Block AS04 (Alaska South 04)

GRAV-D Airborne Data Release User Manual

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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. 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 **AS04** is located in the **A**laska Time Zone, in the **S**outh half (south of 63° latitude). This was the fourth (**04**) block of data completed in that region. Block AS04 is 480 km by 570 km, covering coastal areas of Alaska and ocean areas from 0 to 125 km offshore (Figure 1). The corner coordinates defining Block AS04 are listed in Table 1.

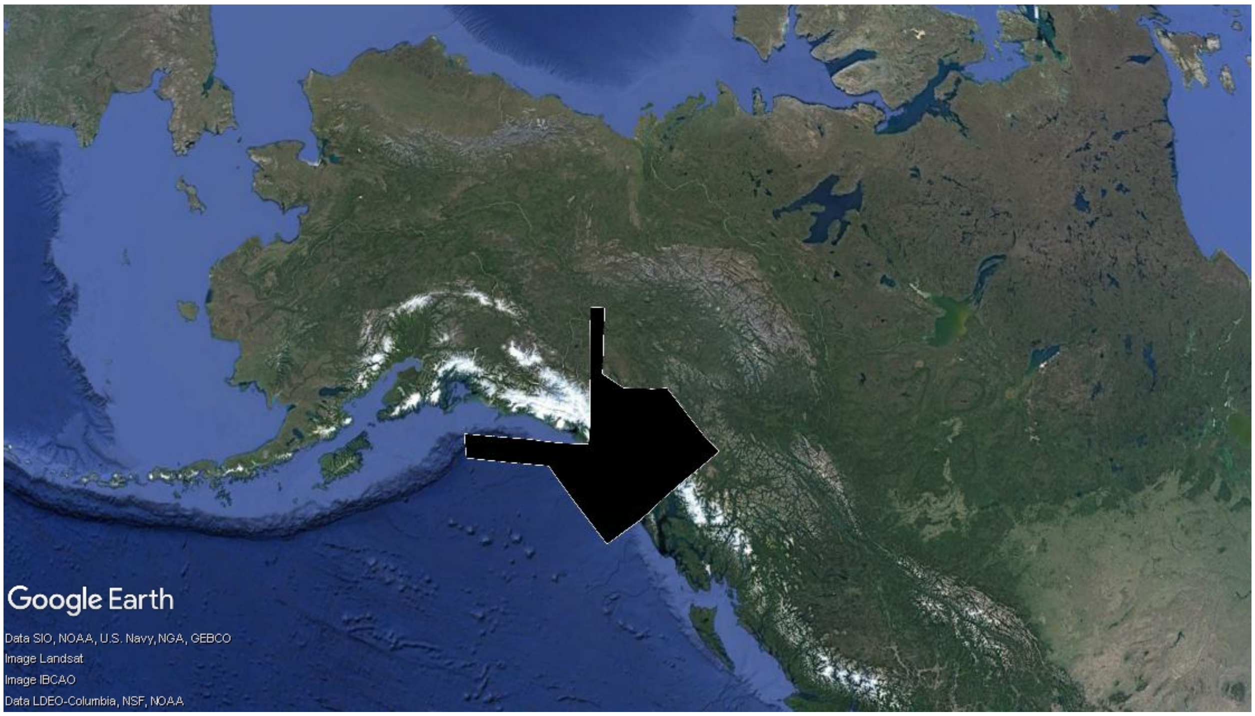


Figure 1: Google Earth Image of the Location of Block AS04 (black rectangle).

Table 1: Latitude and Longitude Coordinates of Corner Points Defining Block AS04

Latitude (decimal degrees)	Longitude (decimal degrees)
-133.91861732	61.10045471
-136.68158778	61.10639099
-138.08690072	61.53130688
-137.93664152	63.56853054
-138.86863948	63.57876406
-138.90533185	59.33963266
-142.57968099	59.35763802
-146.40880478	59.27820785
-146.05413308	58.53503347
-141.08690010	58.59905320
-137.53007086	56.23574985
-134.23529351	57.68133332
-130.79494473	59.04304121

2. Survey Design and Execution

Airborne gravity data in Block AS04 were collected during two surveys: AK15 (Alaska 2015) and AK16 (Alaska 2016). All data and cross flights were done at 20,000 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 AS04 all data lines are East-West and cross lines North-South. The block consists of 39 data lines, 10 cross lines from AK10-1; 2 data lines, 8 cross lines from AK10-2; 11 data lines and 0 cross lines from AK10-3; and 7 cross lines from AK12. 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. AS04101= block AS04's line 101).

