Block PN01 (Pacific North 01)

GRAV-D Airborne Data Release User Manual

Applies to Data Release BETA #2, 8/2014

Edited by Monica A. Youngman and Carly A. Weil

Version Notes

08/2014 BETA #2: Datum updated and GPS processed with precise point positioning. Data in the first BETA 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. 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 **PN01** is located in the **P**acific Time Zone, in the **N**orth half (south of 40° latitude). This was the first (**01**) block of data completed in that region. Block PN01 is 650 km by 450 km, covering coastal areas of California and Oregon as well as ocean areas from 50 to 180 km offshore (Figure 1). The corner coordinates defining Block PN01 are listed in Table 1.

Figure 1: Google Earth Image of the Location of Block PN01 (black rectangle).

Table 1: Latitude and Longitude Coordinates of Corner Points Defining Block PN01

Latitude (decimal degrees)	Longitude (decimal degrees)
37.920922039	-119.421171039
43.778789127	-120.035913790
43.528272400	-125.681487296
37.766676455	-124.547350037

2. Survey Design and Execution

Airborne gravity data in Block PN01 were collected during one survey: CA11 (California 2011). 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.

In the PN01 all data lines are North-South and cross lines East-West. The block consists of 45 data lines, 6 cross lines from CA11. 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. PN01101= block PN01's line 101).

Table 2: Survey Overview

Conducting Organization	NOAA- National Geodetic Survey
Survey Name	CA11
Airport Base of Operations	Sacramento International Airport (SMF) Sacramento, CA FBO: McClellan Jet Services
Geographic Location	California, Oregon, Pacific Ocean
Dates of Airborne Operations	Jan. 4 – Feb. 25th, 2011

Table 3: Aircraft and Instrumentation

Aircraft	Alaska Fire Service (BLM) Pilatus PC-12
Engines, number and type	1, Turboprop
Gravity Instrumentation	Micro-g LaCoste (MGL) TAGS S-137 (relative) MGL A-10 (absolute) MGL G-6, and D-17 (relative)
GPS Instrumentation	NovAtel DL-4 Plus Applanix POS AV 510 (GPS + IMU) NovAtel SPAN-SE with Honeywell µIRS (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	225 knots
Number of Lines Released	Data Lines: 45 Cross Lines: 6 Repeat Lines: 0
Number of Crossovers	214

