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THE GEOGRAPHICAL AND RECTANGULAR COORDINATES IN USE IN IRELAND AND THEIR TRANSFORMATIONS

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THOMAS MURPHY

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Introduction

When gravity surveys were undertaken in Ireland, starting in the year 1949, difficulties arose in ascertaining, with sufficient accuracy, the necessary position of the stations on the globe. To resolve this, geographical coordinates of the corners of the 1:10560 sheet maps of the Ordnance Survey were calculated and published in Bulletin 13 of this series.

In recent years, geophysical surveys carried out at sea used different coordinate systems and some uncertainty arose in our School. In an attempt to define geographical positions unambiguously a series of instructions containing various formulae were drafted mainly for use with small desk calculators. Requests then came from outside sources, both scientific and commercial, for these and this Bulletin was put together in reply. It is intended purely for practical application and does not enter into the history or reasons for the adoption of the various systems.

To illustrate the difficulty in specifying a particular point the various coordinates of the primary trigonometrical station at Howth are given in Tables 1 and 2. At this latitude the length of one second of latitude is 31 m and that of longitude 19 m.

Table 1 Geographical Coordinates of Primary Trigonometrical Station No. 29 - HOWTH

Latitude	Longitude	System
53° 22' 23.130"	-6° 04' 06.105"	A
53° 22' 23.1566"	-6° 04' 06.0065"	AM
53° 22' 27.1308"	-6° 04' 03.9107"	E

The systems have been designated A, AM and E which stand for AIRY, AIRY (MODIFIED) and EUROPEAN DATUM 1950.

Table 2 Rectangular Coodinates of Primary Trigonometrical Station No. 29 - HOWTH

Easting	Northing	System
328 544.546	237 616.315	A
328 546.344	237 617.186	AM
695 063.538	5 918 031.753	E

The ED50 coordinates are for ZONE 29

The differences between the coordinates of each system arise from many causes the principal ones being due to the ellipsoid, the datum, the measurement and remeasurement, and the adjustment used. These are set out in Table 3 together with the parameters of the ellipsoids.

Table 3 Coordinate Systems

System	A	AM	E
Ellipsoid	AIRY	AIRY (MODIFIED)	INTERNATIONAL 1930
Semi-major diameter	6 377 563.396	6 377 340.189	6 378 388
Ellipticity	1/299.325	1/299.325	1/297
Datum	Greenwich	Greenwich approx.	Potsdam
Triangulation	1783-1832	1952-1964	1952-1964
Adjustment	1858	1975	1970 Scientific

The rectangular coordinates of Table 2 are Transverse Mercator Coordinates derived from the geographicals of Table 1 by standard procedures such as given in Appendix 1 using the parameters and derived constants of Appendix 2.

It will be noted that in Appendix 2, while the geographical coordinates of the origin of the A and the AM systems are the same the ellipsoids and scale factors are not. This results in the following. Starting from the same geographical coordinates in both systems and using the appropriate constants for each, the same rectangular coordinates result. This was done by the Ordnance Survey geodesists for reasons which will not be gone into and has, unfortunately, caused a certain amount of confusion. This topic will be returned to later.

The rectangular coordinates in the AM system are known as the NATIONAL GRID COORDINATES.

If the accuracy required is not as high as given by Appendix 1 then the formula of Appendix 3, which does not require trigonometrical functions, can be used with judicious truncating of the constants.

Uses of the various systems

The AIRY system formed the basis for the coordinates printed on the 1:63360 (one inch to a mile) Ordnance Survey sheet maps and smaller scale ones derived therefrom. It was used in the deduction of the geographical coordinates for the corners of the 1:10560 (six inches to a mile) county sheet maps carried out by the Dublin Institute for Advanced Studies. It is used for the Admiralty Charts around Ireland issued by the Hydrographic Office of Great Britain.

The AIRY (MODIFIED) system is being used for the new maps of the Ordnance Survey.

The EUROPEAN DATUM 1950 system, being international, is used for all geophysical work at sea and legally for the definition of fishing rights and exploration licences. There is thus disagreement with the Admiralty Hydrographic charts.

Transformation of geographical coordinates

This can easily be carried out by a translation of Cartesian coordinates such as given in Appendix 4 and 5. In some cases for example between ED50 and OSGB 1970 SN the relationship is fixed (Olliver, 1981) but between AIRY 1858 and ED50 it has been found that a better fit for Ireland is obtained using the following:

ΔX	+ 456
ΔY	− 6
ΔZ	+ 548

which are used in the Appendix. This was achieved by comparing the values given for the Principal Triangulation stations listed by Wolff 1919 and the present values used by the Ordnance Survey for ED50.

