Block AN03 (Alaska North 03)

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 **AN03** is located in the **A**laska Time Zone, in the **N**orth half (north of 63° latitude). This was the third (**03**) block of data completed in that region. Block AN03 is 350 km by 80 km in interior, central Alaska (Figure 1). The corner coordinates defining Block AN03 are listed in Table 1.

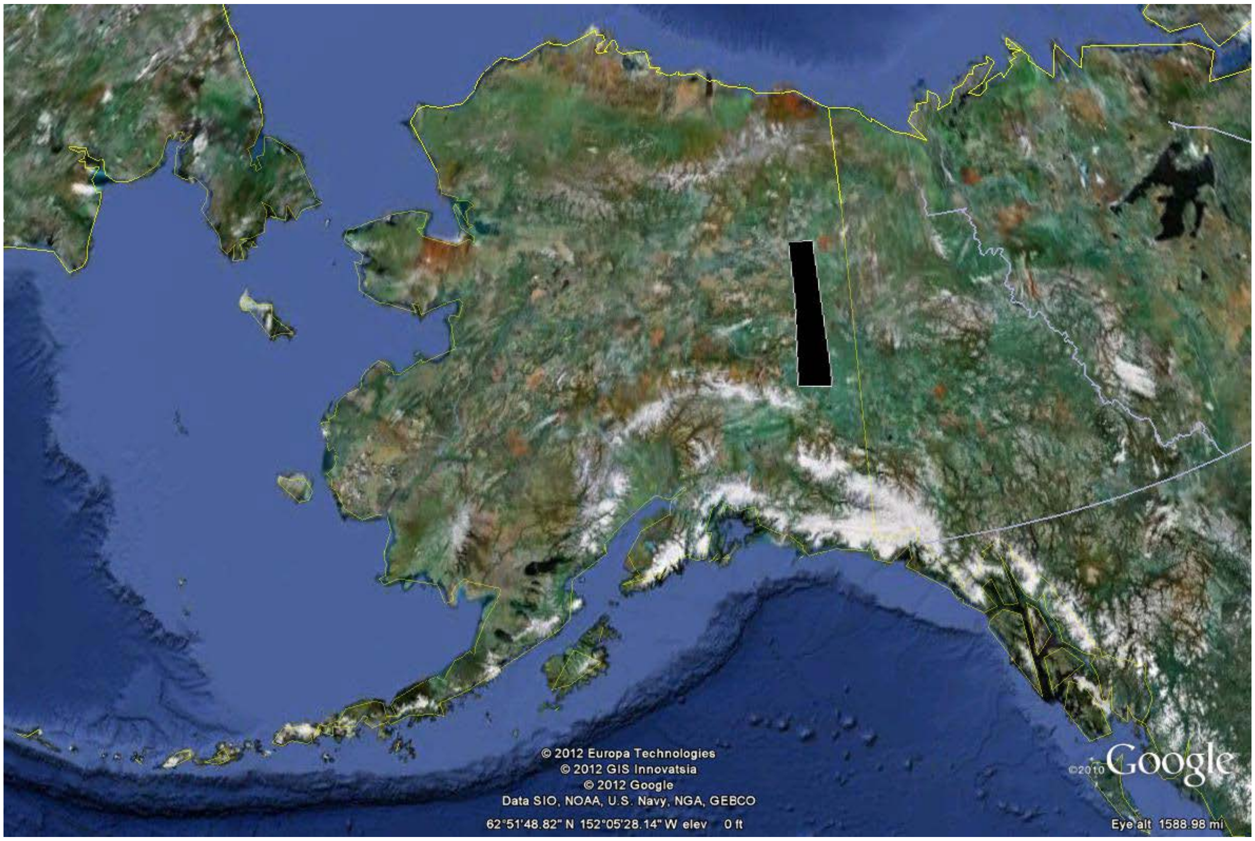

Figure 1: Google Earth Image of the Location of Block AN03 (black rectangle).

