REFERENCE FRAMES IN PRACTICE: THE ROLE OF PROFESSIONAL, SCIENTIFIC, STANDARDS AND COMMERCIAL ORGANISATIONS

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Key words: reference frames, coordinates, coordinate reference systems, transformations, international collaboration

ABSTRACT

It is well known that the current, and growing, trend towards the use of satellite positioning systems and global satellite mapping systems to produce position-based products in a global reference frame can introduce serious practical difficulties if the results need to be related to older maps and/or digital data. Special problems arise, for instance, in the fields of navigation, map revision, cadastral surveying and geomatics operations to support hydrocarbon exploration and production.

The difficulty fundamentally arises because of the need to transform the data into the (usually local) coordinate systems used to describe the older data (or vice-versa). In principle, coordinate transformations are straightforward mathematical procedures but in practice they can cause serious problems for one or more of the following reasons.

- *Not all of those who need to undertake this work have a sufficiently strong (or sufficiently up to date) education in basic geodesy.*
- *The distortions and inconsistencies of the local datum are not sufficiently well known.*
- *The numerical information needed (including transformation parameters) is not readily available.*
- *The language used to describe the various parameters and physical quantities is not uniform.*

This paper reviews the work of a number of international organisations in addressing some or all of these problems. It is concluded that there is currently insufficient co-ordination between the work of the many groups with interests in this field - but, despite this, progress is slowly being made, especially in the collection and distribution of information, education of users and adoption of a common set of definitions. Proposals are made for common goals for cooperation between the organisations involved and a role is proposed for FIG in such cooperation.

1. INTRODUCTION

A fundamental activity in land surveying is the integration of spatial data from various sources into a single consistent data set. This is often achieved using a single common geodetic reference frame, or datum. In the past, it was often sufficient to integrate such data using a locally or even arbitrarily defined datum. A number of factors have led to an increasing need to base spatial data products on a common reference frame that extends across the whole globe. These factors include growing reliance on satellite positioning systems and development of satellite based mapping systems affording increasingly higher resolution. Another major influence is the trend to spatial data infrastructures with national, regional and even global coverage. Also, an important part of such infrastructure is the reliance on national and international standards.

The challenge for many countries then has been a need to deal with these requirements for new global reference frames while also dealing with the legacy of existing data sets based on a locally defined reference frame. Whether a country or commercial organisation decides to move to a new global reference frame or to persist with the existing system, there is a need to establish a relationship between the two reference frames.

There are also a number of very practical issues that arise due to the fact that most practical surveying is carried out using some sort of Cartesian coordinate system, usually Eastings, Northings and height. It is usually not difficult to locate the formulae used to define the projection used for the Eastings and Northings - but most international practitioners will have come across situations in which even this was hard to come by. In contrast, the parameters specifying the strict definition of the local datum are not always easy to obtain. Perhaps even more disturbing is the fact that many users of position are still not sufficiently well informed to distinguish between different datums - believing that latitudes and longitudes are unique and that the only reasons for differences in Eastings and Northings are related to choice of projection formulae. Also it is relevant to note that the Cartesian triad (Eastings, Northings and height) describes a three-dimensional position through unrelated horizontal and vertical reference frames - a further complication to what appears so simple at a first glance. The term "Compound Coordinate Reference System" has been suggested to describe this Cartesian triad.

To handle all of the problems referred to here, there is a need for a good understanding of the definition and realisation of the reference frames involved, a practical approach to their implementation and application, and a recognition that processes need to be in accordance with agreed standards and guidelines. These needs are addressed on a number of levels by several international organisations that are described in detail in this paper.

It is also worth mentioning that the international organisations referred to in the following are not the only ones with a stake in this subject. For example, National Mapping Agencies (NMAs) play a key role individually as it is they who decide the exact details of their national system(s) and it is they who are usually responsible for determining and publicising official transformation parameters. There are now several groupings of NMAs, for instance CERCO (Comité Européen des Responsables de la Cartographie Officielle), see Leonard (2000), which explicitly lists the creation of European reference systems and international technical standards amongst its responsibilities:.

Finally here it is worth remembering that there are also many other organisations (and even individuals) that have assumed responsibilities in this field. This might be for a variety of reasons, including as part of their general mission, or out of pure research or altruistic interest, or expediency (industry will usually adopt an NMA solution when it is available, but may have a particular problem that needs solving for which there is an absence of NMA guidance). Examples include the UK Offshore Operators Association (UKOOA, see http://www.ukooa.co.uk/) who made specific recommendations for coordinate transformations in hydrocarbon-related work in UK waters. Also the US Department of Defense, (DoD) who have computed sets of transformation parameters to

WGS84 for virtually the whole world (see for example the original publication: DMA (1984), which is now available on-line at http://164.214.2.59/GandG/puborder.html), and many individual researchers and consultants working in this field.

