Chapter 27

A note on geographical systems and maps of Montserrat

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Abstract: It is often critically important that geospatial data are measured and mapped accurately, particularly for quantitative analyses and numerical modelling applications. Defining a geographical coordinate system requires a non-unique combination of geodetic techniques (e.g. ellipsoids, projections and geoids). The choice of geographical system presents scope for ambiguity and confusion about geographical data, especially those archived without appropriate metadata. Experience has shown that these confusions have been a repeating source of either frustration or inadvertent error for those using geographical data from Montserrat. This is, in part, probably due to common usage of multiple datums and the existence of numerous topographical datasets recorded during the past 150 years. Here, we attempt to provide a brief introduction to geodetic principles and their application to Montserrat geographical data. The differences between common datums are illustrated and we describe variations in magnetic declination as they apply to field use of magnetic instruments. We include a record of the source of the large-scale mapping datasets that have been used and analysed ubiquitously in the literature. The descriptions here are intended as an introductory reference resource for those using geospatial data from Montserrat.

Accurate mapping is essential in most areas of geoscience. To understand geospatial data we adopt coordinate systems in which we are able define position and velocity. However, the choice and specification of the coordinate system is not unique and, over the centuries, geodists have derived a multitude of methods for describing three-dimensional (3D) geographical data. Commonly, this invokes the use of a reference ellipsoid, which models the approximate shape of the Earth’s surface; a projection, which translates that ellipsoid into two dimensions (2D); and, sometimes, a specific reference surface from which height is measured (e.g. sea level). Confusion between different coordinate systems can be – and has been on occasions – a source of significant error when using and comparing geospatial data. The explanations and data given here include a brief summary of the most commonly used systems on Montserrat. Descriptions and derivations of various ellipsoids, geoids and projections are widely available elsewhere (e.g. Robinson et al. 1995). Specifications are also provided here to assist configuration of field tools such as handheld GPS (global positioning system) receivers. A summary of the changes in magnetic declination for Montserrat since 1995 is also included. The information herein is intended purely as a practical introduction for those using geospatial data from Montserrat, not as an exhaustive description of cartographical methods.

Ellipsoids, projections and geoids

There exists a plethora of simple geometrical ellipsoidal models that approximately describe the shape of the Earth. An ellipsoid’s shape and size is defined by the lengths of its three mutually perpendicular radii. A geodetic ellipsoid is symmetrical around its polar axis such that its shape may thus be defined by just two parameters: the equatorial and polar radii (a and b, respectively). These may be given explicitly or via a flattening factor, f, that relates a to b, where \( f = (a - b)/a \). Flattening is also often cited in inverse form: \( 1/f \). The origin (centre) of any two ellipsoids may be offset in space. An ellipsoid may, thus, be described by five parameters: the offset of its origin from the Earth’s centre of mass (\( dX, dY \) and \( dZ \) – see Fig. 27.1); the equatorial radius; and either the polar radius or the flattening factor. In some cases, additional parameters may be required (e.g. coordinate axis rotation), but this will not apply herein. Ideally, an ellipsoid would approximate mean sea level (or, more specifically, the geoid – see below) on a global scale. However, this is not the case due to the unevenness, which means that even globally defined ellipsoids can vary from mean sea level by over 100 m in some regions. Accordingly, this has given rise to many different ellipsoid definitions, with models often optimized to fit sea level well over a particular geographical region.

Adopting an ellipsoid as a simplified geometrical representation of the Earth allows for geometrical translation of features on the surface of that ellipsoid onto a 2D plane (i.e. a map). However, in performing such translations (projections), geometrical relationships (e.g. distance, azimuth, shape, area) cannot all be fully preserved on any single map. The method for projecting information from the ellipsoid onto a map thus depends on which properties takes precedence and requires the according compromises. Numerous projections exist, but focus is given here only to those in common use on Montserrat. The Transverse Mercator (TM) method offers a suitable strategy for map projection on Montserrat and is described in brief in the next section. For small areas, such as Montserrat, distortions due to the curvature of the ellipsoid can usually be neglected. It is notable, however, that such assumptions may be inappropriate for precision applications (e.g. ground deformation surveying).