Table 1: Latitude and Longitude Coordinates of Corner Points Defining Block AN03

Latitude (decimal degrees)	Longitude (decimal degrees)
66.719150609	-144.261078380
63.607962060	-144.188612040
63.570876162	-142.610131409
66.719284277	-142.854122777

2. Survey Design and Execution

Airborne gravity data in Block AN03 were collected during two surveys: AK10-2 (Alaska 2010, second occupation) and AK-12 (Alaska 2012). 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 AN03 all data lines are North-South and cross lines East-West. The block consists of 7 data lines, 4 cross lines from AK10-2 and 1 cross line from AK12-1. 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. AN03101= block AN03's line 101).

Table 2: Survey Overview

Conducting Organization	NOAA- National Geodetic Survey	
Survey Name	AK10-2	AK12
Airport Base of Operations	Fort Wainwright Airport (FBK) Fairbanks, AK FBO: Alaska Fire Service	
Geographic Location	Central Alaska	
Dates of Airborne Operations	Sep. 15th – Oct. 25th, 2010	Oct. 9 – Oct. 29th, 2012

Table 3: Aircraft and Instrumentation

Aircraft	BLM Pilatus PC-12 (N190PE)
Engines, number and type	1, Propeller
Gravity Instrumentation	Micro-g LaCoste (MGL) TAGS S-137 (relative) MGL A10 25 (absolute) MGL G-81 and D-17 (relative)
GPS Instrumentation	NovAtel DL-4 Plus Applanix POS AV 510 (GPS + IMU) (AK10-2) SPAN (GPS + IMU) (AK12)

Table 4: Survey Design and Execution

Line Spacing	Data Lines: 10 km Cross Lines: irregular spacing
Type of Layout	Regular data lines & irregular cross lines
Nominal Survey Altitude	20,000 ft
Nominal Aircraft Ground Speed	250 knots
Number of Lines Released	Data Lines: 7 (AK10-2) Cross Lines: 4 (AK10-2), 2 (AK12) Repeat Lines: 0
Number of Crossovers	41

