Documentation for the GPS Benchmark Data Set of 23-July-98

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Introduction

The GPS benchmark data set was obtained from a synoptic data based retrieval on July 23, 1998. The general retrieval parameters were that each point must be in the conterminous United States, must have an orthometric height in the NAVD 88 datum established by geodetic leveling, and must have an ellipsoidal height in the NAD 83 datum established by GPS surveys of 10 ppm horizontal accuracy (or better). Both the NAVD 88 and the NAD 83 datums are tide-free. After retrieval, the data were cleansed of outliers that could not be ascribed to gravimetric geoid model error. The result is a data set suitable for testing of geoid and global geopotential models. Details on the data components, the datums, retrieval parameters, and the data cleansing process can be found below. The data are located at www.ngs.noaa.gov/GEOID/GPSBMS/gpsbms.html

The GPS Ellipsoidal Heights

The National Geodetic Survey (NGS) has recently completed a major project: establishment of a high accuracy Federal Base Network (FBN), and an associated Cooperative Base Network (CBN), through nationwide measurement of GPS baselines of 1 ppm accuracy or better. The FBN stations are located at a nominal 1° x 1° spacing, are surveyed to 1 ppm accuracy, and are maintained at the expense of NGS. A portion of the FBN is set at a nominal 3° x 3° spacing, and is surveyed to 0.1 ppm accuracy. NGS encourages individual states to establish additional 1 ppm stations at about 15' x 15' spacing. These additional stations are designated CBN. The FBN and CBN stations are often observed in a single cooperative GPS survey, frequently known as a High Accuracy Reference Network (HARN). These surveys are typically performed on a state-by-state basis (Milbert and Milbert 1994, Bodnar 1990).

One of the objectives of the FBN/CBN effort is to upgrade the accuracy of the geodetic control within a state. This is done by occupation of existing high order control points, connected by classical, terrestrial measurements, with subsequent readjustment. It is clear that those FBN/CBN points which are on NAVD 88 leveled benchmarks provide a powerful data set for accuracy assessment and improvement of geoid and global geopotential models. Figure 1 displays the locations of 5168 points that are leveled benchmarks with NAVD 88 Helmert orthometric heights, and which have GPS measured ellipsoidal in the NAD 83 reference system as of July 23 1998. The irregular distribution illustrates the state-by-state approach to the surveying, and the differing levels of state participation.

The FBN/CBN (HARN) survey effort began with Tennessee in 1990, and fieldwork on the project was completed in Illinois in 1997. Over this period major advances were made in GPS receivers, processing models, vector reduction software, orbit accuracy, and in the GPS

constellation itself. In addition, the surveys were designed to provide accurate *horizontal* control. Data reduction and analysis procedures focused on horizontal accuracies. Typical observing procedures are static, and involve occupation of a point for about 6 hours on two different days (three days for 0.1 ppm). Orbit relaxation was used for the 0.1 ppm coordinates until 1994 when improved orbit accuracies removed the need for that particular process. Meteorological data were not always taken on site. Only recently has the influence of antenna phase center variation (Schluper et al. 1994) been incorporated into processing software. For these reasons, the FBN/CBN surveys can bot be considered as a homogenous set. And, one must expect a level of error in the GPS ellipsoidal heights greater than that associated with continuously operating GPS receivers.

In addition to the heterogenous character of the FBN/CBN, an additional category of GPS surveys is designated the User Densification Network (UDN). The UDN consists of GPS or conventional horizontal surveys of 10 ppm relative accuracy or better and/or second-order, class II geodetic leveling. These surveys were performed by (or for) national, state, or local governments or other entities, and are deemed as providing significant contribution to the public good. NGS acts as a depository and dissemination point for these data. Since UDN surveys are frequently performed for horizontal control requirements, one can see a wide variation in the ellipsoid height accuracies. Sometimes, UDN height accuracy is very good, due to the shorter line spacing of the survey points. The UDN GPS benchmarks were retrieved due to the information they may provide on fine scale geoid model error. One should note that the character of UDN surveys, plus the issues discussed above regarding the FBN/CBN surveys, cause the GPS benchmark ellipsoid heights to have heterogenous accuracy.