A geoid is an equipotential surface that closely aligns with mean sea level around the globe – typically to within a couple of metres of local mean sea level – and can be measured through precise gravitational surveying. Unlike an ellipsoid, the geoid is complex in its shape, with undulations caused by the heterogeneous distribution of mass around the Earth. Recent geoid models have been derived using a combination of data from spaceborne gravity surveys (e.g. GRACE and GOCE). The geoid offset for a specific location – given as the vertical offset between the geoid model and an ellipsoid – may be computed using published model spherical harmonic coefficients or interpolated from gridded geoid data (NGA 2012).
Datums used on Montserrat

For reasons discussed below, the two most commonly used ellipsoids are the Clarke 1880 and World Geodetic System 1984 (WGS84) ellipsoids. Geographical coordinates are usually expressed either in terms of geodetic latitude and longitude (in degrees) or via a TM projection. Heights are measured relative to a vertical reference surface – usually the ellipsoid or, sometimes, a geoid model. It is important to be sure that a common datum (the combination of ellipsoid, projection and vertical reference) is used when considering multiple spatial datasets. Similarly, it is critical that the implications of the projection (i.e. distortion) are considered in analyses where spatial data are manipulated or analysed quantitatively.

Pre-eruption maps of Montserrat are derived from aerial photographs acquired in the 1950s on behalf of the British Government’s Directorate of Overseas Surveys (DOS 1983). The map data derived from these surveys were plotted using the Clarke 1880 ellipsoid and either geodetic coordinates or a customized metric TM projection, referred to herein as the British West Indies (BWI) grid. This datum is used by the Government of Montserrat Lands and Survey Department, and was initially adopted by staff and colleagues at the Montserrat Volcano Observatory (MVO: e.g. Kokelaar 2002). In recent years, the use of the WGS84 and Universal Transverse Mercator (UTM) datum has become more prevalent for representing data gathered on Montserrat as it provides a standardized approach to referencing geographical data. The following summaries describe these systems, and appropriate parameters are given in Tables 27.1 and 27.2.

### Table 27.1. Parameters for two ellipsoids commonly used on Montserrat (from Butler et al. 2012)

| Name      | Offset (to WGS84) | Equatorial radius, a (m) | Inverse flattening ratio, 1/f |
|-----------|-------------------|--------------------------|-------------------------------|
|           | dX (m) | dY (m) | dZ (m) |                           |                           |
| WGS 1984  | –      | –      | –      | 6378137.000 | 298.257223563 |
| Clarke 1880 | 174    | 359    | 365    | 6378249.145 | 293.465000000 |

### Table 27.2. Parameters that define the two TM projections most commonly used for Montserrat geographical data (from Butler et al. 2012)

| Parameter      | BWI grid | UTM Zone 20N (=Zone 20Q) |
|----------------|----------|--------------------------|
| Ellipsoid      | Clarke 1880 | WGS 1984 |
| Projection     | Transverse Mercator | Transverse Mercator |
| Central latitude | 0°       | 0°                  |
| Central Meridian | 62° W     | 63° W               |
| False Easting (m) | 400 000   | 500 000             |
| False Northing (m) | 0        | 0                        |
| Scale factor   | 0.9995   | 0.9996                |
| EPSG Code      | 2004     | 32620                  |

Earth-centred Earth-fixed coordinates

Positions given in Earth-Centred Earth-Fixed (ECEF) coordinates refer to a 3D Cartesian coordinate system, with its origin at the Earth’s centre of mass (the WGS84 origin, as shown in Fig. 27.1) and axes aligned as follows: the Z axis is approximately aligned with Earth’s axis of rotation (the International Earth Rotation Service, IERS, Reference Pole). The X axis is perpendicular to Z and passes through the IERS Reference Meridian (near the Greenwich Meridian), and the Y axis is mutually perpendicular to Z and X (NIMA 2004).

Values of position, distance, angle and velocity can be defined explicitly and unambiguously in this system without the need of a reference surface or projection. This can be advantageous when handling position or velocity data outside of a geographical context, as there is no distortion due to projection. However, ECEF coordinates bear no intuitive relationship to other features on the Earth and are often not useful for cartographical or geographical applications.

