Block AN01 (Alaska North 01)

GRAV-D Airborne Data Release User Manual

Applies to Data Release BETA #1, 3/2015

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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."

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1. Block Description

GRAV-D Block **AN01** is located in the **Alaska** Time Zone, in the **N**orth half (north of 63° latitude). This was the first (**01**) block of data completed in that region. Block AN01 is 320 km by 440 km in inland central Alaska (Figure 1). The corner coordinates defining Block AN01 are listed in Table 1.

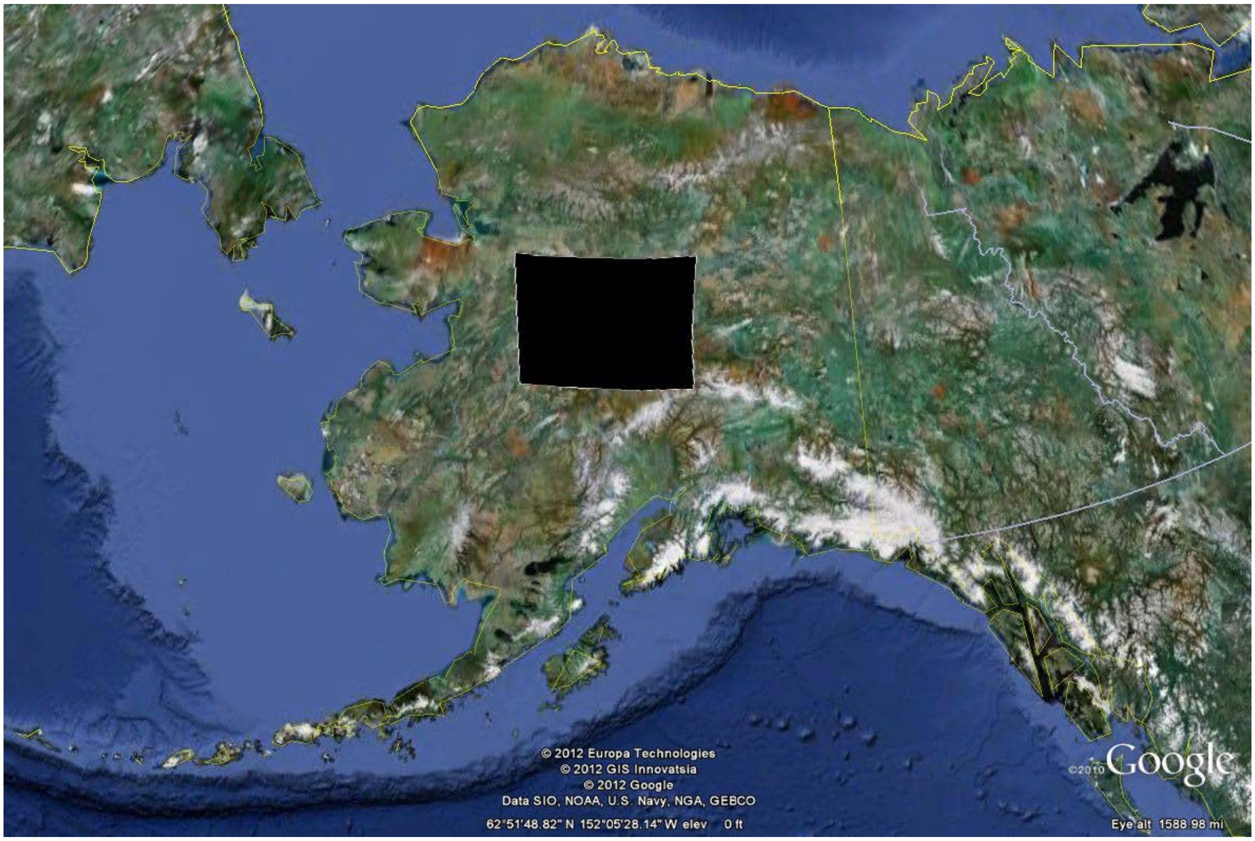


Figure 1: Google Earth Image of the Location of Block AN01 (black rectangle).

