NATO STANDARD

AGeoP-21

GEODETIC DATUMS, PROJECTIONS, GRIDS AND GRID REFERENCES

Edition A Version 1
FEBRUARY 2016

NORTH ATLANTIC TREATY ORGANIZATION

ALLIED GEOGRAPHIC PUBLICATION

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NORTH ATLANTIC TREATY ORGANIZATION (NATO)

NATO STANDARDIZATION OFFICE (NSO)

NATO LETTER OF PROMULGATION

25 February 2016

1. The enclosed Allied Joint Geographic Publication AGeoP-21, Edition A, Version 1, GEODETIC DATUMS, PROJECTIONS, GRIDS AND GRID REFERENCES which has been approved by the nations in the Military Committee Joint Standardization Board, is promulgated herewith. The agreement of nations to use this publication is recorded in STANAG 2211.

2. AGeoP-21, Edition A, Version 1 is effective upon receipt.

3.

4. This publication shall be handled in accordance with C-M(2002)60.

Dieter Schmaglowski
Deputy Director NSO
Branch Head P&C

Edvardas MAŽEIKIS
Major General, LTUAF
Director, NATO Standardization Office

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RESERVED FOR NATIONAL LETTER OF PROMULGATION

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RECORD OF RESERVATIONS

CHAPTER	RECORD OF RESERVATION BY NATIONS

Note: The reservations listed on this page include only those that were recorded at time of promulgation and may not be complete. Refer to the NATO Standardization Document Database for the complete list of existing reservations.

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RECORD OF SPECIFIC RESERVATIONS

[nation]	[detail of reservation]
DEU	Page B-7, Para B.7, SubPara 2. e does not apply for DEU, because DEU is not participating in STANAG 2577 (GARS)
FRA	France will not apply this STANAG to all air force systems, including those whose removal from service is imminent and those that have been upgraded or whose upgrade has already been planned and is pending. In addition, already completed geographical products will only be updated based on national needs.
LVA	LVA reserves the right to use the national height reference systems that height translation (transformation) tool and / or the height difference between the mean values will be added. The requirements will be introduced gradually and synchronized with the already approved geospatial information production (or a new product launch) cycles.
TUR	(1) Due to huge distortions arising from tectonic activities; in addition to 7-parameter Helmert Datum Transformation method, TUR is also using horizontal and vertical transformations separately where sub-meter precision (40-50 cm) is required. (2) TUR is using her own high resolution and precise regional geoid model as a vertical reference frame instead of global geoid models. But, the transformation parameters between regional and global models are available.
Note: The reservations listed on this page include only those that were recorded at time of promulgation and may not be complete. Refer to the NATO Standardization Document Database for the complete list of existing reservations.	

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TABLE OF CONTENTS

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CHAPTER 1 GENERAL INFORMATION

1.1. INTRODUCTION

The purpose of AGeoP-21 is to establish the U.S. Department of Defense World Geodetic System 1984 (WGS 84) as the standard geodetic system for geospatial information used by NATO. The document also defines how datums, coordinates, projections, grids and position reporting are to be applied to geospatial information and used by NATO.

Participating nations agree to:

1. Use geodetic datums, coordinate systems, projections, grids, area and position reporting systems, and datum transformation methods in the manner specified by this AGeoP for the production, exchange and use of geospatial information by and for NATO;

2. Reduce the number of regional datums and coordinate systems, whenever possible, during revision or recompilation of maps, charts, geodetic data and products for NATO.

1.2. IMPLEMENTATION

Participating nations agree to the following statements for the purpose of implementing this standard:

1. All geospatial information will be referenced to the WGS 84 horizontal and vertical datums where possible, unless an exception is specified below or a local datum has been designated in accordance with BI-SC Directive 80-4.

2. Geospatial information, with the exception of raster, should use geographic coordinates (latitude, longitude) based on the WGS 84 ellipsoid, expressed in decimal degrees.

3. Raster data and products should be stored in the projected coordinate system intended for the display and use of the product, provided it is based on WGS 84 or equivalent (see ANNEX D). This will prevent distortion, improve performance and reduce storage space.

4. In cases where the preferred coordinate system cannot be adopted, the local geodetic datums, their associated ellipsoids, special projections and grids within the NATO area of responsibility (NAOR) will conform to BI-SC Directive 80-4. Detailed descriptions of the preferred projection and guidelines for using other projections are provided in ANNEX B.

5. The Military Grid Reference System (MGRS), based on the WGS 84 and the Universal Transverse Mercator (UTM) coordinate system, is the preferred method for position reporting by NATO ground units and ground combat operational forces. When MGRS cannot be used in one of the areas identified in BI-SC Directive 80-4, then the local grid reference system will be used until such time as WGS 84 and MGRS can be made available in the area. ANNEX B provides detailed descriptions of MGRS and the local grid reference systems in use within the NAOR.

6. All geospatial information for hydrographic use will have depths referenced to an appropriate chart datum in accordance with International Hydrographic Organisation (IHO) Technical Resolution 3/1919, as amended. The relationship between chart datum and a WGS 84 vertical datum should also be given.
Geospatial information for all other purposes will use WGS 84 vertical reference surfaces for heights where possible. ANNEX C provides more information about vertical datums, transformation of heights and the use of the WGS 84 as a global vertical reference.

7. For geodetic applications the WGS 84 ellipsoid is the preferred vertical reference surface for geospatial information. When gravity-related heights of geospatial information are required, the most recent WGS 84 geoid model (as of this publication, EGM 2008) shall be used to build the global vertical reference surface (the next model is anticipated for 2020). Local geoid models may still be used where greater accuracy is required (see ANNEX C).