Ellipsoids

Two ellipsoids have been used predominantly in mapping Montserrat over the past century: the WGS84 ellipsoid and the more...
region-specific Clarke 1880 ellipsoid. Geodetic coordinates (degrees of latitude and longitude) can be used in conjunction with any ellipsoid but a given position will mark a different position on the ground, depending on the ellipsoid used.

In recent decades, the WGS84 ellipsoid has become an international standard for geodetic applications, against which other systems’ parameters are conventionally referenced. The origin of the coordinate system (Fig. 27.1) is taken as the Earth’s centre of mass, measured and updated using satellite and orbital measurements, and is coincident with the ECEF origin. The WGS84 ellipsoid was devised as an approximate fit to the global mean sea level (via the geoid), and thus typically results in regional deviations of many tens of metres. The WGS84 ellipsoid reference surface is around 41 m above sea level near Montserrat (Fig. 27.2), for example. Owing to changes in the location of the Earth’s centre of mass and the accuracy with which it can be measured, the WGS84 has undergone several revisions since it was first realized. While the differences between versions are small – usually negligible for navigation purposes, for example – they can be significant for precision surveying applications.

The Clarke 1880 ellipsoid differs in both shape (more oblate) and origin (offset by about 540 m) from the WGS84 ellipsoid (Table 27.1, Fig. 27.1). The Clarke 1880 ellipsoid surface is about equivalent to sea level in the Lesser Antilles region, and the British Ordnance Survey adopted it for twentieth century mapping work. Significant horizontal and vertical offsets can exist between coordinates referenced to the Clarke 1880 ellipsoid v. the WGS84 ellipsoid. For example, a point in Montserrat defined by geodetic coordinates (lat./long.) on the Clarke 1880 ellipsoid would be about 400 m NE of the point with the same coordinates on the WGS84 ellipsoid. The offset is due to the difference in ellipsoid shape and origin, and the exact difference depends on the 3D position of the point in question. Furthermore, the vertical difference between the two ellipsoids also varies spatially. In Montserrat, the offset is around 38 m (WGS84 is higher); variations are illustrated in Figure 27.2. These examples highlight the importance of explicit datum referencing to avoid position ambiguity or errors.

**Projections**

The common map projection employed for Montserrat is the TM projection. The TM method figuratively uses a cylinder, wrapped around the ellipsoid, with its central axis parallel to the ellipsoid’s equatorial plane. The great circle at which the ellipsoid meets the cylinder is the ‘central meridian’ on the ellipsoid. The projection is then performed by ‘unwrapping’ the cylinder from the ellipsoid, translating features on the ellipsoid onto a 2D plane (see illustrations by Robinson et al. 1995). Distortion caused by this type of projection is minimized along the chosen central meridian and it is therefore ideal to select a central meridian close to the region of interest. Northing and Easting coordinates may then be measured, in units of length, eastwards from the central meridian and northwards from the equatorial plane, respectively. Often, an arbitrary offset is applied to the Easting coordinate so that positions west of the central meridian do not have negative values. TM projections can, thus, be readily tailored to specific cartographical requirements, as desired, and can be applied to any ellipsoid. The BWI grid is an example of a TM projection used for mapping parts of the West Indies region (e.g. DOS 1983), typically in conjunction with the Clarke 1880 ellipsoid (Table 27.2).

The UTM system is a series of standardized TM projections that cover the globe in a series of 60 numbered ‘zones’; each zone has
its own central meridian, spaced 6° of longitude from the next zone. Any position in the world can be identified by values of Easting, Northing and UTM Zone number, and whether the point is in the northern or southern hemisphere. Subdivision of latitudinal zones in the UTM system (denoted by letters) is somewhat redundant as long as the hemisphere is specified. The UTM system uses the WGS84 ellipsoid (Table 27.2). Montserrat falls within UTM Zone 20Q (also 20-North or 20N – the latter raising ambiguity with latitude Zone N).

It is notable that the choice of TM projection does not inherently define the vertical reference surface (ellipsoid or geoid) against which elevation is measured. However, two common pairings have generally been used on Montserrat: the Clarke 1880 ellipsoid with BWI TM grid or the WGS84 ellipsoid with UTM grid.

