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Caribbean datums and the integration of geographical data

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ABSTRACT. **Modern electronic positioning systems are capable of locating a point in the vicinity of the Earth's surface to very high precision. Depending on the sophistication of equipment in use, whether the requirement is relative or absolute and the data processing time available, accuracy from 10 m down to a few millimetres can be achieved in three dimensions. While it is not difficult to measure the position of a point using today's technology, it can be problematic to relate measurements made today to those made in the past. Advances in applications such as Geographical Information Systems (GIS) for example, that integrate geographic data from a wide range of sources may give misleading results if one position on the surface of the Earth can have a number of different coordinate values. This paper is aimed at explaining the reasons behind such dilemma while giving particular examples that relate to the Caribbean region. It defines and explains the different conventions that are adopted while providing local parameters that enable conversion between modern and some of the traditional datums. The reliability of this information is shown to be variable and there is a need for improvement in the quality of parameters that are made publicly available.**

1. INTRODUCTION

The study of geodesy has advanced significantly in recent times, particularly as the analysis of satellite data has provided a global approximation of the geoid. Variations in density through the Earth mean that this figure is a smooth undulating surface similar to that of a flattened pear. The problem of mapping such a surface is impractical, so for this purpose a spheroid or ellipsoid is used to approximate the geoid. Positions are then provided as geodetic coordinates that are in polar form as shown in Figure 1. Difficulties arise with the way that data has been acquired and stored at national levels, with the compatibility between national conventions, and in integrating further information that is acquired using modern technology. Problems that arise are particularly pronounced when the region is made up of small island states. The Caribbean for example has numerous traditional mapping datums, one or more for each island, and the current trend in regional research and monitoring necessitates integration of data from the different states as well as the superposition of new information. The purpose here is to examine the existing situation with regard to availability and precision of datum conversion parameters. In order to achieve this, the different mapping conventions and processes that are implemented are explained. This commences with a description of the figures that are used to represent the Earth and the adoption of a datum point.

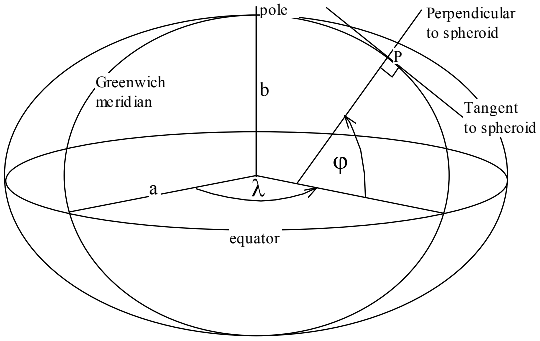

Figure 1. Geodetic latitude (φ) and longitude (λ)

2. SPHEROIDS

Historically, a horizontal datum for a country was established by coordinating a single point in geographical coordinates on a selected spheroid. Astronomical observations would be used to locate the datum point and to provide orientation from there to other points. Triangulation techniques from this origin established other geodetic control points for the country and coordinates for all such points would be computed in geodetic coordinates on a spheroid. Spheroids of different dimensions have been used to represent the Earth, the size and shape of these were observed on the Earth's surface using triangulation techniques and by making astronomical observations. Until recent times, the precise measurements required could only be made on land, so for each landmass different spheroids were adopted. There are in excess of 150 different spheroids that have been used since 1800. Some

Table 1. Parameters of Some Spheroids

Spheroid Name	Semi-major Axis, a (m)	Semi-minor Axis, b (m)	Flattening, f	Eccentricity squared, e^2
Clarke 1858	6378293.645	6356617.938	1/294.26	0.006785
Clarke 1866	6378206.400	6356583.800	1/294.9787	0.006769
Clarke 1880	6378249.145	6356514.870	1/293.465	0.006804
Clarke 1880 modified	6378249.145	6356514.966	1/293.4663	0.006803
South American 1969	6378160.000	6356774.719	1/298.25	0.006695
International 1924	6378388.000	6356911.946	1/297	0.006723

were designed to best fit the geoid over some region; others used all of the world data that was available at the time. Dimensions of some that have been used in the mapping and charting of the Caribbean are given in Table 1 where numerical values are from DMA Technical Manual (1990) and definitions for datums that use these particular spheroids.