High accuracy GPS surveys (1 ppm or better) were processed through either OMNI or PAGE4 reduction software. These programs do a complete computational removal of the solid Earth tide, including the permanent part of the solid Earth tide. While solid Earth tide corrections are not required for lower accuracy (10 ppm) GPS surveys, these data are constrained to fit the FBN/CBN. Thus, the GPS ellipsoidal heights are in a tide free system.

The NAD 83/ITRF94(1996.0) Transformation

The coordinates of the GPS benchmarks stored in the NGS database are in the NAD 83 datum. While most of the points in that datum are from a horizontal, classical network, the NAD 83 was controlled by VLBI and Doppler data sets, and can be considered three-dimensional. Over the years, as GPS surveys were incorporated into the network, they were connected into the three-dimensional framework. The NAD 83 reference system differs from modern ITRF systems, primarily due to a non-geocentricity. Richard Snay, National Geodetic Survey, has computed the seven parameter Helmert transformation from NAD 83 to ITRF94 (1996.0) with 8 points common to both reference systems. The RMS of fit was 13 millimeters (mm).

Transformation from NAD 83 to ITRF94(1996.0):

Delta X	-0.9738	+/-0.0261 m
Delta Y	+1.9453	+/-0.0215 m
Delta Z	+0.5486	+/-0.0221 m

Rotation X	-0.02755	+/-0.00087 arc sec	
Rotation Y	-0.01005	+/-0.00081 arc sec	
Rotation Z	-0.01136	+/-0.00066 arc sec	
Scale	-0.00778	+/-0.00264 ppm	(0.0 scale difference applied)

Note that in the application of the transformation, the scale difference is not applied. The reason is historical. After the NAD 83 readjustment, GPS surveys were performed. It was felt that the scale of these GPS surveys was superior to that of the existing network. So, while the GPS vectors were rotated into the NAD 83 frame prior to adjustment, no scale difference was ever applied. For this reason, when one considers the set of GPS coordinates in the NAD 83 reference system, the scale should be essentially identified to that of the ITRF94(1996.0).

The transformation above was applied to the set of GPS benchmarks in the NAD 83 reference system to obtain the file of GPS benchmarks in the ITRF94(1996.0) system. All points, whether flagged as outliers or not, were transformed. Note that the transformation has no influence whatsoever on the NAVD 88 orthometric heights.

The Benchmark Orthometric Heights

The NAVD 88 datum is expressed in Helmert orthometric heights, and was computed in 1991. The network contains over 1 million kilometer (km) of leveling at precisions ranging from 0.7 to 3.0 mm/√km, and incorporates corrections for rod scale, temperature, level collimation, astronomic, refraction, and magnetic effects (Zilkoski et al. 1992). For geoid analysis in a local region, leveling can be considered nearly error free. Accuracy assessment of leveling at a national scale is problematic. An interesting result is that shown in Figure 8 of Zilkoski et al. (1992). Two independent leveling data sets that of Canada and that of the United States, match at the 11 cm level or better at 14 points along the Canadian-U.S. border. While repeatability is not a measure of accuracy, the agreement is remarkable.

The NAVE 88 datum was realized by a single datum point, Father Point/Rimouski, in Quebec, Canada. The strategy and the value of the constraint were based on a number of factors. But, the foremost requirement was to minimize recompilation of national mapping products. Thus, there is no guarantee that the NAVD 88 datum coincides with the normal potential, U°_ defined by the GRS80 system, nor with the level of global mean sea level. Smith and Milbert (1998) estimate that the NAVD 88 vertical datum is 31.1 cm below the current best estimate of the Earth's best-fit global geopotential. Tests show the vertical datum bias to be nearly constant throughout the conterminous United States.