So the key question is how can all of these many organisations best interact in order to provide the most benefit to an extremely varied (in terms of both education and application area) user community? Whilst not attempting an answer to this question, this paper seeks to raise the key issues and provide the technical information needed for an informed debate.

2. SCIENTIFIC ORGANISATIONS

Almost all of the scientific work related to the definition and realisation of coordinate systems is done under the auspices of the International Association of Geodesy (IAG) (see http://www.gfy.ku.dk/~iag/), in some cases in collaboration with The International Astronomical Union (IAU). The IAG is actually one of seven associations within the International Union of Geodesy and Geophysics (IUGG) (see http://www.omp.obs-mip.fr/uggi/), and both the IUGG and the IAU are members of the UN-based International Council of Scientific Unions (ICSU). Most countries that are members of the IAG subscribe through their major national scientific society (typically called 'academy of sciences') whereas for FIG the subscribing organisation is usually the primary professional surveying or geomatics body in the country concerned. The key difference is therefore that IAG is concerned with scientific aspects of coordinate systems whereas the FIG is concerned with more practical considerations.

The IAU's influence has largely been felt through IAU and IUGG joint stewardship of the International Earth Rotation Service (IERS, see http://hpiers.obspm.fr/), which was established in 1988 to replace the Earth rotation section of the Bureau International de l'Heure (BIH). The BIH and IERS traditionally concentrated on Earth rotation (including time) and practitioners only used their products when carrying out classical astronomical measurements and computations. Over the last ten years, however, the importance of the IERS has grown dramatically due to its role in defining the International Terrestrial Reference Frame (ITRF) and in jointly overseeing, with the IAG, a number of important geodetic services. This point is developed later in this section.

The recent history of the IAG's direct role in the definition of coordinate systems goes back to the IUGG General Assembly in Lucerne in 1967 when a new set of parameters for the model of the Earth was approved, see IAG, (1971). This was followed in 1980 by an updated set (generally referred to as GRS80) which to date is the most recent, see Moritz (1984). These sets of parameters include estimates of a number of physical parameters for the Earth and its gravity field, including the mean equatorial 'sea-level' radius (the semi-major axis of a best fitting ellipsoid), the geocentric gravitational constant, the angular velocity and the dynamic form factor. From these, the flattening of a best fitting ellipsoid, standard gravity formulae (for gravity reductions) and many other 'derived' constants can be computed. Before 1967 IAG recommendations were rather more *ad hoc* and generally explicitly recommended usage of specific 'named' ellipsoids (e.g. the Hayford Ellipsoid in 1924). Of course until satellite positioning was possible datums were defined locally by NMAs and the only 'international' issue was the choice of reference ellipsoid, and perhaps also the choice of projection. The role of the IAG was therefore relatively unimportant. Some countries adopted 'latest IAG values' for their ellipsoid when defining new coordinate systems - but most continued to use whatever they had done in the past.

Beginning in the 1970s, and most certainly through the 1980s, the situation changed enormously as NMAs and practitioners began to use Transit Doppler and later GPS for positioning. At that time it could be said that the US DoD, took on (in a *de facto* manner) the international role of providing international (global) reference frames, e.g. WGS66, WGS72 and WGS84. Actually WGS84 links to GRS80 in that the US DoD based some of its parameters on the GRS80 values. Also during this time it became necessary to extend definitions to include more physical models, including, for instance, spherical harmonic models for the Earth's gravity field.

We have now come full circle with the IAG 'in charge' again. This has come about through the establishment of a number of specialist services such as the International GPS Service (IGS, see http://igscb.jpl.nasa.gov/), the International Laser Ranging Service (ILRS, see http://ilrs.gsfc.nasa.gov/) and the International VLBI Service (IVS, see http://lupus.gsfc.nasa.gov/ivs/ivs.html). All of these services supply coordinates to the IERS for the computation of the ITRF, which is basically a set of coordinates and velocities (for around 500 points) worldwide. The DoD have now linked WGS84 to the ITRF, making it a dynamic system in the sense that coordinates of points in WGS84 will, if sufficiently accurately determined, be seen to change with time due to plate tectonics and other geophysical phenomena. In contrast to this most NMAs have selected 'regional epoch realisations' of ITRF when adopting coordinate reference frames, eg ETRF89 and GDA94.