For each spheroid a semi-minor and a semi-major axis are defined such that the surface best fits the curvature of the Earth. Therefore, the centres of the different spheroids that have been adopted are not necessarily coincident and neither are their axes necessarily parallel to each other. So, when a datum point and geodetic control network for a country are specified, the spheroid and datum on which the geodetic coordinates are provided must be identified. In situations where different spheroids have been adopted it is apparent that a single point will have more than one defined position, depending on the particular spheroid in use. Furthermore, even on the same spheroid a single point can have different sets of coordinates depending on the datum that is in use. For example, the Provisional South American Datum of 1956 uses the International 1924 spheroid and has La Canoa in Venezuela as its datum point, observations made on this datum give coordinates for Naparima Hill, Trinidad as 10º17’02.416” North, 61º27’22.606” West. This location provides the datum point for the Naparima datum of Trinidad and Tobago which also adopts the International 1924 spheroid, on this datum Naparima Hill has coordinates 10º16’44.860” North, 61º34’22.620” West. So, it is shown that the same point using the same spheroid can have different coordinates using different datums. In this case a few hundred miles separate the datum points and yet the horizontal displacement between the two coordinates for the single point provided is around 650 metres in space.

With the advent of modern satellite aids to positioning that operate on a global basis, a best fitting global spheroid is essential. It is the motion of the satellites themselves that has been observed and used to improve geoidal and hence spheroidal models. Unfortunately there is still disagreement when it comes to applications for positioning on the Earth using satellite data. The Global Positioning System (GPS) that is operated by the United States Department of Defense uses the World Geodetic System of 1984 (WGS84) spheroid with dimensions a = 6378137 m, b = 6356752.314 m as its reference. Another satellite system, GLONASS, that was developed by the former Soviet Union adopts PZ90, which has a = 6378136 m and b = 6356751.362 m. There is a small difference between these dimensions, however the spheroids are further separated by the displacement of their origins in space.

3. PROJECTIONS

Neither the sphere nor the spheroid can be developed to produce a flat sheet, so in producing a map the accepted spheroidal figure of the Earth must be stretched in some way, which gives rise to distortion. The way in which the spheroidal surface is manipulated to produce a map is known as the projection. A grid is placed over the projection to provide a rectangular horizontal coordinate frame to identify points in terms of their distance east and north of some origin. The way that the origin is selected is critical to computations, and the size of the grid will change across the map due to variation in scale with the projection. The concept of scale is straightforward in that the map scale (s_0) is a factor that is multiplied by a distance on the map to give the equivalent distance on the ground. Due to distortion within the projection however, this will not be uniform across the map, but will vary, so a scale factor (s_f) is introduced such that at some point on the map the scale is given by:

$$s = s_0 \times s_f$$

There are a number of types of projection that are in use, a full review is given by Maling (1992). Two that are commonly used for mapping purposes are the Transverse Mercator (TM), and the Lambert Conical Orthomorphic. These projections are both orthomorphic, which means that for any point on the map the scale in the east-west direction is the same as that in the North South direction. This is not true for all projections; for example the early mapping of Trinidad, prior to 1963, used a Cassini Soldner Projection that is not orthomorphic.

To avoid large variations in scale factor nationally, countries that cover a large variation in longitude tend to be mapped using Lambert while those that cover a large amount of latitude use a TM projection. Projections that are used in countries of the Caribbean are identified in Table 2. In some cases, countries are mapped on more than one projection, which leads to a point on the Earth being defined by multiple pairs of grid coordinates, however these are usually significantly different and any confusion becomes obvious. This list provides some of the datums that exist throughout the region, it is not complete and does not necessarily provide the main mapping system for the country. For details of the convention adopted within a particular state, the Survey Board for that particular country should be contacted. It should also be noted that the mapping systems provided in Table 2 are not necessarily adopted or designated by the Survey Board of the country that they represent. In Trinidad, for example, the South American 1969 datum was not adopted by the Lands and Surveys Board of Trinidad and Tobago for mapping purposes, but has been used extensively for mapping South America, and these islands appear on some such sheets.

4. EARTH CENTRED EARTH FIXED (ECEF) COORDINATES

While these are not in everyday used for mapping, an understanding of the relationship between ECEF coordinates and geodetic coordinates is an essential element in the appreciation of datum conversions. The spheroid is a three dimensional figure that is obtained by rotating an ellipse about its semi-minor axis, so a three dimensional Cartesian framework can then be located within this figure such that the origin is at the centre of the rotated ellipse. The Z-axis is then established to be coincident with the semi-minor axis (the axis of rotation and pole) and the XY plane lies on the rotated semi-major axis, which is equivalent to the equatorial plane. The direction of X or Y has then to be defined and it is usually adopted such that the X-axis points towards an arbitrary reference meridian. The computational procedure for converting from φ, λ, h to XYZ and *vice versa* is well defined. As XY and Z form a full three dimensional space and are not restricted to the surface of a spheroid, so φ and λ have to be enhanced with height above the spheroid (h) to define the same space.

