Progress Update on the U.S. Gravity for the Redefinition of the American Vertical Datum (GRAV-D) Project and Lessons Learned for Geoid Modelling

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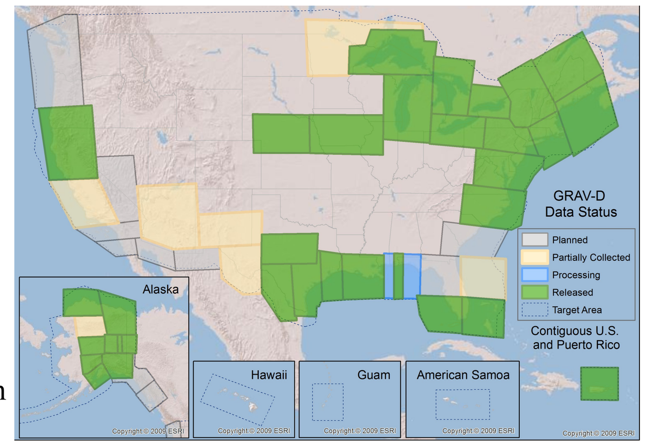
I. Abstract

The U.S. National Geodetic Survey is collecting airborne gravity with the Gravity for the Redefinition of the American Vertical Datum (GRAV-D) Project to produce a geoid supporting heights accurate to 2 centimeters where possible with a modernized U.S. vertical datum in 2022. This year GRAV-D will approach 50% of the country with airborne data collected to support the geoid, with over 75% of this data complete and publicly available. In this poster we provide an update on data collection status and present areas of known geoid improvement. We also discuss challenges faced when using airborne gravity to improve the geoid over a large, geographically diverse area with varying amounts of corroboratory data.

II. Background

The mission of NOAA's National Geodetic Survey is to define, maintain, and provide access to the National Spatial Reference System, which includes the official U.S. datums: the North American Datum of 1983 (NAD83), and the North American Vertical Datum of 1988 (NAVD88). In 2022 NGS will be replacing the official datums to address known systematic issues. The vertical datum will use newly collected airborne gravity data obtained through the GRAV-D project.



There are three parts to the GRAV-D project: 1) a complete snapshot of the U.S. and territories with airborne gravity to support a geoid accurate to 1 centimeter where possible, 2) a long term monitoring program, and 3) partnerships to collect gravity measurements.[1] An airborne platform was selected to provide medium wavelength information to complement existing gravity data sources and to easily bridge the littoral gap between marine and terrestrial gravity measurements. Data collection is about 42% complete.

III. Methods

To achieve a 1 centimeter geoid, the goal is to collect gravity data accurate to 1 mGal (1 Gal = 1 cm/s^2). A common method of evaluating gravity data accuracy is to compare to the Earth Gravitational Model of 2008 (EGM2008),[2] but this is the model that should be improved with the airborne data. A number of steps are taken to evaluate the data, identify areas where EGM2008 is not correct, and demonstrate the improvement when compared to independent sources. For example, gravity models from the Gravity field and steady-state Ocean Circulation Explorer (GOCE) mission provide for a useful first evaluation of the new airborne data.

Data Collection

Data are collected at 20,000 feet (6096 meters) at roughly 250 knots airspeed using a Micro-g LaCoste Turn-key Airborne Gravimetry System (TAGS) and a NovAtel SPAN IMU. An absolute gravity tie is measured at the parking location of the aircraft. Data lines are 10 kilometers apart and cross lines roughly 80 kilometers. Blocks are laid out based on the distance the aircraft can fly, geographical features, location of airports, and the target area of the project. A variety of government and private aircraft are used to fill a year round surveying schedule. Stable flying conditions are required, so aircraft with too much in-flight motion will not produce acceptable data. Prior to every survey, each aircraft and instrument configuration is tested to ensure that data quality meets specifications.

Data Processing and Quality Evaluation

For final processing a tightly coupled GPS+IMU solution is created using precise point positioning with Inertial Explorer (IE) 8.5 and incorporating a lever arm correction. Using the position solution, gravity is processed using NGS' Newton v1.2 software.[3] Data are released in blocks to allow for quality control through crossover analysis and adjacent line statistics.

Crossover error analysis is 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. To remove biases, each line is adjusted to make the median airborne gravity value match the median gravity value of EGM2008. The bias-corrected difference between the cross line and data line gravity values is the residual. The standard deviation and mean of the residuals is reported to identify where cross lines are the source of the error rather than the data lines. In addition, the quality of gravity data is evaluated by calculating the correlation between adjacent data lines. However, this 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.