For all other purposes the preference is for geospatial information to use the WGS 84 geoid as the vertical reference surface, with orthometric heights expressed in meters. In all cases it should be specified which vertical reference surface has been used and how the relative height is expressed.

8. When geospatial information, and associated mapping, charting, and geodetic data and products are prepared on WGS 84, transformation parameters must be provided if geospatial information referenced to another datum is still in operational use by NATO in the same area. The format for notes relating the existing reference system to WGS 84 for land maps, aeronautical charts and photomaps is given in STANAG 3676. Similar information for nautical charts is given in IHO Special Publication No. 60.

9. Guidelines on the use of datum transformation algorithms and parameters are provided in ANNEX D.

10. NATO approved local-to-WGS 84 datum transformation parameters for horizontal and vertical data are published and available through the U.S. National Geospatial-Intelligence Agency (NGA) at:

http://earth-info.nga.mil/GandG/coordsys/datums/index.html

NGA (SN), Mail Stop L-41
Office of Geomatics
National Geospatial-Intelligence Agency
3838 Vogel Road
Arnold, MO 63010-6205

E-Mail address: GandG@nga.mil
http://www.nga.mil

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ANNEX A BASIC CONCEPT AND TERMS

Definitions are provided to explain terms within the context of this AGeoP. It is recognized that other definitions may apply in other contexts.

Coordinate Conversion	Coordinate operation in which both coordinate reference systems are based on the same datum. [ISO 19111:2007] Note: A coordinate conversion uses parameters which have specified values that are not determined empirically. Example: Conversion from an ellipsoidal coordinate reference system based on the WGS 84 datum to a Cartesian coordinate reference system also based on the WGS 84 datum, or change of units such as from radians to degrees or feet to meters.
Coordinate Reference	A position derived from a unique combination of a datum and a coordinate system; can be measured in linear or angular units.
Coordinate System	Set of mathematical rules for specifying how coordinates are to be assigned to points. [ISO 19111:2007]
Datum	Parameter or set of parameters that define the position of the origin, the scale, and the orientation of a coordinate system. [ISO 19111:2007]
Geodetic Datum	Datum describing the relationship of a two- or three-dimensional coordinate system to the Earth. [ISO 19111:2007]
Geoid	Equipotential surface of the Earth's gravity field which is everywhere perpendicular to the direction of gravity and which best fits mean sea level either locally or globally. [ISO 19111:2007]
Geospatial Information	Geospatial Information are facts about the earth referenced by geographic position and arranged in a coherent structure. This includes topographic, aeronautical, hydrographic, planimetric, relief, thematic, geodetic, geo-referenced imagery, geophysical products, data, information, publications and materials. These will be available in either analogue or digital formats.

[MC 0296/2]

Grid — Network composed of two or more sets of curves in which the members of each set intersect the members of the other sets in an algorithmic way.

[ISO 19123:2005]

Map Projection — Coordinate conversion from an ellipsoidal coordinate system to a plane.

[ISO 19111:2007]

Mean Sea Level — Average level of the surface of the sea over all stages of tide and seasonal variations.

Note: Mean sea level in a local context normally means mean sea level for the region calculated from observations at one or more points over a given period of time. Mean sea level in a global context differs from a global geoid by not more than 2 m.

[ISO 19111:2007]

Reference Ellipsoid — A geometric figure that approximates the size and shape of the Earth. Rotating an ellipse about its shortest (minor) axis generates this figure. An ellipsoid is commonly defined by its semi-major axis and flattening. The flattening is a ratio that indicates the deviation of the ellipsoid from a sphere. The closer the flattening term is to zero, the closer the ellipsoid is to a sphere.

Reporting System — A system designed to simplify the reporting of positions for military purposes.

Examples include: GEOREF, and the Military Grid Reference System (MGRS).

Transformation — A process for transforming coordinates referenced to one datum into coordinates referenced to another datum. Process generally requires parameters derived from observational data.

Vertical Datum — Datum describing the relation of gravity related heights or depths to the Earth.

Note: In most cases, the vertical datum will be related to mean sea level. Ellipsoidal height are treated as related to a three-dimensional ellipsiodal coordinate system referenced to a geodetic datum. Vertical datums including sounding datums (used for hydrographic purposes), in which case the height may be negative heights or depths.

[ISO 19111:2007]

Figure A-1 illustrates the relationships between datums, coordinate systems, coordinate conversions, and datum transformations.