**Geoids and ‘sea level’**

The Earth Gravitational Model 1996 (EGM96: NGA 2012) is used as the reference geoid for the WGS84. Earlier and more recent geoid models exist, with varying sophistication and accuracy. The WGS84 geoid provides a separate alternative as a standard vertical reference surface with the attraction that it is, by definition, close to the average ocean surface level. Figure 27.2 shows the vertical offset of the WGS84 EGM96 geoid from the WGS84 ellipsoid around Montserrat. The geoid has not generally been used as a vertical reference for Montserrat geographical data owing partly to the additional complexity of computing or interpolating geoid offsets (e.g. Fig. 27.2). However, it is necessary to recognize that multiple vertical datums exist in the WGS84. Heights referenced to the geoid (EGM96) are often used for larger-scale mapping and/or spaceborne surveying, such as the Shuttle Radar Topography Mission (SRTM) global topography model.

A third convention for measuring topographical height is mean sea level. Sea level can be measured using one or more tide gauges in the area of interest. Commonly, however, heights given ‘above sea level’ (asl) refer directly to the geoid height (NIMA 2000). This introduces ambiguity in the use of the term ‘sea level’. There are currently no reference tide gauge sea-level measurements on Montserrat.

**Maps of Montserrat**

The most widely available published map of Montserrat (DOS 1983) is referenced to the Clarke 1880 ellipsoid, and has coordinates expressed in the BWI TM grid (Easting and Northing, in metres, height in feet) and in geodetic coordinates (latitude and longitude, in degrees and minutes). Digital Elevation Models (DEMs) derived from this map (described later), along with various archived georeferenced data from Montserrat, use the same system. Since about 2009, MVO have adopted the WGS84 ellipsoid as a reference and use the UTM grid (Zone 20Q, Easting and Northing in metres, ellipsoidal height also in metres). Datum parameters (given in Table 27.2) may be used to correctly configure instruments, such as handheld GPS receivers, and software appropriately.

**Converting between coordinate systems**

It is often desirable or necessary to convert geospatial data from one coordinate system to another. For example, quantitative analyses might be performed using ECEF coordinates and then converted to geographical coordinates for visualization. Conversion formulae are derived from the geometrical form of each reference system, and are described widely in the literature. There also exist numerous programs and web-based tools for performing coordinate transformations. The software tools named here do not represent an exhaustive list of available options but are given as a starting point. A comprehensive database of reference systems is maintained online by Butler et al. (2012).

The ArcGIS software package (ESRI, Redlands, California) and open-source equivalents (e.g. QGIS, www.qgis.org) are popular and powerful interfaces for handling and manipulating geospatial data. Such data may be explicitly assigned to a map datum and the software is generally capable of relating or converting data between multiple coordinate systems. ArcGIS and many similar programs use the Geospatial Data Abstraction Library (GDAL) to perform datum translations. GDAL may be freely downloaded and used as a stand-alone, multi-platform program. Programs such as GDAL and proj (Evenden 2003) perform command-line and batch-mode conversion that allows straightforward incorporation into other programs and scripts. Coordinate systems are often indexed using a unique European Petroleum Survey Group (EPSG) code, as listed by Butler et al. (2012) and in Table 27.2. The following example command uses the ‘cs2cs’ command in proj to convert a position on Montserrat (near the volcanic vent) from Clarke 1880 BWI TM to WGS84 UTM 20Q coordinates:

Input:

```
> cs2cs + init = epsg : 2004 + to += init = epsg : 32620
```

```
  380915  1847084  700
```    

Output:

```
> 587842.27  1847829.34  661.98
```    

In this example, EPSG codes (Table 27.2) are used as shorthand for the two map datums. Datum parameters and other details

![Fig. 27.3. Magnetic declination at 16°42'N, 62°11'W (SW flank of SHV) between 1995 and 2015, according to the IGRF-11 model. These corrections may be used to calibrate field compasses or adjust uncorrected azimuth data.](image-url)
Digital maps of Montserrat

DEM s are grids, rasters or point files containing topographical height information. They are an extremely useful resource for many geospatial applications. In the context of Montserrat, DEMs have been essential for measuring topographical changes during the Soufrière Hills Volcano (SHV) eruption, as well as for providing constraint on numerical models of eruptive processes. The following descriptions briefly document the origin of large-scale Montserrat DEMs that have been widely used by the volcanology community.

