Block AS01 (Alaska South 01)

GRAV-D Airborne Data Release User Manual

Applies to Data Release #2 Beta, 8/2014

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Version Notes

08/2014 BETA #2: Datum updated. Data in the first v.1 release (3/2013) were processed in ITRF00. Data in this version (BETA #2) were reprocessed using ITRF08.

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 **AS01** is located in the **A**laska Time Zone, in the **S**outh half (south of 63° latitude). This was the first (**01**) block of data completed in that region. Block AS01 is 390 km by 490 km, covering coastal areas of Alaska and ocean areas from 5 to 140 km offshore (Figure 1). The corner coordinates defining Block AS01 are listed in Table 1.

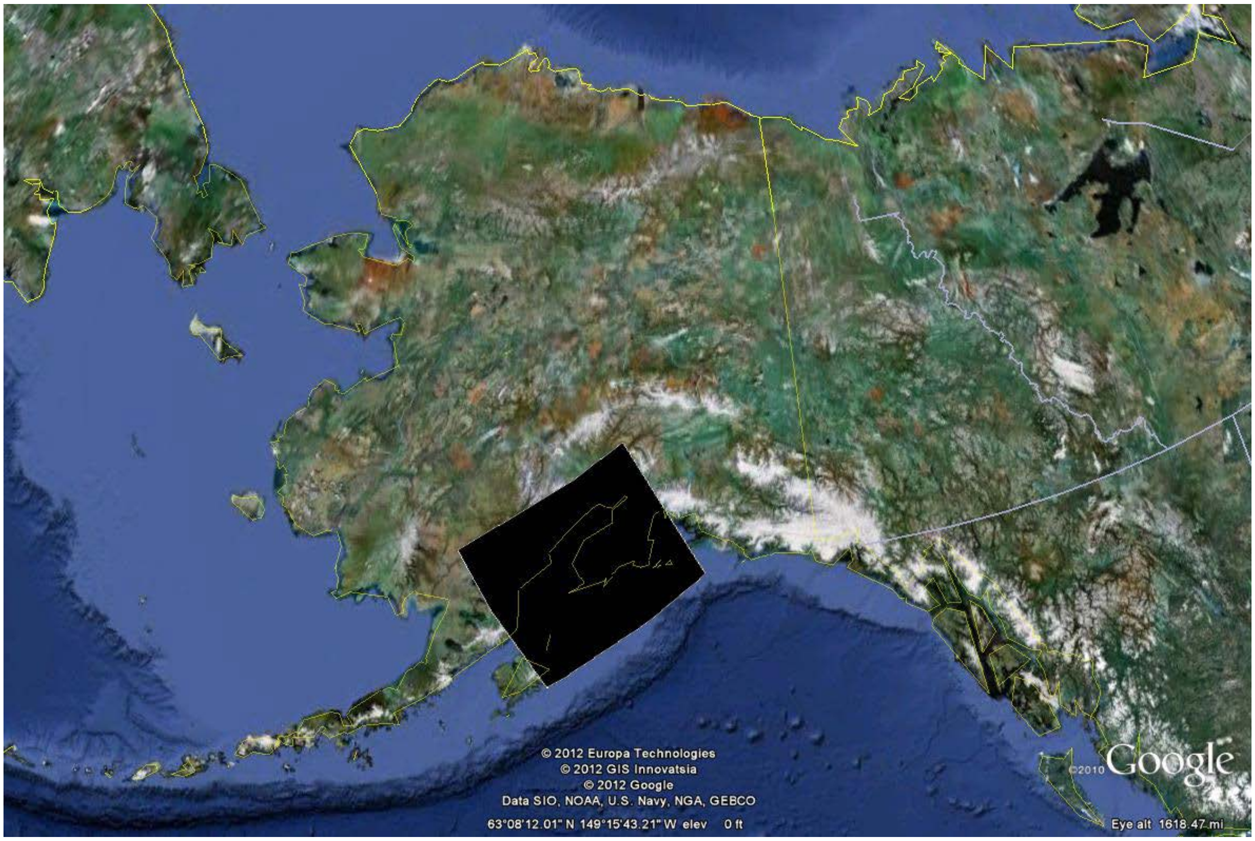

Figure 1: Google Earth Image of the Location of Block AS01 (black rectangle).