It must also be appreciated that the ECEF coordinates X, Y and Z are spheroid dependent. The centres of two different spheroids are not necessarily coincident and their axis need not be parallel, so ECEF coordinates for a point will change with a change of spheroid.

4.1 . International Terrestrial Reference Frame (ITRF)

Boucher and Altamimi (1996) document ITRF and early variations, more recent information can be found on the International Earth Rotation Service (IERS, 2001) web site. Essentially it is an ECEF coordinate frame that is independent of any spheroid, instead it is defined by a set of points in space. These points exist physically on the surface of the Earth and astronomical and satellite observations are made at these stations. Coordinates of the network of stations are adjusted simultaneously as a three dimensional triangulation scheme. Repeating measurements through time enables the axis of rotation of the Earth and centre of mass to be identified hence the origin and Z-axis of a Cartesian system are defined. An arbitrary meridian is used to define the direction of the X-axis. Coordinates of the points used to define the ITRF are made publicly available, as is data that is being continually logged at these stations. Information on the points includes velocity components to account for movement of the Earth's crust. Within the Caribbean there are stations that conform to the National Geodetic Survey (NGS) of America and the International GPS Service (IGS) specifications that are providing data. These are located on the islands of Jamaica, St. Croix, Puerto Rico and Cuba. NIMA (1997) states that the ITRF Cartesian system is coincident with the corresponding ECEF framework for the WGS84 spheroid at the centimetre level.

5. HEIGHT

For the purposes of most land survey operations the height that is adopted is that above some function of sea level, for example the mean value (MSL), where this datum is established through observation by tide gauge(s). The surveyor will normally use leveling techniques to approximate the height of points on land under the assumptions that the sea would adopt a uniform surface under the land if the land were removed and that level surfaces above

Table 2. Projections Adopted

Country	Datum	Spheroid	Projection
Anguilla	A4 astro 1957	Clarke 1880	British West Indies TM
	NAD 1927	Clarke 1866	TM
Antigua	USNHO astro 1943	Clarke 1880	British West Indies TM
Barbuda	NAD 1927	Clarke 1866	TM (with UTM grid)
Barbados	Challenger astro 1938	Clarke 1880	Barbados National TM
	Challenger astro 1938	Clarke 1880	British West Indies TM
	NAD 1927	Clarke 1866	BWI TM (with UTM grid)
Belize	NAD 1927	Clarke 1866	TM & UTM
	British Honduras 1922	Clarke 1858	TM Colony Coordinates
Cayman Islands	IAGS astro Grand Cayman	Clarke 1866	UTM (formerly TM)
	LC 5 astro Cayman Brac.	Clarke 1866	UTM (formerly TM)
	LC 5 astro Little Cayman	Clarke 1866	UTM (formerly TM)
Colombia	South American 1969	S. American 1969	UTM
	Prov. South Am. 1956	International 1924	UTM
	Bogota Observatory	International 1924	Colombia TM
Costa Rica	NAD 1927	Clarke 1866	Costa Rica Lambert N&S
Cuba	NAD 1927	Clarke 1866	Cuba Lambert North & South
Dominica	M12 astro 1945	Clarke 1880 mod	British West Indies TM
	NAD 1927	Clarke 1866	
Dominican Rep.	NAD 1927	Clarke 1866	Dominican Republic Lambert
Grenada	GS 80 astro 1953	Clarke 1880 mod	British West Indies TM
	NAD 1927	Clarke 1866	British West Indies TM
Guadeloupe	Guadeloupe	International 1924	UTM
	NAD 1927	Clarke 1866	Guadeloupe Gauss Laborde
Guatemala	NAD 1927	Clarke 1866	Guatemala Lambert N&S
Guyana	Prov. S. American 1956	International 1924	UTM
	Local	International 1924	British Guiana Colony
Haiti	NAD 1927	Clarke 1866	TM (with UTM grid)
	NAD 1927	Clarke 1866	Haiti Lambert
Honduras	NAD 1927	Clarke 1866	TM (with UTM grid)
	NAD 1927	Clarke 1866	Honduras Lambert N&S
Jamaica	Fort Charles Flagstaff	Clarke 1866	Jamaica Lambert Metre
	Fort Charles Flagstaff	Clarke 1880	Jamaica Lambert Foot
	NAD 1927	Clarke 1866	
Martinique		International 1924	UTM
Mexico	NAD 1927	Clarke 1866	Angular Polyhedric & UTM
	Isla Socorro astro	Clarke 1866	UTM
Montserrat	M36 astro 1958	Clarke 1880 mod	British West Indies TM
Netherlands Antilles		International 1924	TM
		International 1924	UTM
Nicaragua	NAD 1927	Clarke 1866	Nicaragua Lambert N&S
	NAD 1927	Clarke 1866	UTM
Panama	NAD 1927	Clarke 1866	TM
	Panama (Colon)	Clarke 1866	Panama Lambert & Polyconic
Puerto Rico	Puerto Rico 1901	Clarke 1866	TM & UTM
	NAD 1927	Clarke 1866	Lambert
St Croix	NAD 1927	Clarke 1866	St Croix Lambert
St Kitts & Nevis	K12 astro 1955	Clarke 1880	British West Indies TM
	NAD 1927	Clarke 1866	TM
St Lucia	DOS3 astro 1955	Clarke 1880 mod	British West Indies TM
St Vincent	VI Fort Charlotte	Clarke 1880 mod	British West Indies TM
Trinidad and Tobago	Old Trinidad	Clarke 1858	Trinidad Cassini Soldner
	Tobago	Clarke 1858	Tobago Cassini Soldner
	Naparima	International 1924	UTM
	South American 1969	S. American 1969	UTM
Venezuela	Prov. S American 1956	International 1924	UTM
		International 1924	Venezuela TM
		International 1924	Puerto La Cruz Polyhedric
		International 1924	Lake Maracaibo Lambert
		International 1924	Loma Quintana Lambert
		International 1924	Venez. Comp. Secant Conic
	South American 1969	S. American ‘69	UTM
Virgin Is (UK)	Puerto Rico 1901	Clarke 1866	UTM
Virgin Is (USA)	NAD 1927	Clarke 1866	Lambert