Table 1: Latitude and Longitude Coordinates of Corner Points Defining Block AN01

Latitude (decimal degrees)	Longitude (decimal degrees)
66.121706320	-158.624315064
63.365932055	-157.429980995
63.570999712	-148.918352228
66.431615881	-148.993140477

2. Survey Design and Execution

Airborne gravity data in Block AN01 were collected during two surveys: AK09 (Alaska 2009) and AK10-1 (Alaska 2010). All data and cross flights were done at 12,500 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 AN01 all data lines are East-West and cross lines North-South. The block consists of 46 data lines and 7 cross lines from AK09. 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. AN01101= block AN01's line 101).

Table 2: Survey Overview

Conducting Organization	NOAA- National Geodetic Survey (NGS) DOD – National Geospatial Intelligence Agency (NGA)	NOAA-National Geodetic Survey
Survey Name	AK09	AK10-1
Airport Base of Operations	Eielson Air Force Base, AK (EAFB) Fairbanks, AK	Ted Stevens Anchorage International Airport (ANC) Anchorage, AK FBO: Penn Air
Geographic Location	Central Alaska	
Dates of Airborne Operations	July 6th – August 12th, 2009	Jun. 27 – Aug. 26th, 2010

Table 3: Aircraft and Instrumentation

Aircraft	Naval Research Labs (NRL) King Air RC-12	NOAA Turbo Commander (N45RF) (AK10-1)
Engines, number and type	2, 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: 7.5 km Cross Lines: 37.5 km	Data Lines: 10 km Cross Lines: ~40 km
Type of Layout	Regular data lines & regular cross lines	
Nominal Survey Altitude	12,500 ft	20,000 ft
Nominal Aircraft Ground Speed	220 knots	250 knots
Number of Lines Released	Data Lines: 46 Cross Lines: 7	Data Lines: 0 Cross Lines: 4
Number of Crossovers	429	