So, at the highest level, we have the IAG playing a clear and unique role in contributing to the definition and maintenance of the ITRF, which is becoming the *de facto* standard for the global reference frame. It also contributes in other ways, both from a scientific and more practical perspective. It is in the latter of these that there is potential for important synergy with the work of other organisations. There is also, however, the danger of wasteful duplication of efort and confusion. The situation with regard to the IAG's scientific work is clearer and usually involves scientists collaborating to solve highly technical problems that, whilst eventually impacting on practitioners, is likely to do so in a way that improves the quality or efficiency of their work rather than fundamentally changing philosophy. The IAG currently carries out most of this scientific work through Special Study Groups (SSGs). At present the one most directly relevant to the topic of this paper is SSG 1.181: Regional Permanent Arrays. This is, of course, of very direct interest to a wide variety of organisations, including NMAs, because it is through the establishment of permanent arrays that most countries will in future realise and maintain their reference system.

A key way in which the IAG interacts with scientists and practitioners dealing with coordinate system issues is through its Commission X GRGN (Global and Regional Geodetic Networks). IAG Commission X's role is one of *stimulation and co-ordination* through the dissemination of information, standardisation, co-operation and education. It is a large 'organisation' with sub-commissions (mainly concentrating on specific geographical areas) and Working Groups (concentrating on specific technical problems - rather like SSGs) and its stated goals (see http://lareg.ensg.ign.fr/GRGN/) for the 1999-2003 IAG quadrennium are as follows.

- To expand the present GRGN web site in order to give a proper source of information of relevant activities, including sub-commissions and working groups, but also related activities at national or international level, such as survey agencies, international programs or projects, services such as IGS, IERS or others. This site should also provide information on standards and terminology, catalogue of datums and cartographic coordinate systems.

- To expand the list of national representatives and involve them more in the Commission activities (for instance updates of the web system).
- To stimulate new sub-commissions.
- To update the list and charters of the Working Groups.
- To stimulate the development of a modern frame for Africa (AFREF).
- To stimulate the organisation training schools related to the GRGN field (modern networks, ITRF, GPS,..).
- To promote ITRF as the international frame and realise its densification for all type of uses, help to remove misunderstandings with respect to WGS84, and promote ITRF for the new global navigation satellite systems, such as the European Galileo program.

One of the most active of the sub-commissions of IAG Commission X is the Sub-Commission for Europe (EUREF) which is playing a highly practical role (including interacting directly with NMAs) in the realisation and maintenance of a new European reference frame. EUREF now consists of a large number (around 100) of permanent reference stations and the IAG Commission X provides the mechanisms for the creation of the agreements for data transfer and processing. This is an excellent example of the practical result of a scientific endeavour. Much of the other work of Commission X is also relevant to, and similar to, that of FIG (see §3) - especially that of IAG Commission X Working Group 1 (Datums and Coordinate Systems) which is very close to that of FIG WG-5.5 (Reference Frames in Practice).

3. PROFESSIONAL ORGANISATIONS

Professional organisations can play a useful role in the practical implementation of reference frame issues due to their broad representation comprising the government, academic and private sectors of the surveying/geomatics profession.

The International Federation of Surveyors (FIG) is a federation of professional surveying organisations taking in almost 100 countries. Credibility on the international scene is strengthened by FIG being officially recognised by the United Nations as a Non-Government Organisation (NGO).

FIG is well placed to undertake the co-ordination of reference frame issues, especially those international aspects that are common across many countries. At the broadest level, FIG passed resolutions at its 1990 General Assembly dealing with reference frame matters. Resolution 5.2 at that General Assembly called on member organisations to support the adoption of a global geocentric reference system as proposed by IAG/IUGG and consistent with the ITRS for a particular epoch. Another resolution (5.3) makes recommendation to member organisations in relation to accurate geoid modelling to facilitate the relationship of orthometric heights with the ellipsoidal heights that come from satellite positioning systems.

The technical work of the FIG is undertaken by its Commissions and Task Forces. As has been outlined already, a consistent reference frame is fundamental to many surveying activities and has relevance to several FIG Commissions. Hydrographic and Engineering Surveying (represented by Commissions 4 and 6 respectively) rely heavily on reference frame consistency in both the horizontal and vertical dimensions. Reference frame issues are important in cadastral processes (represented by

Commission 7), either directly in cadastral surveys or in digital cadastral databases. A major topic in Spatial Information Management (represented by Commission 3) is the concept of spatial data infrastructures, which rely heavily on a fundamental principle of being able to relate different spatial data sets using a consistent reference frame. Another FIG group of relevance is the FIG Task Force on Standards.

While all these parts of FIG have an interest in reference frame matters, the one with direct responsibility is Commission 5, which deals with Positioning and Measurement. Commission 5 has two working groups that are directly relevant, Working Group 5.2 on Height Determination Techniques and Working Group 5.5 on Reference Frame in Practice (in which the authors are members).