The British Ordnance Survey’s DOS used photogrammetric survey data – collected in the mid-twentieth century – to generate a series of published topographical maps. In 1986, G. Wadge manually digitized the latest edition (DOS 1983) from original DOS acetate contour sheets. DEM accuracy is affected by error in photogrammetric topography retrieval – exacerbated by dense vegetation on the island – and digitization error. The latter was estimated at about one-third of the 50 ft contour interval (G. Wadge pers. comm.). The resulting ‘1995’, or ‘pre-eruption’, DEM (at 10 m grid intervals) has since been used extensively by the research community. The original DEM was generated using the Clarke 1880 ellipsoid and BWI TM grid.

The accumulation of erupted volcanic material since 1995 has resulted in major changes in the island’s topography and coastline. Various surveying work has been conducted throughout the eruption to measure and record these changes at different spatial and temporal scales (e.g. Jones 2006; Wadge et al. 2008). An airborne LiDAR (Light Detection And Ranging) survey was commissioned by the MVO in 2010, and yielded the most extensive and detailed topographical survey recorded since the start of the eruption. The survey was conducted using a helicopter-mounted scanner with on-board high-rate GPS tracking, which was later processed using ground-control GPS data supplied by the MVO. The survey covered most of the island to the south of the Centre Hills, except for regions above about 750 m (asl), which could not be surveyed due to low cloud cover. The 2010 DEM has 1 m grid intervals and we estimate a RMS (root mean square) point error of 0.17 m from independent GPS measurements. The original DEM data used WGS84 UTM 20Q coordinates with heights referenced to the WGS84 (EGM96) geoid, later converted to ellipsoid height values.

Space-borne topographical surveying provides an attractive alternative to airborne and ground-based surveying methods, providing wide, contemporaneous coverage. Generating of DEMs using satellite radar interferometry can be impeded by degradation of active volcanic terrain – a problem that will be reduced in data from recent, high-repeat-rate satellite missions (e.g. Tait & Ferrucci 2013). DEM data from such endeavours are typically automatically fit existing topographical data (e.g. SRTM) and then adopt the cartographic conventions of the original DEM. Georeferenced satellite topography and imagery data (e.g. radar intensity images: Wadge et al. 2011) commonly use the WGS84 UTM systems, with either geoid or ellipsoid vertical reference.

Bathymetric data around Montserrat have been compiled and updated in a similar fashion: original data were derived from 1:50,000 scale British Admiralty sea charts based on nineteenth and twentieth century surveys. Numerous additional surveys conducted since 1998 have been used to map bathymetric changes around Montserrat, particularly the evolution of submarine deposits offshore from the Tar River Valley (due east from the SHV). Le Friant et al. (2004, 2010) documented the details of various bathymetric surveys. An estimate of near-shore bathymetry – usually inaccessible to large survey ships – was given by Wadge et al. (2010). The map in Figure 27.2 shows a current DEM, combining data from recent surveys.

Magnetic declination

Magnetic declination (the difference in angle between magnetic and true north) changes in space and time. It is important to account properly for declination in work that requires the use of a magnetic compass (e.g. surveying, wind vane installation). In Montserrat, a correction of about 14°W is required, and this has changed at an average (not constant) rate of about 3°W a⁻¹ during the course of the eruption. Figure 27.3 shows the variation of magnetic declination on Montserrat since 1995, estimated using the International Geomagnetic Reference Field (IGRF-11: Finlay et al. 2010). Magnetic inclination (dip of the magnetic field from horizontal) is usually not as critical for standard surveying purposes; on Montserrat, magnetic inclination dips at about 40° and changes by about 0.2° a⁻¹ (becoming shallower). Alternative magnetic field models and further information are available from NOAA (2012).

Summary

This note is intended as a brief introduction, to highlight and document geodetic practices as they have been used in geoscience on Montserrat. We have included a rudimentary description of the fundamental geodetic tools used for handling and manipulating geospatial data, and highlight the importance of understanding the influence of their use and mis-use. We have also indicated the conventions that have been used most commonly by researchers during the course of the eruption on Montserrat.

