ORDNANCE SURVEY

OSTN15_OSGM15 Lite User Guide

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This user guide is designed to provide an overview of *OSTN15_OSGM15 Lite* which is the compact version of the Ordnance Survey grid transformation in Great Britain OSTN15™, and the Ordnance Survey Geoid model (OSGM15™). This guide is based on the user guide for the full OSTN15/OSGM15 transformation and it gives guidelines and advice to help users understand the information contained in the data, as well as providing detailed technical information and the data format specification. It assumes that users have an understanding of coordinate systems and datums. If you find an error or omission in this user guide, or otherwise wish to make a comment or suggestion as to how we can improve the user guide, please contact us at the address shown below under contact details.

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Version History

Version	Date	Description	Authors
1.0	09/04/2020	1st version	Ordnance Survey
1.1	12/11/2020	Small amendments to copyright and trademarks text	Ordnance Survey

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Use of the transformation models

Within Great Britain coordinates are transformed using the Ordnance Survey National Grid Transformation model (OSTN15). OSGM15 is used to transform heights throughout GB.

The original OSTN15, OSGM15 (and Polynomial transformation models for Ireland) were created by a consortium comprising Ordnance Survey Limited Great Britain, Ordnance Survey Ireland (OSi), and Land & Property Services (LPS) Northern Ireland. These organisations are responsible for the official, definitive topographic mapping of their respective countries. The OSTN15/OSGM15 Lite model detailed in this guide has been created by Ordnance Survey Limited Great Britain.

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01 Introduction

Coordinate transformations and the Geoid model

All Ordnance Survey mapping relates to a coordinate reference system. In Great Britain Ordnance Survey coordinates relate to OSGB36™ (the National Grid). This reference system was traditionally realised on the Earth's surface by monumented triangulation stations. The users of mapping products, in both the public and private sectors, have invested in geographical information systems (GIS) and asset management systems based on these grid systems, which have been accepted as de facto national standards.

The National Grid is capable of supporting surveying and mapping in GB to meet all the requirements of users both now and in the future; however, an increasing number of spatial datasets are available in GNSS (Global Navigation Satellite System, e.g. GPS) compatible coordinate systems. When two or more coordinate datasets are to be integrated, it is essential that each relates to the same coordinate reference system, irrespective of accuracy issues.

In order to relate GNSS-derived positions to Ordnance Survey's mapping, GNSS coordinates need to be transformed to National Grid, which requires a specialised datum transformation. For this reason Ordnance Survey of Great Britain has developed OSTN15, the standard datum transformation for Great Britain. OSTN15 replaces the previous model OSTN02™.

Ordnance Survey mapping also includes height information that relates to a regional vertical datum. Height information in Great Britain refers to Ordnance Datum Newlyn (ODN), which is established from mean sea level. Although ODN is the national height datum used across mainland Great Britain there are a number of additional datums that are used on the surrounding islands, for example: Lerwick on the Shetland Islands; Stornoway15 on the Outer Hebrides; Douglas02 on the Isle of Man and St Marys on the Scilly Isles.

Orthometric heights in these systems have in the past been realised via a network of bench marks (BMs). These traditional levelling networks cover the whole of Great Britain, Northern Ireland and the Republic of Ireland. However, heights from precise GNSS surveying are relative to a reference ellipsoid that approximates to the shape of the Earth, but does not coincide with mean sea level. To enable GNSS to be used to determine orthometric heights, the Ordnance Surveys and LPS have jointly developed a model to establish the precise relationship between the two vertical reference surfaces. The resulting geoid model OSGM15 incorporates all the above vertical datums.

OSTN15

Ordnance Survey of Great Britain has developed the horizontal transformation OSTN15. This transformation consists of a 700km by 1,250km grid of translation vectors at 1km resolution. This provides a fit between the GNSS coordinate system European Terrestrial Reference System 1989 (ETRS89) and the OSGB36 National Grid. OSTN15 is in agreement with major triangulation stations at the level of 0.1m root mean square error (RMSE).

OSTN15 has been developed from the national primary, secondary and tertiary triangulation station network. It contains over 3,200 points directly observed by GNSS and more than 1,000 from the original retriangulation observations adjusted on the ETRS89 datum.

Within Great Britain OSTN15, in conjunction with the ETRS89 positions of the OS Net® permanent GNSS stations, is now the official definition of OSGB36 National Grid coordinate system. This means that using

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OSTN15 with the OS Net Network, surveyors using GNSS have no need to occupy triangulation stations in order to relate GNSS coordinates to National Grid coordinates.

Ordnance Survey Geoid model OSGM15

To provide the third dimension of the transformation, the Ordnance Surveys and LPS have, with others, developed the Geoid model OSGM15. The model is derived from precise gravity surveys across UK, Ireland, and surrounding waters; additionally, the model includes data from the global geopotential model (EGM96) and the GRACE gravity mission (GGM02). Alignment to each regional vertical datum is based on precise GNSS observations at bench marks. Within Great Britain these include the Ordnance Survey fundamental bench mark (FBM) network.

The OSGM15 model can be used with GNSS determined positions to establish height above mean sea level, as defined by the respective vertical datums, to the accuracies shown in the table below. The Ordnance Surveys and LPS recommend the use of the Geoid model OSGM15 and the national CORS networks (OS Net in GB) to produce orthometric height compatible with Ordnance Survey mapping. The standard error of the main datums are:

Table 1. Standard errors of OSGM15 datums.

OSGM15 Region	Standard error (m)
Great Britain	0.01
Orkney	0.02
Shetland	0.02
Outer Hebrides	0.01
Isle of Man	0.03
St Marys (Scilly Isles)	0.01

Statistics (rms, m) of the changes in the various datums compared to the previous model OSGM02 (OSGM15-OSGM02):

Table 2. Changes from OSGM02 to OSGM15.

OSGM15 Region	Change from OSGM02 (m)
Great Britain	0.026
Orkney	0.021
Shetland	0.013
Outer Hebrides	0.175
Isle of Man	(no change)
St Marys (Scilly Isles)	0.365

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Ordnance Survey Great Britain intend that OSGM15 is the official definition of the relationship between GNSS ellipsoid heights and orthometric height in Great Britain. In the way that GNSS and the transformation model OSTN15 define the horizontal coordinate system, precise GNSS surveying using the Ordnance Survey Great Britain OS Net Network in conjunction with the Geoid model will become the standard method of determining orthometric height.

OSTN15_OSGM15 Lite

Within Great Britain OSTN15 and OSGM15 are released as a combined data file using the same 1km grid (see later sections of this guide for details). OSTN15_OSGM15 Lite is simply a decimated version of the original OSTN15/OSGM15 data file that uses a 20km grid in place of the original 1km grid. This sacrifices some transformation accuracy for a greatly reduced grid parameters file size. The OSTN15_OSGM15 Lite parameter file is 400 times smaller than the regular file making it more suited for use in applications where data storage is at a premium and where faster searching of the parameter file is advantageous but the highest possible accuracy of the 1km OSTN15/OSGM15 model is not required.