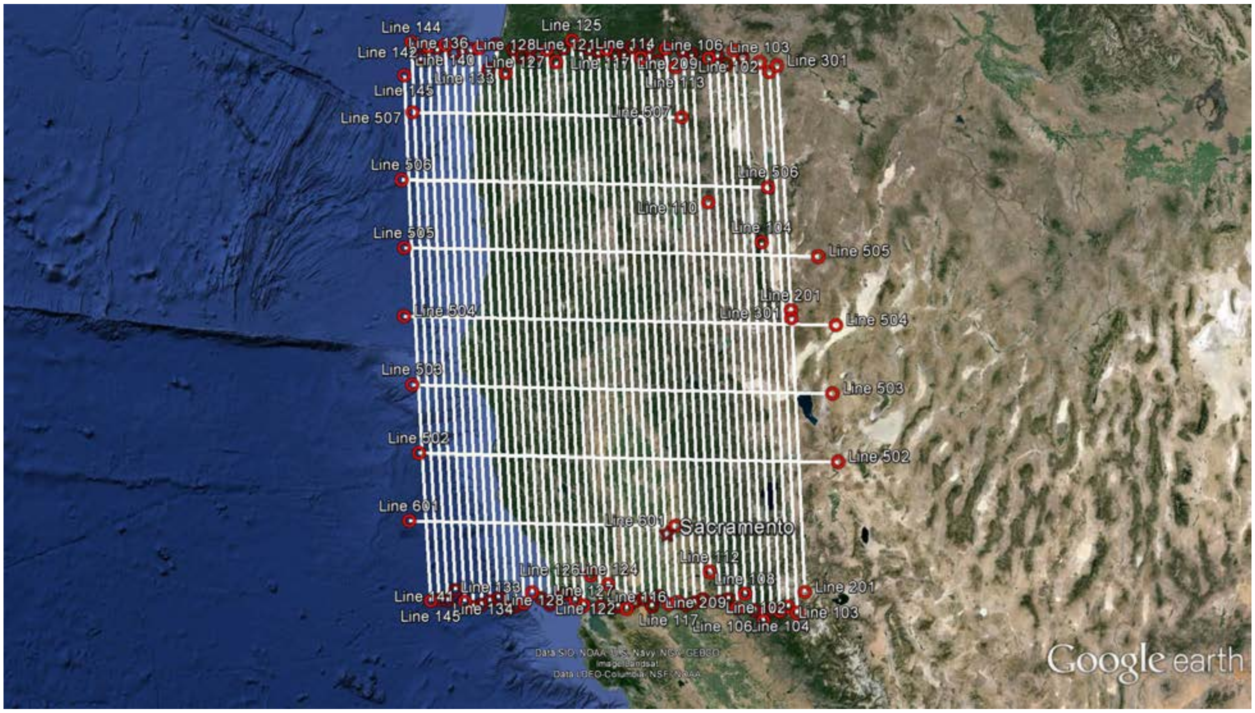

Figure 2: Data Coverage for PN01. Data lines start in the east at 101 to 145 (CA11: red from Sacramento International Airport). Airports marked with red star.

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 antenna: NovAtel DL-4 Plus (included as part of the TAGS gravimeter timing unit), a Trimble (inside the Applanix POS AV 510 system), and a NovAtel (inside the SPAN-SE system). The NovAtel DL-4 Plus had a data rate of 1 Hz, the Trimble of 10Hz, and the SPAN NovAtel of 20Hz. The Applanix POS AV 510 and NovAtel µIMU systems also contained Inertial Measurement Units (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 fuselage. 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 Applanix 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.) The SPAN IMU was mounted on the TAGS cover plate in front of the Applanix along the centerline. 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).

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

Instrument/Location	X (m)	Y (m)	Z (m)
Aircraft Center of Gravity	0.27	0.00	0.40
Aircraft GPS Antenna	-0.63	-0.01	-1.22
Applanix POS AV 510 IMU	0.0	0.0	-0.49

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

Instrument/Location	X (m)	Y (m)	Z (m)
GPS Antenna	-.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	2011 Day of Year Available
SMF (CA11)	Kinematic	NovAtel (0009)	F01-28, F30-35	10-15, 17-21, 32-35, 37, 40-44, 50-53
		Trimble (mgps)	F01-35	10-15, 17-21, 32-35, 37, 40-44, 50-53
		SPAN	F08, F10-30, F32-35	18, 20-21, 32-35, 37, 40-44, 51-53
	Static	Ashtech EAST	F01-35	10-15, 17-21, 32-35, 37, 40-44, 50-53
		Ashtech WEST	F01-20, 22-35	10-15, 17-21, 32-35, 37, 41-44, 50-53
		Ashtech MIDDLE	F01-18, 20-35	10-15, 17-21, 32-35, 37, 40-44, 50-53

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 0.013 m and the average vertical position accuracy is 0.014 m.

3.1.2 Ground Gravity Tie

Updated absolute gravity measurements were performed by NGS with a Micro-g LaCoste A-10 gravimeter in summer of 2012. The A-10 was set up at the exact location of the aircraft. In Sacramento, CA the location is designated as KMCC TAGS (38.659603156°N, 121.393214267°W) and it has an absolute gravity value of 979985.3147 ± 0.0082 mGal.

3.1.3 Gravity Filtering

For block PN01, 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 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 PN01, the result of the crossover analysis is shown in Table 8 and in Figure 3.

Table 8: Gravity Crossover Error Analysis for the PN01 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	6,815	267	2.76	2.76	0.15	1.95

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.