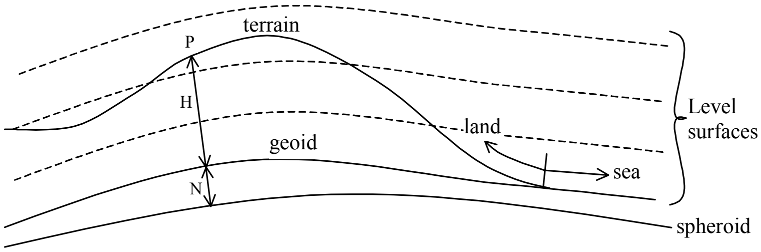

Figure 2. Height Datums

that of the sea are parallel to that which the sea would adopt. Only under special circumstance would efforts be made to evaluate and compensate for errors induced by discrepancies from these assumptions. The height datum is established for a country and it is heights above this datum that are provided for physical features such as benchmarks.

When navigational charts are produced it is common to provide water depths below some low water line, for example lowest astronomical tides (LAT) is used by the admiralty, this being the lowest water level expected under the deterministic tide raising forces. While tides are predictable, actual water levels are subject to random events such as variations in atmospheric pressure. It is therefore difficult to establish an absolute level for the datum and a threshold (typically 0.1 m) may be incorporated into the definition of chart datum. A low water datum is normally adopted because most charts are intended for navigational purposes and by providing lowest expected values a safety margin is introduced. In contrast, when a chart provides height of a land mass this will often be related to some high level, such as mean high water springs (MHWS). Again this is done for safety reasons, to ensure that clearance under bridges is near the minimum value. Two height datums may therefore exist on a navigational chart, neither of which is likely to conform to that of a map of the same area. The exact datums used will depend on the organisation that is producing the chart and different countries will adopt the use of different datums.

Modern satellite positioning devices perform computations that refer to a smooth mathematical surface and therefore provide height (h) above the spheroid in the first instance. To convert these heights to those provided on most maps the geoid/spheroid separation (N) at the particular point of interest must be known. The situation is shown in Figure 2. Edwards (1999) investigated the separation between the geoid and the WGS84 spheroid for Trinidad and found that the geoid is between 41 m and 44 m below the spheroid, varying from the north to the south of the island respectively. Smith and Small (1999) document the CARIB97 (2001) geoidal model that is freely available for the Caribbean region; this covers a large area, but does not provide the resolution that may be required for detailed land mapping purposes.

6. DATUM TRANSFORMATIONS

Fusion or integration of data that have been obtained from a number of sources is a typical requirement of modern technology. In the case of geographical applications, which involve data that includes a position as an attribute, compatibility in terms of a common datum is a requirement. For example, information that is entered into applications such as GIS is typically digitized from existing maps and charts, and new data that is superimposed are likely to have been derived using GPS technology. Existing maps and charts for a given area will not necessarily be referenced to the same datum and data that are acquired using GPS will be provided in WGS84 format. While most GPS receivers make provision for alternative datums, the selection of any datum other than WGS84 will provide results that will have been transformed from the reference frame in which the system parameters are defined. It will be shown here that such parameters are subject to error and should be validated against the precision requirement of the survey in the region of operation prior to their application.

