Mapping Matters

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Your Questions Answered

The layman's perspective on technical theory and practical applications of mapping and GIS

Question: Data re-projection is done all the time by both GIS neophytes and advanced users, but a slightly wrong parameter can wreak havoc with respect to a project's destiny if undetected. Many update projects were originally performed in NAD27 and the client now wants the data moved to a more up-to-date datum. What happens behind the scenes when data gets re-projected? Other than embarking on an expensive ground survey effort, what assurances exist to give the user confidence that what has been done is correct? What special considerations should be taken into account when data is re-projected and what are the potential pitfalls? Is every dataset a candidate to be re-projected, if not, why not?

Complicating the re-projection piece, older projects may have been done in NGVD29 and need to be moved to NAVD88. Similar to what is above, what happens behind the scenes, and how do we know the result is correct? What are some of the commonly performed vertical shifts done in the industry? Is there a standardized practice to perform this task? What impact, if any, does this vertical shift play on contours. Why do some firms/clients/consultants feel it necessary to recollect spot elevations and regenerate the contours in the new vertical datum, rather than just shifting the contours generated from the older vertical datum? Under what circumstances would a vertical shift be ill-advised?

Dr. Abdullah: I personally consider this question among the most important issues I face as a mapping scientist. Despite full awareness of the importance of coordinate and datum conversions and the role they play on the accuracy of the final delivered mapping products, most users and providers have a very limited understanding and knowledge of the topic. The question accurately describes the common mistakes, misunderstandings, concerns and anxiety that many concerned users experience when accepting or rejecting a mapping product. I will try to address all aspects of the question as much as I can for its importance. I will start by describing "what is happening behind the scenes".

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Datums and Ellipsoids: Defined by origin and orientation, a datum is a reference coordinate system that is physically tied to the surface of the Earth with control stations and has an associated reference ellipsoid (an ellipse of revolution) that closely approximates the shape of the Earth's geoid. The ellipsoid provides a reference surface for defining three dimensional geodetic or curvilinear coordinates and provides a foundation for map projection. Here in the United States, the old horizontal North American Datum of 1927 (NAD27) was replaced with a more accurate datum called the North American Datum of 1983 or NAD83. NAD83, which is a geocentric system with its center positioned close to the center of the Earth, utilizes the GRS80 ellipsoid that was recommended by the International Association of Geodesy (IAG). The NAD27, on the other hand, is a non-geocentric datum, utilizes an old reference ellipsoid or oblate spheroid (an ellipsoid of revolution obtained by rotating an ellipse about its shorter axis) called the Clark1866 spheroid.

Conversion Types: There are two types of conversions that can occur during any re-projection: datum transformation and projection system transformation. Datum transformation is needed when a point on the Earth used to reference a map's coordinate system is redefined. As an example of datum transformation is upgrading older maps from the old American datum of NAD27 to the newer NAD83 datum. The coordinate system (not the coordinate values) such as the State Plane may be kept the same during the transformation but the reference datum is replaced. Projection system transformation is needed when a map's projected coordinates are moved from one projection system to another, such as when a map is converted from a State Plane coordinate system to Universal Transverse Mercator (UTM). Here, the horizontal datum (i.e. NAD83) of the original and the transformed map may remain the same.

Datum Transformations: In the process of updating older maps produced in reference to NAD27, a datum transformation is required to move the reference point for the map from NAD27 to NAD83. Several different methods for transforming coordinate data are widely accepted in the geodetic and surveying communities. In North America, the most widely used approach is an intuitive method called NADCON (an acronym standing for North American Datum conversion) to translate coordinates in NAD27 to NAD83. NADCON uses a method in which are first and second order geodetic data in National Geodetic Services of NOAA (NGS) data base is modeled using a minimum curvature algorithm to produce a grid of values. Simple interpolation techniques are then used to estimate coordinate datum shift between NAD 83 and NAD27 at non-nodal points.. Those who utilize NADCON rarely obtain bad conversion results. Most of the common blunders and mistakes made by users while using different conversion tools result from not fully understanding the basics of geodetic geometry. As such, the process of conversion should be handled by individuals who have some understanding and experience in dealing with datum and coordinates conversion.