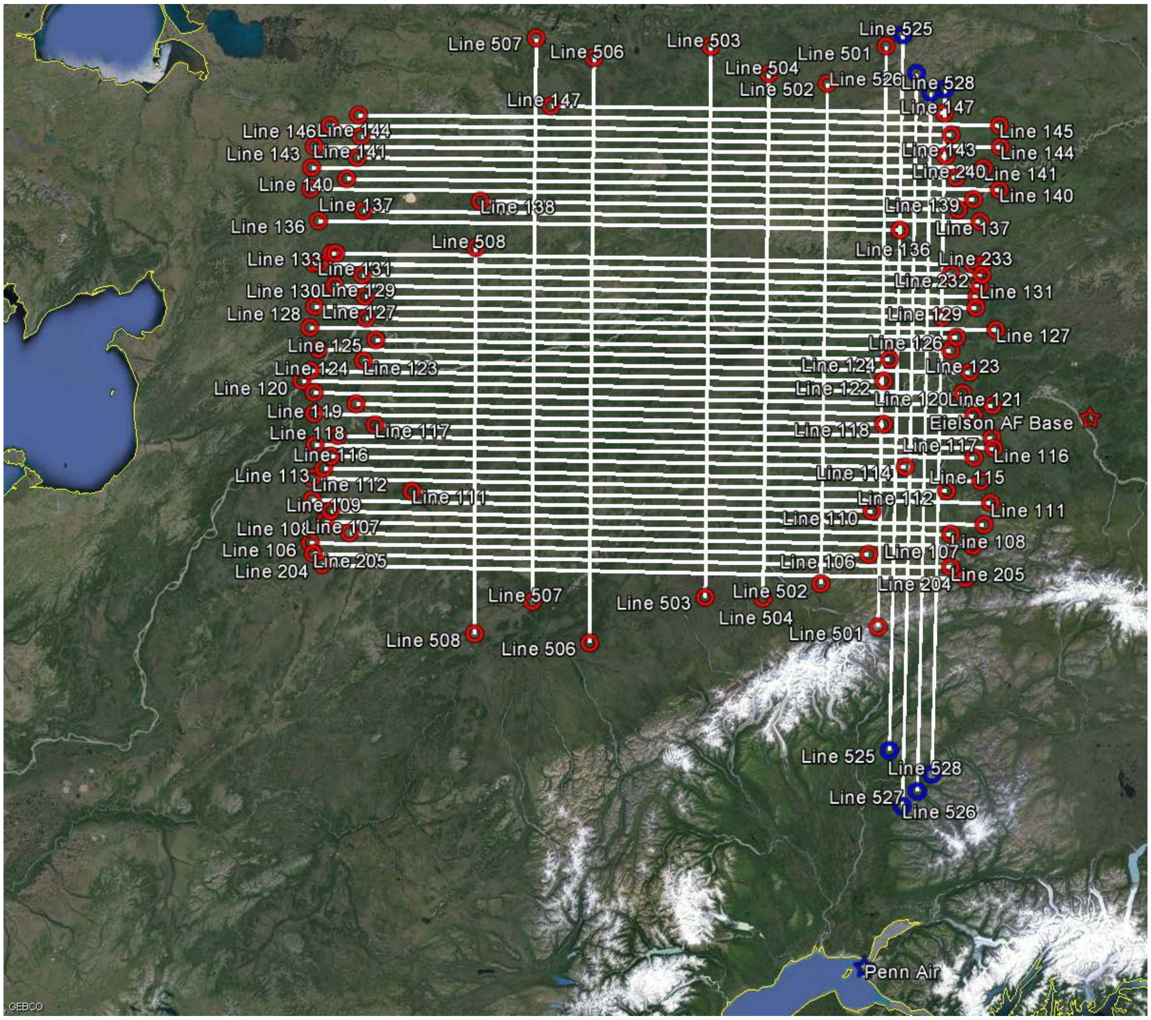


Figure 2: Data Coverage for AN01. Data lines start in the south at 204 to 147 (AK09, red from Eleison Air Force Base and AK10-1, blue from Ted Stevens Anchorage International Airport). Airports marked with red and blue star.

2.1 GPS/IMU Instrumentation

The NRL King Air RC-12 and NOAA Turbo Commander both had one GPS antenna available for scientific measurements. 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 for AK09, three Trimble R8 recorded at 1 Hz served as GPS base stations throughout the survey. For AK10-1, three Ashtech Z-Surveyor 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 cargo area of the NRL King Air RC-12. 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).

In order to meet Navy safety guidelines a specific rack was commissioned for this survey. The TAGS was mounted forward of center in the fuselgue plane, just left of the centerline. 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 NRL King Air RC-12

Instrument/Location	X (m)	Y (m)	Z (m)
Aircraft Center of Gravity	0.0	0.42	0.5
Aircraft GPS Antenna	-1.059	0.439	-1.122
Applanix POS AV 510 IMU	0.0	0.15	-0.349

Table 6: Lever Arm Measurements FROM the Center of the Gravimeter's Sensor TO the Other Instruments, for this Installation on the NOAA Turbo Commander

Instrument/Location	X (m)	Y (m)	Z (m)
Aircraft Center of Gravity	0.00	0.00	-0.56
Aircraft GPS Antenna	0.16	0.13	-1.25
Applanix POS AV 510 IMU	0.03	0.00	-0.50

3. GPS and Gravity Data Processing

3.1 Whole-Survey Applicable Details

3.1.1 GPS

Table 7: GPS High Rate Data Availability (1 Hz or higher) During 12,500 ft Data Collection

Airport	Type	Receiver	Flight Available	2009 Or 2010 Day of Year Available
EAFB	Kinematic	NovAtel (0009)	F04-24, F26-F29, F33	197-199, 204-208, 210-217,223
		Trimble (mgps)	F04-F15, F17-F33	197-199, 204-208, 210-214, 216-217, 222-223
	Static	NovAtel (0016)	F04-F11, F17-F33	197-199, 204-205, 208, 210-214, 216-217, 222-223
		NovAtel (2450)	F04-F18, F20-F32	197-199, 204-208, 210, 211-214, 216-217, 222-223
		NovAtel (0635)	F07-F29, F31-F32	198-199, 214-208, 210-214, 216-217, 222-223
FBK	Kinematic	NovAtel (0013)	F19, F20	289, 291
		Trimble (mgps)	F19, F20	289, 291
	Static	Ashtech (East)	F19, F20	289, 291
		Ashtech (User)	F19, F20	289, 291
		Ashech (West)	F19, F20	289, 291

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 0.0094 m and the average vertical position accuracy is 0.0116 m.