ETRS89 explained

The Ordnance Survey transformations and OSGM15 link the Ordnance Survey coordinate reference systems and vertical datums to the GNSS-compatible coordinate system ETRS89. In Europe, ETRS89 is a precise version of the better known WGS84 reference system optimised for use in Europe; however, for most purposes it can be considered equivalent to WGS84.

Specifically, the motion of the European continental plate is not apparent in ETRS89, which allows a fixed relationship to be established between this system and Ordnance Survey mapping coordinate systems.

Additional precise versions of WGS84 are currently in use, notably ITRS (International Terrestrial Reference System); these are not equivalent to ETRS89. The difference between ITRS and ETRS89 is in the order of 0.25 m (in 1999), and growing by 0.025 m per year in UK and Ireland. This effect is only relevant in international scientific applications. For all navigation, mapping, GIS, and engineering applications within the tectonically stable parts of Europe (including UK and Ireland), the term ETRS89 should be taken as synonymous with WGS84.

Benefits

Together, the Ordnance Survey transformations and OSGM15 provide the complete solution to relating GNSS (WGS84) datasets to Ordnance Survey mapping in three dimensions. Used with the OS Net GNSS network, they allow GNSS surveying within the National Grid or the Irish Grid, and to the appropriate vertical datum, without the need to visit any Ordnance Survey traditional control points. OSGM15 additionally brings improvements over the previous model (OSGM02) in particular conformity with the latest coordinate realisation of the National GNSS networks, and local improvements in the Outer Hebrides, Scilly Isles and the west coast of Scotland.

The Outer Hebrides are now represented with a single homogenous datum (Stornoway15) aligned to the Stornoway Tide Gauge Bench Mark. This means that archive orthometric heights of benchmarks on North Uist, Benbecula, South Uist and Barra will no longer be realised by OSGM15 and should not be used unless there is a need to directly compare with previous surveys.

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The Scilly Isles datum, St Marys, is now better realised by OSGM15, however, results from the previous model (OSGM02) will show a large discrepancy when compared to OSGM15.

Applications

The Ordnance Survey transformations and OSGM15 are of interest to:

- GNSS surveyors who need to relate their survey to the National Grid or the Irish Grid and/or OD orthometric heights – used with the national CORS networks (OS Net in GB), these products remove the need to visit traditional Ordnance Survey horizontal and vertical control points; and

- GIS, GPS, CAD and navigation system developers who need to integrate GNSS (WGS84) datasets with Ordnance Survey mapping – these products provide the complete solution to these users at all Ordnance Survey mapping scales.

Software for OSTN15 and OSGM15

All the transformations have been coded into a software application – "Grid InQuest II". The software allows for individual coordinate input and output via a GUI and also batch input/output via text files. A command line interface and dll, along with examples of their use in a variety of programming languages, are also included. Users wishing to incorporate the pre-prepared .dll into other applications should refer to the Grid InQuest II user guide.

Grid InQuest II download packages for Windows® (32 bit and 64 bit), Linux® (32 bit and 64 bit) and OSX® are available from https://bitbucket.org/PaulFMichell/gridinquestii and the Ordnance Survey web site.

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02 Data Overview

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Basic principles

Specifications of OSTN15 Lite horizontal transformation

Transformation:	horizontal datum transformation between ETRS89 and OSGB36
Transformation type:	interpolated square grid of easting and northing shifts
Estimation method:	Delaunay triangulation
Grid resolution:	20km
Grid interpolation:	bilinear
Accuracy:	0.08m (RMS) with respect to the full 1km grid version of OSTN15
Extent:	700km east by 1,240km north

Specifications of OSGM15 Lite Geoid model

Transformation:	vertical, ETRS89 ellipsoid to orthometric height
Transformation type:	interpolated square grid of geoid heights above ETRS89 ellipsoid
Estimation method:	Spherical Fast Fourier transformation with modified Stokes kernels
Grid resolution:	20km (same grid as OSTN15)
Grid interpolation:	bilinear
Accuracy:	0.04m (RMS) with respect to the full 1km grid version of OSGM15

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Data structure

OSTN15_OSGM15 Lite – format and layout of the data

Within Great Britain OSTN15_OSGM15 Lite is released as a combined data file using the same 20km grid for both horizontal (OSTN15) and vertical (OSGM15) parameters. This grid covers an area 700km east–west and 1,240km north–south, the origin being the false origin (0, 0) of the projected ETRS89 coordinates.

The entire transformation grid is fully populated so as to avoid a transformation "cliff" at the 10km boundary that was part of the previous transformation (OSTN02). HOWEVER – great caution should be exercised to avoid using the transformation in areas where OSGB36 National Grid is not practical or required.

Each record occupies a separate line in the file with the south-west corner of the grid being the first record in the file (there is no header line). The format of each record is indicated by the following table.

Table 3. OSTN15_OSGM15 Lite data structure.

Record no[1]	ETRS89 easting[2] (m)	ETRS89 northing[3] (m)	OSTN15 east shift[4](m)	OSTN15 north shift[5](m)	OSGM15 Geoid Ht[6] (m)	Geoid datum flag[7]
1	0	0	90.750	-82.020	55.127	15
2	20,000	0	91.040	-81.914	54.748	15
3	40,000	0	91.331	-81.807	54.416	15
and so on	*and so on*	*and so on*				
36	700,000	0	103.110	-84.180	44.304	16
37	0	20,000	90.740	-81.442	55.318	15
38	20,000	20,000	91.031	-81.336	55.023	15
and so on	*and so on*	*and so on*				
2265	640,000	1,240,000	107.659	-52.593	45.987	16
2266	660,000	1,240,000	108.172	-52.807	45.422	16
2267	680,000	1,240,000	108.683	-53.029	44.937	16
2268	700,000	1,240,000	109.189	-53.264	44.635	16

Where:

1. The record number is a sequential number starting at 1 for the origin point (0,0) and finishing at 2268 for the north-east corner (700 000, 1 240 000).
2. ETRS89, National Grid projection, grid intersection easting coordinate in metres.
3. ETRS89, National Grid projection, grid intersection northing coordinate in metres.
4. The shift in eastings, at the intersection, between ETRS89 and OSGB36 National Grid, that is:
   ETRS89 east + OSTN15 east shift = OSGB36 National Grid easting.

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5. The shift in northings, at the intersection, between ETRS89 and OSGB36 National Grid, that is:
   ETRS89 north + OSTN15 north shift = OSGB36 National Grid northing.
6. The height of the Geoid above the ETRS89 ellipsoid, in metres, at the intersection, that is:
   ETRS89 height – OSGM15 Geoid height = orthometric height above mean sea level.
7. The Geoid datum flag is a number representing the local height datum or area of applicability of the transformation. See the table below for details of the datum flag references.