Table 2: Survey Overview (AK10-1/AK10-2/AK10-3/AK12)

Conducting Organization	NOAA- National Geodetic Survey	
Survey Name	AK15	AK16
Airport Base of Operations	Juneau International Airport (KJNU) FBO: Atlantic Aviation 1890 Renshaw Way Juneau, AK 99801	
Geographic Location	Southern Alaska	
Dates of Airborne Operations	April 4^{th} – July 8^{th} 2015	April 1^{st} – May 15^{th} 2016

Table 3: Aircraft and Instrumentation

Aircraft	Dynamic King Air 200T	
Engines, number and type	2, Turboprop	
Gravity Instrumentation	MGL G-81 and D-17 (relative) Micro-g LaCoste (MGL) TAGS S-137 (relative) MGL FG-5 102 (absolute)	MGL G-81 and D-17 (relative) Micro-g LaCoste (MGL) TAGS S-161 (relative) MGL FG-5 102 (absolute)
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: ~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: 75 Cross Lines: 8 Repeat Lines: 0
Number of Crossovers	267

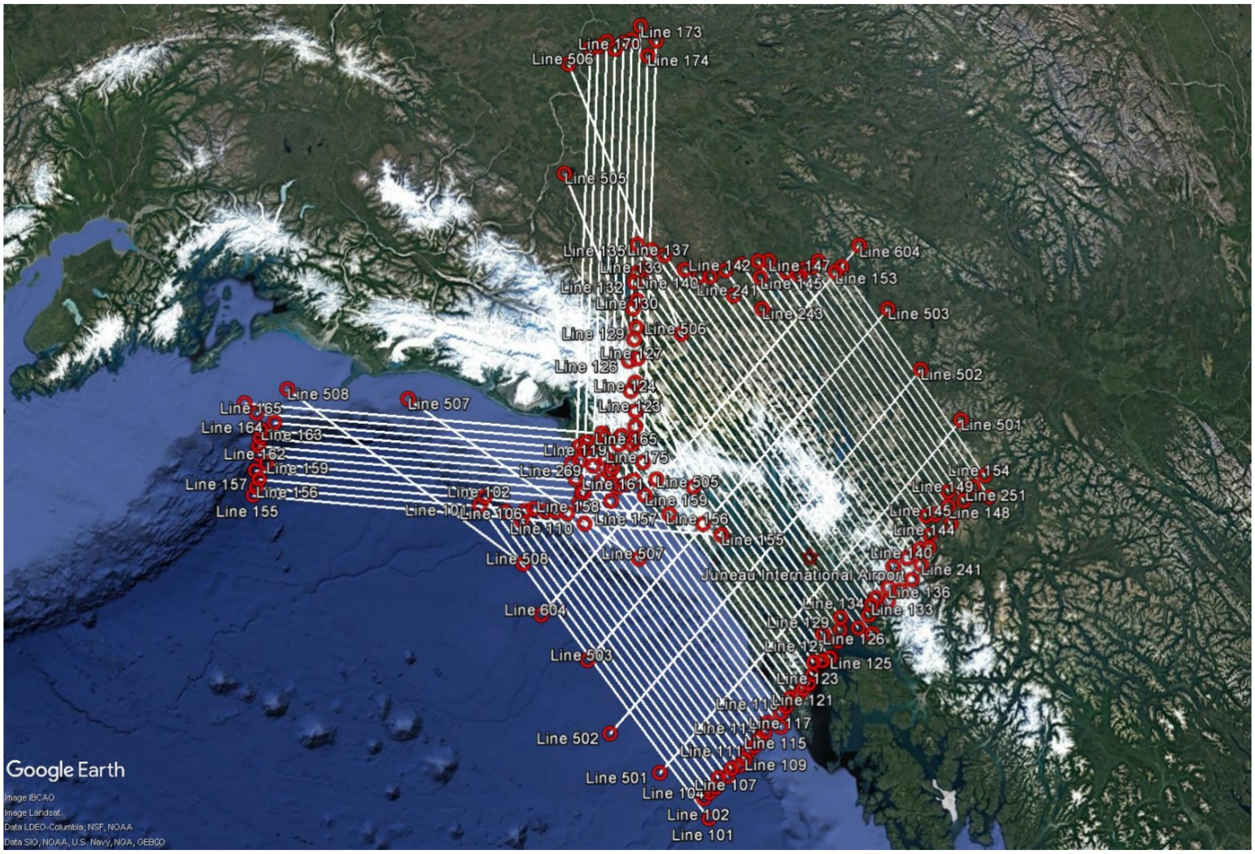


Figure 2: Data Coverage for AS04. Airport marked with a star.

2.1 GPS/IMU Instrumentation

The Dynamic King Air 200T 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.

On the ground, two 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 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).

For both the NOAA Turbo Commander the BLM Pilatus PC-12 the TAGS was mounted to the seat tracks in the center of the fuselage. The IMU was mounted on top of the TAGS and in the center of the frame. Table 5 and Table 6 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 Dynamic King Air 200 T

Instrument/Location	**X (m)**	**Y (m)**	**Z (m)**