3.1.2 Ground Gravity Tie

A relative gravity survey was conducted to transfer an existing absolute gravity measurement made in 2008 (FAIRBANKS CIGO, 64.866783959°N, 147.850196333°W). This was performed by NGS in the summer of 2009 with two LaCoste & Romber (L&R) G-model relative gravimaters. Sevens loops were made from CIGO to a new mark near the aircraft (M-1) and from M-1 to the location of the gravimeter in the aircraft. For AK09 the location is designated as EIL TAGS (64.650160520°N, 147.083395207°W) and it has an absolute gravity value of 982202.6769 ± 0.0083 mGal at 162.5 cm above the tarmac. For AK10-1, the location is designated as FBK TAGS (61.19751983 °N, -149.99663 °W) and it has an absolute gravity value of 981903.3548 ± 0.00798 at 80.6 cm above the tarmac.

3.1.3 Gravity Filtering

For block AN01, flights were accomplished two surveys 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

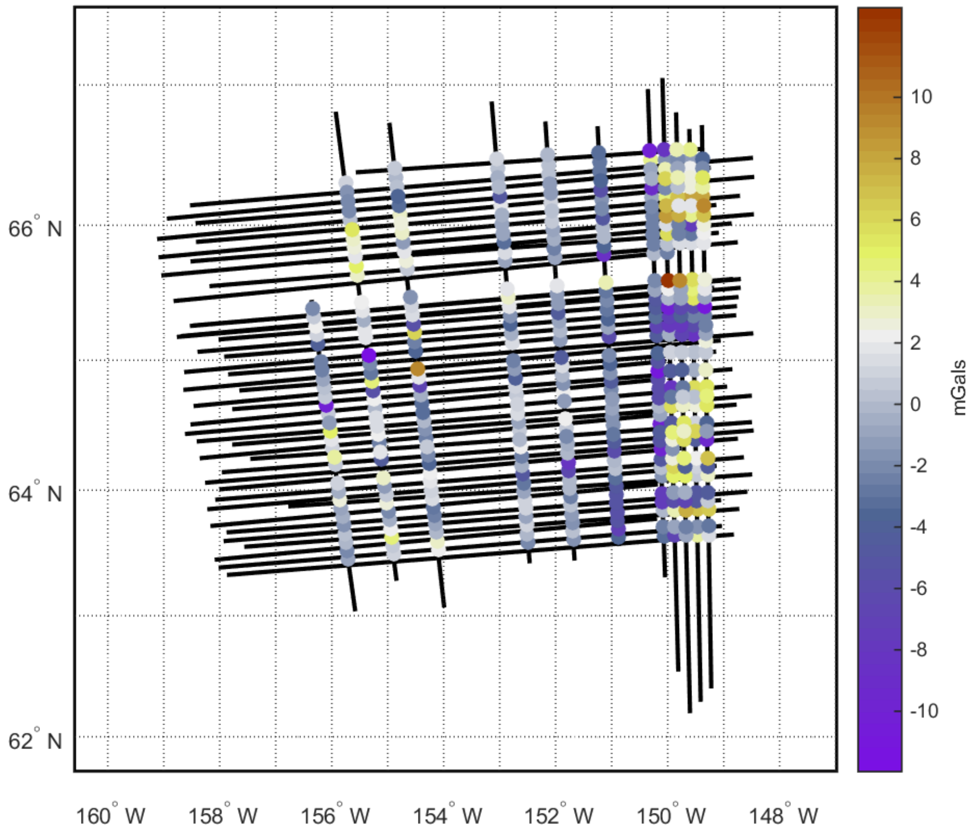
3.2.1 Gravity Error Analysis

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 AN01, the result of the crossover analysis is shown in Table 8 and in Figure 3.

Table 8: Gravity Crossover Error Analysis for the AN01 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)
12,500	3,810	4,068	429	3.90	3.87	-0.50	2.76

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.