Geoid Evaluation

For a first assessment as to where and to what degree the airborne gravity data are able to improve the geoid it is useful to compare (a) EGM2008 as a control against (b) EGM2008 updated with airborne gravity, in terms of their relative match to the latest GOCE gravity model. For these comparisons we have used the *Timewise Release 5* GOCE Model for the independent satellite verification. Model (b) is computed by adopting EGM2008 as a reference field and using the airborne gravimetry to 'update' the EGM2008 over the survey areas. For this test, the updated model (b) is permitted to closely reproduce the airborne gravimetry inside the survey area. Both models (a) and (b) are then truncated and tapered so as to retain spectral power in those low harmonic degrees where the GOCE gravity model is considered reliable.

Case Study 1: Lake Michigan[4]

Block:	EN03 (Eastern time zone, north of 40 degrees latitude)
Aircraft:	Pilatus PC-12, Gulfstream Jet Prop Commander 1000
Dates:	Three surveys, September 2011 and August 2013
Total Lines:	53 (47 data and 6 cross lines)

Crossover Analysis

Number of Crossovers:	241
RMS of residuals:	2.33 mGal
RMS error:	1.65 mGal

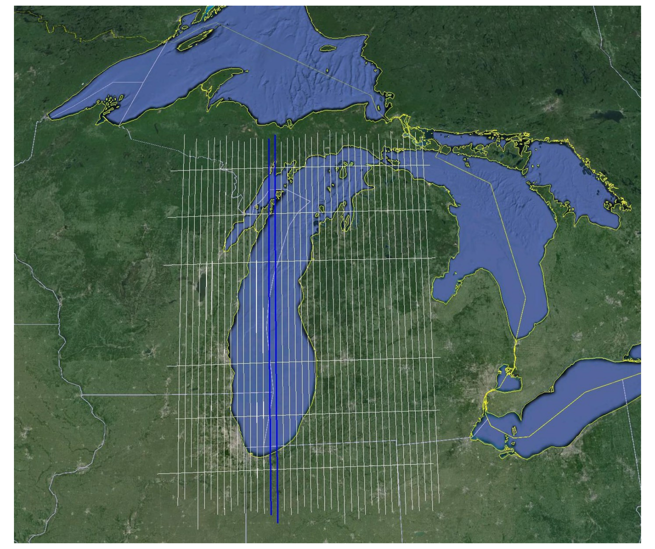


Figure 1: Flight lines for Block EN03 with lines 125 and 126 highlighted in blue

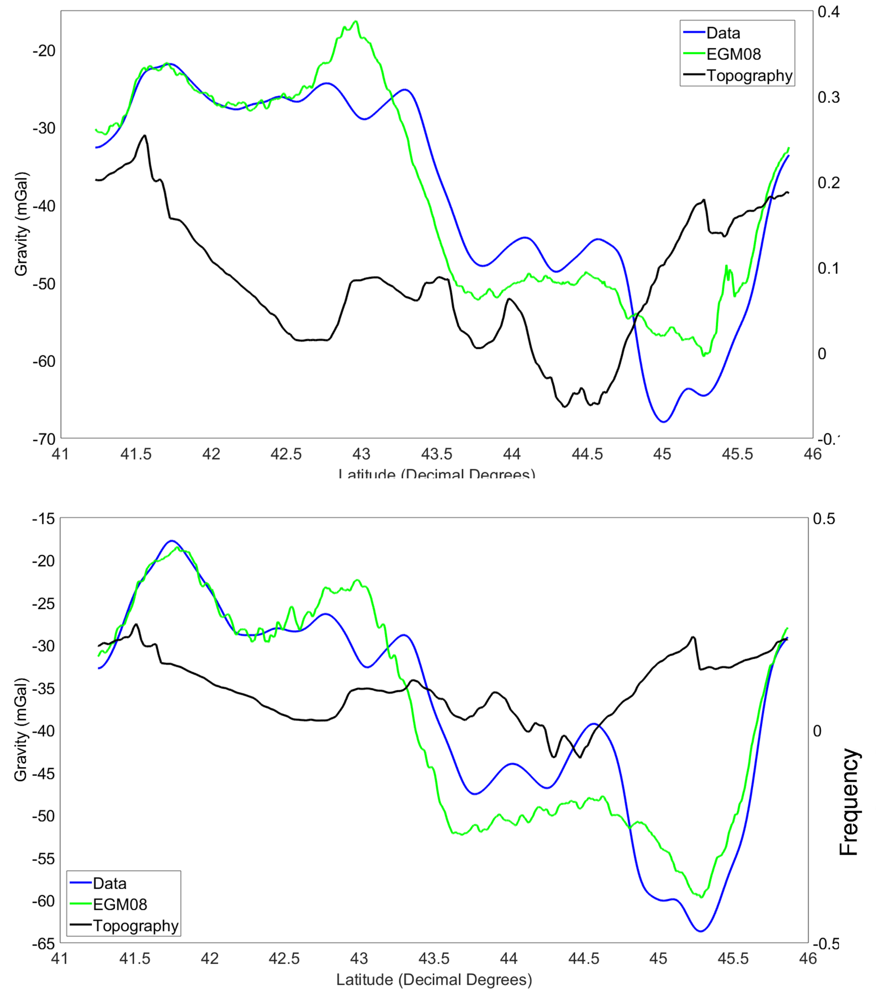


Figure 2: Free Air Disturbance Adjacent lines 125 (top) and 126 (bottom) in Block EN03 support differences with EGM2008

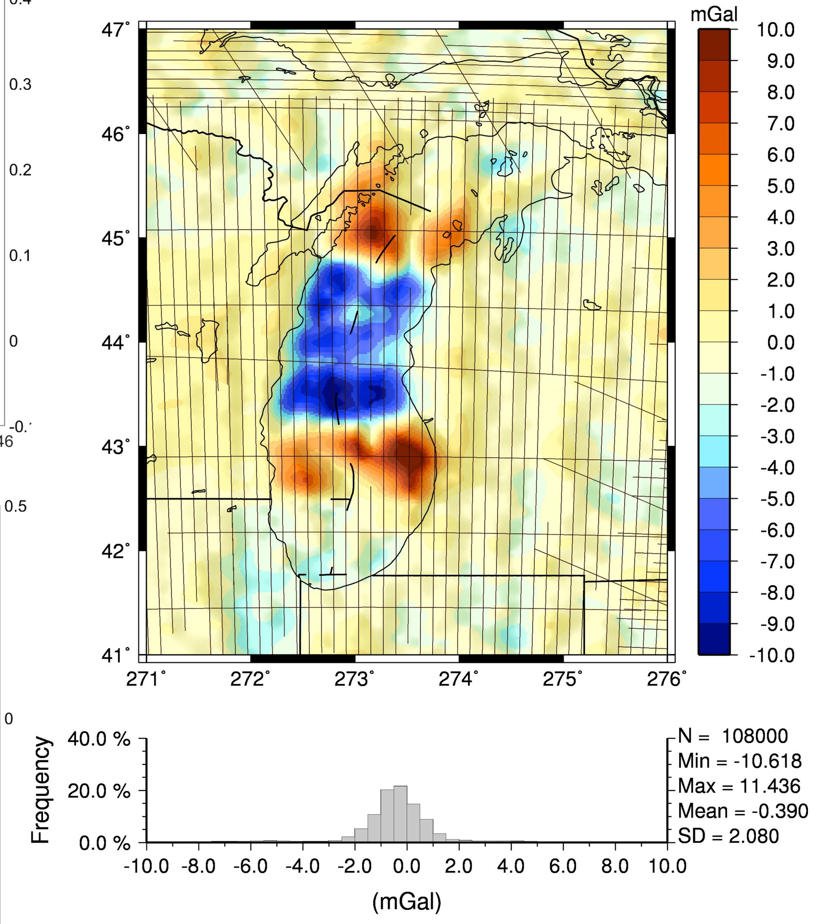


Figure 3: Interpolated airborne gravity data for Lake Michigan, residuals with respect to EGM2008.