In addition to the general requirement of having an NAVD 88 Helmert height in the conterminous United States, the leveled benchmarks were also selected according to a number of categories:

A - Adjusted.
B - Hand Keyed but not Verified.
C - Computed from nearby Bench Marks.

R - Reset.
M - Readjusted due to earth movement.
H - From Horizontal Branch.

Benchmarks in other categories were not retrieved:

P - POSTED - Force Fix to NAVD88.
N - Determined by Single Spur.
O - From Horizontal Branch but Other Agency.

Briefly, “adjusted” benchmarks form the bulk of NGS data. Using more recent software, these level surveys were checked and adjusted into the network. “Hand keyed” benchmarks refer to historical data (typically associated with the NGVD 29 datum) that have been adjusted and keyed manually, but have not been processed through the full set of more recent data checking and adjustment software. “Computed from nearby bench marks” refers to the same to the same historical data as “hand keyed,” but are incomplete in some respect, most likely due to superseded and/or missing adjusted heights. “Results” benchmarks denote geodetic leveling over short distances to establish a replacement mark for a benchmark, and usually have only one network point connection. “Readjusted due to earth movement” benchmarks have elevations computed from the most recent leveling measurements in areas of known vertical motion. “From horizontal branch” benchmarks represent short level tie data measured by NGS in the course of performing horizontal control surveys.

For the categories that were not retrieved: “Posted” benchmarks were withheld from the NAVE 88 general readjustment due to excessive misclosures. After the readjustment, the troublesome survey lines were fit to the network, and the points were flagged. “Determined by single spur” benchmarks are established from only one network point, and are not considered sufficiently reliable for this data set. “From horizontal branch but other agency” benchmarks are short level ties performed by other agencies when conducting horizontal control surveys. Due to issues of data reduction, this category was not retrieved. In addition, control points obtained from standard trigonometric leveling were not considered to be of sufficient accuracy. And, benchmarks established from GPS surveys were not used. While such orthometric heights can be accurate, a data set independent of any underlying geoid model was desired.

Note that no retrieval criterion was placed on the accuracy of the leveling surveys for the benchmarks. Instead, the data set format (Appendix 1) contains codes for the relative accuracy of the orthometric heights. It was felt that, given the high relative accuracy of geodetic leveling, that even lower order leveling could provide valuable checks.

The NAVD 88 vertical datum (while subject to a constant offset) should be considered as a tide free system. The leveling reduction program does a complete computational removal of both the direct and indirect components of the Earth tide, including the permanent part, as part of the “astronomic” correction (Balazs and Young 1982).

In closing this section one must recall that a Helmert orthometric height is not a true

orthometric height. This difference lies in the error in the estimate of the mean value of gravity along the plumb line between the surface and the geoid. The Helmert height is based on a model of an infinite Bouguer plate with a uniform density of 2.67 gm/cm³. Variations in density and topographic relief will cause departures of Helmert heights from true orthometric heights. As a gauge on the influence of rock density variation, Heiskanen and Moritz (1967, pp. 169) show a 4 mm error in Helmert height for a point at 1000 m elevation and with a constant 0.1 gm/cm³ surficial density departure from 2.67 gm/cm³. Such error is proportional, so that if one assumes an average density of 2.87 gm/cm³ (e.g., diorite/gabbro combination or an alkaline basalt as found in the Rocky Mountains) distributed as a Bouguer plate with an elevation of 3000 m, then one would obtain a Helmert height error of 2.4 cm. Terrain variations also influence the mean value of gravity along the plumb line. Heiskanen and Moritz (1967, pp. 169) quote a comparison of a Niethammer height and a Helmert height for a point at 2504 m elevation in the Alps. The error in estimating the mean gravity (23 mGal) causes a height error of 6 cm. Thus, one can expect a certain level of GPS benchmark/geoid model misclosure in the mountains solely due to the character of Helmert orthometric heights.