However, in the case of the AIRY (MODIFIED) Ellipsoid a simple translation does not given a good fit. Instead power series formulae have been evolved and listed in Appendices 6 and 7. These give the transformations within the area of Ireland with an accuracy of $\pm$0.01" in latitude and $\pm$0.02" in longitude.

Transformation of Rectangular to Geographical Coordinates

The procedure given by the Ordnance Survey publications requires the use of Tables and this is thought to be inconvenient. Instead by confining the area betweeen the parallels 51° and 55.5° suitable formulae have been devised both for A and AM in Appendices 8 and 9 and for E in Appendix 10. Appendix 9 is a less accurate method; $\pm$0.2" while 8 and 10 are accurate to $\pm$0.001".

Grouping A and AM together as above requires an explanation and has been referred to already as having caused some confusion. If the position of a point is obtained in National Grid Coordinates from, say, the new 1:5000 scale maps of the Ordnance Survey, transformed to geographical coordinates then these, by definition, are AM not A coordinates.

Differences between coordinates

Up to now, the differences between the A and the AM systems as exemplified by Table 1 are small and in most cases quite negligible but both these differ significantly from E. However much larger differences can be encountered for the following reasons.

As mentioned earlier the geographical coordinates of the sheet corners of the 1:10560 sheets were compiled and are obtainable from the Dublin Institute for Advanced Studies. These have been converted to rectangular coordinates using the method of Appendix 3 and lists of these are available in manuscript form at the Institute. From these it is possible to define a point to better than one second of arc or to a few metres as 1 mm on the map is equivalent to 10 metres. A linear interpolation of these sheet corners can be used to obtain the corners of the 1:2500 sheets and tests have shown that the coordinates of a point can be obtained from these sheets to at least one metre.

The geographical coordinates of the 1:63360 sheets can be obtained from the Ordnance Survey and the rectangular coordinates computed. Depending on the position of the point on a particular sheet the coordinates can be obtained to at least 100 metres. The array of coordinates are in manuscript form and are available at the Institute.

The coordinates thus derived from the 1:10560 and the 1:63360 sheets are referred to as AIRY geographical coordinates and AIRY grid coordinates.

The derivation of these has been given in Bulletin 13 and, as was pointed out, there is a great uncertainty regarding the adjustment of the original data and it is well known that there are discontinuities across each county boundary. These may be quite large, even up to 60 m.

The retriangulation of the country, 1952-64, and subsequent adjustments has made it possible to improve the accuracy of the coordinates of the corners of the original 1:10560 and 1:2500 sheets. The National Grid coordinates of the corners are available but only in a restricted manuscript and have not been released by the Ordnance Survey for general use (Walsh, 1977). If these National Grid coordinates are converted to geographicals by a method such as given in Appendix 9 the latter will differ from those deduced from the original 1:10560 map and from the published 1:63360. The discrepancy depends on the county. It is negligible for some and up to one second in latitude and longitude in others. It is not always constant throughout a county. To distinguish between the two sets it is suggested that these geographicals be referred to as AIRY (MODIFIED) Latitude and Longitude until such time as these become completely accepted.

Other Ellipsoids

Although the ellipsoids already mentioned are the ones in normal use for mapping purposes in Ireland other ellipsoids are used for special purposes. For example in Gravity Surveying the International Gravity Formula 1980 is used to deduce the BOUGUER ANOMALY. This is based on the International Ellipsoid 1967 semi-major diameter 6378160 m ellipticity 1/298.25. The latitude required is deduced from the National Grid Coordinates.

With the advent of Satellite Doppler positioning, discrepancies will undoubtedly arise but if the system is mentioned when the coordinates are given there should be no ambiguity.

Nautical Charts

The situation regarding Nautical Charts around the coast which are all of non Irish origin is somewhat different. It must be understood that they cannot be compared with Ordnance Survey Maps as they are intended to serve a completely different purpose principally the presentation of the hazards to navigation. It is not always clear what is the basis of some of the charts, the origins often being lost. The coordinates are on a rectilinear grid and certain defined points may be, probably are, accurately positioned but the coast line is quite obviously depicted not defined. It is assumed but not stated that the Admiralty Charts (British) are based on the AIRY Ellipsoid.