Table 1: Latitude and Longitude Coordinates of Corner Points Defining Block AS01

Latitude (decimal degrees)	Longitude (decimal degrees)
60.069260575	-156.762991995
57.191066087	-152.582647743
59.752917013	-145.919860018
62.646399500	-149.447786410

2. Survey Design and Execution

Airborne gravity data in Block AS01 were collected during one survey: AK08 (Alaska 2008). All data and cross flights were done at 35,000 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 AS01 all data lines are Northeast-Southwest and cross lines Northwest-Southeast. The block consists of 40 data lines, 7 cross lines from AK08. 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. AS01101= block AS01's line 101).

Table 2: Survey Overview

Conducting Organization	NOAA- National Geodetic Survey Navy - Naval Research Laboratory
Survey Name	AK08
Airport Base of Operations	Ted Stevens Anchorage International (ANC) Anchorage, AK FBO: Signature
Geographic Location	Southern Mainland Alaska
Dates of Airborne Operations	July 12th – July 30th, 2008

Table 3: Aircraft and Instrumentation

Aircraft	NOAA Cessna Citation II (N52RF)
Engines, number and type	2, Jet
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	35,000 ft
Nominal Aircraft Ground Speed	280 knots
Number of Lines Released	Data Lines: 40 (AK08) Cross Lines: 7 (AK08) Repeat Lines: 0
Number of Crossovers	220

