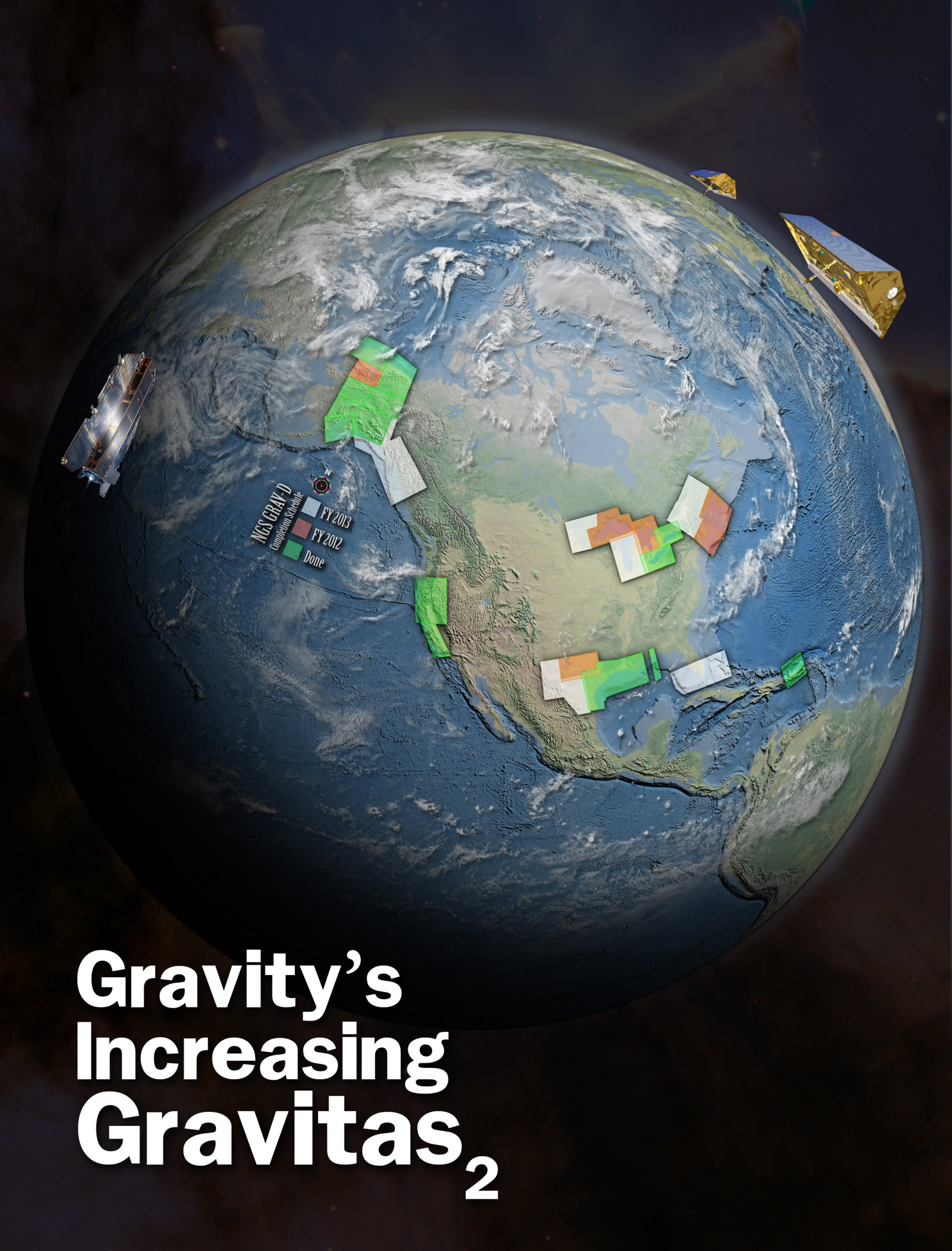


Gravity's Increasing Gravitas$_2$

Gravity's Increasing Gravitas

The importance of gravity in land surveying (Part 2 of 2)

Written and Illustrated by V. Kelly Bellis, PLS

HEY! You out there – HEADS UP!! NAVD88 will be DOA22 ... *before you know it!*

Refinements in the ability to measure gravity, and with those refinements the subsequent gravity surveys across much of the United States over the past 120 years, have allowed scientists to continually refine the resolution of the geoid and surveyors' ability to measure orthometric heights. Today's advancement in measuring techniques largely afforded through the Global Navigational Satellite System (GNSS) and the unprecedented ability to measure gravity on the ground, airborne and from outer space will allow the geoid's resolution to be vastly increased.

