# Block EN01 (Eastern North 01)

*GRAV-D Airborne Data Release User Manual*

*Applies to Data Release BETA, 3/2013*

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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 **EN01** is located in the **E**astern Time Zone, in the **N**orth half (north of 40° latitude). This was the first (**01**) block of data completed in that region. Block EN01 is 260 km by 400 km in the Great Lakes, covering coastal areas of New York and Ontario as well as Lake Ontario (Figure 1). The corner coordinates defining Block EN01 are listed in Table 1.

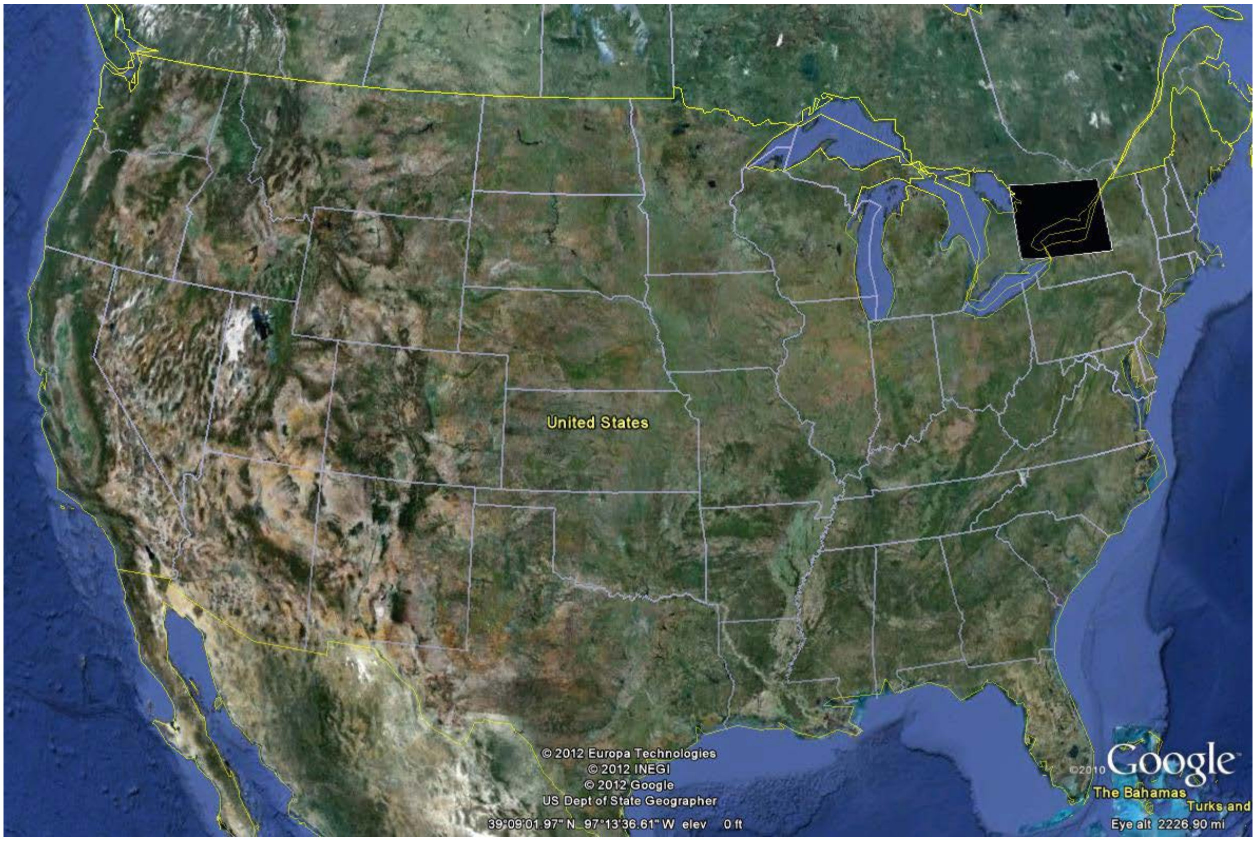


*Figure 1: Google Earth Image of the Location of Block EN01 (black rectangle).*

*Table 1: Latitude and Longitude Coordinates of Corner Points Defining Block EN01*

| Latitude (decimal degrees) | Longitude (decimal degrees) |
|---|---|
| 43.000599229 | -80.152907658 |
| 42.703728497 | -75.720647169 |
| 45.060603082 | -75.443145857 |
| 45.384589426 | -80.070611988 |

## 2. Survey Design and Execution

Airborne gravity data in Block EN01 were collected during one survey: NY11 (New York 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. Figure 2 shows the data coverage, plotted in Google Earth.