The procedure identified in the sections above is that given coordinates in latitude, longitude and

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Notes for Table 2

1. NAD 1927 is the North American Datum 1927 which has an origin at Meades Ranch (39°13’26.686” North, 98°32’30.506” West) and uses the Clarke 1866 spheroid.
2. British West Indies TM is the Transverse Mercator projection that was implemented by the Directorate of Overseas Surveys of Great Britain for the West Indies. It has a central meridian of 62°, a scale factor at this longitude of 0.9995, latitude of origin at the equator and a false Eastings of 400 km.

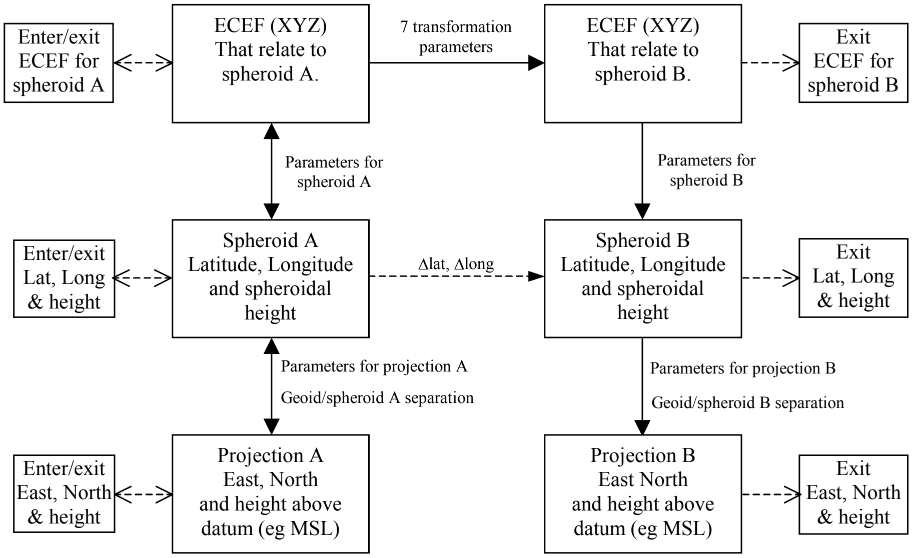

Figure 3. Datum Transformation Process

height on a particular datum, the grid coordinates on some projection can be computed and *vice versa*. The problem now is to transform positional information to an alternative datum and perhaps to a grid that is defined on this second datum. The conversion is normally achieved through a Bursa-Wolf seven-parameter transformation that operates on ECEF coordinates. The computational process is as shown in Figure 3, where coordinates may be entered in any of the three formats on the left side of the diagram. Given the appropriate parameters for the transformation and details of the second spheroid and projection, coordinates in any other format shown on the right can be computed.

Spheroid parameters would normally be the dimension of the semi-major axis and one of the other parameters given in Table 1. Projection parameters would depend on the type of projection. If height is incorporated, then a geoidal model as documented in section 5 is also required. The seven parameters that convert ECEF coordinates between spheroids cater for a shift between origins of the spheroids, rotations about the axis and variation in the spheroidal dimension. Figure 4 shows the concept of three translation parameters (ΔX, ΔY, ΔZ), three rotation parameters (rX, rY, rZ) and scale (s). Computer software that performs the computational processes identified in Figure 3 is readily available and would normally be incorporated into applications for surveying and GIS.

The seven transformation parameters that are used do not represent the change of spheroid completely. The scale value (s) simply represents the change in size of the spheroid, but as the spheroid itself is described by two parameters one number is insufficient to change its shape. As the eccentricity, or flattening values, for spheroids are similar, the error induced in a change of spheroid by the approximation of variation in shape by a single scale value is negligible.

6.1 Transformation Values

Transformation parameters are identified as transforming between a particular pair of datums and the transformation is reversible simply by changing the sign of the values for translation and rotation and inverting the scale. From the numerical example provided in section 2, where different geographical coordinates are provided for one point on the same spheroid, it should be noted that

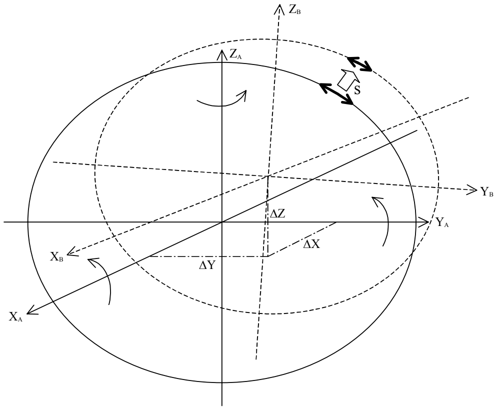

Figure 4. Transformation Parameters

the datum is important in identifying a transformation and not a spheroid.