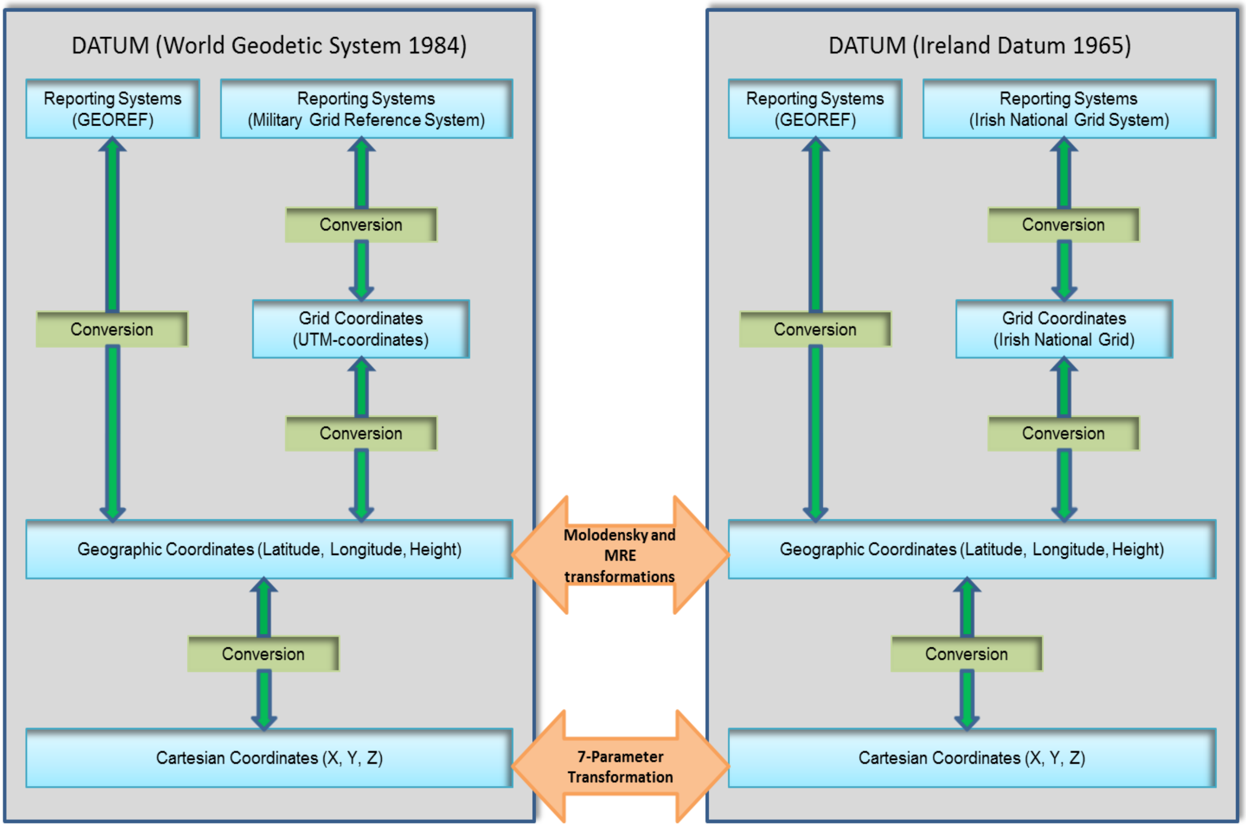

Figure A-1 Relationships between Datums and Coordinate Systems

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ANNEX B COORDINATE SYSTEMS, GRIDS, AND REPORTING SYSTEMS

B.1. CARTESIAN COORDINATE SYSTEM

1. A three-dimensional Cartesian coordinate system that is fixed to the earth is the basic system to mathematically describe positions.

2. In the case of an Earth-centered, Earth-fixed (ECEF) coordinate system such as WGS 84, the origin coincides with the center of mass of the Earth. The Z-axis coincides with the mean rotation axis of the Earth. The X-axis lies in the planes of the equator and the Greenwich (reference) meridian. The Y axis is perpendicular to both the X- and Z-axes completing the right-handed coordinate system.

3. In the case of a local geodetic datum, the associated Cartesian coordinate system is similarly defined, but its origin and orientation are related to the position of a reference ellipsoid. It is therefore Earth-fixed but not Earth-centered.

4. Cartesian coordinates are well suited for mathematical modeling (e.g., within integrated navigation systems). However, it is difficult to relate changes in Cartesian coordinates to the operational situation on or close to the Earth’s surface. Therefore, in operational applications, Cartesian coordinates are converted within the man-machine interface into more familiar coordinate systems (e.g., geodetic or grid coordinates) for display.

B.2. GEODETIC (ELLIPSOIDAL) COORDINATE SYSTEMS

1. An ellipsoidal or geodetic coordinate system defines the positions of points with respect to the surface of a reference ellipsoid. Geodetic coordinate reference systems are based on a geodetic datum and an ellipsoidal coordinate system, i.e., latitude, longitude, and ellipsoidal height.

2. Geodetic latitude of a point is the angle between the plane of the equator and a line perpendicular to the ellipsoid surface and passing through the point. Geodetic latitude is 90°N at the North Pole, 0° at the equator and 90°S at the South Pole.

3. Geodetic longitude of a point is the angle between initial (zero) meridian, commonly Greenwich, and the meridian of the point measured in the plane of the equator. The meridian of the point is defined as the half-plane containing the point and rotation axis of the ellipsoid. Geodetic longitude values range from 180°W to 180°E. Longitude is not defined at the poles.

4. Latitude and longitude coordinates in electronic data files used in the exchange of geographic information should be presented to users in decimal degrees to facilitate interoperability. Height values should be given in meters.

5. Any deviation from this convention must be clearly stated in the documentation of the file format.

6. The conversion formulae to convert Cartesian to geodetic coordinates and the reverse are provided in the following two sections.

B.3. GEODETIC TO CARTESIAN CONVERSION

Cartesian coordinates are derived from geodetic coordinates using the following equations:

$$X = (R_N + h) \cos \varphi \cos \lambda$$
$$Y = (R_N + h) \cos \varphi \sin \lambda \qquad \text{B-1}$$
$$Z = [R_N (1 - e^2) + h] \sin \varphi$$

and,

$$e^2 = f\,(2\text{-}f) \qquad \text{B-2}$$

$$R_N = \frac{a}{\sqrt{(1 - e^2\, sin^2(\varphi)}} \qquad \text{B-3}$$

where,

a	semi-major axis of reference ellipsoid
f	flattening of reference ellipsoid
e^2	first eccentricity of reference ellipsoid, squared
R_N	radius of curvature of reference ellipsoid in the prime vertical
φ	geodetic latitude
λ	geodetic longitude
h	height above ellipsoid

B.4. CARTESIAN TO GEODETIC CONVERSION

Geodetic longitude λ can be obtained by:

$$\lambda = \text{atan2}\left(\frac{Y}{X}\right) \qquad \text{B-4}$$

Determining geodetic latitude and height become more involved. Various methods, including iterative and non-iterative approximation algorithms, and closed form solutions exist. Many of these methods have singularities and limiting conditions.