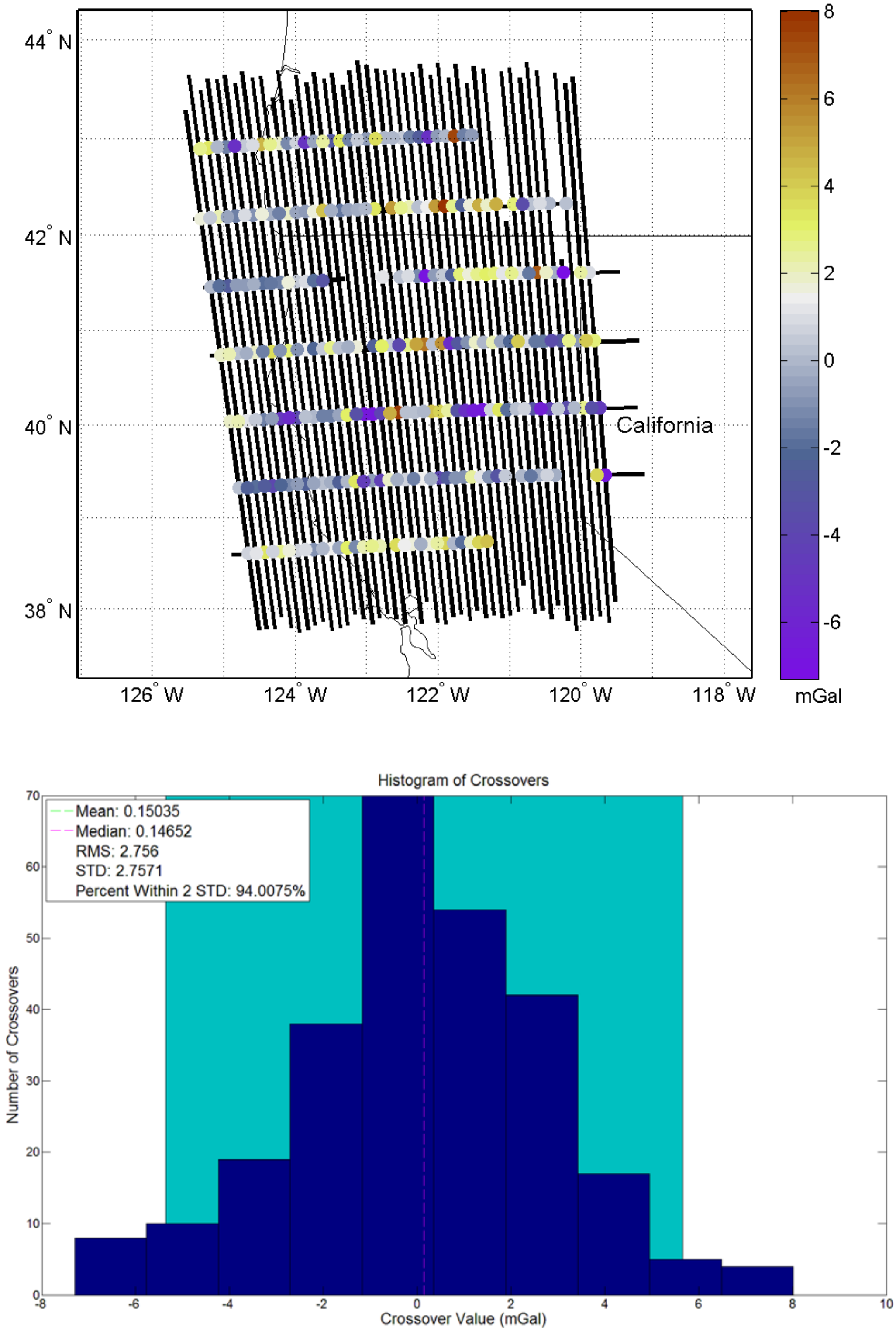

Figure 3: Crossover Residuals, Histogram, and Statistics for Block PN01.

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)
601	1.57	1.51
502	2.15	-0.91
503	3.49	-1.04
504	2.65	0.60
505	2.67	0.00
506	2.80	0.12
507	2.35	1.24

