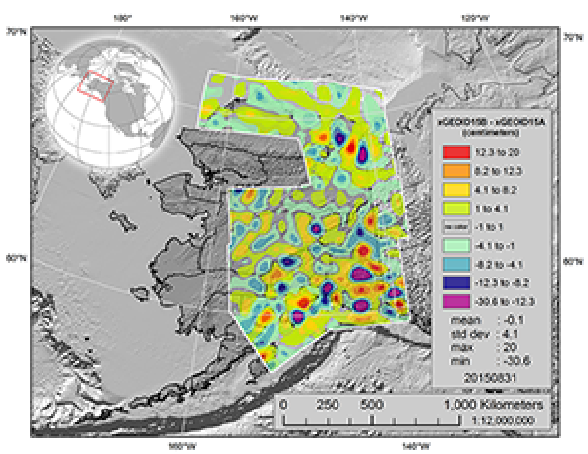
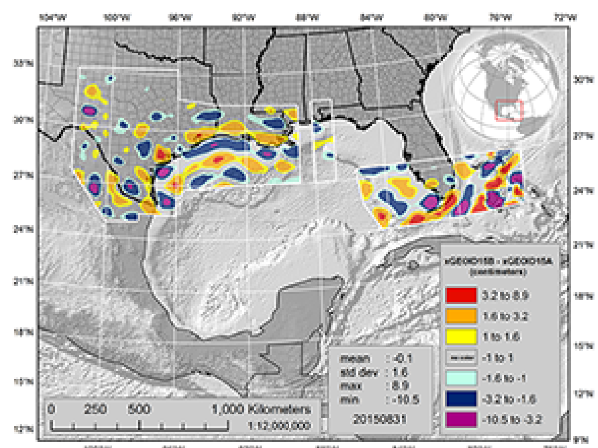
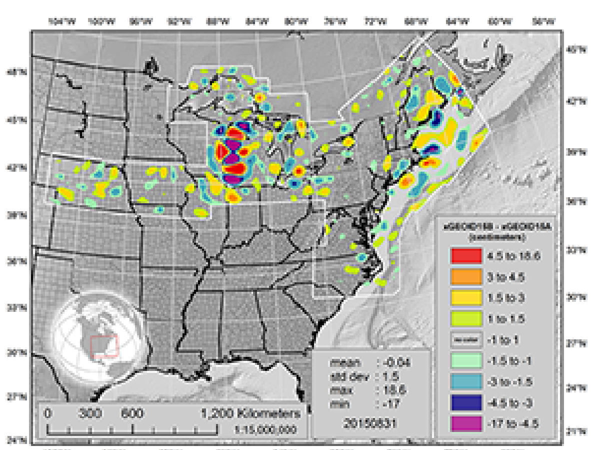
xGEOID15 Supplemental Information - Technical Details for xGEOID15 Models

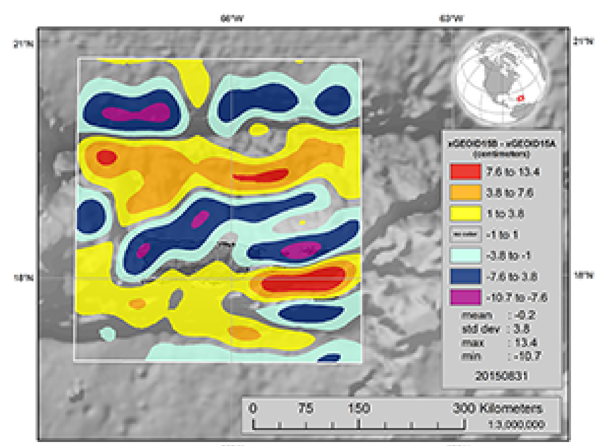
GRAV-D Airborne Gravity Contribution

The xGEOID15A and xGEOID15B models are identical except that xGEOID15B includes the available GRAV-D airborne gravity data. So, the difference between the two models shows the important contribution of the airborne gravity data to the accuracy of our geoid models. Since the differences are only in areas where the GRAV-D airborne gravity data have been used, examining the regional plots given below will illustrate the varying levels of improvement in, due to GRAV-D, seen indifferent parts of the country.









Panels (clockwise, double click to zoom in) show the contribution of GRAV-D airborne gravity in Alaska, Gulf of Mexico region, states in the Northeast and Puerto Rico/Virgin Islands. The contribution of airborne gravity can reach decimeters in areas where there is no terrestrial gravity data or terrestrial data of low quality, such as in Alaska and Lake Michigan. In areas with good gravity coverage and quality, the addition of the GRAV-D airborne gravity data causes changes that are at the centimeters level.