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References

BUTLER, H., SCHMIDT, C., SPRINGMEYER, D. & LIVNI, J. 2012. Spatial Reference. http://spatialreference.org

DOS 1983, Tourist Map of Montserrat: Emerald Isle of the Caribbean, 6th Edition, Scale 1:25 000, Directorate of Overseas Surveys, British Government’s Ministry of Overseas Development, London.

EVENEN, G. I. 2003. Cartographic Projection Procedures for the UNIX Environment – A User’s Manual. United States Geological Survey, Open File Report 90-284.

FINLAY, C. C., MAUS, S. E. et al. 2010. International Geomagnetic Reference Field: the eleventh generation. Geophysical Journal International, 183, 1216–1250, http://dx.doi.org/10.1111/j.1365-246X.2010.04804.x

GDAL. 2012. Geospatial Data Abstraction Library, Version 1.9. Open Source Geospatial Foundation, www.gdal.org (accessed December 2012).

JONES, L. D. 2006. Monitoring landslides in hazardous terrain using terrestrial LiDAR: an example from Montserrat. Quarterly Journal of Engineering Geology & Hydrogeology, 39, 371–373.

KOKELAAR, B. P. 2002. Setting, chronology and consequences of the eruption of Soufrière Hills Volcano, Montserrat (1995 to 1999). In:
Druitt, T. H. & Kokelaar, B. P. (eds) The Eruption of Soufrière Hills Volcano, Montserrat, from 1995 to 1999. Geological Society, London, Memoirs, 21, 1–43.

Le Friant, A., Deplus, C. et al. 2010. Eruption of Soufrière Hills (1995–2009) from an offshore perspective: insights from repeated swath bathymetry surveys. Geophysical Research Letters, 37, L11307, http://dx.doi.org/10.1029/2010GL043580

Le Friant, A., Harford, C. L., Deplus, C., Boudon, G., Sparks, R. S. J., Herd, R. A. & Komorowski, J.-C. 2004. Geomorphological evolution of Montserrat (West Indies): importance of flank collapse and erosional processes. Journal of the Geological Society, London, 161, 147–160.

NGA 2012. WGS 84 Earth Gravitational Model 96 (EGM96). National Geospatial-Intelligence Agency, NASA/Goddard Space Flight Center, St. Louis, Missouri, USA. http://earth-info.nga.mil/GandG/wgs84/gravitymod (accessed December 2012).

NIMA 2000. Department of Defense World Geodetic System 1984. 3rd edn. National Imagery and Mapping Agency, Reston, VA.

NOAA 2012. Geomagnetism. National Oceanic and Atmospheric Administration, Washington, DC. http://www.ngdc.noaa.gov/geomag/ (accessed December 2012).

Robinson, A. H., Morrison, J. L., Muehlecke, P. C., Kimerling, A. J. & Guptill, S. C. 1995. Elements of Cartography, 6th edn. Wiley, Hoboken, NJ.

Tait, S. & Ferrucci, F. 2013. A real-time, space-borne volcano observatory to support decision making during eruptive crises: European volcano observatory space services. UKSim 15th International Conference on Computer Modelling and Simulation, 283–289, 10–12 April 2013. http://dx.doi.org/10.1109/UKSim.2013.121

Wadge, G., Macfarlane, D. G. et al. 2008. Lava dome growth and mass wasting measured by a time series of ground-based radar and seismicity observations. Journal of Geophysical Research, 113, B08210, http://dx.doi.org/10.1029/2007JB004566

Wadge, G., Herd, R., Ryan, G., Calder, E. S. & Komorowski, J.-C. 2010. Lava production at Soufrière Hills Volcano, Montserrat: 1995–2009. Geophysical Research Letters, 37, L00E03, http://dx.doi.org/10.1029/2009GL041466

Wadge, G., Cole, P., Stinton, A., Komorowski, J.-C., Stewart, R. & Toombs, A. C. 2011. Rapid topographic change measured by high resolution satellite radar at Soufrière Hills Volcano, Montserrat, 2008–2010. Journal of Volcanology and Geothermal Research, 199, 142–152, http://dx.doi.org/10.1016/j.jvolgeores.2010.10.011