Block AN08 (Alaska North 08)

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 **AN08** is located in the **A**laska Time Zone, in the **N**orth half (north of 63° latitude). This was the eighth (**08**) block of data completed in that region. Block AN08 is approximately 550 km by 330 km, covering coastal areas of Alaska and ocean areas from 40 to 200 km offshore (Figure 1). The corner coordinates defining Block AN08 are listed in Table 1.

Figure 1: Google Earth Image of the Location of Block AN08 (black rectangle).

Table 1: Latitude and Longitude Coordinates of Corner Points Defining Block AN08

Latitude (decimal degrees)	Longitude (decimal degrees)
64.60509090	-168.62015560
65.52417356	-158.29446774
69.12438575	-160.08677871
69.08647042	-164.00175094
69.24688097	-164.12657508
68.73528749	-169.467828397

2. Survey Design and Execution

Airborne gravity data in Block AN08 were collected during one survey: AK16-2 (Alaska 2016 Second Occupation). 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 AN08 all data lines are East-West and cross lines North-South. The block consists of 47 data lines, 7 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. AN08101= block AN08's line 101).

Table 2: Survey Overview

Conducting Organization	NOAA- National Geodetic Survey
Survey Name	AK16-2
Airport Base of Operations	Nome Airport (AOM) Nome, AK FBO: Bering Air Inc
Geographic Location	Northern Alaska
Dates of Airborne Operations	May 15th-July 11th 2016

Table 3: Aircraft and Instrumentation

Aircraft	King Air 200T
Engines, number and type	2, Turboprop
Gravity Instrumentation	Micro-g LaCoste (MGL) TAGS S-161 (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: ~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: 47 Cross Lines: 7 Repeat Lines: 0
Number of Crossovers	245