Creation of xGEOID15A

The gravity data sets and gravity spherical harmonic coefficients models used to create xGEOID15A are as follows:

- GOCO05S satellite gravity model (Mayer-Gürr et al. 2015)
- EGM2008 (Pavlis et al. 2012)
- NGS Terrestrial gravity data
- 3" digital elevation model (Li et al. 2008)

The reference (global spherical harmonic) gravitational model for xGEOID15A was computed by augmenting EGM2008 with the GOCO05S satellite gravity model, which includes the last 14-month low orbital GOCE data. This year's experimental procedure combined EGM2008 and GOCO05S in the space domain, unlike last year's combination of model coefficients in the frequency domain. This experimental procedure operated on global 5’x5’ grids of gravity disturbances that had been generated from each of the two models. For this approach, application of non-stationary, local error models to these two 5’x5’ grids of disturbances allowed them to be combined into one, composite 5’x5’ grid. Harmonic analysis of this composite grid yielded a combination spherical harmonic gravitational model (Nmax=2190). Low-degree (n < 50) distortions in this combination model were then corrected with GOCO05S, yielding the final reference model for xGEOID15A. This final model was designated 'REF15A'. Additionally, a 1’x1’ reference gravitational geoid was computed from the REF15A model, using the same procedure to that was used for the EGM2008 gravimetric geoid.

The REF15A reference model was then combined with the NGS terrestrial data, in a classic remove-restore approach (Wang et al. 2012). In this particular case, the REF15A gravity anomalies were subtracted from the NGS terrestrial gravity anomaly station values, yielding residual gravity anomalies, where the high frequency terrain effects that are beyond the REF15A resolution were also removed by the Residual Terrain Model (RTM, Forsberg 1984). Data used for the RTM computation are the combined digital elevation (Li et al. 2008) from Shuttle Radar Topography Mission (SRTM, Farr et al. 2007) and the digital elevation version 2 of Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER, Tachikawa et al. 2011). These residual gravity anomalies were then gridded onto a 1’x1’ grid, and then simultaneously filtered and converted to residual geoid heights using a spherically-banded (n > 280) Stokes kernel applied in the space domain. Both the REF15A reference field and the RTM effects were then restored to the residual geoid heights. The result was xGEOID15A.

Creation of xGEOID15B

The xGEOID15B model was created in a nearly identical way as xGEOID15A, except for the inclusion of the NGS GRAV-D airborne gravimetry. Thus xGeoid15B was comprised of:

- GOCO05S satellite gravity model
- EGM2008

- NGS Terrestrial gravimetry
- 3" digital elevation model
- GRAV-D airborne gravity data

The general approach for xGEOID15B was the same as for xUSGG2011 (Smith et al. 2013): to use the airborne data to update/augment the reference (global spherical harmonic) gravitational model, and then proceed with an identical computational method as used in creating the "A" model. The method for including the airborne data into the reference model was described in the following for area 1, 2 and Alaska. Note: Bolded GRAV-D block names below indicate those additional blocks that were not included into xGeoid14B.

- 'Area 1' included surveys in:
    - the Great Lakes (EN01, EN02, EN03, EN04 and EN05),
    - the East Coast (EN06, EN07, EN08, EN09, EN10, ES03, ES04),
    - the South East (ES01, ES02),
    - the Midwest (CN02, CN03),
    - and California (PN01).
- 'Area 2' included surveys in:
    - the Gulf of Mexico (CS01, CS02, CS03, CS04, **CS05, CS06**),
    - and Puerto Rico and the Virgin Islands (TS01).
- Alaska (AS01, **AS02, AS03, AS04, AN01, AN02, AN03, AN04**, AN05, AN06) were handled slightly differently from Area 1.

Area 1 Processing

The seventeen airborne surveys in 'Area 1' were processed according to the following method, newly derived for 2015. First, adjoining or overlapping surveys were processed together as a single survey. Then, EGM2008 reference gravity values were subtracted from all the published airborne survey values, yielding residual gravity disturbances. Residuals were crossover adjusted, solving for line biases only (not tilts). For overlapping surveys, this was performed as a single adjustment, allowing survey lines from many of the surveys to contribute to the adjustment of adjacent and overlapping surveys. In this way, all surveys from the Great Lakes and the East Coast were adjusted together. Likewise, the two Southeast surveys were adjusted together, as were the two Midwest surveys. A rudimentary error model was applied to all adjustments, for which the standard deviation applied to each crossover value was computed from the unadjusted crossover value. For each survey, crossover adjusted residuals were compared against unadjusted residuals in terms of inter-line variability, and the most variable version was discarded. The remaining residuals were cleaned by:

- removing extreme outliers, and
- removing residuals corresponding to large prediction errors from gridding.