Data Set Cleansing

The objective in cleaning the gravity data set was to flag those points whose error could not be ascribed to a high resolution geoid height model. The basic approach entails locating misclosures between a point's ellipsoid height, h, orthometric height. H, and geoid height, N, where these heights are expected to obey the theoretical relationship:

$$h=H+N$$

Since the geoid is formed by integration of gravity data, one can expect geoid error to be correlated over distance. Thus, the appearance of a large (e.g., 3 m) leads one to suspect the GPS or the leveled heights as the probable source. Such outliers are flagged in the data set (see data set formats, Appendix 1), the data record is never deleted.

A geoid model was created by applying the NAD 83/ITRF94(1996.0) datum transformation in reverse tothe G96SSS geoid height model. The result is a gravimetric geoid model in the NAD 83 system, which is denoted G96S83. This model is used to compute misclosures in the sense of:

E=G96S83 geoid height - (NAD 83 ellipsoid height - NAVD 88 orthometric height).

A mean offset of 47.2 cm was computed and removed from the misclosures. This mean offset is a combination of the 12.0 cm offset in the underlying G96SSS model and a 35.2 cm offset in the NAVD 88 vertical datum (when both are referred to global mean sea level). A fit of a tilted plane to the misclosures indicates the possibility of a 0.01 ppm trend in the North-South direction. The lack of an East-West tilt indicates that there is no strong height dependence in the NAVD 88 datum bias, as heights in the conterminous U.S. have a strong East-West correlation.

The simple Gaussian covariance function of Smith and Milbert (1998) (where L=400 km

and $C° = (0.095)^2 m^2$) was used to predict the expected misclosure by using least-squares collocation with noise (Moritz 1980, p. 102-106). The collocation was not used to establish an optimal height conversion or geoid improvement. Rather collocation was used to model the general trends of the misclosures and easily highlight local departures (outliers) from the trend.

The residuals from the collocation fits were examined over a progressively tighter set of tolerances, where a new collocation computation was performed after a given set of outliers were flagged for rejection. The first round of rejections were made with a+/= 50 cm tolerance. And, in subsequent rounds, the tolerances were eventually lowered to +/- 10 cm. In no circumstance was a point automatically rejected for exceeding a tolerance. Each large misclosure was graphically displayed to show its relationship to its neighbors in a 1° x 1° degree block before a judgement was made. In addition, when outliers were found in mountainous regions, such as the Rocky Mountains or the Appalachians, those points were typically not flagged for rejection. This is due to certain theoretical and computational inaccuracies related to terrain corrections and gravity reductions in the G96SSS geoid model computation (Smith and Milbert 1998). While it is likely that a number of GPS benchmark outliers in the mountains are due to GPS or leveling error, the points are not rejected unless the error is unequivocal. In addition, an outlier was not rejected if it did not have sufficient neighbors to verify that it was a localized error.

211 GPS benchmark points were flagged for rejection. The misclosures range from a maximum of +/- 4 meters to +/- 10 cm. It was found that one could not reliably identify outliers below a 10 cm level, although this varied with the region of the country. The RMS of 5168 collocation residuals, after cleansing, was 5.25 cm. This RMS value was assigned as the random error component in the last round of the collocation with noise computation.

In two circumstances, all GPS benchmark points were rejected in an area, irrespective of their misclosures. These cases were regions of known subsidence due to the pumping of underground water. One region was the Houston-Galveston area in Texas, and the other region was the Casa Grande area in Arizona. While it is true that the leveling and the GPS work can be considered correct for those points, the absence of vertical motion models makes these points useless for geoid studies.