NovAtel SPAN-SE IMU (S-137)	0.15	0.10	-0.41

Instrument/Location	**X (m)**	**Y (m)**	**Z (m)**
NovAtel SPAN-SE IMU (S-161)	-0.017	0.019	-0.433

Table 6: Lever Arm Measurements FROM the SPAN TO the GPS Antenna

Instrument/Location	**X (m)**	**Y (m)**	**Z (m)**
GPS Antenna	-0.374	1.355	1.734

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 20,000 ft Data Collection

Airport	Type	Receiver	Flight Available	2009 Day of Year Available
AK15	Kinematic	NovAtel (0009)	F01-F41	144-145, 148-153, 159-167, 176, 179, 181, 185-187
		NovAtel (SPAN)	F01-F41	144-145, 148-153, 159-167, 176, 179, 181, 185-187
	Static	Ashtech East	F01-F41	144-145, 148-153, 159-167, 176, 179, 181, 185-187
		Ashtech West	F01-F41	144-145, 148-153, 159-167, 176, 179, 181, 185-187
AK16	Kinematic	NovAtel (0009)	F01-F27	100-102, 104, 106, 110-113, 116-117, 120, 125, 130-132, 135
		NovAtel (SPAN)	F01-F27	100-102, 104, 106, 110-113, 116-117, 120, 125, 130-132, 135
	Static	NovAtel 47	F01-F27	100-102, 104, 106, 110-113, 116-117, 120, 125, 130-132, 135
		NovAtel 49	F01-F27	100-102, 104, 106, 110-113, 116-117, 120, 125, 130-132, 135

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 0.004 m and the average vertical position accuracy is 0.007 m.

3.1.2 Ground Gravity Tie

Updated absolute gravity measurements were performed by NGS with a Micro-g LaCoste A-10 gravimeter in May of 2011. At both airports 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 Juneau, AK the location is designated as FBK TAGS (58.360353°N, --134.588684°W) and it has an absolute gravity value of 981754.4518 ± 0.008 mGal at 162.5 cm above the tarmac.