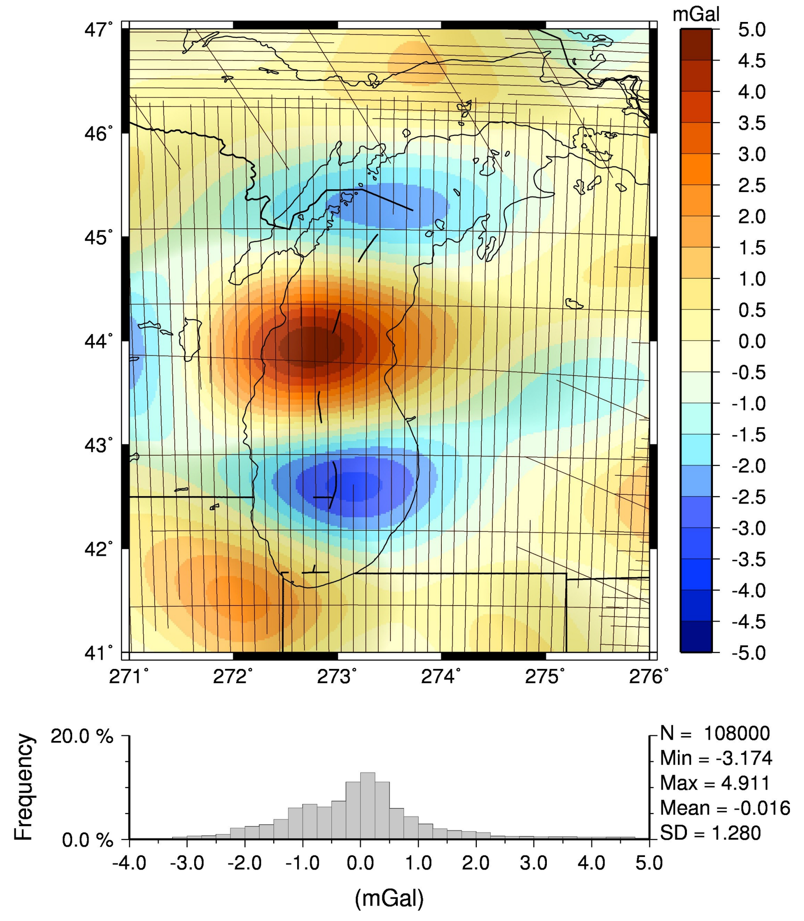


Figure 4: EGM2008 compared to GOCE (TIM5) for Lake Michigan

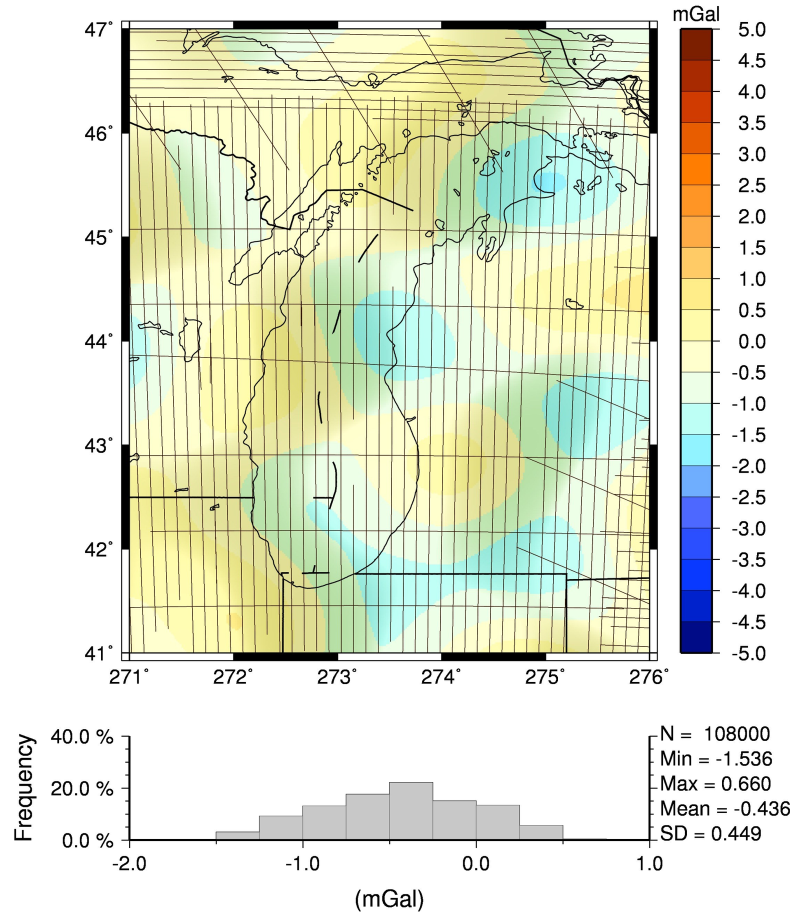


Figure 5: EGM2008 plus airborne gravity data compared to GOCE (TIM5) for Lake Michigan

Case Study 2: Alaska[5]

Blocks:	AS01, AS02, AS03, AN01, AN02, AN03, AN04, AN05, AN06 (Alaska time zone, north/south of 63 degrees latitude)
Aircraft:	Pilatus PC-12, Gulfstream Jet Prop Commander 1000, King Air , Orion P-3
Dates:	Six surveys, July 2008 and May 2011
Total Lines:	395

Crossover Analysis

Number of Crossovers:	1830
RMS of residuals:	0.93 - 3.90 mGal
RMS error:	0.68 - 2.76 mGal