Certain patterns were seen in the process of outlier examination. For example, it was necessary to flag a disproportionate number of “reset” benchmarks. As discussed earlier, these points are established through short level ties to replace existing or destroyed marks. However, these surveys are typically only single mark ties, and are less reliable. It is seen that the reset GPS benchmarks, as a category, provide useful information on the geoid. However, the number of rejections demonstrate that reset benchmarks must be used with caution.

Another pattern seen in outlier examination was the presence of isolated misclosures along the coast. In some cases these points contain the word “TIDAL” in their name. On occasion, a series of nearly identical, sizable misclosures can be found for points on islands. These sets of GPS benchmark outliers are most likely due to the fact that the orthometric heights are not in the NAVD 88 datum. Rather, the elevations are on some local vertical datum derived from a tide gage.

Other patterns seen are of a regional character. For example, the GPS benchmark misclosures in South Carolina are remarkably small. This HARN survey was one of the most recent GPS survey, and was performed with short station spacing. The GPS ellipsoid heights are extremely accurate in this state. In addition, recent, extensive leveling was performed. These data show very small misclosures (2.6 cm RMS), and demonstrate the high accuracy of the geoid model in low elevation areas.

By contrast, the GPS benchmark misclosures in Florida show systematic patterns of approximately +10 cm and - 10 cm. The misclosures are so prevalent that it is essentially impossible to distinguish points as outliers. Many points share systematic offsets in the ellipsoid heights. These problems are also seen in network adjustments of GPS vectors (which do not involve the geoid or leveled benchmarks). The GPS network in Florida was only the second HARN ever performed. And, the adjusted ellipsoid heights were subject to all the systematic effects discussed at the beginning of this paper. While newer GPS surveys have been performed, they often tie into the old, erroneous control, and propagate these systematic errors. For an example of the situation in Florida, one can inspect the misclosures in the vicinity of 30.5° N, 278.3°E. One can find misclosures of - 12.6 cm and +9.1 cm for two points only 10 km apart. The troublesome GPS benchmarks are not flagged for rejection because it is not clear which points, irrespective of the size of misclosures, can be considered correct.

Problems in the GPS ellipsoid height network are not confined to Florida. For example, one may find a set of systematic outliers along the coast of New Jersey (34.9° N, 285.5°E). These are GPS ellipsoid height problems, since numerous problems have been found in GPS adjustments in that state due to inconsistent network adjustment constraints (Maralyn Vorhauer, personal communication, 1998).

It must be repeated that GPS benchmarks were only flagged if the misclosure was clearly due to a GPS or a level network source. Patterns of misclosures can be found, for example, in the Rocky Mountains. But, such misclosures may be due to the geoid model and are retained. One notable pattern of misclosures, found in a low elevation area, is on the Eastern shore of Lake Michigan (43.4-44°N, 273.5-273.7°E). It is believed that these misclosures are of gravimetric origin, probably related to marine data taken on the Lake itself. These misclosures are not flagged for rejection.

Finally, a cautionary note must be made regarding the possibility of long scale (200-400+km) systematic error in the GPS heights. A number of HARN surveys were controlled by 0.1 ppm stations established with orbit relaxation procedures. Intercomparisons with newer GPS ellipsoid height control, derived form CORS (continuously operating reference stations), show systematic height errors can reach the 8- 10 cm level. It is believed that the collocation residual RMS of 5.25 cm may reflect a portion of this error. Despite these instances of GPS network problems, the GPS benchmark data set has been found to be very useful in geoid and geopotential model tests.

Tests Using GPS Benchmarks

A brief sketch is now made of geoid and global geopotential tests that have been performed with the growing NGS GPS benchmark data set. This section illustrates the utility of GPS benchmarks in the evaluation and improvement of geoid and global geopotential models.

Milbert (1991a) reported one of the first evaluations of the GEOID90 model using data in the Commonwealth of Virginia. Even at this early time of GPS surveying, it was possible to isolate a 13 cm discrepancy at benchmark TOANO 2. This discrepancy was traced to the fact that TOANO 2 was on a local mean sea level datum, and not part of NGVD 29. A portion of that report can be found in Milbert (1992). Some results from one of the first studies of a statewide HARN (Oregon) can be found in Milbert (1991b).

