



Coordinate Referencing Systems & Transformations

Component 1.3

Technical Guide



Responsibility for the Content

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Foreword

The Digital National Framework (DNF) is an industry standard for integrating and sharing business and geographic information from multiple sources. It is being developed for use within the United Kingdom although the concepts and principles could be applied elsewhere. It aims to be: (i) definitive by using a detailed and maintained reference base, (ii) inclusive by being open and adopting industry best practice, (iii) structured and formalised to the extent that data once created can be shared and used many times, (iv) reliable through the delivery of data integrity, (v) cost-effective through reduction in the costs of data from multiple sources and (vi) flexible by enabling information exchange.

The basic principles at the core of DNF are as follows:

- ~ The concept and methods shall be driven by the strategic needs of the wider GI community and the needs of the information industry;
- ~ Data should be collected only once and then re-used;
- ~ Base reference data should be captured at the highest resolution whenever economically possible.
- ~ Information following capture may, where appropriate, be used to meet analysis and multi-resolution publishing requirements.
- ~ DNF will incorporate and adopt existing *de facto* and *de jure* standards, wherever they are proven and robust.

DNF is being developed and promoted by an industry body with membership drawn from data providers, system vendors and integrators and users. Both the commercial and government sectors within Great Britain are represented. All members have a common interest in the integration, sharing and utilisation of geographic information. Direction and strategy comes from an Expert Group. This in turn oversees and approves the work of a Technical Group responsible for the development of all technical documentation including this document.

This document is one of a series of technical documents being developed in support of DNF. Included in the series are data models, technical guides, guidelines, best practice, examples and case studies. Web-based services such as identifier registration are also being developed in support of this documentation.

For more information on the Digital National Framework visit <http://www.dnf.org> .

If you have any comments or suggestions on this document, please e-mail contact@dnf.org , your response will be acknowledged.



1 Introduction

1.1 Purpose of the document

This document outlines the different spatial coordinate systems that are currently in common use in the United Kingdom, the transformations between these systems and how they support the Digital National Framework [DNF]. These systems support the DNF by being those systems and transformations agreed by the DNF Expert Group as being fully defined, definitive and fully operational as to ensure data integrity during the course of data collection, data manipulation and data transformations.

The document is not intended as a reference source itself, but will provide definitive links to the reader where the authoritative source of information can be located and is maintained.

The paper includes a set of definitions introduced within the text, a list of abbreviations and a set of references (publications and web links) at the end of the document.

The science and technology of positioning continues to evolve and the document will be maintained at regular intervals.

2 Scope

There are many thousands of local, regional and global coordinate reference systems in existence which best fit a particular requirement. This document records and outlines those coordinate systems and transformations that are essential to the development of the geographic information infrastructure in the United Kingdom. This includes satellite and offshore positioning (GPS, or more broadly GNSS), regional systems (ETRS89) and map projection systems (OSGB36 and Irish Grid).

The source of the definition of these systems is provided as are the transformations. These are primarily defined as web links, but an outline is provided to ensure the reader appreciates the overall context within which spatial positioning is achieved and information transformed from one system to another.

The document should provide the general reader with an overview, and for the professional, the sources of definitive information for the execution of industry standard projects, tasks and infrastructure.

This guidance is applicable to those organisations creating, maintaining or owning geographic data which they may wish to use or have used in the context of the Digital National Framework. It is for use by any organisation wishing to conform to the principles of DNF who may require that their data can be shared and used by other DNF adopters.



This document describes the DNF Roadmap component 1.3 and users should also refer to related Technical Guides on Temporal Referencing and others such as the Data Association Model.

3 Definition of terms

3.1 Terms

The following terms, arranged in alphabetical order, are used in this document. Where a term used in a definition is defined elsewhere, it is shown in *italics*.

See <http://www.dnf.org/Pages/technical%20guidance/terminology.asp> for a full list of terms used in the DNF.

3.1.1 Chart Datum

The vertical datum to which soundings are reduced on the published chart. Traditionally this is chosen to be so low that the tide will not frequently fall below it.

3.1.2 Ellipsoid

A reference surface which approximately fits the size and shape of the Earth.

EXAMPLE: Airy, Modified Airy, or GRS80

3.1.3 Coordinate System

Set of mathematical rules for specifying how coordinates are to be assigned to points

EXAMPLE: the British National Grid, or The Irish Grid

3.1.4 Coordinate Reference

Position of a Geographic Object given using coordinates.

3.1.5 Coordinate Reference System

Coordinate system that is related to the real world by a datum.