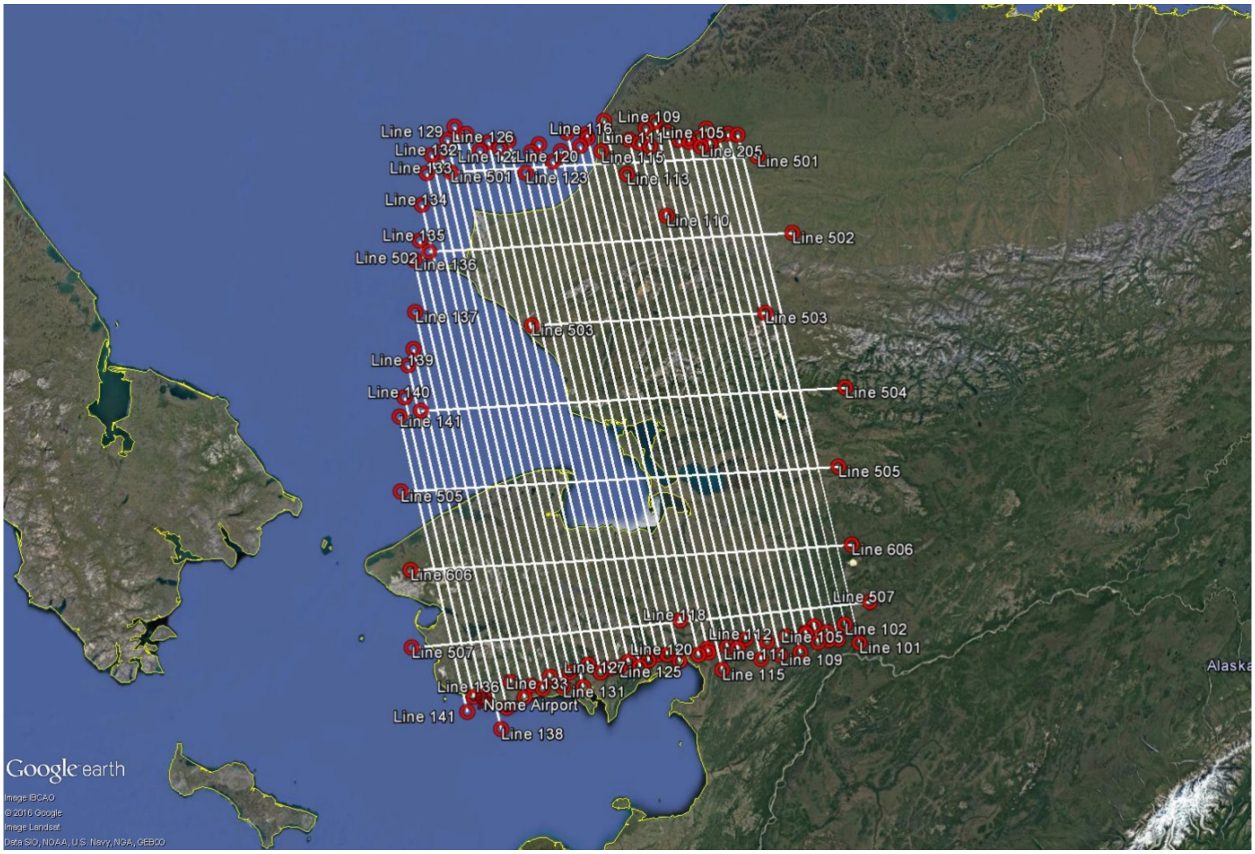

Figure 2: Data Coverage for AN08. Data lines start in the east at 101 and continue west to 141. Airports marked with red star.

2.1 GPS/IMU Instrumentation

The King Air 200T had one GPS antenna available for scientific measurements. Two 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

Instrument/Location	**X (m)**	**Y (m)**	**Z (m)**
NovAtel SPAN-SE IMU	-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	2016 Day of Year Available
OAM	Kinematic	NovAtel (0009)	F01-F52	138-141 143 149-151 153-156 158-162 164 166 168-171 177 180-185 187-189 191
		NovAtel (SPAN)	F01-F52	138-141 143 149-151 153-156 158-162 164 166 168-171 177 180-185 187-189 191
	Static	Ashtech West	F11-F52	150-151 153-156 158-162 164 166 168-171 177 180-185 187-189 191
		Ashtech East	F01-F52	138-141 143 149-151 153-156 158-162 164 166 168-171 177 180-185 187-189 191

Data were processed using WGS84 and ITRF08. 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 0.005 m and the average vertical position accuracy is 0.008 m.

3.1.2 Ground Gravity Tie

Absolute gravity measurements were performed by NGS with a Micro-g LaCoste A-10 gravimeter in summer of 2015. 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 Nome, AK the location is designated as PAOM TAGS (64.51184°N,-165.4361°W) and it has an absolute gravity value of 982259.520 ± 0.00788 mGal at 159.385 cm above the tarmac.

3.1.3 Gravity Filtering

For block AN08, 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 AN08, the result of the crossover analysis is shown in Table 8 and in Figure 3.

Table 8: Gravity Crossover Error Analysis for the AN08 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	6,683	245	4.02	4.03	0.19	2.85

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.

