Recent Activities at the National Geodetic Survey

GRAV-D

The Gravity for the Redefinition of the American Vertical Datum (or GRAV-D) project got off the ground, literally, in 2007 when NGS’s first airborne gravity flights took place. Today the GRAV-D airplanes continue to fly! With a second airborne gravimeter acquired in December 2011, NGS has been able to continue to meet, and slowly exceed, its stated completion goals every year. As of August 31, 2014 the GRAV-D project is over 38% complete toward fully covering the country with consistent, accurate airborne gravity. Data products are continually released as they are collected and are available here: www.ngs.noaa.gov/GRAV-D/data_products.shtml

One of the major lessons learned with the GRAV-D Project has been that limiting aircraft motion by using aircraft with an up-to-date autopilot and stable frame is critical to acquiring high quality gravity data, but it is sometimes difficult to predict which aircraft will perform well. Each aircraft has a unique personality in the air and certain motion, even if not felt by the passengers, translates into large errors in the gravity data. While the project does not have a dedicated aircraft, NGS has partnered with a variety of government and private entities to maintain a fleet of aircraft that have been proven to collect quality gravity data, which allows GRAV-D to survey almost year round. Aircraft that have been used include the U.S. Department of Interior Bureau of Land Management Pilatus, U.S. Navy King Air, NOAA Cessna Citation, NOAA P-3, NOAA Turbo Commander, Fugro King Air, Fugro Cessna Conquest, and Dynamic Aviation King Air.

DR. DRU SMITH, DR. DANIEL R. ROMAN AND MONICA YOUNGMAN
Even the best aircraft will have some motion and will encounter less than optimal flying conditions and GRAV-D flights are done in a challenging high-altitude, high-speed configuration. To address these realities and deliver the precision and accuracy required to support gravimetric geoid modeling, NGS continues to research better ways to measure aircraft motion, determine aircraft position, and remove the effects of aircraft motion. Recent aircraft positioning research has focused on using an inertial measurement unit (IMU) to determine the orientation of the aircraft when it moves and to adjust the traditional GPS positions. For gravity processing, research ongoing since 2008 has improved commonly-used airborne processing techniques and been included into “Newton”, NGS’s internally developed gravity processing software.

In the future, the GRAV-D project is also looking for ways to increase efficiencies and accuracy through upgraded meters or alternative platforms. Newer gravimeters are designed to tolerate more aircraft movement and may allow the project to use less stable aircraft or fly in less optimal weather conditions. For alternative platforms possible launch of GRACE Follow-On (GFO) slated for 2017, plans must be in place to ensure continuity in the longest wavelengths of the gravity field. Additionally, this monitoring will provide the basis for models of the gravity field change that will affect the placement of the new geopotential datum over time. The so-called “N-dot” represents the temporal change in the geoid (N) and must be accounted for if cm-level orthometric heights are to continue to be obtainable from GNSS observations on a dynamic Earth over the coming decades.

**GEOID models**

On June 30, 2014, NGS issued two experimental gravimetric geoid models—xGEOID14A and xGEOID14B. The primary difference between the two is that xGEOID14B is NGS’s first publicly released geoid model containing airborne gravity from GRAV-D. Astute readers may notice that the name of these gravimetric geoid models more closely resembles the names of hybrid geoid models that NGS has issued in the past (GEOID09, GEOID12A), and doesn’t seem to follow the naming conventions of previous gravimetric models (USGG2009, USGG2012). This was intentional! Here’s why: The hybrid geoid model transforms between two official datums of the NSRS (NAD 83 and NAVD 88). But in 2022, when NAVD 88 is replaced with a geoid-based vertical datum and NAD 83 is replaced with a geocentric reference frame, the gravimetric geoid model created at that time will be the zero height surface of the new datum, and the need for a “hybrid” geoid will go away. That is, in 2022 the gravimetric geoid model will be the geoid which connects the two official datums.

