# DGIWG 116-1

## Elevation Surface Model Standardized Profile

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**Abstract:** This Elevation Surface Model standardized profile specifies a content model for geospatial elevation surface data of any spatial resolution. It supports the modelling of material surfaces such as bare earth, vegetation canopy, and bathymetric surfaces.

## i. Submitting organizations

France, Germany, Sweden, Czech Republic, Turkey, United Kingdom, and USA

## ii. Revision history

| Date | Release | Primary clauses modified | Description |
|---|---|---|---|
| 05/31/2009 | 0.1 | All | Initial version submitted for nation review and comment. |
| 03/11/2010 | 0.2 | All | 2nd draft based on DGIWG initial review comment resolution. |
| 10/15/2010 | 0.3 | All | 3rd draft for Technical Panel discussion |
| 01/10/2011 | 0.4 | All | 4th draft for Technical Panel discussion |
| 11/30/2012 | 0.4.5 | 9, Annex D | Final draft to be reviewed by ESM Project Team and submitted for publication |
| 12/18/2012 | 0.4.6 | 1, 9, Annex E | Edits addressing FR and CZ comments on v.0.4.5 |
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| 01/02/2013 | 1.0.0 | 4.1.13 and 4.1.25 | Final edits with definitions from ISO 19111 and associated notes |
| 04/25/2013 | 1.0.0 | Annex E | Alignment with DGIWG Metadata Foundation ed.0.6.0 |
| 12/20/2013 | 1.0.0 | 10.3, Annex E | Revision of ESM tiling guidance, |
| 05/23/2014 | 1.0.1 | Annex E | Alignment of ESM metadata with final DGIWG Metadata Foundation |
| 19/10/2017 | 1.1.0 | 3, Annex E | Alignment on DMF 2.0 (and mapping of instrument metadata on DMF 2.0) |

## iii. Future work

Incorporation of the TIN model into the application schema, once defined as a coverage in GML and GMLCOV (OGC).

## Contents

## Figures



## Tables

# Introduction

This profile standardizes the information content required for the exchange of surface elevation information within and among DGIWG member nations. It specifies a data model that may be used to describe a variety of surfaces including bare earth, vegetation canopy, and bathymetric depth. Digital Terrain Elevation Data (DTED) has been the predominant format for defense community elevation products with post spacings of 30m and larger. DTED is a product with a specific encoding format that is incapable of adequately depicting the higher resolution data collected by new elevation data sensors. Many defense applications now require this data, and newer encoding formats are available that are capable of carrying additional information about the data. The new capabilities allowed by the standardisation of the information content of the datasets will improve discovery, interoperability, and exploitation of the data.

The intent is to increase the level of interoperability with and between organizations producing and using elevation data. The data model is applicable to a variety of spatial resolutions and accuracies and it specifies the elevation data content separately from the encoding method.

To attain maximum flexibility for exchange of surface elevation data, this standardized profile identifies a large set of metadata elements that may be used to describe a variety of types of elevation datasets. It may be used to generate specifications for narrowly defined products by specifying fixed values in place of the range of metadata values allowed here.

This profile is based on relevant standards established by the International Organization for Standardization (ISO) for geographic information, and, where applicable, for information technology. It is consistent with the International Hydrographic Organization (IHO) Universal Hydrographic Data Model (S-100).

ISO 19123 defines a conceptual schema for the spatial characteristics of coverages. Coverages support mapping from a spatiotemporal domain to attribute values where attribute types are common to all geographic positions within the spatiotemporal domain. The concept of coverages provides a more flexible way to describe elevation data as mathematical surfaces, in a manner that can be easily integrated with other types of geographic information or with other coverage data.

An application schema is the conceptual schema for data (e.g. elevation data) required by one or more applications. ISO 19129 includes the concept of a “content model” as the “information view” of an application schema. This view includes descriptions of the elements composing the domain object (grid, TIN, points, etc.), the corresponding range values, the spatial referencing, and associated metadata of various types. A content model addresses only the information needed to describe the semantic meaning of the data, exclusive of the interchange format or portrayal of the data.

The DGIWG Metadata Foundation (DMF) defines a comprehensive list of metadata elements for geospatial data. It is based on NATO STANAG 2586, the NATO Geospatial Metadata Profile (NGMP). DMF is also based on the ISO 19115 standards for geographic metadata. These standards form the basis of the ESM metadata requirement. They are extended where necessary with metadata elements describing particular aspects of elevation surface data, and addressing specific requirements of the defense community.

This standardized profile is concerned with both the underlying information structure of an elevation surface model and the format for exchanging elevation surface models. However, defining the content in terms of its encoding binds the content to that single encoding format and makes format conversion difficult. This profile allows for a variety of encoding formats to be used to carry the elevation data values, and the common content model described in this profile allows for a mapping to the structures defined in the various encoding standards. Within the metadata, descriptions of elevation datasets could vary based on the interpretation of metadata producers, and interoperability is primarily supported through the requirement for XML-encoded metadata. ISO XML schemas provide a definitive, rule-based encoding for validation of DMF and ESM metadata requirements.

# 1 Scope

Elevation measurements describe the position of the material surface above or below a vertical datum. This Elevation Surface Model (hereafter 'ESM') standardized profile specifies a content model for geospatial elevation surface data of any spatial resolution. It supports the modelling of material surfaces such as bare earth, vegetation canopy, and bathymetric surfaces. Four optional data structures are described: grids, Triangulated Irregular Networks (TIN), point coverages, and point sets. The grid, TIN and point coverage structures are defined by the ISO 19123:2005 coverage geometry classes CV_ContinousQuadrilateralGridCoverage, CV_TINCoverage, and CV_DiscretePointCoverage. The geometry for ESM point sets is provided by the GM_Point class, defined in ISO 19107. These structures are the most commonly stored and exchanged by systems managing elevation data. While it is acknowledged that coverages can be derived from a collection of discrete features (and vice versa), other discrete data elements (e.g. contour lines) are not specifically addressed by this profile.

# 2 Conformance

The degree to which an elevation data product specification complies with the content models defined in this profile can be measured using an abstract test suite. Any data or product specification claiming conformance with this profile shall pass all requirements described in the abstract test suite provided in Annex A.

# 3 Normative References

The following normative documents contain provisions that, through reference in this text, constitute provisions of this profile.

**International Standards**

ISO 639-2:1998 Codes for the representation of names and languages

ISO/TS 19103:2005 Geographic information - Conceptual schema language

ISO 19107:2003 Geographic information – Spatial schema

ISO 19108:2002/Cor 1:2006 Geographic information – Temporal schema

ISO 19109:2003 Geographic information – Rules for application schema

ISO 19111:2007 Geographic information – Spatial referencing by coordinates

ISO 19115:2003 Geographic information – Metadata

ISO 19115/Cor.1:2006 Geographic information – Metadata – Technical Corrigendum 1

ISO 19115-2:2009 Geographic information - Metadata: Extensions for imagery and gridded data

ISO 19123:2005 Geographic information - Schema for coverage geometry and functions

ISO 19129:2008 Geographic information – Imagery, gridded and coverage data framework

ISO 19138:2006 Geographic information – Data quality measures

ISO 19139:2006 Geographic information – Metadata – XML schema implementation

IHO S-100 edition 1.0.0 – Hydrographic Geospatial Standard for Marine Data and Information

NATO MC 0296/2**,** NATO Geospatial Policy, IMSTAM (GE0)-0001-2010 (SD3) dated 27 September 2010

STANAG 2215 IGEO (Edition 7, July 2010) Evaluation of Land maps, Aeronautical charts and Digital Topographic data

DGIWG - 114: DGIWG Metadata Foundation (STD-DP-12-010) version 2.0.0, 12 July 2017

**National Standards**

NGA.STND.0036 1.0.0 WGS84, Department of Defense World Geodetic System 1984: Its Definition and Relationships with Local Geodetic Systems, 8 July 2014 http://earth-info.nga.mil/GandG/publications/NGA_STND_0036_1_0_0_WGS84/NGA.STND.0036_1.0.0_WGS84.pdf

NGA.STND.0037 2.0.0 GRIDS, Universal Grids and Grid Reference Systems, 28 February 2014 http://earth-info.nga.mil/GandG/publications/NGA_STND_0037_2_0_0_GRIDS/NGA.STND.0037_2.0.0_GRIDS.pdf

NGA.SIG.0012 2.0.0 UTMUPS, Implementation Practice – The Universal Grids and the Transverse Mercator and Polar Stereographic Map Projections, 25 March 2014 http://earth-info.nga.mil/GandG/publications/NGA_SIG_0012_2_0_0_UTMUPS/NGA.SIG.0012_2.0.0_UTMUPS.pdf

# 4 Terms and definitions, and abbreviated terms

## 4.1 Terms and definitions

Terms and definitions have been taken from the references cited in the Normative References (section 3) and the Bibliography.

### 4.1.1 absolute accuracy

closeness in position of reported coordinate values to true values or values accepted as being true. Also referred to as external accuracy.

[ISO 19113]

### 4.1.2 aggregation

a form of association that specifies a whole-part relationship between the aggregate (whole) and a constituent part

[ISO 19103]

### 4.1.3 class

description of a set of objects that share the same attributes, operations, methods, relationships, and behavior

[ISO 19103]

### 4.1.4 continuous coverage

**coverage** that returns different values for the same feature attribute at different **direct position**s within a single **spatial** object**, temporal object, or spatiotemporal object** in its **domain**

[ISO 19123]

### 4.1.5 coordinate

one of a sequence of numbers designating the position of a point in N-dimensional space

[ISO 19111]

### 4.1.6 coordinate reference system

coordinate system which is related to the real world by a datum

[ISO 19111]

### 4.1.7 coverage

**feature** that acts as a **function** to return values from its **range** for any direct position within its spatial, temporal, or **spatiotemporal domain**

[ISO 19123]

EXAMPLE Examples include a digital image, polygon overlay, or digital elevation matrix.

NOTE In other words, a coverage is a feature that has multiple values for each attribute type, where each direct position within the geometric representation of the feature has a single value for each attribute type.

### 4.1.8 coverage geometry

configuration of the **domain** of a **coverage** described in terms of **coordinates**

[ISO 19123]

### 4.1.9 data compaction

reduction of the number of data elements, bandwidth, cost, and time for the generation, transmission, and storage of data without loss of information by eliminating unnecessary redundancy, removing irrelevancy, or using special coding

[ANSI T1.523-2001]

NOTE Whereas data compaction reduces the amount of data used to represent a given amount of information, data compression does not.

### 4.1.10 data compression

reduction in the amount of storage space (bits) required to represent an image or dataset, or reduction in the length of message required to transfer a given amount of information.

[ISO 10918-1]

NOTE Data compression does not reduce the amount of data used to represent a given amount of information, whereas data compaction does. Both data compression and data compaction result in the use of fewer data elements for a given amount of information.

### 4.1.11 dataset

identifiable collection of data that can be represented in an exchange format or stored on a storage media

NOTE A dataset may be a smaller grouping of data, which though limited by some constraint such as spatial extent or feature type, is located physically within a larger dataset. Theoretically, a dataset may be as small as a single feature or feature attribute contained within a larger dataset. A hardcopy map or chart may be considered a dataset.

[ISO 19115]

### 4.1.12 dataset series

collection of datasets sharing the same product specification

[ISO 19115]

NOTE The datasets in a series may have been derived from the same sensor or platform, or may adhere to a common product specification. They typically share the same geometry (e.g. grid or TIN).

### 4.1.13 depth

distance of a **point** from a chosen reference **surface** measured downward along a line perpendicular to that **surface**

NOTE 1 A depth above the reference surface will have a negative value. [ISO 19111]

NOTE 2 Depth is positive if measured downward or inside of the reference surface. Depth is distinguished from **height** in that it is a directional measurement.

### 4.1.14 direct position

position described by a single set of **coordinates** within a **coordinate reference system**

[ISO 19107]

### 4.1.15 domain

well-defined set

[ISO 19103]

NOTE Domains are used to define the domain set and range set of operators and functions.

### 4.1.16 elevation

distance of a **point** from mean sea level measured along a line perpendicular to the mean sea level **surface**, positive if upwards or outside of the mean sea level **surface.**

NOTE Elevation can be expressed as a **height** above mean sea level or a **depth** below mean sea level.

### 4.1.17 evaluation < coverage>

determination of the values of a **coverage** at a **direct position** within the **spatiotemporal domain** of the **coverage**

[ISO 19123]

### 4.1.18 feature

abstraction of real world phenomena

[ISO 19101]

### 4.1.19 feature attribute

characteristic of a **feature**

[ISO 19109]

NOTE A feature attribute type has a name, a data type and a domain associated to it. A feature attribute instance has an attribute value taken from the value domain of the feature attribute type.

### 4.1.20 function

rule that associates each element from a **domain** (source, or domain of the function) to a unique element in another domain (target, co-domain, or **range**)

[ISO 19107]

NOTE The range is defined by another domain.

### 4.1.21 geoid

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

[ISO 19111]

NOTE “Level **surface**” means an equipotential **surface** of the Earth’s gravity field which is everywhere perpendicular to the direction of gravity.

### 4.1.22 geometric object

spatial object representing a set of **direct positions**

[ISO 19107]

NOTE A geometric object consists of a **geometric primitive**, a collection of geometric primitives, or a geometric complex treated as a single entity. A geometric object may be the spatial characteristics of an object such as a **feature** or a significant part of a feature.

### 4.1.23 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 a systematic way

[ISO 19123]

NOTE The curves partition a space into grid cells.

### 4.1.24 grid point

**point** located at the intersection of two or more curves in a **grid**

[ISO 19123]

### 4.1.25 height

distance of a point from a chosen reference **surface** measured upward along a line perpendicular to that **surface**

NOTE A height below the reference surface will have a negative value.

#### 4.1.25.1 ellipsoidal height (h)

distance of a point from the **ellipsoid** surface measured upward along a line perpendicular to the **ellipsoid,** positive if upwards or outside of the **ellipsoid**. Also known as geodetic height.

NOTE Only used as part of a three-dimensional coordinate system and never on its own.

#### 4.1.25.2 gravity-related height (H)

**Height** dependent on the Earth's gravity field

NOTE In particular, orthometric height or normal height, which are both approximations of the distance of a point above the mean sea level.

#### 4.1.25.3 geoid height (N)

distance of a point on the geoid from the ellipsoid surface measured upward along the line perpendicular to the ellipsoid, positive if above the ellipsoid.

[ISO 19111]

NOTE 1 The reference **surface** is based on the **geoid** and may be approximated by an ellipsoid or hydrographic **surface**. Height is distinguished from elevation in that it is a directional measurement. A height below the reference **surface** will have a negative value. Negative height is also called depth. This definition also applies to altitude.

NOTE 2 Ellipsoidal height = gravity-related (orthometric) height + **geoid** height

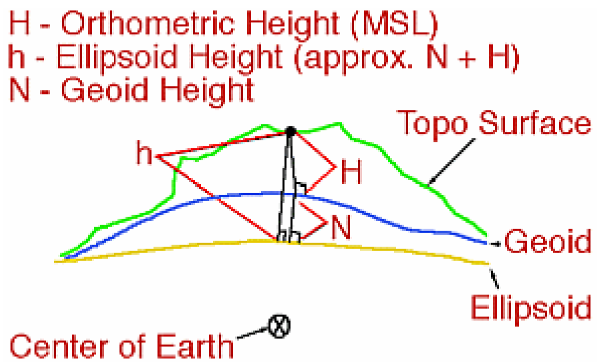



**Figure 1 - Height**

### 4.1.26 point

0-dimensional **geometric primitive**, representing a position within a coordinate reference system

[ISO 19107]

### 4.1.27 point coverage

**coverage** that has a spatial domain composed of **points**

[ISO 19123]

### 4.1.28 point set

a set of vertices in a three-dimensional coordinate system. These vertices are usually represented by easting, northing, and height values.

[derived from ISO 19123]

### 4.1.29 post

The locations of the intersections of rows and columns within an **elevation grid**. Post spacing for a **rectified grid** is a measure of its horizontal resolution

[derived from NATO STANAG 3809: DTED]

### 4.1.30 quad tree

expression of a two-dimensional object as a tree structure of quadrants, which are formed by recursively subdividing each non-homogeneous quadrant until all quadrants are homogeneous with respect to a selected characteristic, or until a predetermined cut-off depth is reached

[ISO 2382]

### 4.1.31 range

<coverage>

set of feature attribute values associated by a **function** with the elements of the **domain** of a **coverage**

[ISO 19123]

### 4.1.32 record

finite, named collection of related items (objects or values)

[ISO 19107]

NOTE Logically, a record is a set of pairs <name, item >.

### 4.1.33 rectified grid

**grid** for which there is an affine transformation between the grid **coordinates** and the coordinates of an external **coordinate reference system**

[ISO 19123]

NOTE If the coordinate reference system is related to the earth by a datum, the grid is a georectified grid.