Table 4. OSGM15 datum flags.

Geoid datum flag	Datum name	Region
1	Newlyn	UK mainland
2	St Marys	Scilly Isles
3	Douglas02	Isle of Man
4	Stornoway15	Outer Hebrides
6	Lerwick	Shetland Isles
7	Newlyn (Orkney)	Orkney Isles
15	Newlyn Offshore	Offshore (from 2km offshore up to transformation boundary)
16	Outside transformation area	Outside transformation area

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Transformation extents

The map below indicates the extents of the various datum flags as shown in Table 4 above. The diagram is taken from the main OSTN15 OSGM15 user guide so includes the extents of transformations in Ireland and Northern Ireland which are not part of OSTN15_OSGM15 Lite.

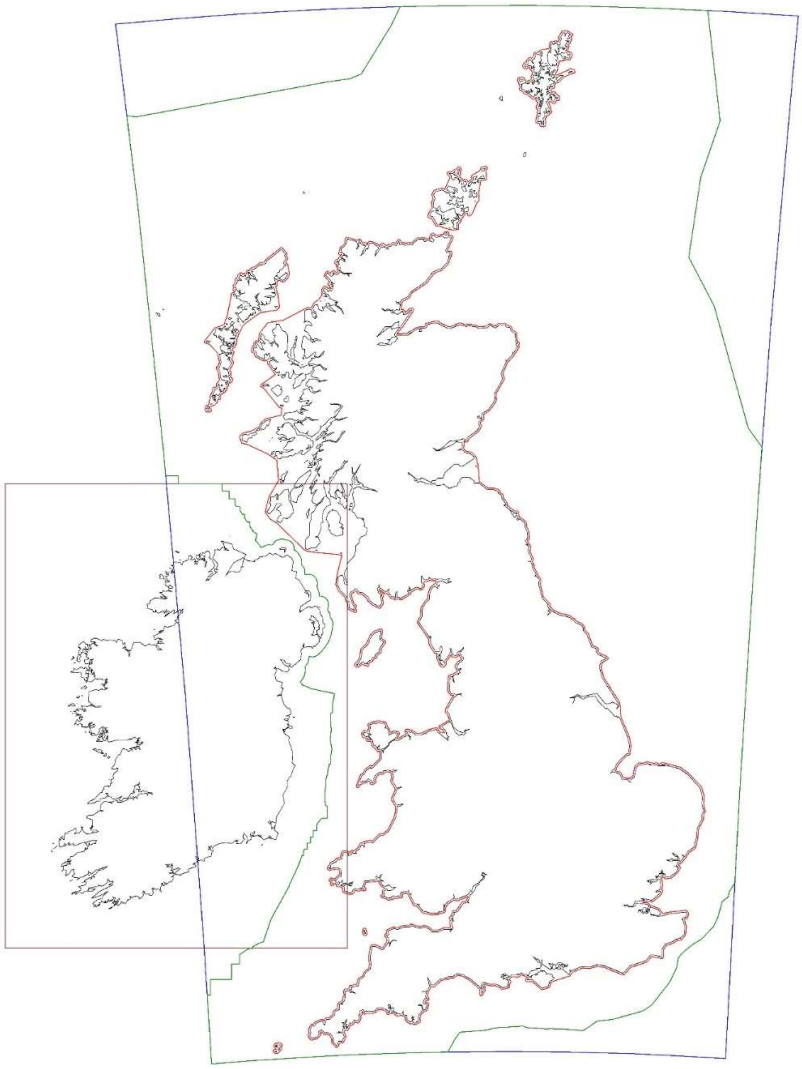

Figure 1. OSGM15 datum flag extents.

= Extent of OSGM15 Irish grids

= Extent of OSTN15/OSGM15 grid

= Extent of OSGM15 "Newlyn Offshore" datum (flag 15)

= Extents of Great Britain OSGM15 land based datums: Newlyn, St Marys, Douglas02, Stornoway15, Lerwick, Newlyn (Orkney)

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03 OSTN15 and OSGM15 Lite transformation explained

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Transforming ETRS89 coordinates to OSGB36 National Grid and orthometric heights

This chapter explains the algorithms that must be coded to implement the OSTN15_OSGM15 Lite transformation

To transform a 3D ETRS89 coordinate to OSGB36 plane coordinates and an orthometric height, the ETRS89 easting and northing is first obtained using the projection formula with GRS80 ellipsoid parameters and National Grid projection parameters in Annexe 2. Within the 20 km square where the point falls, a bilinear interpolation is used to obtain the exact transformation value for the point from the values at the four corners of the square. These values are added to the ETRS89 easting and northing to obtain the OSGB36 values and subtracted from the ETRS89 height to obtain an orthometric height. The inverse transformation (OSGB36 to ETRS89) is accomplished by an iterative procedure.

Calculating which data records to use

To find the record numbers in the OSTN15_OSGM15 Lite file corresponding to the 20km square within which a given ETRS89 easting and northing falls, use the following algorithm:

east_index = integer_part_of (easting/20000)
north_index = integer_part_of (northing/20000)

record_number_SWcnr = east_index + (north_index x 36) + 1
record_number_SEcnr = record_number_SWcnr + 1
record_number_NWcnr = record_number_SWcnr + 36
record_number_NEcnr = record_number_SWcnr + 37

For example, to find the records for (437293E, 115543N):

east_index = integer_part_of (437293/20000)
= 21

north_index = integer_part_of (115543/20000)
= 5

record_number_SWcnr = east_index + (north_index x 36) + 1
= 21 + (5 x 36) + 1 = 202

record_number_SEcnr = record_number_SWcnr + 1
= 202 +1 = 203

record_number_NWcnr = record_number_SWcnr + 36
= 202 + 36 = 238

record_number_NEcnr = record_number_SWcnr + 37
= 202 + 37 = 239

Procedure for transforming ETRS89 to OSGB36 coordinates and orthometric height

To transform an ETRS89 easting and northing (x, y), obtained using the procedure in Annexe 2, to a National Grid easting and northing (e, n), the easting and northing shifts interpolated from the data file parameters should be added to the x and y coordinates, respectively. The ETRS89 height (H) is transformed to orthometric by subtracting the geoid shift.

The point to be transformed is very unlikely to lie exactly on one of the nodes of the grid so, to calculate the shifts at any other points, an interpolation is required using the values from the 4 corners of the 20km square within which (x, y) falls.

The first stage in the transformation is to identify in which 20km grid cell the ETRS89 point lies. Use the algorithm from the previous section to first compute the east and north index values and then the 4 required data records from the transformation parameter file.