Milbert (1995) first used a nationwide GPS benchmark data set for geoid improvement in computing the G9501C geoid model by collocation of 1889 geoid/GPS benchmark misclosures. The empirical covariance function was extremely smooth, having a correlation length of 500 km (and power of $(18.5)^2$ cm^2). The residual statistics for G9501 had a variance of $(6.5)^2$ cm^2 which dropped to a covariance of $(2.6)^2$ cm^2 for points spaced only 5 km apart. This 6.5 cm figure was an independent measure of the random noise in the GPS ellipsoid heights.

Rapp (1997) discusses the problem of computing a geoid undulation from a set of geopotential coefficients, and uses GPS benchmarks to illustrate the need to apply an appropriate correction. This study lead to the computation of the correction coefficients available at the NIMA EGM96 WWW page (http:/164.214.2.59/GandG/wgs-84/egm96.html).

The global geopotential model, EGM96, was computed after the “beta” test of 5 models (Lemoine el al., 1997). Smith and Milbert (1997a) analyzed the beta models with 2497 GPS benchmarks in th conterminous United States. Through analysis of misclosure statistics gathered into elevation cohorts, the X02 and X05 models were found to be best. In addition, commission error was identified in the North United States. When the EGM96 model was released, Smith and Milbert (1997b) found a quasi-periodic error around spherical harmonic degree 40 that was confirmed with GPS benchmarks in Oklahoma. One can also find test of these models by Bursa, et al. (1997) and Bursa, et al. (1998) using a 1835 point GPS benchmark data set.

The experiment in combining GPS benchmarks with a gravimetric geoid by Milbert (1995) led to the development of an operational product, GEOID96, which is described in Milbert and Smith (1996), Milbert and Smith (1997), and Smith and Milbert (1998). This latter study illustrates cases where the GPS benchmarks remove long-wavelength commission error in the underlying gravimetric geoid model, G96SSS, while retaining the high relative accuracy over shorter length scales. Smith and Milbert (ibid) also point out that systematic errors in the GPS or the leveling networks, that extend over long distances (e.g., 400 km), will be absorbed into the geoid in this approach.

Numerous studies have been performed of the GEOID96 model, typically using new GPS survey data on benchmarks. One test, by Milbert (1997) explored the GEOID96 model in Ohio. Milbert attempted to develop a local covariance function for improvement, but was hampered by

the current distribution and accuracy of the GPS benchmarks in the state. An abridged version of this study is available (Milbert 1998).

Although not within the conterminous United States, Smith and Small (1998) used an NGS GPS bench marks data set of 31 points to evaluate the CARIB97 geoid model. They found local leveling errors and inter-island discrepancies caused by use of local mean sea level datums for the islands. They recommend future studies that would incorporate models of permanent ocean dynamic topography.

Future Developments

The GPS benchmark data set is a milestone, since it incorporates the completion of the HARN projects. However, the NGS GPS benchmark data set will evolve as the GPS network of the United States continues to grow and improve. The NGS is currently engaged in a new nationwide GPS survey effort for height modernization. The objective of this project is to obtain a set of GPS ellipsoid heights accurate to +/-2 cm (two-sigma). Associated with this new effort will be the analysis of existing GPS control, and the eventual readjustment of the network in 2002. This project will represent an approximate fivefold increase over the current ellipsoidal height accuracy of the nationwide GPS network.

As the new surveys for height modernization proceed, it will be necessary to make format changes to this file to better characterize vertical accuracy in ellipsoidal and orthometric height. Note that in this document, vertical accuracies relative to the coordinate system origin are not stated. They are only inferred, in a qualitative sense, from various codes in the format. It is anticipated that realistic height accuracies in a network or datum sense will be assigned in the course of analysis of the national spatial reference system. The result will be future data sets that are not only more accurate, but will also have better defined accuracies, and will support more sophisticated statistical analysis.

