Progress of GEOID2022

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Q&A doc

Q: As the name "Geoid ##" has traditionally been used for the hybrid geoid model (versus xGeoid or USGG), why is it used for this gravimetric model?
A: The name "GEOIDxxxx" was the name of the official transformation model between the official geometric and orthometric datums of the past. That hasn't changed, only the method has.

Q: Does it replace the EGM2008 geoid too?
A: EGM2008 will be replaced by NGA's EGM2020 model. EGM2008 is a global geopotential model rather than a geoid model in itself. A geopotential model describes Earth's gravity field everywhere above its surface while a geoid model combines this information with topography and other information to map a particular surface of equal gravitational potential. A global geopotential model is a fundamental component of a geoid model.

GEOID2022 differs from EGM2008 in terms of extent, accuracy, and resolution. GEOID2022 covers a little more than a quarter of the Earth, including North America and other U.S. territories while EGM2008 is global in scope. EGM2008 has a 10 km spatial resolution, while GEOID2022 has 2 km. Higher spatial resolution reduces the error of omission. GEOID2022 further benefits from more than a decade of additional satellite and airborne gravity data not present in EGM2008.

More on the difference between global geopotential models and geoid models:
[There is no such thing as "The" EGM96 geoid: Subtle points on the use of a global geopotential model]

Q: Is NGA gravity data referenced to WGS84 rather than ITRF?
A: The NGA gravity data in our database are geolocated in NAD83 and positioned vertically in NAVD88. Most of these data were collected prior to the widespread adoption of GPS and were positioned horizontally using topographic maps with a horizontal accuracy of 10 meters or worse. Most horizontal position errors associated with the gravity data are too large for the differences to matter. Horizontal position errors have a negligible effect on the accuracy of the geoid, but the geoid is sensitive to height errors.

Q: Was data for Cuba available. If so, was it used?
A: Yes, we have dense coverage over Cuba and other Caribbean islands that originated from NGA's terrestrial gravity database. This data is part of xGEOID20. Much of this data comes from historical, pre-1950s surveys. The Technical Details document for xGEOID19 contains illustrations of the terrestrial gravity data distribution for the NGS terrestrial gravity database.

Q: What is the best degree/order of GOCO06S applied in the current computation? or the maximum degree/order is applied?
A: GOCO06S was combined with our initial reference model using a cosine taper from degree and order 150 to 220. The taper function was evaluated and optimized using GSVS data. Quoting our recent technical report (NOAA Technical Report 78) for xGEOID20:

> "The model was then merged with the latest satellite gravity model GOCO06s (Kvas et al. 2021) from degree 2 to 230. To have a smooth combination, a cosine taper function at degree 120 was applied from degrees 150 to 220."

Q: As a real-time network operator, I have the ability to broadcast both NAD83 and ITRF2020. Will Geoid2022 or the xGeoid currently work with the ITRF coordinates?
A: Both NAD83 and ITRF2020 are geometric reference frames. The GEOID2022 (or its proto type xGEOID) is used to compute the orthometric height in a simple relationship

H(orthometric) = h(ITRF2020) - N(GEOID2022)

NAD83 is the horizontal datum and it is not compatible with GEOID2022, because it is not geocentric.

Q: Comparing the NGA and NGS geoid computation tools I see large differences. Any ideas why?
A: NGA's EGM2008-based geoid model and and NGS's hybrid geoid models are applicable to different definitions of height. Hybrid geoid models like GEOID18 are meant to convert between NAD83 ellipsoidal heights and NAVD88 orthometric heights, whereas geoid models based on EGM2008 relate physically consistent orthometric heights to geocentric WGS84 ellipsoidal heights. NAVD88 has systematic errors that result in a 1.5 meter tilt across the contiguous United States, illustrated in Slide 6. GEOID18 applies post-hoc corrections to a gravimetric geoid model to predict orthometric heights in NAVD88. GEOID2022 will be a more physically self-consistent conversion surface between ellipsoidal heights in NATRF2022 and orthometric heights in NAPGD2022. GEOID2022 will have a number of improvements to EGM2008 that will also result in height differences at the scale of centimeters to decimeters.