66° N
64° N
62° N
160° W
158° W
156° W
154° W
152° W
150° W
148° W
10
8
6
4
2
0
-2
-4
-6
-8
-10
mGals

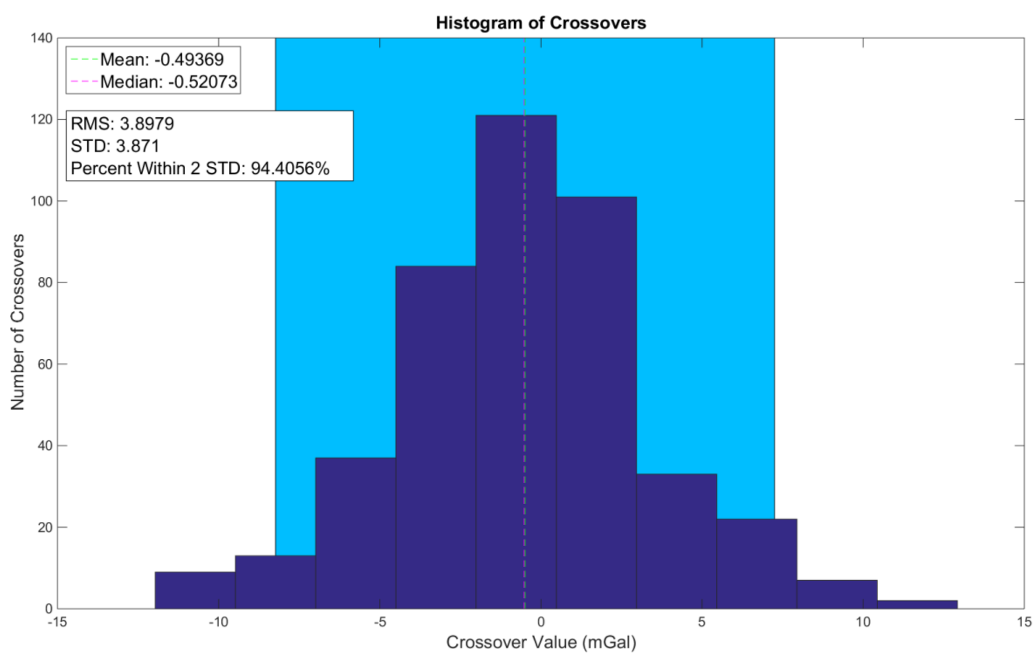

Histogram of Crossovers
Mean: -0.49369
Median: -0.52073
RMS: 3.8979
STD: 3.871
Percent Within 2 STD: 94.4056%
Number of Crossovers
Crossover Value (mGal)

Figure 3: Crossover Residuals, Histogram, and Statistics for Block AN01. 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	3.42	-3.74
502	2.28	-2.91
503	1.95	-0.28
504	2.10	-0.95
506	3.04	-0.19
507	3.27	0.66
508	2.74	-0.44
525	5.70	0.65
526	4.67	0.56
527	4.32	0.91
528	4.61	0.99

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
38	76.02%	18.59%

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 AN01, however, there were no reflown lines.

A final way of estimating data quality is by comparing the full-field gravity results from block AN01 with the global gravity model EGM08's full-field gravity over the same area, at the same altitude. By subtracting the airborne from the EGM08 data (out to degree and order 2190), we produce a residual and statistics on that comparison (Figure 4).

3.3 Flight- and Line-Specific Details

3.3.1 GPS processing- by flight

As described in the "GRAV-D General Airborne Gravity Data User Manual", GPS data were processed in POSPac v.4.4 for GPS+IMU position solutions or in GrafNav v.8.50.4923 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.	Rover GPS Unit	Solution Type	Elevation Mask (degrees)	Line Num.	NGS Quality Grade
AK09 EAFB	4	Trimble	GPS+IMU	5	204	96.79
					205	100.00
	5	Trimble	GPS+IMU	5	145	88.65
					146	98.04
	6	Trimble	GPS+IMU	5	106	100.00
					107	100.00
	7	Trimble	GPS+IMU	5	108	100.00
					109	99.78
	8	Trimble	GPS+IMU	5	110	100.00
					111	100.00
	9	Trimble	GPS+IMU	5	112	100.00
					113	97.96
	10	Trimble	GPS+IMU	5	114	98.90
					117	96.97
	11	Trimble	GPS+IMU	5	115	100.00
					116	100.00
	12	Trimble	GPS+IMU	5	118	96.61
					119	98.52
	13	Trimble	GPS+IMU	5	506	94.47
	14	NovAtel	GPS+IMU	5	508	100.00
	15	Trimble	GPS+IMU	5	120	100.00
					121	100.00
	16	Trimble	GPS only	5	122	92.80
					123	99.81
	17	Trimble	GPS+IMU	5	124	100.00
					125	99.30
	18	Trimble	GPS+IMU	5	126	100.00
					127	79.32
	19	Trimble	GPS+IMU	5	128	97.58
					129	92.28
	20	Trimble	GPS+IMU	5	130	100.00
					131	100.00
	21	Trimble	GPS+IMU	5	132	98.08
					133	95.95
	23	Trimble	GPS+IMU	5	136	100.00
					137	96.49
	24	Trimble	GPS+IMU	5	501	100.00
					502	90.90
	25	Trimble	GPS+IMU	5	503	100.00
					504	95.11
	26	Trimble	GPS+IMU	5	138	94.51
	27	Trimble	GPS+IMU	5	139	100.00
					140	96.10
	28	Trimble	GPS+IMU	5	141	96.36
					240	98.21
	29	Trimble	GPS+IMU	5	507	85.63
	31	Trimble	GPS+IMU	5	232	95.84
					233	100.00
	32	Trimble	GPS only	5	143	97.76
					144	79.04
	33	Trimble	GPS+IMU	5	147	100.00
FBK	19	Trimble	GPS+IMU	5	527	100.00
					528	99.77
	20	Trimble	GPS+IMU	5	525	90.24
					526	96.83