Working Group 5.5 on Reference Frames in Practice (WG-5.5) will not be undertaking fundamental research into reference frame definition. As outlined earlier in §2, that is seen as the role of the International Association of Geodesy (IAG). Similarly, formal recommendations for reference frame identification, specification and adoption is not the role of WG-5.5. This is best left to NMAs and international standards organisations (dealt with later in this paper, §4).

Given these respective roles, WG-5.5 has decided that the role of FIG can best be pursued by a Work Plan that concentrates on making reference frame information more available to the practising surveyor. This will be achieved through two categories of product designed to package reference frame information in an accessible and readily understandable form.

The first type of product from WG-5.5 will be the so-called Technical Fact Sheet. These are short documents that explain, in readily understandable English, basic theoretical concepts, practical applications and issues and which summarise the activities of organisations with specific responsibilities in this field. The following are candidates for Technical Fact Sheets.

- WGS84
- Global and Local geoid models
- Types of coordinates
- Map projections
- Classical (local) datums
- ITRF
- Practical transformation procedures
- Role of other international organisations
- Commercial activities (OPENGIS)
- Approaches of GPS manufacturers and software developers

The second type of product from WG-5.5 will be the Local Information Sheet. These are designed to describe the current situation in individual countries. The emphasis is on the provision of a brief background with contact information and to be a conduit between practising surveyors and the information they require. It is expected that the information will normally be provided to the Commission 5 representative in that country by the appropriate official organisation, such as the NMA. Local Information Sheets will contain the following information.

- Formal references to detailed (and easily accessible) technical papers describing the history and current state of reference systems and height datums in that country.
- A brief summary of standard geomatic products available in that country and information on the associated reference system.
- A web address or other contact method, from which the reader can find the latest information regarding relevant transformation methods and associated parameters.
- Any relevant comments indicating special issues relating to that country (for example whether transformation parameters are freely available and/or whether or not commercial products are available to undertake transformations). Also any known future policies (for example with respect to moving to a global geocentric frame) could be summarised.

It is important to note that FIG-5.5 is not attempting to collect 'numerical' information on datums and transformations *per se*. It seeks merely to collect, and keep up to date, information on such issues as the 'general philosophy' of datum definition and transformations in specific countries. A key element of every Local Information Sheet is the web link to (or other contact information for) the authority in that country (usually the NMA) with formal responsibility for these issues.

Examples of both of these products may be found in the Appendices to this paper and at the WG-5.5 web site (http://www.ge.ucl.ac.uk/fig5_5). As more of these products are developed, the intention is to publish them via that web site and for paper versions, if required, to be available from the FIG Permanent Office. The examples to be found today (March 2000) on this site should be seen very much as 'first draft'. FIG WG-5.5 is anxious to receive comments from interested parties either on their content or style.

4. STANDARDS ORGANISATIONS

There have been, and continue to be, several initiatives to “standardise” reference frames. These are not attempting to define a standard reference frame, that being an IAG activity. Instead they are initiatives to describe reference frames in a consistent manner. Although modern geodetic science has a preferred approach, users have to work with legacy data that may be referred to frames that some consider to be obsolete.

Information describing coordinate reference frames, often referred to as coordinate system metadata, has been on the agenda of national and international standards organisations as well as industry. These can be considered to be of two classes as follows.

- Standards for non-geomatics activities, for example road transportation and telematics, where there is a need to include position, usually through coordinates, and where the authors have a range of understanding of reference frames. These often make somewhat naive assumptions regarding coordinates, the most frequent one being that latitude and longitude are unique. The geomatics profession has been slow to recognise that it could and should have contributed to these standards. On the other hand there are examples where geomatics knowledge has been incorporated.
- Standards for the geomatics field, particularly Geographic Information, where the drafting will have had a significant contribution on reference frame description by knowledgeable geomaticians.

Beginning in the 1980s, national standards for geographic information have been drafted in several countries. These all make provision for the identification of the national map grid of the country concerned, usually from a list of options when there are several zones or multiple reference frames.

In the mid 1990s the International Standards Organisation (ISO) began work to define a suite of standards for geographic information/geomatics. The ISO process is one of several iterations, beginning with agreement on scope, the formation of a working group to produce an internal working draft, circulation to ISO members of a committee draft, public circulation of a draft international standard, and publication of an international standard. There is a review procedure for international standards after five years. New standards are developed through ISO technical committees formed by subsets of ISO members. The members of ISO are the national standards organisations such as the American National Standards Institute (ANSI), Nederlands Normalisatie-instituut (NNI), etc.