Once the Global Positioning System (GPS) came along, the discrepancies inherent in the original NAD83, which was first adjusted in 1986 and referred to as NAD83/86 to differentiate it from newer adjustments of NAD83, became apparent. New adjustments of NAD83 (HARN adjustment, designated NAD83 199X, where 199X is the year each state was re-adjusted) resulted in more accurate horizontal datums for North America. The multi-year HARN adjustments added more confusion to the already complicated issue of the North American Datum, especially when the user had to convert back–and-forth to the World Geodetic System of 1984 (WGS84)-based GPS coordinate determination. An ellipsoid similar to the GRS80 ellipsoid is used in the development of the World Geodetic

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System of 1984 (WGS84) coordinates system, which was developed by the Department of Defense (DoD) to support global activities involving mapping, charting, positioning, and navigation. Moreover, the DoD introduced WGS84 to express satellite positions as a function of time (orbits). The WGS84 and NAD83 were intended to be the same, but because of the different methods of realization, the datum differed slightly (less than 1 meter). Access to NAD83 was readily available through 250,000 or more of non-GPS surveyed published stations which were physically marked with a monument. WGS84 stations, on the other hand, were accessible only to DoD personnel. Many military facilities have WGS84 monuments that typically were positioned by point positioning methods and processed by the U.S. military agencies using precise ephemeris.

In 1994, the DOD decided to update the realization of WGS84 to account for plate tectonics since the original realization, as well as the availability of more accurate equipment and methods on the ground. In that decision, the new WGS84 was made coincident with the International Terrestrial Reference Frame (ITRF) realization known as ITRF92 and was designated WGS84(G730), where G730 represents the GPS week number when it was implemented. In the late 1980s, the International Earth Rotation Service (IERS) introduced the International Reference System (ITRS) to support those civilian scientific activities that require highly accurate positional coordinates. Furthermore, the ITRS is considered to be the first major international reference system to directly address plate tectonics and other forms of crustal motion by publishing velocities and positions for its world wide network of several hundreds stations. The IERS, with the help of several international institutions, derived these positions and velocities using highly precise geodetic techniques such as GPS, Very Long Base Line Interferometery (VLBI), Satellite Laser Ranging (SLR), Lunar Laser Ranging (LLR), and Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS). Every year or so since introducing ITRF88, the IERS developed a new ITRS realization such as ITRF89, ITRF90,…, ITRF97, ITRF00, etc Since the tectonic plates continue to move, subsequent realization of WGS84 were published such as WGS84(G873) and WGS84(G1150). One of the newest realization is equal to ITRF 2000 2001.0 (i.e., ITRF 2000 at 1/1/2001).

As time goes on, the NAD83 datum drifts further away from ITRF realization unless a new adjustment is conducted. The later HARN adjustments, for example, are closer in values to the NGS coordinated network of Continuously Operating Reference Stations (CORS) system than the earlier ones. CORS provides GPS carrier-phase and code-range measurements in support of three-dimensional positioning activities throughout the United States and its territories. Surveyors can apply CORS data to the data from their own receivers to position points. The CORS coordinates in the U.S. are computed using ITRF coordinates and then transformed to NAD83. The problem with using ITRF for this purpose lies in the fact that the coordinates are constantly changing with the recorded movement of the North American tectonic plate. In the latest national adjustment of NAD83, conducted in 2007, only the CORS positions were held fixed while adjusting all other positions. This resulted in ITRF coordinates for all NGS positions used in the adjustment as opposed to only CORS published ITRF positions.

Projection System Transformation: Projected coordinates conversion, such as converting geographic coordinates (latitude and longitude) of a point to the Universal Transverse Mercator (UTM) or a State Plane Coordinates System, represents another confusing matter among novice users. State plane coordinate systems, for example, may include multiple zones (e.g., south, north, central, etc.) for the same state, and unless the task is clear, the user may assign a certain coordinates set to the wrong zone during conversion. The vertical datum conversion poses a similar risk as here in the U.S., maps were originally compiled in reference to the old North-America Geodetic Vertical Datum of 1929 (NGVD29) and conversion is necessary to relate data back and forth between the NGVD29 and the new more accurate vertical datum of 1988 (NAVD88). Similar problems arose since most surveying practices are conducted using GPS observations. Satellite observations are all referenced to the ellipsoid of WGS84 and the user has to convert the resulting elevation to geoid-based orthometric heights using a published geoid model.

As for NAD83 updates, the geoid model also went through many re-adjustments and different geoid models were published over the years such as geoid93, geoid99, geoid03, and the most recent geoid06, which only covers Alaska so far. Without having details about the data at hand, a user may easily assign the wrong geoid model during conversion, resulting in sizable bias in elevation for a small project. When a new geoid model is published, a new grid of geoid heights (the separation between ellipsoid and geoid) is provided and most conversion packages utilize these tabulated values to interpolate the elevation for non-nodal positions. As for the vertical datum conversion between NGVD29 and NAVD88, a program similar to NADCON called VERTCON is used throughout the industry to convert data from the old to the new vertical datum.