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APPENDIX

Appendix	1	Formulae for the computation of TRANSVERSE MERCATOR COORDINATES.
Appendix	2	Constants for use in formulae of Appendix 1.
Appendix	3	Transformation of GEOGRAPHICAL to NATIONAL GRID COORDINATES.
Appendix	4	Transformation of Geographical Coordinates; AIRY 1858 to EUROPEAN DATUM 1950.
Appendix	5	Transformation of Geographical Coordinates; EUROPEAN DATUM 1950 to AIRY 1858.
Appendix	6	Transformation of Geographical Coordinates; AIRY (MODIFIED) to EUROPEAN DATUM 1950.
Appendix	7	Transformation of Geographical Coordinates; EUROPEAN DATUM 1950 to AIRY (MODIFIED).
Appendix	8	Transformation of NATIONAL GRID to GEOGRAPHICAL COORDINATES (Formula 1).
Appendix	9	Transformation of NATIONAL GRID to GEOGRAPHICAL COORDINATES (Formula 2).
Appendix	10	Transformation of ED50 ZONE 29 to GEOGRAPHICAL COORDINATES.

Notes

1) With the exception of Appendix 1 the formulae given should be used only for the areas given in the text.

2) West Longitude is used throughout and entered in the formulae with a negative sign.

3) Programmes for computation using HEWLETT PACKARD calculators 67 and 97 are obtainable from the Institute.

APPENDIX I

Formulae for the Computation of Transverse Mercator Coordinates

φ = Latitude

λ = Longitude

Easting = $\left(P(\mathrm{IV}) - P^3(\mathrm{V}) - P^5(\mathrm{VI})\right) \times k_\circ + E_\circ$

Northing = $\left((\mathrm{I}) + P^2(\mathrm{II}) + P^4(\mathrm{III})\right) \times k_\circ + N_\circ$

Where P = $0{\cdot}36 \times (\lambda^\circ - \lambda^\circ_\circ)$

$\lambda^\circ_\circ$ = Longitude of Origin

$k_\circ$ = Central Scale Factor

$E_\circ, N_\circ$ = Coordinates of Origin

I = $b(\varphi - \varphi_\circ) + A \times \varphi + B \times \sin 2\varphi + C \times \sin 4\varphi + D \times \sin 6\varphi - E$

b = Semi-minor diameter

$\varphi^\circ_\circ$ = Latitude of Origin

A = $b\left(n + \frac{5}{4}n^2 + \frac{5}{4}n^3\right)$

B = $-\frac{b}{2}\left(3n + 3n^2 + \frac{21}{8}n^3\right)$

C = $\frac{b}{2}\left(\frac{15}{8}n^2 + \frac{15}{8}n^3\right)$

D = $-\frac{b}{2}\left(\frac{35}{24}n^3\right)$

E = $A \times \varphi_\circ + B \times \sin 2\varphi_\circ + C \times \sin 4\varphi_\circ + D \times \sin 6\varphi_\circ$

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

II = $\frac{\nu}{4} S^2 \sin 2\varphi$

III = $\frac{\mathrm{II}}{12} S^2 \cos^2\varphi\,(5 - \tan^2\varphi + 9\eta^2)$

IV = $\nu\, S \cos\varphi$

V = $-\frac{\mathrm{IV}}{6} S^2 \cos^2\varphi \left(\frac{\nu}{\rho} - \tan^2\varphi\right)$

VI = $0{\cdot}0813 - 0{\cdot}00103\,\varphi^\circ$

ν = $\frac{a}{(1 - e^2\sin^2\varphi)^{\frac{1}{2}}}$

ρ = $\frac{\nu(1 - e^2)}{(1 - e^2\sin^2\varphi)}$

η = $\frac{\nu}{\rho} - 1$

a = Semi-major diameter

e^2 = $(\text{eccentricity})^2$

S = $\sin 1'' \times 10^4 = 0{\cdot}048\,481\,368$

In the formulae for I and E above, φ and $\varphi_\circ$ are in radians.

APPENDIX 2

Constants for use in formulae of Appendix 1

Coordinates	National Grid		ZONE 29 ED50
System	AIRY	AIRY(MODIFIED)	EUROPEAN DATUM 1950
Semi major diameter	6 377 563.396	6 377 340.189	6 378 388
Semi minor diameter	6 356 256.909	6 356 034.446	6 356 911.946
e^2	0.006 670 54	0.006 670 54	0.006 722 67
Latitude of Origin	53.5°	53.5°	0°
Longitude of Origin	-8°	-8°	-9°
Central Scale factor	1	1.000035	0.9996
E_o	200 000	200 000	500 000
N_o	250 000	250 000	0
A	+10 657.699 6	+10 657.327 6	+10 742.553 92
B	-15 979.859 4	-15 979.301 6	-16 107.034 70
C	+16.711 1	+16.710 5	+16.976 17
D	- 0.021 7	- 0.021 7	- 0.022 23
E	- 5 399.307 3	- 5 339.121	0

