml

5. References

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