From the appropriate data records extract the parameter values as show in Figure 2 below:

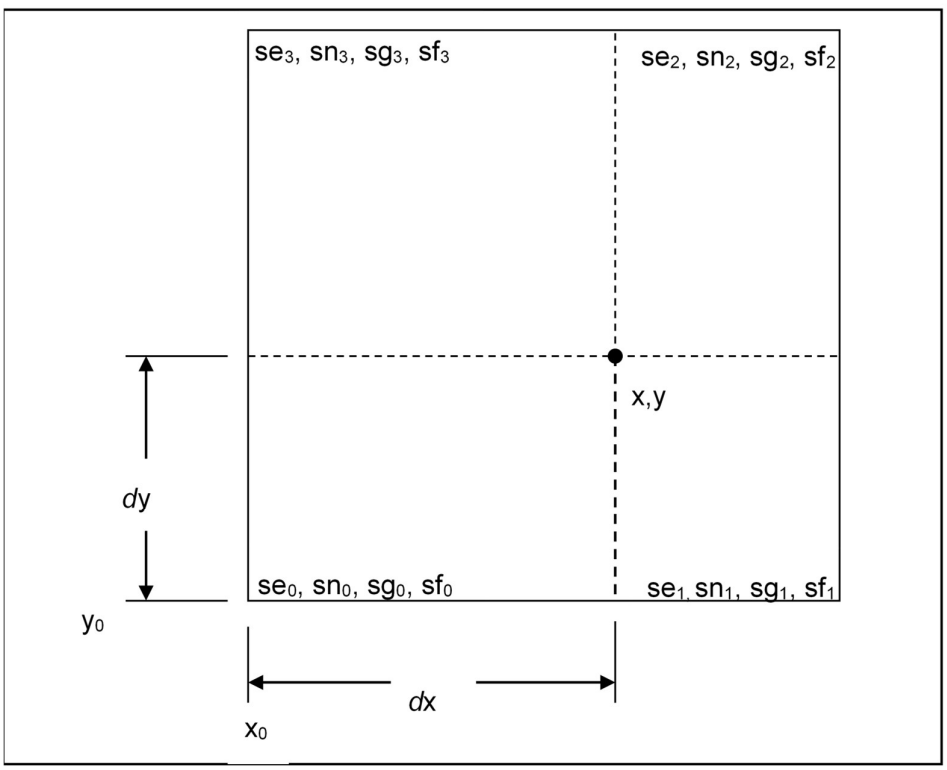

Figure 2. Parameters required for transformation computation.

In Figure 2:

se_0 se_1, se_2, se_3 are the shifts in eastings;
sn_0, sn_1, sn_2, sn_3 are the shifts in northings;
sg_0, sg_1, sg_2, sg_3 are the shifts in height;
sf_0, sf_1, sf_2, sf_3 are the datum flags;
dx, dy are the offsets of the point x, y from the SW corner of the cell (x_0, y_0).

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To interpolate the shifts at (x, y) proceed as follows:

$dx = x - x_0$
$dy = y - y_0$

$t = dx / 20000$
$u = dy / 20000$

$se = (1 - t)(1 - u)\, se_0 + (t)(1 - u)\, se_1 + (t)\,(u) se_2 + (1 - t)(u)\, se_3$
$sn = (1 - t)(1 - u)\, sn_0 + (t)(1 - u)\, sn_1 + (t)\,(u) sn_2 + (1 - t)(u)\, sn_3$
$sg = (1 - t)(1 - u)\, sg_0 + (t)(1 - u)\, sg_1 + (t)\,(u) sg_2 + (1 - t)(u)\, sg_3$

These shifts must then be added to the point x, y to give the National Grid position (e, n):

$e = x + se$
$n = y + sn$

The orthometric height is calculated by subtracting the height shift from the ETRS89 height:

$h = H - sg$

To determine the appropriate datum flag to apply to the point use the following algorithm:

if ($sf_0 = sf_1$) and ($sf_1 = sf_2$) and ($sf_2 = sf_3$) # all flags are equal
then DatumFlag = sf_0
else if (t <= 0.5) and (u <= 0.5) # point is in SW quadrant (or dead centre)
then DatumFlag = sf_0
else if (t > 0.5) and (u <= 0.5) # point is in SE quadrant
then DatumFlag = sf_1
else if (t > 0.5) and (u > 0.5) # point is in NE quadrant
then DatumFlag = sf_2
else # if none of the above are true point must be in NW quadrant
then DatumFlag = sf_3

Inverse transformation (OSGB36 to ETRS89)

To compute ETRS89 eastings and northings from OSGB36 coordinates, an iterative procedure is required:

1. To start the iteration, compute the ETRS89 to OSGB36 easting, northing and height shifts at the OSGB36 point, using the OSGB36 easting and northing and the method described above. Subtract these shifts from the OSGB36 coordinates to obtain the first estimate of the ETRS89 easting and northing.

2. Use the first estimate of the ETRS89 eastings and northings to obtain the next set of shift values. Apply these to the input OSGB36 coordinates to obtain further improved values of the ETRS89 easting and northing and height.

3. If the difference between any *n* and *n+1* iteration shift value is greater than 0.001 metres repeat step 2 until this is not the case. The final shifts are applied to the OSGB36 coordinates.

4. If ETRS89 latitude and longitude coordinates are required, obtain these from the final ETRS89 easting and northing by the procedure described in Annexe 3.

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04 Quality Statement

Coverage

OSTN15_OSGM15 Lite covers Great Britain and the Isle of Man.

The OSGM15 model in GB contains datum flags in order to relate to mean sea level as defined by the specific vertical datum for each region. The datum flag that forms part of each data record specifies to which datum the geoid-ellipsoid separation value relates.

Accuracy

OSTN15

The 1km grid square version of OSTN15 is the definitive OSGB36/ETRS89 transformation. OSTN15 (1km) in combination with the ETRS89 coordinates of the OS Net GNSS network stations, rather than the fixed triangulation network, now define the National Grid. This means that, for example, the National Grid coordinates of an existing OSGB36 point, refixed using GNSS from OS Net and OSTN15 (1km), will be the correct ones. The original archived OSGB36 National Grid coordinates of the point (if different) will no longer be true OSGB36, by definition, but the two coordinates (new and archived) will agree on average to better than 0.1 m, (68% probability).

To determine the accuracy of the 20km grid OSTN15 Lite it has been compared at over 4000 points with the results at those same points from the definitive OSTN15 transformation. The comparison is shown in Table 5 below.

Table 5. Comparison of 20km grid OSTN15 Lite with the definitive 1km grid OSTN15

	Easting difference (m)	Northing difference (m)	Horizontal difference (m)
Min	-0.252	-0.569	0.001
Max	0.241	0.301	0.570
Mean	-0.002	0.004	0.064
RMS	0.057	0.054	0.079

The 95% horizontal difference value is 0.150m.