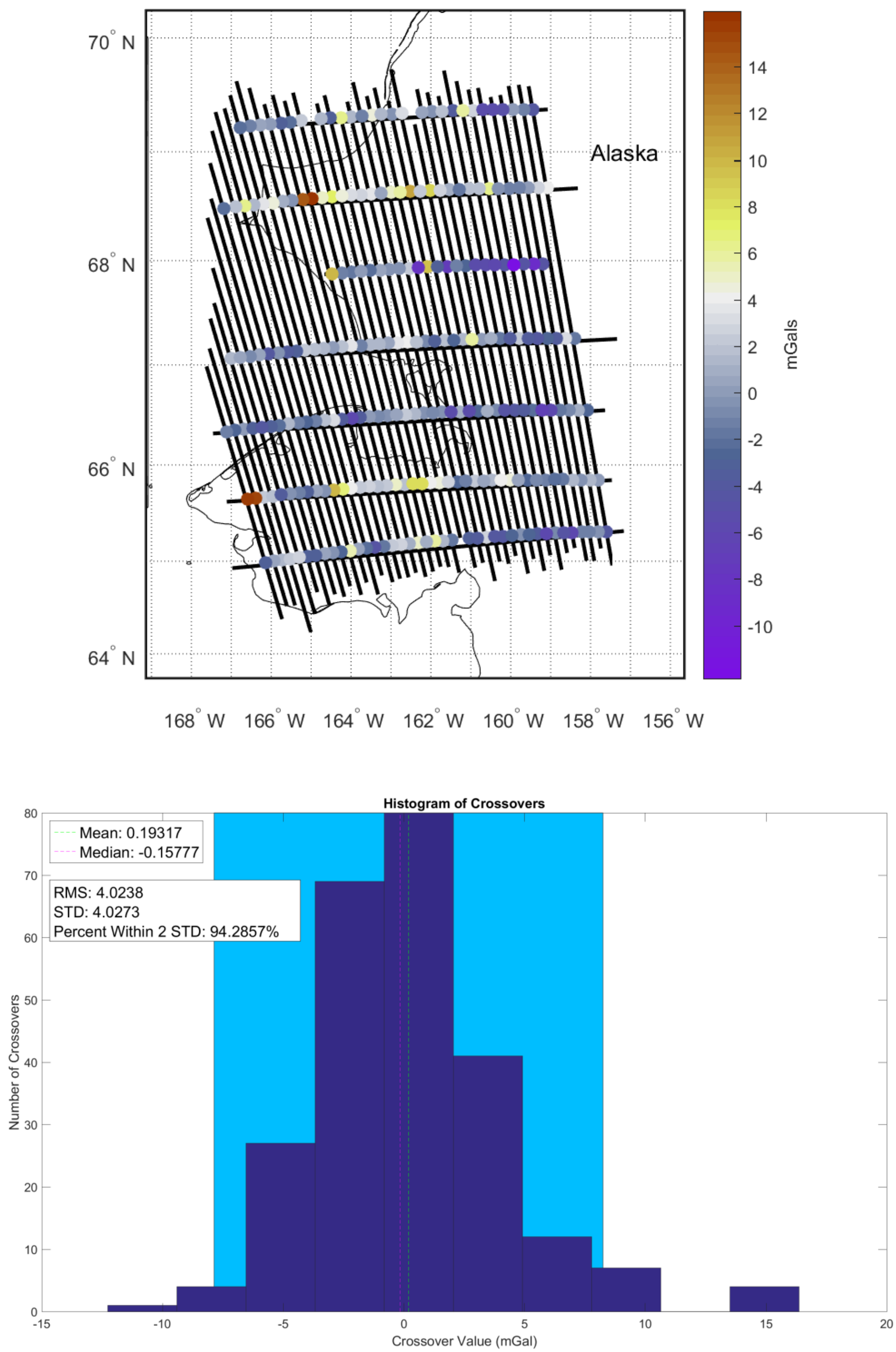

Figure 3: Crossover Residuals, Histogram, and Statistics for Block AN08. Color scale in mGals.

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	3.10	-0.25
502	4.20	3.57
503	5.15	-2.50
504	2.54	0.05
505	2.41	-1.69
606	4.36	2.29
507	3.05	-0.90

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
34	99.72%	0.23%

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 AN08, 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 Inertial Explorer (IE) 8.5. 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 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 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 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
AK16-2	5	SPAN	GPS+IMU	5	119	100.00
					120	100.00
	6	SPAN	GPS+IMU	5	117	100.00
					118	100.00
	7	SPAN	GPS+IMU	7.5	115	100.00
	9	SPAN	GPS+IMU	5	113	100.00
					114	100.00
	12	SPAN	GPS+IMU	7.5	111	100.00
					112	100.00
	15	SPAN	GPS+IMU	5	101	100.00
					102	100.00
	17	SPAN	GPS+IMU	5	103	100.00
	21	SPAN	GPS+IMU	5	123	100.00
					124	100.00
	25	SPAN	GPS+IMU	4	121	100.00
					122	100.00
	26	SPAN	GPS+IMU	7.5	139	100.00
					140	100.00
					141	100.00
	27	SPAN	GPS+IMU	5	125	100.00
					126	100.00
	29	SPAN	GPS+IMU	7.5	505	100.00
					507	100.00
	32	SPAN	GPS+IMU	7.5	127	100.00
					128	100.00
	33	SPAN	GPS+IMU	5	129	100.00
					130	100.00
	35	SPAN	GPS+IMU	7.5	131	100.00
					132	100.00
	36	SPAN	GPS+IMU	5	133	100.00
					134	100.00
	37	SPAN	GPS+IMU	5	138	100.00
					503	100.00
					504	100.00
	38	SPAN	GPS+IMU	7.5	135	100.00
					136	100.00
	39	SPAN	GPS+IMU	7.5	109	100.00
	42	SPAN	GPS+IMU	7.5	107	100.00
					108	100.00
	45	SPAN	GPS+IMU	5	204	100.00
					210	100.00
	47	SPAN	GPS+IMU	5	137	100.00
					501	100.00
					502	100.00
	48	SPAN	GPS+IMU	5	205	100.00
					206	100.00
					606	100.00
	51	SPAN	GPS+IMU	5	216	100.00