### 4.1.34 relative accuracy

closeness of the relative positions of **features** in a **dataset** to their respective relative positions accepted as or being true

[ISO 19113]

### 4.1.35 spatiotemporal domain

**domain** composed of spatiotemporal objects

[ISO 19123]

NOTE The spatiotemporal domain of a **continuous coverage** consists of a set of **direct positions** defined in relation to a collection of geometric objects.

### 4.1.36 surface

connected 2-dimensional **geometric object**, locally representing the continuous image of a region of a plane

[ISO 19107]

NOTE The boundary of a surface is the set of oriented, closed curves that delineate the limits of the surface.

### 4.1.37 tessellation

partitioning of a space into a set of conterminous **geometric objects** having the same dimension as the space being partitioned

[ISO 19123]

NOTE A tessellation composed of congruent regular polygons or polyhedra is a regular tessellation; One composed of regular, but non-congruent polygons or polyhedra is semi-regular. Otherwise, the tessellation is irregular.

### 4.1.38 Tile

A rectangular array of points on the reference grid, registered with and offset from the reference grid origin and defined by a width and height

[ISO/IEC 15444-1]

### 4.1.39 triangulated irregular network (TIN)

**tessellation** composed of triangles

[ISO 19123]

#### 4.1.40 vector

quantity having direction as well as magnitude

[ISO 19123]

NOTE A directed line segment represents a vector if the length and direction of the line segment are equal to the magnitude and direction of the vector. The term vector data refers to data that represents the spatial configuration of features as a set of directed line segments.

### 4.2 Symbols, notation and abbreviated terms

In this Profile, conceptual schemas are presented in the Unified Modelling Language (UML). An overview of the use of UML in geographic information standards is provided in ISO 19103, and Annex B of this profile provides a guide to UML notation.

Most of the model elements used in the schema defined in this profile are derived from ISO standards developed by ISO Technical Committee 211 (Geographic Information/Geomatics), which has provided a naming convention that assigns a unique two-character prefix to a class of data to identify the package and standard from which it comes. UML Object Constraint Language (OCL) is used to explicitly document all constraints. The implementations of ISO classes defined by this profile are given the prefix 'ESM'.

**Table 1 - Sources of externally defined UML classes**

| Prefix | Standard | Package |
|---|---|---|
| - | ISO 19103 | Basic Types |
| CI | ISO 19115 | Citation and responsible party information |
| CV | ISO 19123 | Coverage |
| DS | ISO 19115 | Dataset |
| EX | ISO 19115 | Extent information |
| FC | ISO 19110 | Feature Catalogue |
| GF | ISO 19109 | General feature model |
| GM | ISO 19107 | Geometric primitive |
| LI | ISO 19115 | Lineage information |
| MD | ISO 19115 | Metadata |
| MI | ISO 19115-2 | Imagery Metadata |
| MX | ISO 19139 | Metadata for Data Interchange |
| SC | ISO 19111 | Spatial Ref by Coordinates |
| RS | ISO 19115 | Reference system information |
| TM | ISO 19108 | Temporal schema |

## 4.3 Abbreviated terms

| | |
|---|---|
| BIIF | Basic Imagery Interchange Format Standard (ISO/IEC 12087-5) |
| DEM | Digital Elevation Model |
| DTED | Digital Terrain Elevation Data |
| ESM | Elevation Surface Model |
| GeoTIFF | Geographic Tagged Image File Format |
| GML | Geography Markup Language |
| HDF5 | Hierarchical Data Format Version 5 |
| IHO | International Hydrographic Organization |
| ISO | International Organization for Standardization |
| JPEG | Joint Photographic Experts Group |
| NATO | North Atlantic Treaty Organization |
| NITF | National Imagery Transmission Format |
| NSIF | NATO Secondary Imagery Format |
| TIN | Triangulated Irregular Network |
| TRE | Tagged Record Extension (of NITF / NSIF) |
| UML | Unified Modelling Language |
| UTM | Universal Transverse Mercator |
| XML | eXtensible Markup Language |

# 5 Applicability and use

This profile is applicable to the exchange of elevation surface data. It does not specify how such data is to be collected or used, but provides a common elevation data model to Defense communities. This common underlying model, based on international standards, permits the implementation of a concept of operations in which multiple producers and multiple users exchange elevation surface data. A common content model is provided, defining the minimum information required for the exchange and effective use of elevation data. The content model is independent of the encoding format and will serve as the basis for an ESM Application Schema. Compliance with the ESM content model will allow exchange of elevation data in user-specified encoding formats. The ESM Profile is also intended to result in a higher degree of interoperability across user domains and support the requirement for greater level of detail and quality reporting in elevation datasets.

# 6 Elevation Data Structure

## 6.1 Concept of Coverages

Elevation data is relatively simple data. It consists of a set of elevation values together with metadata that describes the meaning of these values. The elevation values are organized according to a spatial schema. For most types of elevation data, this schema takes the form of a coverage.

The Open Geospatial Consortium developed the coverage concept that is described in ISO 19123. A coverage is defined as a subtype of feature in that it represents real world phenomena in terms of a set of attributes. It acts as a function to return one or more attribute values for any direct position within its spatiotemporal domain. A set of known attribute values associated with specified positions is provided to drive the coverage function. This concept forms the basis of this standardized profile; however, it does not compromise the inherent simplicity of elevation data. Such data is still primarily a set of elevation values upon which a coverage function can operate.

A continuous coverage returns a distinct attribute value for each position in the domain. Continuous coverages are in effect interpolation functions across a set of data values. The coverage function allows one to interpolate attribute values across the spatiotemporal domain. Elevation models are inherently continuous coverages. The interpolation method to be used is described as part of the metadata associated with a coverage.

A coverage may also be a discrete function that returns a single value over the entire area of a specified element within the domain of the coverage. Discrete coverages are used to represent classification schemes and in other situations where the coverage attributes represent discrete variables. In general, it is not possible to interpolate between the values of a discrete coverage. An elevation point coverage (6.10) is an example of a discrete coverage. Contour line coverages, which are not addressed by this profile, are another example.

One of the advantages of using a coverage approach is that a coverage can include multiple attribute values for each point, so it can be used to represent more than one characteristic of the location represented by the point. However, a coverage cannot be used to represent multiple elevation surfaces. To support the case of multiple surfaces being represented in a single dataset, this standard addresses the point set structure (6.11), in which the elevation of each point is carried as one of its spatial coordinates.

A regular row-column grid of attribute values is not the only way of driving a coverage function. Different types of grids with various traversal orders may be defined. The attribute values may also be organized in other ways such as Triangulated Irregular Networks (TIN) or a point coverages with unstructured sets of Z values at X,Y locations. However, the regular quadrilateral grid is the coverage geometry used for most elevation data. TIN and point data are more useful for some applications. Conversions are possible between grid and TIN descriptions of the same area, and point data may be derived from grids and TINs.

## 6.2 CV_Coverage

The class CV_Coverage (Figure 2) from ISO 19123 is a generalization of the discrete and continuous coverage types. It has three attributes and three associations, and these relationships are inherited by the Elevation coverage classes specified in this profile. The attribute *domainExtent* describes the spatial and/or temporal extent of the domain coverage. The data type EX_Extent is defined in ISO 19115. The attribute *rangeType* describes the structure and composition of the attribute data record. The data type RecordType is specified in ISO/TS 19103. The attribute *commonPointRule* identifies a method for resolving potential conflicts between attribute values resulting from evaluation of a coverage at a direct position when that position falls on the boundary between two value objects, such as two grid cells or two of the triangles in a TIN.

Associated with a CV_Coverage is the specification of the Coordinate Reference System to which the objects in the domain are referenced. Also associated are domain and range specifications. CV_DomainObject represents an element of the domain of the coverage and CV_AttributeValues represents and element from the range of the coverage. In the case of a discrete coverage, the multiplicity of CV_Coverage.rangeElement equals that of CV_coverage.domainElement because there is only one instance of CV_AttributeValues for each instance of CV_DomainObject. For a continuous coverage, there is a transfinite number of instances of CV_AttributeValues for each CV_DomainObject.

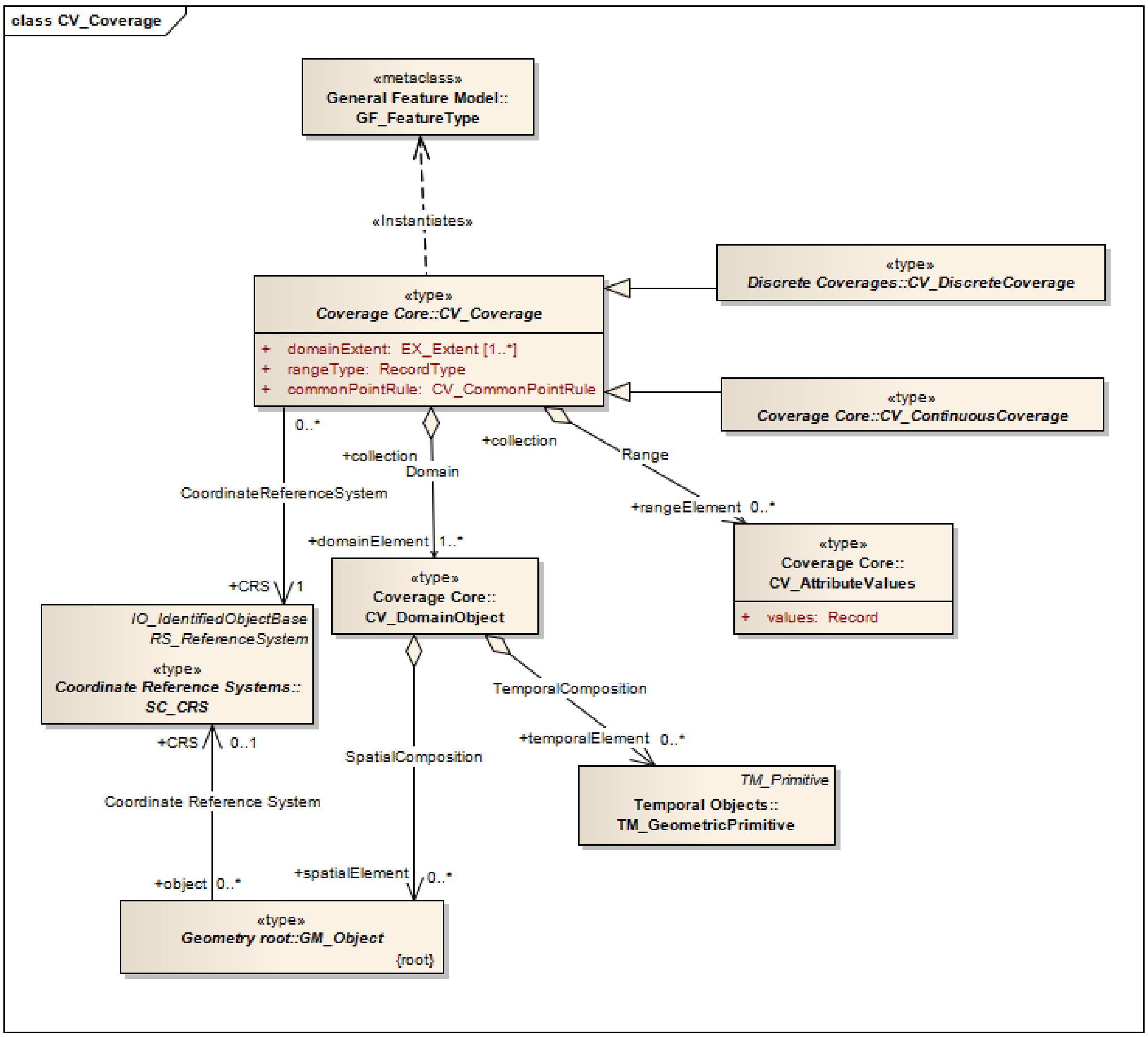



**Figure 2 - CV_Coverage**

## 6.3 ESM Coverages

### 6.3.1 Introduction

ESM_Coverage (see Figure 3) specifies a set of attributes common to all types of coverages. In this profile only the Grid, Elevation TIN and Elevation Point coverage types are addressed. Point sets (which do not meet the definition of a coverage) are addressed in section 6.11. The class ESM_Coverage is an abstract class that specifies a set of attributes common to all types of coverages that may be contained in an ESM_Collection. ESM_Coverage is a realization of the Type CV_Coverage specified in ISO 19123 and implements attributes for that type. The attributes are *domainExtent*, *rangeType*, and *commonPointRule*.

### 6.3.2 domainExtent

The attribute *domainExtent* describes the spatial extent of the domain of the ESM_Coverage. It uses the data type EX_GeographicExtent specified in ISO 19115.

### 6.3.3 rangeType

The attribute *rangeType* describes the range of the ESM_Coverage. It uses the data type RecordType specified in ISO/TS 19103. An instance of RecordType is a list of name/datatype pairs, each of which describes an attribute type included in the range of the coverage. The name field shall be used to identify the type of surface that each elevation value describes.

NOTE The definition of the attribute type shall be provided by a feature catalogue.

EXAMPLE For a coverage containing elevation values for bare earth, vegetation canopy, and a radar reflective surface, the attribute types could be described as: "bare earth surface elevation:Real, vegetation canopy surface elevation:Real, radar reflective surface elevation:Real".

### 6.3.4 commonPointRule

The attribute *commonPointRule* describes the procedure used for evaluating the ESM_Coverage at a position that falls on the boundary or in an area of overlap between geometric objects in the domain of the coverage. It takes a value from the code list CV_CommonPointRule specified in ISO 19123. The rule shall be applied to the set of elevation values that results from evaluating the coverage with respect to each of the geometric objects that share a boundary. For elevation coverages, the values of the CV_CommonPointRule shall be 'average', 'high', or 'low'. For example, data used for aeronautical purposes might make use of the 'high' value to ensure that vertical obstructions are emphasised.

The use of the *commonPointRule* occurs where a set of geometric objects are involved, such as the triangles in a TIN.

## 6.4 ESM Collection

An ESM collection (Figure 3) consists of one or more ESM datasets. The datasets in an ESM collection do not necessarily share the same geometry. They might include one or more coverage types or point sets over a specified area. For example, an ESM collection may consist of a grid coverage and a point set over the same area, where the grid coverage represents an elevation surface and the point set a number of more accurately measured elevation points. Alternatively, a collection may consist of multiple coverages of the same type representing different elevation surface types (7.4.2). A dataset series is a type of collection in which the component datasets typically share the same geometry. The datasets in a series may have been derived from the same sensor or platform, or may adhere to a common product specification.

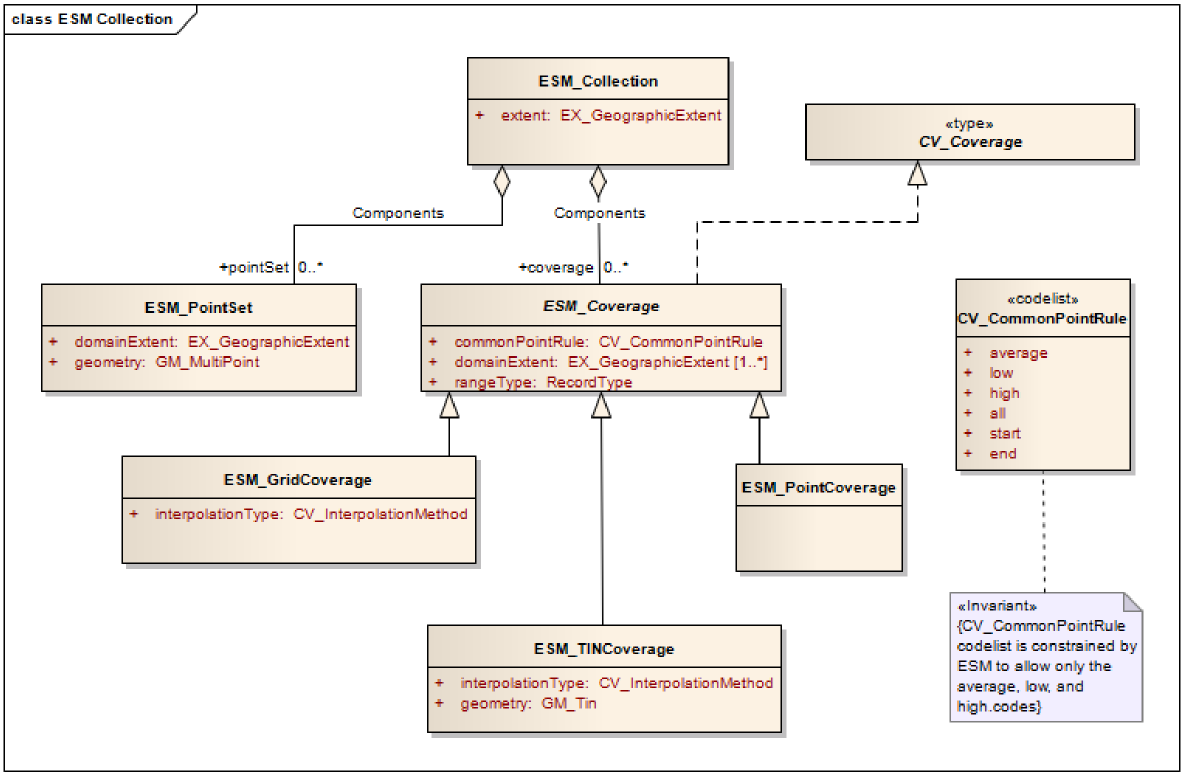



**Figure 3 - ESM Collection**

## 6.5 ESM Grids

The grid structure is the most common geometric representation for elevation data. The other types can be derived from an elevation grid. A grid is defined by the intersection of two (or more) sets of curves called grid lines and the intersection points are called grid points. The area defined by four adjacent grid points is a grid cell. This standardized profile addresses only quadrilateral grids, in which grid lines are straight and grid cells are parallelograms. There is one set of grid lines for each dimension of space, so in a common two-dimensional grid there are two sets of grid lines. The grid points at the intersections are often referred to as posts in elevation data. Figure 4 illustrates a simple quadrilateral grid.