An iterative solution developed by Hirvonen and Moritz uses the following equations to solve for φ and h:

An initial estimate for latitude is provided by:

$$\varphi_0 = arctan \frac{Z}{(1-e^2)\sqrt{X^2+Y^2}} \quad \text{B-5}$$

This estimate is inserted in equation B-3 and h is solved for:

$$h_i = \frac{\sqrt{X^2+Y^2}}{\cos\varphi_{i-1}} - R_{Ni} \quad \text{B-6}$$

an updated latitude is found:

$$\varphi_i = \arctan \frac{Z}{\left(1-\frac{e^2 R_{Ni}}{R_{Ni}+h}\right)\sqrt{X^2+Y^2}} \quad \text{B-7}$$

Iteration continues until some convergence criteria is met.

B.5. PROJECTIONS AND PLANE COORDINATE SYSTEMS

1. Projections are a special class of coordinate conversions that convert geodetic coordinates (latitude and longitude) to the plane coordinate system of a map sheet or computer display. A projection introduces distortions in the spatial relationships between features. Many projections have been developed to minimize these distortions based on specific application and use.

2. Although no single projection is suitable for every possible application, interoperability requirements for NATO forces make the selection and application of a universal projection highly desirable. Systems with a dynamic display that are required to show geospatial data at any scale and on any part of the globe will best be served with a conformal projection that has global coverage. For this purpose the Mercator projection is recommended when coverage does not extend to the geographic poles.

The preferred projection for NATO land use is the Universal Transverse Mercator (UTM). Within the NAOR two other projections, the Lambert Conformal Conic (LCC) and Mercator are also used, mainly for aeronautical and hydrographic purposes, respectively. For polar regions, and the higher latitudes, the Polar Stereographic is an acceptable projection for both aeronautical and nautical charts. Table B-1 summarizes projections for Land, Maritime, and Air mapping.

Domain	Projection	Condition
	Mercator	For use in dynamic systems where there is a requirement for conformal display at any scale at any location on the globe (except the poles)
Land	Universal Transverse Mercator	In regions of longitudinal extent not greater than 6 degrees
Maritime	Transverse Mercator	1:50,000 or larger
	Mercator	Smaller than 1:50,000
	Lambert Conformal Conic or Polar Stereographic	Latitudes higher than 70 degrees but not covering the pole
	Polar Stereographic	Covering the pole and from the pole to 70 degrees of latitude
Air	Mercator	Aeronautical charts with scales of 1:500,000 and smaller for general navigational and operational purposes
	Lambert Conformal Conic	
	Polar Stereographic	

Table B-1 Summary of Projections for Domains and Conditions

3. Aeronautical charts with scales of 1:500,000 and smaller for general navigational and operational purposes, are to apply the following projections:

a. Mercator;

b. Lambert Conformal Conic; and

c. Polar Stereographic.

The layout in detail of these projections will depend on such various factors as position, size and shape of the area to be covered by the chart series, and the layout of the sheet lines in the series.

4. Aeronautical charts series at scales 1:500,000 and 1:1,000,000, with topographical detail, will be arranged in equal bands of latitude reckoned from the equator. The width of the bands will be 8°, 4°, or 2° of latitude depending on the scale of the chart series and the size of the sheets.

5. When the Lambert conformal conic and the polar stereographic projections are common to one series, the following will apply:

a. The scale factors shall be made coincident along their common latitude.

b. The distance of the standard parallels, in from the north and south edges of each band, shall be 1° 20' for the 8° bands, 40' for the 4° bands and 20' for the 2° bands. Where the 2° series are developed from the 4° series, the original 40' spacing may be retained and where the 4° series are developed from the 8°, the original 1° 20' may be retained.

6. In order to reduce to a minimum the number of sheets required to cover an area which overlaps on several bands of latitude, a Lambert conformal conic projection, specially adapted to the area concerned, may be used.

7. Aeronautical charts, in digital form, are to use the equal Arc-second Raster Chart/map (ARC) system. The ARC system provides a rectangular coordinate and projection system, at any scale for the entire ellipsoid based on the WGS 84. The ARC system is to provide raster graphic data in a virtually seamless manner, and permits direct display in a nearly conformal presentation.

The ARC system is define by the Defence Geospatial Information Working Group (DGIWG), and is capture in as DGIWG 016, DIGEST Support Document 3 - The ARC System.

B.6. GRIDS

1. A product of great practical importance from any projection is the rectangular grid, which provides a convenient plane coordinate system for military use. The grid is formed by two sets of parallel lines, intersecting at right angles, forming squares. The grid defines its own scale, the "grid meter," and its own orientation, "grid north".

2. The **preferred grid for NATO use is the Universal Transverse Mercator (UTM) grid**. This system was developed for worldwide application between 80° S and 84° N.

3. The mathematical formulae for the geodetic-to-UTM and UTM-to-geodetic coordinate conversions may be found in NGA.SIG.0012_2.0_UTMUPS.

4. Other grids currently in use within the NAOR include:

   a. The British National Grid based on the Transverse Mercator map projection and the Airy ellipsoid.

   b. The Irish Grid based on the Transverse Mercator map projection and the Modified Airy ellipsoid.

   c. The Nord and Sud Maroc Grids, the Nord and Sud Algerie Grids, and the Nord and Sud Tunisie Grids, all based on the Lambert Conformal Conical map projection and the Clarke 1880 ellipsoid.

For the parameters of the ellipsoids associated with these grids (and the global systems) see Table B-2.