APPENDIX 3

Transformation of Geographical to National Grid Coordinates

$$E = P(199135.366 - 4130.362\varphi_1 - 30.68\varphi_1^2 + 0.22\varphi_1^3) - P^3(13.4378 + 2.4304\varphi_1 - 0.07304\varphi_1^2) - P^5(0.026) + 200\,000$$

$$N = (-139\,384.421 + 111\,219.253\varphi_1 + 9.666\varphi_1^2 - 0.032\varphi_1^3) + P^2(3697.809 - 22.5126\varphi_1 - 2.27085\varphi_1^2 + 0.007633\varphi_1^3) + P^4(1.0807 - 0.0839\varphi_1 + 0.00067\varphi_1^2)$$

Where $\varphi_1 = \varphi^\circ - 50$

$P = 0.36(\lambda^\circ + 8)$

Accuracy $\pm$ 0.01 m

APPENDIX 4

Transformation of Geographical Coordinates *

AIRY 1858 to EUROPEAN DATUM 1950

$$(\varphi_A, \lambda_A) \quad \text{to} \quad (\varphi_E, \lambda_E)$$

$$\tan\varphi_E = \frac{Z_E}{X_E} \times \frac{\cos\lambda_E}{0{\cdot}993\,277\,33}$$

$$\tan\lambda_E = \frac{Y_E}{X_E}$$

Where

$$X_E = V\cos\varphi_A\cos\lambda_A + 456$$

$$Y_E = V\cos\varphi_A\sin\lambda_A - 6$$

$$Z_E = 0{\cdot}993\,329\,46\ V\sin\varphi_A + 548$$

$$V = \frac{6\,377\,563}{(1 - 0{\cdot}006\,670\,54\sin^2\varphi_A)^{\frac{1}{2}}}$$

APPENDIX 5

Transformation of Geographical Coordinates *

EUROPEAN DATUM 1950 to AIRY 1858

$$(\varphi_E, \lambda_E) \quad \text{to} \quad (\varphi_A, \lambda_A)$$

$$\tan\varphi_A = \frac{Z_A}{X_A} \times \frac{\cos\lambda_A}{0{\cdot}993\,329\,46}$$

$$\tan\lambda_A = \frac{Y_A}{X_A}$$

Where

$$X_A = V\cos\varphi_E\cos\lambda_E - 456$$

$$Y_A = V\cos\varphi_E\sin\lambda_E + 6$$

$$Z_A = 0{\cdot}993\,277\,33\ V\sin\varphi_E - 548$$

$$V = \frac{6\,378\,388}{(1 - 0{\cdot}006\,722\,67\sin^2\varphi_E)^{\frac{1}{2}}}$$

* Approximate. Geoidal heights not allowed for.

APPENDIX 6

Transformation of Geographical Coordinates

AIRY (MODIFIED) to EUROPEAN DATUM 1950

$$(\varphi^\circ_{AM}, \lambda^\circ_{AM}) \quad \text{to} \quad (\varphi^\circ_E, \lambda^\circ_E)$$

$$\varphi^\circ_E = 0{\cdot}999\,843\,8\,\varphi^\circ_{AM} - 0{\cdot}000\,005\,4\,\lambda^\circ_{AM} + 0{\cdot}000\,000\,476\,\lambda^{\circ 2}_{AM} + 0{\cdot}009\,390\,4$$

$$\lambda^\circ_E = 0{\cdot}000\,034\,245\,\varphi^\circ_{AM} + 0{\cdot}999\,851\,83\,\lambda^\circ_{AM} - 0{\cdot}002\,141\,3$$

Accuracy ± 0·01" in latitude , ± 0·02" in longitude

APPENDIX 7

Transformation of Geographical Coordinates

EUROPEAN DATUM 1950 to AIRY (MODIFIED)

$$(\varphi^\circ_E, \lambda^\circ_E) \quad \text{to} \quad (\varphi^\circ_{AM}, \lambda^\circ_{AM})$$

$$\varphi^\circ_{AM} = 1{\cdot}000\,156\,2\,\varphi^\circ_E + 0{\cdot}000\,005\,4\,\lambda^\circ_E - 0{\cdot}000\,000\,476\,\lambda^{\circ 2}_E - 0{\cdot}009\,392\,17$$

$$\lambda^\circ_{AM} = -0{\cdot}000\,034\,25\,\varphi^\circ_E + 1{\cdot}000\,148\,19\,\lambda^\circ_E + 0{\cdot}002\,140\,5$$