Numerical evaluation of transformation parameters is normally achieved by undertaking a control survey of identical points on both datums. To solve for the seven variables (seven parameters) at least seven points would be required, however scale might be removed from this list as it can be computed from spheroid details. Furthermore, as spheroids are of similar dimensions, the value for the scale parameter is often accepted as unity. To arrive at an angle of rotation about an axis, the difference in distance between fixed points on the surface of different spheroids is observed. The radius of the Earth is in the order of 6.4×10^6 km, so over short distances the difference in the length of a line between two identical points as measured on different spheroids will be negligible when compared to the radius of the Earth. In such circumstances, the difference in distance and hence the computed value for the rotation of the axis will be less than the error budget for such measurements, hence the rotation cannot be evaluated. It is recommended by Trimble Navigation Ltd (1996) that the control survey area should cover an area of at least 100 km by 100 km of the surface of the spheroid when evaluating rotation parameters. They go on to note that "A seven parameter transformation can give significantly wrong answers when calculated over a small area. Especially when you survey outside of the area bounded by your control or your control geometry is poor". These limitations mean that rotational parameters are usually not computed or provided. The seven parameter transformation is thus often reduced to just three parameters of translation, these being added to the $X_A Y_A Z_A$ Cartesian equivalents for spheroid (or rather datum) A to give equivalent values for datum B and subtracted for the reverse computation. This is known as a Molodensky transformation and is simply a block shift in space.

Table 3 provides National Imagery and Mapping Agency (NIMA, 1997) values for translation parameters between local and the WGS84 spheroid for some of the datums used in the Caribbean. Precision estimates are also provided. Where sufficient redundancy is incorporated in the control networks that were used to derive these values then the precision is derived from the distribution of the parameters obtained, otherwise precisions are allocated some fixed value.

As an alternative to the 7-parameter (Bursa-Wolf) transformation, Figure 3 indicates the option to transform between latitude and longitude. This is known as an affine transformation and provides shift in origin (2 parameters), rotations about the axis (2 parameters, because the coordinate frame is not orthogonal) and scale (two parameters, one with each axis). If the transformation parameters are required over a small region, and the differences in latitude and longitude observed at control points on both datums over the area of interest are found to compare, then it would be reasonable to reduce the number of parameters implemented. Alternatively, consider the section of Table 3 that provides

Table 3. Datum Transformation Parameters from Local to WGS84

Local Geodetic Datum	Region	Transformation Parameters		
		ΔX(m)	ΔY(m)	ΔZ(m)
NAD 1927	Mean solution	-8 ±5	160 ±5	176 ±5
	Caribbean	-3 ±3	142 ±9	183 ±5
	Central America	0 ±8	125 ±3	194 ±5
	Cuba	-9 ±25	152 ±25	178 ±25
	Mexico	-12 ±8	130 ±6	190 ±6
Bogota observatory	Colombia	307 ±6	304 ±5	-318 ±6
Provisional South American 1956	mean solution	-288 ±17	175 ±27	-376 ±27
	Colombia	-282 ±15	169 ±15	-371 ±15
	Guyana	-298 ±6	159 ±14	-369 ±5
	Venezuela	-295 ±9	173 ±14	-371 ±15
South American 1969	mean solution	-57 ±15	1 ±6	-41 ±9
	Colombia	-44 ±6	6 ±6	-36 ±5
	Trinidad & Tobago	-45 ±25	12 ±25	-33 ±25
	Venezuela	-45 ±3	8 ±6	-33 ±3
USNHO Astro 1943	Antigua	-270 ±25	13 ±25	62 ±25
K12 astro 1955	St Kitts & Nevis	-7 ±25	215 ±25	225 ±25
LC5 astro	Cayman Brac.	42 ±25	124 ±25	147 ±25
M36 astro 1958	Montserrat	174 ±25	359 ±25	365 ±25
Naparima	Trinidad & Tobago	-10 ±15	375 ±15	165 ±15
Puerto Rico 1901	Puerto Rico	11 ±3	72 ±3	-101 ±3

transformation parameters for the NAD 1927 datum. This particular datum is used across a huge land mass and translation parameters computed for the whole region are not reliable, so it is broken down into areas and translation parameters evaluated for each area. There will then be discontinuities in the transformations at boundaries between areas and to avoid this inconsistency NIMA (1997) have performed multiple regression analysis of ninth order using latitude and longitude as the regression variables. For large land masses similar regression equations may be available that transform latitude and longitude directly between datums. This technique should only be used across contiguous land masses and therefore the equations that apply to NAD 1927 and South American 1969 datums should not be used in the Caribbean islands. Caution should also be adopted in applying these models at the boundary of their evaluation.