ISO Technical Committee 211 (TC211, see http://www.statkart.no/isotc211/) was formed to draft the suite of geographical information/geomatics standards. Initial working drafts were described as parts of international standard ISO-15046, but these have now been re-numbered as ISO-19101 through 19120. ISO 19111 deals with Spatial Referencing by Coordinates and describes the parameters required to identify reference frames and transformations between reference frames. Other standards in the ISO suite that are particularly relevant to reference frames include 19113 Quality Principles, 19114 Quality Evaluation Procedures and 19115 with Metadata. Most of these standards are currently at the committee draft stage and are expected to be published as international standards during 2001. In March 2000 an additional work item, a compilation of parameter values for coordinate reference systems, was agreed by TC211[1].

Technical committees and their working groups may include liaison members from approved organisations with cognate interests. Liaison members may contribute to the formation of standards, but cannot participate in the formal voting in the various stages of development. FIG is a liaison organisation to ISO TC211.

When ISO TC211 was formed, the European Committee for Standardisation (Comité Européen de Normalisation, CEN) had work in progress on European standards for geographical information. This was being conducted by CEN technical committee 287. Having been overtaken by the ISO initiative, the work was published as a draft but not as a full European Standard. However the CEN work was used as the basis of the ISO drafts.

5. COMMERCIAL ORGANISATIONS

[1] One of the more difficult issues that the ISO spatial referencing working group has had to contend with is terminology. Geodetic terminology has subtlety changed with time, and unfortunately has adopted meanings to words which a layman may not always recognise. For example, when geomaticians use the term “datum shift” they are not actually shifting datums or anything else, but transforming coordinate values from one reference to another. Another area of confusion surrounds reference frames and reference systems. To a geodesist, geodetic coordinates relate to a reference frame that is the realisation of the mathematically abstract reference system. But to a layman, coordinates belong to a coordinate system. ISO has developed the term *coordinate reference system* for a reference frame comprising of two elements - *datum* and *coordinate system*. In ISO parlance, this paper should have been titled “Coordinate Reference Systems in Practice”!

National and international standards do not always exist when users wish to exchange data. Industry groups often devise their own standards outside of the formal Standards process. For example, the military organisations within NATO have a geographical information standard, *Digest*, which includes the identification of coordinate reference. Similarly, the international oil industry, through organisations such as UKOOA, has long had standards for the interchange of seismic navigation data, describing the content and format required for such information, as well as recommendations for coordinate system and coordinate transformation defining parameters and compatible formulae (see European Petroleum Survey Group (EPSG) guideline 7 and geodetic data set at http://www.petroconsultants.com/products/geodetic.html). To these communities, international standards come too late. The international standards may be *de jure* but the community standard is *de facto.*

There is a similar dichotomy within the community of vendors of geographic information systems, not only for reference frame identification where each vendor will have compiled his list of data required by his users, but also in general computing where the lack of standards led each vendor to develop his own. This has inhibited portability of data between applications. The Open GIS Consortium (OGC or OpenGIS) was formed to address this problem. It is a not-for-profit commercial organisation based in the United States and open to worldwide vendors and customers of geographic information technology. Its goals are to increase the use of GIS systems through the agreement and adoption of computing standards, and in particular the development of extensions to computing standards where these are considered to be inadequate for geographic information. One of the OGC activities is the specification and development of a coordinate transformation service, which uses EPSG geodetic data for parameter values. OGC and ISO TC211 have signed a collaborative agreement, which should result in compatible *de jure* and *de facto* standards for reference frames.

6. CONCLUSIONS

In summary it can be seen that there are a large number of international organisations working hard and making significant progress in developing practically useful products and providing important information, in the general field of coordinate reference frames. These include scientific organisations, such as the IAG and IAU (along with their Special Study Groups, Commissions, and specialist technical services), organisations representing practising surveyors, such as FIG (along with its Working Groups), international standards organisations, such as ISO (with its Technical Committees), consortia of commercial organisations, such as OGC, and groups of national mapping agencies (such as CERCO). Also several national-level organisations (such as the US DoD) are active in collecting and publishing reference frame information. In an ideal world, however, these organisations would be more carefully co-ordinated, have distinct and clearly defined (but linked) roles, and would be working towards a common set of goals - which could include the following.

- A standard language to enable efficient dialogues to take place.
- Provision of easily accessible (both from a communications and language perspective) relevant didactic material.
- Internationally accepted recommendations for the description of the definition of, and of transformations between, local and global reference frames.
- A standard way to describe the quality of transformations, and hence of the coordinates that result from their application.

In fact at present we have somewhat disparate groups, which are sometimes duplicate each other's work and which often find it difficult to make progress due to a lack of knowledge as to what is being done by others. It is certainly the case that many practitioners do not know what is (and what is not) being done for them, and they are not always sure where to turn to for information.