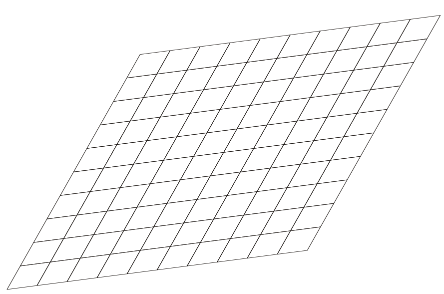


**Figure 4 - An example of a quadrilateral grid**

A rectified grid is related to the earth or other reference by an affine transform based on the location of the origin of the grid and the orientation of and spacing along each axis. It is a uniformly spaced grid, so that the location of one cell in a georectified grid can be determined based on another cell's location, the cell interval, and the grid orientation.

Georeferencable grids include a coordinate transform that can be used to calculate the location of any cell in the grid, but each cell's location must be calculated independently. Georectified gridded data are normally obtained from unrectified data through georectification (also called geometric correction).

This profile is concerned only with rectified quadrilateral grids. Most existing elevation data formats are based on simple rectified quadrilateral grids, which are only a small subset of the grid coverages defined by ISO 19123. The only thing that distinguishes an elevation grid coverage from other quadrilateral grid coverages is that the attributes represent elevation values.

## 6.6 ESM Grid Coverage

### 6.6.1 ESM Grid Coverage Model

The class ESM_GridCoverage (Figure 5) represents a set of elevation values assigned to the points in a 2-dimensional grid. Several organizations of grids are possible with different grid traversal orders, and variable or fixed grid cell sizes. This standard is concerned with two types of grid organizations, the simple quadrilateral grid (Figure 4) with equal cell sizes traversed by a linear sequence rule, and the variable cell size quadrilateral grid traversed by a Morton Order sequence rule (6.7.8). The variable cell size grid organization is known as the Quad Tree for a two dimensional grid.

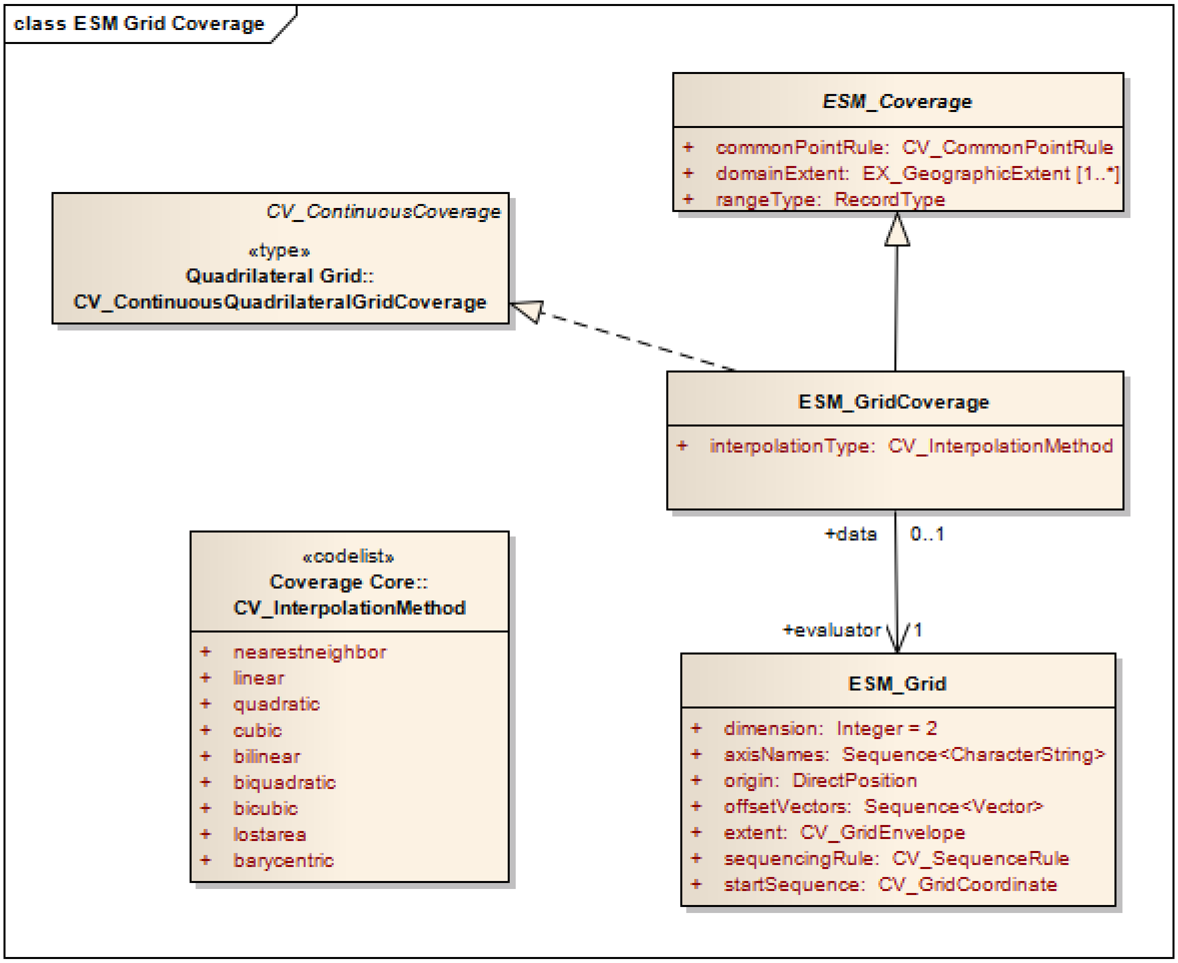



**Figure 5 - ESM Grid Coverage**

### 6.6.2 ESM Grid Coverage Class

The class ESM_GridCoverage is subclass of ESM_Coverage. It represents the set of values assigned to the points in a 2-dimensional grid. The class is a realization of the type CV_ContinuousQuadrilateralGridCoverage from ISO 19123.

### 6.6.3 interpolationType

The attribute *interpolationType* describes the interpolation method recommended for evaluation of the ESM_GridCoverage. For grid coverages, the value shall be ‘nearest neighbour’, ‘bilinear’, ‘biquadratic’, 'bicubic', or a user-defined interpolation. A user-defined interpolation method must be documented in a product specification.

**Nearest neighbor** interpolation can be applied to any coverage. It generates a feature attribute value at a direct position by assigning it the feature attribute value associated with the nearest domain object in the domain of the coverage. Nearest Neighbor interpolation is generally not recommended for elevation data, although it may produce acceptable results when resampling to generate a grid with much lower resolution than the source grid.

**Bilinear interpolation** is used to interpolate feature attribute values at direct positions within a quadrilateral grid using the function:

$$v = a_0 + a_1x + a_2y + a_3xy$$

The following is a common algorithm for this interpolation technique. Given a direct position, p, contained in a grid cell whose vertices are V, $V + V_1$ , $V + V_2$ , and $V + V_1 + V_2$ , with feature attribute values at these vertices of $W_1$, $W_2$, $W_3$, and $W_4$, respectively, there are unique numbers i and j, with $0 \le i < 1$, and $0 \le j < 1$ such that $p = V + iV_1 + jV_2$ . The feature attribute value at p is:

$$W = (1-i)(1-j)W_1 + i(1-j)W_2 + j(1-i)W_3 + ijW_4$$

**Biquadratic interpolation** is also used to compute feature attribute values at direct positions within a quadrilateral grid. It is based on the assumption that feature attribute values vary as a biquadratic function of position within the grid cell:

$$v = a_0 + a_1x + a_2y + a_3x^2 + a_4xy + a_5y^2 + a_6x^2y + a_7xy^2 + a_8x^2y^2$$

ISO 19123 references sources for algorithms for implementing biquadratic interpolation.

**Bicubic interpolation** is also used to compute feature attribute values at direct positions within a quadrilateral grid. Bicubic interpolation uses the function:

$$v = a_0 + a_1x + a_2y + a_3x^2 + a_4xy + a_5y^2 + a_6x^2y + a_7xy^2 + a_8x^2y^2 + a_9x^3 + a_{10}y^3 + a_{11}x^3y + a_{12}xy^3 + a_{13}x^3y^2 + a_{14}x^2y^3 + a_{15}x^3y^3$$

ISO 19123 references sources for algorithms for implementing bicubic interpolation.

### 6.6.4 data

The role name *data* identifies the ESM_Grid that contains the values of the ESM_Coverage.

## 6.7 ESM Grid Content

### 6.7.1 ESM Grid Model

The class ESM_Grid (Figure 6) represents the data content of an ESM_GridCoverage. It contains the data values as a sequence of records.

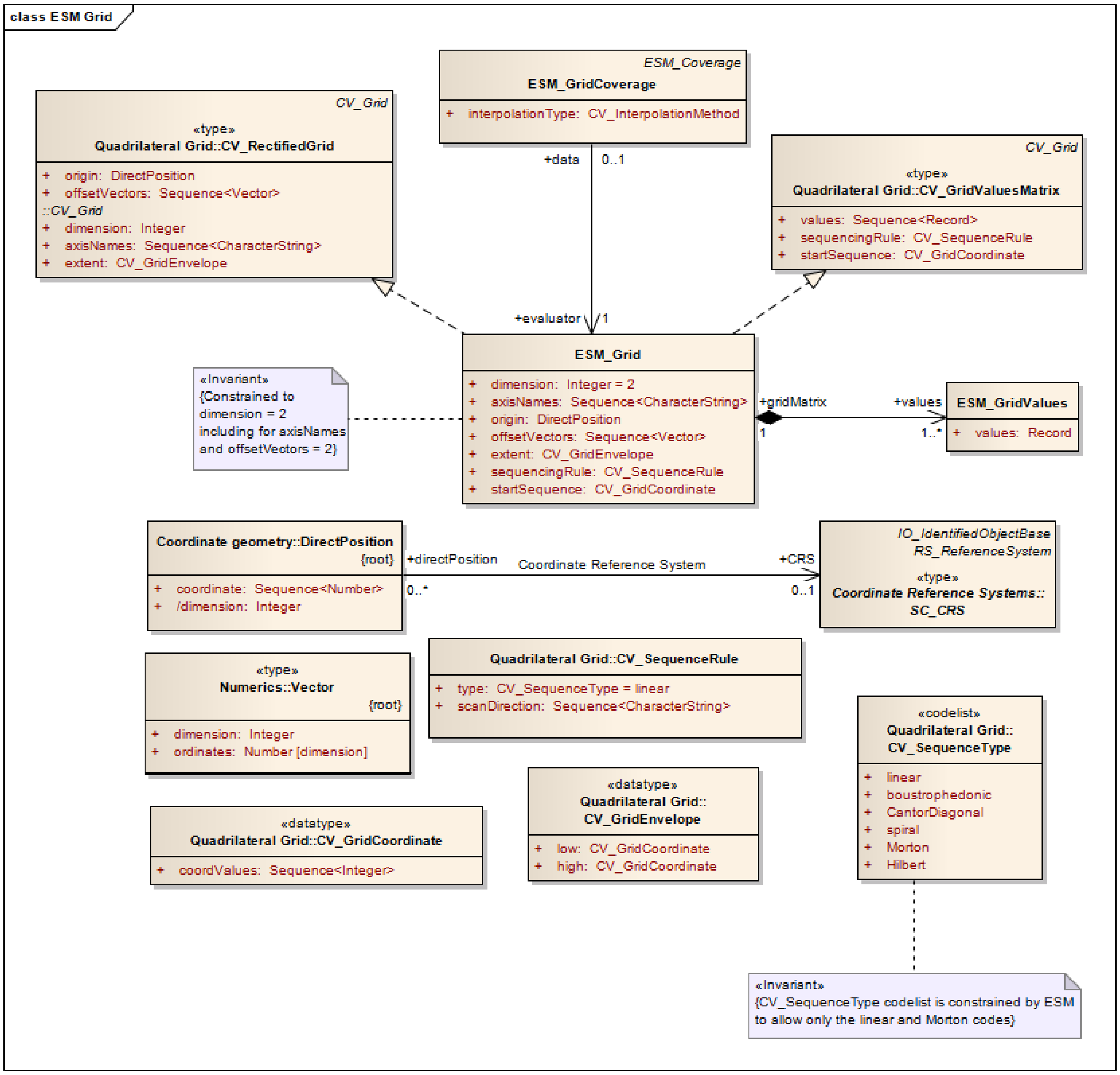



**Figure 6 - ESM Grid**

### 6.7.2 ESM Grid Class

The class ESM_Grid is a realization of the CV_RectifiedGrid and CV_GridValuesMatrix classes from ISO 19123, and the attributes are inherited from the ISO classes.

### 6.7.3 dimension

The attribute *dimension* specifies the dimensionality of the grid.

### 6.7.4 axisNames

The attribute *axisNames* specifies the names of the grid axes. Axes are often named for their orientation relative to the external coordinate reference system, with “north” and “east” being very common examples.

### 6.7.5 origin

The attribute *origin* specifies the coordinates of the grid origin with respect to an external coordinate system. The data type DirectPosition, specified in ISO 19107, has an association through the role name *coordinateReferenceSystem* to the class SC_CRS (ISO 19111) which specifies the external coordinate reference system (7.4.6).

### 6.7.6 offsetVectors

The attribute *offsetVectors* specifies the spacing between grid points and the orientation of the grid axes with respect to the external coordinate reference system identified through the attribute *origin*. It uses the data type Vector specified in ISO/TS 19103.

### 6.7.7 extent

The attribute *extent* specifies the area of the grid for which elevation data are provided. It uses the type CV_GridEnvelope specified in ISO 19123 to provide both the CV_GridCoordinates of the corner of the area having the lowest grid coordinate values and the CV_GridCoordinates of the corner of the area having the highest grid coordinate values. CV_GridCoordinate is specified in ISO 19123.

### 6.7.8 sequencingRule

The attribute *sequencingRule* specifies the method to be used to assign values from the sequence of elevation values to the grid coordinates. It uses the data type CV_SequenceRule specified in ISO 19123.

CV_SequenceRule has two attributes. The attribute *type* identifies the technique used to move from one point to the next. Only the values "linear" and "Morton" shall be used for data that conforms to this standard. Both linear and Morton can be extended to a 3-dimensional grid, which is not addressed by this profile. The attribute *scanDirection* contain a list of signed attribute names; scanning starts in a direction parallel to the first axis listed, and moves from row to row in the direction parallel to the next axis listed.

Linear scanning cannot be used if data has been aggregated as a result of data compaction. In that case the value of the *sequencingRule* shall be 'Morton'. Morton ordering is discussed in detail in Annex C.

### 6.7.9 startSequence

The attribute startSequence : CV_GridCoordinate shall identify the grid point to be associated with the first record in the values sequence. The choice of a valid point for the start sequence is determined by the type and scanDirection attributes of CV_SequencingRule.

### 6.7.10 values

The *values* attribute of the ESM_GridValues class shall be a sequence of Records each containing one or more elevation values to be assigned to a single grid point. The Record shall conform to the RecordType specified by the *rangeType* attribute of the ESM_GridCoverage class with which the ESM_Grid class is associated. Only elevation values are required when the sequence rule is of *type* 'linear'.

Note that the coverage may describe more than one surface, in which case the Record contains more than one elevation value for each grid point. Each surface is evaluated independently. Aggregations of points resulting from data compaction shall be the same for all surfaces described by a coverage.

## 6.8 Variable Cell Size Grids

The class IF_RiemannGriddedData from ISO 19129 is a subclass of the class IF_GridCoverage that implements the class CV_ContinuousQuadrilateralGridCoverage from ISO 19123. The Riemann class defines a variable cell size grid where adjacent cells that have the same attribute values are aggregated along the traversal order. This grid, known as a quad tree in 2 dimensions, is of particular use for large volumes of sensor data where many adjacent cells have similar values and can be aggregated into larger cells.