3.1.3 Gravity Filtering

For block AS04, 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

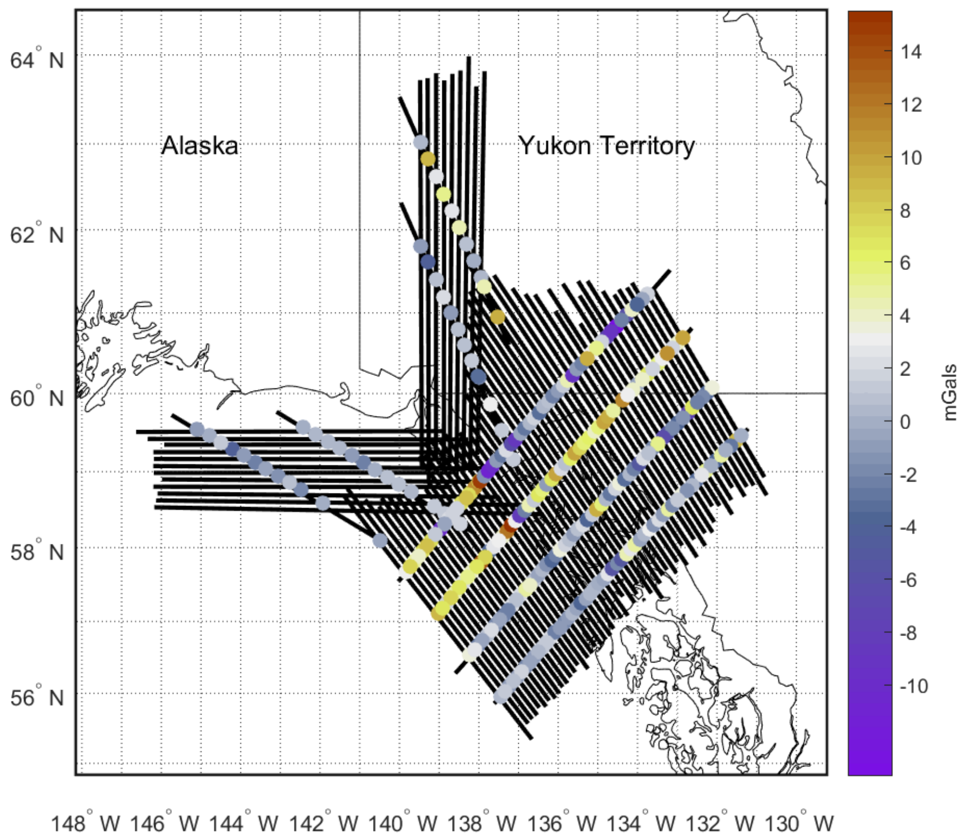
3.2.1 Gravity Error Analysis

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 AS04, the result of the crossover analysis is shown in Table 9 and in Figure 3.

Table 8: Gravity Crossover Error Analysis for the AS04 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	6,825	267	4.64	4.46	1.31	3.28

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 10. 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.


64° N
62° N
60° N
58° N
56° N
Alaska
Yukon Territory
14
12
10
8
6
4
2
0
-2
-4
-6
-8
-10
mGals
148° W 146° W 144° W 142° W 140° W 138° W 136° W 134° W 132° W 130° W