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Judgment Calls: As for the question of whether "every dataset is a candidate to be re-projected", the answer is simply NO. To transform positional coordinates between ITRF96 and NAD83(CORS96), U.S. and Canadian officials jointly adopted a Helmert transformation for this purpose. Helmert Transformation, which is also called the "Seven Parameter Transformation", is a mathematical transformation method within a three-dimensional space used to define the spatial relationship between two different geodetic datums. The IERS also utilized a Helmert transformation to convert ITRF96 and other ITRS realization. The NGS has included all of these transformations in a software package called Horizontal Time-Dependent Positioning (HDTP), which a user can down load from the NGS site http://www.ngs.noaa.gov/TOOLS/Htdp/Htdp.html.

While the Helmert transformations are appropriate for transforming positions between any two ITRS realization or between any ITRS realization and NAD83(CORS96), more complicated transformations are required for conversions involving NAD27, NAD83/86, and NAD83(HARN) as the inherited regional distortion can not reliably be modeled by simple Helmert transformation. Even with the best Helmert transformation employed in converting positions from NAD27 to NAD83(CORS96), the converted positions may still be in error by as much as 10 meters. In a similar manner, NAD83(86) will contain distortion in the 1 meter level while NAD83(HARN) will contain a distortion in the 0.10 meter level.

In summary on the conversion possibilities and tools, HTDP may be used for converting between members of set I of reference frames [NAD83(CORS96), ITRF88, ITRF89,.., and ITRF97] while NADCON can be used for conversion between members of set II of reference frames [NAD27, NAD83(86), and NAD83(HARN)]. No reliable transformation tool is available to convert between members of set I and set II of reference frames, in addition no conversion is available for transforming positions in

NAD83(CORS93) and/or NAD83(CORS94) to any other reference frames. As for WGS84 conversions, it is generally assumed that WGS84(original) is identical to NAD83(86), WGS84(G730) is identical to ITRF92, and that WGS84(G873) is identical to ITRF96. Other transformations between different realizations of WGS84 and ITRF are also possible.

Based on the above discussions, data conversion between certain NAD83 and WGS84 is not always possible or reliable. As I mentioned earlier, existing data in NAD83 may not be accurately converted to certain WGS84 realizations as NGS did not publish all reference points in WGS84 and most WGS84 reference points are limited to military personnel. Unless a new survey is conducted in WGS84, it is always problematic to convert older versions of NAD83-based data from and to the newer WGS84 realizations. Conversion packages that make such tasks possible assume the term "WGS84" to be equal to the first realization of WGS84, which was intended to be equal to NAD83/86.

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Free Conversion Tools:

GEOTRANS: The US Army Corps of Engineers provides a coordinate transformation package called "GEOTRANS" free to any US citizen. In a single step, user can utilize GEOTRANS to convert between any of the following coordinate systems, and between any of over 100 datums: Geodetic (Latitude, Longitude), Geocentric 3D Cartesian, Mercator Projection, Transverse Mercator Projection, Polar Stereographic Projection, Lambert Conformal Conic Projection, UTM, UPS, MGRS. The "GEOTRANS" is also distributed with user manual and Dynamic Link Library (DLL) which users can use it in their software

CorpsCon: Another good free package called CorpsCon is distributed by US Army Topographic Engineering Center (TEC) and solely for coordinates conversion for territory located within the United States of America.

Effect of Datum Conversion on Contours: When existing sets of contours are converted from one vertical datum to another, the resulting contours do not comply with the rules set governing contour modeling. Contours are usually collected or modeled with exact multiples of the contour interval (e.g., for 5-ft contours, it is 300, 305, 310, etc.). Applying a datum shift to these contours could result in the addition or subtraction of sub-foot values depending on the datum difference; therefore the contours will no longer represent exact multiples of the contour interval (for the previous 5-ft contour example, the new contours may carry the following values 300.35, 305.35, 310.35, etc., assuming that the vertical datum shift is about 0.35 ft). Consequently, after conversion, a new surface should be modeled and a new set of contours that are an exact multiple of the contour interval should be generated.

Similar measures should be taken for the spot elevations, as they represent a highest or lowest elevation or a region between two contours without exceeding the contour interval. When the new contours are generated, the new contours are no longer in the same locations as the previous set of contours. The existing spot elevations may no longer satisfy the condition for spot elevations, and new spot elevations may need to be compiled. Vertical shift based on one shift value is not recommended for large projects as the geoid height may change from one end of the project to another. The published gridded geoid heights data should be consulted when converting the vertical datum for large projects that span a county or a state. Small projects may have one offset value and therefore applying one shift value that is derived from the suitable geoid model tables for the project area may be permissible.