Table 12: Gravity Processing Results

Survey	Flight Num.	Line Num.	Times of Deleted Data
AK09 EAFB	4	204	
		205	
	5	145	
		146	
	6	106	
		107	
	7	108	
		109	
	8	110	
		111	
	9	112	
		113	
	10	114	82810-83307
		117	
	11	115	
		116	
	12	118	
		119	90165-90404
	13	506	
	14	508	
	15	120	
		121	
	16	122	
		123	
	17	124	
		125	
	18	126	
		127	
	19	128	82146-82874
		129	
	20	130	
		131	
	21	132	
		133	
	23	136	
		137	
	24	501	
		502	
	25	503	
		504	
	26	138	
	27	139	
		140	
	28	141	
		240	
	29	507	
	31	232	
		233	
	32	143	
		144	
	33	147	
FBK	19	527	
		528	
	20	525	
		526	

Table 12: Bias from EGM08 by Line

Survey	Flight Num.	Line Num.	Bias from EGM08
AK09 EAFB	4	204	0.62
		205	0.58
	5	145	-0.13
		146	1.08
	6	106	1.04
		107	0.74
	7	108	2.54
		109	2.78
	8	110	0.43
		111	0.75
	9	112	0.57
		113	0.45
	10	114	3.36
		117	3.36
	11	115	4.50
		116	3.03
	12	118	-0.13
		119	-0.01
	13	506	2.52
	14	508	3.24
	15	120	3.72
		121	1.70
	16	122	3.83
		123	4.02
	17	124	3.07
		125	3.59
	18	126	3.42
		127	3.71
	19	128	4.10
		129	2.78
	20	130	2.48
		131	1.35
	21	132	1.14
		133	0.40
	23	136	1.91
		137	1.12
	24	501	-0.71
		502	-2.00
	25	503	0.05
		504	0.11
	26	138	3.49
	27	139	1.45
		140	0.78
	28	141	0.50
		240	1.00
	29	507	1.84
	31	232	0.85
		233	0.14
	32	143	3.13
		144	2.13
	33	147	0.06
FBK	19	527	2.19
		528	1.34
	20	525	1.10
		526	1.43