Table 12: Gravity Processing Results

Survey	Flight Num.	Line Num.	Time(s) of Data Deleted
AK16-2	5	119	
		120	
	6	117	
		118	
	7	115	
	9	113	
		114	
	12	111	
		112	
	15	101	
		102	
	17	103	
	21	123	
		124	
	25	121	
		122	
	26	139	
		140	
		141	
	27	125	
		126	
	29	505	
		507	
	32	127	
		128	
	33	129	
		130	
	35	131	
		132	
	36	133	
		134	
	37	138	
		503	
		504	
	38	135	
		136	
	39	109	
	42	107	
		108	
	45	204	
		210	
	47	137	
		501	
		502	
	48	205	
		206	
		606	
	51	216	

Table 13: Bias from EGM08 by Line

Survey	Flight Num.	Line Num.	Bias from EGM08
AK16-2	5	119	1.68
		120	1.07
	6	117	1.37
		118	2.09
	7	115	0.96
	9	113	4.56
		114	4.55
	12	111	2.87
		112	1.27
	15	101	4.91
		102	2.65
	17	103	0.53
	21	123	1.05
		124	0.32
	25	121	1.34
		122	-0.47
	26	139	1.04
		140	0.94
		141	1.63
	27	125	-1.09
		126	0.05
	29	505	0.30
		507	2.86
	32	127	3.46
		128	3.55
	33	129	2.15
		130	1.51
	35	131	3.28
		132	3.49
	36	133	2.79
		134	3.33
	37	138	2.43
		503	1.06
		504	3.58
	38	135	4.15
		136	3.22
	39	109	4.63
	42	107	1.38
		108	4.04
	45	204	4.01
		210	3.30
	47	137	3.95
		501	1.35
		502	4.18
	48	205	5.19
		206	5.21
		606	3.95
	51	216	3.78