It is apparent that for many of the datums used in the small island states of the Caribbean there have been no surveys conducted to provide transformation parameters at state level. Authorities within some states have undertaken local surveys and parameters may be available on request. It is not unusual to find alternatives to the values given in Table 3, for example the Organisation of American States (2001) provide values for St. Kitts and Nevis (K12 astro 1955) that are stated as being provided by the British Ordnance Survey. The values given for ΔX, ΔY and ΔZ are 9 m, 183 m and 236 m respectively, precision values are not quoted. In this case the ΔY value is 7 m beyond the 25 m precision that corresponds to the value quoted in Table 3. Both sets of numbers are provided by reputable surveying and mapping organisations, yet it is impossible to know which is more accurate without undertaking further survey work.

6.2. Accuracy of a Transformation

By way of a numerical example to indicate differences in coordinates and the effect of precision of transformation parameters, consider a point that is located on the island of Montserrat on the local datum and mapping convention. Reading the grid coordinates for the end of the jetty at Plymouth from the map locates it at 375925 m east, 1846440 m north and taking the height of this point to be zero metres (MSL). Using application software to convert this point to geodetic coordinates gives 16º42'13.18" North and 62º13'33.03" West on the Clarke 1880 (modified) spheroid. The separation between the geoid and this particular spheroid is unknown and must therefore be assumed to be zero at this location. The spheroid is the best fitting figure to the geoid and therefore the separation should be zero on average, so with the lack of further information this average value is accepted. Converting these geodetic coordinates to equivalent ECEF values for this spheroid gives:

X=2847571.55 m
Y=-5406809.64 m
Z=1821286.81 m.

To obtain WGS84 geodetic values the transformation parameters given in Table 3 above for this particular datum must be applied. These are shown in the first line of Table 4, which also then gives the computed WGS84 geodetic coordinates and corresponding UTM grid values for the projection of this spheroid.

There is a large uncertainty of 25 m in the transformation parameters given in Table 3 for this particular datum shift. Rows 2 to 7 of Table 4 show that the effect of varying just one parameter by 10 m moves the grid coordinates by between 5 and 10 m horizontally and varying all three parameters simultaneously by this amount produces a shift on the ground of 17 m.

Table 4 also provides height of the point above the WGS84 spheroid, this is negative which means that the geoid is below the spheroid at this location. Use of the CARIB97 model produces a value to indicate that in this region the geoid is indeed around 41 m below the WGS84 spheroid. However, in order to obtain the values given in Table 4, an assumption was made about the separation between the geoid and the Clarke 1880 modified spheroid. As the transformation process that is being applied is simply a translation, then any value that is applied for the separation between the geoid and the Clarke spheroid will have a direct equal effect on the WGS84 height value. For example, if it were assumed that the geoid is 10 m below the Clarke spheroid, then the WGS84 height would increase from –38 m to –48 m. The corresponding shift in latitude and longitude would be very small, in the order of 10^{-5} seconds. So, the transformation of height between datums is an issue, but it may normally be considered separately to that of latitude and longitude.

The transformation of GPS derived positions to conventional datums offshore is a special problem. The transformation parameters available are computed primarily by comparing coordinates in both systems on land and their accuracy can degenerate rapidly when moving away from this domain. Modern satellite positioning technology works well offshore, the difficulty of obtaining valid transformation parameters is hindered by the

Table 4. WGS84 and UTM Coordinates for a Transformed Point

Parameters			Spheroid coordinates			Grid coordinates (UTM)		Offset (m)
ΔX(m)	ΔY(m)	ΔZ(m)	Latitude North	Longitude West	Height	East (m)	North (m)	
174	359	365	16° 42’ 20.52”	62° 13’ 22.19	-38.29	582854.65	1847160.20	-
164	359	365	16° 42’ 20.57”	62° 13’ 22.49	-42.76	582845.80	1847161.51	8.9
174	349	365	16° 42’ 20.44”	62° 13’ 22.35	-29.82	582850.00	1847157.64	5.3
174	359	355	16° 42’ 20.21”	62° 13’ 22.19	-41.17	582854.69	1847150.63	9.6
184	359	365	16° 42’ 20.48”	62° 13’ 21.89	-33.83	582863.50	1847158.90	8.9
174	369	365	16° 42’ 20.61”	62° 13’ 22.03	-46.77	582859.30	1847162.76	5.3
174	359	375	16° 42’ 20.83”	62° 13’ 22.19	-35.42	582854.62	1847169.78	9.6
184	369	375	16° 42’ 20.87”	62° 13’ 21.73	-39.43	582868.12	1847171.03	17.3

lack of comparable coordinates on an existing datum. The existence of fixed offshore structures in some regions does provide some data, but this is sparse and results are therefore unreliable.