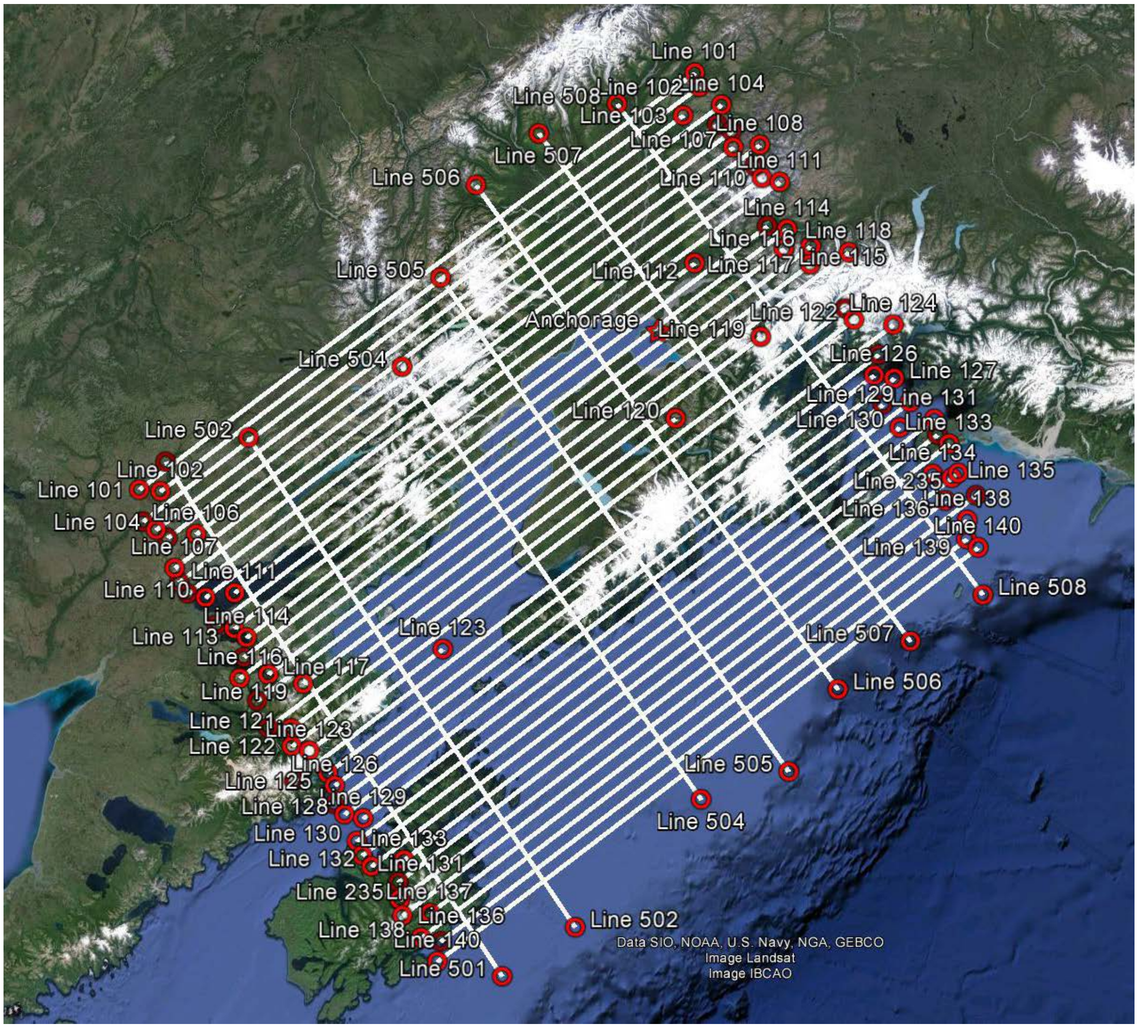

Figure 2: Data Coverage for AS01. Data lines start in the northwest at 101 to 140. Cross lines start in the southwest at 501 to 508 (AK08). Airports marked with red star.

2.1 GPS/IMU Instrumentation

The NOAA Cessna Citation II had two GPS antennas available for scientific measurements and both were used at different times during the survey. 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, one backup NovAtel DL-4 Plus (TAGS timing unit) recorded at 1 Hz and one 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 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).

At the time, the TAGS was in its original, experimental rack and not approved by the FAA for mounting to seat tracks. An FAA-approved rack was later acquired by GRAV-D in 2010. Thus, for this survey the TAGS was mounted in the far back of the plane, in the center of the cargo area. 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 Cessna Citation II

Instrument/Location	**X (m)**	**Y (m)**	**Z (m)**
Aircraft Center of Gravity	0.85	0.00	0.40
Aircraft GPS Antenna (Rear)	2.87	-0.15	-0.91
Aircraft GPS Antenna (Front)	3.81	-0.20	-0.88
Applanix POS AV 510 IMU	0.15	-0.10	-0.41

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)

Airport	Type	Receiver	Flight Available	2008 Day of Year Available
ANC (AK08)	Kinematic	NovAtel (0013)	F01-24	193-212
		Trimble (mgps)	F01-24	193-212
	Static	NovAtel (0016)	F01-24	193-212

Data were processed using WGS84 and ITRF08 with precise point positioning. 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 0.053 m and the average vertical position accuracy is 0.043 m.

3.1.2 Ground Gravity Tie

Updated absolute gravity measurements were performed by NGS with a Micro-g LaCoste A-10 gravimeter in spring of 2011. The A-10 was set up at the exact location of the aircraft and the gravity value was reported at 125 cm above the tarmac. The positions were determed from the GPS collected during the gravity survey while the plane was parked. In Anchorage, AK the location is designated as SIG TAGS (61.164050000°N, 149.986029833°W) and it has an absolute gravity value of 981905.6048 ± 0.0081 mGal.

3.1.3 Gravity Filtering

For block AS01, flights were accomplished in one survey 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. 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 AS01, the result of the crossover analysis is shown in Table 7 and in Figure 3.

Table 7: Gravity Crossover Error Analysis for the AS01 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)
35,000	10,668	10,714	260	2.14	2.06	0.60	1.52

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.