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
39	99.77%	0.28%

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 PN01, 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 POSPac v.4.4 for GPS+IMU position solutions or in GrafNav v.8.5.4320 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 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
CA11 SMF	01	NovAtel 0009	GPS+IMU	5	102	100.00
					301	100.00
	02	NovAtel 0009	GPS+IMU	5	126	100.00
					127	93.68
	03	NovAtel 0009	GPS+IMU	5	124	100.00
					125	100.00
	04	NovAtel 0009	GPS+IMU	5	130	91.16
					131	100.00
	05	Novatel 0009	GPS+IMU	5	128	100.00
					129	91.64
	06	Trimble	GPS+IMU	5	104	100.00
	07	NovAtel 0009	GPS+IMU	5	103	98.73
					201	100.00
	08	NovAtel 0009	GPS+IMU	5	108	95.57
	09	NovAtel 0009	GPS+IMU	5	106	100.00
					107	100.00
	10	NovAtel 0009	GPS+IMU	5	110	88.27
					111	100.00
	11	NovAtel 0009	GPS+IMU	5	132	100.00
					133	100.00
	12	SPAN	GPS+IMU	5	144	100.00
					145	100.00
	13	SPAN	GPS+IMU	5	142	100.00
					143	100.00
	14	SPAN	GPS only	5	112	100.00
					113	100.00
	15	SPAN	GPS+IMU	5	122	100.00
					123	100.00
	16	SPAN	GPS+IMU	5	114	100.00
					115	100.00
	17	SPAN	GPS+IMU	5	140	100.00
					141	100.00
	18	SPAN	GPS+IMU	5	205*	100.00
	19	SPAN	GPS+IMU	5	138	100.00
					139	100.00
	20	SPAN	GPS+IMU	5	502	100.00
	21	SPAN	GPS+IMU	5	116	100.00
					117	100.00
	22	SPAN	GPS+IMU	5	136	100.00
					137	100.00
	23	SPAN	GPS+IMU	5	134	100.00
					135	100.00
	24	SPAN	GPS+IMU	5	118	100.00
					119	100.00
	25	SPAN	GPS+IMU	5	503	100.00
					504	100.00
	26	SPAN	GPS+IMU	5	120	100.00
					121	100.00
	27	SPAN	GPS+IMU	5	601	100.00
					506	100.00
	28	SPAN	GPS+IMU	5	209*	100.00
	31	SPAN	GPS+IMU	5	505	100.00
					507	100.00

**Lines 205 and 209 were originally flown during Flight 06 and 08 respectively but due to poor data quality the line were relfown*

Table 12: Gravity Processing Results

Survey	Flight Num.*	Line Num.	Times of Data Deleted
CA11 SMF	01	102	
		301	
	02	126	
		127	
	03	124	80429-81252
		125	
	04	130	88075-88535, 88880-89177
		131	93237-93725
	05	128	
		129	
	06	104	75599-76449
	07	103	83705-84213
		201	
	08	108	
	09	106	84322-85343
		107	
	10	110	
		111	
	11	132	
		133	
	12	144	
		145	
	13	142	
		143	
	14	112	90220-90516
		113	97915-98273
	15	122	
		123	
	16	114	
		115	
	17	140	
		141	
	18	205	
	19	138	
		139	
	20	502	91893-92220
	21	116	
		117	
	22	136	
		137	
	23	134	
		135	
	24	118	
		119	
	25	503	
		504	
	26	120	
		121	
	27	601	
		506	
	28	209	
	31	505	87698-88024
		507	

Table 13: Bias from EGM08 by Line

Survey	Flight Num.*	Line Num.	Bias From EGM08
CA11 SMF	01	102	-0.91
		301	-1.76
	02	126	0.62
		127	1.80
	03	124	1.53
		125	0.78
	04	130	1.40
		131	0.23
	05	128	2.64
		129	1.93
	06	104	1.05
	07	103	1.73
		201	1.70
	08	108	2.00
	09	106	2.28
		107	2.48
	10	110	1.86
		111	0.69
	11	132	0.86
		133	0.67
	12	144	0.10
		145	-0.74
	13	142	0.17
		143	-0.41
	14	112	1.40
		113	1.10
	15	122	0.77
		123	0.53
	16	114	1.51
		115	0.94
	17	140	0.16
		141	-0.23
	18	205	2.40
	19	138	0.49
		139	-0.03
	20	502	-0.01
	21	116	1.53
		117	0.50
	22	136	0.43
		137	-0.59
	23	134	1.28
		135	-0.13
	24	118	1.28
		119	0.35
	25	503	-0.93
		504	0.93
	26	120	2.36
		121	0.49
	27	601	0.80
		506	0.50
	28	209	2.30
	31	505	0.90
		507	2.14