The Riemann coverage template differs from the continuous quadrilateral grid coverage template in that the traversal order for the Riemann grid is Morton and the aggregation rule for adjacent cells is applied. It is necessary to describe the minimum grid cell dimensionality and axis order using the attributes ‘dimension’ and ‘axisNames’ inherited by CV_GridValuesMatrix from CV_Grid.

Variable sized cells are actually aggregations of small equally sized cells as defined by CV_GridValueCell. The nature of the Morton order means that only the size of each cell need be stored along with the cell value. The position of each cell is uniquely defined by the cell size and the traversal order. In a simple regular grid the location of each cell is uniquely defined by the Row, Column traversal order. In a Riemann grid the location of each cell is defined by the cell size (aggregation level) and the Morton order.

In continuous coverages, a coverage function returns a value for every point in the area covered based on an interpolation function. The Grid Value Matrix is a set of values which drives the interpolation function. In this case the value matrix is a subclass of CV_GridValuesMatrix that includes the additional parameter defining the cell size as a level of aggregation. That is, 0 represents the base minimum cell size, and 1 represents the aggregation of one level of adjacent neighbors, and 2 represents the aggregation of one more level of adjacent neighboring cells.

## 6.9 ESM TIN Coverage

### 6.9.1 Introduction

A TIN covers an area with a unique set of non-overlapping triangles where each triangle is formed by three points. The geometry for a TIN is described in ISO 19107 and TIN coverages are described in ISO 19123. Most of the points in a well-constructed TIN fall on the inflection points (ridges, drains, summits and pits) of the surface it represents, so it may represent the surface more accurately than a grid of the same point density. TIN coverages are particularly useful for representing elevation in some applications. It is easier to calculate an intersection with a coverage surface when it is represented as a TIN. Attributes can be applied to each triangular face, and it is easy, but computationally intensive, to process the faces geometrically, in order to calculate contour lines. The major advantage of a TIN is in those applications where it is desirable to calculate the intersection of a path with the elevation surface. An example TIN showing variable-size TIN triangles and the TIN vertices is shown in Figure 7. There are two common methods of storing TIN data: as triangles with references to their vertices, or as points with references to their neighbouring points.

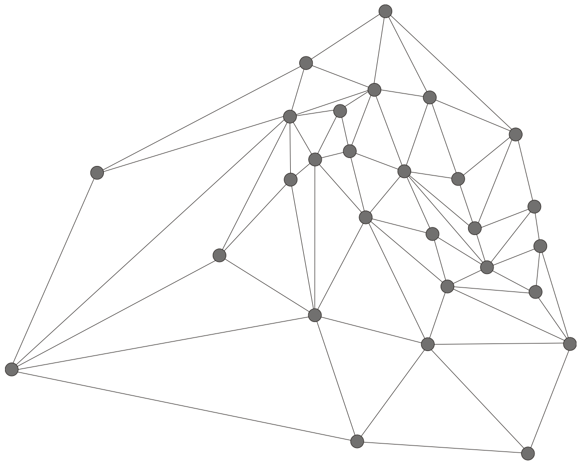


**Figure 7 - Example TIN Triangles**

### 6.9.2 Elevation TIN Coverage Model

A TIN elevation coverage is a subclass of CV_ContinousCoverage (ISO 19123) characterized by a GM_TIN (ISO 19107). The attribute values in the value record for each CV_GeometryValuePair of a CV_TINcoverage represent elevation values. Any additional attributes related to a TIN triangle may be described as attributes of the component triangles. The class ESM_TINCoverage is illustrated in Figure 8.

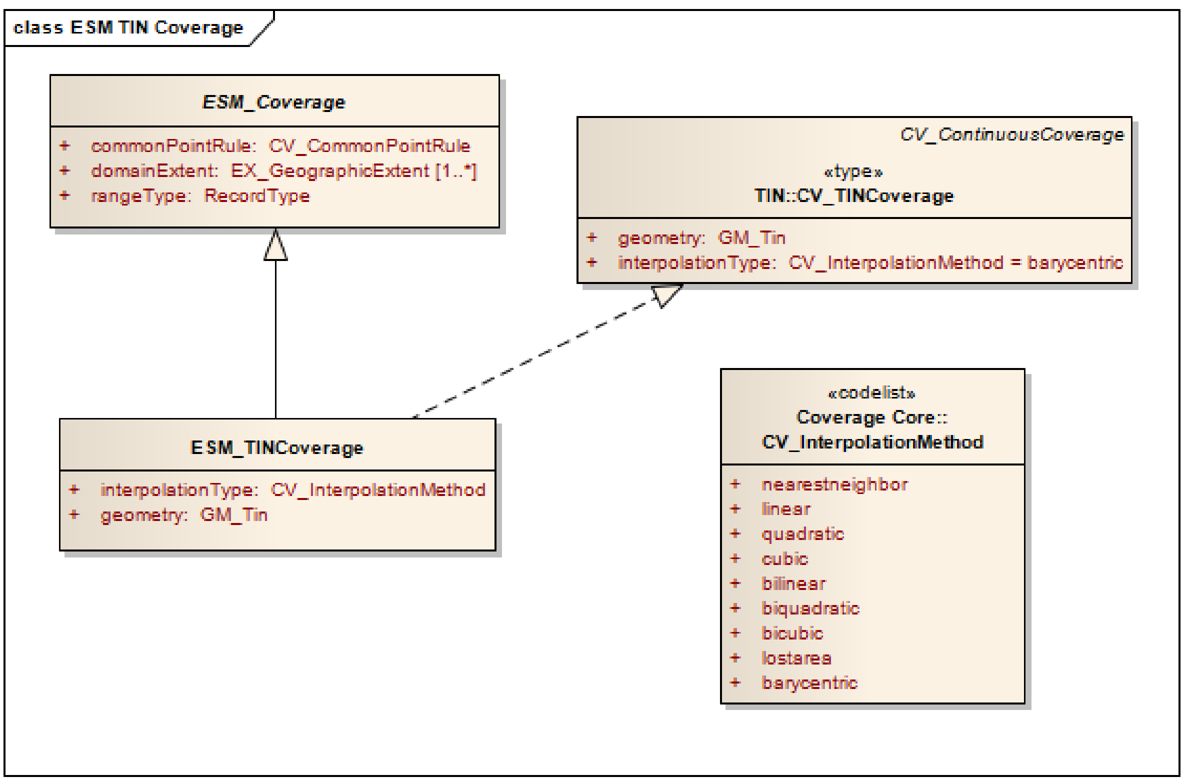



**Figure 8 - ESM TIN Coverage**

### 6.9.3 ESM_TINCoverage Class

The class ESM_TINCoverage is a realization of the Type CV_TINCoverage from ISO 19123. CV_TINCoverage is an aggregation of CV_ValueTriangle, which uses GM_Triangle (ISO 19107) as its geometry. Each of the vertices of the GM_Triangle represents a specific elevation.

### 6.9.4 interpolationType

The attribute *interpolationType* specifies the interpolation method recommended for the evaluation of the ESM_TINCoverage. The value is taken from the code list CV_InterpolationMethod specified in ISO 19123. For TIN coverages, the default value is 'barycentric'.

The barycentric position S within a value triangle composed of the CV_PointValuePairs (P1, V1), (P2, V2), and (P3, V3), is (i, j, k), where S = iP1 + jP2 + kP3 and the interpolated attribute value at S is V = iV1 + jV2 +kV3.

### 6.9.5 geometry

The attribute *geometry* contains the network of triangles that form the basis of the TIN. The class GM_Triangle is used to construct GM_TIN (ISO 19107). GM_TIN has a *controlPoint* attribute which contains a set of GM_Positions (ISO 19107), and GM_Positions are unions of either DirectPositions or references to GM_Points from which DirectPositions can be derived. The triangles within a TIN lie on a 2-dimensional manifold with the X,Y coordinates of the points at the vertices of the triangles representing the direct position on the manifold and the attribute value representing the elevation above the reference surface (e.g. the WGS84 ellipsoid).

## 6.10 ESM Point Coverage

### 6.10.1 ESM Point Coverage Model

An ESM point coverage is a type of CV_DiscretePointCoverage from ISO 19123. The attribute values in the value record for each CV_GeometryValuePair represent elevation values.

The class ESM_PointCoverage (Figure 9) represents a set of elevation values assigned to a set of arbitrary X,Y points. Each point is identified by a horizontal coordinate geometry pair (X,Y) and assigned one or more elevation values as attribute values. The point set does not necessarily have any systematic organization, although the arrangement of the points may depend upon the characteristics of the sensor or process by which they were generated.

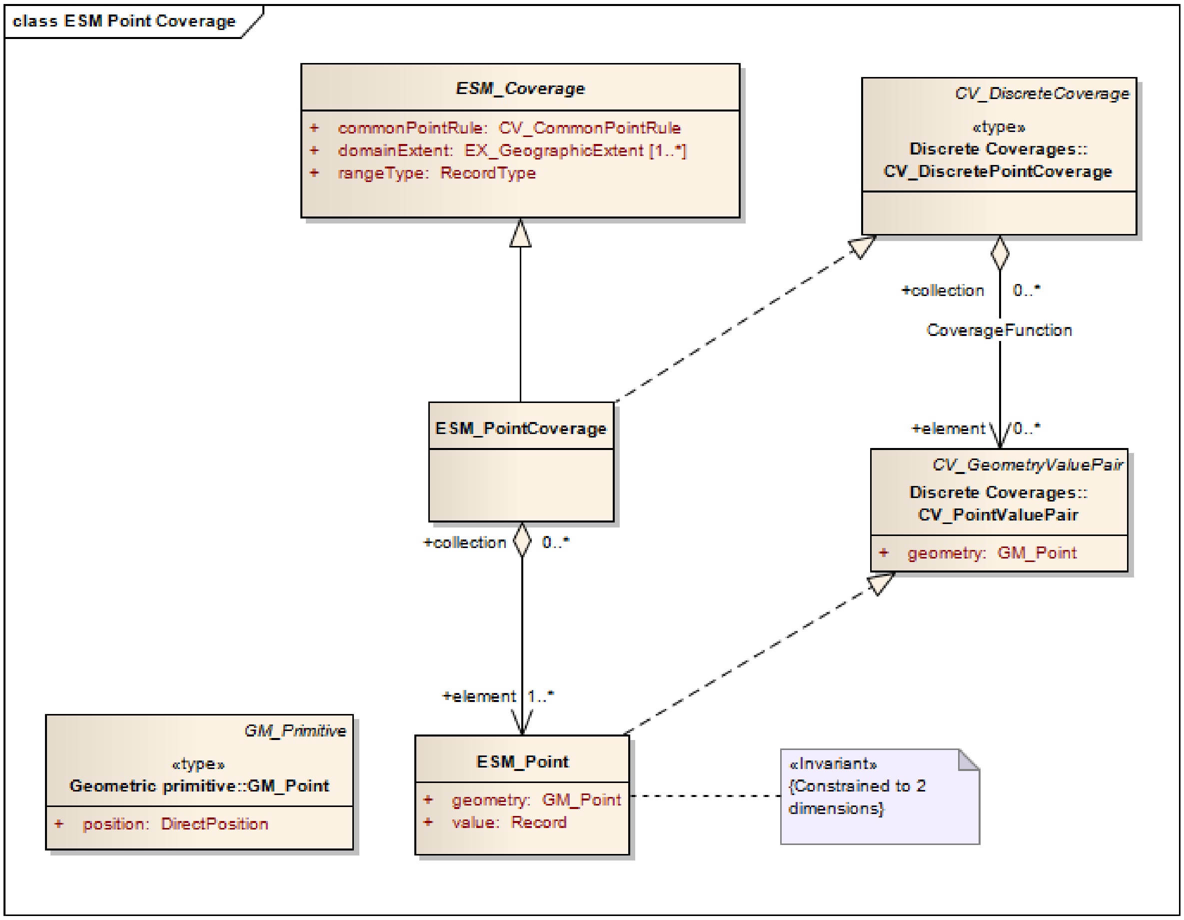



**Figure 9 – ESM Point Coverage**

### 6.10.2 ESM Point Coverage Class

The class ESM_PointCoverage is a subclass of ESM_Coverage and a realization of the Type CV_DiscretePointCoverage specified in ISO 19123. It is an aggregation of points, each of which is associated with one or more elevation values carried as attributes. It implements the attributes and associations inherited from ESM_Coverage as well as those specified for CV_DiscretePointCoverage. A point coverage supports the description of multiple surfaces using 2-dimensional points with elevation values described as attributes in a record. This is different from a point set which is a set of 3-dimensional points each of which relates to only one surface.

### 6.10.3 element

The role name *element* identifies the set of ESM_Points contained in the ESM_PointCoverage.

### 6.10.4 ESM Point Class

The class ESM_Point is a realization of the Type CV_PointValuePair specified in ISO 19123. It represents a point that has a Record of one or more elevation values associated with it. The location of a point is specified by the attribute *geometry* which contains an instance of GM_Point as specified in ISO 19107. The position of the GM_Point shall be constrained to 2 dimensions and specified with reference to WGS84 (8.2). A Record may contain one or more elevation values where each value corresponds to a different surface.

## 6.11 Point Sets

Point sets consist of point features that are referenced to a 3-dimensional coordinate reference system. In other words, a member of an elevation point set differs from an ESM_Point in that its elevation is carried as a coordinate rather than an attribute. A point set is therefore not a coverage, but is only the spatial domain of a coverage. Point set data is generated by certain types of sensors. A point cloud collected by a LiDAR sensor is an example of a point set. Each point in a point set has only one elevation value and represents only one elevation surface type. Through processing it is possible to convert a point set into a point coverage.

# 7 Metadata

## 7.1 Introduction

Associated with each dataset (either an ESM_Coverage or an ESM_Point set) and with each ESM_Collection is metadata. The information provided by the metadata allows and enhances data discoverability, access and transfer. It can also allow a determination of the data's fitness for use in a particular application. Metadata is organized in various ways according to the exchange format that carries the information. At one level, all of the information within the dataset, other than the set of value objects, may be considered metadata. Thus, an 'attribute' in one exchange format may appear as 'metadata' in another. Additionally, implementation of specific metadata elements could vary based on the interpretation of the metadata producers. This profile specifies that standardization of the metadata vocabulary and entity relationships will be achieved through conformance with the DGIWG Metadata Foundation (DMF) and ISO 19115 metadata schema. Annex E of this profile includes a DMF-compliant data dictionary for minimum required ESM metadata. ISO rules for encoding the schemas in XML are also required by this profile. The XML schemas will enhance interoperability by providing a common specification for describing, validating and exchanging metadata associated with elevation datasets.

## 7.2 Metadata Hierarchy Levels

In practice, metadata may be associated with any class or subset of data, including individual points or cells, a grouping of data within a dataset, a single fundamental dataset, or an aggregation of datasets. The description of metadata is hierarchical, so that any metadata element at a higher level applies at a lower level, unless superseded by more detailed metadata at the lower level. For example, an individual hydrographic sounding within a bathymetric depth coverage might carry information about the accuracy of the individual sounding, and this would supersede accuracy metadata described for the region of the dataset that includes the sounding.

## 7.3 Data Interchange

ISO 19115 defines a dataset (DS_Dataset) as an identifiable collection of data. A dataset can be represented in an exchange format or stored on a storage media. It must have one or more related metadata entity sets (MD_Metadata), which may optionally relate to aggregations of datasets (DS_Aggregate).

However, a dataset cannot be defined as a physical entity of exchange, but rather as a logical entity that can be identified by its associated metadata. Therefore, metadata based transfers of geospatial information require the 19115 model to be extended (Figure 10). To support interchange by transfer, two new concepts are introduced by ISO 19139; the transfer dataset (MX_Dataset) and the transfer aggregate (MX_Aggregate). In the context of the transfer, the dataset data is organized into data files (MX_DataFile). The ESM_Collection (6.4) is a realization of the transfer aggregate. Both transfer datasets and aggregates may reference support files (MX_SupportFile) which contain resources needed to exploit the data or complementary information. Examples of support files include feature and portrayal catalogues, codelists, and documents defining units of measure or coordinate reference systems.

