New datums by the end of the next decade for the United States of America

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Summary

The National Geodetic Survey (NGS) is the lead federal agency on the Federal Geodetic Control Subcommittee (FGCS), which is a part of the broader Federal Geographic Data Committee (FGDC). While the FGDC focuses on broader collaboration involving geospatial data, the FGCS focuses on maintaining the National Spatial Reference System (NSRS) to ensure maximum accuracy and consistency when referencing the geospatial data. NGS is a responsible for maintaining the NSRS and access to it. The NSRS is composed of a number of elements including the North American Datum of 1983 (NAD 83) and the North American Vertical Datum of 1988 (NAVD 88). Both of these show significant problems when viewed in the context of global observing systems such as GNSS and data from the GRACE gravity satellite mission (Tapley et al. 2005). Meter level biases and slopes are seen in NAD 83, while NAVD 88 shows similar problems with 30-50 cm regional variations. Both of these are problematic given expectation by users for centimeter-level of accuracy. NGS is moving to adopt new datums to replace NAD 83 and NAVD 88 by the end of the next decade. These changes will impact not only federal agencies but all those who rely upon the products of those agencies. Examples would include map products from the USGS, flood plain maps (FIRMettes), cadastral information at the county level, and numerous GIS applications. This also will impact commercial and engineering operations that rely upon precise positioning and the local gravity field variations including shipping and port operations, pipelines, and surveys. NGS intends to replace NAD 83 with a new ellipsoidal datum more consistent with more recent reference frameworks (e.g., ITRF05). More significantly, NAVD 88 will be replaced by a gravimetric geoid height model. This model will work in conjunction with the new ellipsoidal datum to provide consistent, cm-level accurate, GNSS-derived orthometric heights. These heights will be capable of being transformed to express geopotential numbers to provide dynamic or other types of heights. The new vertical datum will be developed through the Gravity for the Redefinition of the American Vertical Datum (GRAV-D) project (Smith 2007). This project will collect gravity field information from numerous sources and spectrally meld them into a seamless whole.

Introduction

The Federal Geographic Data Committee (FGDC 2010) is an interagency committee that promotes the coordinated development, use, sharing, and dissemination of geospatial data on a national basis. This nationwide data publishing effort is known as the National Spatial Data Infrastructure (NSDI). The NSDI is a physical, organizational, and virtual network designed to enable the development and sharing of this nation's digital geographic information resources. FGDC activities are administered through the FGDC Secretariat, hosted by the U.S. Geological Survey. Subordinate to that, the Federal Geodetic Control Subcommittee exercises governmentwide leadership in coordinating the planning and execution of geodetic surveys, in developing standards and specifications for these surveys, and in the exchange of geodetic survey data and technical information. FGCS coordinates agency responsibilities which include standards setting, testing new geodetic instrumentation and operational systems, coordination of user agency requirements, and dissemination of government data to user agencies. NGS has begun efforts to update elements of the NSRS which have significant impacts both inside and outside the federal government. These steps are necessary given the significant errors that are known to exist in the existing datums.

NAD 83

The North American datum of 1983 replaced the previous datum, the North American Datum of 1927. While NAD 83 uses a GRS-80 ellipsoid consistent with many other models, the main problem lies with the reference system's geocenter. A datum is composed of both the ellipsoidal shell and the positioning and orientation of that shell. Any systematic problems with the geocenter will produce significant errors in the datum. For NAD 83, the bulk of the data used to determine the geocenter came from the old Transit system (Schwarz 1989) and was defined just at the dawn of the GNSS era. Subsequent analysis has shown that NAD 83 has a significant offset – approximately two meters from those of the ITRS models (e.g., ITRF05) or the National Geospatial-Intelligence Agency (NGA) reference system (WGS-84). See Figure 1 for a graphic of this. Additionally, Table 1 highlights how NAD 83 compares to previous ITRS models.

One significant fact that can be gleaned from Table 1 is that the series seems to have converged. The transformations from the most recent set of models seem to show very similar offsets. The transformations from ITRF00 and ITRF05 are generally within a millimeter of the other values for the X, Y, and Z. Hence, any new ellipsoidal datum adopted by NGS based on a similar model will likely see little disagreement from any subsequent ITRS model. While the initial jump may be significant (up to two meter shift in horizontal or vertical coordinates), this would not likely be repeated thereafter.

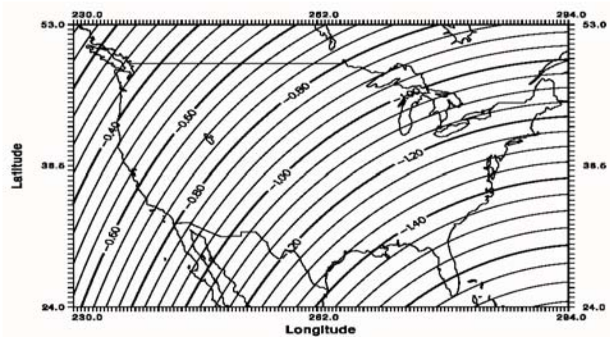

Figure 1. Difference in meters of ellipsoid height between the geocenters of NAD 83 and ITRF00.