To give you an idea of the improvements in measuring gravity being made from outer space where the effects of the Earth's gravity field are the weakest to measure, the GOCE instrument is measuring gravity's effect to within one part in 10 billion! One scientist likened one in ten billion as being able to measure the change of mass of a super tanker from an added single snow flake!! Closer to Earth, gravity measurements made using airborne equipment further refine gravity's image. Such improved resolutions in going from outer space to airborne data could be viewed as being analogous in going from a thumbnail image to a high resolution photograph. Terrestrial based gravity measurements are even more focused, but are very point specific. Lacing these three types of datasets will provide the best overview of the Earth's gravity field.

The current gravity surveys being completed by the National Geodetic Survey (NGS) through its *Gravity for the Redefinition and the American Vertical Datum* (GRAV-D) project will tie satellite and terrestrial gravity datasets together from newly acquired airborne data to produce for the first time ever a consistent continental-scale geoid baseline. How does that translate into measurable terms for Joe surveyor?

Gravity Stations Dotted Across America

U.S. Coast & Geodetic

Gravity Stations by year: 1891-1949

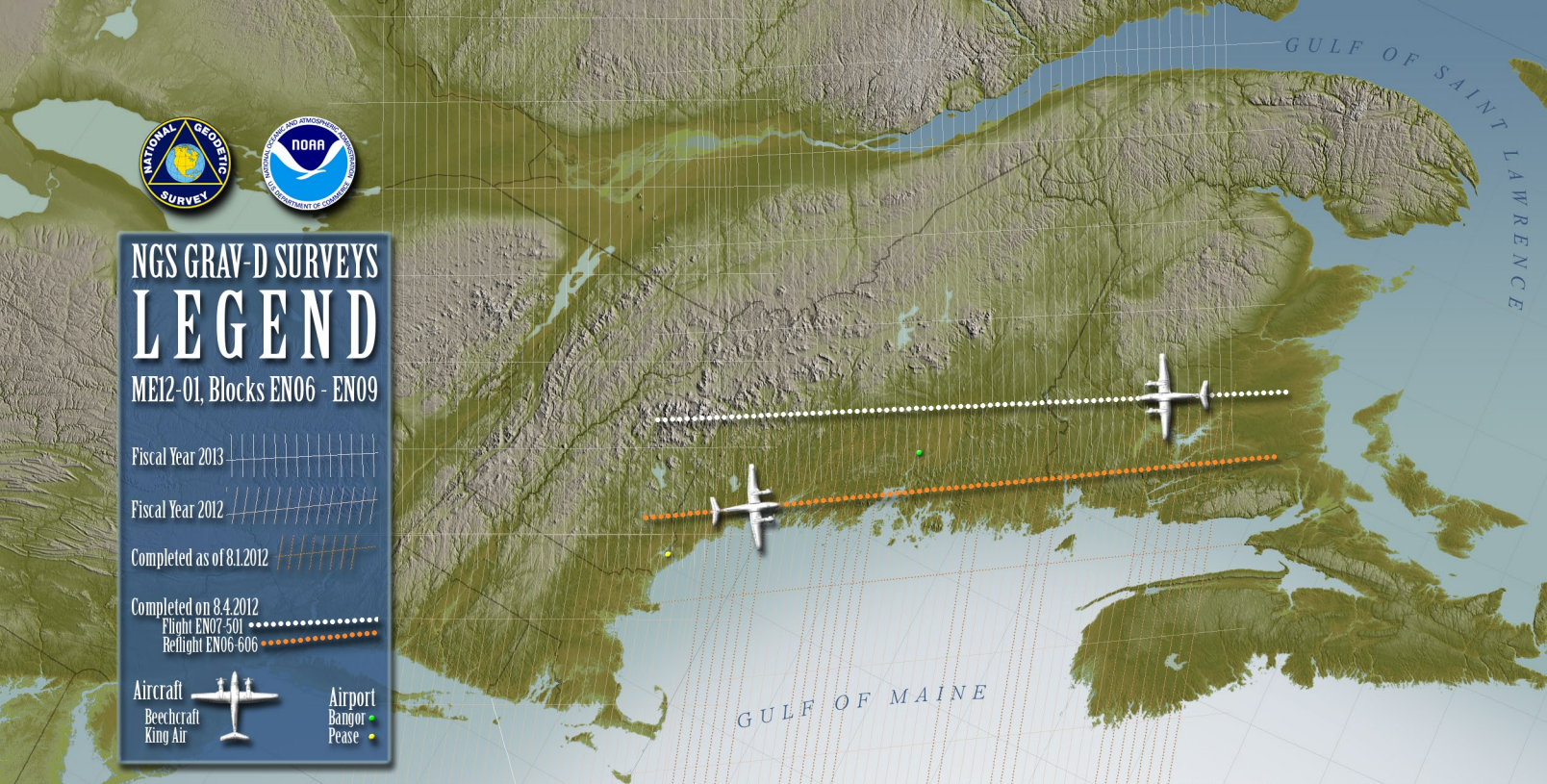
1891_{6}	1910_{23}	1924_{3}	1935_{90}
1893_{1}	1911_{32}	1925_{1}	1936_{61}
1894_{26}	1914_{21}	1926_{2}	1937_{115}
1895_{6}	1915_{72}	1930_{2}	1938_{152}
1896_{4}	1916_{42}	1931_{1}	1939_{97}
1899_{3}	1917_{3}	1932_{75}	1940_{29}
1902_{1}	1919_{8}	1933_{54}	1941_{26}
1906_{1}	1921_{10}	1934_{131}	1948_{53}
1909_{17}	1922_{5}		