In the EN01 all data lines are East-West and cross lines Northwest-Southeast. The block consists of 26 data lines, 5 cross lines from NY11. 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. EN01101= block EN01's line 101).

*Table 2: Survey Overview*

| | |
|---|---|
| Conducting Organization | NOAA- National Geodetic Survey |
| Survey Name | NY11 |
| Airport Base of Operations | Buffalo Niagara Intl (BUF)<br>Buffalo, NY<br>FBO: Western Aviation Jet Center |
| Geographic Location | Buffalo, NY |
| Dates of Airborne Operations | Aug. 8 – Sept. 2, 2011 |

*Table 3: Aircraft and Instrumentation*

| | |
|---|---|
| Aircraft | Hawker Beechcraft King Air E90A |
| Engines, number and type | 2, Turboprop |
| Gravity Instrumentation | Micro-g LaCoste (MGL) TAGS S-137 (relative)<br>MGL FG-5 102 (absolute)<br>MGL D-43 (relative) |
| GPS Instrumentation | NovAtel DL-4 Plus<br>Applanix POS AV 510 (GPS + IMU)<br>NovAtel SPAN-SE (GPS + IMU) |

*Table 4: Survey Design and Execution*

| | |
|---|---|
| Line Spacing | Data Lines: 10 km<br>Cross Lines: ~80 km |
| Type of Layout | Regular data lines & diagonal cross lines |
| Nominal Survey Altitude | 20,000 ft |
| Nominal Aircraft Ground Speed | 220 knots |
| Number of Lines Released | Data Lines: 26<br>Cross Lines: 5<br>Repeat Lines: 0 |
| Number of Crossovers | 62 |