It would seem that there could be enormous advantages, especially in terms of effectiveness, in bringing together all of the organisations involved in defining or using reference frames in order to set clear goals, including specifying the various products that the community at large needs. It is also necessary to identify an efficient and transparent way in which everyone can work together to achieve them. This activity is something that could usefully be facilitated by FIG. Moreover, as one of the key organisation involved, FIG certainly has its own important role to play but it must do this with a clear understanding of what is being done by others and the main purpose of this paper is to provide information to help in this respect. For instance FIG can take a lead in clarifying terminology by producing a WG5.5 Technical Fact Sheet building on ISO terminology - and by using this terminology in its own literature. FIG WG5.5 should be encouraged to liaise closely with both ISO TC211 and IAG Commission X WG1 to ensure compatibility of products (especially with respect to terminology), and to keep to a minimum the duplication of effort. Finally, of all of the organisations involved, FIG probably has the most direct contact with NMAs and can play an important role in encouraging cooperation in the production of WG5.5 Local Information Sheets.

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APPENDIX 1 - EXAMPLE OF A TECHNICAL FACT SHEET

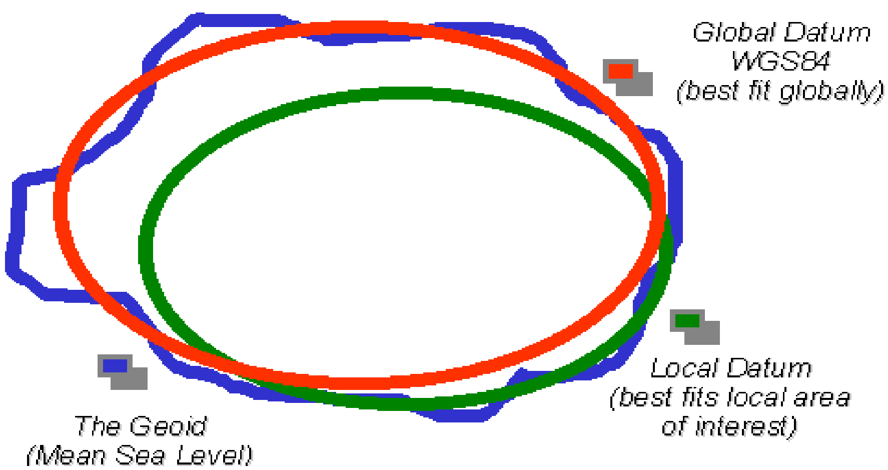
International Federation of Surveyors
Fédération Internationale des Géomètres
Internationale Vereinigung der Vermessungsingenieure

Commission 5: Positioning and Measurement
Working Group 5.5: Reference Frames in Practice

FIG Fact Sheet 5.501 - The World Geodetic System of 1984 (WGS84)

Geodetic Datum in General

The depiction of three-dimensional position requires a three dimensional surface. A convenient surface to represent the earth is the geoid. It is the equipotential surface of the earth's gravity field that on average coincides with mean sea level in the open oceans. Due to variations in gravity, the geoid undulates significantly and a regular mathematical model is required for the calculations associated with a datum. An appropriate mathematical model is an ellipsoid (or spheroid). Geodetic datum tend to use ellipsoids which best represent the geoid in the area of interest. An example of the spatial relationship between a local datum, a global datum and the geoid is represented in the following Figure.



Prior to the development of space based measurement systems, locally defined geodetic datum were sufficient. However, satellite positioning systems require a single global geodetic datum and GPS, GLONASS and other space based measurement techniques have had some fundamental influences on datum definition and use.

- Satellites move around the centre of mass of the earth and require a datum which is geocentric.
- Their global nature has meant that what has previously been considered geodetic science is having increasing importance in day to day surveying.
- Height from these systems is measured above the ellipsoid which has required better geoid models.
- There has been a trend to revise local working datum to be more compatible with measurements from systems such as GPS and GLONASS.
- Their three dimensional nature has led to a need to closely relate horizontal and vertical datum.

A global datum is based on the Conventional Terrestrial Reference System (CTRS). An important underlying concept is that reference systems definitions are purely definitions and must be *realized* through some defined process. Three particularly relevant realizations of the CTRS are WGS84 as used for GPS, PZ90 as used for

GLONASS and the International Terrestrial Reference Frame (ITRF - see Boucher and Altamimi, 1996). WGS84 and PZ90 are established and maintained by military organisations while the ITRF is produced by a scientific institution, the International Earth Rotation Service (IERS).

The World Geodetic System of 1984

The geodetic datum used for GPS is the World Geodetic System of 1984 (WGS84). The significance of WGS84 comes about because GPS receivers rely on WGS84. The satellites send their positions in WGS84 as part of the broadcast signal recorded by the receivers (the so-called Broadcast Ephemeris) and all calculations internal to receivers are performed in WGS84.