EXAMPLE: ETRS89



3.1.6 Coordinate Reference Frame

The realisation, through a network of reference points on the ground, which enables access to a *coordinate reference system*.

EXAMPLE: OSGB36

3.1.7 Coordinate Transformation

Change of coordinates from one [*coordinate*] *reference system* to another

EXAMPLE: OSTN02

3.1.8 DNF Coordinate Position

A point defined by a coordinate value derived using two or three dimensional coordinates and used to and in conjunction with the DNF model.

3.1.9 Geoid

Level surface which best fits mean sea level either locally or globally.

3.1.10 Vertical Datum

Point from which all heights are measured.

EXAMPLE: Newlyn Datum, Belfast Lough Datum

3.2 Abbreviations

ETRS89	European Terrestrial Reference System 1989
EUREF	the IAG Reference Frame sub-commission for Europe
FBM	Fundamental Bench Mark
Galileo	Emerging European GNSS
GLONASS	Global'naya Navigatsionnaya Sputnikovaya Sistema (Russian GNSS)
GNSS	Global Navigation Satellite Systems (the generic term for satellite navigation systems, includes GPS, GLONASS and Galileo)



GPS	Global Positioning System (American GNSS)
IAG	International Association for Geodesy
IG	Irish Grid
ITF	International Reference Frame
ITM	Irish Transverse Mercator
ITRF	International Terrestrial Reference Frame
ITRS	International Terrestrial Reference System
LAT	Lowest Astronomical Tide
MSL	Mean Sea Level
NG	National Grid
ODN	Ordnance Datum – Newlyn
OSGB36	Ordnance Survey Great Britain 1936
SOA	Service Oriented Architecture
TRF	Terrestrial Reference Frame
VORF	Vertical Offshore Reference Frame
WGS84	World Geodetic System – 1984



4 Background

Different geoinformation technologies need to use different processes and in doing so they may use different coordinate systems. They might share a common objective to transform this data into a common coordinate system or this may be the responsibility of another organisation.

Equally some users may wish to use a coordinate system more suited to their environment, yet still enjoy the benefits of DNF connectivity and interoperability. A primary aim of DNF is to support interoperability including the need to move information across coordinate systems reliably and with as much consistency as definitive transformations allow. There are many coordinate systems in use and this paper aims only to describe those that are; national, fully defined, maintained, have transformation parameters to other DNF compatible systems and support DNF.

4.1 Coordinate types

There are three types of coordinates in common use: plane (Eastings (E), Northings (N) or sometimes X, Y), cartesian (X, Y, Z) and geographical (ϕ , λ {latitude and longitude}).

- **Plane coordinates** are two dimensional only and are used on a local to national (e.g. National Grid) scale. A projection is used to allow the curved surface of the Earth to be portrayed onto a flat sheet of paper or plane. The type of projection is carefully chosen for the region to be mapped in order to minimise error or distortion in; conformality (feature shape), direction, scale, distance or area.
- **Cartesian coordinates**, most commonly 'Earth centred, Earth fixed' are often used in the scientific community. Coordinates are defined by the combination of the *origin* of the axis and their *direction* in relation to the earth.
- **Geographical coordinates** can be used to show the same information as Cartesian coordinates, but are a more common method of stating a terrestrial position, certainly on a global scale. Two angles, latitude and longitude, define a point on the Earth, or more correctly, they define a point on the surface of an *ellipsoid*.



There is no one agreed 'latitude and longitude' coordinate system. There are many different prime meridians and many different circles of zero latitude (equators), although by convention the former generally pass somewhere near Greenwich, and the latter somewhere near the rotational equator. Likewise there are many different ellipsoids – usually tailored to nearest fit the shape of the Earth at one country or region, though some do attempt to 'best fit' to whole Earth. Therefore, to use latitudes and longitudes with any certainty one must know which ellipsoid and datum you are dealing with.

Height can be defined as the distance above, or below, a reference datum surface. This is usually either above or below the ellipsoid (ellipsoidal height) or the geoid. Height systems in most countries are related to a level surface, for example – mean sea level (MSL) at a specific location and point in time. In Great Britain for example, a geoid model is used to promulgate ODN across the country. If GNSS is being used, where height is relative to a global coordinate system, a geoid / ellipsoid separation model is needed to transform from one height datum to another.