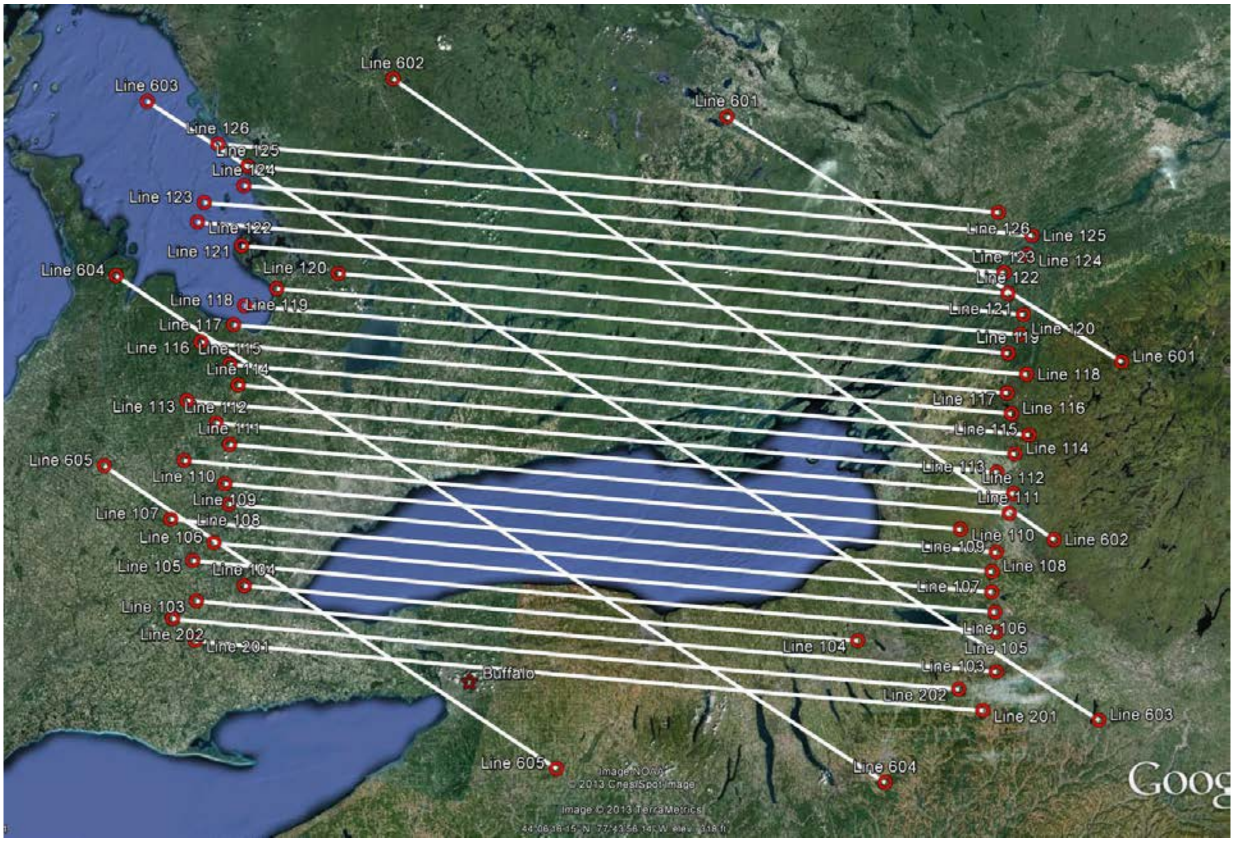


*Figure 2: Data Coverage for EN01. Data lines start in the south at 201 (a reflight of 101) to 126. Airports marked with red star.*

## 2.1 GPS/IMU Instrumentation

The King Air E90A 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 had a data rate of 1 Hz, the Trimble of 10 Hz, and the SPAN NovAtel of 20Hz. The NovAtel µIMU 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 3.2.1 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 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 top of the TAGS, behind the Applanix IMU, and in the center of the frame. 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 Dynamic Aviation King Air E90A*

| Instrument/Location | X (m) | Y (m) | Z (m) |
|---|---|---|---|
| Aircraft Center of Gravity | 0.00 | 0.219 | 0.413 |
| Aircraft GPS Antenna | -1.582 | 0.219 | -1.063 |
| Applanix POS AV 510 IMU | 0.13 | 0.015 | -0.5 |

*Table 6: Lever Arm Measurements FROM the SPAN TO the GPS Antenna, for this Installation on the Dynamic Aviation King Air E90A*

| Instrument/Location | X (m) | Y (m) | Z (m) |
|---|---|---|---|
| GPS Antenna | -.204 | -1.582 | 0.513 |

# 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 |
|---|---|---|---|---|
| BUF | Kinematic | NovAtel (0009) | F02-F09,F13-F17 | 222-225,228,232,234-235 |
| | | SPAN | F02-F09,F13-F17 | 222-225,228,232,234-235 |
| | | Trimble (mgps) | F02-F09,F13-F17 | 222-225,228,232,234-235 |
| | Static | Ashtech (Middle) | F02-F09,F13-F17 | 222-225,228,232,234-235 |
| | | Ashtech (North) | F02-F09,F13-F17 | 222-225,228,232,234-235 |
| | | Ashtech (South) | F02-F09,F13-F17 | 222-225,228,232,234-235 |

*Table 8: NGS GPS Base Station Position(s)*

| Airport | Base Name | Antenna Type | Latitude (dec deg) | Longitude (dec deg) | Ellipsoidal Height (m) |
|---|---|---|---|---|---|
| BUF | Ashtech (Middle) | ASH701975.01A | 42.944870424 | -78.731476055 | 177.9702 |
| | Ashtech (North) | ASH701975.01A | 42.945845154 | -78.731926077 | 177.59 |
| | Ashtech (South) | ASH701975.01A | 42.945240336 | -78.732952273 | 177.2374 |

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 0.040 m and the average vertical position accuracy is 0.028 m. All GPS+IMU solutions were calculated using the Applanix IMU.

### 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 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 Buffalo, NY the location is designated as BUF TAGS (42.94732°N, -78.7357094°W) and it has an absolute gravity value 980353.39503 ± 0.0028 mGal.

### 3.1.3 Gravity Filtering

For block EN01, 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. Also, a pre-fliter was applied to the GPS solution for input into the offlevel correction. 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 EN01, the result of the crossover analysis is shown in Table 8 and in Figure 3.