Ellipsoid	Semi-major axis (m)	Reciprocal of Flattening (1/f)
Airy 1830	6377563.396	299.3249646
Modified Airy	6377340.189	299.3249646
Clarke 1880	6378249.145	293.465
GRS 80	6378137	298.257222101
WGS 72	6378135	298.26
WGS 84	6378137	298.257223563

Table B-2 Geometric Parameters for Selected Ellipsoids

5. Grids may be shown superimposed on another projection, such as UTM grid shown on an aeronautical chart, to aid in interoperability. In such cases, the grid may be slightly curved.

6. For nautical charts, participating nations agree that the prescribed military grid shall be added (by means of ticks and, where necessary, intersections) to available continuous coastal charts series of scales 1:100,000 and larger. In the absence of such continuous coastal coverage, the grid should be added, as required, to charts between scales of 1:25,000 and 1:300,000.

7. A note should be included on the chart informing the user of the meaning and application of the prescribed military grid and how to use the grid ticks.

Note: To facilitate the drawing of the UTM grid on existing charts of various projections, the use of NGA.STND.0037_2.0.0_GRIDS and NGA.SIG.0012_2.0.0_ UTMUPS is recommended.

B.7. REPORTING SYSTEMS

1. Reporting systems were originally designed to simplify and secure the reporting of positions for military purposes. The existing ones are based on the coordinate systems previously described.

2. Participating nations agree to the following:

   a. The graticule of geographic latitude and longitude shall be portrayed on all maps and charts which are used by the NATO Armed Forces.

   b. The Geographic Reference System (GEOREF), as described in NGA.STND.0037_2.0.0_GRIDS shall be shown on all aeronautical charts which are used by the NATO Armed Forces. This system shall be depicted either on the face of the chart or by marginal diagram.

   c. MGRS shall be depicted on aeronautical charts at the scale of 1:250,000 which are used by the NATO Armed Forces. The MGRS portrayal information is described in NGA.STND.0037_2.0.0_GRIDS.

   d. MGRS may be portrayed in addition to GEOREF on small scale aeronautical charts in such a way as to not obliterate other aeronautical information.

   e. The Global Area Reference System (GARS) is a standardized battle space area reference system designed to facilitate battle space deconfliction in the air, on land, and in the sea. The usage of GARS is primarily an operational-level, administrative measure, used to coordinate geographic areas rapidly for operational environment deconfliction and synchronization of operations. GARS shall not be used to define geographic locations, nor shall it be used in a system that requires precise position data (e.g. weapon systems). The GARS is described in NGA.STND.0037_2.0.0_GRIDS.

   f. Members shall not be bound to conform to this agreement in respect of maps and charts produced for mission specific, non-standard datasets.

B.8. GRID REFERENCE SYSTEMS

1. For the preferred UTM grid within NAOR, the **Military Grid Reference System (MGRS)** is defined and used on a global basis. The MGRS portrayal information is described in NGA.STND.0037_2.0.0_GRIDS.

2. The reporting system used with the **British National Grid** has the following basic features:

   a. A single zone covers the whole of the British Isles, less Ireland.

   b. The zone is divided into 100,000-meter squares with each square uniquely identified by a two-letter code. The code sequence is based on a 5x5 matrix of letters with A at the top left square, proceeds row by row omitting I, and ends with Z in the bottom right square.

   c. The first letter identifies the 500,000-meter square. Six of these codes cover the zone with S in the bottom left position. The second letter identifies the 100,000-meter square sub-division of the 500,000-meter square.

   d. The British National Grid is described further in the Defence Geographic Centre Technical Manual GSGS 5191.

3. The reporting system used with the **Irish Grid** is identical to the system used with the British National Grid except that there is only one 500,000-meter square which uses the letter I. The Irish Grid is described further in the Defence Geographic Centre Technical Manual GSGS 5191

4. The **North African Grids** do not have any special reporting systems. The full grid values, to the level of precision required, must be given. For example, 50003000 is the grid reference of the origin to 100 meter precision.

ANNEX C VERTICAL DATUM

C.1. INTRODUCTION

1. WGS 84 is the U.S. Department of Defense definition of a global reference system for geospatial information. WGS 84 offers two possible global vertical reference surfaces: the WGS 84 ellipsoid and a WGS 84 Earth Gravitational Model (EGM) derived geoid. The WGS 84 EGM geoid is an approximation to mean sea level.

2. In addition there are currently hundreds of local vertical datums in use, each based on a local definition of mean sea level. This multiplicity of local datums and reference systems is a detriment to interoperability of NATO armed forces.

C.2. WGS 84 ELLIPSOID

1. The definition of WGS 84 includes an ellipsoid of revolution that, for geospatial applications, is identical to the Geodetic Reference System (GRS) 1980 ellipsoid. The ellipsoid is a simple, geometric figure with approximately the same size and shape as the Earth.

2. The parameters of a best fitting Earth ellipsoid are known to a high degree of precision and rarely change. The ellipsoid, therefore, provides the simplest and most stable surface to which height reference can be made. Database updates and maintenance are reduced due to the stability of the WGS 84 ellipsoid parameters.

3. The NAVSTAR Global Positioning System (GPS) currently used for positioning and navigation by many NATO forces produces a Cartesian position with respect to the center of the WGS 84 ellipsoid. This position is readily converted into geodetic coordinates of latitude, longitude, and ellipsoidal height. Ellipsoidal heights are therefore referred to the surface of the ellipsoid.

4. It should be noted that the transformation of an ellipsoidal height to a local mean sea level height adds error to the resulting transformed height and should generally be avoided. It is therefore recommended that GPS equipment use WGS 84 ellipsoidal heights to the largest degree practical. (See Section C.6. for guidance on the use of height data other than ellipsoidal heights).