NGS plans to release an “xGEOID” model every year from this point forward until the final replacement of NAVD 88 is available. At that time, the “x” discriminator will be removed and the final gravimetric geoid model used in the new vertical datum will have a name simply beginning with “GEOID.”

NGS is investigating putting a gravimeter on an Unmanned Aerial Vehicle (UAV). Working on a UAV would allow the project to efficiently collect data in difficult areas, such as Western Alaska and the Aleutian Islands, where there are minimal resources to support manned missions. There are a number of hurdles to overcome, such as engineering the meter into a small space as well as remotely controlling or automating the gravimeter, but research is currently being conducted to make this a reality.

In addition to aerogravity collection efforts, plans for long term gravity field monitoring are starting to coalesce. With the potential loss of the GRACE gravity mission in the next few years and the earliest
While the current variety of hybrid geoid models (such as GEOID12A) will no longer be produced after 2022, a datum conversion surface will be continued so that users may transform orthometric heights in the new vertical datum (or “geopotential reference frame” as it is being called more often), to orthometric heights in NAVD 88.

**Geoid Slope Validation Surveys**
The target differential accuracy for the geoid model which will be used in the vertical datum that replaces NAVD 88 is one centimeter over any distance. In order to determine how well that target is being met, NGS will complete three significant surveys intended to quantify geoid accuracy over increasingly complicated regions (“low and flat”, “high and flat” and “high and rugged”). These surveys are each called a “geoid slope validation survey” or GSVS.

The first of these surveys (GSVS11) took place in the summer and early fall of 2011. A line of 218 geodetic control marks were installed running mostly north/south from Austin to Rockport, Texas. Ellipsoid heights, orthometric heights, deflections of the vertical (DoV) and accelerations of gravity were all determined at each point using GPS, leveling, the DIADEM (Digital Astronomical

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**Leveling crews hard at work in Iowa during the geoid slope validation survey of 2014.**
Deflection Measuring System) camera of ETH Zurich and a mix of absolute and relative gravimetry, respectively. Additional data collected included a 1 meter resolution LIDAR DEM and digital imagery along the line. The slope of the geoid was determined from the GPS and leveling, as well as from the DoVs. Error budgets for each measurement source were carefully determined. These independent measures of the geoid slope were then compared to various gravimetric geoid models, both with and without airborne gravity from the GRAV-D project. The results were irrefutably positive: With (and only with) the addition of GRAV-D airborne gravity, NGS was able to model the geoid at a differential accuracy of one centimeter over all distances from 0 to 300 km. Full results were published in Journal of Geodesy.

Building on the success of GSVS11, the second survey (“high and flat”) took place in the summer of 2014 (GSVS14) on an east-west line running from Denison to Kirkwood, Iowa. One of the many reasons this line was chosen was that the topography was flat yet there is a significant gravimetric signature intersecting the line due to the mid-continent rift zone. Similar surveys were done as in Texas. Initial results were announced at the December AGU meeting in San Francisco.

The third (“high and rugged”) survey has not yet been planned. It will likely take place sometime in the 2016–2018 range, and most likely somewhere in or around the Rocky Mountains. In order to properly constrain error budgets for this survey, significant new research and/or literature searches will need to be conducted to account for 2nd and 3rd order effects (e.g. the effect of rugged topography on geodetic leveling). NGS must make sure its software properly accounts for these effects.

Dr. Dru Smith has been the Chief Geodesist at NGS since 2005, and most recently led the development of the NGS Ten Year Strategic Plan. During his years at NGS, he has been involved in geoid modeling, ionosphere research and most recently in updating the datum transformation software GEOCON.

Daniel R. Roman earned his Ph.D from the Ohio State University in 1999 after which he started working for NGS. He has served for more than a decade in geoid modeling and is now the Chief, Spatial Reference Systems Division.

Monica Youngman is the acting project manager for the National Geodetic Survey’s Gravity for the Redefinition of the American Vertical Datum (GRAV-D) project. Monica received a Masters degree from Duke University in Environmental Management as well as Bachelor of Science in physics and a Bachelor of Arts in political science from Iowa State University.