Q: Is this data being integrated with FEMA flood maps?
A: Updates to FEMA flood maps are done at the local / state level and are required to use the most recent version of the NSRS. When the improved heights and new datums are released in mid-2025 they will be available for use in this process, but it will be up to the local and state authorities, and the customers affected by the flood map updates to ensure that it is.

Q: Once GEOID2022 is created, forming NAPGD2022, can it accept changes, say as more or better gravity data arrive, 5-50 years from now? How 'stable' is the resulting datum, as these changes arrive? Not the dynamic component, I'm talking about additions or subtractions from the geoid model
A: NGS plans to update the model in future and will always welcome additional gravity data.

It is difficult to predict the changes caused by new data, but our uncertainty estimates provide a useful guide. Generally speaking, if an area already has high quality data and good coverage, the changes should be on the order of 1 centimeter. Topographically flat parts of the contiguous United States with good gravity coverage can expect centimeter-level stability over the lifetime of the model.

For areas with no gravity data or poor data quality, the changes may be several centimeters. Rugged terrain may also see changes of a few centimeters as well, as modeling techniques improve. Changes of more than 10 centimeters are possible in remote corners of the model domain, including Greenland, Alaska, and northern Canada.

Q: In WI, Great Lakes loading will be an interesting dynamic problem, mostly geometrically (for ellipsoid heights). When the lakes fill up ~1 m & push regional ground down geometrically 1-2 cm, I assume OPUS will give real NATRF2022 ellipsoid heights in the current epoch, showing the drop. However the state's real-time GNSS network (WISCORS) will probably hold the base ellipsoid height values fixed for years, and not change them for periodic lake loading effects. Thus we would see a difference between WISCORS and OPUS results. WISCORS users would have to remember that the epoch of their survey is not really the date of survey, but (mostly) the date the WISCORS base ellipsoid heights were determined. At any rate, important for users to store GNSS as vectors (from an actual base) so those kinds of discrepancies can be understood later on.
A: The Great Lake loading effect is important for heights, but we don't anticipate large impacts on the geoid. Based on the definition of the orthometric height (H=h-N), the

changes will be reflected in the orthometric height change. One rule of thumb says that 1 cm change in ground change would cause 0.1 cm change in the geoid. For new datum, not only the location, but the time epoch are needed for present and future.

The loading effect has not been modeled in GEOID2022. GEOID2022's dynamic component is designed to reflect decadal timescales so the geoid model matches its definition as a surface that best fits *mean* sea level. Annual and interannual variations are not modeled for this reason.

Q: What hurdles do you foresee to the development of a clock-based (relativistic) geopotential datum?
A: The chief obstacle to such a scheme is technological. The clock accuracy must be 1 part in 10^{18} to match the centimeter-level accuracy of our current geoid models. Scientists around the globe are working towards the goal, but portable, survey-friendly solutions to this problem do not yet exist. Relativistic geodesy is, at least in principle, compatible with our geopotential datum, but we have not yet fully explored how this might work in practice.

Q: Can you elaborate on how a Dynamic Geoid Model would work?
A: The dynamic geoid was first implemented as part of xGEOID20. It consists of a geoid change rate grid based on long-term gravity data from the Gravity Recovery and Climate Experiment (GRACE) combined with high-resolution Antarctic ice mass loss data from ICESat, ICESat-2, and airborne lidar surveys. The time-dependent geoid model is accessible using our interactive computation tool for xGEOID20.

The development of the dynamic component of the geoid is performed as part of GeMS, the Geoid Monitoring Service. This model is supported and validated by dedicated surveys in Alaska and repeat absolute gravity measurements throughout the United States.