*Table 9: Gravity Crossover Error Analysis for the EN01 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 | 6,230 | 62 | 1.75 | 1.76 | 0.11 | 1.24 |

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.

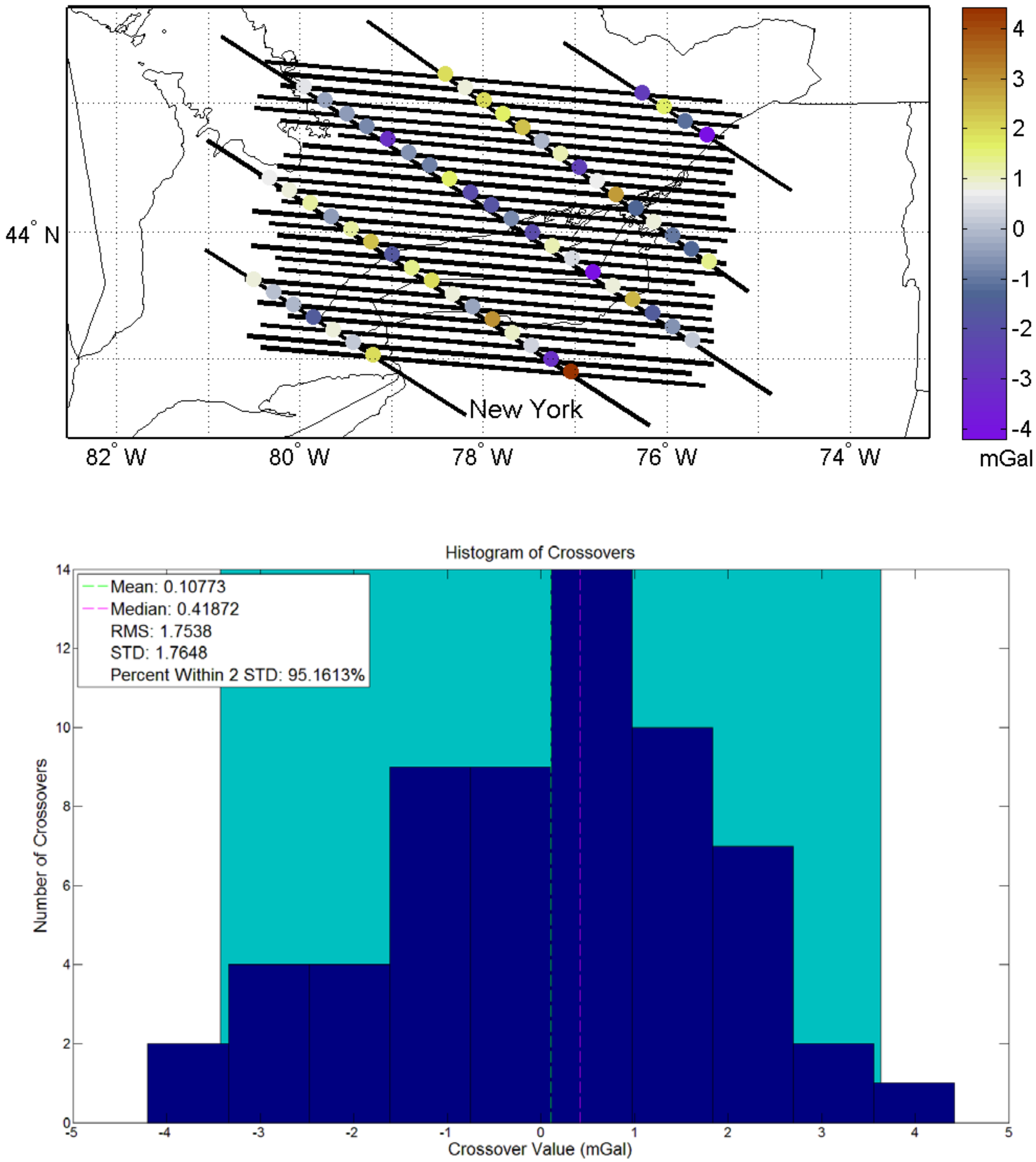


*Figure 3: Crossover Residuals, Histogram, and Statistics for Block EN01. Color scale in mGals.*

*Table 10: 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 | 2.45 | -1.58 |
| 602 | 1.56 | 0.63 |
| 603 | 1.61 | -0.61 |
| 604 | 1.76 | 0.85 |
| 605 | 1.09 | 0.32 |