OSGM15

The heights output by precise GPS positioning in the ETRS89 coordinate system are geometric distance above the WGS84 (GRS80) reference ellipsoid. Note that GNSS heights are typically two to three times less precise than horizontal positions. OSGM15 converts GNSS ellipsoid heights to orthometric heights above mean sea level.

In mainland Great Britain, the datum (origin point) representing mean sea level is Ordnance Datum Newlyn, defined at Newlyn in Cornwall. On the islands surrounding Great Britain, mean sea level is defined by specific independent vertical datums that are all incorporated in OSGM15.

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The estimated accuracies of the definitive 1km grid version of OSGM15, for each regional vertical datum, are included in Table 6 in the Introduction. The figures quoted assume precise ellipsoidal heights are used; for lower quality GNSS observations additional height error budget must be included.

To determine the accuracy of the 20km grid OSGM15 Lite it has been compared at over 4000 points with the results at those same points from the definitive OSGM15 transformation. The comparison is shown in Table 6 below.

Table 6. Comparison of 20km grid OSGM15 Lite with the definitive 1km grid OSGM15

	Height difference (m)
Min	-0.248
Max	0.168
Mean	-0.004
RMS	0.040

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Annex 1 Worked examples

Transforming ETRS89 GNSS coordinates to OSGB36 and orthometric height

To transform the coordinates near Ordnance Survey HQ, at a position given by ETRS89 geographical coordinates 50° 56' 17.244158" N, 001° 28' 14.209267" W, 58.39 m, to OSGB36 and orthometric height, proceed as follows.

Step 1: Compute ETRS89 eastings and northings

See the projection procedure at Annexe 2

Latitude = 50° 56' 17.244158" N
= 50.938123377222°

Longitude = 001° 28' 14.209267" W
= -1.470613685278°

The parameters for the GRS80 ellipsoid are:
a = 6 378 137.0000
b = 6 356 752.3141

Following the procedure in Annexe 2, the calculation yields the following:
ETRS89 eastings (x) = 437196.1505
ETRS89 northings (y) = 115621.9314

The ETRS89 eastings and northings (to the nearest mm) are therefore:
x = 437196.150
y = 115621.931

Step 2: Transform ETRS89 eastings and northings to OSGB36 and ETRS89 height to orthometric height

Calculate the index and record numbers:

east_index = integer_part_of (x / 20000)
= int (437196.150 / 20000)
= int (21.8598075)
= 21

north_index = integer_part_of (y / 20000)
= int (115621.931/ 20000)
= int (5.78109655)
= 5

The corresponding records to extract from the OSTN15_OSGM15 Lite parameter file are therefore:

record_number_SWcnr = east_index + (north_index x 36) + 1
= 21 + (5 x 36) + 1
= 202

record_number_SEcnr = record_number_SWcnr + 1
= 202 +1
= 203

record_number_NWcnr = record_number_SWcnr + 36
= 202 + 36
= 238

record_number_NEcnr = record_number_SWcnr + 37
= 202 + 37
= 239

The records are shown in the table below (labels e.g. se_0 etc refer to the parameters as depicted in Figure 2).

Table 7. ETRS89 to OSGB36 transformation records from OSTN15_OSGM15 Lite file.

Record no	ETRS89 easting (m)	ETRS89 northing (m)	OSTN15 east shift(m)	OSTN15 north shift(m)	OSGM15 Geoid Ht (m)	Geoid datum flag
202	420000 (x_0)	100000 (y_0)	se_0 = 96.428	sn_0 = -79.125	sg_0 = 46.826	sf_0 = 1
203	440000	100000	se_1 = 96.842	sn_1 = -79.225	sg_1 = 46.240	sf_1 = 1
238	420000	120000	se_3 = 96.348	sn_3 = -78.801	sg_3 = 46.939	sf_3 = 1
239	440000	120000	se_2 = 96.870	sn_2 = -78.865	sg_2 = 46.383	sf_2 = 1

The values required for the interpolation are:

dx = $x - x_0$
= 437196.150 – 420000
= 17196.150

dy = $y - y_0$
= 115621.931 – 100000
= 15621.931

t = dx / 20000
= 17196.150 / 20000
= 0.8598075

u = dy / 20000
= 15621.931 / 20000
= 0.7810966

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The interpolated shifts are:

$$
\begin{aligned}
se &= (1-t)(1-u)\,se_0 + (t)(1-u)\,se_1 + (t)\,(u)se_2 + (1-t)(u)\,se_3 \\
&= ((1 - 0.8598075)(1 - 0.7810966)*96.428) + ((0.8598075)(1 - 0.7810966)*96.842) \\
&\quad + ((0.8598075)(0.7810966)*96.870) + ((1 - 0.8598075)(0.7810966)*96.348) \\
&= 96.7940
\end{aligned}
$$

$$
\begin{aligned}
sn &= (1-t)(1-u)\,sn_0 + (t)(1-u)\,sn_1 + (t)\,(u)sn_2 + (1-t)(u)\,sn_3 \\
&= ((1 - 0.8598075)(1 - 0.7810966)*-79.125) + ((0.8598075)(1 - 0.7810966)*-79.225) \\
&\quad + ((0.8598075)(0.7810966)*-78.865) + ((1 - 0.8598075)(0.7810966)*-78.801) \\
&= -78.9337
\end{aligned}
$$

$$
\begin{aligned}
sg &= (1-t)(1-u)\,sg_0 + (t)(1-u)\,sg_1 + (t)\,(u)sg_2 + (1-t)(u)\,sg_3 \\
&= ((1 - 0.8598075)(1-0.7810966)*46.826) + ((0.8598075)*(1 - 0.7810966)*46.24) \\
&\quad + ((0.8598075)(0.7810966)*46.383) + ((1 - 0.8598075)(0.7810966)*46.939) \\
&= 46.4306
\end{aligned}
$$

The se and sn shifts are then added to x and y to give the National Grid position (e, n):

$$
\begin{aligned}
e &= x + se \\
&= 437196.150 + 96.7940 \\
&= \mathbf{437292.944}
\end{aligned}
$$

$$
\begin{aligned}
n &= y + sn \\
&= 115621.931 + -78.9337 \\
&= \mathbf{115542.997}
\end{aligned}
$$

The orthometric height is calculated by subtracting the height shift from the ETRS89 height:

$$
\begin{aligned}
h &= H - sg \\
&= 58.39 - 46.4306 \\
&= \mathbf{11.96}
\end{aligned}
$$

All the geoid datum flags are equal so the appropriate height datum flag to apply is 1 which corresponds (see Table 4) to Ordnance Datum Newlyn.