C.3. WGS 84 EGM DERIVED GEOID

1. The WGS 84 geoid is computed by NGA using the latest EGM. A grid of geoid heights and a recommended FORTRAN program to interpolate between grid points are available from NGA:

http://earth-info.nga.mil/GandG/wgs84/gravitymod/index.html

If a previous model is being used for consistency with other systems or products, it must be identified to avoid confusion between models.

2. A general comparison of the EGMs is shown in the table C-1. When using derived heights the model used should be referenced. For applications requiring a higher degree of accuracy the use of height above the WGS 84 ellipsoid (HaE) and/or high-precision local geoids may be appropriate. Consult your NATO Geo Officer in charge with questions.

	Degree, Order	**Resolution**	**Available Grid**	**Average Global RMS**
EGM84	180, 180	1˚ x 1˚	30′ x 30′	2 – 6 m
EGM96	360, 360	30′ x 30′	15′ x 15′	.5 – 1 m
EGM08	2190, 2190	5′ x 5′	2.5′ x 2.5′	≈ 15 cm

Table C-1 NGA Earth Gravitational Models

C.4. LOCAL VERTICAL DATUMS

Local vertical datums are usually referred to as “mean sea level” at a particular tide gauge. In these cases the accuracy of the mean sea level definition will be affected by the time scale over which the mean sea level was determined, the oceanographic effects that create a small permanent sea surface topography and any vertical land movements. A vertical datum may also be defined at a specific place that has not been connected to a tide gauge. There may be discrepancies of up to several meters between heights referenced to different vertical datums due to the different definitions and leveling.

C.5. HYDROGRAPHIC DATUMS

Hydrographic charts relate depths to a Chart Datum (CD), defined to ensure that depths quoted are safe for navigation. CD is usually defined as the lowest observed or theoretical sea level possible for the area, such as Mean Lower Low Water (MLLW) or Lowest Astronomical Tide (LAT). Users must carefully note the CD for a specific chart because many different types of chart datums are in use. The relationship between CD and a WGS 84 EGM geoid derived value varies with the sea surface topography and the tidal range at a point. Hydrographic charts carry a legal responsibility for safe navigation, and so it is not possible to adopt a WGS 84 EGM derived vertical datum for normal hydrographic applications because the CD/WGS 84 EGM relationship cannot be modeled with sufficient accuracy. NATO hydrographic agencies should endeavor to model the relationship between CD and WGS 84. Whenever possible, they should store heights/depths with respect to the WGS 84 datum within their databases, noting which EGM was used and the interpolation method. The CD/WGS 84 relationship data must be available for use with specialized applications. During future survey work, surveyors should measure the CD/WGS 84 relationship as part of the IHO required connection of CD to the land survey datum (IHO 1994, 1998).

C.6. PREFERRED VERTICAL DATUMS

1. With the exception of hydrographic applications, the WGS 84 EGM geoid is the preferred vertical reference to replace local and regional mean sea level datums for geospatial information. The geoid model should be integrated into user interfaces to provide height above geoid and other gravity-related heights from ellipsoidal height data.

2. World Height System: WGS 84 is a three-dimensional coordinate reference system. It supports the following height systems:

a. Geodetic height relative to the WGS 84 ellipsoid.

b. Orthometric height relative to the WGS 84 Geoid computed from the WGS 84 EGM.

c. Normal height relative to the WGS 84 Quasi-Geoid computed from the WGS 84 EGM. The quasi-geoid and the use of normal heights are not described explicitly in the WGS 84 report, but the computations are straightforward.

Therefore, WGS 84 does provide a World Height System, the geodetic height. However, WGS 84 does not currently provide vertical datum transformations to local mean sea level and other vertical datums. Current techniques and international standards center on defining a World Height System based on a geopotential value on the surface of a geoid and on a model of gravity field of the Earth, simply defining the geopotential of this geoid (W_0) to be equal to the geopotential of a reference ellipsoid (U_0), $W_0 \equiv U_0$. Establishing definitive values for W_0 and U_0 is strictly a matter of convention.

To facilitate internal consistency with current and future NATO systems, the W_0 and U_0 values as shown in Table C-2 are appropriate for NATO activities and operations. Appropriate offsets and adjustments to other height systems must be accounted for on a case by case basis and will be published at a future date.

	Geopotential of the WGS 84 ellipsoid	$U_{0\ WGS\ 84}$ = 6.26368517 x 10^{+07} meters^2 / second^2
$W_0 \equiv U_0$	Geopotential of the WGS 84 geoid	$W_{0\ WGS\ 84}$ = 6.26368517 x 10^{+07} meters^2 / second^2

Table C-2 Values for WGS 84 World Height Systems

C.7. VERTICAL DATUM TRANSFORMATIONS

1. Vertical datum transformations are described for relationships between ellipsoidal and national/local gravity related height systems and, as a separate case, the transformation between ellipsoidal and hydrographic datums.

2. For the first case, some degree of approximate vertical datum transformation will be included within a 7-parameter Helmert (position vector) transformation (see Annex D), provided that it has been derived using local datum heights with the local coordinates and WGS 84 ellipsoidal heights with the WGS 84 coordinates. This will only compensate for the mean datum difference and mean slope difference, but will not compensate any local geoid variations. The accuracy of this method will depend on the amount of variation in the geoid locally.