PACES Gravity Database

Gravity Surveys by various sources up through the present housed by the Pan-American Center for Earth and Environmental Studies (PACES)

each pixel represents a gravity station, but because of the scale, there are more stations not shown from the PACES dataset of 1,277,637 gravity stations from various government, private and academic gravity surveys spaning several decades.

Prepare to have your mind blown: Orthometric heights will be able to be determined to within 1 - 2 cm *anywhere* in country, nearly a fifty-fold improvement when compared to a determination made today (NAVD88's surface compared with USGG2009's geoid).



Note: BGR used only for the two easternmost airborne gravity surveys (Blocks EN06 and EN07)

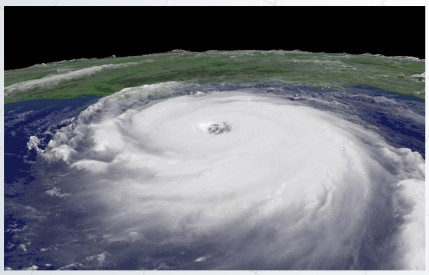
See the cover illustration for an overview of the locations of the Blocks of GRAV-D Gravity Surveys for the northeast in particular and for the enitrty of the country for the coming fiscal year.

But educating the so-called user community of the benefits of an entirely gravimetric geoid model will be the easy part. Educating the law makers and policy makers at both the federal and state levels to embrace the new height system by the time (2022?) it becomes available from NGS will be an entirely different matter - if it's even possible.

Gorillas in the Room

The National Flood Insurance Act of 1968, its amendments and the subsequent National Flood Insurance Program (NFIP) still have yet to fully reflect the abandonment of the National Geodetic Vertical Datum of 1929 (NGVD29) and the resolute adoption of today's current North American Vertical Datum of 1988 (NAVD88). Flood Insurance Rate Maps (FIRMs), their associated Flood Studies and the Base Flood Elevations (BFEs - if determined) are predicated upon a vertical datum from over 83 years ago. In so many ways this is more astonishing than discerning the added mass of the snow flake on the super tanker.