(The July 23, 1998 data set is located at www.ngs.noaa.gov/GEOID/GPSBMS/gpsbms.html)

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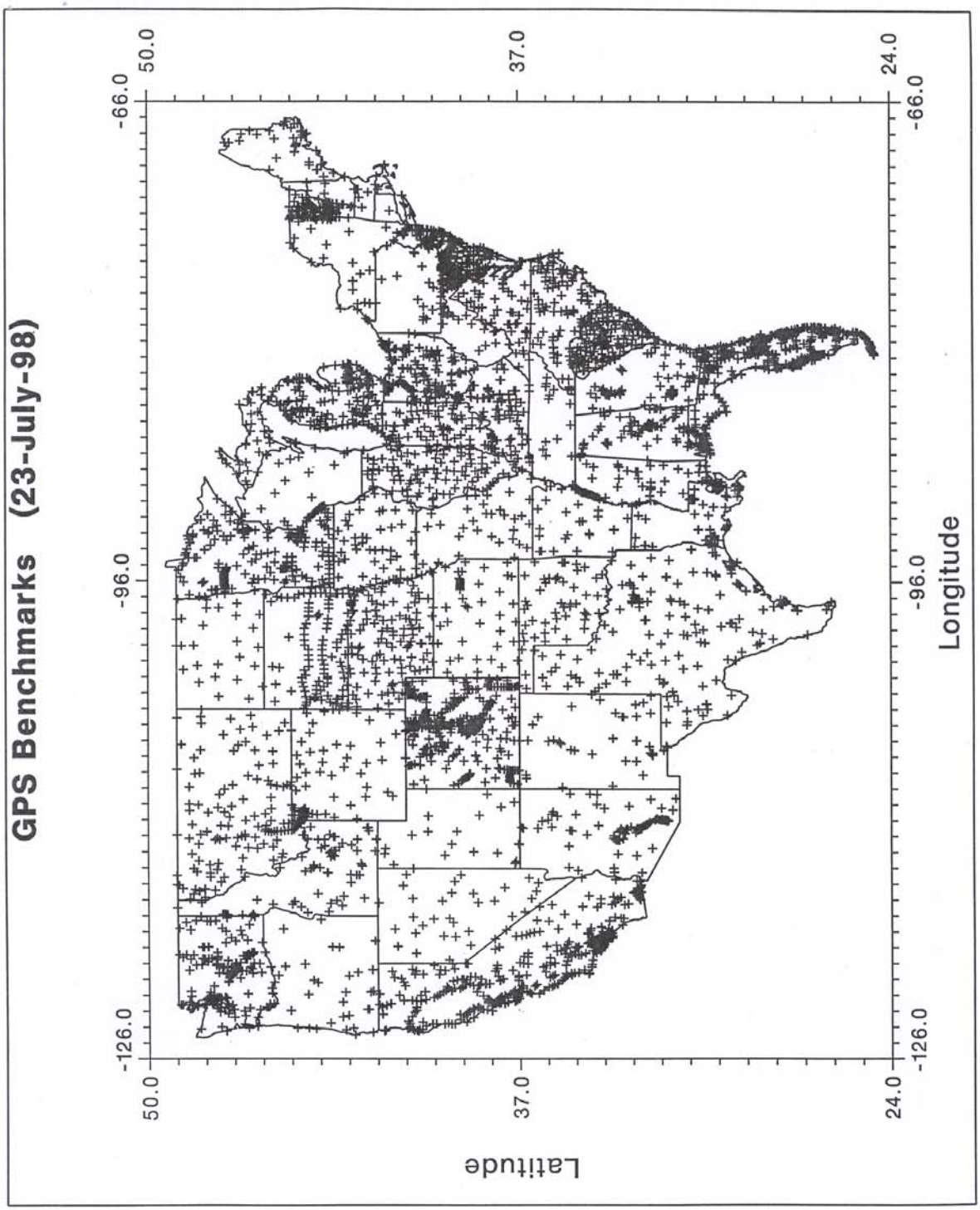