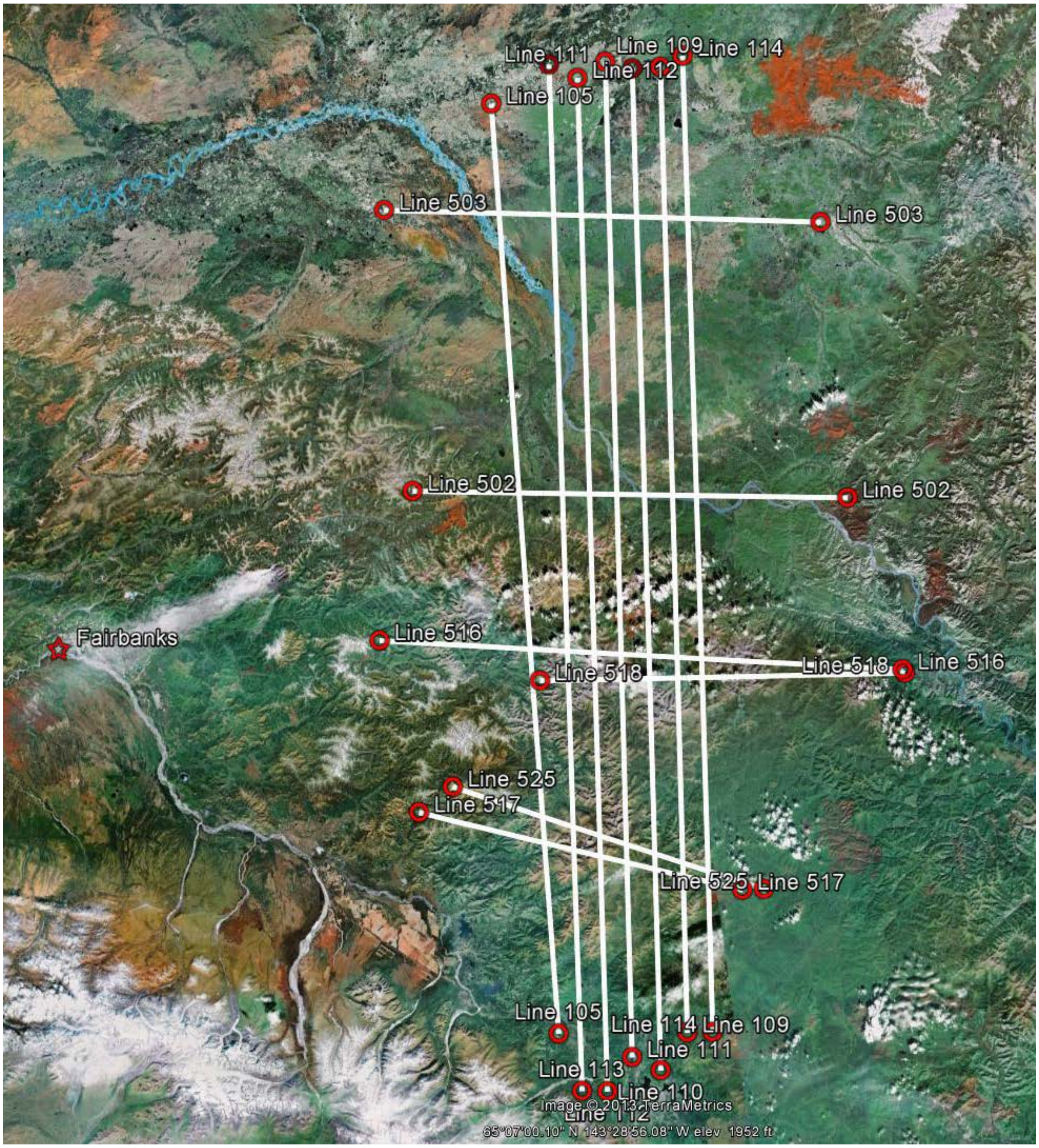

Figure 2: Data Coverage for AN03. Airport marked with red star.

2.1 GPS/IMU Instrumentation

The BLM Pilatus PC-12 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, three Ashtech Z-Surveyors recorded at 1 Hz and 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 center of the fuselague. 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 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 6 lists the lever arm measurement between the TAGS and the SPAN-SE (distances measured along the body of the aircraft: X positive toward the right, Y positive toward the nose, and Z positive up). The SPAN was only installed for the AK12 survey.

Table 5: Lever Arm Measurements FROM the Center of the Gravimeter's Sensor TO the Other Instruments, for this Installation on the BLM Pilatus PC-12

Instrument/Location	X (m)	Y (m)	Z (m)
Aircraft Center of Gravity	0.27	0.00	0.40
Aircraft GPS Antenna	0.73	0.03	-1.18
Applanix POS AV 510 IMU (AK10-2 only)	0.03	0.00	-0.50

Table 6: Lever Arm Measurements FROM the SPAN TO the GPS Antenna, for this Installation on the Pilatus PC-12 (AK12 only)

Instrument/Location	X (m)	Y (m)	Z (m)
GPS Antenna	-0.01	0.67	0.62

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)

Airport	Type	Receiver	Flight Available	2009 Day of Year Available
FBK AK10-2	Kinematic	NovAtel (0013)	F06,F11-F13, F19, F20, F25	271, 279-281, 289, 291, 298
		Trimble (mgps)	F06,F11-F13, F19, F20, F25	271, 279-281, 289, 291, 298
	Static	Ashtech East	F06,F11-F13, F19, F20, F25	271, 279-281, 289, 291, 298
		Ashtech User	F06,F11-F13, F19, F20, F25	271, 279-281, 289, 291, 298
		Ashtech West	F06,F11-F13, F19, F20, F25	271, 279-281, 289, 291, 298
FBK AK12	Kinematic	NovAtel (SPAN)	F13	301
		NovAtel (0016)	F13	301
	Static	Ashtech 3552	F13	301
		Ashtech Hela	F13	301
		Ashtech North	F13	301

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 0.030 m and the average vertical position accuracy is 0.023 m. For flights from AK10-2, GPS+IMU solutions were calculated using Applaanix IMU. For the flight from AK12, the GPS+IMU solution was calculated using the SPAN.