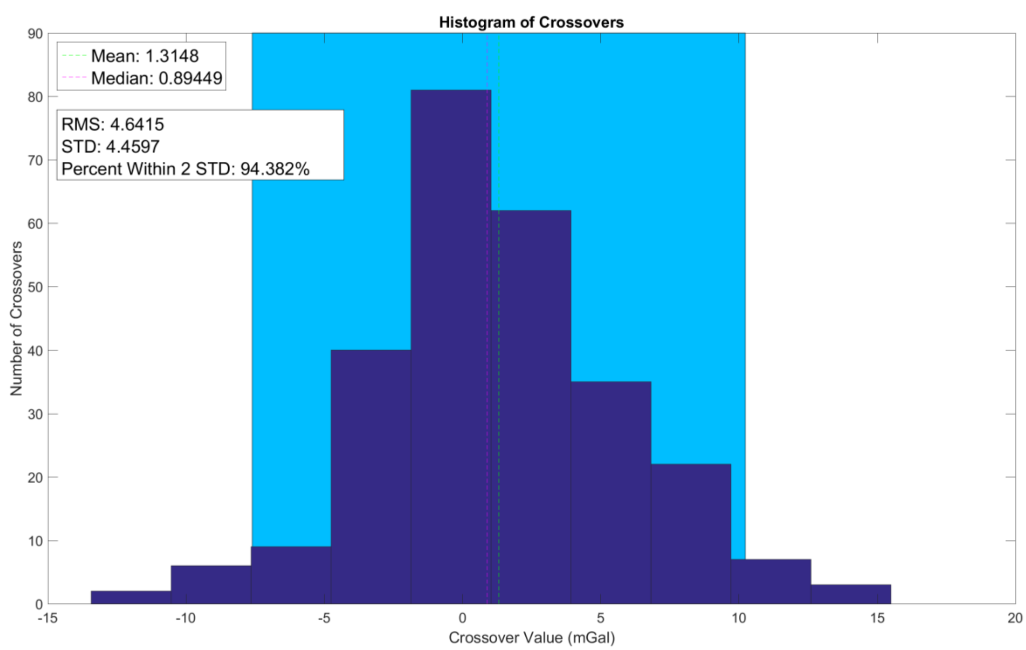

Histogram of Crossovers
Mean: 1.3148
Median: 0.89449
RMS: 4.6415
STD: 4.4597
Percent Within 2 STD: 94.382%
Number of Crossovers
Crossover Value (mGal)
0
10
20
30
40
50
60
70
80
90
-15
-10
-5
0
5
10
15
20

Figure 3: Crossover Residuals, Histogram, and Statistics for Block AS04. 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	2.68	0.29
502	3.35	0.03
503	4.42	5.00
604	6.05	0.58
505	2.15	-0.01
506	3.35	3.51
507	1.11	0.30
508	1.41	-0.94

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 11) 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
66	92.56%	13.35%

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 AS04, however, there were no reflown lines.

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.8.50.2507 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
AK15	1	SPAN	GPS+IMU	7.5	116	100.00
					117	100.00
	2	SPAN	GPS+IMU	7.5	113	100.00
					114	100.00
	3	SPAN	GPS+IMU	5	111	100.00
					112	100.00
	4	SPAN	GPS+IMU	7.5	109	100.00
					110	100.00
	6	SPAN	GPS+IMU	7.5	107	100.00
					108	100.00
	7	SPAN	GPS+IMU	5	165	100.00
					166	100.00
	8	SPAN	GPS+IMU	5	163	100.00
					164	100.00
	9	SPAN	GPS+IMU	7.5	161	100.00
					162	100.00
	10	SPAN	GPS+IMU	5	159	100.00
					160	100.00
	11	SPAN	GPS+IMU	5	157	100.00
					158	100.00
	12	SPAN	GPS+IMU	7.5	155	100.00
					156	100.00
	13	SPAN	GPS+IMU	7.5	105	100.00
					106	100.00
	14	SPAN	GPS+IMU	7.5	103	100.00
					104	100.00
	15	SPAN	GPS+IMU	7.5	507	100.00
					508	100.00
	16	SPAN	GPS+IMU	5	101	100.00
					102	100.00
	18	SPAN	GPS+IMU	5	115	100.00
					118	100.00
	19	SPAN	GPS+IMU	7.5	168	100.00
	20	SPAN	GPS+IMU	5	170	100.00
					171	100.00
	21	SPAN	GPS+IMU	7.5	172	100.00
					173	100.00
	22	SPAN	GPS+IMU	5	174	100.00
					175	100.00
	23	SPAN	GPS+IMU	5	505	100.00
					506	100.00
	26	SPAN	GPS+IMU	7.5	503	100.00
	28	SPAN	GPS+IMU	5	119	100.00
					120	100.00

	Flight Num.	Rover GPS Unit	Solution Type	Elevation Mask (degrees)	Line Num.	NGS Quality Grade
	29	SPAN	GPS+IMU	7.5	121	100.00
					122	100.00
	30	SPAN	GPS+IMU	7.5	123	100.00
					124	100.00
	31	SPAN	GPS+IMU	5	125	100.00
					126	100.00
	32	SPAN	GPS+IMU	7.5	127	100.00
					128	100.00
	33	SPAN	GPS+IMU	7.5	167	100.00
					269	100.00
	35	SPAN	GPS+IMU	5	129	100.00
					130	100.00
	36	SPAN	GPS+IMU	7.5	131	100.00
					132	100.00
	37	SPAN	GPS+IMU	7.5	133	100.00
					134	100.00
	38	SPAN	GPS+IMU	7.5	135	100.00
					136	100.00
	39	SPAN	GPS+IMU	7.5	501	100.00
					502	100.00
	40	SPAN	GPS+IMU	5	137	100.00
					138	100.00
	41	SPAN	GPS+IMU	7.5	139	100.00
					140	100.00
AK16	7	SPAN	GPS+IMU	7.5	153	100.00
					154	100.00
	8	SPAN	GPS+IMU	7.5	142	100.00
	9	SPAN	GPS+IMU	7.5	152	100.00
	10	SPAN	GPS+IMU	5	149	100.00
					150	100.00
	11	SPAN	GPS+IMU	7.5	147	100.00
					148	100.00
	12	SPAN	GPS+IMU	5	145	100.00
					146	100.00
	13	SPAN	GPS+IMU	7.5	144	100.00
					243	100.00
	14	SPAN	GPS+IMU	7.5	241	100.00
					251	100.00
	22	SPAN	GPS+IMU	5	604	100.00