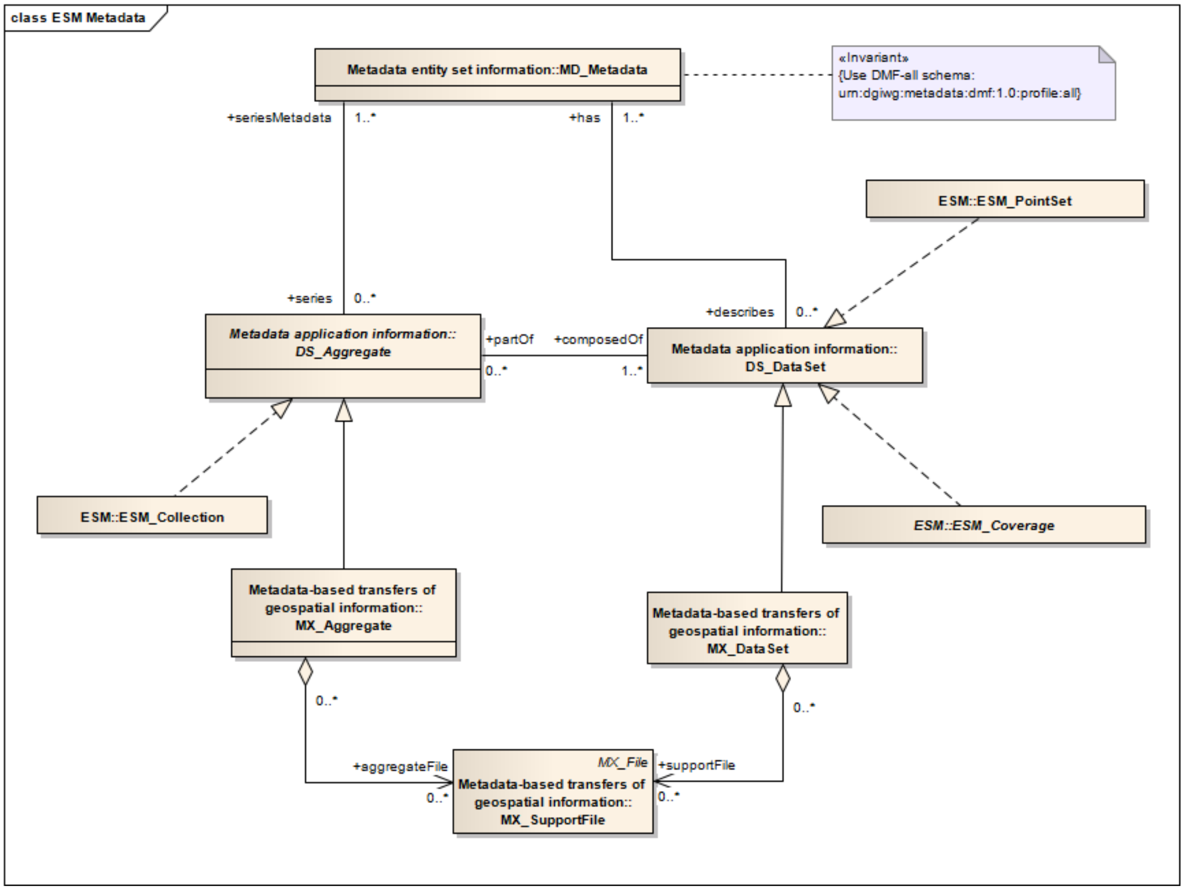



**Figure 10 – General Interchange Organization**

In an actual (physical) transfer, the aggregation of datasets follows constraints (e.g. media capacity) and requirements which outweigh this conceptual design, but the initial nature of the aggregation can be expressed through the hierarchyLevel attribute of MD_Metadata using the codelist MD_ScopeCode. The concept of a transmittal is introduced in ISO 19129 to identify the information that is physically exchanged. A transmittal may be a dataset, a part of a dataset, or several datasets, depending on the encoding format and the exchange media. A transmittal on a physical media such as a DVD may carry a number of datasets, whereas a transmittal over a low bandwidth telecommunications line may carry only a small part of a dataset. Transmittal metadata describes the transfer data file (MX_DataFile). This metadata is integral to the transmittal and may be changed by the exchange mechanism to other exchange metadata as required for the routing and delivery of the transmittal. A common exchange mechanism would be to carry a whole dataset on one physical media such as a CD-ROM. Transmittal metadata is dependent upon the mechanism used for exchange, and may differ from one exchange media or encoding format to another. An example of transmittal metadata would be counts of the number of data bytes in a unit of exchange. It is recommended that the transmittal metadata include the resource format (MD_Format) to describe the exchange format of the corresponding value data.

## 7.4 Metadata Content Requirements

The specification of minimum required metadata elements in Annex E complies with the DGIWG Metadata Foundation (DMF) and schema defined in ISO 19115. It defines the minimum set required to serve the full range of metadata applications, including the enablement of data discovery, access, transfer and use, and the determination of the data's fitness for use. In the following subsections, metadata requirements that represent additional constraints or recommendations beyond those provided by the DMF and ISO standards are described.

### 7.4.1 Intended Use

Communities of practice have unique requirements with respect to density, accuracy and other characteristics of the data, and this profile does not prohibit data producers or users from representing any data for any specific use. However, in order to prevent inappropriate use of elevation data based on characteristics such as spatial resolution and data quality, this profile requires that producers include the intended use of the data as a metadata element. The MD_Usage class of metadata is required in the ESM metadata specification (Annex E).

### 7.4.2 Surface Type

Surface type is an important attribute of the data but is difficult to describe. There are two relevant concepts: material surface and observed surface. A material surface is a surface along which two bodies of different types of material are in contact. An observed surface is a surface detected by a remote sensor. The two do not always correspond. This profile requires the documentation of surface type definitions in a feature catalogue. The surface type(s) defined by the elevation values shall be declared in the metadata, using the Keywords element defined in Table E.10. Including the surface type as a searchable keyword will make the elevation dataset discoverable by surface type, which may be necessary to support the intended use of the data.

A material surface may be detected by a remote sensor because the materials on opposite sides of the surface react differently to incident energy or emit energy differently. In the simple case, energy is reflected or emitted directly from the surface, so the observed surface corresponds closely to the material surface. In other cases, incident energy penetrates a material surface but is scattered back to a sensor before reaching the next material surface. If the depth of penetration is less than the resolution of the sensor, the sensor will average the positions from which energy is returned to generate an apparent surface below or behind the actual material surface. This is especially true for LiDAR, radar, sonar, and seismic sensors.

For most practical applications, it is the material surfaces that are of interest. These include:

Bare earth

Vegetation canopy

Bedrock

Water (open water and/or subterranean water table)

Sea floor (and bottom surfaces of other water bodies)

Ice

Built-up surfaces (including pavements)

When it is not clear that an observed surface corresponds to a material surface, the surface should be identified by the wavelength or frequency of the sensed radiation.

### 7.4.3 Estimated Values

No material surface is truly continuous. However, it is often possible to derive heights of one surface type from those of another. For example, heights for a "bare earth" surface can be estimated for points occupied by buildings either by subtracting building heights or by interpolating between bare earth points outside the building footprint. When estimated values are included in the dataset, information about the method used for the estimation shall be included in a product specification and in the metadata using the ‘Method used to estimate values’ metadata element (Table E.1)

### 7.4.4 Accuracy

ISO 19138 provides the data producer with guidance in choosing appropriate data quality measures for reporting, and assists the user in the evaluation of the usefulness of a dataset by standardizing the components and structures of data quality measures. The final choice must be based upon the type of data, the production process and the resources available. The resulting values and the method employed should be declared so that producers and users can understand the assessment and its validity. The stated accuracy requirement of a finished elevation product will be dependent on the intended use of the data. NATO STANAG 2215 – Evaluation of Land Maps, Aeronautical Charts and Digital topographic Data, Edition 6, specifies Circular and Linear Map Accuracy Standard (CMAS and LMAS) requirements, but does not address high resolution datasets. This standardized profile addresses all spatial resolution levels but only requires that horizontal/vertical accuracy values be expressed at a confidence level of at least 90 percent (circular/linear error at ≥ 90 percent probability). In general, applications that require high density also require high relative accuracy. As accuracy requirements become more stringent, assigning a single value of horizontal and vertical error for an entire dataset becomes an unsatisfactory solution. Therefore, Annex F of this profile describes the metadata contents that are required to permits rigorous, high fidelity error estimates to be computed on a post-by-post basis for a grid coverage. For high-resolution datasets (Table ), the data accuracy information shall be included in the metadata and shall include error propagation estimates. Reporting of this information may require the inclusion of quality coverages in addition to the elevation value coverage. In this case, a reference to the accuracy coverage shall be made in the metadata (QE_CoverageResult class from ISO 19115-2). If a dataset is subdivided into regions according to the quality of the elevation measurements, the geographic extents to which the accuracy values apply must be specified. General metadata requirements for accuracy reporting of any elevation dataset are included in Annex E.

### 7.4.5 Void and Suspect Areas

Identification of void areas is a requirement that only applies to grids since TINS, point coverages and point sets have no need for ‘fill’ or ‘pad’ values. The gridded data formats that are used to carry elevation data generally have some provision to declare a value for void areas. Some data producers assign large negative values to postings for void areas to retain the array alignment of raster data. Since this profile supports bathymetric data as well as land heights, using a negative value for void points in the grid cannot be recommended for all elevation datasets. Due care must be taken to avoid confusion with actual data values. The value shall be declared in the metadata, either by using the rangeElementDescription role from 19115-2 or by defining a void polygon using the extentTypeCode attribute of EX_GeographicExtents (see Table E.1). ‘Completeness’ metadata is also required per Annex D (DQ_DataQuality). Suspect areas have associated elevation values that are obviously outside of the logical range for the surface described. Suspect areas can be adequately addressed using elements of the DQ_DataQuality class.

### 7.4.6 Coordinate Reference Systems

ISO 19115, the DMF, and this profile require the use of an identifier for the reference system. The allowed horizontal reference systems are World Geodetic System 1984 (hereafter WGS84) and UTM or UPS projection on WGS84. The allowed vertical reference systems are the WGS84 Ellipsoid, WGS84 Geoid, or a hydrographic datum. The Earth Gravity Model (EGM) version shall be specified when the WGS84 geoid is the vertical reference system. This may be accomplished through the use of the Temporal Reference System element listed in Table E.1. Section 8 provides guidance on the implementation of ESM allowed reference systems.

### 7.4.7 Units of measure

The units of measure shall be implied by the specified coordinate reference system. User-defined reference systems are not allowed by this profile, and therefore a specific declaration of the horizontal or vertical units of measure is not required. The unit of measure for the UTM/UPS system is meters. The unit of measure for the WGS84 (geographic) horizontal reference system shall be expressed as decimal degrees. The vertical unit of measure for WGS84 is also meters, and meters shall be implied as the unit of measure when hydrographic datums are used.

### 7.4.8 Processing history

Information describing the processing that has been applied to the data shall be documented using the lineage metadata elements. This shall include information about the source, the method of data capture, and any information on the transformation, conversion, or resampling that has been applied to the data.

### 7.4.9 Data Maintenance

Information describing the approach, currency and history of maintenance is to be documented in the metadata. Maintenance of datasets is not mandatory, but it shall be clear from the metadata whether a dataset is maintained or is static.

### 7.4.10 Dataset Identifiers

A system for assigning permanent unique identifiers to each and every dataset, data subset, and metadata file is essential for the successful application of this standardized profile. This can be accomplished by using a concatenation of identifiers in which each identifier is unique within a specified scope. The largest scope specified by this profile is the organization that produces, maintains, or distributes elevation surface data. Within the scope of an organization, the following rules shall be applied.

- A persistent elevation collection shall be assigned an identifier that is unique within the scope of the organization that maintains the collection. A transient collection, such as a transmittal, need not be assigned a permanent identifier.
- A fundamental dataset shall be assigned an identifier that is unique within the scope of the organization that produced it.
- A tile or sub-group within a fundamental dataset shall be assigned an identifier that is unique within the scope of that fundamental dataset.
- A metadata file shall be assigned an identifier that is unique within the scope of the organization that produced it

# 8 Reference Systems

## 8.1 Types of referencing

Position relative to the earth is described in terms of a coordinate reference system. Three-dimensional geospatial data positions are usually referenced to a compound coordinate reference system (ISO 19111) composed of a 2-dimensional horizontal reference system (8.2) and a one-dimensional vertical reference system (8.3). For high-resolution elevation data, the realization epoch (date of observation recorded as temporal extents) is also required, to account for the movement of positions on the Earth over time.

## 8.2 Horizontal reference systems

### 8.2.1 Introduction

Horizontal positions of elevation points shall be directly or indirectly referenced to the World Geodetic System 1984 (WGS84) [DMA TR 8350.2]. Horizontal referencing of points in a grid is a special case (8.2.4).

### 8.2.2 Direct referencing

For direct referencing, horizontal positions of points included in TIN coverages, point coverages, and point sets shall be expressed as WGS84 latitude and longitude.

### 8.2.3 Indirect referencing

For indirect referencing, horizontal positions of points included in TIN coverages, point coverages, and point sets shall be expressed as Northing and Easting in the Universal Transverse Mercator (UTM) or Universal Polar Stereographic (UPS) Grid Systems [NIMA TM 8358.2] based on the WGS84 datum and ellipsoid. The unit of measure for both UTM and UPS is meters.

### 8.2.4 Grid referencing

#### 8.2.4.1 Introduction

The points in a grid are referenced to an internal grid coordinate system. The internal coordinate reference system for a rectified grid is specified by an origin (6.7.5) and two offset vectors (6.7.6) that are specified in terms of an external coordinate reference system. This standard permits referencing of grids to two external coordinate reference systems. A grid coordinate system may be directly referenced to WGS84 coordinates, or it may be referenced to a UTM Grid based on the WGS84 datum.

NOTE A rectified grid is specified with respect to a particular external coordinate reference system. Representation in any other coordinate reference system will distort the shape of a cell and the parallelism of its sides.

#### 8.2.4.2 Grid coordinates referenced to WGS84 coordinates

The position of the origin of a grid referenced to WGS84 coordinates shall be specified as WGS84 latitude and longitude. The offset vectors that describe the grid shall be parallel to the meridians and parallels of the WGS84 coordinate system, and their ordinates shall be specified in terms of arc seconds angular measure.

#### 8.2.4.3 Grid coordinates referenced to the UTM Grid

The position of the origin of a grid referenced to the UTM Grid System shall be specified as UTM Northing and Easting in meters. Ordinates of the offset vectors that describe the grid shall be expressed in meters. The reference origin for UTM datasets will be the origin of the UTM zone in which the data is located. UTM zone origins are specified by the intersection of the UTM zone central meridian with the equator. This intersection is assigned the UTM coordinates 500000.0 E, 0.0 N for zones in the northern hemisphere and coordinates 500000.0 E, 10000000.0 N for zones in the southern hemisphere. If the point spacing of a given dataset is specified as {ΔE, ΔN}, then points in the Northern hemisphere will be defined at {500000± i*ΔE, 0+ j*ΔN}. The values i and j are integer values of points in the Easting and Northing direction (respectively), +i*ΔE signifies an easterly direction from the central meridian, -i*ΔE signifies a westerly direction from the central meridian, and +j*ΔN signifies a northerly direction from the equator. In a similar fashion, points in the Southern hemisphere are specified by {500000± i*ΔE, 10000000- j*ΔN}, where i and j are integer values of points in the Easting and Northing direction (respectively),+i*ΔE signifies an easterly direction from the central meridian, -i*ΔE signifies a westerly direction from of the central meridian, and -j*ΔN signifies a southerly direction from the equator [NOTE: for gridded data, the points are stored in row/column order]. Adhering to this system will assure that coincident points are maintained across the various levels of horizontal resolution within a zone. This will allow for direct comparison between datasets and direct decimation of higher-resolution data to lower resolutions. Figure 11 shows an example of UTM Point Locations in Northern Hemisphere.

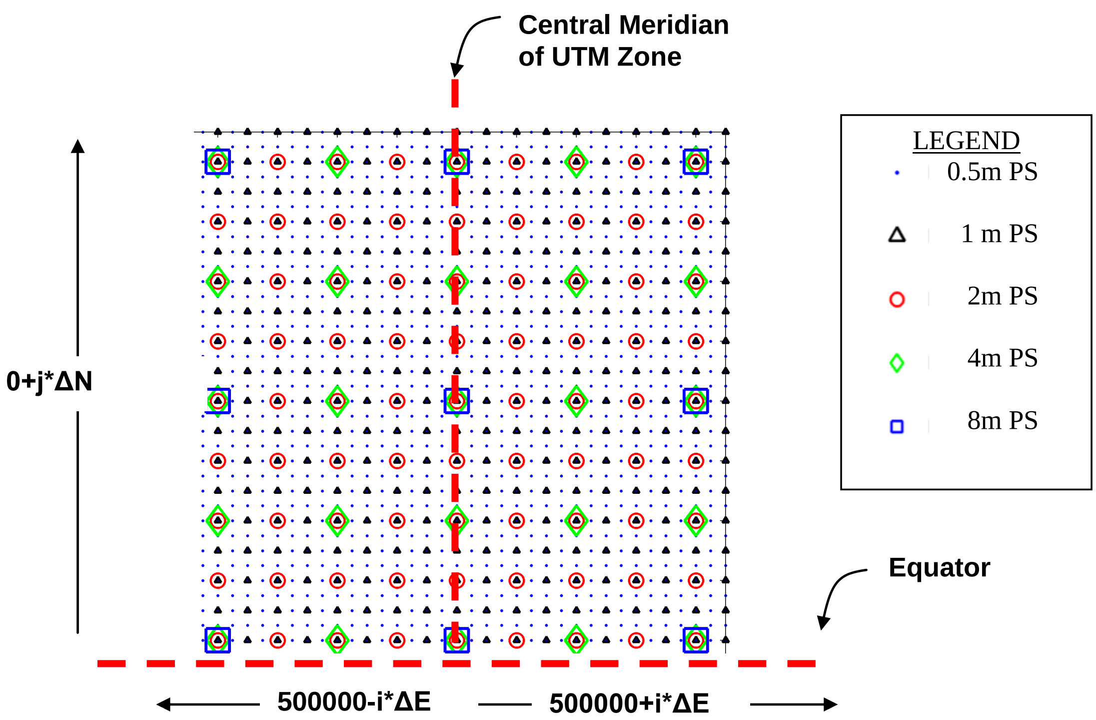



**Figure 11 - Example of UTM Point Location In Northern Hemisphere**

(Note that the various symbols represent different resolution levels, but illustrate collocated points)

## 8.3 Vertical reference systems

A vertical reference system consists of a surface identified as a datum from which heights are measured and an axis normal to the surface through the point for which the height is stated. The WGS84 ellipsoid, which is the fundamental datum used by the Global Positioning System, is preferred as the common datum for all elevation surface data. However, reference to a geoid is often more useful for terrestrial applications. Since water depths vary with the tides, bathymetric data is normally referenced to a datum defined in terms of tide state.