For the latter approach, the residuals were gridded by least-squares collocation. A simple data error model was applied within the collocation procedure, which set the error variance of each 'scattered' residual point equal to the signal variance computed for residuals local (within 30') to that point. Input 'scattered' residuals that differ by more than some arbitrary threshold from the gridded values are discarded. This threshold was determined empirically for each survey.

Cleaned residuals for each of the seventeen airborne surveys were aggregated together. These composite residuals were then interpolated to a 1'x1' equiangular grid, and captured in a spherical harmonic model (Nmax = 2190), very much according to Smith et al. (2013). The resulting spherical harmonic model of the residuals was then arithmetically added to EGM2008, yielding a final spherical harmonic model (Nmax = 2190) that reproduced EGM2008 gravity disturbances away from the airborne survey areas, and reproduced a 'cleaned' counterpart for the airborne data inside the survey areas. This airborne-supported model was then compared to EGM2008 in terms of relative match to NGS GPS on Leveled Bench Marks data (GPSL). Local error covariances for each of the two models were approximated for overlapping 2-degree regions, based on their relative match to the GPSL. These local error models were used to spatially combine the airborne-supported model and EGM2008 into a single, filtered model (Nmax = 2190). This "filtered' model was designated 'AREA1'.

Area 2 Processing

The seven airborne surveys in 'Area 2' were processed by using a modified procedure that was applied for xUSGG2011. This procedure was very similar to process the surveys in 'Area 1'. The major differences were:

- No cross-over adjustment was applied to the Area 2 residual gravity disturbances.
- Residual disturbances were cleaned by removing outliers and by inspection. Least squares collocation was not used in the cleaning process.
- For the Gulf surveys only, the residuals were processed in the same way as for AREA1. The resulting 'filtered' model was designated 'GULF1'.
- For the Puerto Rico and the Virgin Islands survey, the 'filtered' combination of the airborne-supported model and EGM2008 was performed at the coefficient level, and not in the space domain. This is much closer to the combination procedure described in Smith et al., (2013), in which a degree-wise transfer function is used to combine the two models. Unlike Smith et al., (2013), this transfer function was tuned against local GPSL in the survey area. This 'filtered' model was designated 'PRVI1'.

Alaska Processing

For the ten Alaskan GRAV-D surveys, these were processed and combined with EGM2008 into a filtered harmonic model, using procedures that were almost identical to that used to generate the 'AREA1' model described above. All the Alaskan surveys were processed together as a single block. This included the cross-over adjustment, data cleaning and harmonic capture into a spherical harmonic model. However, unlike the 'AREA1' model, the 'filtered' combination of the airborne-supported Alaska model and EGM2008 was performed at the coefficient level, using the same procedure employed for the computation of 'PRVI1'. However, unlike 'PRVI1', the transfer function for combining the airborne-supported model with the EGM2008 reference model was not tuned against local GPS/L in the survey area. Instead, a general transfer function was selected, based on a priori knowledge of airborne survey error. This aligns much more closely to the procedure described in Smith et al. (2013). The filtered harmonic model for Alaska was designed 'AK1'.

Combining Into a Composite Model

The procedures described above yielded four filtered models, each incorporating airborne gravimetry surveys from separate, non-overlapping areas. The models were: AREA1, GULF1, PRVI1, and AK1. Note that, a new satellite gravity model GOCO05S was used for xGEOID15B.

At this stage, the models were combined together to yield a single, filtered model that incorporated all of the airborne information from each of the four contributing models plus EGM2008. This was done by using each model to generate a 2’x2’ equiangular grid of gravity disturbances on the WGS84 ellipsoid, and then seamlessly combining these gridded gravity disturbances to yield a global, composite 2’x2’ gravity disturbance grid. This composite grid was constructed so as to reproduce the gravity disturbances directly affected by the airborne survey data for each of the four input grids. When sufficiently far away from the survey areas, the grid reproduced the EGM2008 gravity disturbances. Harmonic analysis of this composite grid yielded a composite, filtered harmonic model.

This composite model was then combined with GOCO05S, using the same procedure as that were used to combine EGM2008 and GOCO05S to yield the REF15A reference model supporting xGEOID15A. This final model, designated REF15B, served as the reference (global spherical harmonic) gravitational model for xGEOID15B.

In the final step of creating the xGEOID15B, the same procedure described above (in computing the xGEOID15A) was used to combine the REF15B reference model with the NGS terrestrial data. The resulting geoid model was xGEOID15B.

References

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