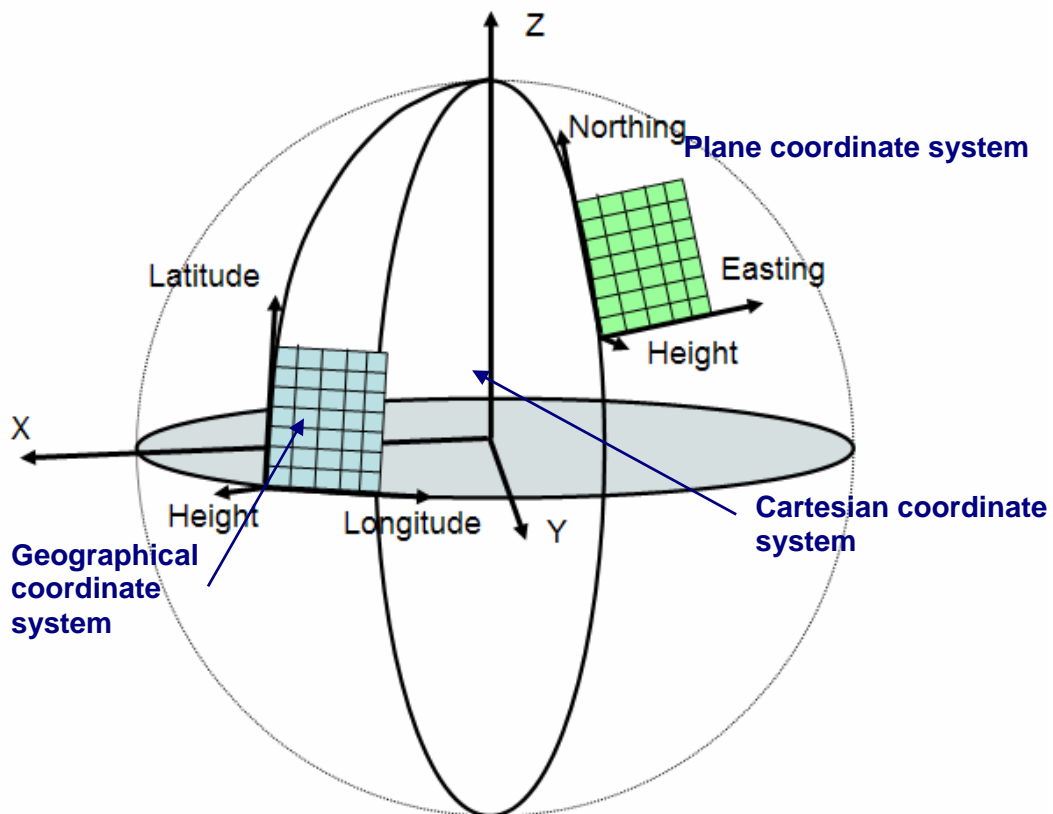


Figure 1: Overview of coordinate types that are used by DNF information processes.



5 Coordinate Systems

5.1 System versus Frame

A coordinate reference system, or geodetic datum, is a set of parameters which define the origin, direction of axis and relationship to the earth. A coordinate reference frame is often established to enable access to coordinates in a particular coordinate reference system. An obvious example is the National Grid which is a 'traditional' horizontal coordinate system and a partnering reference frame - OSGB36 which was observed mostly by theodolite triangulation of triangulation pillars.

5.2 Coordinate systems in use in the United Kingdom

5.2.1 Plane Coordinate systems

National Grid, a plane horizontal coordinate system, which consists of: a traditional geodetic datum using the Airy ellipsoid; a reference frame called OSGB36[®] (Ordnance Survey Great Britain 1936) and a Transverse Mercator map projection (allowing the use of easting and northing coordinates). OSGB36 National Grid is the national standard coordinate system for topographic mapping in Great Britain, including all Ordnance Survey mapping. National Grid coordinates are nowadays determined by an ETRS89 coordinate plus a transformation, rather than theodolite triangulation. [OSGB-1, 2006].

Irish Grid (IG) is the traditional plane coordinate system used by Northern Ireland and the Republic of Ireland for national mapping purposes. [OSNI-1, 2006]. This is similar to the system used in Great Britain, but refers to a different datum and uses a modified form of the Airy ellipsoid. Irish Grid is used for all mapping produced by Ordnance Survey of Northern Ireland and Ordnance Survey of Ireland.

Within Ireland, to overcome the need to apply a transformation when surveying using satellite positioning systems Ordnance Survey Ireland and Ordnance Survey Northern Ireland have introduced a more appropriate coordinate reference system and associated map projection.