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. 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 FBK TAGS (64.83982°N, 147.598283°W) and it has an absolute gravity value of 982229.157 ± 0.008 mGal at 163.7 cm above the tarmac.

3.1.3 Gravity Filtering

For block AN03, all flights 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 AN03, the result of the crossover analysis is shown in Table 8 and in Figure 3.

Table 8: Gravity Crossover Error Analysis for the AN03 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	5,971	41	2.18	2.00	-0.92	1.54

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.

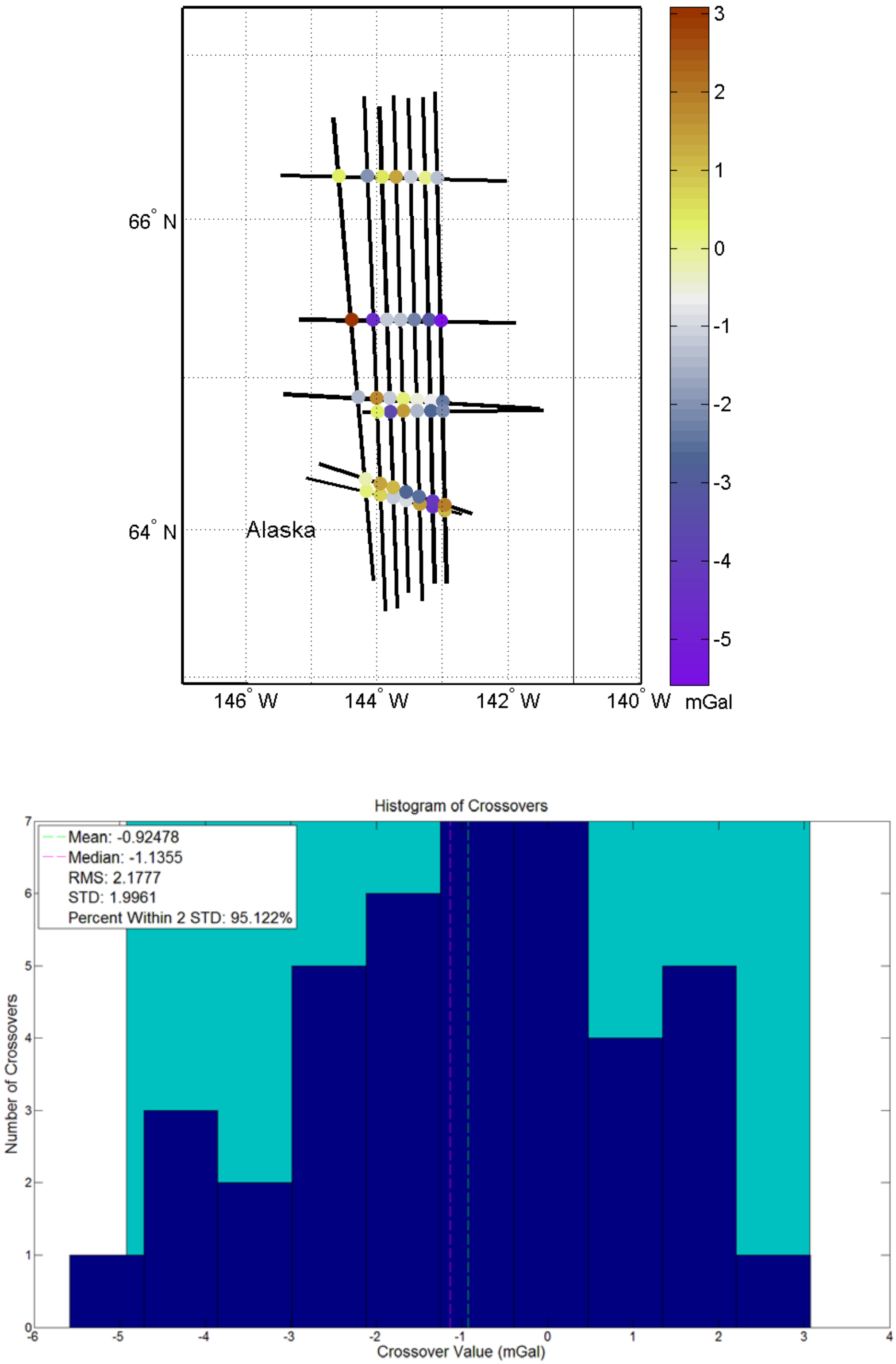

Figure 3: Crossover Residuals, Histogram, and Statistics for Block AN03. Color scale in mGals.

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)
502	2.82	-2.14
503	1.18	-0.36
516	1.34	-0.62
517	2.02	-0.43
518	1.90	-1.34
525	2.38	-0.72

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
5	99.31%	0.76%

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 AN03, however, there were no reflown lines.

3.3 Flight- and Line-Specific Details

3.3.1 GPS processing- by flight