Table 1. Net translation along X, Y, & Z axes from NAD 83 and various ITRS realizations relative to epoch 1997.0. Note the millimeter differences in the translations for ITRF00 and ITRF05.

Reference Frame	X Shift (m)	Y Shift (m)	Z Shift (m)	Total Shift (m)
ITRF92	-0.983	1.909	0.505	2.206
ITRF93	-1.011	1.906	0.505	2.216
ITRF96	-0.991	1.907	0.513	2.210
ITRF97	-0.989	1.907	0.503	2.206
ITRF00	-0.996	1.901	0.521	2.208
ITRF05	-0.996	1.902	0.522	2.210

Another limitation of NAD 83 is that there no velocity vectors are built into it. Hence, no allowance is made for crustal movement in regions that experience significant changes (e.g., California). The new ellipsoidal datum would account for these velocities and provide a consistent ellipsoidal framework for positioning. Additionally, gravimetric geoid height models are developed using a geocentric ellipsoidal frame work and then transformed into NAD 83 when developing a hybrid geoid height model. The USGG2009 model (Wang et al. 2010) was developed using ITRF00, while the derivative GEOID09 model (Roman et al. 2010) made the necessary transformation between ITRF00 and NAD 83. GEOID09 heights are then interpolated and applied to ellipsoidal heights obtained in either ITRF08 or WGS-84, which are also transformed into NAD 83. These transformations likely increase error. A simpler solution is to adopt an ellipsoidal datum with the best estimate of the geocenter to determine the reference frame in conjunction with a geoid height model. This limits the number of unnecessary transformations and thereby improves the accuracy of the coordinates.

NAVD 88

This then leads to the second element of the NSRS that requires updating: the North American Vertical Datum of 1988 (Zilkoski et al. 1992), which replaced the National Geodetic Vertical Datum of 1929 (NGVD 29). NAVD 88 represented a significant improvement over NGVD 29. NAVD 88 accounted for local gravity variations, used better corrections to observations, and did not constrain to multiple tide stations thereby eliminating twisting of the datum by not accounting for ocean topography variations along the east, west, and Gulf coast shorelines. However, the adjustment that developed NAVD 88 also propagated significant errors that accumulated westward. This was not evident until comparisons with geoid height models were developed using GRACE gravity data (Tapley et al. 2005), which are considered cm-level accurate at scales up to 500 km.

NGS has available to it nearly 20,000 control points where cm-level accurate GNSS-derived ellipsoidal heights are know on leveled bench mark heights above the NAVD 88 datum. The difference between the ellipsoidal and orthometric heights at these control points provides a point estimate of the separation between NAD 83 and NAVD 88. This should provide an estimate of a geoid height model, which can also be obtained from GRACE data. Geoid height estimates from both methods are subtracted to form differences to which a smoothing operator is applied to remove wavelengths shorter than 500 km to which GRACE is not sensitive. Figure 2 highlights these differences. It is clearly seen that while NAVD 88 might show good agreement on the east and Gulf coasts, significant errors accumulate along the west coast. Comparisons in southern Florida and northern Washington bare this out. NAVD 88 has a significant bias and tilt with several smaller features present that represent regional variations at the 30-50 cm level. Such errors make it difficult to use NAVD 88 with GNSS data and speak of accuracy.

GRAV-D

The Gravity for the Redefinition of the American Vertical Datum (GRAV-D) project (Smith 2007) was developed at NGS as a part of the Ten Year Plan (NGS 2008) to establish new ellipsoidal and vertical datums that could meet the requirements for cm-level accuracy. GRAV-D is well underway. Airborne collections are occurring in Alaska this year and next to develop a more consistent datum in that region. This aerogravity will be internally checked and then spectrally merged with GRACE gravity field data to create a consistent and accurate gravity field through 20 km resolution. In turn, the merged model will be used to assess millions of surface gravity data from terrestrial and shipborne campaigns. Standardizing these data will eliminate artifacts within the surface data – particularly in regions where surveys were performed separately but overlapped. These data will also be combining spectrally as will data determined through terrain modeling.

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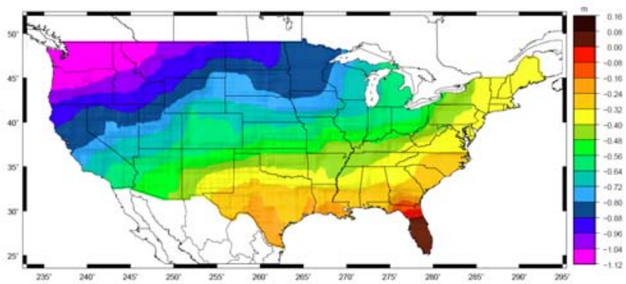

Figure 2. Approximate level of error determined in NAVD 88 based on comparison with signal over 500 km wavelengths in the GRACE gravity field.