The Irish Transverse Mercator (ITM) is a newly derived GNSS compatible mapping projection that is associated with ETRS89 and the GRS80 ellipsoid. ITM is valid across both the Republic of Ireland and Northern Ireland. [OSNI-2, 2006]



5.2.2 Cartesian and Geographical Coordinate Systems

The European Terrestrial Reference System 1989 (ETRS89) is a very well defined, stable, homogenous, geocentric coordinate system that is fully compatible with the system used by GNSS, for example WGS84 for GPS. Unlike WGS84 however, ETRS89 is fixed in time and is accurately realised on the ground (ETRS89 is coincident with the International Terrestrial Reference System at the epoch 1989.0 and fixed to the stable part of the Eurasian Plate). ETRS89, and its' corresponding reference frame, is defined, realised and maintained by EUREF - the IAG Reference Frame Sub-Commission for Europe. ETRS89 has been adopted as the primary system for accurate coordinate positioning across Europe. ETRS89 in Great Britain is realised by The National GPS Network and has been adopted as the primary coordinate system in Great Britain as it provides a compatible coordinate system for GNSS users as well as allows an accurate and stable transformation to OSGB36 National Grid to be developed. [EUREF, 2006]

The World Geodetic System 1984 (WGS84) is the coordinate system used by GPS. It consists of a three-dimensional Cartesian coordinate system and an associated ellipsoid, so that WGS84 positions can be described as either XYZ Cartesian coordinates or latitude, longitude and ellipsoid height coordinates. WGS84 is used as the horizontal datum for United Kingdom Hydrographic Office charts. [USCG, 2006]

The International Terrestrial Reference System (ITRS) is an alternative realisation of WGS84 that is produced by the International Earth Rotation and reference systems Service (IERS). Because the ITRF is of higher quality than the military WGS84 TRF, the WGS84 datum now effectively takes its definition from ITRS. Like WGS84, ITRS is fixed to the earth's tectonic plates so its' realization moves over time. To avoid the need to continually modify the coordinates of a point, the ITRF has a year of realisation (e.g. ITRF00) so that coordinates can be wound forward or back so that they are realised at the same period in time (epoch). [ITRF, 2006]

5.2.3 Height Datums

National height datums are traditionally vertical coordinate systems which relate to a measure of mean sea level at a tide gauge. Networks of benchmarks promulgate the heights across the country, making up a terrestrial reference frame. Key height datums are;

Ordnance Datum Newlyn (ODN) has a tide gauge datum with origin at Newlyn (Cornwall) and a terrestrial reference frame observed by spirit leveling between 200 fundamental bench marks (FBMs) across Britain. The TRF is densified by more than half a million lower-accuracy bench marks and is valid across mainland Great Britain. [OSGB-3, 2006]

In addition, there are many other official height datums in use across Great Britain. The Shetlands, Scilly Isles, St. Kilda, Outer Hebrides and the Isle of Man for example. [OSGB-3, 2006]



The vertical datum for Northern Ireland is the Belfast Lough Datum. [OSNI-3, 2006] This is used for all levelling information in Northern Ireland however, when combining Ordnance Survey Northern Ireland and Ordnance Survey Ireland small-scale mapping (1:50,000 scale and smaller) heights in Northern Ireland are referred to Malin Datum, which is in the Republic of Ireland. Since the difference between these two datums is approximately 0.037m there is minimal effect on published height values.

Chart Datum - A vertical level so low that the tide will not frequently fall below it. It is the level below which soundings are given on Admiralty charts, and above which are given the drying heights of features. Chart Datum tends to be at Lowest Astronomical Tide in Great Britain. The relationship between chart datum and the Ordnance Survey height datums is known at specific locations.

6 Transformations

A datum transformation is a mathematical operation which enables coordinates in one coordinate system to be transformed, into coordinates in another system (and vice versa). There are many methods to carry out this task, to varying degrees of accuracy, but this is not an exact science as a result of the homogeneity of the system, and a datum transformation should have an accompanying accuracy flag associated with it.

A transformation can only be carried out once a set of common locations, coordinated within both coordinate systems, has been defined. A mathematical model can then be used to provide an estimated 'difference' between the two coordinate sets. This can then be used to convert from one system to the other within the bounds of the transformation. Depending on the size of the area and the complexity of the coordinate systems in question, the transformation could range from a simple set of three X,Y,Z shift parameters to a very complicated model.