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 11: Average Data Line Correlation*

| Number of Correlations | Average Data Line Correlation | Standard Deviation of Correlations |
|---|---|---|
| 24 | 96.54 | 1.89 |

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 EN01, 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.7.80.2315 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 12: GPS+IMU and GPS-only Kinematic Processing Results*

| Survey | Flight Num. | Base GPS Unit(s) | Rover GPS Unit | Solution Type | Elevation Mask (degrees) | Line Num. | NGS Quality Grade |
|---|---|---|---|---|---|---|---|
| NY11 | 02 | South | Trimble | GPS+IMU | 10 | 103 | 92.98 |
| | | | | | | 104 | 62.87 |
| | | | | | | 105 | 63.18 |
| | 03 | South | Trimble | GPS+IMU | 10 | 106 | 99.15 |
| | | | | | | 107 | 96.10 |
| | | | | | | 108 | 100.00 |
| | 04 | Middle | Trimble | GPS+IMU | 10 | 109 | 85.13 |
| | | | | | | 110 | 70.71 |
| | | | | | | 111 | 80.03 |
| | 05 | Middle | NovAtel | GPS+IMU | 8 | 112 | 100.00 |
| | | | | | | 113 | 100.00 |
| | | | | | | 114 | 97.07 |
| | 06 | Middle | Trimble | GPS+IMU | 8 | 115 | 100.00 |
| | | | | | | 116 | 76.00 |
| | | | | | | 117 | 97.88 |
| | 07 | Middle | Trimble | GPS+IMU | 8 | 118 | 99.64 |
| | | | | | | 119 | 84.85 |
| | | | | | | 120 | 99.97 |
| | 08 | South | Trimble | GPS+IMU | 8 | 123 | 97.71 |
| | | | | | | 124 | 100.00 |
| | 09 | Middle | Trimble | GPS+IMU | 8 | 125 | 89.29 |
| | | | | | | 126 | 81.46 |
| | 13 | Middle | Trimble | GPS+IMU | 10 | 605 | 100.00 |
| | 14 | Middle | SPAN | GPS+IMU | 8 | 121 | 96.00 |
| | | | | | | 122 | 89.57 |
| | 15 | Middle | Trimble | GPS+IMU | 8 | 603 | 99.98 |
| | | | | | | 604 | 91.26 |
| | 16 | Middle | Trimble | GPS+IMU | 8 | 601 | 84.00 |
| | | | | | | 602 | 100.00 |
| | 17 | Middle | Trimble | GPS+IMU | 8 | 201* | 100.00 |
| | | | | | | 202* | 94.09 |

**Lines 201, 202 was originally flown during Flight 01 but due to poor data quality the line were relfown.*

*Table 13: Gravity Processing Results*

| Survey | Flight Num. | Line Num. | Times of Deleted Data Sections (s) | Comments |
|---|---|---|---|---|
| NY11 | 02 | 103 | None | |
| | | 104 | None | |
| | | 105 | None | |
| | 03 | 106 | None | |
| | | 107 | None | |
| | | 108 | None | |
| | 04 | 109 | None | |
| | | 110 | None | |
| | | 111 | None | |
| | 05 | 112 | None | |
| | | 113 | None | |
| | | 114 | None | |
| | 06 | 115 | None | |
| | | 116 | None | |
| | | 117 | None | |
| | 07 | 118 | None | |
| | | 119 | None | |
| | | 120 | None | |
| | 08 | 123 | None | |
| | | 124 | None | |
| | 09 | 125 | None | |
| | | 126 | None | |
| | 13 | 605 | None | |
| | 14 | 121 | None | |
| | | 122 | 26554-26867 | Spike Removed |
| | 15 | 603 | None | |
| | | 604 | None | |
| | 16 | 601 | None | |
| | | 602 | None | |
| | 17 | 201 | None | |
| | | 202 | None | |