Table 12: Gravity Processing Results

Survey	Flight Num.	Line Num.	Time of Deleted Data Section(s)
AK15	1	116	
		117	
	2	113	
		114	
	3	111	
		112	
	4	109	
		110	
	6	107	
		108	
	7	165	
		166	
	8	163	
		164	
	9	161	
		162	
	10	159	
		160	
	11	157	
		158	
	12	155	
		156	
	13	105	
		106	
	14	103	
		104	
	15	507	
		508	
	16	101	
		102	
	18	115	
		118	
	19	168	
	20	170	
		171	
	21	172	
		173	
	22	174	
		175	
	23	505	
		506	
	26	503	
	28	119	
		120	

	Flight Num.	Line Num.	Time of Deleted Data Section(s)
	29	121	
		122	
	30	123	
		124	
	31	125	
		126	
	32	127	
		128	
	33	167	
		269	
	35	129	
		130	
	36	131	
		132	
	37	133	
		134	
	38	135	
		136	
	39	501	
		502	
	40	137	
		138	
	41	139	
		140	
AK16	7	153	
		154	
	8	142	
	9	152	
	10	149	
		150	
	11	147	
		148	
	12	145	
		146	
	13	144	
		243	
	14	241	86164-86489
		251	90543-90831
	22	604	

Table 13: Bias from EGM08 by Line

Survey	Flight Num.	Line Num.	Bias from EGM08
AK15	1	116	0.33
		117	-0.39
	2	113	0.81
		114	-0.14
	3	111	0.34
		112	0.24
	4	109	4.58
		110	2.42
	6	107	4.36
		108	3.19
	7	165	8.07
		166	14.22
	8	163	1.00
		164	0.50
	9	161	3.10
		162	1.22
	10	159	0.80
		160	1.19
	11	157	1.24
		158	1.28
	12	155	0.40
		156	1.24
	13	105	0.23
		106	0.66
	14	103	2.91
		104	2.08
	15	507	1.41
		508	1.36
	16	101	1.42
		102	-0.06
	18	115	1.48
		118	0.68
	19	168	4.25
	20	170	2.98
		171	2.77
	21	172	7.76
		173	14.06
	22	174	3.76
		175	5.62
	23	505	5.23
		506	5.89
	26	503	5.94
	28	119	7.58
		120	10.21

	Flight Num.	Line Num.	Bias from EGM08
	29	121	8.94
		122	4.82
	30	123	3.26
		124	1.40
	31	125	1.91
		126	-0.19
	32	127	2.61
		128	1.89
	33	167	4.62
		269	4.01
	35	129	3.06
		130	0.42
	36	131	0.84
		132	1.38
	37	133	0.65
		134	0.34
	38	135	1.61
		136	0.93
	39	501	1.46
		502	0.85
	40	137	-1.24
		138	2.07
	41	139	1.86
		140	4.41
AK16	7	153	1.75
		154	-1.92
	8	142	0.34
	9	152	2.09
	10	149	5.12
		150	0.76
	11	147	2.38
		148	2.69
	12	145	4.24
		146	3.02
	13	144	3.05
		243	2.51
	14	241	-0.20
		251	3.24
	22	604	1.52

