POSITIONAL ACCURACY, A SPATIAL DATA FOUNDATION

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Abstract

A spatial data infrastructure needs to be built on a solid positional foundation. It is desirable if the data are both compatible and homogeneous to reduce duplication and uncertainty. Nationally, regionally and globally this condition is best underpinned by a uniform geodetic infrastructure on a single, well-defined datum as a fundamental layer in a spatial data set. When regional spatial data sets are built of different data on mixed datums, the situation is more complex and where the geodetic datums vary considerably, transformation is a practical method of bringing together data based on individual geodetic datums. These parameters are developed by comparing the position of known points on local geodetic networks to a uniform regional datum.

However beyond the application of transformation techniques or the use of a single datum underpinning data sets, the accuracy of individual points or data sets within a spatial infrastructure needs to be tagged so that multiple data sets can be integrated without anomalies. Experience with the traditional use of *Class* and *Order* for geodetic accuracy and the trend to the use of *Positional Uncertainty* in metadata standards are discussed for Australia applications and in the Asia Pacific Spatial Data Infrastructure.

Introduction

It is estimated that at least "*80 % of public and private decision-making is based on some spatial aspects"* and "*the market for tracking, route-finding and guiding, notification and alert services in North America and Western Europe reaching $US15 billion by 2005*" (Østensen, 2001). The integration of previously diverse data sets, including some we don't even recognise at the moment, can be expected to grow enormously. With this growth, to maintain integrity and usability, there is a need to understand the complete relationship between spatial data sets, including the coordinates themselves, their reference frame (datum) and accuracy.

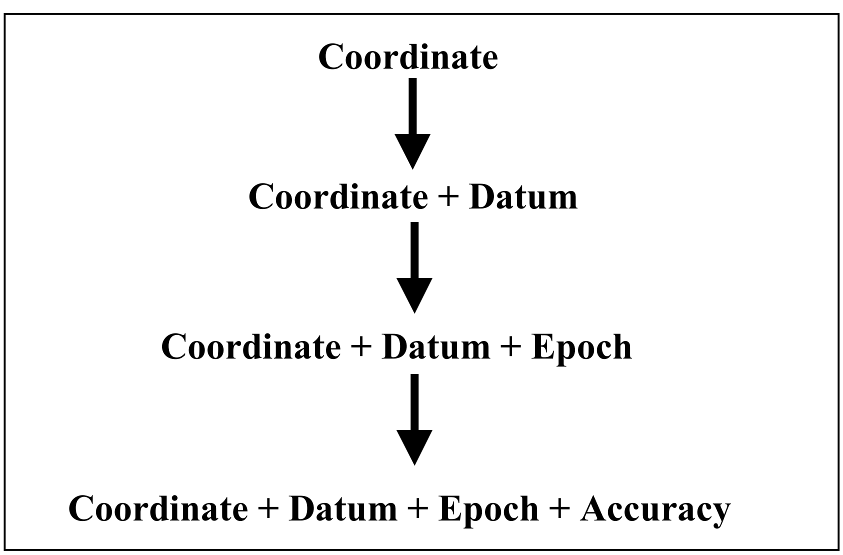

Figure 1: Evolution of position definition

Coordinates & Datum

In the distant past, positions were simply described by a geographic coordinate (latitude and longitude) - just as we all probably did with our school atlas. This was all that was needed because the accuracy of the position was very coarse and we typically worked in a restricted environment and everyone we dealt with knew what we meant. In the early days of navigation and exploration, positions were astronomically determined and were probably lucky to have an accuracy of several hundred metres. The description of many Australian State boundaries were simply a longitude or latitude. This was adequate at the time, but in these days of GPS and easily obtained metre-accurate positions, it can lead to confusion if not treated cautiously. Unfortunately, the school atlas attitude to coordinates, where they are considered immutable, is still prevalent.

Coordinates in Australia

As positioning progressed from simple astronomical positions to more accurate surveyed coordinates, it became necessary to quote the reference frame (or datum) with the coordinates to ensure the position was correctly defined. This was an issue in the early days of the Australian geodetic surveys (and the maps based on these surveys) as different surveys used different origins (e.g. Sydney Observatory, Perth Observatory). The resulting positions could have differences of up to several hundred metres.