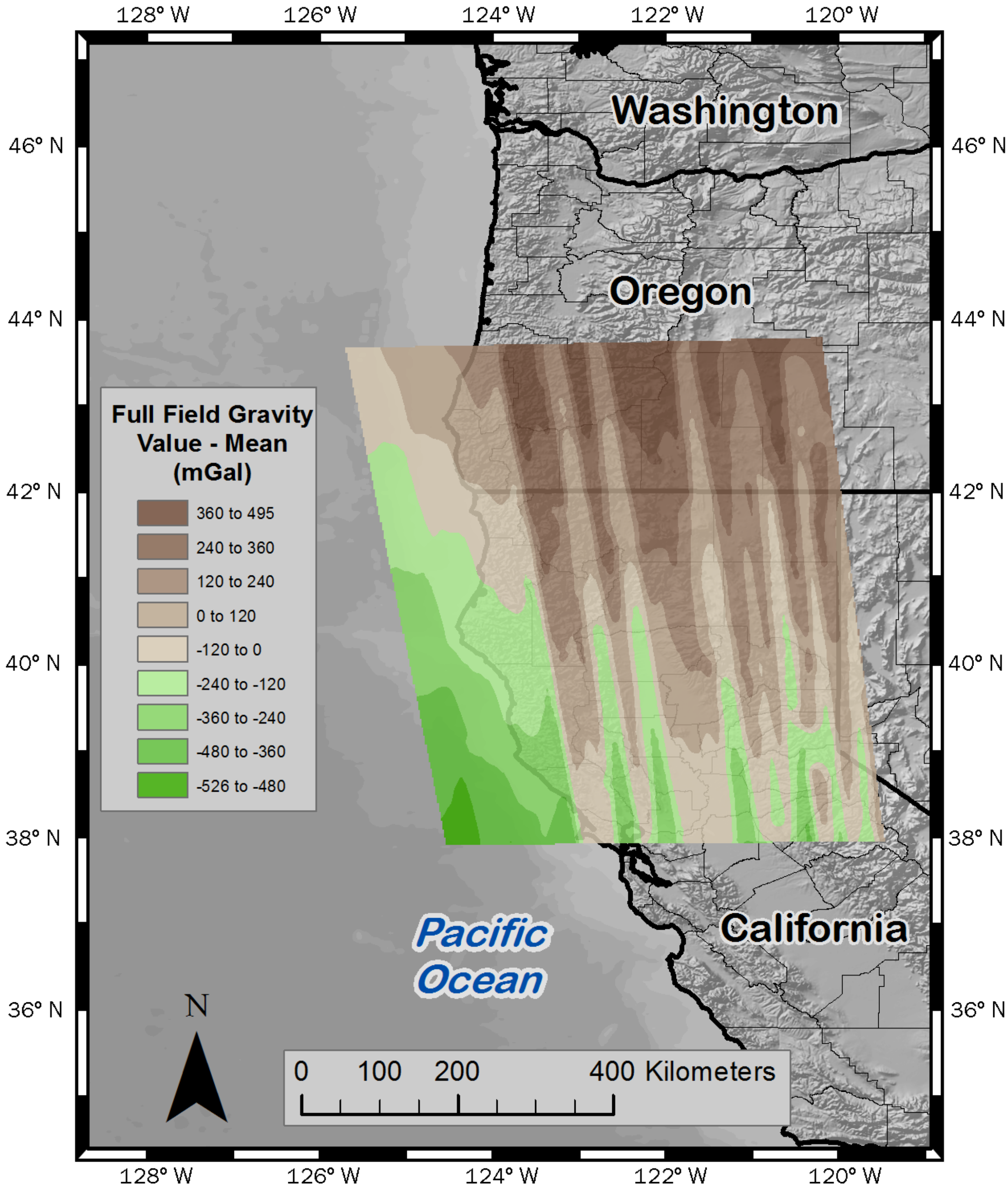

Figure 4: Full-field gravity at altitude (mean removed) for Block PN01. This is the data in the gravity release ".txt" file and includes the effects of differing altitudes along flight lines.