For flights from AK10-2 using the Applanix IMU, 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. For the flight from AK12 using the SPAN, 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 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 GrafNav, POSPac, and 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 4), although other gravity products such as free-air anomalies or free-air disturbances (Figure 5) 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
AK10-2 FBK	06	Trimble	GPS Only	5	105	100.00
	11	Trimble	GPS+IMU	5	516	100.00
	12	Trimble	GPS+IMU	5	517	100.00
	13	Trimble	GPS+IMU	5	518	100.00
	19	Trimble	GPS+IMU	5	525	79.78
	20	Trimble	GPS+IMU	5	109	100.00
					110	97.05
					111	100.00
					112	100.00
	25	Trimble	GPS+IMU	5	113	100.00
					114	100.00
AK12 FBK	13	SPAN	GPS+IMU	5	502	100.00
					503	100.00

Table 12: Gravity Processing Results

Survey	Flight Num.	Line Num.	Times of Deleted Data Section(s)
AK10-2 FBK	06	105	None
	11	516	None
	12	517	None
	13	518	None
	19	525	None
	20	109	None
		110	None
		111	None
		112	None
	25	113	None
		114	None
AK12 FBK	13	502	None
		503	None

Table 13: Bias from EGM08 by Line

Survey	Flight Num.	Line Num.	Bias from EGM08
AK10-2 FBK	06	105	-0.15
	11	516	-0.02
	12	517	-1.51
	13	518	-1.64
	19	525	-1.93
	20	109	-1.17
		110	1.12
		111	-0.41
		112	-0.48
	25	113	-0.92
		114	0.11
AK12 FBK	13	502	2.29
		503	-0.72