The advent of the Australian Geodetic Datum (AGD) in 1966 (Bomford, 1967) was another good reason to quote the datum with coordinates, but as the AGD was generally adopted, the datum was often assumed when referring to post-1966 Australian positions. In 1984, an updated version of AGD coordinates was produced, to make use of new observations and improved adjustment techniques. These updated coordinates, now known as AGD84 coordinates, differ from the original AGD66 coordinates by between 2 and 7 metres (Allman, 1984).

The need to quote the datum became even more critical with the early satellite positioning systems and their various approximations of an earth-centred (geocentric) datum (e.g. NSWC-9Z2, WGS72, WGS84) which differed from each other by a few tens of metres and from the AGD by about 200 metres (Steed, 1990). This issue was most emphasized when Australia adopted its new coordinate datum, the Geocentric Datum of Australia (GDA), which is compatible with the GPS system (WGS84) but differs from the AGD by about 200 metres (ICSM, 2001a).

Although Australia has adopted GDA94, and the National and State survey control networks have been recomputed in terms of this datum, many data sets are still in terms of AGD66 or AGD84 and cannot be recomputed as they are compiled, not observed data. There are a number of ways to transform such positions from AGD to GDA, all based on a number of suitable sites with positions known in terms of both datums (common points). These methods include simple block shifts, simple origin shifts and ellipsoid change (Molodensky's formulae) and the 7-parameter similarity transformation. The accuracy of these transformation methods depends on the number, quality and distribution of the common points and must be combined with the uncertainty of the coordinates to be transformed, to give the uncertainty of the transformed position.

However, another transformation method has been developed for use in Australia - the recently released AGD66/84-GDA94 National Transformation Grids (Collier & Steed, 2001). These grids are freely available in the Canadian NTv2 format that is included in most popular GIS software packages and can also be used with freeware software specifically developed to transform between AGD and GDA94 using the transformation grid files. This transformation method can transform individual points or many thousands and is simple for the user (merely a transparent addition of a shift in latitude & longitude). The shifts in the grid files have been developed from many thousands of common points and account not just for the datum transformation, but also distortion in the existing control networks, resulting in a much more accurate result. The NTv2 format of these files includes an estimated accuracy of the transformation process that can be used to estimate the total uncertainty of the transformed positions.

Global Coordinates

The World Geodetic System 1984 (WGS84) reference frame used with GPS was defined by the United States National Imagery and Mapping Agency as the latest in a series of global systems (NIMA, 2000). However, this reference frame has changed on at least two occasions since then, although the name has not changed, as the changes were not considered significant for navigation users.

GDA is based on a 1992 version of a global reference frame known as the International Terrestrial Reference Frame (ITRF) (Boucher, 1993) which is developed from the combination of station coordinates derived from a variety of space-geodetic observations at many global sites (VLBI, LLR, SLR, GPS and DORIS since 1994). ITRF positions are now routinely used for many civilian applications and are used as the basis of many national coordinate systems. Originally, WGS84 was significantly different from ITRF, but the changes to WGS84, referred to previously, have brought it into close alignment with ITRF (Malys, 1997).

Coordinates Changing with Time

Although coordinates have traditionally been used as stable quantities, the positions on the earth that they represent are not. Large portions of the earth (plates) move relative to each other, as evidenced by earthquakes and volcanoes. This tectonic motion is now measurable and for Australia is about 7 centimetres per year in a North-Easterly direction.

ITRF positions include the velocities for plate tectonics and it is critical that the instant in time (epoch) is also supplied with an ITRF position. This was managed with GDA by adopting the ITRF92 coordinates as they were at 1 January 1994. GDA positions are therefore completely described as GDA94, which includes both their datum and epoch.

Because GDA94 was held fixed at 1 January 1994, but ITRF/WGS84 are adjusted for plate tectonics, there is now a difference of about ½ metre between GDA94 positions and ITRF/WGS84 positions obtained directly from satellite observations (Steed, 2000). This difference is not critical for users with coordinates that have an accuracy of a metre or more, but it is for the growing group of users with coordinates with an accuracy of better than a metre. This group is rapidly growing because of the availability of augmented GPS systems which can supply real-time positions, currently with an accuracy of about a metre, but very soon with an accuracy approaching a few of decimetres (Sharpe, 2001). By their nature these systems produce ITRF positions, but parameters to transform between ITRF at various epochs and GDA94 have been developed for these high accuracy users (www.auslig.gov.au/geodesy/datums/gda-itrf.pdf).