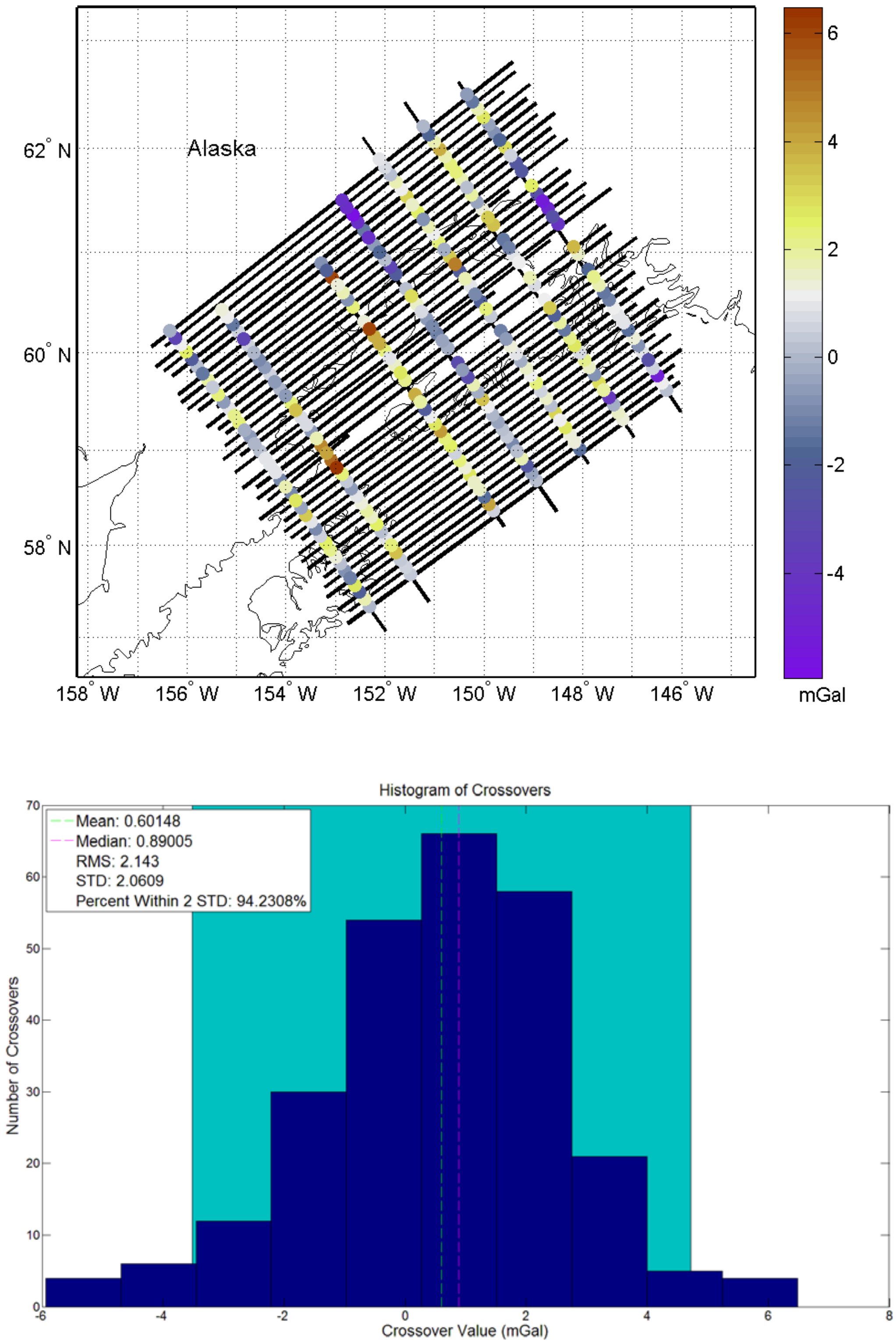

Figure 3: Crossover Residuals, Histogram, and Statistics for Block AS01. Color scale in mGals.

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)
501	1.53	0.51
502	1.92	1.16
504	1.96	1.89
505	2.12	-0.87
506	1.50	1.02
507	1.74	1.05
508	2.33	-0.47

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 9) 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
37	98.55%	2.28%

A final way of estimating data quality is by comparing the full-field gravity results from block AS01 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

GPS data were processed in POSPac v.4.4 for GPS+IMU position solutions or in GrafNav v.8.50.2923 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 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 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
AK08 ANC	01	Trimble	GPS only		508	100.00
					506	100.00
	02	Trimble	GPS only		502	92.88
					504	100.00
	03	Trimble	GPS+IMU		126	100.00
					125	100.00
	04	Trimble	GPS+IMU		128	100.00
					127	100.00
	05	Trimble	GPS+IMU		505	100.00
					507	100.00
	06	Trimble	GPS only		101	100.00
					102	100.00
	07	Trimble	GPS+IMU		124	100.00
					123	100.00
	08	Trimble	GPS+IMU		130	100.00
					129	100.00
	09	Trimble	GPS+IMU		122	100.00
					121	100.00
	10	Trimble	GPS+IMU		109	100.00
					110	100.00
	11	Trimble	GPS+IMU		103	100.00
					104	100.00
	12	Trimble	GPS+IMU		132	100.00
					131	100.00
	13	Trimble	GPS+IMU		120	100.00
					119	100.00
	14	Trimble	GPS+IMU		134	100.00
					133	100.00
	15	Trimble	GPS+IMU		118	99.94
					117	100.00

