Vertical Datum Conversion in the Lake Erie Coastal Area

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ABSTRACT

Seamless integration of land-elevation and water-depth information in coastal environments is required in many geospatial applications and decision-making processes. Vertical datum conversion is the central component of the integration process. This study introduces a methodology of vertical datum conversion in Lake Erie, which utilizes the public published models and toolkits developed by National Geodetic Survey (NGS) to form a new transformation system. In this research, a system of vertical datum conversion was developed and a test area was chosen to verify conversion results. The system we developed can be widely used in the coastal area of the Great Lakes, either for spatial data integration or coastal management.

Categories and Subject Descriptors

H.4 [**Information Systems and Applications**]: Datum Conversion System

General Terms

Algorithms, Experimentation, Verification

Keywords

Lake Erie, vertical datum, conversion, methodology, system, grid, difference model, software, VDatum, and benchmark

1. INTRODUCTION

Federal, state, and local government agencies may use various geospatial data which are based on different datums for coastal management and decision-making. Seamless integration of geospatial data in coastal environment is required by many agencies to improve the effectiveness and efficiency of the decision-making process. Datum conversion is indispensable for the integration of geospatial data based on different datums. Since vertical datums in coastal zone are various and complicated. The key component of the integration process is vertical datum conversion, which makes all data, land-based or water-based, consistent and integrative. The zero surface to which heights refer is called "vertical datum." There are several types of heights, such as ellipsoid heights, orthometric heights, and geiod heights (Li et al. 2004, Mayer et al. 2004, Maune, 2001). Therefore there are various vertical datums involved if data integration is performed in the water-land interaction zone. A vertical datum is realized using a set of constants or models, a specific coordinate system, and points that have been consistently determined by observations, corrections, and computations (Li et al. 2002, Zilkoski, 2001). Data based on different vertical datums cannot be combined or mixed directly; otherwise it will result in large errors. Therefore, vertical datum transformation is important. With this transformation, the data will be consistent and can be integrated seamlessly for geospatial applications. In addition to coastal management and decision-making, the datum conversion technology can be applied to any applications that involve geospatial data integration.

This research addresses a systematic methodology for vertical datum conversion in the Lake Erie coastal zone. The system developed in this research can perform the conversion between any two different datums. To verify conversion accuracy, a test area was chosen, a number of benchmarks were selected, and reliable accuracy was obtained.

2. METHODOLOGY

2.1 Vertical Datums

Two types of vertical datums are often used in studies on the coastal area around Lake Erie: the ellipsoid datums including World Geodetic System 1984 (WGS84), North American Datum of 1927 (NAD27), and North American Datum of 1983 (NAD83); and the orthometric datums including North American Vertical Datum 1988 (NAVD88), North American Geodetic Vertical Datum 1929 (NGVD29), Canadian Geodetic Vertical Datum 1928 (CGVD28), and International Great Lakes Datum 1985 (IGLD85). Among these datums, NAD83 is the horizontal control datum for North America; NAD27 is the former horizontal control datum for North America; NAVD88 is the vertical control datum for the United States; NGVD29 is the former vertical control datum for North America; CGVD28 is the vertical control datum for Canada. IGLD85 is the datum that is used in the Great Lakes area and that uses dynamic heights based on gravity of the measured point and normal gravity of 45degree latitude (IGLD85 Report, 1995). For the former control datums, although they are obsolete, many maps and charts were based on them; to utilize these former products, it is important to convert their data to new datums so that they can be compared with new ones.

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Each point in this area may have the height defined in several datums. The conversion system is designed to compute the desired height in any other datum when its value in one datum is provided. The key is to build the relationship between these datums and express it in a suitable way.