Coordinates and Accuracy

Accuracy should not be confused with precision. Accuracy is the relationship of a measurement to the "truth", while the precision of a measurement is its repeatability, whether or not it is close to the "truth". Sometimes the quoted accuracy of positions in a spatial data set may actually be the precision.

The accuracy of a position may be a measure of the true relationship between two or more positions (the relative accuracy) or it may be the measure of the true relationship of a position to the coordinate datum ("absolute" accuracy).

When the accuracy of a spatial data set is given, it is often a relative accuracy. While this is very useful when checking and manipulating this data set, it is of much less value when it is integrated with a data set from a completely different source. As the accuracy relationship between two independent data sets is rarely known, the only way to understand their accuracy relationship is through their common link to the datum – the "absolute" accuracy.

Metadata Standards

The International Standards Organisation (ISO) draft standard 19115 provides a schema for describing digital geographic data sets using a comprehensive set of mandatory and conditional metadata elements and this standard is currently being implemented through the MetaData Working Group of the ANZLIC Spatial Information Council.

Currently, ANZLIC's MetaData Guidelines for geographic data include a mandatory field for positional accuracy, to allow a " *brief assessment of the closeness of the location of spatial objects in the data set in relation to their true position on the Earth*" (ANZLIC, 2001). However this is a 4,000-character text field, which invites a range of verbose possibilities that would be very difficult, if not impossible, to use in an automated matching of diverse data sets. What would be of more benefit is a simple numeric quantity that is meaningful to all users and simple to use in an automated process.

For many years the Inter-governmental Committee on Surveying and Mapping (ICSM) has maintained through its Geodesy Technical Sub-Committee (GTSC) its Special Publication 1 (SP1) - "Standards and Practices for Control Surveys" (ICSM, 2000b). This document uses the concepts of *Class* and *Order* to define the quality and relative accuracy of control surveys and their coordinates. Although this publication is widely used in Australia to report the quality of survey control, the concept of *Class* and *Order* is difficult to understand, particularly for non-specialists. In addition, this document does not cater for the now increasingly available accurate positions that are available from augmented GPS systems, independent of the local survey control. Examples of these augmented systems are the real-time Wide Area Differential GPS services (WADGPS) that produce positions with an accuracy of the order of a metre and their imminent successors that will produce positions with an accuracy of a few decimetres. On-line geodetic GPS processing is also available and with suitable observations will provide ITRF &

GDA94 positions with an accuracy of a few centimetres, with about 15 minutes turnaround (Dawson, 2000).

Recognizing the growing use of diverse spatial data flowing from the fundamental survey networks, and the increasing need for an "absolute" accuracy indicator, in 2000 ICSM recommended that by 2005, the concept of *Order* would be replaced by *Positional Uncertainty* and *Local Uncertainty*. Up until 2005, both systems would operate in parallel.

Positional Uncertainty and *Local Uncertainty* are concepts similar to those used in the United States (FGDC, 1998) in that they use a simple and meaningful value in metres to describe a circle of uncertainty. A 95% confidence level is used as it is more likely to represent a users understanding of achievable accuracy and as it is in line with the recommendations of the Australian National Standards Commission (NSC, 1998). For geodetic surveys, these values are readily computed from the error ellipse information that will continue to be maintained (Leahouts, 1985).

> *Positional Uncertainty is the uncertainty of the coordinates or height of a point, in metres, at the 95% confidence level, with respect to the defined reference frame. This value is the total uncertainty propagated from the datum, which in Australia is realised by the Australian Fiducial Network (AFN) or, in case of heights, the Australian Height Datum.*
>
> *Local Uncertainty is the average measure, in metres at the 95% confidence level, of the relative uncertainty of the coordinates, or height, of a point(s), with respect to adjacent points in the defined frame.*
>
> (ICSM, 2000c)

An immediate example of the application of these values is the Australian Antarctic Geodetic network, which provides positions in terms of ITRF2000 with their *Positional Uncertainty* (www.auslig.gov.au/geodesy/antarc/aagn.txt).

Positional Uncertainty can be generated for other forms of spatial data using the most appropriate method. In some cases this may be simply based on previous experience or a manufacturer's recommendation, while in other cases, such as coordinates digitised from a topographic map, it may include the uncertainty of all components of the map production process (survey control, aerotriangulation, photogrammetric modelling & pointing and plotting).