	16	Trimble	GPS+IMU		116	100.00
					115	100.00
	17	Trimble	GPS+IMU		113	100.00
					114	100.00
	18	Trimble	GPS+IMU		107	100.00
					108	100.00
	19	Trimble	GPS+IMU		105	100.00
					106	100.00
	20	Trimble	GPS+IMU		111	100.00
					112	100.00
	21	Trimble	GPS+IMU		136	100.00
	22	Trimble	GPS+IMU		138	100.00
					137	100.00
	23	Trimble	GPS+IMU		140	100.00
					139	100.00
	24	Trimble	GPS+IMU		501	100.00
					235*	100.00

**Line 135 was originally flown during Flight 21 and was reflown for repeatability evaluation. While both were acceptable, Line 235 was determined to be slightly better and was released with this data.*

Table 11: Gravity Processing Results

Survey	Flight Num.	Line Num.	Times of Deleted Data Sections (s)	Comments
AK08 ANC	01	508	None	None
		506	None	None
	02	502	89220-89588	Spike Removed
		504	95506-96007	Spike Removed
	03	126	None	None
		125	None	None
	04	128	None	None
		127	None	None
	05	505	None	None
		507	None	None
	06	101	None	None
		102	None	None
	07	124	None	None
		126	None	None
	08	130	None	None
		129	None	None
	09	122	None	None
		121	None	None
	10	109	None	None
		110	None	None
	11	103	None	None
		104	None	None
	12	132	None	None

		131	None	None
	13	120	None	None
		119	None	None
	14	134	None	None
		133	None	None
	15	118	None	None
		117	None	None
	16	116	83841-84312	Spike Removed
		115	87830-88540	Spike Removed
	17	113	68424-69703	Spike Removed
		114	72831-74002	Spike Removed
	18	107	None	None
		108	None	None
	19	105	None	None
		106	None	None
	20	111	None	None
		112	None	None
	21	136	None	None
	22	138	None	None
		137	None	None
	23	140	None	None
		139	None	None
	24	501	None	None
		235	None	None

Table 12: Bias from EGM08 by Line

Survey	Flight Num.	Line Num.	Bias from EGM08 (mGals)
AK08 ANC	1	508	-0.49
		506	2.58
	2	502	1.68
		504	2.05
	3	126	-0.97
		125	-2.51
	4	128	0.09
		127	-1.42
	5	505	-0.85
		507	1.51
	6	101	1.76
		102	1.39
	7	124	-0.17
		123	0.44
	8	130	0.26
		129	-0.98
	9	122	1.69
		121	0.66

	10	109	1.59
		110	-0.13
	11	103	1.75
		104	0.22
	12	132	2.22
		131	0.41
	13	120	1.62
		119	1.45
	14	134	0.94
		133	0.31
	15	118	1.67
		117	1.72
	16	116	2.55
		115	1.90
	17	113	2.36
		114	3.13
	18	107	1.48
		108	0.52
	19	105	1.42
		106	0.21
	20	111	1.73
		112	-0.02
	21	136	1.39
	22	138	2.28
		137	0.05
	23	140	0.91
		139	-0.62
	24	501	-0.23
		235	0.04