2.2 Investigative Method

If the relationship between two datums can be expressed in a simple mathematic model, the transformation between them will be easily accomplished. Unfortunately, the mathematic model between datums is either too complicated or inexistent, except for the one between NAD83 and WGS84. NAD83 is based on a geocentric origin and the Geodetic Reference System 1980 (GRS80). The ellipsoid of GRS80 is very similar to the ellipsoid of WGS84, and the relationship between them is very simple. Actually, the transformation between these two ellipsoids is a 3D seven-parameter Helmert transformation (Schwarz, 1989). But for transformation involving other datums, the mathematic model that describes the relationship is too complex to implement. An easy and effective way is to render their relationship, i.e., difference, as data grids; then the datum transformation process can use these grids and do a simple interpolation for each point. These data grids are generated using numerous observed difference values.

NGS has developed geodetic toolkits using these data grids to compute the datum shift. These toolkits include the following: NADCON (Mulcare, 2004), which computes the horizontal shift between NAD27 and NAD83; VERTCON (Milbert, 1999), which computes the height shift between NGVD29 and NAVD88; GEOID99 (NGS, 2000), which computes the height difference between NAD83 and NAVD88. Besides these, an online Toolkit of NGS can be used to perform height conversion between NAVD88 and IGLD85. These toolkits can provide the modeled datum shift in the form of grids. The modeled datum shift is based on nationwide observations and adjustments, so the data grids are also nationwide. And these data and software have all been published. We can download the grid files of our interest area from the Internet to use in our system. For CGVD28, the Geodetic Survey Division of Natural Resources Canada developed the Canadian Gravimetric Geoid 2000 (CGG2000) (Véronneau, 2000) model to compute the difference in height between NAD83 and CGVD28. In this research, the latest model of CGG2000, HTv2.0, was downloaded from the Internet, and the data grids were extracted from its database. Collections of all these data grids comprise the conversion part of our database.

2.3 Database and Procedure

As mentioned above, Table 1 lists all the data grids extracted from the published resource on the Internet.

Table 1. Components of the Grid Model

ID	Description	Grid Spacing	Source
1	NAD83-NAD27	15'	NADCON
2	NAVD88-NGVD29	3'	VERTCON
3	NAVD88-NAD83	1'	GEOID99
4	CGVD28-NAD83	1'	HTv2.0
5	NAVD88-IGLD85	3'	http://www.ngs.noaa.gov/TOOLS/IGLD85/

The data grids listed in this table are combined into the database of our system. When the system does the conversion between any two datums listed on Table 1, it introduces the corresponding grid models, reads node values of the grid at which the point locates, and interpolates the value for that point.

Additionally, a comprehensive transformation tool VDatum developed by Milbert and Hess has been implemented in six sites around the United States. Its open code is a useful source for our system. And according to the algorithms of VDatum (Milbert, 2002), it is unnecessary and inefficient to do the transformation directly between any two datums. The efficient way is to find some datums as principle datums that connect all datums together. Then the transformation of any two datums can pass through the path linked by the principle datums. As we can see on Table 1, NAD83 and NAVD88 connect all other listed datums. Then in our system, we can see the path of all datums as follows (Figure 1).

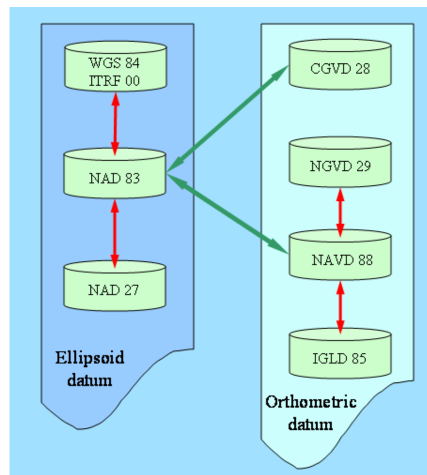

Figure 1. Transformation Routine

According to this figure, for example, if we want to convert the data from CGVD28 to NAVD88, the system will find the minimum path from CGVD28 to NAVD88. Then it converts the data from CGVD28 to NAD83, then to NAVD88. To use this procedure, the user first needs to provide the point’s height and its location (Latitude and Longitude) and then select the CGVD28 as the source datum, NAVD88 as the target datum. Transformation for a set of points is also supported by this system.