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Inverse transformation OSGB36 coordinates and orthometric height to ETRS89 coordinates

Due to the grid on which the transformation parameters “sit” being in ETRS89 the transformation from OSGB36 coordinates and orthometric height to ETRS89 coordinates requires an iterative procedure in order to converge on the correct ETRS89 coordinates.

To transform the OSGB36 coordinates (437292.944, 115542.997, 11.96), from the previous ETRS89 to OSGB36 example, back to ETRS89 proceed as follows.

Step 1: Use the OSGB36 coordinates as the initial input to the transformation process and compute the first iteration of the shifts

x = e
= 437292.944

y = n
= 115542.997

east_index = integer_part_of (x / 20000)
= int (437292.944 / 20000)
= int (21.8646472)
= 21

north_index = integer_part_of (y / 20000)
= int (115542.997 / 20000)
= int (5.77714985)
= 5

The corresponding records to extract from the OSTN15_OSGM15 Lite parameter file are therefore:

record_number_SWcnr = east_index + (north_index x 36) + 1
= 21 + (5 x 36) + 1
= 202

record_number_SEcnr = record_number_SWcnr + 1
= 202 +1
= 203

record_number_NWcnr = record_number_SWcnr + 36
= 202 + 36
= 238

record_number_NEcnr = record_number_SWcnr + 37
= 202 + 37
= 239

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The records are shown in the table below (labels e.g. se_0 etc refer to the parameters as depicted in Figure 2).

Table 8. OSGB36 to ETRS89 transformation records from OSTN15_OSGM15 Lite file.

Record no	ETRS89 easting (m)	ETRS89 northing (m)	OSTN15 east shift(m)	OSTN15 north shift(m)	OSGM15 Geoid Ht (m)	Geoid datum flag
202	420000 (x_0)	100000 (y_0)	se_0 = 96.428	sn_0 = -79.125	sg_0 = 46.826	sf_0 = 1
203	440000	100000	se_1 = 96.842	sn_1 = -79.225	sg_1 = 46.240	sf_1 = 1
238	420000	120000	se_3 = 96.348	sn_3 = -78.801	sg_3 = 46.939	sf_3 = 1
239	440000	120000	se_2 = 96.870	sn_2 = -78.865	sg_2 = 46.383	sf_2 = 1

The values required for the interpolation are:

$$dx = x - x_0 = 437292.944 - 420000 = 17292.944$$

$$dy = y - y_0 = 115542.997 - 100000 = 15542.997$$

$$t = dx / 20000 = 17292.944 / 20000 = 0.8646472$$

$$u = dy / 20000 = 15542.997 / 20000 = 0.77714985$$

The interpolated shifts are:

$$se_{first} = (1 - t)(1 - u)\, se_0 + (t)(1 - u)\, se_1 + (t)\,(u) se_2 + (1 - t)(u)\, se_3$$
$$= ((1 - 0.8646472)(1 - 0.77714985)*96.428) + ((0.8646472)(1 - 0.77714985)*96.842) + ((0.8646472)(0.77714985)*96.870) + ((1 - 0.8646472)(0.77714985)*96.348)$$
$$= 96.7964$$

$$sn_{first} = (1 - t)(1 - u)\, sn_0 + (t)(1 - u)\, sn_1 + (t)\,(u) sn_2 + (1 - t)(u)\, sn_3$$
$$= ((1 - 0.8646472)(1 - 0.77714985)*-79.125) + ((0.8646472)(1 - 0.77714985)*-79.225) + ((0.8646472)(0.77714985)*-78.865) + ((1 - 0.8646472)(0.77714985)*-78.801)$$
$$= -78.9355$$

$$sg_{first} = (1 - t)(1 - u)\, sg_0 + (t)(1 - u)\, sg_1 + (t)\,(u) sg_2 + (1 - t)(u)\, sg_3$$
$$= ((1 - 0.8646472)(1-0.77714985)*46.826) + ((0.8646472)*(1 - 0.77714985)*46.24) + ((0.8646472)(0.77714985)*46.383) + ((1 - 0.8646472)(0.77714985)*46.939)$$
$$= 46.4273$$

The se_{first} and sn_{first} shifts are **subtracted** from the OSGB36 coordinates to give the first iteration ETRS89 coordinates (x_{new1}, y_{new1}):

x_{new1} = e - se_{first}
= 437292.944 - 96.7964
= **437196.147**

y_{new1} = n - sn_{first}
= 115542.997 - -78.9355
= **115621.932**

Step 2: Repeat the transformation process with the previous iteration ETRS89 coordinates and compute the next iteration of the shifts

Repeat Step 1 using x_{new1}, y_{new1} as the input coordinates to the transformation process.

x = x_{new1}
= 437196.147

y = y_{new1}
= 115621.932

This yields the following shifts and improved ETRS89 coordinates:

x_{new2} = e - se_{second}
= 437292.944 - 96.7940
= **437196.150**

y_{new2} = n - sn_{second}
= 115542.997 - -78.9337
= **115621.931**

Step 3: Check the difference between shifts from previous iteration and repeat the transformation process as required

Test the difference between the shifts from the first and second iterations against the 0.001m threshold. If either difference is greater than the threshold then repeat the transformation process using the most recent values of x and y as the input.

δse = $|(se_{second} - se_{first})|$
= |(96.7940 - 96.7964)|
= 0.0024

$\delta sn = |(sn_{second} - sn_{first})|$
$= |(-78.9337 - -78.9355)|$
$= 0.0018$

The threshold test fails since both shift differences are greater than 0.001.

Loop around steps 2 and 3 until the shift differences are below the threshold. At this point the final values of se, sn and sg should be applied to e, n and h to compute the final ETRS89 values. The table below summarises the iteration results for this worked example.

Table 9. Values from iteration steps in OSGB36 to ETRS89 transformation.

Iteration	se (m)	sn (m)	sg (m)	ETRS89 easting (m)	ETRS89 northing (m)
1	96.7964	-78.9355	46.4272	437196.147	115621.932
2	96.7940	-78.9337	46.4306	437196.150	115621.931
3	96.7940	-78.9337	46.4306	437196.150	115621.931

$x_{final} = e - se_{third}$
$= 437292.944 - 96.7940$
$= \mathbf{437196.150}$

$y_{final} = n - sn_{third}$
$= 115542.997 - -78.9337$
$= \mathbf{115621.931}$

$H_{final} = h + sg_{third}$
$= 11.96 + 46.4306$
$= \mathbf{58.39}$

Use the procedure in Annexe 3, to convert the ETRS89 easting and ETRS89 northing coordinates to latitude and longitude gives:

Latitude = 50.9381233716°
= 50° 56' 17.244147" N

Longitude = -1.47061369206°
= 001° 28' 14.209291" W

The geographical ETRS89 coordinates are slightly different from the original input ones used in the ETRS89 to OSGB36 example due to rounding in the projection and transformation processes. However, the difference is insignificant since they agree at the mm level.