*Table 14: Bias from EGM08 by Line*

| Survey | Flight Num. | Line Num. | Bias from EGM08 (mGals) |
|---|---|---|---|
| | 2 | 103 | -1.26 |
| | | 104 | 0.98 |
| | | 105 | -1.18 |
| | 3 | 106 | -1.10 |
| | | 107 | 0.67 |
| | | 108 | -0.62 |
| | 4 | 109 | -0.68 |
| | | 110 | 1.74 |
| | | 111 | 0.22 |
| | 5 | 112 | -0.26 |
| | | 113 | 1.67 |
| | | 114 | 0.62 |
| | 6 | 115 | -1.11 |
| | | 116 | 0.64 |
| | | 117 | -1.11 |
| | 7 | 118 | -1.26 |
| | | 119 | 0.47 |
| | | 120 | -0.58 |
| | 8 | 123 | -0.23 |
| | | 124 | 0.10 |
| | 9 | 125 | -1.33 |
| | | 126 | -0.11 |
| | 13 | 605 | -0.26 |
| | 14 | 121 | -1.57 |
| | | 122 | 0.21 |
| | 15 | 603 | -0.97 |
| | | 604 | 0.73 |
| | 16 | 601 | -1.17 |
| | | 602 | 0.17 |
| | 17 | 201 | -1.27 |
| | | 202 | -0.14 |

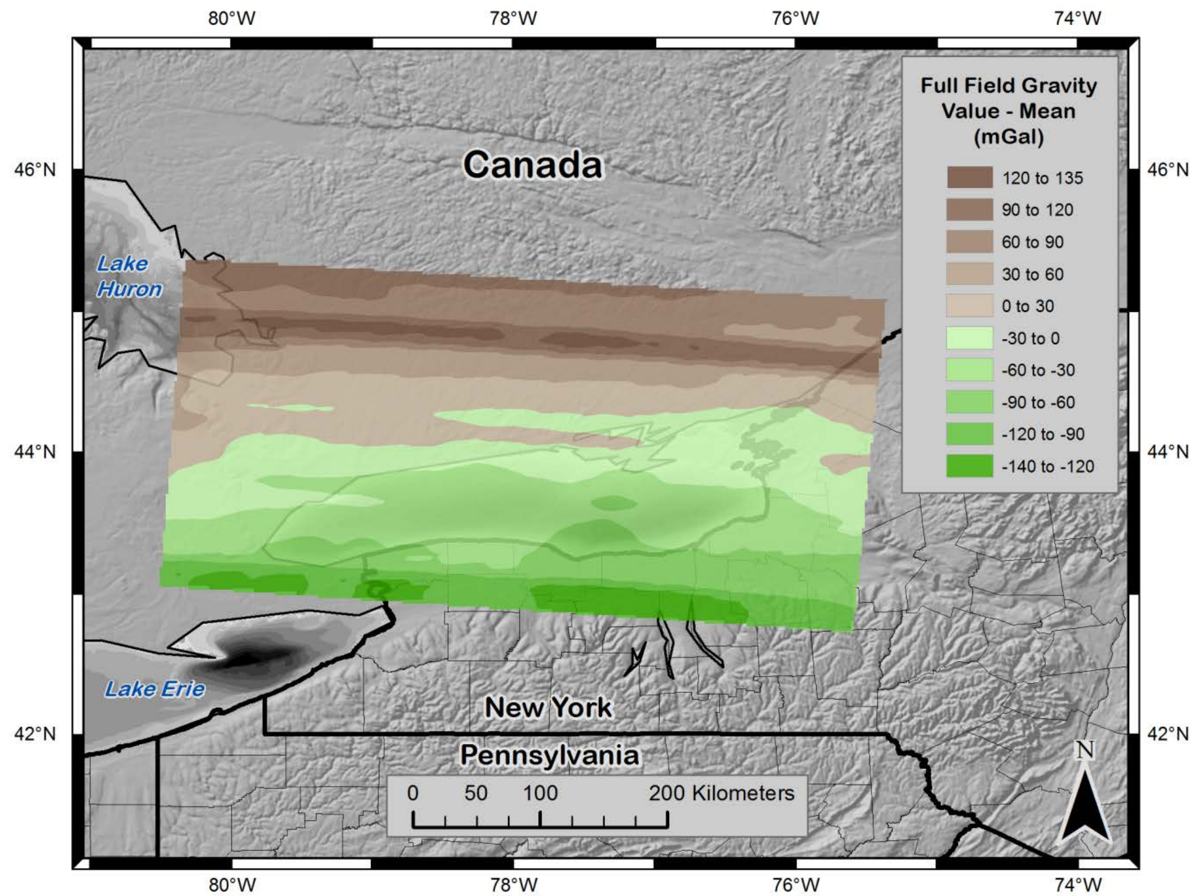


*Figure 4: Full-field gravity at altitude (mean removed) for Block EN01. This is the data in the gravity release ".txt" file and includes the effects of differing altitudes along flight lines.*