3. A more accurate vertical datum transformation will be possible using a correction model to compensate for the amount of variation in the local geoid. Direct application of the EGM geoid model will correct for most of the local vertical geoid variation, but not any error in the local vertical datum definition. An additional correction (D) can be applied in combination with the EGM geoid heights to improve

the vertical transformation. Production agencies can derive a formula for (D) as follows:

a. Compute EGM geoid heights (N) for all sites where both the local gravity related height (H) and WGS 84 ellipsoidal height (h) are known. These sites should be well distributed over the area covered by the vertical datum.

b. Compute the value D = N – (h-H), the difference between EGM and the locally observed datum difference.

c. Model the value D over the area covered by the vertical datum using a low order polynomial (one parameter will model the bias, three parameters will include the slope, six parameters will also remove some curvature, etc.). The computation of (D) can be included in a vertical datum transformation or can be tabulated in a database.

4. The highest accuracy can be achieved by using precise local geoid models, but for this it will be necessary to consult an expert. Users requiring this should consult the responsible NATO Chief Geo Officer in charge.

5. Vertical datum transformation for hydrographic datums are more complex and must generally be addressed on chart-by-chart and area-by-area bases. In these cases, the mean WGS 84 ellipsoidal height of the chart datum over the area of the chart or dataset should be provided with the chart or dataset. Applying this bias allows ellipsoidal heights to be correlated with chart depths. These biases must be determined by the responsible hydrographic agencies.

6. NGA established and maintains a database of local vertical datum corrections. These corrections may be accessed and downloaded at: http://earth-info.nga.mil/GandG/wgs84/index.html

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ANNEX D DATUM TRANSFORMATIONS

D.1. INTRODUCTION

1. WGS 84 is the U.S. Department of Defense definition of a global reference system for geospatial information. The number of local geodetic datums (including those based on astronomic definitions alone) used throughout the world (including isolated islands, etc.), exceeds several hundred. This multiplicity of local datums and reference systems is a detriment to interoperability for NATO armed forces.

2. Until all geospatial information, and related mapping, charting, and geodesy data and products for NATO's operations are available in a single global system, it is imperative to provide transformation relationships between local datums and the WGS 84 to field users within NAOR.

D.2. IMPLEMENTATIONS OF WGS 84

1. Geodetic data and products supporting NATO operations shall use the WGS 84 datum. In all cases the datum tag and geodetic survey epoch shall be given [e.g. WGS 84 (G1150) epoch 2003.5; WGS 84 (G1762) epoch 2014.5].

2. Geospatial data not intended for survey control or geodetic applications may use any datum that conforms to the International Earth Rotation and Reference Systems Service (IERS) Conventions 2010 for an ECEF coordinate reference system as these datums are considered equivalent to the WGS 84 datum for NATO operations. Coordinates referenced to any of the systems cited below are considered equivalent to those of WGS 84, and therefore do not require datum transformations:

a. World Geodetic System 1984 (WGS 84) (e.g., realization G1762).
b. International Terrestrial Reference System (ITRS) (e.g. reference frame ITRF2008).
c. European Terrestrial Reference System 1989 (ETRS89) (e.g. reference frame ETRF2000)

D.3. TRANSFORMATION AND COORDINATE ERRORS

1. Transformation equations and parameters provide a means of transforming coordinates referenced to one datum into coordinates referenced to a different datum. It is critical to understand that this process generally introduces inaccuracies into the transformed coordinates. These inaccuracies are in addition to any existing errors in the original coordinates.

2. The amount of error added to the positional error of the original point by the transformation process itself depends on the type of equations used, the quantity and quality of geodetic control data from which the parameters were derived, the size of the area covered by the transformation parameters, and the distance from the control data. Any quoted accuracy statement will only apply to the geographical area covered by the data used to derive a set of transformation parameters. Extrapolation outside the stated area carries an increased risk of error.

3. Due to the inherent inaccuracy in the transformation process, it is recommended that transformations should be avoided whenever possible, but especially when high accuracy is required such as for targeting. This information should be compiled directly from WGS 84 source material or WGS 84 related measurements.

D.4. WORLD GEODETIC SYSTEM 1972 AND TRANSFORMATION TO WGS 84

1. World Geodetic System 1972 is the predecessor to WGS 84. Like WGS 84 it was developed by the U.S. Department of Defense to provide a global datum for mapping and charting. WGS 84 was developed to improve the accuracy and agreement with international scientific standards.

2. As a unique solution the transformation from WGS 72 to WGS 84 coordinates is performed using the following equations:

$$\varphi_{\mathrm{WGS84}} = \varphi_{\mathrm{WGS72}} + \frac{4.5 \cos \varphi_{WGS72}}{6378135 \sin 1''} + \frac{0.3121057 \times 10^{-7} \sin 2\,\varphi_{WGS72}}{\sin 1''} \text{ (arc seconds)}$$

$$\lambda_{\mathrm{WGS84}} = \lambda_{\mathrm{WGS72}} + 0.554'' \text{(arc seconds)}$$

D.5. TRANSFORMATION METHODS

1. The local and/or regional geodetic datum often contains unknown and non-linear distortion, implies a poor quality geoid solution (or no geoid at all), and is extremely deficient in absolute accuracy. This leads to a choice of different transformation algorithms and parameters for different applications (e.g., mapping and charting). The decision regarding which set applies requires the careful collection of coordinate sets and research of alternatives. This must be the responsibility of the NATO Chief Geo Officer in charge.

2. In general, two 3-dimensional Cartesian coordinate systems in space are related to each other by the following equations, known as seven-parameter Helmert (position vector) transformation where:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{WGS84} = \begin{bmatrix} \Delta X \\ \Delta Y \\ \Delta Z \end{bmatrix} + (1+\Delta S)\begin{bmatrix} 1 & -R_Z & R_Y \\ R_Z & 1 & -R_X \\ -R_Y & R_X & 1 \end{bmatrix}\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{LOCAL} \quad \text{D-1}$$

where,

- ΔX Translation along the X-axis
- ΔY Translation along the Y-axis
- ΔZ Translation along the Z-axis
- R_X Rotation about the X-axis
- R_Y Rotation about the Y-axis
- R_Z Rotation about the Z-axis
- ΔS Scale Factor

The conversion between geodetic latitude, longitude and ellipsoidal height to the Cartesian coordinates X, Y, Z and the inverse can be found in ANNEX B.