The ICSM proposal for *Positional Uncertainty* and *Local Uncertainty* was discussed at a meeting of ANZLIC's MetaData Working Group, in Wellington New Zealand in June 2001. The purpose of this meeting was to develop the workplan for the development and implementation of an ANZLIC profile of the forthcoming ISO 19115 metadata standard. At this meeting it was agreed that the ICSM proposal should be feasible under the existing structure of the Draft ISO 19115 standard, as this standard provides for numeric fields for both absolute and relative positional accuracy. It was therefore recommended that these elements be considered for inclusion in the forthcoming ANZLIC metadata profile, a draft of which will be prepared for community consultation (Freeman, 2001).

Case Studies

There are many possibilities to illustrate the need for a common datum and "absolute" accuracy for spatial data, ranging from the very simple but critical needs of safety of life situations, through infrastructure at the local government level, to major international data sets.

Safety of Life

Although perhaps not apparent at first glance, with the increasing use of spatial data for dispatching and emergency systems, it is absolutely critical for the individual involved to have all aspects of such a system smoothly integrated in terms of datum and accuracy.

In the USA, and therefore probably also Australia in the near future, mobile phones will automatically supply a position when used to lodge an emergency call (Balbach, 2000). This position may be coarse if generated from a signal triangulation, or it may have an accuracy of just a few metres if generated from an integrated GPS. In either case the accuracy and datum of the position, and associated dispatch maps and vehicle location systems, must be well understood, by the software and users. The total uncertainty may be a matter of only a few tens or hundreds of metres, but that could mean a difference of several dozen houses in the case of an ambulance searching a dense suburban environment, or the wrong side of an impassable river or gorge, in the case of a search party on foot in the bush.

Similarly, a few metres may not seem much of a worry with the positioning system in a fire-fighting helicopter, but add a smoke-filled sky, perhaps the darkness of night and the uncertain position of an overhead power line from a separate data set, and the pilot has a right to be concerned.

Local Infrastructure

One consequence of a variation in spatial accuracy is that features may not appear in the correct relationship if they have been generated by different methods. For example, *"a stormwater pipe or communications cable may appear inside a property boundary when in reality it is in the road reserve. This discrepancy, due to inadequate and variable spatial accuracy, will severely limit the potential application of both sets of data*" (Twin, 2000). This situation could equally apply to nearby power, water and gas lines, with potentially disastrous consequences.

AUSLIG maintains a Great Circle distance calculator on its web site for coarse applications (www.auslig.gov.au/mapping/names/distance.htm). This calculator automatically extracts coordinates from the place names Gazetteer. However, feedback indicates that some users have unrealistic expectations about the accuracy of the resulting distance. Although a general indication of the accuracy is included with the calculator, it is not possible to provide an actual accuracy because there is no accuracy listed with the positions in the names gazetteer. Ideally each position would include an estimated accuracy that could then be used to generate an estimated accuracy of the calculated distance. While this is a seemingly trivial example, distances are calculated from positions in spatial data in more critical situations and the same principle applies.

Antarctica

In Antarctica there are many overlapping international interests. On such area is the Larsemann Hills, which is a coastal area of exposed rock, lakes and low rolling hills on the Lars Christensen Coast, Princess Elizabeth Land in East Antarctica, about 80 km South-West of Australia's Davis Station.

This area has been subject to surveying and mapping by Australia, Russia and China, each producing their own survey control networks and maps at different scales and in terms of different datums. Resolution 5 of the Geodesy and Geographic Information Working Group Report to the XXVI Scientific Committee on Antarctic Research (SCAR) meeting in July 2000, was aimed at that unification of geodetic and mapping datums throughout Antarctica by the year 2001 (www.scar-ggi.org.au/tokyo/scar_rpt.pdf). To this end, during the 2000-2001 Antarctic Summer, AUSLIG carried out Geodetic GPS surveys to link all three survey networks in terms of ITRF2000 and develop transformation parameters between them. Transformation parameters were produced as a result of this survey, but with a half metre level of accuracy, due to the (unknown) uncertainty of the coordinates (Johnston, 2001).