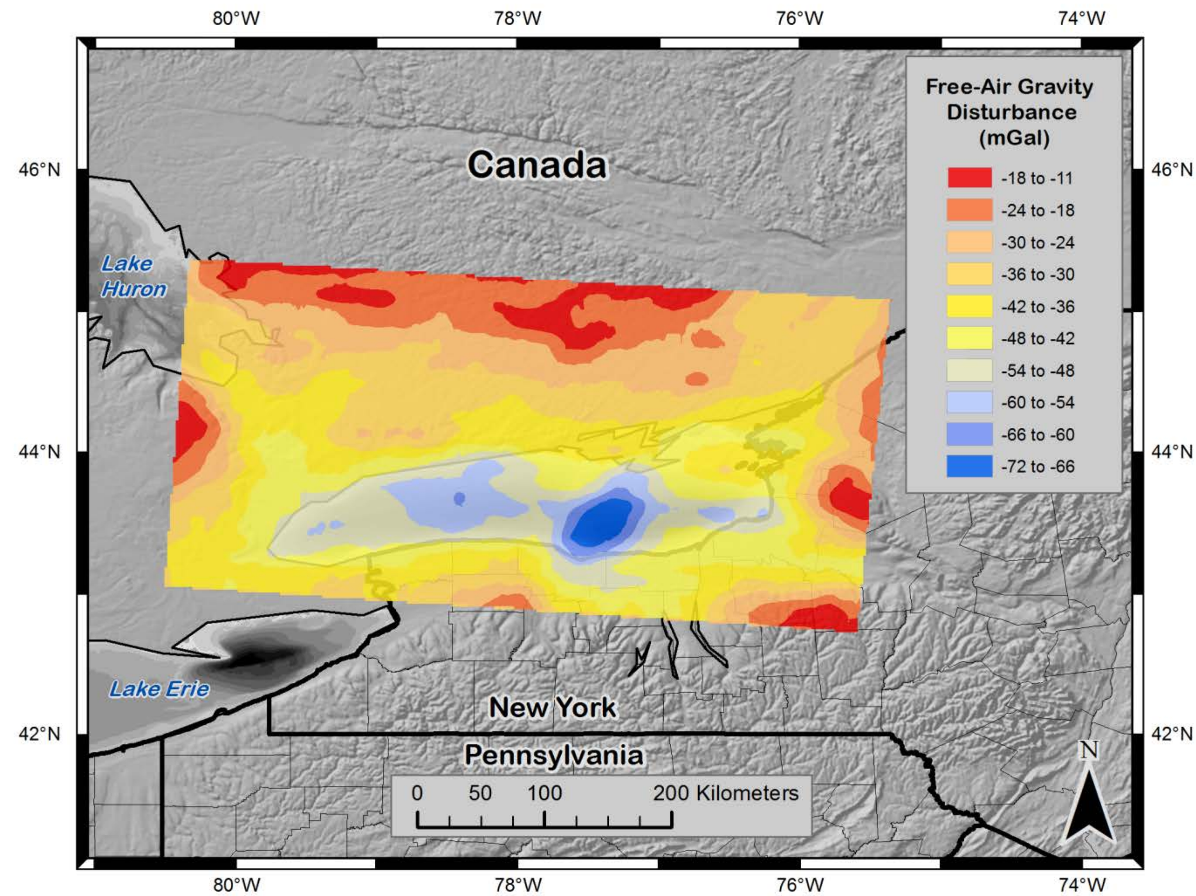


*Figure 5: Free-air gravity disturbance for Block EN01 with respect to the WGS-84 ellipsoid.*

# 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 EN01 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 EN01". Available *DATE*. Online at: http://www.ngs.noaa.gov/GRAV-D/data_EN01.shtml

To reference the block and survey details, reference the block user manual:
GRAV-D Science Team (2013). "Block EN01 (Eastern 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_EN01.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_EN01.shtml

# 5. References

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