Accuracy ± 0·01" in latitude , ± 0·02" in longitude

APPENDIX 8

Transformation of National Grid to Geographical Coordinates (Formula I)

$$Q = E \times 10^{-6} - 0{\cdot}2$$

$$L_1 = 5961{\cdot}716\,828\left(\left[3{\cdot}016\,298\,902 \times 10^{-9}(N + 139\,384{\cdot}421) + 1\right]^{\frac{1}{2}} - 1\right)$$

9.00

$$L = L_1 + 8{\cdot}96 \times 10^{-6}(N + 139\,384{\cdot}421 - 111\,219{\cdot}253\,L_1 - 9{\cdot}666\,L_1^2 + 0{\cdot}032\,L_1^3)$$

$$\varphi^\circ = L + 50 + \frac{1}{3600}\Big(-Q^2(3018{\cdot}138 + 106{\cdot}584\,L + 2{\cdot}0705\,L^2 + 0{\cdot}0815\,L^3) + Q^4(57{\cdot}2 + 3{\cdot}489\,L + 0{\cdot}281\,L^2) - Q^6(1{\cdot}34 + 0{\cdot}24\,L)\Big)$$

$$\lambda^\circ = -8 + \frac{1}{3600}\Big(32\,342{\cdot}258\,85\,Q\left[0{\cdot}993\,329\,46\tan^2(L+50) + 1\right]^{\frac{1}{2}} - Q^3(786{\cdot}98 + 58{\cdot}579\,L + 2{\cdot}4\,L^2 + 0{\cdot}2109\,L^3) + Q^5(24{\cdot}1 + 2{\cdot}2\,L + 0{\cdot}4\,L^2)\Big)$$

Accuracy ± 0·001"

0·0001"

APPENDIX 9

Transformation of National Grid to Geographical Coordinates (Formula 2)

$$Q = E \times 10^{-6} - 0{\cdot}2$$

$$L = (0{\cdot}107\,197\,7 \times N + 35\,551\,818{\cdot}98)^{\frac{1}{2}} - 5961{\cdot}2815$$

$$\varphi^\circ = L + 50 - Q^2\,(0{\cdot}028\,84\,L + 0{\cdot}000\,8\,L^2 + 0{\cdot}839\,1) + Q^4 \times 0{\cdot}001\,(L + 15)$$

$$\lambda^\circ = -8 + Q\,(0{\cdot}290\,37\,L + 0{\cdot}007\,665\,L^2 + 0{\cdot}000\,29\,L^3 + 13{\cdot}948)$$
$$- Q^3(0{\cdot}014\,29\,L + 0{\cdot}001\,28\,L^2 + 0{\cdot}220\,5)$$

Accuracy $\pm$ 0·2"

APPENDIX 10

Transformation of European Datum 1950 Zone 29 to Geographical Coordinates

$$Q = \frac{1}{0{\cdot}9996}\,(E \times 10^{-6} - 0{\cdot}5)$$

$$R = \frac{1}{0{\cdot}9996}\,N$$

$$L_1 = 5899{\cdot}997\,751\left([3{\cdot}047\,482\,558 \times 10^{-9}(R - 5540\,958{\cdot}752) + 1]^{\frac{1}{2}} - 1\right)$$

$$L = L_1 + 8{\cdot}96 \times 10^{-6}(R - 5540\,958{\cdot}752 - 111\,232{\cdot}98\,L_1 - 9{\cdot}7233\,L_1^2 + 0{\cdot}030\,16\,L_1^3)$$

$$\varphi^\circ = L + 50 + \frac{1}{3600}\Big(-Q^2(3017{\cdot}4495 + 106{\cdot}455\,26\,L + 2{\cdot}092\,3\,L^2 + 0{\cdot}0799\,L^3)$$
$$+ Q^4(57{\cdot}06 + 3{\cdot}55\,L + 0{\cdot}27\,L^2) - Q^6(1{\cdot}34 + 0{\cdot}24\,L)\Big)$$

$$\lambda^\circ = -9 + \frac{1}{3600}\Big(+Q \times 32\,338{\cdot}077\,62\,[0{\cdot}993\,277\,33\,\tan^2(L+50) + 1]^{\frac{1}{2}}$$
$$- Q^3(787{\cdot}009 + 58{\cdot}214\,L + 2{\cdot}494\,8\,L^2 + 0{\cdot}202\,469\,L^3) + Q^5(24{\cdot}1 + 2{\cdot}2\,L + 0{\cdot}4\,L^2)\Big)$$

Accuracy $\pm$ 0·001"

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