Conversion Errors and Accuracy Requirements: As a final note, the previous discussions on the effect of conversion accuracy on the final mapping product may not pose a problem if the accuracy requirement is lenient and the discrepancy between the correct and assumed coordinates values fall within the accuracy budget. To clarify this point, the difference between NAD83(86) and NAD83(HARN) in parts of Indiana, is about 0.23 meter. Therefore, if you provide mapping products such as an ortho photo with 0.60 meter resolution or GSD (scale of 1:4800) and whose accuracy is specified according to the ASPRS accuracy standard to be an RMSE of 1.2 meter, the 0.23 meter errors inherited in the produced ortho photo due to the wrong coordinates conversion may go by undetected, as opposed to providing ortho photos with 0.15 meter resolution (scale of 1:1,200) with an accuracy requirement of 0.30 meter where the error in the data consumes most of the accuracy budget for the product. However, errors should be detected and removed from the product no matter how large or small they are.

Best Practice: In conclusion, I would like to provide the following advice when it comes to datum and coordinate conversion:

1. When it comes to coordinate conversion, DO NOT assign the task to unqualified individuals. The term "unqualified" is subjective and it varies from one organization to another. Large organizations that employ staff surveyors and highly educated individuals in the field may not trust the conversions made by staff from smaller organizations that can not afford to hire specialists. No matter what the size of your organization, practice caution when it comes to assigning coordinate and datum conversion tasks. Play it safe.
2. Seek reliable and professional services when it comes to surveying the ground control points for the project. Reliable surveying work should be performed or supervised and signed on by a professional license surveyor. Peer reviews within the surveying company of the accomplished work represents professional and healthy practices that may save time and money down the road.
3. GIS data users need to remember that verifying the product accuracy throughout the entire project area is a daunting task if it is all possible. Therefore, it is necessary to perform field verification for the smallest statistically valid sample of the data and rely on the quality of the provided services and the integrity of the firm or individuals provided such services for all areas fall outside the verified sample. That is why selecting professional and reputable services are crucial to the success of your project.
4. When contracting surveyors to survey ground control points for the project, ask them to provide all surveyed coordinates in all possible datums and projections that you may use for the data in the future. Surveyors are the most qualified by training to understand and manipulate datums and projections and it does not cost them much to do the conversion for you. It is recommended that in your request for proposal you ask the surveying agency to provide the data in the following systems:

   Horizontal Datum: NAD27 (if necessary), WGS84, NAD83/86 (if necessary), NAD83/latest HARN, NAD83/CORS, NAD83/2007.

   Coordinates System (projected): Geographic (latitude, longitude), UTM (correct zone), Sate Plane Coordinate System

   Vertical Datum: WGS84 ellipsoidal heights; NGVD29 (if necessary), NAVD88 (latest geoid model).

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5. When you are asked to provide data for a client, always make sure that you have the right information concerning the datum and projection. It is common to find that people ask for NAD83 without reference to the version of NAD83. If this is the case, ask them specify whether it is NAD83/86, NAD83/HARN (certain year), NAD83/CORS, or NAD83/2007.
6. If you are handed control data from a client or historical data to support their project, verify the exact datum and projection for that data.
7. If a military client asks you to deliver the data in WGS84, verify whether they mean the first WGS84 where the NAD83 was nominally set equal to WGS84 in the mid 80s. Most of their maps are labeled WGS84, referring to the original WGS84. Otherwise, provide them with NAD83/CORS or ITRF at a certain epoch suitable for the realization they requested, unless they give you access to the WGS84 monument located in or near their facility. The most accurate approach for obtaining WGS84 coordinates is to acquire satellite tracking data at the site of interest. However, it is unrealistic to presume that non-military users have access to this technique.
8. Pay attention to details. People are frequently confused about the vertical datum of the data. Arm yourself with simple, yet valuable, knowledge about vertical datums. If the project is located along the U.S. coastal areas, the ellipsoidal height should always be negative as the orthometric height (i.e., NAVD88) is close to mean sea level or zero value and the geoid height is negative. Therefore, if you are handed data with an incorrectly-labeled vertical datum, look at the sign of the elevations given for the project. A negative sign for elevation data on U.S. coastal projects is an indication that the data is in ellipsoidal heights and not orthometric heights (such as NAVD88).
9. Equip your organization with the best coordinate conversion tools available on the market. Look for a package that contains details of datum and projection in its library. Here apply the concept of the more the better.
10. Cross check conversion from at least two different sources. It is a good practice to make available at least two credited conversion packages to compare and verify conversion results.
11. If you are not sure about your conversion, or the origin of the data that you were handed, always look for supplementary historical or existing ground control data to verify your position. Take advantage of resources available on the Internet, especially the NGS site. Many local and state governments also publish GIS data for public use on their web sites. Even "Google Earth" may come in handy for an occasional sanity check.

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