Q: If we submit a bluebook report with NGS tracking ID that includes GPS observations of a benchmark.. is that data included in GPS-On-Benchmarks program? Or does that data need submitted separately?
A: The scripts run weekly by the GPSonBM team scrape all new GPS data submitted on bench marks in both the NGS IDB and the OPUS Shared solutions, so there is no need to submit data for GPSonBM separately. Note that for bluebooked data, the scripts look at the datasheet shapefiles, and those shapefiles are currently produced on a monthly schedule so there may be a few weeks of lag time between when the data is submitted, when the datasheets are updated, when the shapefiles are updated, and when the GPSonBM priority list and webmap is updated.

Q: Do Canada and Mexico have aerial gravity acquisition programs like the US program?
A: No, nowhere near the same scale. The Canadian Geodetic Survey is currently processing NASA Operation IceBridge airborne gravity data for the Canadian Archipelago. INEGI, Mexico's counterpart to NGS, is also working on terrestrial surveys to fill in coverage caps.

Q: As a real-time network operator, I have the ability to broadcast both NAD83 and ITRF2020. Will Geoid2022 or the xGeoid currently work with the ITRF coordinates?
A: The short answer is yes. NATRF2022 is consistent with the ITRF, so there is no problem computing orthometric height from either set of coordinates using GEOID2022 or an xGEOID model.

Q: Different areas had different height systems, how did you handle the conversions to have orthometric heights only for Geoid2022 works? For the GPS/leveling points, are there corrections made for deformations/any crustal movements? How are the changes in gravity over time catered for in computations?
A: Different types of height occur in areas outside of CONUS/Alaska. NAVD 88 used modeled gravity to calculate heights using a formula.This produces Helmert orthometric heights. Since we didn't have modeled gravity for other areas (e.g., Puerto Rico), we used normal gravity based on the international ellipsoid. This produces normal orthometric heights. They are similar but different.

In the end though that doesn't matter. It was the datum and we simply calculate the difference to NAPGD 2022 as a geopotential surface. That will form the basis of vertcon grids. We did the same thing between NGVD 29 and NAVD 88. Each datum had different heights. While it may not be mathematically rigorous, you can do this if you have enough points to produce a grid of transformation.

In the future, we will rely on NAPGD2022. Keep in mind the 'G' in the acronym is for *geopotential*. You can derive any type of height you want if you truly have a geopotential datum. Now this will be realized as a geoid height model, which is more at orthometric heights. However, we will also produce a grid of gravity from the same geopotential model. This gravity grid will enable conversions to normal or dynamic heights very accurately. Hence, we will use NAPGD 2022 as the basis for determining dynamic heights in IGLD 2020. We will probably look at unifying all of the disparate river datums as well.

Regarding the deformations/crustal movement - there are two components. The first is a *geometric* change in the surface. You can estimate this by performing a GNSS/GPS survey, a lidar survey, or an InSAR survey. That merely tells you that the surface changed/deformed in geometric coordinates. The IFDM can account for this. We'll be calibrating the national deformation model against the IFDM and our NCN to make sure everything is in sync.

The final piece is then that the deformation may result in a mass change. That will affect the geoid height. GeMS is monitoring the change in gravity and, therefore, the geopotential datum. A good example of this is the Great Lakes region.

In the Great Lakes, the ground is rebounding rapidly from the last deglaciation. About 1 cm a year. Most of that just represents the ground springing up. However, as the ground springs up - mantle material flows in from surrounding areas (mainly from under the U.S.). So mass is being introduced, which means the geoid will also go up. As a rule of thumb, the geopotential change is about 10% of the total signal. So in ten years, the ground will go up 10 cm in Canada in ellipsoidal heights, but the geoid goes up one cm too. So orthometric heights will only increase by 9 cm. The two are very inter-related.

Hence, why we will have IFDM to provide a bulk of the change but will monitor NAPGD 2022 with GeMS to ensure that geopotential doesn't fall too far out either.

Q: Maybe I missed this but what will be the final resolution spacing of the 2022 geoid?
A: 1 arcminute by 1 arcminute (~2 km).