Changes in the Earth's climate and the associated increasing intensity and frequency of climatological events, such as the rise of sea levels and significant flooding events in recent years like Hurricane Katrina, only serves to underscore the need to *repair* previous height systems based on poor, inconsistent and missing data. (*Below, satellite view of Katrina on 8.25.2005*)

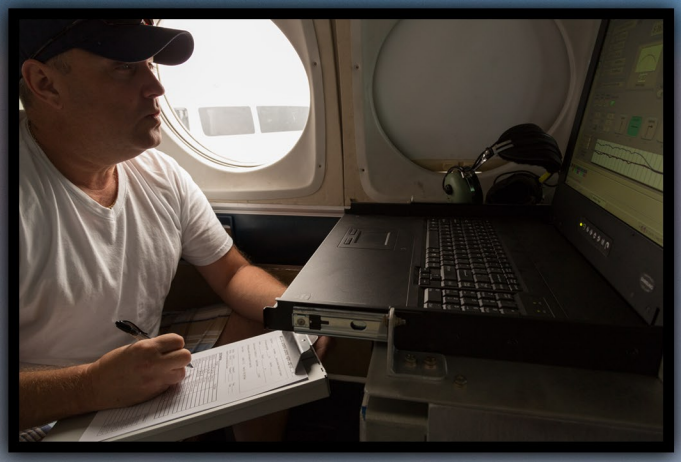


Thanks to the NGS and the GRAV-D surveys currently underway, the technological challenges in defining the nation's next height system are being met. What remains yet unseen are how the societal challenges associated with that new height system's adoption can be in place by the time it arrives.

In addition to FEMA, state and federal departments of transportation need to begin as early as possible in promulgating policies and procedures for the adoption of the new height system upon its arrival.

Since 2008 NGS has been conducting airborne gravity surveys and the cover illustration of this month's issue shows an overview of the areas that have been completed, what is presently being targeted for completion in Fiscal Year 2012, and, the anticipated areas to be surveyed in FY13. In addition to these airborne surveys and their associated terrestrially based control (absolute gravity stations & GPS control stations at each airport central to the airborne gravity surveys), NGS is also conducting *rigorous* Geoid Slope Validation Surveys in selected locations designed to independently corroborate its geoid determinations *within 1cm* - Yowzers!!!

After a glitch with the airborne gravimeter had been ironed out - something that required the troubled TAGS unit to be sent back to the manuafacturer and another installed in a different plane - the gravity surveys for the northeast got reliably underway in mid-July of this year. Numerous flights aboard a twin engine Beechcraft King Air for Blocks EN06 and EN07 were based out of Bangor, Maine. On Saturday, August 4th I was fortunate enough to be aboard one flight and got to see *Master Clamper* Justin Dalhberg in action. The illustration above details our flight lines that morning, both of which were cross lines or cross tracks. The primary flight lines spaced at 10 KM intervals are also shown.



The day earlier had been our original date for these two lines but because of icing conditions toward the New Hampshire end of these lines at the target elevation of 20,000 ft., that morning's flight was scrubbed. Bill Waickman, presently the only other airborne gravity surveyor working for NGS, went out later Friday afternoon on the primary flight lines that extend southerly beyond the Gulf of Maine.

In the photo immediately above, Justin is performing pre-flight still readings after the TAGS unit has warmed to operating temperature and has quieted gravity readings, usually about an hour after having been turned on for the day. In the intervening time, three nearby ground control dual frequency GPS receivers are each turned on to begin collecting data for later post processing with the onboard GPS TAGS data.

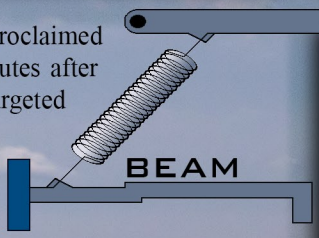
In the photo immediately below, and after all of the necessary setups and pre-flight measurements had been completed for Friday morning's flight, the decision to scrub it is discussed due to icing conditions around the New Hampshire-Maine boundary. Standing with Jason is Navy Pilot LT Mario Singletary. Aircraft Commander LT Joe Sweger and Project Manager and Section Chief Dr. Vicki Childers decide to revisit the planned flight lines and the associated icing conditions in a couple of hours. While the aircraft is perfectly able to adapt to the inclement conditions, the hyper-sensitivity of TAGS unit would pickup its effects as the pilots made the necessary corrections in speed and attitude rendering the data collected undesirable or worse.