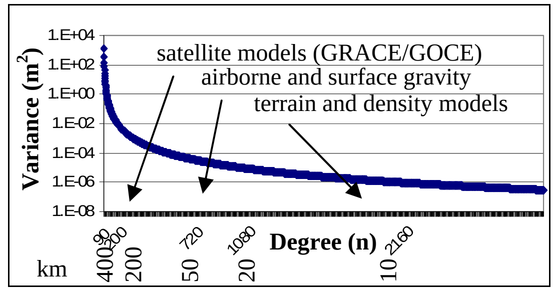

Figure 3. Geoid power versus degree harmonic with equivalent wavelengths (km) and the various sources that will contribute to the final model.

The shortest wavelengths of the gravity field derive from variations in terrain and the density of that terrain. NGS has begun to collect numerous digital terrain models and compared them to globally available models. Additionally, USGS lithology maps are being used to determine expected lateral variations n rock density to provide a very coarse estimate of those variations on the geoid height model. Since the geoid height model is dominated by long wavelength signals, local inaccuracies of such a density anomaly map will not affect the final model as significantly. These densities and potential vertical variations will be revisited when sufficient extra data is available through borehole measurements and seismic surveys. NGS will pursue agreements with other government agencies as well as commercial ventures to gain access to such proprietary to ensure a better overall model. Since the earth's structure is only need down to the geoid or ellipsoid surface, a detailed knowledge of these densities is not required except in more mountainous regions. Figure 3 shows the power spectral density plot of the total gravity field signal by wavelength and highlights the sources from which these data are envisioned to come.

Finally, the scope of this project is necessarily limited to the United States of America, because NGS is a national agency and required to focus on national priorities. However, the long wavelength nature of geoid heights and vertical datums requires some transparency with our neighbors. To that end, both Canada and Mexico are very closely aligned with developing similar new datums. The intent is to develop a common reference system for the entire North American region including the Caribbean and Central America. Such a model would greatly simplify international operations and collaboration.

While this discussion has focused on obtaining gravity field information, it should be noted that numerous papers have described mechanisms for transforming gravity field estimates into geoid height models suitable for use as a vertical datum. Such a datum would provide physical heights that are accurate as well as precise. Heights above NAVD 88 can be faithfully replicated in such regions where the control points are sufficiently dense. However, many regions exists where this control is sparse and/or of poor quality. A gravimetric geoid height model could be updated easily and would also account for changes over time.

In addition to velocities in the ellipsoidal framework, the vertical datum itself changes when the masses of the Earth shift. Monitoring and modeling of the glacial isostatic adjustments associated with Hudson Bay and southeastern Alaska are a part of the GRAV-D project. This will provide a mechanism for removing some of the time variability in the data and assigning an epochal date to a vertical datum based on a geoid height model.

Impact

As these models are adopted U.S. government agencies will not be the only ones impacted. As federal maps and products are updated to reflect the new datums, the associated changes will percolate to others in the North American region. Access to the Continuously Operating Reference System (CORS) of GNSS receivers (Schwarz et al. 2009) will provide (near-)real time access to ellipsoidal coordinates. Meeting such positioning requirements is significant for most all applications. Knowledge of where an observable is located is nearly as significant as the observed value itself. Most applications require that what is being observed be related to other observations. To that end, the planned update to the NSRS will greatly impact most commercial applications particularly those of organizations that receive and process a great deal of point data – such as the exploration industry.

When an assessment must be made in a physical height system, then the geoid height model must also be employed. A significant number of studies can be accomplished entirely in ellipsoidal coordinates, but some cannot be. While a plane might navigate and observe aerogravity over a region in ellipsoidal coordinates, the runway on which it lands must be designed in height system related to the real, physical heights by which water flows.

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Part of the validation of the derived height system will be made by comparison of data along shorelines at tide gages and to lidar profiles over ocean surfaces. This will provide a realistic assessment of the geoid height model as well as a mechanism for transforming from phenomena referenced to oceanic datums (e.g., MSL) to terrestrial application (vertical datum). Being able to express this relationship permits assessing what areas on land will flood when a 30 ft storm surge comes ashore.

Finally, these models will span the region and provide consistent, seamless coordinates in and around the North American region. Such heights will extend into South America and will be capable of being transformed to their height system. Additionally, the update to the International Great Lakes Datum of 1985 (IGLD 85) will also be based on this system. Hence, traffic through the Great Lakes traffic corridor will rely upon these new ellipsoidal and vertical datums.

Conclusions

The NGS is the lead agency of the FGDC and will be implementing new datums by the end of the next decade. The new ellipsoidal datum will replace NAD 83 and be more consistent with models developed by the ITRS and recent versions of WGS-84. Access to this new ellipsoidal datum will likely be through the CORS network and (near-)real time. A geoid height model will be developed based in that new ellipsoidal datum and will provide the mechanism for determining heights in a real, physical height system upon which many engineering and scientific applications rely.

Work on these new datums is well underway. The development of a suitable geoid height model requires a significant investment, which is why NGS started the GRAV-D project. GRAV-D will ensure a consistent set of gravity data from multiple sources and spectrally merge them into a seamless whole. This accurate gravity field will be used to generate an appropriate geoid height model that best reflects the structure and variability of the Earth's crust in the North American region.

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