If local grid coordinate systems are created for a specific project, an engineering works for example, a transformation to a national or global coordinate system can be calculated. Looking ahead, DNF could develop to enable the recording of information about user defined coordinate systems. This will probably be based on the ISO 19111: Spatial Referencing by Coordinates Standard (web link: ISO, 2003). This standard describes the minimum data required to define and store metadata about coordinate reference systems.

Table 1 shows a summary of the DNF recognised transformations in use in the UK. These are the most accurate transformations available between the specified coordinate systems. Other transformations are available, but will probably not be as accurate.



Transformation	Method / Model	More Information (see web links section)
ETRS89 to OSGB36 National Grid	OSTN02™ interpolated grid shift transformation	OSGB 3 & 7
ETRS89 to Irish Transverse Mercator	Map projection, no datum transformation required	OSNI 2 & OSGB 7
ETRS89 to Irish Grid	OSTN02™ polynomial transformation	OSGB 7 & OSNI 4
ETRS89 to WGS84 / ITRSxx	6 parameter transformation	OSGB 4
Irish Grid to Irish Transverse Mercator	OSTN02™ Polynomial transformation and re-projection	OSNI 2 & 4
ITRSxx to WGS84	No official transformation, coincident to <10cm.	For information
ITRSxx / WGS84 to OSGB36 National Grid	Approximate 7 parameter transformation	OSGB 4
ETRS89 to ODN and other GB height datums	OSGM02™ interpolated grid shift transformation	OSGB 6 & 7
ETRS89 to Belfast Lough	OSGM02™ interpolated grid shift transformation	OSGB 6 & 7
Chart datum to Ordnance Survey height datum	Known at specific locations plus an approximate co-tidal interpolation model. A new Vertical Offshore Reference Frame (VORF) is being developed that will provide a more uniform transformation.	<i>Will be added when available.</i>

Table 1. Summary of DNF recognised transformations in use in the UK (note that the same transformation can be used to carry out the reverse operation).

Warning!

Usage of transformations comes with a strong health warning. It is not simply a matter of choosing the one that appears to do the job from a drop-down menu; as mentioned above, they come in all shapes and sizes, degrees of complexity and accuracy. Knowledge of the transformation is therefore required to make sure it is suitable for the task in question. A basic 3 or 7 parameter model may be appropriate if the two coordinate systems are quite uniform, storage space is limited or the application only requires limited accuracy. A more accurate model may be required however if any of these factors are reversed.

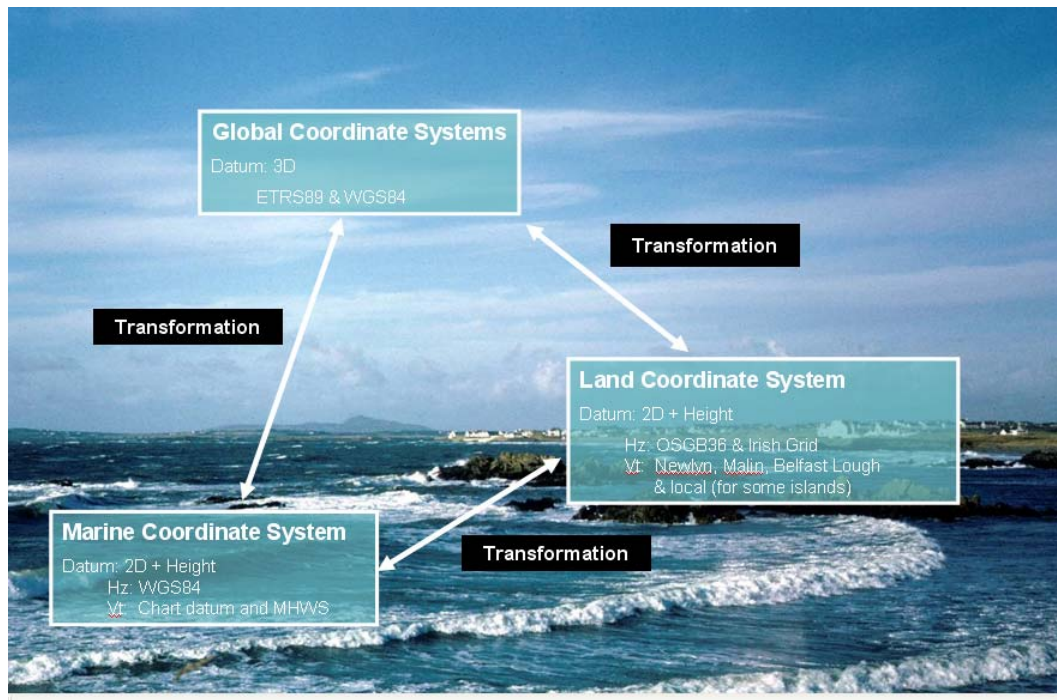


Figure 2. Relationship of Land, Sea and Global Positioning coordinate systems.