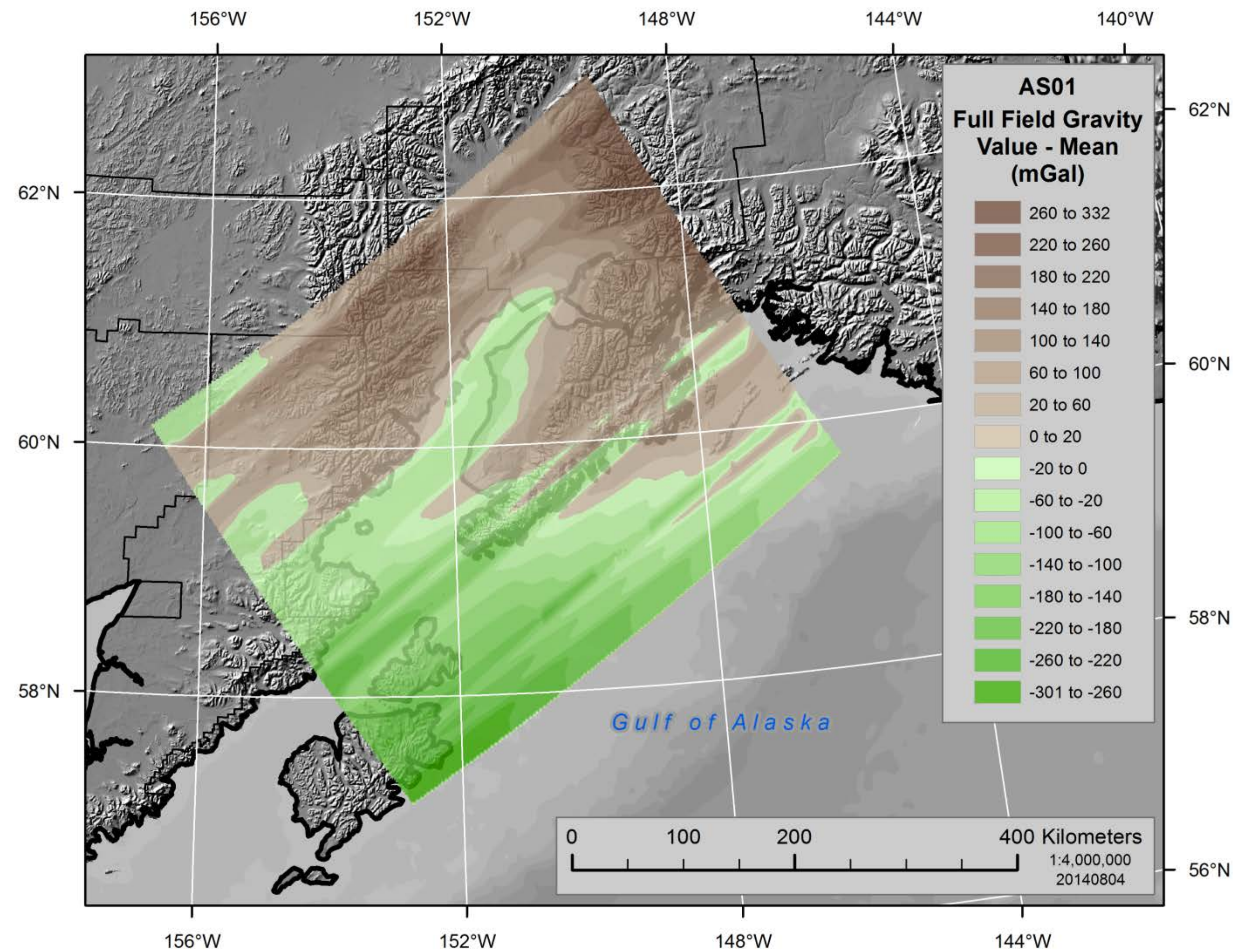

Figure 4: Full-field gravity at altitude (mean removed) for Block AS01. This is the data in the gravity release ".txt" file and includes the effects of differing altitudes along flight lines.