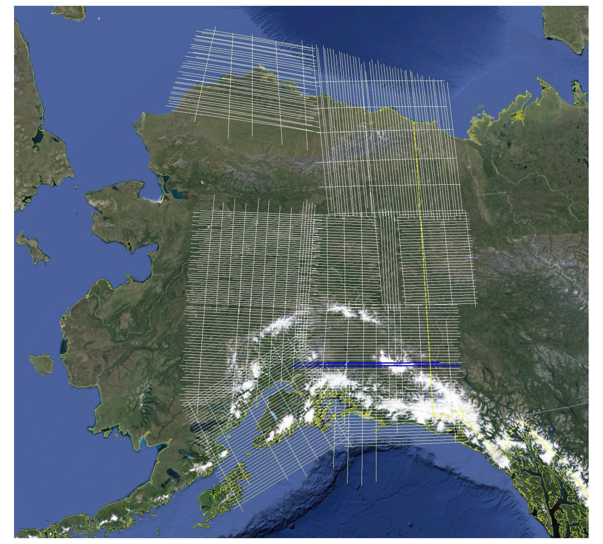
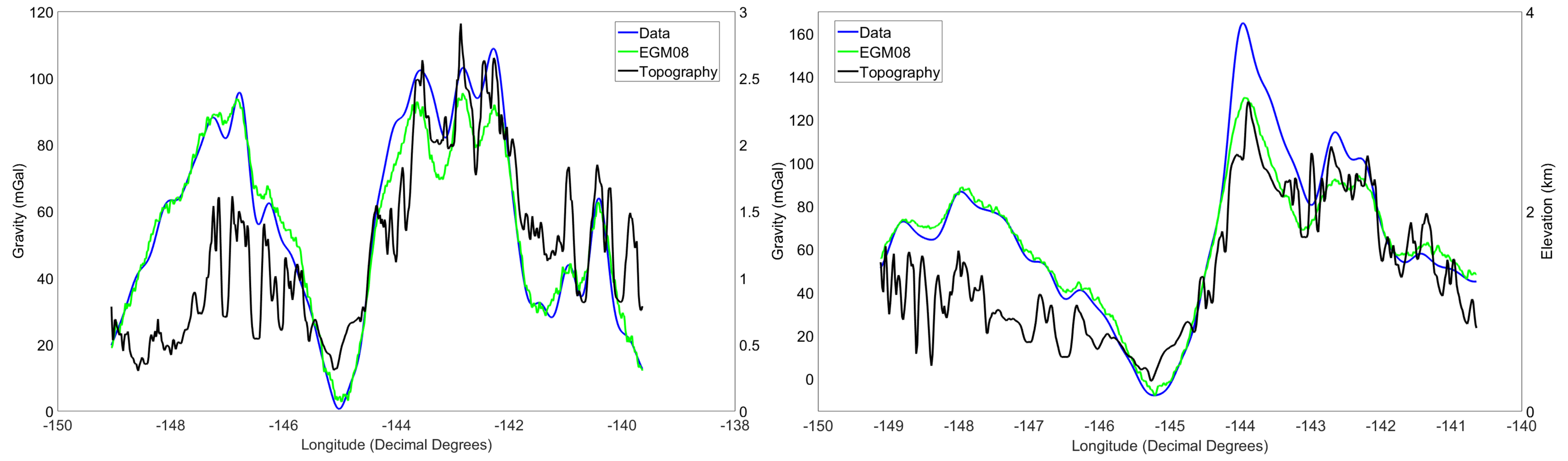


Figure 6 (left): Flight lines for completed Alaska blocks with lines 140 and 141 highlighted in blue

Figure 7 (right): Adjacent lines 140 and 141 in Block AS03 support differences with EGM2008