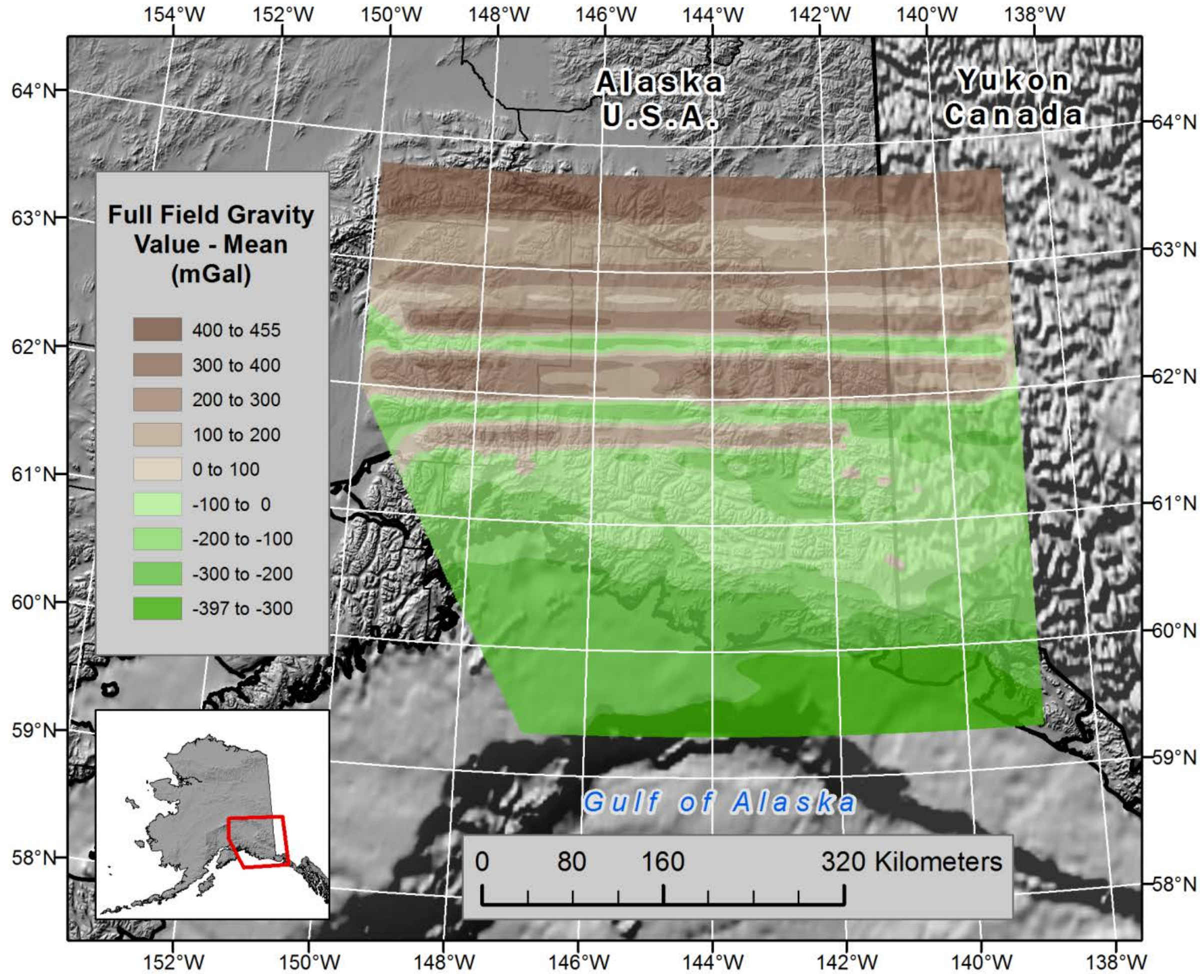


Figure 4: Full-field gravity at altitude (mean removed) for Block AS04. This is the data in the gravity release ".txt" file and includes the effects of differing altitudes along flight lines.

