

# The Adoption of ETRS89 as the National Mapping System for GB, via a Permanent GPS Network and Definitive Transformation.

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## Introduction

Ordnance Survey (OS) is responsible (by Government act) for the national mapping of Great Britain. Part of OS responsibility is to provide access to the national datum and coordinate system. This is OSGB36 datum and the National Grid.

OS now also provides access to the ETRS89 with a permanent GPS network so it is important to provide an accurate transformation between ETRS89 and OSGB36.

This paper describes the current national ETRS89 – OSGB36 transformation and how ETRS89 will be adopted as the national datum from GB via the permanent GPS network and a new definitive version of the transformation.

## Brief History of Coordinate Systems in GB

Great Britain is one of the few countries to have two triangulations observed in the last two centuries [Ordnance Survey 1967]. The first, known simply as the *Principle Triangulation*, was published in 1858 [Clarke 1858]. It was not observed as a single planned scheme but was instead made up piecemeal from observations between 1783 and 1853. Two taped bases provided the scale and origin and azimuth were defined at the Royal Observatory, Greenwich. The adjustment was performed in 21 computing blocks on the Airy ellipsoid.

The second triangulation is known as *The Retriangulation*. It was observed between 1936 and 1953 and computed by hand in seven blocks, as opposed to the 21 for the Principle Triangulation. The original origin at Greenwich had been destroyed but was implied by holding the position of 11 stations fixed to the mean of their Principle Triangulation positions. This means that there is no one point that can be described as the origin of the Retriangulation. Computing blocks 1 and 2 contained the 11 stations and the remaining blocks were adjusted sequentially and fixed to blocks 1 and 2 by fixing boundary stations. The coordinates are on the Airy 1830 ellipsoid and this adjustment is known as the **Ordnance Survey of Great Britain 1936 Datum - OSGB36** [Ordnance Survey 1967].

The OSGB36 datum is still very important today since it is currently the basis for all Ordnance Survey mapping. Although it contains randomly variable scale errors, mainly due to it being computed in blocks and the fact that scale and azimuth were controlled entirely by the 11 stations from the Principle Triangulation (dating back to 1858), it is still adequate for mapping purposes. Coordinates are expressed in the National Grid - a modified Transverse Mercator projection.

Finally we also have a realisation of ETRS89. This was first realised with a EUREF approved network of 26 ground sites – EUREF GB92, which was further densified with approximately 900 more stations to give the network OS(GPS)93. This realisation of ETRS89 has now been

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superseded by one from a network of 30 permanent GPS stations around the country. This network is known as the National Active GPS Network.

## The National Active GPS Network

The Ordnance Survey active GPS network consists of at present 30 permanently installed geodetic quality GPS receivers throughout Great Britain. Two of these stations are actually owned and operated by the Isle of Man Government and a further nine by the General Lighthouse Authority. Most locations in Great Britain are within 75 km of at least one active station, and several serve major urban areas. The active stations record dual-frequency GPS data 24 hours a day at a 1 second epoch rate from geodetic quality receivers. The network control centre at the Ordnance Survey's headquarters in Southampton receives a one-hour packet of GPS data from each active station every hour around the clock. This 15 second data is added to the Ordnance Survey GPS data server for public access via the web site - [www.gps.gov.uk](http://www.gps.gov.uk). The RINEX data is used both internally and is also freely available to surveyors, asset managers, researchers, etc.

## The Current Transformation

The OSGB36 datum described above may be considered as *inhomogeneous* due to its varying scale. It is this inhomogeneity that makes a simple transformation between ETRS89 and OSGB36, such as a 7 parameter Helmert, too inaccurate for national use. E.g. the accuracy of a national 7 parameter transformation is approximately 5 m [Ordnance Survey 1999]. For the UK a national transformation needs to ideally have residuals no larger 0.2 m, since this is the accuracy of the largest scale OS maps. The inhomogeneity of the OSGB36 datum is shown in Figure 1.

Figure 1 indicates the residual transformation errors between ETRS89 and OSGB36, resulting from the application of a national 7 parameter Helmert transformation. It is these varying differences that need to be modelled in order to produce a more accurate transformation.

There are two transformation models that are suitable for modelling such random datum differences. The first type is the *polynomial transformation* (also known as multiple regression transformation). This type of transformation attempts to model the varying differences between two datums as a surface described by a polynomial function. The transformation operates separately on latitude, longitude and height, with an equation for each component.

Tests on polynomial transformations [Greaves 1998] have shown that they can achieve near to the desired 0.2 m accuracy. However the effect of the scale variations in the OSGB36 datum is to make the polynomial transformations very unstable near the edges of the transformation area. The magnitude of the residuals around the edges of the polynomial transformation are in the region of several meters. This

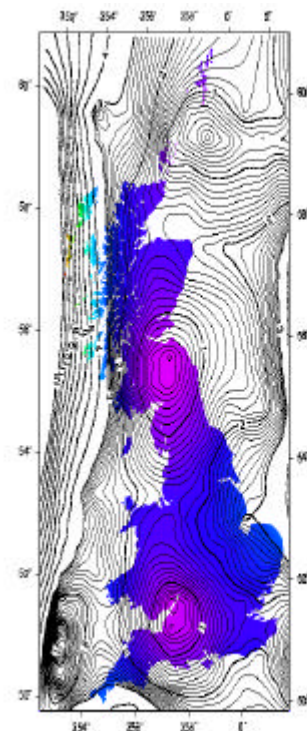


Figure 1. Residuals following a Helmert transformation.