3. RESULTS AND VERIFICATION

In this research, an area from N41°15' to N42°30' (latitude) and from W80°15' to W83°30' (longitude) is chosen as the test area. In this test area, 12 benchmarks in USA are chosen and compared (see Figure 2). Because of space limit, we only list 6 of them in the following tables. Table 2 list these benchmarks’ PID (Point ID), location, height in NAVD88, IGLD85, and NGVD29. Table 3 lists the corresponding values of these benchmarks computed from the NAVD88 values by our system and the differences between the original and the computed values.

Table 2. Information of Selected Benchmarks in USA

ID	PID	Latitude (ddmmss.ss)	Longitude (ddmmss.ss)	NAVD88 (meter)	IGLD85 (meter)	NGVD29 (meter)
1	MC0269	41 41 35.00	83 28 25.00	175.527	175.459	175.717
2	MB1625	41 45 38.00	81 16 56.00	175.981	175.918	176.209
3	MC0331	41 53 56.00	83 21 30.00	176.470	176.406	176.640
4	MC0984	41 32 34.54	82 43 54.65	177.309	177.238	177.521
5	MC0873	41 57 35.00	83 15 25.00	177.652	177.589	177.824
6	MB1563	41 32 23.93	81 38 02.94	177.800	177.731	178.030

Note: the longitudes in this table are positive west.
Benchmark data source: NGS/NOAA website: http://www.ngs.noaa.gov/cgi- bin/datasheet.prl

Table 3. Values Converted from NAVD88 and the Differences between them

ID	PID	IGLD85 (meter)	NGVD29 (meter)	Diff.(IGLD85) (centimeter)	Diff.(NGVD29) (centimeter)
1	MC0269	175.460	175.722	0.1	0.4
2	MB1625	175.918	176.207	0.0	-0.2
3	MC0331	176.407	176.640	0.1	0.0
4	MC0984	177.238	177.523	0.0	0.2
5	MC0873	177.590	177.824	0.1	0.0
6	MB1563	177.731	178.030	0.0	0.0
RMS				0.1	0.3

Note: RMS is computed using all 12 benchmarks.

Table 4. Information of Selected Benchmarks in Canada

ID	Station Number	Unique Number	Latitude (ddmmss)	Longitude (ddmmss)	CGVD28 (meter)
1	11965	70U668	42 17 30	82 42 18	176.800
2	11975	59U3033	42 20 18	82 55 48	177.490
3	11985	70U670	42 14 42	83 06 06	178.280
4	11995	59U510	42 08 00	83 06 54	181.210
5	12005	24U3514	42 03 30	83 06 48	176.970
6	12065	71U102	42 02 18	82 43 54	190.630
7	12120	65U3647	41 54 36	82 30 30	175.780
8	12250	57U9501	42 15 36	81 55 00	175.350

Note: the longitudes in this table are positive west.
Benchmark data source: MEDS/FOC website: http://www.meds-sdmm.dfo-mpo.gc.ca/meds/

Table 5. Differences between the Original and Computed Values

ID	Unique Number	IGLD85 (Original)	IGLD85 (Computed)	Difference (centimeter)
1	70U668	176.800	176.746	5.4
2	59U3033	177.486	177.438	4.8
3	70U670	178.281	178.225	5.6
4	59U510	181.210	181.153	5.7
5	24U3514	176.963	176.911	5.3
6	71U102	190.618	190.570	4.8
7	65U3647	175.784	175.718	6.6
8	57U9501	175.338	175.295	4.3
RMS				6.3

Note: RMS is computed using all 59 benchmarks.