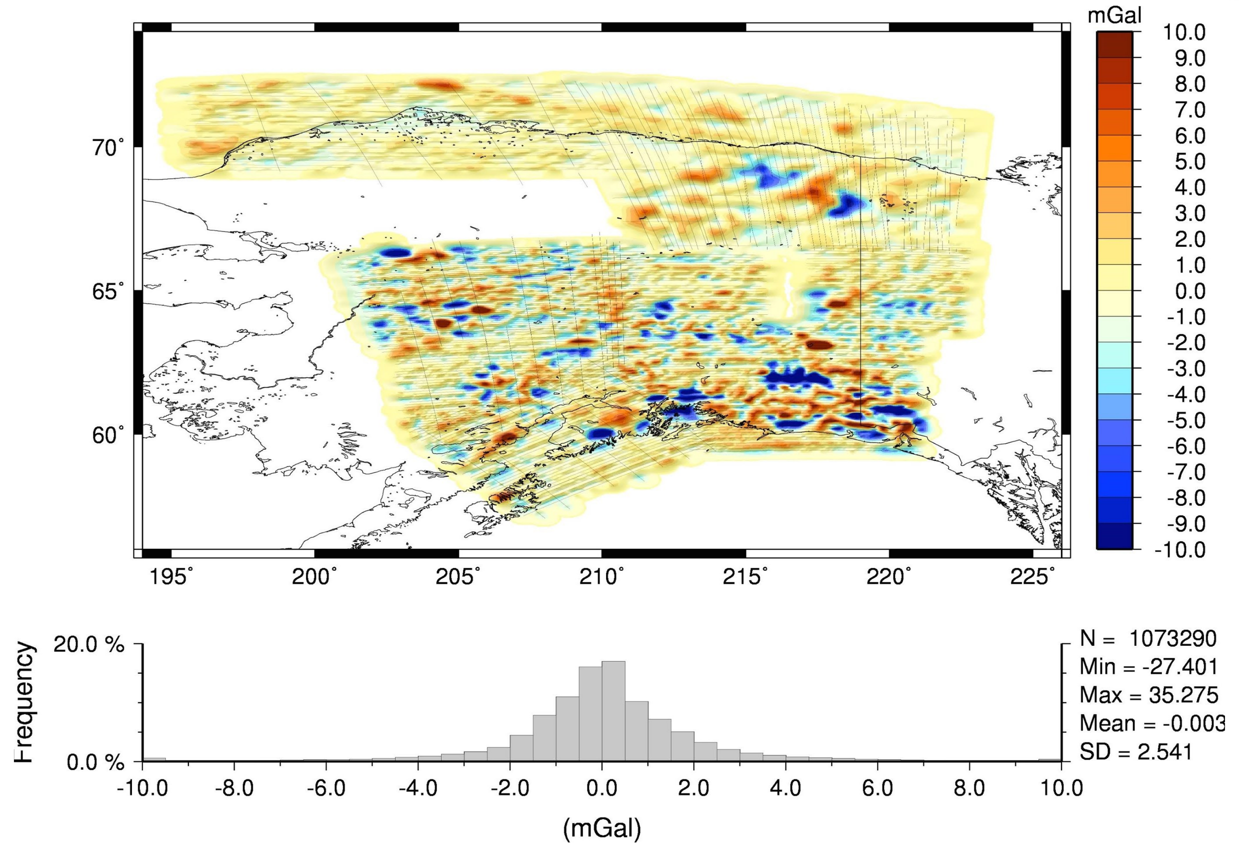


Figure 8: Interpolated airborne gravity data for Alaska

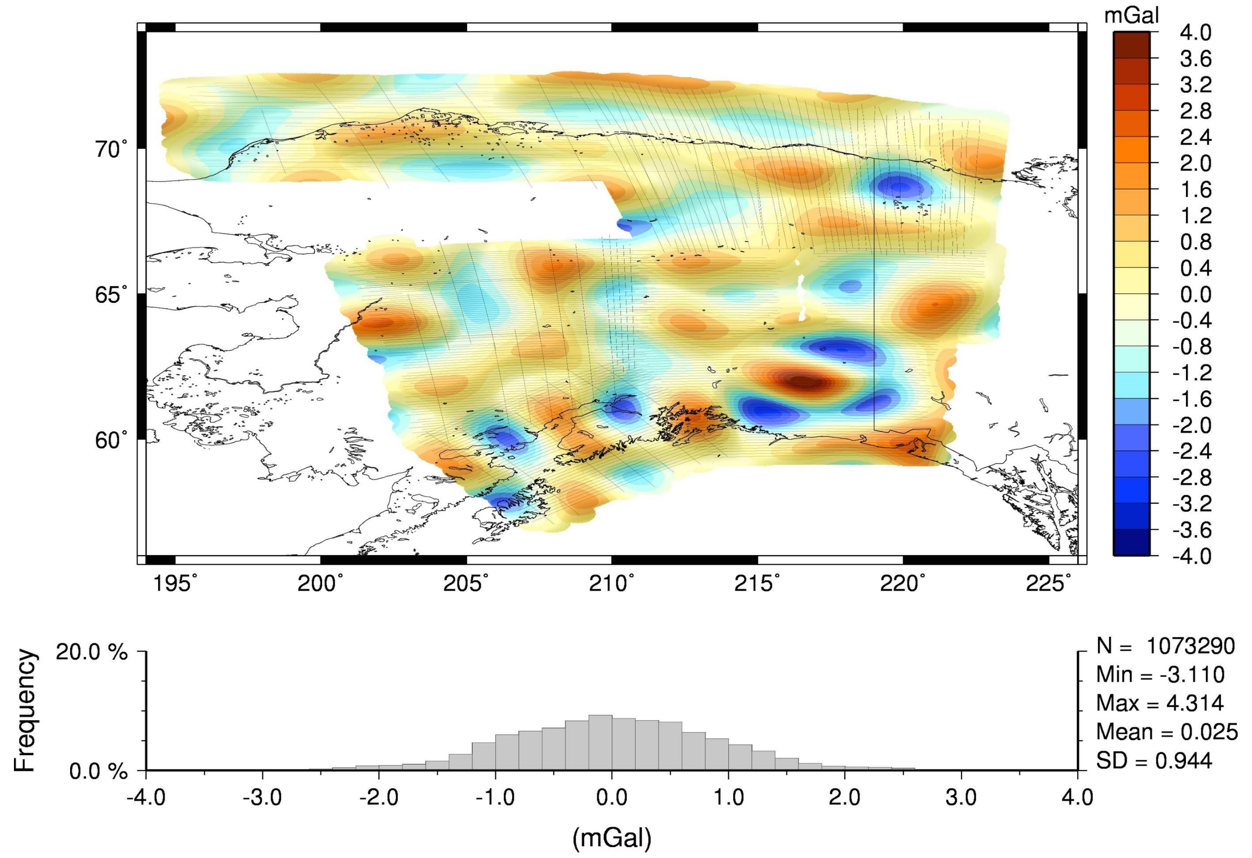


Figure 9: EGM2008 compared to GOCE (TIM5) for Alaska

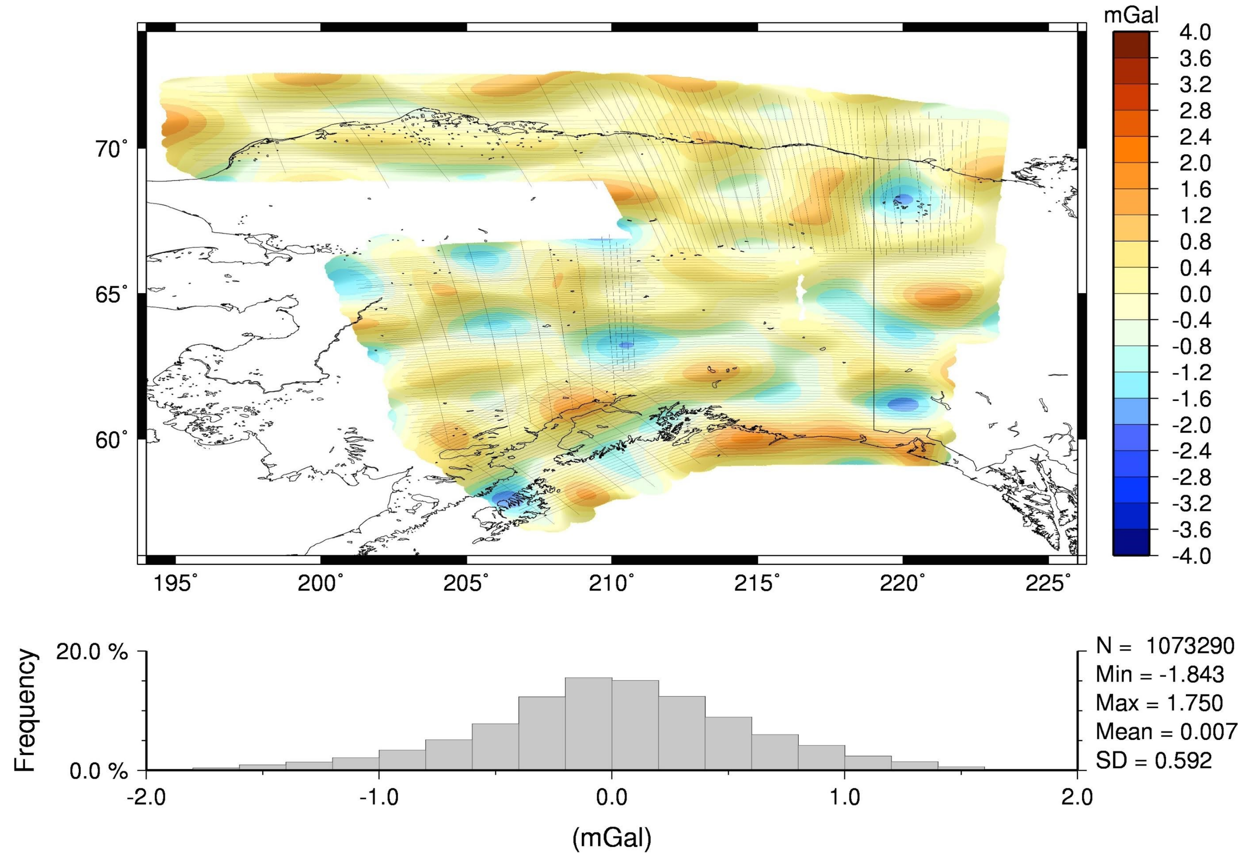


Figure 10: EGM2008 plus airborne gravity data compared to GOCE (TIM5) for Alaska

IV. General Results

The quality of EGM2008 varies geographically as a function of the input data that was available at the time of production. Presented are two example areas, Alaska and Lake Michigan, where the airborne gravity data exhibits very large discrepancies with respect to EGM2008. In both regions, we observe that updating EGM2008 with the airborne data provides for a significantly improved match to the GOCE satellite model. This is despite the fact that EGM2008 is supported globally by the ITG03-Grace model in the low degrees (n=2 to n=120/140).

V. Conclusions

The airborne gravity data has been demonstrated to improve the agreement of EGM2008 with the GOCE data in numerous places. When analyzed in conjunction with the location of CONUS gravimetry stations (not shown here), the airborne data are shown to be particularly useful in areas where surface gravity data are sparse or where there may be errors in the data supporting EGM2008, particularly in areas of Alaska and Lake Michigan. Not surprisingly, the areas where the airborne data differs significantly from the CONUS terrestrial gravimetry are where the airborne data can provide reliable and immediate improvement in our gravity model. For other areas, the airborne gravity will need to