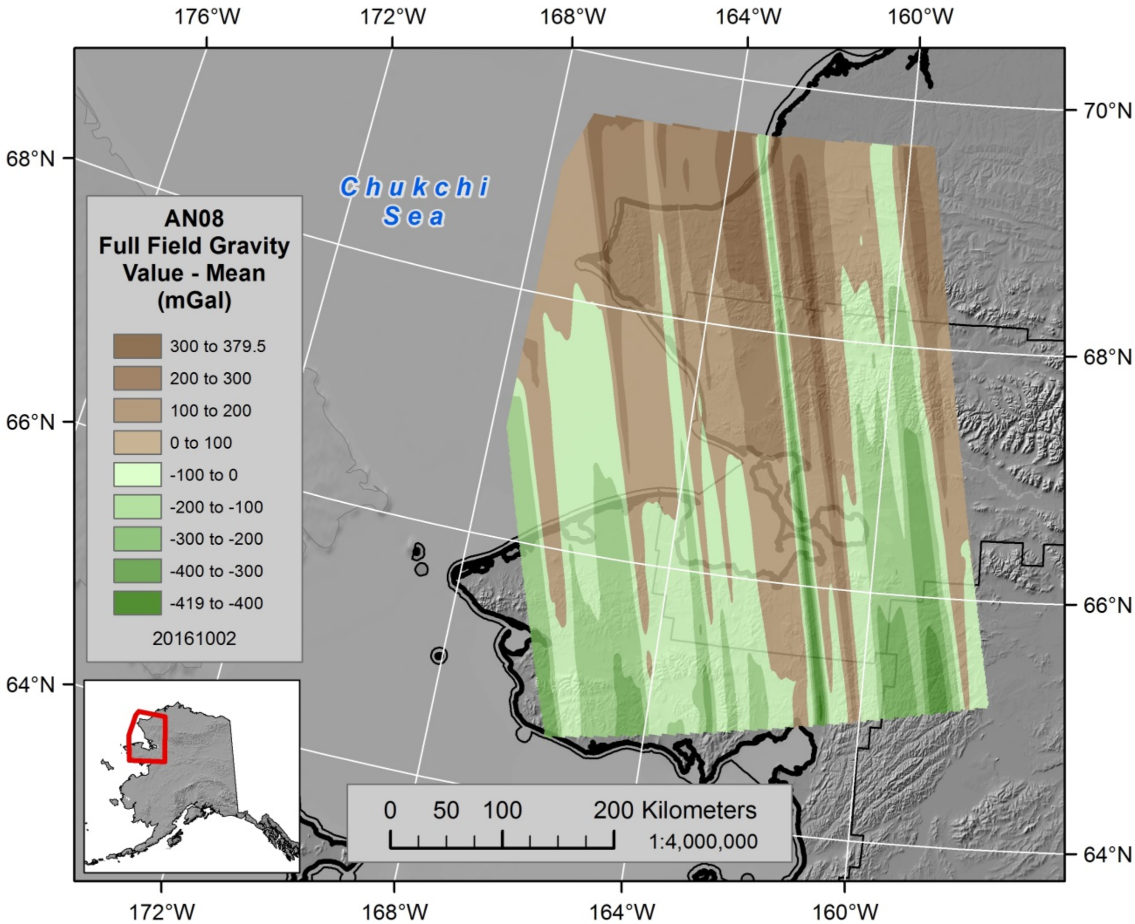

Figure 4: Full-field gravity at altitude (mean removed) for Block AN08. This is the data in the gravity release ".txt" file and includes the effects of differing altitudes along flight lines.

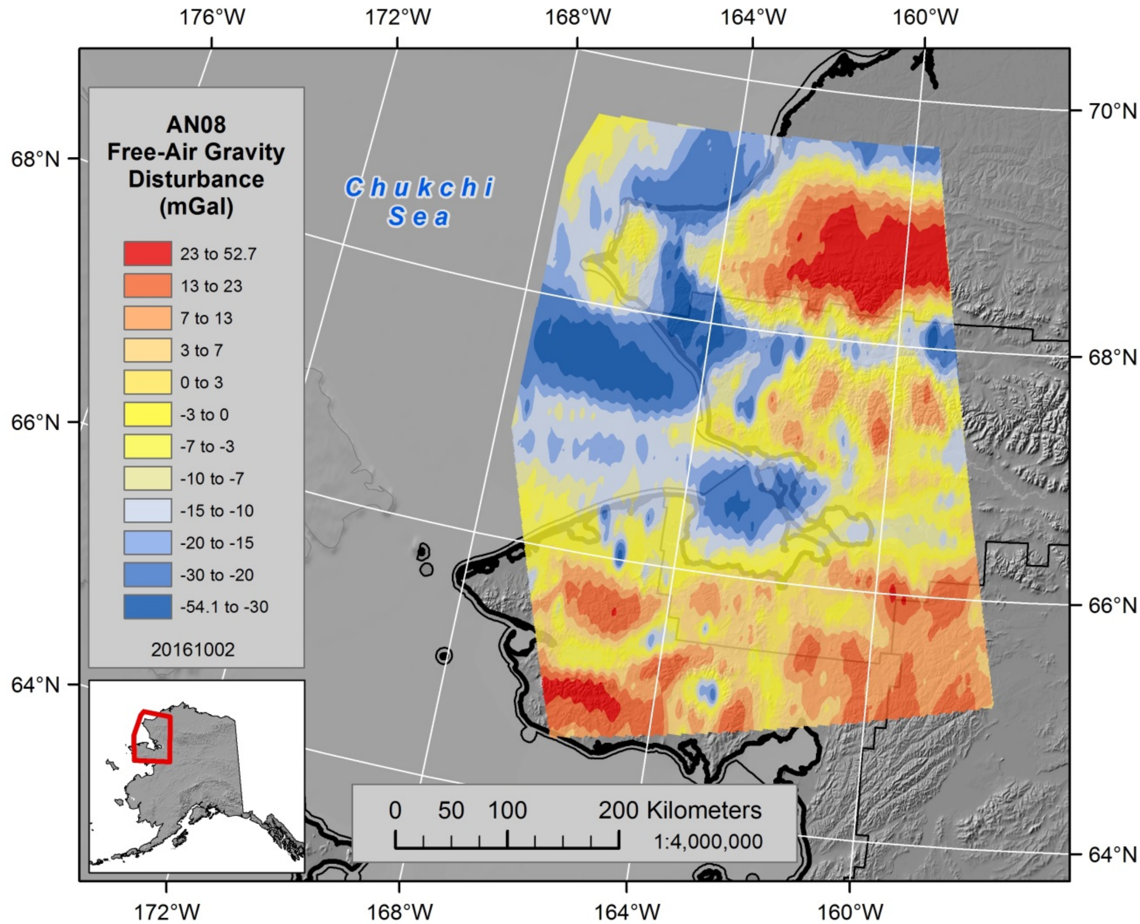

Figure 5: Free-air gravity disturbance for Block AN08 with respect to the WGS-84 ellipsoid.

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 AN08 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 AN08". Available *DATE*. Online at: http://www.ngs.noaa.gov/GRAV-D/data_AN08.shtml

To reference the block and survey details, reference the block user manual:
GRAV-D Science Team (2013). "Block AN08 (Alaska North 06); 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_AN08.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."