3. Determining the transformation parameters requires coordinates in both the local and the WGS 84 coordinate reference systems. If the number of stations is not sufficient to solve for seven parameters, a three-parameter solution can be applied. A special treatment of the equation leads to the three parameter Abridged or Standard Molodenski Equations (AMOL, SMOL), published in NGA.STND.0036_1.0.0_WGS84. The limited set of parameters restricts the accuracy of the resulting transformation solution to several meters. The parameters determined for use with SMOL and AMOL equations provide exactly the same results if used with the Helmert (position vector) equations setting R_X, R_Y, R_Z, and ΔS to zero.

WARNING: The ΔX, ΔY, and ΔZ parameters from a seven-parameter transformation solution must NEVER be used with the Molodenski equations as large errors may result.

4. A third method, the Multiple Regression Equation (MRE) transformations use polynomial functions to model the distortions in the control network from which the local datum was derived. The characteristics of polynomial functions require that the MRE transformations be used strictly in regions with dense coverage of transformation control stations. They are only defined for the specific regions and should therefore never be applied outside of these regions. Details can be found in NGA.STND.0036_1.0.0_WGS84.

5. In cases where the local control network is extremely distorted special transformation methods may be necessary. Contact the responsible NATO Chief Geo Officer in charge for advice in handling these cases.

D.6. PREFERRED TRANSFORMATION METHOD

1. The seven-parameter solution shall be applied as the preferred method wherever possible. This is possible when a validated seven-parameter solution is available for the region and all operational units are capable of using this solution. Due to the limitations of all transformation methods, it is strongly recommended that the NATO Chief Geo Officer in charge be contacted whenever new transformation parameters are determined.

2. Datum transformation methods, other than the seven parameter solution, may still be used for existing military systems which produce maps and charts. However, these should be phased out as soon as practical.

a. All new systems that perform datum transformations should require the implementation of the seven-parameter Helmert (position vector) transformation equations. This includes any systems in the requirements analysis phase.

b. Operational and developmental systems should consider the implementation of Helmert (position vector) transformations when the projected accuracy improvements justify the costs. Consult the NATO Chief Geo Officer in charge for projected transformation accuracy improvements through the implementation of the seven-parameter solutions.

D.7. HORIZONTAL TRANSFORMATION SOLUTIONS AND HEIGHTS

1. Understanding the result of a coordinate transformation in terms of height requires knowledge about the type of data involved in deriving the transformation parameters. Below are two scenarios which may be encountered.

   a. WGS 84 ellipsoidal heights may have been combined with local “mean sea level” heights or ellipsoidal heights. If so, it will be necessary to input the same type of height data into the transformation as was used to derive it.

   b. No information was available for the local vertical datum, therefore the height values were set to zero. If so, parameters derived using this zero height method cannot be used to transform heights.

2. Regardless of the method to determine height values, there is no practical impact on the transformed horizontal coordinates. It is therefore recommended that transformation methods described in this ANNEX be applied only to horizontal coordinates. For vertical datum transformation information, see ANNEX C.

D.8 MAINTAINING TRANSFORMATION PARAMETERS

1. The preferred source for WGS 84 datum transformation parameters is the U.S. National Geospatial-Intelligence Agency (NGA) Internet web site:

http://earth-info.nga.mil/GandG/coordsys/datums/index.html.

2. NGA is constantly working to improve and expand the list of datum transformation parameters. NATO and NATO Nations may submit request for new transformation parameters to: GandG@nga.mil

3. Request for new transformation parameters should include the information below:

   a. Datum transformation method (e.g., Helmert solution, Abridged or Standard Molodenski solution, or Multiple Regression Equations)

   b. A list of the control stations used to compute the transformation parameters. As a minimum the following information should be included for each station:

      (1) Station number/identifier

(2) Local datum latitude, longitude, "mean sea level" or ellipsoidal height (if used), and accuracy estimates. Accuracy estimates are preferred but not required.

(3) WGS 84 latitude, longitude, ellipsoidal height, and accuracy estimates. Accuracy estimates are preferred but not required.

c. A brief description of the method used to compute the transformation parameters. The treatment of heights in the computation must be included in the description. When similarity transformation parameters are provided, the sign convention for the rotational parameters must be clearly stated. A worked example is desirable to aid the description.

d. Include the source (e.g., organization name) of the local control and a brief description of how the coordinates and their accuracy estimates were computed.

e. Include the source of the WGS 84 control and a brief description of how the coordinates and their accuracy estimates were computed.

f. Include boundary coordinates or other unambiguous identification (e.g.country name(s)) of the region for which the transformation parameters are valid.

4. Upon approval, the new transformation parameters will be issued by NGA and posted to:

http://earth-info.nga.mil/GandG/coordsys/datums/index.html

ANNEX E ACRONYMS

AMOL	Abridged Molodenski
ARC	equal Arc-second Raster Chart/map
DGIWG	Defence Geospatial Information Working Group
EGM	Earth Gravitational Model
GARS	Global Area Reference System
GEOREF	Geographic Reference System
GPS	Global Positioning System
GRS	Geodetic Reference System
IERS	International Earth Rotation and Reference Systems Service
IHO	International Hydrographic Organisation
ITRS	International Terrestrial Reference System
MGRS	Military Grid Reference System
MRE	Multiple Regression Equation
SMOL	Standard Molodenski
UTM	Universal Transverse Mercator
WGS	World Geodetic System

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