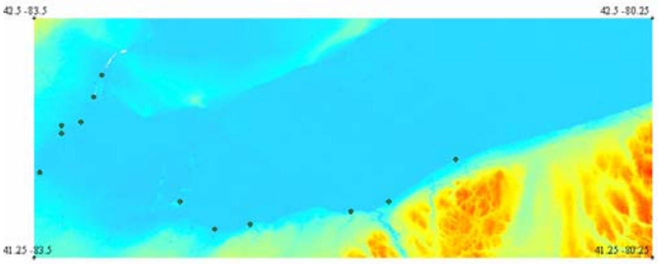

Figure 2. Selected Benchmarks on USA side of Lake Erie

Also, in this area, 59 benchmarks (see Figure 3) around 8 stations in Canada were chosen to verify. Table 4 and Table 5 (above) only list 8 of these benchmarks, including their original values in CGVD28 and IGLD85, the corresponding values in the IGLD85 datum computed from CGVD28, and the differences between them.

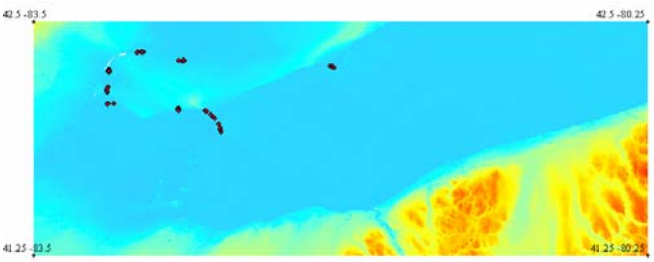

Figure 3. Selected Benchmarks on Canada side of Lake Erie

From Table 3, we can see that the differences between the original and converted values in the United States are very small. But in Table 5, the differences become larger for various reasons. It may be caused by error of the difference model between the two datums when there is direct transformation between the two datums. But if the transformation is indirect, it will be caused by error of all of the difference models used to accomplish the transformation. Here, for transformations from CGVD28 to IGLD85, three grid models are used: CGG2000, GEOID99, and model of difference between NAVD88 and IGLD85. Thus in Table 5, the error is much larger than the error in Table 3. But even the error in Table 5 is not that large, and it is acceptable for geospatial data processes.

4. DISCUSSIONS

This conversion system is simple, but it is easy to extend, if needed. The extension of this system is discussed below.

If we want to accomplish the transformation between some new datums, we need to provide the relationship between the new datums and the existing datums in this system. This relationship, i.e. difference, can be described as a mathematic model, or a grid model.

For vertical datum conversion, more attention must be paid to accuracy. The accuracy of this system depends on the model used between datums and the path of transformation. It shall be considered in different ways. If there is direct transformation between two datums, the accuracy of transformation depends on the accuracy of the difference model between these datums, which is usually in the form of a grid model. Most datums are the result of adjustments based on numerous (millions or more) observations; these observations make it impossible to describe the datums in mathematic models that will fit nearly all of the observations. Thus the grid model is commonly used with three advantages: it easily fits the observations; it is easy to calculate the value needed; and results from the grid model are more reliable and closer to the observations when grid spacing is close to observation spacing. It is apparent that choosing suitable grid spacing is more important to the accuracy of the model than using a more advanced interpolation method.

If there is indirect transformation, the error of all models used in this transformation will be introduced into the conversion error. There are several ways to minimize this error. If the difference model between the source datum and target datum can be obtained, this difference model can be combined into the conversion system so that direct transformation can be executed. Otherwise, the necessary transformation path needs to be minimized. Minimizing the transformation path means reducing the error to the greatest extent. If there are several paths to accomplish the transformation, the system should choose the most accurate path. To do this, more information needs to be included in the system such as the accuracy of the direct transformation between any two datums. This accuracy is quantified according to the accuracy of the difference model between two datums.

The system described in this paper can be used for the seamless integration of spatial data from water to land in the Lake Erie coastal area. Combined with the Water Surface Model, it can determine the relationship between shorelines defined based on different datums.

5. ACKNOWLEDGMENTS

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