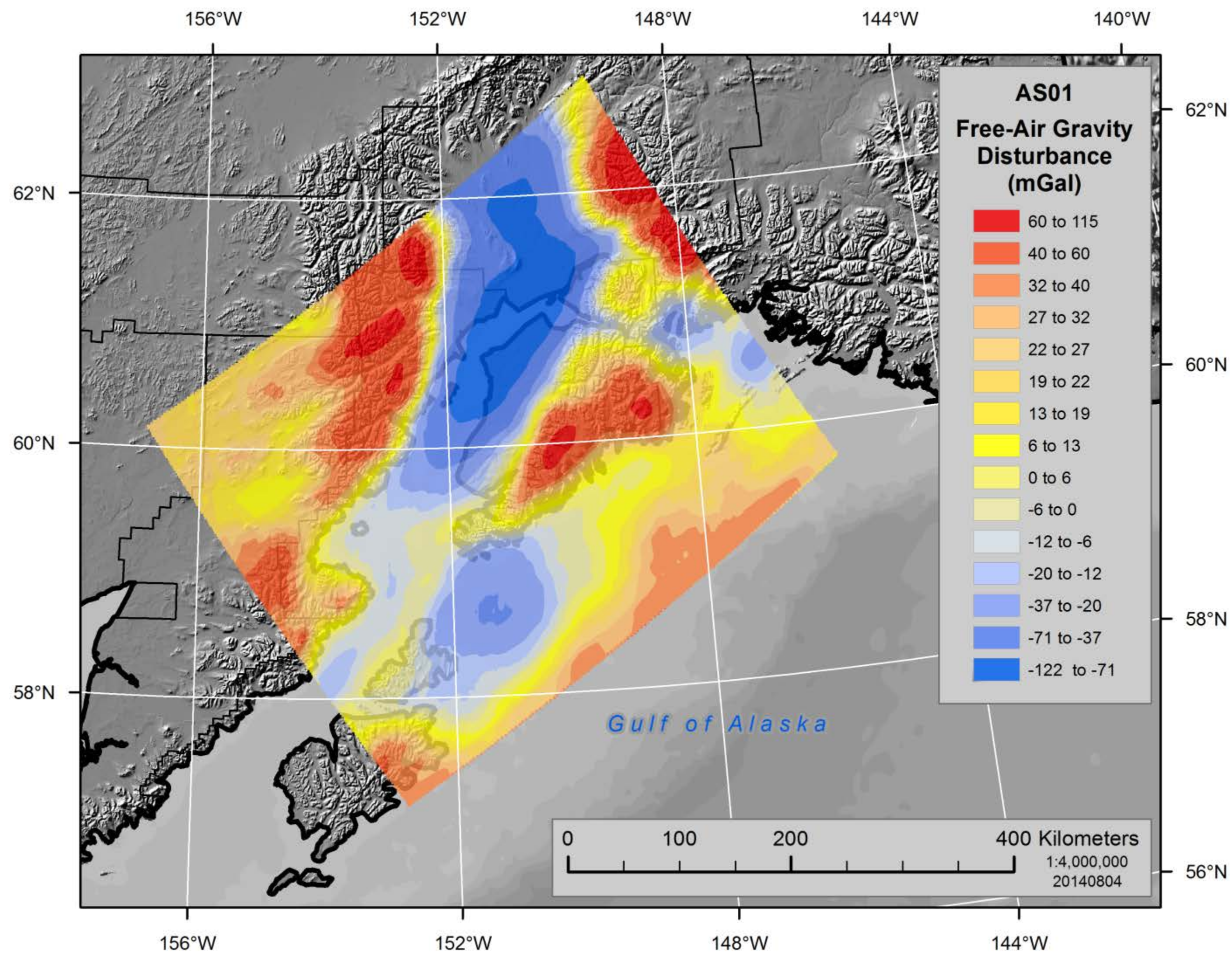

Figure 5: Free-air gravity disturbance for Block AS01 with respect to the WGS-84 ellipsoid.

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

To reference the AS01 data file, reference the webpage:
GRAV-D Team (2014). “Gravity for the Redefinition of the American Vertical Datum (GRAV-D) Project, Airborne Gravity Data; Block AS01”. Available *DATE*. Online at: http://www.ngs.noaa.gov/GRAV-D/data_AS01.shtml

To reference the block and survey details, reference the block user manual:
GRAV-D Team (2014). “Block AS01 (Alaska South 01); GRAV-D Airborne Gravity Data User Manual.” Monica Youngman and Carly Weil, ed. Version 2 Beta. Available *DATE*. Online at: http://www.ngs.noaa.gov/GRAV-D/data_AS01.shtml

To reference the general GRAV-D project operations, reference the General User Manual:
GRAV-D Team (2011). “GRAV-D General Airborne Gravity Data User Manual.” Theresa Damiani, ed. Version 1. Available *DATE*. Online at: http://www.ngs.noaa.gov/GRAV-D/data_AS01.shtml

5. References

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