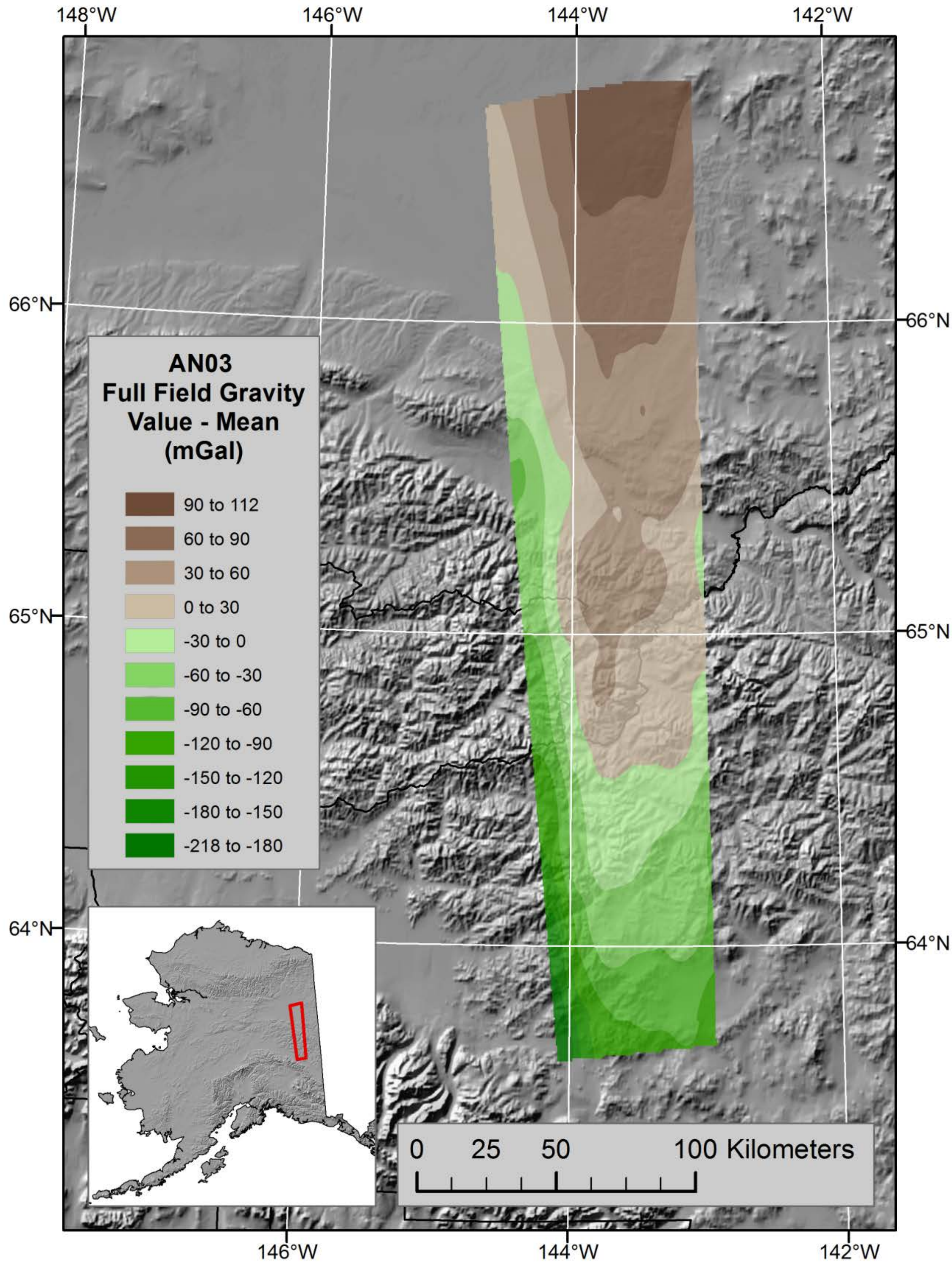

Figure 4: Full-field gravity at altitude (mean removed) for Block AN03. This is the data in the gravity release ".txt" file and includes the effects of differing altitudes along flight lines.