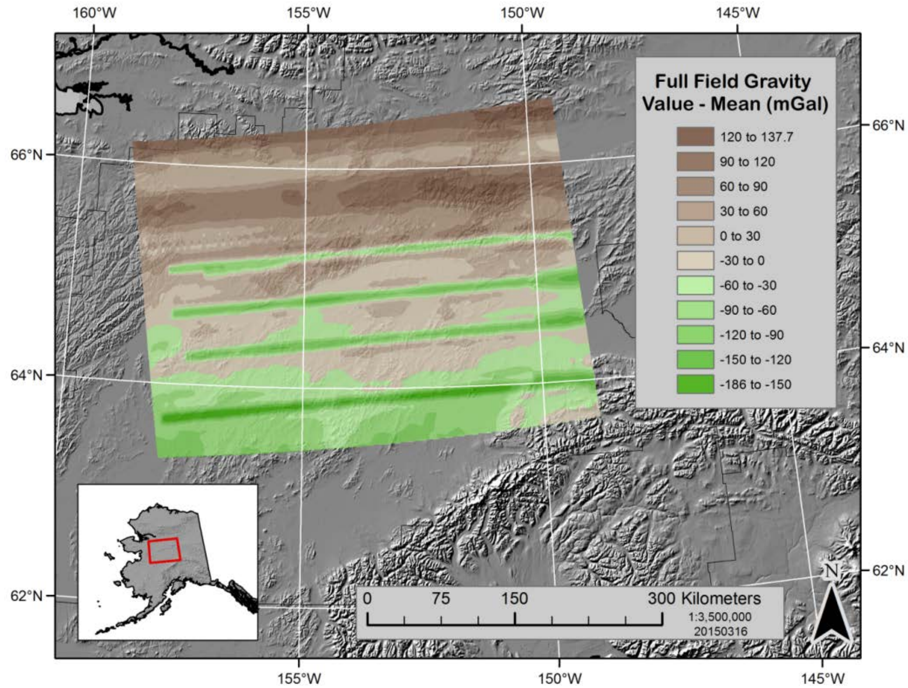


Figure 4: Full-field gravity at altitude (mean removed) for Block AN01. This is the data in the gravity release ".txt" file and includes the effects of differing altitudes along flight lines.

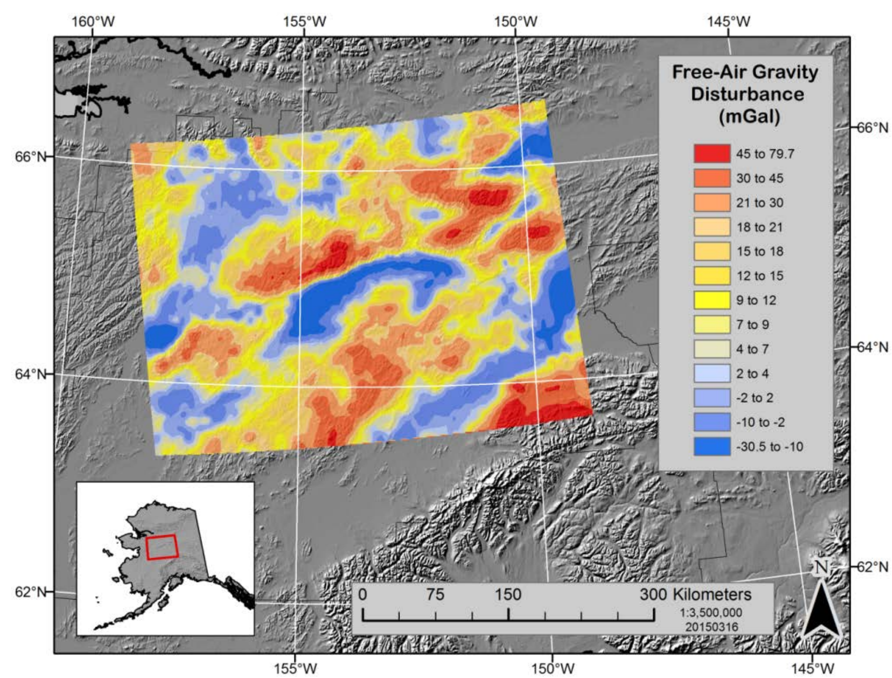


Figure 5: Free-air gravity disturbance for Block AN01 with respect to the WGS-84 ellipsoid.

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 together. 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 Dahlberg, Theresa M. Damiani, Sandra A. Martinka Preaux, Tim Salisbury, Carly A. Weil, Tim Wilkins, and Monica A. Youngman.

To reference the AN01 data file, reference the webpage:
GRAV-D Team (2015). "Gravity for the Redefinition of the American Vertical Datum (GRAV-D) Project, Airborne Gravity Data; Block AN01". Available *Date*. Online at: http://www.ngs.noaa.gov/GRAV-D/data_AN01.shtml

To reference the block and survey details, reference the block user manual:
GRAV-D Team (2015). "Block AN01 (Alaska North 01); GRAV-D Airborne Gravity Data User Manual." Monica Youngman, Carly Weil, and Tim Salisbury, ed. Version BETA #1. Available *Date*. Online at: http://www.ngs.noaa.gov/GRAV-D/data_AN01.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_AN01.shtml

5. References

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