This profile permits the use of any of the following vertical datums:

(1) The WGS84 ellipsoid [DMA TR 8350.2]

(2) The geoid defined by the WGS84 Earth Gravity Field Model (EGM). The specific model (e.g. EGM2008) shall be specified in the metadata.

(3) A sounding datum or hydrographic datum, which is a vertical datum based on a selected tide level related to Mean Sea Level (MSL). The specific tidal datum used depends on the type of tide in the area or on the number and magnitude of high and low tides in one tidal cycle.

In this standard the default is the WGS84 ellipsoid, and when used, the hydrographic datum must be explicitly referenced in the metadata. User-defined vertical datums are prohibited by this profile.

# 9 Spatial Resolution

Spatial resolution is a significant attribute in determining the appropriate usage of an elevation dataset, and standardization of the resolutions within a product line will therefore enhance discoverability. A product specification for gridded data will typically specify the post spacing for the product 'levels'. Elevation datasets with horizontal spatial resolution of 12 meters (.4 arc seconds of longitude at the equator) or higher are defined as high-resolution data by this profile. Five levels of horizontal point spacing are suggested here for high-resolution, projected data (cf. Table 2). The high-resolution levels are given in terms of nominal metric spacings for gridded data referenced to UTM coordinates, as this referencing is recommended for high-resolution data (see Section 8.2.4.3).

**Table 2 - Elevation Grid Resolution Levels for Projected Data (Informative)**

| Level | Horizontal Grid spatial resolution | Horizontal Units |
|---|---|---|
| 1 | 8 | meters |
| 2 | 4 | meters |
| 3 | 2 | meters |
| 4 | 1 | meters |
| 5 | 0.50 | meters |

Point spacing has always been the measure for the spatial resolution of regularly gridded elevation data, and grids with spacings within ±25% of a nominal value for spacing are considered to be at the same level of resolution. While this profile does not require the use of specific levels of horizontal resolution, it is recommended that gridded datasets have a spacing that is consistent with the dataset's vertical accuracy, and also with the type of terrain being modeled. For flat and undulating terrain, a spacing that is between 3 and 20 times the vertical root mean square error ($RSME_v$) is recommended. For complex terrain, a spacing between 3 and 10 times $RSME_v$ is appropriate. Standard deviation based on terrain relief is also useful in determining an appropriate post spacing.

Grids referenced to WGS84 geodetic coordinates (8.2.4.2) are a special case. Because the grid is not projected to a 2D surface, these spacings must be specified in terms of angular measure: arc seconds of latitude and longitude. The linear measure of a second of longitude varies with the latitude, and five latitudinal bands are defined here (Table ) so that the linear spacing between points is roughly equivalent at all latitudes. NATO STANAG 3809 (DTED) defines standard grid spacings at two levels of resolution.This standard extends the definition of standard spacings to cover 2 additional levels for unprojected data. Note that Levels 3 and 4 fall into the ESM categorization of high-resolution data. Grid spacings specified in terms of latitude and longitude are generally not recommended for high-resolution data, but they are appropriate for grids that extend across zone boundaries of the UTM Grid.

**Table 3 - Elevation Grid Resolution Levels for Data Referenced to WGS84 Geographic Coordinates (Informative)**

| Band | Latitude (N/S) | Level 1<br>Lat x Lon | Level 2<br>Lat x Lon | Level 3<br>Lat x Lon | Level 4<br>Lat x Lon |
|---|---|---|---|---|---|
| 1 | 0° - 50° | 3” x 3” | 1” x 1” | 0.4” x 0.4” | 0.1” x 0.1” |
| 2 | 50° - 70° | 3” x 6” | 1” x 2” | 0.4” x 0.8” | 0.1” x 0.2” |
| 3 | 70° - 75° | 3” x 9” | 1” x 3” | 0.4” x 1.2” | 0.1” x 0.3” |
| 4 | 75° - 80° | 3” x 12” | 1” x 4” | 0.4” x 1.6” | 0.1” x 0.4” |
| 5 | 80° - 90° | 3” x 18” | 1” x 6” | 0.4” x 2.4” | 0.1” x 0.6” |

Again these levels are merely suggestions for storage and usage at standardized resolution levels. An elevation database service can be designed to output datasets at any user-specified spatial resolution or projection. For example, a user may want elevation data for a geographic area at multiple resolutions and referenced to the ARC projection system so that the data will align with coinciding raster maps of various scales. DGIWG follows NATO policy for categorization of digital geospatial data by equivalence to paper map scales, as provided in Table 4.

**Table 4 - NATO Resolution Levels for Geospatial Information**

| Level | Paper Map Equivalent Scales (S) | Imagery Resolution (I) | Matrix Resolution (M) |
|---|---|---|---|
| 0 | S ≤ 1:1,000,000 | Not used | M > 100 meters (m) |
| 1 | 1:1,000,000 < S ≤ 1:250,000 | I ≥ 10 meters (m) | 100m ≥ M > 30m |
| 2 | 1:250,000 < S ≤ 1:50,000 | 10m > I ≥ 5m | 30m ≥ M > 10m |
| 3 | 1:50,000 < S ≤ 1:25,000 | 5m > I ≥ 2.5m | 10m ≥ M > 5m |
| 4 | 1:25,000 < S ≤ 1:5,000 | Metric resolution | 5m ≥ M > 1m |
| 5 | S > 1:5,000 | Submetric resolution | 1m resolution or better |

In the case of TIN or point set data, there is no regularity about point spacing, so spacing alone cannot be used as a measure of resolution. Point density (points/$km^2$) is used as a more general measure of spatial resolution for TINs and point sets.

# 10 Considerations for Dense Datasets

High resolution elevation datasets for extensive areas may be extremely large. Approaches to mitigating this problem include variable grid cell sizes, data compaction, and data compression. Differential collection and data compaction introduce or increase the variability of point density, which may require special handling, especially in the case of gridded data.

## 10.1 Data compaction

Data compaction is the reduction of the number of data elements, bandwidth, cost, and time for the generation, transmission, and storage of data without loss of information by eliminating unnecessary redundancy, removing irrelevancy, or using special coding. Data compaction reduces the amount of data used to represent a given amount of information.

The most common form of data compaction applied to elevation data is the removal of unnecessary points. In the case of gridded data, these may be points for which no elevation value is available. Otherwise, the assumption is that a point may be deleted if an appropriate interpolation method may be used to determine its elevation value(s) with sufficient accuracy.

The fundamental issue is the determination of what is “sufficient accuracy.” It is clear that the absolute accuracy of the dataset is not an appropriate measure. Relative vertical accuracy, which is a measure of the accuracy with which the elevation difference between two points can be determined, is a better measure. Even the value of relative vertical accuracy as a threshold depends, however, upon the way in which that accuracy is specified. Relative vertical accuracy has been most commonly expressed as the accuracy of the difference between any pair of points in a dataset.

Relative accuracy is affected by a number of factors including sensor, atmospheric, and terrain characteristics. In general, it can be said that relative accuracy decreases with increasing distance between points. Since the deletion of a point depends upon differences between it and its nearest neighbours, the accuracy threshold for deletion should be a measure of local relative accuracy. The appropriate value may also be a function of the intended use for the data. If data has been compacted, the accuracy threshold used in deciding to delete points from the dataset shall be specified in the associated metadata.

Deleting points from a point set or a point coverage has no impact on the data structure. If, however, data compaction results in significant differences in spatial resolution between areas within the extent of the point set or point coverage, the dataset should be tiled and the differences documented in the metadata associated with the tiles.

In the case of a TIN, deleting a point requires reconstruction of the triangulated network in its vicinity. A better approach may be to select a set of critical points – those at points of significant surface inflection, construct a TIN, and then reinsert the deleted points as necessary to improve accuracy.

In the case of an elevation grid coverage, deletion of points makes it impossible to apply the sequence rule to the elevation values. There are two possible solutions

One approach is to apply a tiling scheme to divide the extent into areas with different point densities. Generally, tile size is selected first (probably on the basis of some set of terrain characteristics), then candidate tiles are selected on the basis of relief within the tiles. Subsetting of the points in a tile is done by decimation, followed by further decimation until the accuracy of interpolation at the deleted points falls below the acceptable threshold. Often establishing an optimal data compaction is not possible using tiling because of the producer's desire to have a common tiling scheme over an entire data product.

Another approach is to include in the *values* Record for each non-deleted point an index to its position within the grid. The index for Morton ordering (C.2), which is generated by interleaving the bits of the binary grid coordinates, is appropriate for this purpose. Retaining the sequence rule supports efficient access to the point Records, although it is not strictly necessary. If the grid can be decomposed into a quad tree (C.1), the subsetting would be by aggregation of adjacent cells for any quad for which the interpolated accuracies are below the threshold.

Since a TIN may represent a surface more accurately than a grid with the same point density, it may be possible to compact an elevation grid by converting it to a TIN. This may also be true for a point set or point coverage, depending upon how the points are distributed within the extent of the dataset.

## 10.2 Data compression

Data compression reduces the amount of storage space required to store a given amount of data, or reducing the length of message required to transfer a given amount of information. Data compression does not reduce the amount of data used to represent a given amount of information, whereas data compaction does. In other words, data compression does not affect the number of elevation points in a dataset; instead, it reduces the number of bits required to record or transmit the data. Because of this, data compression is treated as an aspect of encoding.

Selection of an appropriate algorithm for data compression depends upon the type of data structure. For example, it is not expected that the JPEG algorithm will work well for a TIN because TIN data is not organized like an image.

Compression is of two types, lossy and lossless. Lossy compression discards information which may be considered unimportant in certain applications. JPEG 2000 (ISO/IEC 15444) has a lossless mode that is usable for the compression of gridded elevation data. It is not strictly necessary for a compression algorithm that is used for elevation data to be lossless, but a lossy algorithm shall not be used unless an evaluation of its impact on data accuracy is included in the associated metadata.

Another advantage of JPEG 2000 compression is JPIP (JPEG 2000 Interactive Protocol). JPIP is a compression streamlining protocol that allows data transfer over a network using the least bandwidth required. JPIP has the capacity to download only the requested part of a dataset, saving bandwidth, computer processing on both ends, and time.

Applying a compression algorithm to already compressed data often results in an expansion of the volume of data, especially if the first stage of compression was efficient. However compression can be applied to data that has been reduced by data compaction because the information content of the original data remains. This is especially true of tiling schemes that do not reorganise the data structure.

## 10.3 Tiling

Tessellation (4.1.37) is the conterminous partitioning of a space, and the tiling of a dataset is a regular tessellation (congruent polygons). Tiling is one method of reducing the volume of data in a dataset to manageable proportions. It may be used to organize coverage data of both discrete and continuous types. Within a data warehouse (database) there may be several overlapping tiling schemes defined where any of the tiling schemes may be used as the basis of data extraction from the data warehouse.

A tiling scheme is itself a discrete coverage where the coverage elements are subsets of a dataset. The tiles are the value items of the discrete coverage.

The scheme normally consists of a simple rectangular grid with tiles of equal density. Such a grid coverage may also be defined with tiles of variable density (quad tree). A more complex tiling scheme may also be defined as a discrete polygon coverage. An example polygon tiling scheme is a data collection consisting of elevation cut along political boundaries. These examples types of tiling schemes are illustrated in Figure 13. Other tiling schemes are also possible. In fact, any type of discrete coverage may be used to establish a tiling scheme. A tiling scheme may be defined for an elevation collection of more than one encoded dataset (10.3.2), or within a fundamental dataset of any type. Variable density tiles and irregular polygonal tiles are not supportable internal to a gridded format file. Variable densities can be addressed by separating the data into different encoding files and address them individually with metadata.

NOTE The tiling schemes discussed in this subclause are those applied to a dataset prior to encoding. The encoding process may introduce a different tiling scheme as described in the specification for the encoding format.

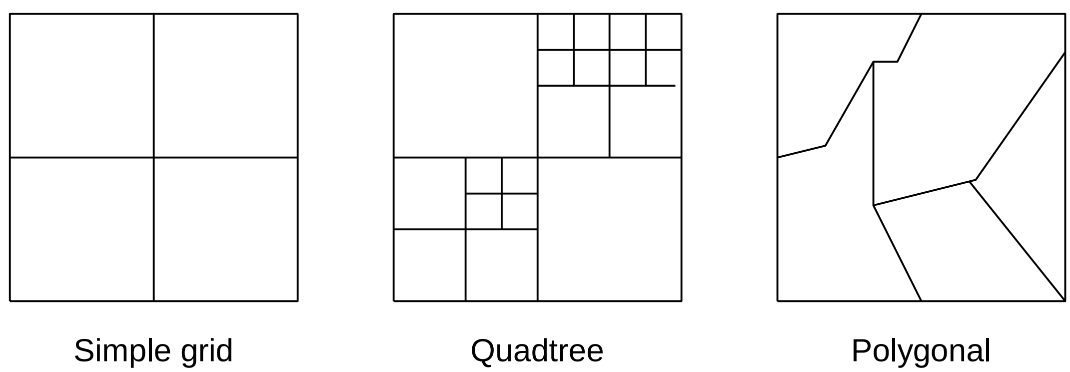



**Figure 13 - Tiling Schemes**

The most common tiling scheme is a simple rectangular grid. The scheme shall be described in the same way as an elevation grid, using two axis names, an origin, and two offset vectors. Individual tiles shall be identified by a pair of integers representing the position of the tile relative to the origin in the direction of each axis. When the tiling scheme is applied to a single elevation grid coverage, the axis names and orientations shall be the same as those of the elevation grid.

Alternatively, a tiling scheme may be structured as a quad tree. The area to be tiled is progressively divided into quadrants with the progression carried further in some areas than others. Individual tiles shall be identified by a pair of integers, where the first identifies the level of subdivision (1 representing the undivided area) and the second identifies the position of the tile within the last quadrant to be divided (Figure 14).

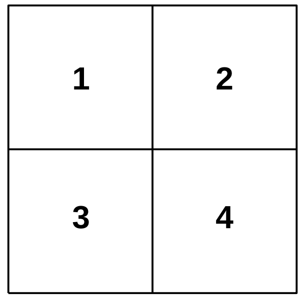



**Figure 14 - Quadrant Numbering**

A more complex tiling scheme may be defined as a set of polygons. This method may be useful when it is necessary to separate areas within the dataset according to unique surface types (e.g. land vs. water). Each polygon shall be assigned an identifier unique within the dataset. The polygon boundaries shall be defined in the metadata as ordered lists of vertices.

### 10.3.1 Effects of variable density tiling

#### 10.3.1.1 Introduction

Variable density tiling schemes introduce two issues. The first is the selection of an appropriate tile size; the second is the aliasing effect that results from variation in density across tile boundaries.

#### 10.3.1.2 Tile size

Using the same tile size is practical only over a small range of tile densities or the amount of data in the more dense tiles becomes unmanageable. Reducing the tile size may result in little or no data content in some of the tiles. A potential solution is to vary the tile size using a quad tree approach.

#### 10.3.1.3 Aliasing

An elevation coverage function uses interpolation to return a value at any point over the area of the coverage. These interpolation surfaces are different for different coverage types. An interpolation surface can be decomposed into 2-dimensional spatial frequencies. In general, the variation of elevation will correspond to low spatial frequencies with a few higher frequency components. A tiling scheme will introduce discontinuities at specific spatial frequencies. A quad tree and a TIN better approximate the natural distribution of the spatial frequencies and therefore provide better fits to the data.

Elevation values at tile boundaries are neighbours to the elevation values in the adjacent tile. Values are not repeated. Two tiles of the same density can be easily fused horizontally to form one larger extent. This is shown in Figure 15.