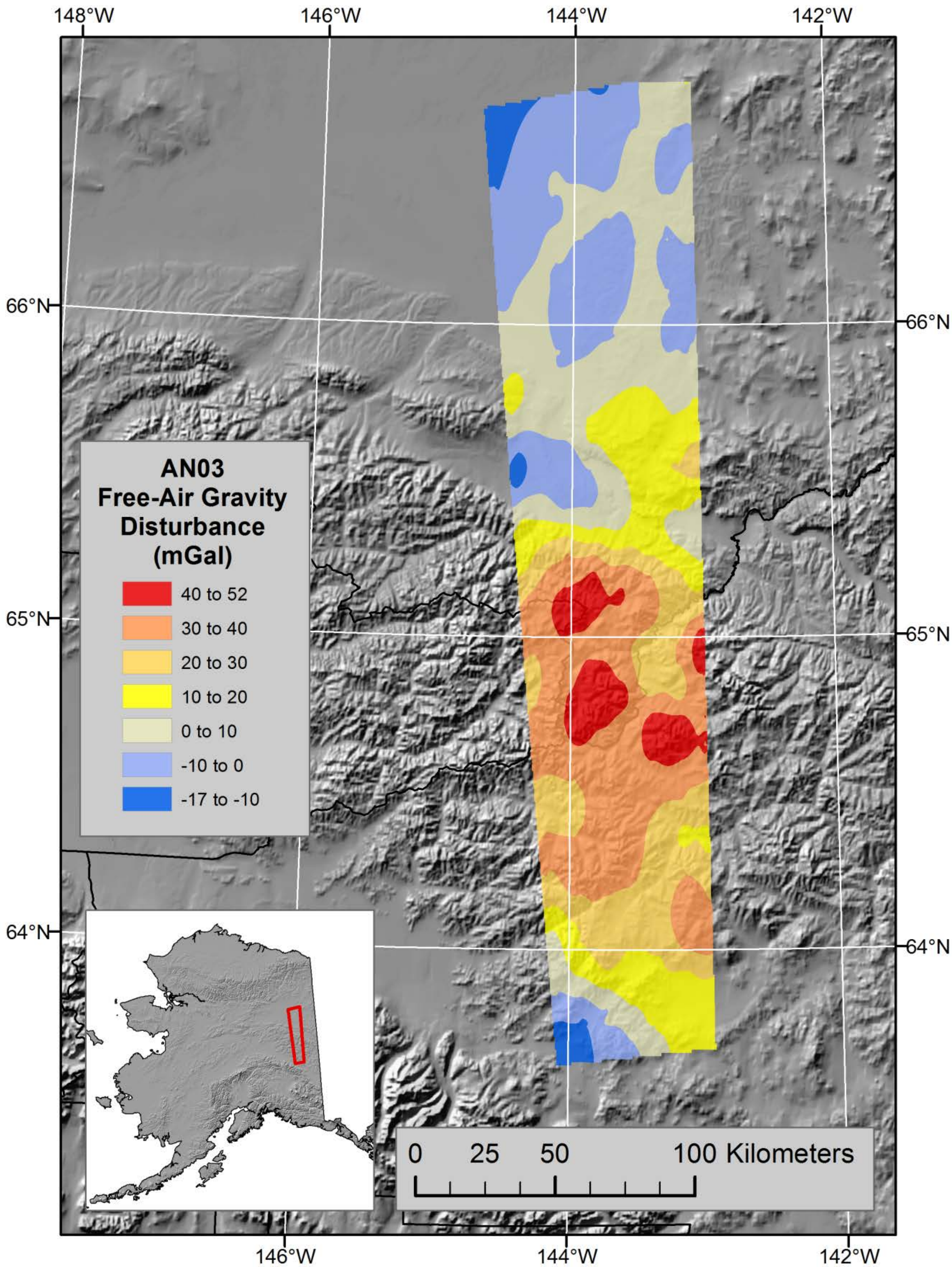

Figure 5: Free-air gravity disturbance for Block AN03 with respect to the WGS-84 ellipsoid.

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 Team, in alphabetical order, are: Vicki A. Childers, Justin Dahlberg, Theresa M. Damiani, Sandra A. Martinka Preaux, Carly A. Weil, Tim Wilkins, and Monica A. Youngman.

To reference the AN03 data file, reference the webpage:
GRAV-D Science Team (2014). “Gravity for the Redefinition of the American Vertical Datum (GRAV-D) Project, Airborne Gravity Data; Block AN03”. Available *DATE*. Online at: http://www.ngs.noaa.gov/GRAV-D/data_AN03.shtml

To reference the block and survey details, reference the block user manual:
GRAV-D Science Team (2014). “Block AN03 (Alaska North 03); GRAV-D Airborne Gravity Data User Manual.” Monica Youngman and Carly Weil, ed. Version BETA. Available *DATE*. Online at: http://www.ngs.noaa.gov/GRAV-D/data_AN03.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.”