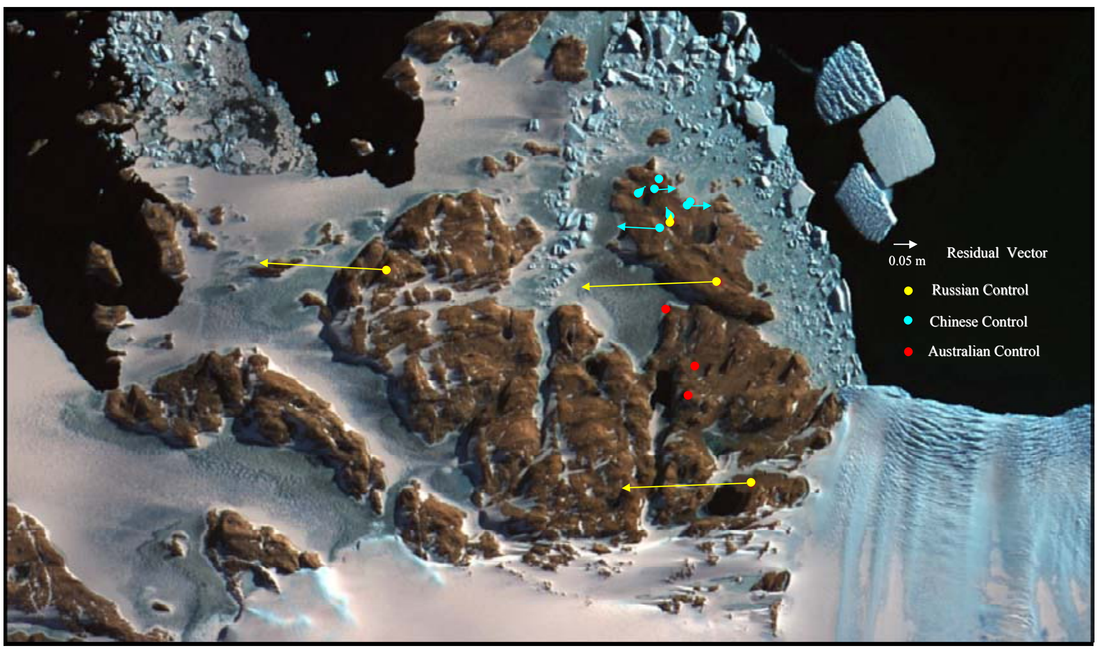

Figure 2 Residual Vectors for Russian and Chinese Stations in the Larsmann Hills

Asia Pacific

AUSLIG has a major role in Working Group 1 of the Permanent Committee on GIS Infrastructure for Asia Pacific (PCGIAP), which is endeavouring to provide a uniform framework for the many countries in the Asia Pacific area. Currently most use local datums that vary considerably from ITRF (e.g. Japan differs by 400 metres and Korea differs by some 3½ km). The goal is to have enough accurate ITRF positions established in each country, to enable their local coordinate system to be related to the global system either by transformation or readjustment, thus allowing them to take advantage of global spatial data and contribute to it.

Pacific nations have a particular problem because of the many islands involved, often each one with a separate datum. For example Kiribati has many islands with 15 different datums (Llewellyn, 2000).

Island	Ellipsoid	Datum
Makin	International	Makin Astro 1965
Butaritari	International	Makin Astro 1965
Marakei	International	HMS Cook Astro 'H' 1962
Abaiang	International	HMS Cook Astro 'H' 1962
Tarawa	WGS84	WGS84
Tarawa	International	Secor Astro 1966
Maiana	International	Maiana Astro 1965
Abemama	International	HMS Cook Astro 1959
Kuria	International	HMS Cook Astro, Kuria 1962
Aranuka	International	HMS Cook Astro, Kuria 1962
Nonouti	International	Nonuiti Astro 1965
Tabiteuea	International	TBZ1 Astro 1965
Beru	International	BRZ1 Astro 1965
Nikunau	International	Nikunau Astro 1965
Onotoa	International	ONZ 7 Astro 1970
Tamana	International	HMS Cook Astro 1962
Arorae	International	Arorae Astro 1965
Kiritimati	International	Christmas 1967 Astro

Table 1: Local data used for mapping in Kiribati (from Llewellyn, 2000)

Conclusion

Positions, through spatial data, are the utility of the 21st century and will be used in an increasing number of applications, with diverse data. However, a position is only fully and comprehensively described when it includes the coordinate value, the datum, the epoch and the accuracy relative to the datum.

A simple and meaningful numeric accuracy indicator should be supplied with all spatial data. ICSM has already adopted such an indicator in the form of *Positional Uncertainty*. *Positional Uncertainty* has already started to be used for geodetic survey control and ANZLIC is investigating its inclusion in its Metadata Guidelines.

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