Note1: The National Grid of Great Britain cannot directly be extended to Northern Ireland and vice versa as these are two discretely different regions. A derived transformation is however currently being looked at.

Note2: The vertical transformation needs to use an ellipsoidal to orthometric height correction (geoid) model.

7 System Parameters

The parameters of most if not all systems and transformations will be added to the DNF Registry during 2007. This will provide access to all the necessary information in one place. It will also be established in a way to support service requests from applications in a Service Oriented Architecture [SOA] environment. ISO 19111: Spatial Referencing by Coordinates Standard (web link: ISO, 2003) could become the basis to describe the minimum data required to define coordinate reference systems.



8 Summary

This document has aimed to give a brief description of generic coordinate systems, the ones most applicable for use in the UK and the most appropriate transformations between any two systems. References have been given which point the user to further information.

There are many different coordinate reference systems available. The need to accurately record which system was used and which, if any, transformation is therefore a necessity.

The use of transformations is important to enable datasets to be merged from different sources. The knowledge of which transformation to use for a specific task however is very important.

9 Recommendations

If transformations are to be used, advice from an expert geodesist is recommended.



10 References

10.1 Publications

Survey Review, Vol. 37, No. 290 (2003)

OSGM02: A New Model for Converting GPS-derived Heights to Local Height Datums in Great Britain and Ireland (*J. C. Illiffe, M. Ziebart, and P. A. Cross R. Forsberg, G. Strykowski and C. C. Tscherning*)

Survey Review, Vol. 37, No. 293 (2004)

OSTN02: A new definitive transformation from GPS derived coordinates to national grid coordinates in Great Britain (*M. Greaves*)

Joint Ordnance Survey Ireland / Ordnance Survey Northern Ireland publication

Making maps compatible with GPS (1999) - Transformations between The Irish Grid and the GPS Co-ordinate Reference Frame WGS84 / ETRF89

(http://www.osni.gov.uk/5.3_making_maps_compatible_with_gps.pdf)

Ordnance Survey (GB) publication

A guide to coordinate systems in Great Britain

http://www.ordnancesurvey.co.uk/gps/docs/A_Guide_to_Coordinate_Systems_in_Great_Britain.pdf

10.2 Web References

EUREF, 2006

<http://lareg.ensg.ign.fr/EUREF/>

ISO, 2003

<http://www.iso.ch/iso/en/CatalogueDetailPage.CatalogueDetail?CSNUMBER=26016>

ITRF, 2006

<http://itrf.ensg.ign.fr/>

OSGB-1, 2006.

http://www.ordnancesurvey.co.uk/oswebsite/gps/information/coordinatesystemsinfo/guide_tonationalgrid/index.html



OSGB-2, 2006

<http://www.ordnancesurvey.co.uk/oswebsite/gps/information/coordinatesystemsinfo/guidecontents/guide5.html>

OSGB-3 2006

http://www.ordnancesurvey.co.uk/oswebsite/gps/osnetfreeservices/about/surveying_osnet.html (Q6)

OSGB-4, 2006

<http://www.ordnancesurvey.co.uk/oswebsite/gps/information/coordinatesystemsinfo/guidecontents/guide6.html> (section 6.5)

OSGB-5, 2006

<http://www.ordnancesurvey.co.uk/oswebsite/gps/information/coordinatesystemsinfo/guidecontents/guide6.html> (section 6.6) - note only accurate to 2-8m

OSGB-6, 2006

http://www.ordnancesurvey.co.uk/oswebsite/gps/osnetfreeservices/about/surveying_osnet.html (Q7)

OSGB-7, 2006

<http://gps.ordnancesurvey.co.uk/convert.asp>

OSNI-1, 2006

http://www.osni.gov.uk/2.1_the_irish_grid.pdf

OSNI-2, 2006

http://www.osni.gov.uk/2.2_a_new_coordinate_system_for_ireland.pdf

OSNI-3, 2006

http://www.osni.gov.uk/3.2_vertical_datums_in_ireland.doc

OSNI-4, 2006

http://www.osni.gov.uk/5.3_making_maps_compatible_with_gps.pdf

USCG, 2006

<http://www.navcen.uscg.gov/gps/default.htm>