From a technical point of view, WGS84 is a particular realization of the CTRS. It is established by the National Imagery and Mapping Agency (NIMA) of the US Department of Defense (for original descriptions see DMA, 1991 and Kumar, 1993). The initial realization of WGS84 relied on Transit System observations and was only accurate at the one to two metre level. At the start of 1994 (start of GPS Week 730) use of a revised value of the gravitation constant (GM) along with improved coordinates for the Air Force and NIMA GPS tracking stations led to *WGS84 (G730)*. That realization was shown to be consistent with the ITRF at the 10 centimetre level (Malys and Slater, 1994). The improved tracking station coordinates came from a combined solution using selected IGS stations (Swift 1994). Further improvements to the tracking station coordinates in 1996 led to *WGS84 (G873)*. The G873 represent GPS Week 873 and refers to the date when the new tracking station coordinates were implemented in the NIMA precise ephemeris process. The G873 coordinates were implemented in the GPS Operational Control Segment on 29 January 1997. Tests have shown WGS84 (G873) to be coincident with the ITRF94 at a level better than 2cm (Malys et al, 1997).

It should also be noted that the ellipsoid used for WGS84 agrees with that of the Geodetic Reference System of 1980 (GRS80 - Moritz, 1980) except for a very small difference in the flattening term. GRS80 is the reference ellipsoid associated with ITRF.

Working with WGS84

It should be noted that there are only two ways to directly produce WGS84 coordinates. The first is by GPS surveying measurements relative to the US DoD’s GPS tracking stations. However, the GPS data from those DoD stations is not typically available to civilians. The second way is by point positioning using a GPS receiver. However, the accuracy of point positions performed by civilians is limited by the policy of Selective Availability to +/- 100m at 95% confidence. Only US DoD or allied military agencies can perform point positioning with centimetre to decimetre accuracy.

Civilian surveyors often require WGS84 coordinates to an accuracy better than that available from point positioning. For example, a common requirement for accurate WGS84 coordinates is to seed the processing of GPS surveying baselines (post-processed or real time). However as outlined above, civilians cannot access WGS84 directly with high accuracy and must therefore resort to indirect means to produce *WGS84 compatible coordinates*.

One way to obtain more accurate WGS84 compatible coordinates is to use local datum coordinates and a published transformation process. In practice, a transformation process is derived between data sets on both datum and any errors in those data sets affect the transformation process. The quasi WGS84 coordinates that result from a transformation process can be in error in an absolute sense by as much as several metres but are usually more accurate in a relative sense. Transformation processes in common use include the three parameter Molodensky method (or block shift), seven parameter (or similarity) transformation, multiple regression equations and surface fitting approaches (see the FIG Fact Sheet on Datum Transformation).

The most rigorous way for civilian surveyors to produce WGS84 compatible coordinates is to perform GPS surveying measurements relative to control stations with published ITRF coordinates. That will produce ITRF coordinates for any new stations. As outlined above, ITRF94 (or later) coordinates can then be claimed to be within a few centimetres of their WGS84 G873 equivalents.

An important mechanism allowing the ITRF to be accessible for geodetic networks anywhere in the world is the ability to access precise ephemeris for the GPS satellites and precise station coordinates from the International GPS for Geodynamics Service (IGS). The IGS has a global network of stations with high quality receivers observing GPS continuously (Zumberger et al 1995).

Given widespread use of GPS, there is a trend for the working geodetic datum to be consistent with recent ITRF and therefore with WGS84. This trend was set with the North American Datum of 1983 as a geocentric datum using the GRS80 ellipsoid. Recent implementations have taken advantage of the continued development of the various ITRF (e.g. for European developments see Seeger, 1994). Australia is also progressing toward adoption of an ITRF based geocentric datum by the year 2000 (Manning and Harvey, 1994). In such cases where the modern geodetic datum is based on a recent ITRF it will be compatible with WGS84 at the few centimetre level.