7. DATA ACQUISITION

The acquisition of a base map for a digital application such as a GIS may involve the digitization of existing paper information. To expand the database other information may be similarly digitized, or acquired in the field using survey techniques. The application will dictate the scale and precision required, and there exists a requirement to ensure that datums are compatible, or that a conversion can be undertaken within the accuracy threshold specified. With regard to data that exists on paper or in digital form the validity, datum and precision must therefore be identified to ensure compatibility with the specified requirements. Alternatively field survey work may need to be undertaken. The acquisition of additional field survey data to accompany existing information could involve the use of traditional methods and existing control, or utilise more modern satellite methods. In the case of traditional land survey techniques any data that is acquired will be immediately compatible with that which exists on maps of the area.

Difficulties arise when using GPS in conjunction with existing data, and many GIS applications link this technology together to superimpose position on mapping information in real time. If the data for the base map is digitized from some traditional mapping convention for the country then it will be based on grid coordinates that are derived from a projection of some aged spheroid. The GPS receiver will perform its computations in ECEF coordinates to provide the user naturally with latitude, longitude and height on the WGS84 spheroid. Many GPS receivers provide an interface that enables the user to select a datum from a list and some give coordinates on a selected grid. User selection of any optional spheroid other than WGS84 will instigate a transformation to take place inside the receiver. Transformation parameters are built into many receivers, their precision is likely to be similar to those provided in Table 3 and hence the results presented in Table 4 are applicable in terms of positional accuracy. Positioning equipment that uses satellite data can provide information to a very high accuracy, current practice can degrade this precision when transforming data to make it compatible with existing information. In large continents, such as the United States, the amount of static GPS data acquired in conjunction with existing mapping control will ensure that a transformation is available to provide a conversion that maintains precision at the metre level. In the UK difficulties were experienced in deriving parameters and an alternative solution was developed, this is documented by Davies (1999). Such accuracy is not readily available for any of the small island states of the Caribbean with the possible exception of Puerto Rico, and yet to gain consistency in fundamental data in a GIS or similar application reliable data is required. With regard to height, it is fortunate that the NGS have shown an interest and provided the CARIB97 model. While this is only relevant for the WGS84 spheroid, it does mean that data acquired by GPS can be related to a function of sea level. Again the precision to which the correction is available may degrade any results that are made by high accuracy GPS receivers.

8. CONCLUSIONS

It is easy to access geographical information in digital format, whether it is available from some distributor, scanned from paper, obtained directly from a satellite receiver, or from some other source, it can be cheap and applications software for its manipulation is readily available. Professionals from a wide variety of disciplines and a similar spread of amateur enthusiasts are using technology that enables them to access geographical information in some form. The software that is used in the manipulation of such data often incorporates facilities to perform spheroid and grid computations and the above text has attempted to identify the key parameters that are required by applications without providing computational procedures. It has also been demonstrated that difficulty arises when the information that is available is on different datums and that the number of variations that have been implemented locally within the Caribbean compound the problem.

The use of an international standard datum for mapping purposes would offer many advantages, for example it would aid in the resolution of many of the boundary disputes that are ongoing between pairs of adjacent countries. The use of satellite receivers for positioning is now common and GPS is likely to be the primary navigation system is use by many commercial and military users for the foreseeable future. Its supporting framework offers an international spheroid that has been adopted by international organisations, including avionic bodies. For the purposes of mapping, the cost of reproducing existing maps and charts in paper form on a new datum would be prohibitive, but the provision of parameters to enable conversion and their public release is a feasible alternative. The potential number of users of this information is enormous and it appears that it is being left to those who are in most need to provide information for the benefit of all. The current situation is that transformation parameters to convert between local and WGS84 latitude and longitude are available in a crude form for a few Caribbean states. Where alternatives exist there are inconsistencies in the data that is available. A regional geoidal model for height also exists, but again its use would degrade results of any measurements that are made. In order to incorporate existing data into geographic studies at a regional level certain assumptions must be made regarding datums. Until a regional geodetic work is undertaken to link previous datums to an international standard, precision in neither the horizontal or vertical control of regional work can be achieved.

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