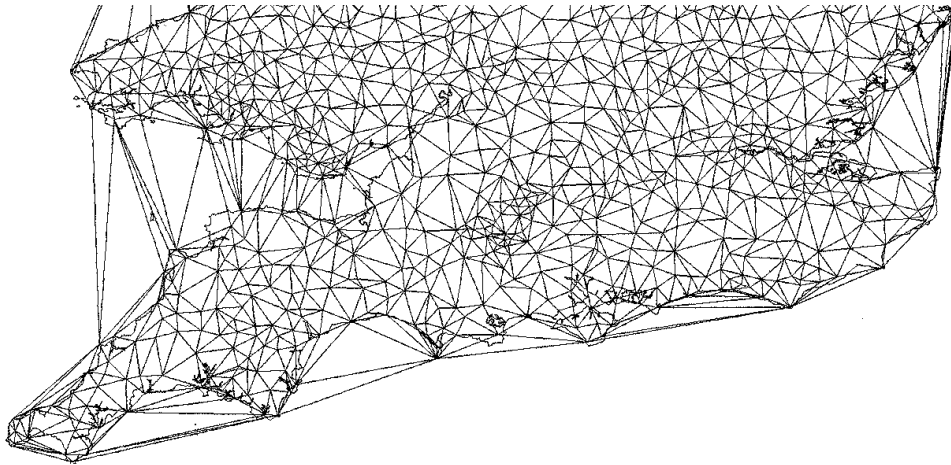
instability near the coast or in inshore areas means that a polynomial model would be unsuitable for a national transformation.

The second type of transformation model is known as the *Grid Look Up Table* and it is this type that has been chosen by the Ordnance Survey for the national ETRS89 to OSGB36 transformation. The transformation is modelled as a grid of varying parameters that covers the entire country. The reasoning behind this method is that the inhomogeneity (distortion) in the transformation is regional and differs from region to region. Better accuracy can be achieved by dividing the transformation into regions and only applying particular parameters to particular regions [Ashkenazi et al 1997].

The most convenient way of applying the grid look up transformation is to use plane coordinates and apply the transformation as linear shifts to the eastings and northings of one system to obtain eastings and northings in another system. In the OS transformation the shifts are calculated between plane coordinates in the National Grid on the OSGB36 datum and plane coordinates projected from the ETRS89 ellipsoid using National Grid projection parameters. The method can be divided up into two parts, :-

- transformation parameter generation;
- user access to the transformation using some algorithm.

To generate the parameters, the network of points used to compute the transformation is divided into Delauney triangles to create a Triangulated Irregular Network (TIN) with the apex of each triangle on a network point. Delauney triangles form the smallest set of triangles possible for a particular network configuration [Ashkenazi et al 1997]. Figure 2 shows an extract of the TIN for southern England.



Each apex of the TIN stores the transformation shift parameters. In reality 2 identical TINs are used – one for the shifts in eastings and another for the shifts in northings. For each individual triangle in the TIN the transformation can be expressed as a polynomial function. An affine linear polynomial is used to describe the changing transformation shifts across each triangle. It can be expressed as follows [Smith & Moore 1997]: -

$$\begin{bmatrix} e_{OSGB} \\ n_{OSGB} \end{bmatrix} = \begin{bmatrix} \mu_e \cos q_e & \mu_n \sin q_n \\ \mu_e \sin q_e & \mu_n \cos q_n \end{bmatrix} \cdot \begin{bmatrix} e_{ETRS} \\ n_{ETRS} \end{bmatrix} + \begin{bmatrix} \Delta e \\ \Delta n \end{bmatrix} \quad (1)$$

where:-  $e_{OSGB}, n_{OSGB}$  = plane coordinates in OSGB36 datum;  
 $e_{ETRS}, n_{ETRS}$  = plane coordinates in system ETRS89;  
 $\mu_e, \mu_n$  = scale factors for east and north axes;

$\theta_e, \theta_n$  = rotations of east and north axes;  
 $\Delta e, \Delta n$  = shifts along east and north axes.

The above function can be solved uniquely from the three vertices of each triangle. Hence for any point within a triangle, with coordinates in ETRS89, the coordinates in system OSGB36 can be calculated.

To apply the transformation as triangles would be very difficult for the user since the task of identifying the triangle that a particular point falls in would require a complicated search algorithm. Also all the information about the triangle and their associated parameters would have to be stored [Ashkenazi et al 1997]. The process is simplified by projecting a regular grid onto the triangles and using the triangle parameters to compute the coordinate shifts at each grid intersection. A 1 km grid is used.

This leads to the second stage of the transformation process - user access by interpolating between shifts at grid intersections to obtain shifts at a specific point. The interpolation between the grid points is carried out using a bi-linear polynomial.