Not all of the TAGS instrument pre-flight readings are easily observed from in front of its computer screen. In the photo above, Justin is using his cell phone to photograph the one reading that's directly on the gravimeter itself and that's a little too difficult to be seen in the cramped quarters of the plane.

All of the pre-flight instrument readings taken are repeated after the survey, the plane is positioned in the exact same location and has had time to once again find a quiet state.

The Earth's gravity field is something not quickly or easily visualized, but for surveyors that are familiar with airborne LiDAR surveys and the rendered surface of the ground that results from this type of broadly acquired data, it will be easy to see the similarities in the process of data collection afforded through the GRAV-D surveys. The monumental difference is, however, the scale of the NGS survey; as coverage in strips 10 km wide one at a time are laid across the entire country and all being done by so few individuals.

Friday, late morning, the decision was made to scrub the original plans of flying the cross lines after seeing that the icing conditions over western Maine remained unabated. Once that the decision was final, then plans quickly switched to flying along the primary flight lines of Block EN06. In the photo immediately below, NGS surveyors Bill Waickman and Justin Dalhberg linger in their makeshift office in conference room of General Aviation just moments before take off.



Seen in the photo above, self proclaimed *Master Clamper*, Justin awaits minutes after take off for the plane to reach its targeted altitude and the first line of the survey. In addition to dutifully noting events during the flight into the flight log for every survey, the airborne gravity surveyor must pay close attention to the TAGS unit, when to release and when to clamp the weighted beam which is at the heart of this type of gravimeter, simplistically illustrated here. In-flight events from the otherwise innocuous to having to suddenly alter course, and their time of occurrence, are noted in the log that later enables processing of the data and moreover, its quality, to be carefully evaluated.

To be certain, the NGS GRAV-D surveys are team events that require thoughtful planning well before any wheels leave the tarmac. Tim Wilkins, sometimes referred to as the recon guy, had arrived in May for the Bangor-based surveys scouting out existing control stations and establishing new ones around the airfield. In addition to terrestrial-based GPS observations, Tim also made precise observations at control points using the A10, an absolute gravity meter, establishing a reference basis for the TAGS' relative gravity measurements.

V. Kelly Bellis is a professional land surveyor and President of Horizon Surveying Company, Inc. in Ellsworth, Maine. Kelly is also an artist and photographer by avocation. He may be reached at kellybellis@gwi.net

Photo above courtesy of NGS geodesist Dan Winester (shown on the left) standing with Tim Wilkins and the absolute gravimeter FG5

Notes

Cover Illustration – Part Two

NGS's advancing geometric datum and modernized height system ties gravity datasets from both space and ground measurements through airborne gravity surveys currently underway across the United States. ESA's GOCE satellite (shown on the left) collects gravity utilizing accelerometers to yield gradient measurements while the pair of satellites known collectively as GRACE (or sometimes as Tom and Jerry ;) make interferometer measurements of their constantly changing distance from each other.

The artist's rendering of the GRACE twins is with grateful appreciation for its use, courtesy of NASA. For more information regarding; GRACE - Gravity Recovery and Climate Experiments, please visit their website at: http://grace.jpl.nasa.gov/

The artist's rendering of the GOCE satellite is with grateful appreciation for its use, courtesy of ESA. For more information regarding; GOCE - Gravity field and steady-state Ocean Circulation Explorer, please visit their website at: http://www.esa.int/SPECIALS/GOCE/.

All spatial content and its associated mapping (including the illustrations of the geoid!) was done using the software program Global Mapper. Many thanks go out to Mike Childs of Blue Marble Geographics for his unparalleled support.

Additional graphic embellishments were done using Adobe's Photoshop, CS6.

PDF copies of this article (both parts one and two) are available at: http://panocea.us/gravitys-increasing-gravitas/

Be sure to check out the Geoid Gallery for additional illustrations and content at: http://panocea.us/geoid-gallery/