Appendix 1 — Formats for GPS on Leveled Benchmarks

Format of the “GPS/Leveling” file (code: eval2 26-feb-92 dgm)

01 - 04	Station Serial Number	integer, right justified
05 - 34	Station Name	character, left justified
35 - 36	Geodetic Lat., deg.	integer, right justified
37 - 38	Geodetic Lat., min.	integer, right justified
39 - 45	Geodetic Lat., sec.	integer, right justified, units 0.00001"
46 - 46	Code (N/S)	character, upper case
47 - 49	Geodetic Lon., deg.	integer, right justified
50 - 51	Geodetic Lon., min.	integer, right justified
52 - 58	Geodetic Lon., sec.	integer, right justified, units 0.00001"
59 - 59	Code (E/W)	character, upper case
60 - 66	Ellipsoidal Height	integer, right justified, units of 1 mm
67 - 67	blank	
68 - 74	Orthometric Height	integer, right justified, units of 1 mm
75 - 75	blank	
76 - 76	GPS Order (Hztl)	character, upper case
77 - 77	Ortho Elevation Code	character, upper case
78 - 78	Ortho Order	character, upper case
79 - 79	Ortho Datum Code	character, upper case
80 - 80	Reject Code	character, upper case

COMMENTS

Station Serial Number

Arbitrary positive index number. Not to be repeated within a given file.

GPS Order (Hztl)

Code	Explanation
A	Length Relative Accuracy (2 sigma) better than 1:10,000,000
B	Length Relative Accuracy (2 sigma) better than 1: 1,000,000
1	Length Relative Accuracy (2 sigma) better than 1: 100,000
2	Length Relative Accuracy (2 sigma) better than 1: 20,000
3	Length Relative Accuracy (2 sigma) better than 1: 5,000

Ortho Elevation Code

Code	Explanation
A	OHT established using FGCS leveling specifications and procedures, adjusted height determined using NGS Vertical Network Branch procedures, leveling data is in the

	NGSIDB.
B	OHT established using FGCS leveling specifications and procedures, adjusted height determined using NGS Vertical Network Branch procedures, leveling data is not in the NGSIDB. (USGS, COE, some state DOT data.)
C	OHT established using FGCS leveling specifications and procedures, adjusted height is 'posted.' See explanation in the footnote (*) below.
H	OHT established using FGCS leveling specifications and procedures except for the two-mark leveling tie requirement. (Horizontal field party level ties, some state DOTs, some GPS level ties).
L	OHT established using leveling RESET specifications and procedures.
F	OHT established by fly-leveling.
T	OHT established by leveling between control points which are not Bench Marks.
R	OHT established by reciprocal vertical angles.
V	OHT established by non-reciprocal vertical angles.
P	OHT established by photogrammetry.
M	OHT established by scaling from a contoured map.
G	OHT established by GPS observations.
D	OHT established by datum transformations.

*Data for level lines containing 'posted' Bms were purposely not included in the NAVD88 general adjustment. Subsequently, these data were adjusted to NAVD88 by forcing them to fit the existing NAVD88 general adjustment heights.

Ortho Order

Code	Explanation
1	Relative Accuracy (2 sigma) better than 0.7 mm x sqrt (km)
2	Relative Accuracy (2 sigma) better than 1.3 mm x sqrt (km)
3	Relative Accuracy (2 sigma) better than 2.0 mm x sqrt (km)

Ortho Order

Code	Explanation
blank	North American Vertical Datum of 1988
9	National Geodetic Vertical Datum of 1929

Reject Code

An asterisk ("*") indicates a rejection (for various experiments)
Blank indicates no rejection.