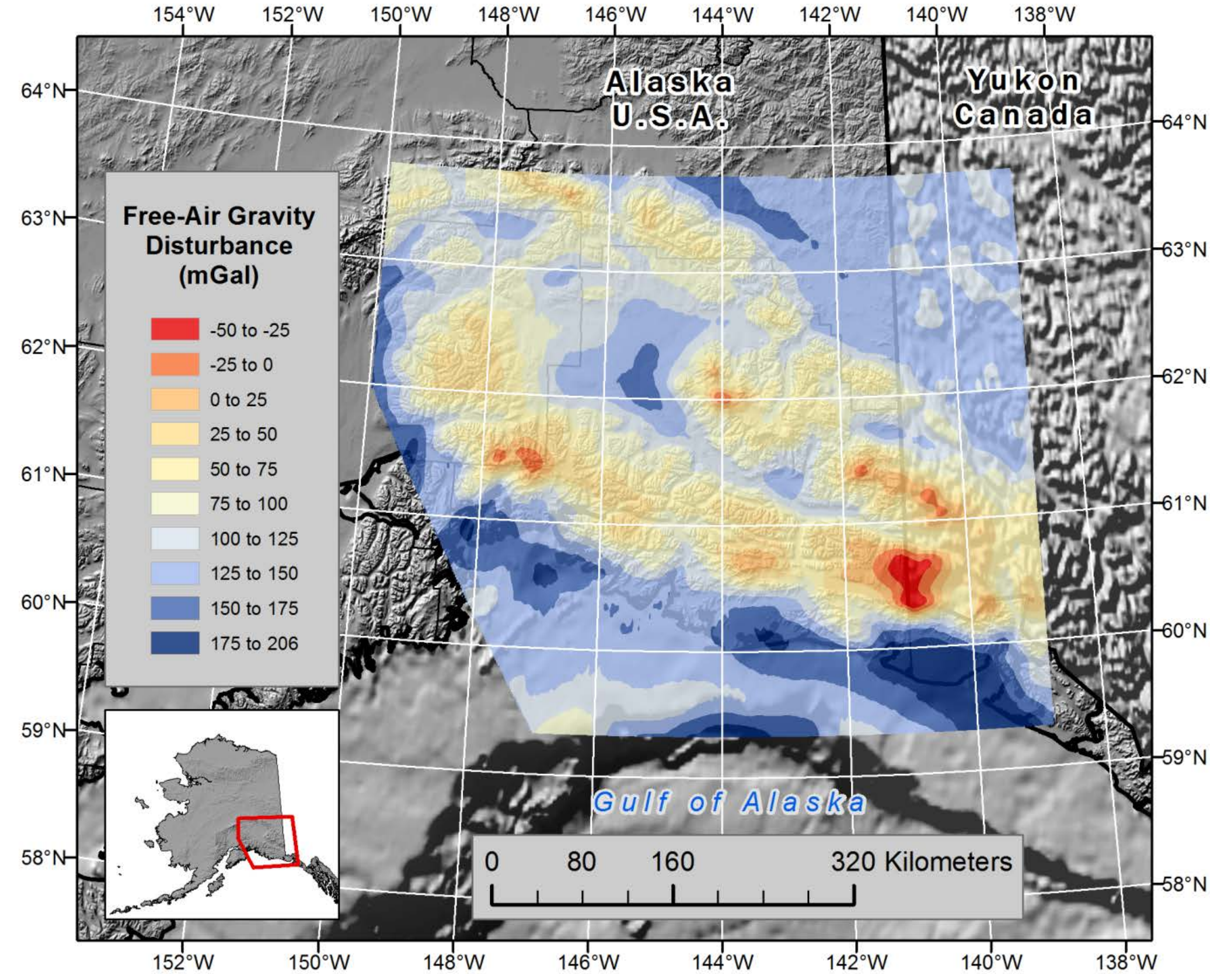


Figure 5: Free-air gravity disturbance for Block AS04 with respect to the WGS-84 ellipsoid.

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. Diehl, Sandra A. Martinka Preaux, Carly A. Weil, and Monica A. Youngman.

To reference the AS04 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 AS04". Available *DATE*. Online at: http://www.ngs.noaa.gov/GRAV-D/data_AS04.shtml

To reference the block and survey details, reference the block user manual:
GRAV-D Science Team (2013). "Block AS04 (Alaska South 03); GRAV-D Airborne Gravity Data User Manual." Theresa Diehl, ed. Version 1. Available *DATE*. Online at: http://www.ngs.noaa.gov/GRAV-D/data_AS04.shtml

To reference the general GRAV-D project operations, reference the General User Manual:
GRAV-D Science Team (2012). "GRAV-D General Airborne Gravity Data User Manual." Theresa Diehl, ed. Version 1. Available *DATE*. Online at: http://www.ngs.noaa.gov/GRAV-D/data_AS04.shtml

5. References

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