The bi-linear interpolation can be expressed as follows [Ashkenazi et al 1997]: -

$$\Delta e = ae_{ETRS} + bn_{ETRS} + ce_{ETRS}n_{ETRS} + d \quad (2)$$

where:-  $\Delta e$  = coordinate easting shift at a grid intersection;  
 $e_{ETRS}, n_{ETRS}$  = ETRS89 plane coordinates of grid intersection;  
 $(a, b, c, d)$  = polynomial coefficients.

Using the  $\Delta e$  shifts at the four grid corners of a particular grid square the polynomial coefficients for that square can be calculated. The coefficients are then used back in equation (2) to interpolate the easting shift at any point within the square. An identical procedure is used for the northings shift ( $\Delta n$ ).

The current national OS grid look up table transformation is known as OSTN97. The data set used in OSTN97 consists of approximately 3300 points with coordinates in both ETRS89 and OSGB36. Only approximately 200 of these points have ETRS89 coordinates derived from direct observation of the point with GPS. These points are mainly National GPS network Passive stations. The rest of the ETRS89 coordinates are derived from a re-adjustment of the retriangulation terrestrial observations, using the 200 Passive stations as fixed control.

OSTN97 achieves a  $1\sigma$  standard error of 0.2 m but there are areas (so called “hot spots”) where it is worse than this. The transformation is available as a utility on the OS GPS web site (<http://www.gps.gov.uk>) and also as a stand alone program for the PC. The raw parameters or a pre made software development kit are also available to developers for inclusion of the transformation in third party applications.

### **The Definitive Transformation (what’s different)**

The Definitive Transformation is a project currently running at OS. Its main aim is to improve the accuracy of the existing OSTN97 transformation so that the 0.2 m accuracy can be achieved at the  $2\sigma$  (95%) level. It will achieve this by coordinating many more OSGB36 points in ETRS89, using GPS observations and the National GPS Network. This observation campaign has been running since April 1999 and is almost complete. So far 2500 extra points have been coordinated and also a

number of the existing points (previously coordinated in ETRS89 by terrestrial observations) have been re-coordinated by GPS. All areas of GB, including the most remote (and small) Scottish islands, now contain transformation points occupied with GPS. The size of the final data set for the transformation computation will be approximately 6000 points.

Tests will also be carried out to determine if the 1 km grid is the optimum grid density for the transformation shift parameters. One of the advantages of the grid look up table method is that it will tend to provide the highest accuracy (particularly if the grid is small) but it will reach a point where the accuracy of the transformation matches the characteristic accuracy of the data from which it is calculated. Once this point is reached further reductions in the grid size will not improve the transformation accuracy [Ashkenazi et al 1997]. In determining the optimum grid density the most accurate transformation will be produced with the minimum possible parameters. This is important because as the grid size decreases the number of parameters to be stored increases rapidly.

The final cost of the project will be in the region of £ 450,000 (approximately €730,000) and it will be completed by April 2002.

Apart from providing a more accurate transformation that is nationally consistent with the accuracy of the largest scale map data offered by OS, the Definitive Transformation will also herald a fundamental change in the definition of Great Britain's mapping datum.

At the present time, despite having a National GPS Network and transformation (OSTN97), the mapping datum of Great Britain (OSGB36) is still defined by the National Grid positions of the original points in the Retriangulation. When the Definitive Transformation is complete it will be used to *define* the National Grid in conjunction with the ETRS89 positions of the National GPS Network stations. This change will mean that, for example, the National Grid coordinates of an existing OSGB36 point, refixed with GPS from the National GPS Network and the Definitive Transformation will be, *by definition*, the correct ones. The original archived OSGB36 National Grid coordinates of the point will be wrong, by definition, but the two coordinates (new and archived) will agree within 0.2 m which is within the accuracy of the map data.

This method of keeping the existing map datum, but redefining it in ETRS89 with a transformation, is much preferred to introducing a completely new map datum based on ETRS89. This is because OS has many customers with millions of pounds invested in their own data tied into OS map data in the OSGB36 datum. To change to a completely new datum would be prohibitively expensive.

## Conclusions

An accurate national ETRS89 to OSGB36 transformation cannot be achieved using a simple 7 parameter Helmert transformation model. A polynomial transformation model approaches the required accuracy but is too unstable around the edges. The grid look up table transformation model is the one most suited to a national transformation for GB.

The existing national transformation OSTN97 achieves 0.2 m accuracy at the  $1\sigma$  level, but requires improvement. The new Definitive Transformation will achieve 0.2 m accuracy at the  $2\sigma$  (95%) level and also be more consistent over the whole of GB.

The Definitive Transformation will also be adopted as part of the new definition of the National Grid, so that – ETRS89 coordinates from the National GPS Network + the Definitive Transformation = true National Grid coordinates. This means that ETRS89 will be adopted as the foundation part of the national coordinate system of GB, thereby allowing users easy access to this

much more accurate and stable coordinate frame. However this access will not be at the cost of a new map datum, so map data users are free to adopt the latest GPS data collection techniques without changing all their existing data to a new datum.

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