be carefully cleaned, filtered and spectrally weighted to support an improved gravity model. These results are consistent by the initial Geoid Slope Validation Survey of 2011 (GSVS11)[6] that concluded the airborne data will support a 1 centimeter geoid and is expected to be validated with the recently completed GSVS 2014 survey and upcoming GSVS 2016 survey.

Conducting an airborne gravity survey for the United States is a unique case compared to similar efforts of other countries because of the large area to be covered compared to the and it presents a number of challenges for collection and geoid modeling. First, the large area to be covered was an important consideration when determining the flight height and line spacing for the project. These parameters needed to be defined in such a way that the project could be accomplished within a set annual budget and by 2022. Second, while a 14 year timeframe is a snapshot in geological terms, it means that technology and processing techniques change and improve during data collection. This means the GRAV-D team is continuously evaluating and incorporating changes when possible, but it is a challenge to prove that newer data is comparable with the older data and a significant amount of work to re-process all older data when a new technique is adopted.

As data are collected an experimental geoid model is released each year[7] and there have been a number of lessons learned for geoid modeling. First, each block is very unique and often has a bias compared to neighboring blocks. This needs to be resolved before incorporating into a geoid model. Second, because of the diverse geography and data characteristics in each block different methods may be more effective at incorporating the airborne gravity data in different areas. Finally, the airborne data is sometimes able to be used out to a higher harmonic degree than anticipated depending on the area, so this needs to be examined more closely in order to get the most information possible.

VI. References

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[2]National Geospatial-Intelligence Agency – NGA (2008). *Earth Gravitational Model 2008 (EGM2008)*. Available 4 May 2015. http://earth-info.nga.mil/GandG/wgs84/gravitymod/egm2008/index.html.

[3]GRAV-D Team, National Geodetic Survey. *GRAV-D General Airborne Gravity Data User Manual*. Dr. Theresa M. Damiani and Monica A. Youngman, ed. Version 2. 2013. Available 4 May 2015. http://www.ngs.noaa.gov/GRAV-D/data_products.shtml

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[5]GRAV-D Team, National Geodetic Survey. *Gravity for the Redefinition of the American Vertical Datum (GRAV-D) Project, Airborne Gravity Data; Blocks AS01, AS02, AS03, AN01, AN02, AN03, AN04, AN05, AN06*. 2013-2015. Available 4 May 2015. http://www.ngs.noaa.gov/GRAV-D/data_products.shtml

[6]Smith, D., Holmes, S., Li, X., Guillaume, S., Wang, Y., Burki, B., Roman, D.. "Confirming Regional 1 cm Differential Geoid Accuracy from Airborne Gravimetry: The Geoid Slope F Validation Survey of 2011." *Journal of Geodesy*, Nov. 2013: Volume 87, Issue 10-12, pp 885-907.

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