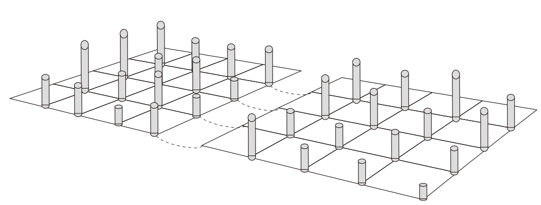


**Figure 15 - Shared Values at Tile Edges.**

Cells at the boundary of tiles may be coincident with cells of different resolution. In this case where two tiles are of different densities, there is a discontinuity at the tile boundary (Figure 16). One must consider the cells as data samples at a varying-sampling rate. There will be a need to conflate the surfaces using rules based on accuracy of the surfaces. This must be accommodated by a smoothing function in the software processing the elevation data.

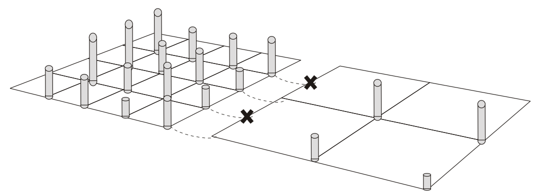


**Figure 16 - Discontinuity at Tile Edge.**

### 10.3.2 Collection tiling schemes

Most gridded data encoding formats support a tiling structure that addresses the sequence and interleave of values within an array of values. Each tile within the tiling scheme is a subset grid, and the tiling scheme itself is essentially a second grid that is superimposed on the first grid, These ‘format tiles’ or ‘blocks’ are internal to the encoded file and are distinguished from ESM collection tiles, which are independent of the encoding.

An ESM collection tiling scheme may be applied to a collection of multiple datasets (coverages or point sets as files in an encoding format). Only one tiling scheme may be defined for a particular collection. The collection tiling scheme is defined after the datasets are encoded into format files. The geographic extents of the ESM collection tiles and the encoded files may be identical (one to one), or a collection tile may comprise multiple encoding files (one to many). In either case, it is not necessary for the entire geographic extents of the tiling scheme to be completely covered by encoded files. ESM collection tiles may represent areas for future production or may include areas where no data is available.

Although it can be described as a coverage itself (Figure 12), the collection tiling scheme is not implemented as part of the geometry of the ESM collection. Instead, the description of the collection tiling scheme shall be documented separately and referenced by the metadata associated with the ESM_Collection resource. The metadata references the tiling scheme documentation by name. The documentation shall include an illustration of the tiling scheme and the accompanying text shall include the dimensions, location and data density of tiles as well as the tile identification mechanism. The tiles shall cover the entire extent of the collection and shall be referenced to the same horizontal coordinate reference system as the collection’s component datasets. Tiles shall not overlap or leave gaps within continuous datasets. When the content of the tiles in the scheme is not homogeneous, a description of how the content differs must be provided.

In the metadata associated with each component dataset in the tiled collection, identification of the tile that contains the dataset is required.

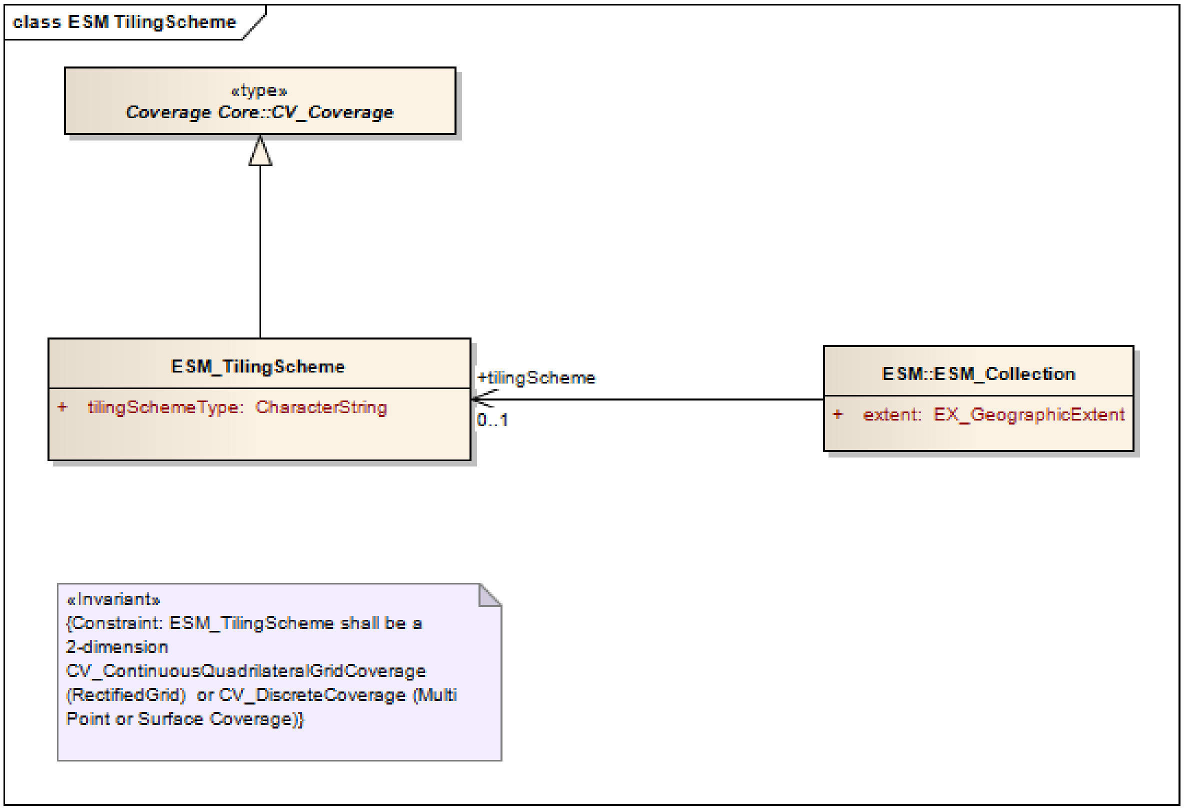



**Figure 12 – ESM Tiling (Informative)**

# 11 Encoding Options

Most data exchange standards are defined in terms of their encoding format, and it is necessary to work backwards to identify the common information elements that describe the underlying data. Often, information about the structure of the format itself dominates. The approach taken in this profile is to separate the information carrier (encoding format specification) design from the content description (ESM abstract content model) design. This approach allows for several different encodings to be used with the same data. Efficient binary encodings are required for the higher density elevation data. There are several efficient encoding formats, in both the public and commercial domains, for holding large volumes of grid cell and TIN data. Because grids and TINs are convertible, several encoding options are available.

To promote compatible data interchange it is desirable to have a common neutral encoding format, even if that format is not optimal for the elevation value file. Among the encoding formats currently in use for storage and exchange of elevation values, none are inherently capable of carrying all of the geographic metadata required by this profile (Annex E). Therefore, a separate metadata encoding is required to describe the elevation dataset. The metadata encoding shall be in conformance with ISO 19139 XML schema, and any exchange of elevation data within and among DGIWG member nations shall include the XML metadata file(s) as part of the transmittal. For the encoding of ESM_GridCoverage data, the prevailing formats are the NITF/NSIF profiles of BIIF, GeoTIFF, DTED (for medium and low resolution data), and HDF5. There are two options for providing the ESM required metadata for grid coverages:

- XML metadata embedded in the encoding format (e.g. JPEG 2000, GMLJP2, GeoTIFF with XML embedded in a private tag)
- Two separate encodings, one for the elevation values and the other for the corresponding metadata: for example, an elevation data file encoded in JPEG 2000 (*filename.jp2)* and an XML metadata file of the same name (*filename.xml*)

For the encoding of ESM_TINCoverage or ESM_PointCoverage data. GML provides the ability to include the associated ISO-compliant metadata. Other encodings may be used for the data when an XML file with the same name carries the metadata.

# Annex A
Abstract Test Suites
(normative)

## A.1 Coverage Type Tests

### A.1.1 Continuous Quadrilateral Grid Coverage Test Case

1) Test Purpose: Verify that an application schema instantiates the classes defined in ISO 19123 of CV_Grid, CV_GridPoint, CV_GridCell, CV_GridValuesMatrix, CV_GridPointValuePair, CV_DiscreteGridPointCoverage, or CV_ContinuousGridCoverage, and CV_GridValueCell with their specified attributes, operations, associations and constraints, in the context of the classes ESM_GridCoverage, ESM_Grid and ESM_GridValues as defined in this profile

2) Test Method: Inspect the documentation of the application schema or profile.

3) Reference: ISO 19123, Section 8

4) Test Type: Capability.

### A.1.2 TIN Coverage Test Case

1) Test Purpose: Verify that an application schema for TIN Coverage instantiates the classes defined in ISO 19123 of CV_TINCoverage, CV_ValueTriangle, and CV_PointValuePair with their specified attributes, operations, associations and constraints, in the context of the classes ESM_TINCoverage, and ESM_Triangle as defined in this standard.

2) Test Method: Inspect the documentation of the application schema or profile.

3) Reference: ISO 19123

4) Test Type: Capability.

### A.1.3 Point Coverage Test Case

1) Test Purpose: Verify that an application schema for Point Coverage instantiates the classes defined in ISO 19123 of CV_DiscretePointCoverage, and CV_PointValuePair, with their specified attributes, operations, associations and constraints, in the context of the classes ESM_PointCoverage and ESM_Point as defined in this standard.

2) Test Method: Inspect the documentation of the application schema or profile.

3) Reference: ISO 19123

4) Test Type: Capability.

### A.1.4 Point Set Test Case

1) Test Purpose: Verify that an application schema for Point Set instantiates the classes defined in ISO 19107 of GM_Point, with its specified attributes, operations, associations and constraints, in the context of the class ESM_PointCoverage as defined in this standard.

2) Test Method: Inspect the documentation of the application schema or profile.

3) Reference: ISO 19107

4) Test Type: Capability.

### A.1.5 Variable Cell Size Grid Test Case

1) Test Purpose: Verify that an application schema for Variable Cell Size instantiates the classes defined in ISO 19123 of CV_Grid, CV_GridPoint, CV_GridCell, CV_GridValuesMatrix, CV_GridPointValuePair, CV_DiscreteGridPointCoverage, or CV_ContinuousGridCoverage, and CV_GridValueCell with their specified attributes, operations, associations and constraints, with the CV_ContinuousCoverage CV_InterpolationMethod attribute set to NearestNeighbour and the CV_GridValuesMatrix CV_SequenceRule attribute set to (x,y) Morton.

2) Test Method: Inspect the documentation of the application schema or profile.

3) Reference: ISO 19123

4) Test Type: Capability.

## A.2 Metadata Test Suite

The ESM Metadata Specification (Annex E) is a profile of the DGIWG Metadata Foundation (DMF). Mandatory elements listed in Table E.1 comprise the minimum metadata requirement for ESM datasets. Software applications capable of producing, ingesting, using and managing ESM metadata shall be measured for compliance using the test cases describe in this section as they are applied to one of the various metadata element requirements classes defined by the DMF;

- DMF/Core defines the minimum set of metadata elements to be implemented. This set satisfies the requirements for discovery.
- DMF/Common is an additional set of metadata elements for a more complete description of any type of resources supported by DMF. It extends DMF/Core and covers discovery and basic evaluation requirements.
- DMF/Services extends DMF/Core for service metadata and can be used in conjunction with DMF/Common.
- DMF/Data extends DMF/Common for data related resources (i.e. dataset, series and tile). DMF/Data adds metadata elements for evaluation and use.
- DMF/Data+ extends DMF/Data for the implementation of coverage quality results and other metadata elements introduced in ISO 19115-2 but having some applications for any geospatial products.
- A DMF/Imagery requirement class extending DMF/Data for imagery is foreseen but is not yet defined.
- DMF/NATO extends DMF/Common for NATO and more generally military oriented needs (extensions defined in NGMP, particularly security). It is needed to handle metadata to be exchange with NATO in conformance with NGMP. DMF/NATO can be implemented with DMF/Core and possibly any other requirement class.
- DMF/Specific is an extension of the ISO metadata standards for high level military implementation of the DMF metadata elements.

### A.2.1 Metadata Completeness Test Case

a) Test Purpose: to determine conformance by the inclusion of all metadata sections, metadata entities, and metadata elements that are specified with an obligation of "mandatory" or mandatory under the conditions specified.

NOTE Many elements designated as mandatory are contained within optional entities. These elements become mandatory only when their containing entity is used.

b) Test Method: a comparison between this International Standard and a subject metadata set to be tested shall be performed to determine if all metadata defined as mandatory in Annex E are present. A comparison test shall also be performed to determine if all metadata elements defined as conditional in Annex E are present if the conditions set out in this International Standard apply.

c) Reference: Annex E.

d) Test Type: Basic.

*The following test cases apply at all levels of obligation – mandatory, conditional, and optional.*

### A.2.2 Maximum occurrence Test Case

a) Test Purpose: to ensure each metadata element occurs no more than the number of times specified in this profile.

b) Test Method: examine a subject metadata set for the number of occurrences of each metadata section, metadata entity, and metadata element provided. The number of occurrences for each shall be compared with its "Max Occur" attribute specified in Annex E.

c) Reference: Annex E.

d) Test Type: Basic.

### A.2.3 Data type Test Case

a) Test Purpose: to determine if each metadata element within a subject metadata set uses the specified data type.

b) Test Method: the value of each provided metadata element is tested to ensure its data type adheres to the data type specified.

c) Reference: DMF.

d) Test Type: Basic.

### A.2.4 Domain Test Case

a) Test Purpose: to determine if each provided metadata element within a subject metadata set falls within the specified domain.

b) Test Method: the values of each metadata element are tested to ensure they fall within the specified domain.

c) Reference: Annex E.

d) Test Type: Basic.

### A.2.5 Schema Test Case

a) Test Purpose: to determine if a subject metadata set follows the application schema based on this profile.

b) Test Method: ensure that all required information content specified by this profile is contained within an elevation dataset.

c) Reference: Annex E and ESM application schema or profile.

d) Test Type: Basic.

### A.2.6 Tiling Scheme Test Case

a) Test Purpose: to determine if the tiling scheme is referenced by the metadata and the data set is properly indexed into the tiling scheme.

b) Test Method: ensure that the referenced tiling scheme documentation includes the dimensions, location and data density of tiles. Ensure that the tile identification in the metadata of each dataset in the collection corresponds to the tile identification mechanism in the tiling scheme documentation.

c) Reference: Section 10.3 and IHO S-100 Part 8

d) Test Type: Basic

## A.3 User-defined Extension Metadata Test Suite

### A.3.1 Exclusiveness Test Case

a) Test Purpose: to verify that each user-defined metadata section, metadata entity, and metadata element is unique and not already defined in the ESM Profile or DMF.

b) Test Method: each user-defined metadata entity and metadata element is tested to ensure it is unique and not previously used.

c) Reference: ESM Annex E; DMF

d) Test Type: Basic.

### A.3.2 Definition Test Case

a) Test Purpose: to verify that user-defined metadata entities and metadata elements have been defined as specified by DMF Annex C.

b) Test Method: each user-defined metadata entity and metadata element is tested to ensure that all attributes have been defined.

c) Reference: DMF Annex C.

d) Test Type: Basic.

### A.3.3 Metadata Requirement Class Test Case

a) Test Purpose: to verify that user-defined metadata within a subject metadata can be assigned to a DMF Requirement Class.

b) Test Method: all user-defined metadata in a subject metadata set is tested in accordance with DMF.

c) Reference: DMF.

d) Test Type: Basic.

## A.4 Metadata Profiles

### A.4.1 Metadata Profiles Test Case

a) Test Purpose: to verify that a candidate profile of the DMF follows the rules for profiling defined by the DMF.

b) Test Method: apply rules for profiles defined by DMF to the candidate profile

c) Reference: DMF Annex B

d) Test Type: Basic.

# Annex B
UML Notation

## B.1 UML notations

The diagrams that appear in section 6 of this profile are presented using the Unified Modelling Language (UML) static structure diagram with the ISO Interface Definition Language (IDL) basic type definitions and the UML Object Constraint Language (OCL) as the conceptual schema language. Information content is presented in UML Packages. Each package contains one entity (a UML Class), which can be specified (subclassed) or generalized (superclassed). These entities contain elements (UML class attributes) which identify the discrete units of information. Entities may be related to one or more other entities.

## B.2 UML model relationships

### B.2.1 Associations

The UML association types used in this International Standard are described in Figure B.1.
An association is used to describe a relationship between two or more classes. UML defines three different types of relationships, called association, aggregation and composition. The three types have different semantics. An ordinary association shall be used to represent a general relationship between two classes. The aggregation and composition associations shall be used to create part-whole relationships between two classes. The direction of an association must be specified. If the direction is not specified, it is assumed to be a two-way association. If one-way associations are intended, the direction of the association can be marked by an arrow at the end of the line.