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Annex 2 Converting latitude and longitude to easting and northings

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Ellipsoid and projection constants

The formulae in this annexe and Annexe 3 require ellipsoid constants and projection constants, given in the tables below.

Important note: When converting OSGB36 coordinates between (easting, northing) and (latitude, longitude) in either direction, use the Airy 1830 ellipsoid constants. When converting ETRS89 coordinates between (easting, northing) and (latitude, longitude) in either direction, use the GRS80 ellipsoid constants. Use the same National Grid projection constants for both ETRS89 and OSGB36 coordinates.

Table 10. Ellipsoid constants.

Ellipsoid	Semi major axis *a* (m)	Semi minor axis *b* (m)	Used for the following coordinate systems
Airy 1830	6 377 563.396	6 356 256.909	OSGB36 National Grid
GRS80	6 378 137.0000	6 356 752.3141	ETRS89

The ellipsoid squared eccentricity constant e^2 is computed from *a* and *b* by:

$$e^2 = \frac{a^2 - b^2}{a^2} \tag{2-1}$$

Table 11. Projection constants.

Projection	Scale factor on central meridian (F_0)	True origin (ϕ_0 and λ_0)	Map coordinates of true origin (m) (E_0 and N_0)
National Grid	0.9996012717	lat 49° N long 2° W	E 400 000 N -100 000

Projection formulae

To project a position from the graticule of latitude and longitude coordinates (ϕ and λ)to a grid of easting and northing coordinates (E, N) using a transverse Mercator projection, for example OSGB36 National Grid, use the following formulae. All angles must be expressed in radians. Ellipsoid constants *a*, *b* and e^2 and the projection constants listed below are required:

N_0 – northing of true origin
E_0 – easting of true origin
F_0 – scale factor on central meridian
ϕ_0 – latitude of true origin
λ_0– longitude of true origin and central meridian.

$$n = \frac{a-b}{a+b} \tag{2-2}$$

$$v = aF_0(1 - e^2\sin^2\phi)^{-0.5} \tag{2-3}$$

$$\rho = aF_0(1 - e^2)(1 - e^2\sin^2\phi)^{-1.5} \tag{2-4}$$

$$\eta^2 = \frac{v}{\rho} - 1 \tag{2-5}$$

$$M = bF_0\left(\begin{array}{l}\left(1+n+\frac{5}{4}n^2+\frac{5}{4}n^3\right)(\phi-\phi_0)-\left(3n+3n^2+\frac{21}{8}n^3\right)\sin(\phi-\phi_0)\cos(\phi+\phi_0)\\ +\left(\frac{15}{8}n^2+\frac{15}{8}n^3\right)\sin(2(\phi-\phi_0))\cos(2(\phi+\phi_0))-\frac{35}{24}n^3\sin(3(\phi-\phi_0))\cos(3(\phi+\phi_0))\end{array}\right) \tag{2-6}$$

$$\mathrm{I} = M + N_0$$

$$\mathrm{II} = \frac{v}{2}\sin\phi\cos\phi$$

$$\mathrm{III} = \frac{v}{24}\sin\phi\cos^3\phi(5-\tan^2\phi+9\eta^2)$$

$$\mathrm{IIIA} = \frac{v}{720}\sin\phi\cos^5\phi(61-58\tan^2\phi+\tan^4\phi)$$

$$\mathrm{IV} = v\cos\phi$$

$$\mathrm{V} = \frac{v}{6}\cos^3\phi\left(\frac{v}{\rho}-\tan^2\phi\right)$$

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$$\mathrm{VI} = \frac{\nu}{120}\cos^5\phi\left(5 - 18\tan^2\phi + \tan^4\phi + 14\eta^2 - 58\eta^2\tan^2\phi\right)$$

$$N = \mathrm{I} + \mathrm{II}(\lambda - \lambda_0)^2 + \mathrm{III}(\lambda - \lambda_0)^4 + \mathrm{IIIA}(\lambda - \lambda_0)^6 \tag{2-7}$$

$$E = E_0 + \mathrm{IV}(\lambda - \lambda_0) + \mathrm{V}(\lambda - \lambda_0)^3 + \mathrm{VI}(\lambda - \lambda_0)^5 \tag{2-8}$$

Worked example

ETRS89 latitude and longitude (ϕ and λ) projected to ETRS89 eastings (E) and ETRS89 northings (N).

Latitude ϕ	=	50° 56' 17.244158" N
	=	0.889037967720 rad
Longitude	=	001° 28' 14.209267" W
	=	-0.025667050833 rad

The parameters for the GRS80 ellipsoid are:

a	=	6 378 137.0000
b	=	6 356 752.3141

The projection parameters are:

N_0	=	-100000 m
E_0	=	400000 m
F_0	=	0.9996012717
ϕ_0	=	49° N = 0.855211333477 rad
λ_0	=	2° W = -0.034906585040 rad

Intermediate values are shown here to 10 decimal places. Compute all values using double-precision arithmetic and the maximum precision allowed by software/operating system/coding language.

e^2	=	6.6943800355E-03
n	=	1.6792203978E-03
ν	=	6.3884989991E+06
ρ	=	6.3714473544E+06
η^2	=	2.6762592126E-03
P	=	9.2395342069E-03
M	=	2.1548850365E+05
I	=	1.1548850365E+05
II	=	1.5629373164E+06
III	=	1.8132276430E+05
IIIA	=	-1.6946427483E+04
IV	=	4.0257720784E+06
V	=	-1.3736991794E+05
VI	=	-1.0697593049E+05

ETRS89 eastings (E)	=	437196.1505
ETRS89 northings (N)	=	115621.9314

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Annex 3 Converting easting and northings to latitude and longitude

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Projection formulae

Obtaining latitude and longitude (ϕ and λ)from eastings and northings (E, N) is an iterative procedure. The values for the ellipsoid and projection constants a, b, e2, N_0, E_0, F_0, ϕ_0 and λ_0, given in annexe 2, are required. Remember to express all angles in radians.

First compute ϕ' :

$$\phi' = \left(\frac{N - N_0}{aF_0}\right) + \phi_0 \tag{3-1}$$

Then compute M from equation 2-6 in Annexe 2, substituting ϕ' for ϕ.

If |(N - N0 – M)| ≥ 0.01mm obtain a new value for ϕ' using:

$$\phi'_{new} = \left(\frac{N - N_0 - M}{aF_0}\right) + \phi' \tag{3-2}$$

Recompute M using the new value for ϕ'.