Relevant Internet Links:

WGS84 NIMA Publications - Includes links to a PDF file of "DMA 1991" as referenced above plus other useful WGS84 documents and software at http://164.214.2.59/geospatial/products/GandG/pubs.html
Geodetic Reference System of 1980 (GRS80) - Moritz, 1980 - Internet Version at http://www.gfy.ku.dk/~iag/handbook/geodeti.htm
International Terrestrial Reference Frame (ITRF) at http://lareg.ensg.ign.fr/ITRF/
International GPS for Geodynamics Service (IGS) at http://igscb.jpl.nasa.gov/

Other Relevant FIG Fact Sheets:

FIG Fact Sheet 5.002 - Datum Transformation

References:

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Swift E., 1994, Improved WGS84 Coordinates for the DMA and Air Force GPS Tracking Sites, Presented at The Institute of Navigation, ION GPS 94, Salt Lake City, Utah, September.
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APPENDIX 2 - EXAMPLE OF A LOCAL INFORMATION SHEET

International Federation of Surveyors
Fédération Internationale des Géomètres
Internationale Vereinigung der Vermessungsingenieure
Commission 5: Positioning and Measurement
Working Group 5.5: Reference Frames in Practice

FIG Local Information Sheet 5.501 - Great Britain

Organisation
Great Britain includes England, Scotland and Wales. It does not include Northern Ireland or the Republic of Ireland. The national mapping agency, Ordnance Survey Great Britain, is responsible for national reference frames. Ordnance Survey operates a helpline to which all enquiries should be directed in the first instance.

Reference frames summary
Historical basis of mapping: All national mapping is based on the National Grid, which is a Transverse Mercator projection of the triangulation network OSGB36 observed 1935-1962, using the Airy 1830 ellipsoid. A different National Grid exists for Ireland. Heights are shown as orthometric heights relative to Ordnance Datum Newlyn, a single tide-gauge mean sea level datum observed 1915-1921, and realised by a primary national network of 200 Fundamental levelled bench marks.

GPS reference system: The national standard GPS reference system is ETRS89, which is obtained by a 6-parameter transformation of ITRS96 published by IERS. ETRS89 is a WGS84 variant tied to the stable part of the European plate. It current (1999) differs from ITRS96 by about 25cm, growing by 2.5cm per year.

National GPS Network: The primary reference frame for GB since 1992 has been the National GPS Network, including 750 roadside marks with ETRS89 coordinates, observed in 1991-92. In 1999 the National GPS Network is being upgraded by the addition of about 30 active GPS stations (i.e. continuously observing automatic stations), such that all points in GB will be within 100km of an active station (150km in Scottish Highlands). Also, new passive stations have been added at all Fundamental height benchmarks, bringing the total passive network to 900 stations. Passive stations are now re-observed on a 5 year cycle.

Realisation of National Grid: The National Grid is currently formally realised by the stations and archive coordinates of the triangulation network OSGB36. The National Grid Transformation OSTN97 is an interpolated grid of horizontal plane shift parameters covering GB at 1km resolution, which converts ETRS89 GPS coordinates to National Grid coordinates with an accuracy of 20cm (RMS). In 2002, an improved version of this transformation will become the definition of the National Grid, and use of the triangulation network will be discouraged.

Realisation of Ordnance Datum Newlyn: The orthometric height datum is currently formally realised by the fundamental bench mark network and archive of levelled coordinates. The National Geoid Model OSGM91 is an interpolated grid of offsets between the ETRS89 ellipsoid and a gravimetric geoid model aligned to Ordnance Datum Newlyn. The accuracy of OSGM91 as assessed by GPS/levelling is better than 10cm (95% confidence). The use of the National GPS Network and OSGM91 for establishing new orthometric height benchmarks is encouraged. Reliance on densification benchmarks for orthometric height control is not recommended.

Product availability
OSTN97 and OSGM91 are licensed to software vendors for incorporation in GPS, GIS and navigation software packages. A list of current licensed data distributors is available on the OS Website. These products are not available direct to users from OS. National GPS network Passive station coordinates and information are available

from OS Technical Sales. Active station coordinates and GPS data are not yet available, but are expected to become available via an Internet server during 1999. Traditional control information (triangulation stations and height benchmark information) is available from Ordnance Survey Technical Sales.

Special Issues

The triangulation network OSGB36 contains scale and orientation distortions causing errors in coordinates at the 5-10 metre level. No simple GPS datum transformation for the whole of GB can fit National Grid coordinates to better than 5m accuracy. For precise work, the datum transformation required can change over short distances. Therefore, Ordnance Survey discourage the use of simple datum transformations in Great Britain - the national standard transformation OSTN97, which models OSGB36 distortions at 1km resolution, should be used.

References

The 'GPS positioning and coordinate systems' page on the OS Website has links to all the OS information available about Reference Frames in Great Britain.
The address is: http://www.ordsvy.gov.uk/services/gps-co/index.htm
Papers currently available on this site include:
A Guide to Coordinate Systems in Great Britain - a 42-page booklet explaining many geodetic concepts and detailing coordinate systems and reference frames used in GB.
Information Paper 12/1998 - GPS and mapping in the 21st century - a publicity document outlining current Ordnance Survey geodetic policy.
Improving Access to the National Coordinate Systems - an article first appearing in Surveying World magazine, giving an overview of current geodetic developments in Britain to the land surveying profession.