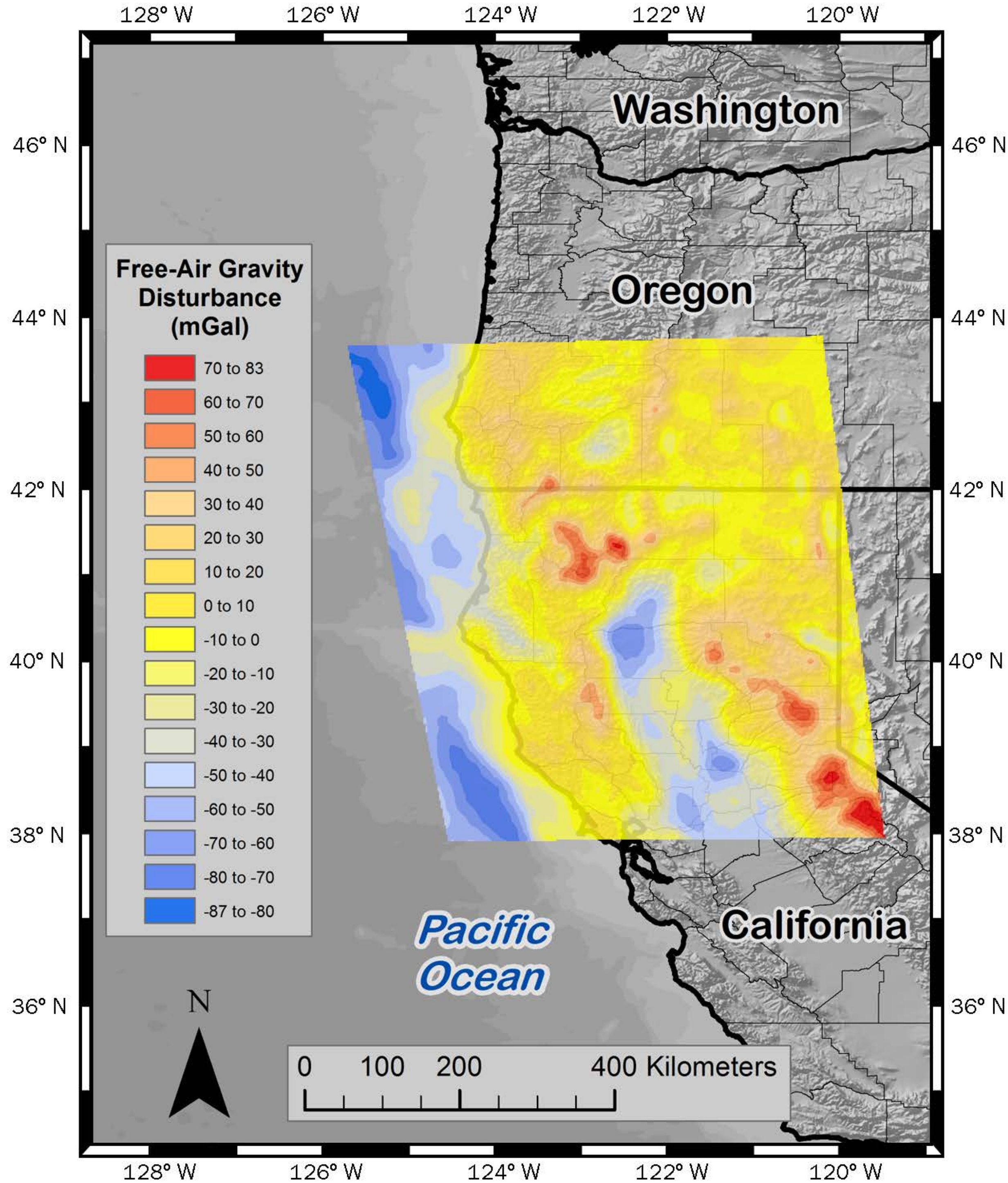

Figure 5: Free-air gravity disturbance for Block PN01 with respect to the WGS-84 ellipsoid.

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

To reference the PN01 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 PN01". Available *DATE*. Online at: http://www.ngs.noaa.gov/GRAV-D/data_PN01.shtml

To reference the block and survey details, reference the block user manual:
GRAV-D Team (2014). "Block PN01 (Pacific North 01); GRAV-D Airborne Gravity Data User Manual." Monica Youngman and Carly Weil, ed. Version 1. Available *DATE*. Online at: http://www.ngs.noaa.gov/GRAV-D/data_PN01.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_PN01.shtml

5. References

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