Iterate the loop of testing |(N - N0 – M)| against the 0.01mm threshold and computing a new value for ϕ' until |(N - N0 – M)|< 0.01mm then compute ν, ρ and η^2 using equations 2-3, 2-4 and 2-5 from Annexe 2. Then compute the following:

$$\text{VII} = \frac{\tan\phi'}{2\rho\nu}$$

$$\text{VIII} = \frac{\tan\phi'}{24\rho\nu^3}\left(5 + 3\tan^2\phi' + \eta^2 - 9\tan^2\phi'\eta^2\right)$$

$$\text{IX} = \frac{\tan\phi'}{720\rho\nu^5}\left(61 + 90\tan^2\phi' + 45\tan^4\phi'\right)$$

$$\text{X} = \frac{\sec\phi'}{\nu}$$

$$\text{XI} = \frac{\sec\phi'}{6\nu^3}\left(\frac{\nu}{p} + 2\tan^2\phi'\right)$$

$$\text{XII} = \frac{\sec\phi'}{120\nu^5}\left(5 + 28\tan^2\phi' + 24\tan^4\phi'\right)$$

$$\text{XIIA} = \frac{\sec\phi'}{5040\nu^7}\left(61 + 662\tan^2\phi' + 1320\tan^4\phi' + 720\tan^6\phi'\right)$$

$$\phi = \phi' - \mathrm{VII}(E - E_0)^2 + \mathrm{VIII}(E - E_0)^4 - \mathrm{IX}(E - E_0)^6 \tag{3-3}$$

$$\lambda = \lambda_0 + X(E - E_0) - XI(E - E_0)^3 + \mathrm{XII}(E - E_0)^5 - \mathrm{XIIA}(E - E_0)^7 \tag{3-4}$$

Worked example

ETRS89 eastings (E) and ETRS89 northings (N) unprojected to ETRS89 latitude and longitude (ϕ and λ)

ETRS89 eastings (E)	=	437196.150
ETRS89 northings (N)	=	115621.931

The parameters for the GRS80 ellipsoid are:

a	=	6 378 137.0000
b	=	6 356 752.3141

The projection parameters are:

N_0	=	-100000 m
E_0	=	400000 m
F_0	=	0.9996012717
ϕ_0	=	49° N = 0.855211333477 rad
λ_0	=	2° W = -0.034906585040 rad

Intermediate values are shown here to 10 decimal places. Compute all values using double-precision arithmetic and the maximum precision allowed by software/operating system/coding language.

ϕ' #1	=	0.889031231021 rad
M #1	=	215445.581129353
N-N_0-M #1	=	176.349870647303 m
ϕ' #2	=	0.889058891169 rad
M #2	=	215621.816319479
N-N_0-M #2	=	0.114680521190 m
ϕ' #3	=	0.889058909157 rad
M #3	=	215621.930925439
N-N_0-M #3	=	0.000074561161 m
ϕ' #4	=	0.889058909168 rad
M #4	=	215621.930999951
N-N_0-M #4	=	0.000000048633 m

e^2	=	6.6943800355E-03
ν	=	6.3884994391E+06
ρ	=	6.3714486709E+06
η^2	=	2.6761210995E-03
M	=	2.1562193100E+05
$E - E_0$	=	3.7196150000E+04
VII	=	1.5136433683E-14
VIII	=	2.9426507672E-28
IX	=	7.6080038467E-42
X	=	2.4840594948E-07
XI	=	4.0976449257E-21
XII	=	1.2781277597E-34
XIIA	=	4.8066437531E-48

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Latitude ϕ	=	0.8890379677 rad
	=	50° 56' 17.244147" N
Longitude	=	-0.0256670509 rad
	=	001° 28' 14.209291" W

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Annex 4 Glossary

The following is a list of technical terms used in this user guide, together with a fuller definition.

Datum
A point, line, surface or set of these, with respect to which positions of objects can be stated as unique sets of coordinates.

de facto national standard
A national standard by adoption rather than legally enforced.

ellipsoid (biaxial)
The 3D geometric figure obtained by rotating an ellipse about its minor axis. Used in geodesy to approximate the shape of the earth.

ETRF89
European Terrestrial Reference Frame 1989 – the Europe-fixed realisation of WGS84. Governed by EUREF as a standard reference frame for Europe.

ETRS89
European Terrestrial Reference System 1989 – a coordinate system that is the Europe-fixed precise version of WGS84. Governed by EUREF as the standard fixed reference system for Europe. ETRS89 is related to the state-of-the-art WGS84-consistent system ITRS2000 by a six-parameter kinematic transformation published by IERS.

EUREF
EUREF (European Reference Frame): a sub-commission of the International Association of Geodesy, Commission X.

geocentric datum
A reference system that uses the centre of mass of the earth as its origin; the popularity of these systems today derives from their usefulness in describing satellite orbits.

Geoid model
A model of the level surface which is closest to mean sea level over the oceans. This surface is continued under land as the fundamental reference surface for height measurement.

GNSS
Global Navigation Satellite System – generic term for one or more satellite navigation systems including (but not limited to) GPS (USA), GLONASS (Russia), Galileo (Europe), Beidou (China).

GPS
Global Positioning System – an outdoor positioning technique using a constellation of US Department of Defense satellites and a portable receiver to dynamically determine coordinates. For high precision, several receivers are used and their relative positions are determined.

GRS80
A global reference ellipsoid used in the WGS84 coordinate system. Also known as the WGS84 ellipsoid.

IERS
International Earth Rotation Service.

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ITRF
International Terrestrial Reference Frame – the state-of-the-art global realisation of the WGS84 reference system, using observations from worldwide networks of active geodetic stations of the VLBI, SLR, GPS and DORIS techniques.

ODN
Ordnance Datum Newlyn – the levelling-based vertical reference frame for most of the British Isles, with a single tide gauge constraint in Newlyn in Cornwall.

OSGB36
Ordnance Survey Great Britain 1936 – the British horizontal mapping datum, observed by triangulation from 1936 and traditionally realised on the ground by triangulation stations. With the release of the definitive transformation, OSTN02, OSGB36 is now realised by the ETRS89 coordinates of the National GPS Network in conjunction with the OSTN02 transformation.

OSGM02
Ordnance Survey National Geoid Model 2002 – now superceded, a gravimetric Geoid model that is aligned with the national height datums of Great Britain, Northern Ireland and Ireland. Replaced by OSGM15.

OSGM15
Ordnance Survey National Geoid Model 2015 – a gravimetric Geoid model that is aligned with the national height datums of Great Britain, Northern Ireland and Ireland.

OSTN15
Ordnance Survey National Grid Transformation 2015 – a grid shift type horizontal transformation between the ETRS89 datum and OSGB36 National Grid.

Realisation
A spatial reference system made real on the ground by monumented points with estimated coordinates and errors.

Transformation
A procedure to change from one coordinate system to another.

WGS84
World Geodetic System 1984 – the global geodetic reference system used to describe the position of GPS satellites and ground stations.

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