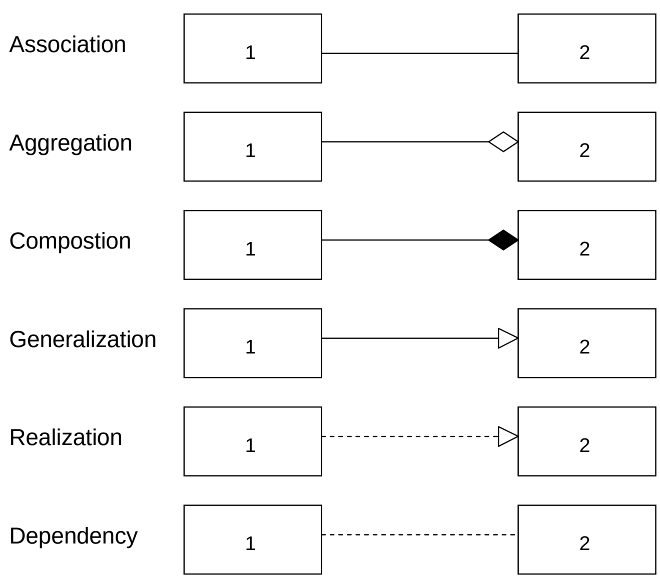



**Figure B.1 – UML Associations**

### B.2.2 Aggregation

An aggregation association is a relationship between two classes, in which one of the classes plays the role of container and the other plays the role of a containee. The open diamond-shaped aggregation symbol in Figure B.1 shows that the class 2 object is an aggregation of one or more class 1 objects. The aggregation association should be used when the containee objects (class 1), can exist without the container object (class 2). Aggregation is a symbolic short-form for the part-of association but does not have explicit semantics. It allows multiple aggregations to share the same objects. If stronger aggregation semantics are required, composition should be used as described below. It is possible also to define role name and multiplicity at the diamond shaped end as well.

### B.2.3 Composition

A composition association is a strong aggregation. In a composition association, if a container object is deleted then all of its containee objects are deleted as well. The composition association should be used when the objects representing the parts of a container object cannot exist without the container object. Figure B.1 shows a composition association, in which the diamond shaped composition symbol has a solid fill. Here the class 2 object consist of one or more class 1 objects, and the class 1 objects cannot exist unless the class 2 object also exists. The required (implied) cardinality for the owner class is always one. The containers, or parts, cannot be shared among multiple owners.

### B.2.4 Generalization

A generalization is a relationship between a superclass and the subclasses that may be substituted for it. The superclass is the generalized class, while the subclasses are specified classes

### B.2.5 Realization

A realization is a specialized abstraction relationship between two classes, one representing a specification (the supplier) and the other represents an implementation of the latter (the client). The meaning is that the client element must support all the behaviour the supplier element but need not to match its structure or implementation. In Figure B.1, the dashed line with triangular end indicates that the class 2 object is realized by the class 1 object.

### B.2.6 Instantiation / Dependency

A dependency relationship shows that the client class depends on the supplier class/interface to provide certain services, such as:

- Client class accesses a value (constant or variable) defined in the supplier class/interface;
- Operations of the client class invoke operations of the supplier class/interface;
- Operations of the client class have signatures whose return class or arguments are instances of the supplier class/interface.

An instantiated relationship represents the act of substituting actual values for the parameters of a parameterized class or parameterized class utility to create a specialized version of the more general item.

### B.2.7 Roles

If an association is navigable in a particular direction, the model shall supply a “role name” that is appropriate for the role of the target object in relation to the source object. Thus in a two-way association, two role names will be supplied. Figure B.2 represents how role names and cardinalities are expressed in UML diagrams.

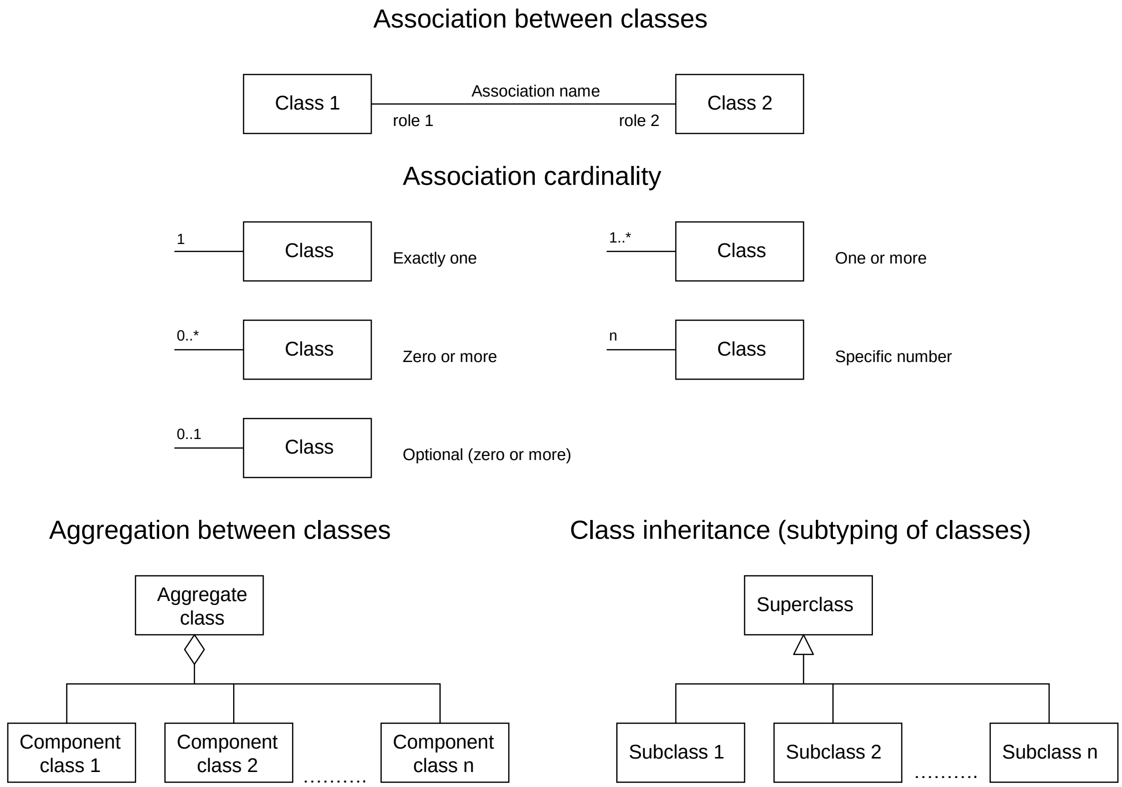



**Figure B.2 – UML Class Relationships**

## B.3 UML model stereotypes

A UML stereotype is an extension mechanism for existing UML concepts. It is a model element that is used to classify (or mark) other UML elements so that they in some respect behave as if they were instances of new virtual or pseudo metamodel classes whose form is based on existing base metamodel classes. Stereotypes augment the classification mechanisms on the basis of the built-in UML metamodel class hierarchy. Below are brief descriptions of the stereotypes used in this document.

In this document the following stereotypes are used:

a. <<Type>> class used for specification of a domain of instances (objects), together with the operations applicable to the objects. A type may have attributes and associations.

b. <<Enumeration>> data type whose instances form a list of named literal values. Both the enumeration name and its literal values are declared. Enumeration means a short list of well-understood potential values within a class.

c. <<DataType>> a descriptor of a set of values that lack identity and whose operations do not have side effects. Datatypes include primitive pre-defined types and user-definable types. Pre-defined types include numbers, string, and time. User-definable types include enumerations.

d. <<CodeList>> used to describe a more open enumeration. <<CodeList>> is a flexible enumeration. Code lists are useful for expressing a long list of potential values. If the elements of the list are completely known, an enumeration should be used; if the only likely values of the elements are known, a code list should be used.

e. <<Union>> describes a selection of one of the specified types. This is useful to specify a set of alternative classes/types that can be used, without the need to create a common super-type/class.

f. <<Abstract>> class (or other classifier) that cannot be directly instantiated. UML notation for this is to show the name in italics.

g. <<Leaf>> package that contains definitions, without any sub-packages.

## B.4 Package abbreviations

**Two letter abbreviations are used to denote the package that contains a class. The package abbreviations precede the class names, connected by a "_". See**

Table 1 in section 4.2 for a list of package abbreviations used in this profile and the ISO standards that define them.

# Annex C
Quad trees and Morton ordering
(Informative)

## C.1 Quad tree Structures

The quad tree is commonly used to recursively subdivide an area bounded by a parallelogram (usually a rectangle) into smaller quadrants until all quadrants are homogeneous with respect to a selected characteristic. In the context of elevation data, this has two applications. When subdivision performed in order to make all quadrants homogeneous with respect to point density, the resulting structure describes a tiling scheme. When subdivision performed until all quadrants are homogeneous with respect to elevation value, the resulting structure is an elevation grid with variable cell sizes. Each cell contains a single elevation point. The size and shape of the base cells of the grid (the smallest grid cells) are described by the *offsetVectors* attribute of the ESM Grid class (6.7.2). The quadrants are aggregates of the base cells. In most cases, their values of the points they contain will have been derived by data compaction (10.1) of a set of points collected at a density equivalent to the base cell size.

NOTE A grid cell is defined as an area bounded by four adjacent grid points. This is the grid cell that provides the basis for interpolation. In discussing the quad tree structure and Morton ordering, the cell needs to be considered as being centred on a grid point. In other words, the grid cells are displaced by half the length of each offset vector.

The quad tree structure is very useful for subdividing an area of interest in order to collect elevation data at different point densities, whether the results are structured as a quad tree tiling scheme or as an elevation grid with a quad tree organization. Its use for aggregating values from a previously collected regular grid is problematic. If the cell size varies in a grid, it must do so in a regular way so that the grid tessellation still covers the bounded area, and the traversal method must be able to sequence the cells in an order. Neither the original grid nor any of its quadrants can be subdivided into quadrants unless the number of base cells along each axis is a multiple of two. The grid can only be subdivided to the point at which the minimum quadrant is equivalent to a base cell if its extent, expressed as the number of base cells along each axis, is a power of two.

## C.2 Morton Ordering

Morton ordering can be used advantageously for regular elevation grids in which all cells are of the same size. The position of a record within the sequence of *values* (6.7.10) is equal to the bit interleaved binary values of the grid coordinates of the point. Given the list of the grid axes specified by CV_SequenceRule.scanDirection, the bits of the coordinate corresponding to an axis are less significant than those of the coordinate corresponding to the next axis in the list. This means that for X,Y ordering the odd bits map to the X coordinate and the even bits map to the Y coordinate, and the opposite for Y,X ordering. For a negative scan direction, the bit order of the appropriate coordinate needs to be reversed before interleaving.

The Morton indexing technique can be applied to a sparsely populated grid provided that the index (bit interleaved binary grid coordinates) is carried in each *values* Record.

Morton ordering is the most appropriate sequencing method for an elevation grid with variable cell sizes and a quad tree structure. It is most easily explained if the quadrants of the quad tree are considered to be aggregates of the base cells. Because there is not a Record of *values* for each base cell, it is necessary to include a quadrant index with each Record. It is also necessary to know the size of each quadrant, which can be expressed as the square root of number of base cells aggregated into the quadrant.

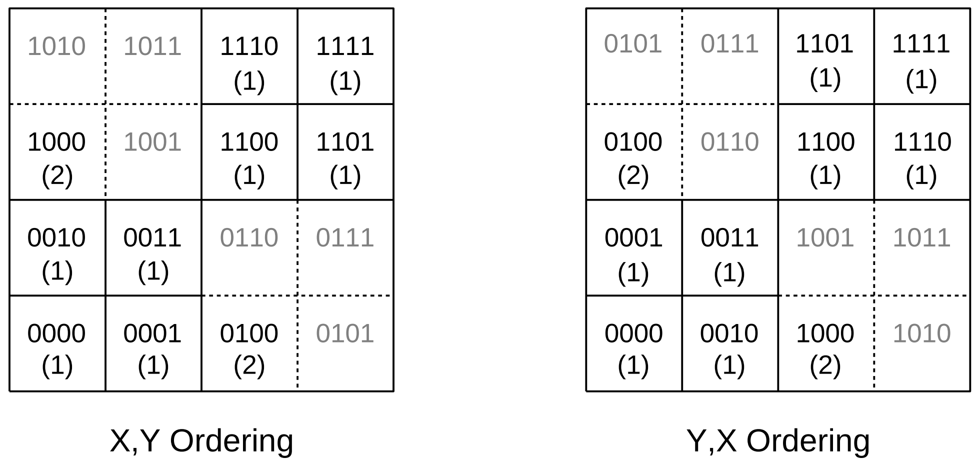



**Figure C.1 – Morton Ordering**

Note: Cell indices shown in black are used as quadrant indices; those in grey are not. Quadrant sizes are given in parentheses.

The combination of using the interleaved binary grid coordinates of a grid point as the index to its values Record and including a measure of cell size in the Record can also be applied to grids of odd sizes and shapes.

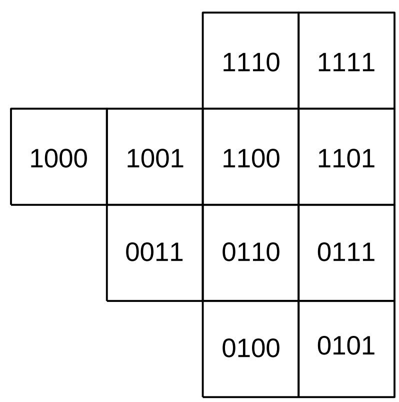



**Figure C.2 – Morton Ordering in an Irregular Grid**

This technique is widely used in the hydrographic community to handle sonar depth measurements.

# Annex D
ESM Data Dictionary
(normative)

## D.1 Data Dictionary Overview

This data dictionary describes the characteristics of the UML models used in this document (Figures 2, 3, 5, 6, 8). The tables in this annex follow the layout of tables used in ISO 19115:2003 Annex B. In the ESM Data Elements tables (D.3), the Data Type/Class column specifies a set of distinct values for representing the data elements (e.g. integer). The data type attribute is also used to define data entities, stereotypes and data associations. If the data type of an entity or element is a class, it specifies the name of the class. If it is an association, it specifies the associated class. The Obligation/Condition column specifies the requirement for the element as mandatory (M) or optional (O). The Domain column specifies the values allowed. If the data type is a class, the domain specifies the ISO standard where the class is defined, or the specific domain if the class is defined in this standard. For data entities, the Domain column specifies the line numbers covered by the entity.

## D.2 Codelists

The codelists used by the ESM standard are specified in Table D.1. The examples provided are not all-inclusive. For further guidance on metadata codelists, see the DGIWG Metadata Foundation.

**Table D.1 - ESM Codelists**

| Name | Example(s) |
|---|---|
| CV_SequenceType (Figure 6)<br>type of sequencing method that shall be used for mapping grid coordinates to a position within the sequence of records of feature attribute values.<br>Note: the ESM-allowed authoritative namespaces are a subset of ISO 19123:2005 CV_SequenceType: | “linear”<br>*or*<br>“Morton” |

| Name | Example(s) |
|---|---|
| CV_InterpolationMethod (Figures 5 and 8)<br>a code that identifies the interpolation method that shall be used to derive a feature attribute value at any direct position within the CV_ValueObject. The attribute is optional – no value is needed for an analytical coverage (one that maps direct position to attribute value by using a mathematical function rather than by interpolation).<br>Note: the allowed authoritative namespaces are: ISO 19123:2005: | “nearestNeighbor”<br>*or*<br>“linear”<br>*or*<br>“quadratic”<br>*or*<br>“cubic”<br>*or*<br>“bilinear”<br>*or*<br>“biquadratic” |
| CV_CommonPointRule (Figure 3)<br>code that identifies method for handling cases where the DirectPosition input to the *evaluate* operation falls within two or more of the geometric objects. The interpretation of these rules differs<br>between discrete and continuous coverages. In the case of a discrete coverage, each CV_GeometryValuePair provides one value for each attribute. The rule is applied to the set of values associated with the set of CV_GeometryValuePairs that contain the DirectPosition. In the case of a continuous coverage, a value for each attribute shall be interpolated for each CV_ValueObject that contains the DirectPosition. The rule shall then be applied to the set of interpolated values for each attribute.<br>Note: the ESM-allowed authoritative namespaces are a subset of ISO 19123:2005 CV_CommonPointRule: | “average”<br>*or*<br>“low”<br>*or*<br>“high” |

## D.3 ESM Data Elements

The following tables define the data elements used in ESM.

**Table D.2 - CV_Coverage (Figure 2)**

| | Name/Role Name | Definition | Obligation/Condition | Max Occurrence | Data Type/Class | Domain |
|---|---|---|---|---|---|---|
| 1 | GF_FeatureType | metaclass that is instantiated as classes that represent individual feature types. A feature is an abstraction of real world phenomena. | | | <<MetaClass>> | ISO 19109 |
| 2 | CV_Coverage | information describing a coverage feature | Use obligation/ condition from referencing object | Use maximum occurrence from referencing object | Aggregated Class (CV_DomainObject, CV_AttirbuteValues) | Lines 5-7 |
| 3 | CV_DiscreteCoverage | subclass of coverage that returns the same record of feature attribute values for any direct position within a single CV_DomainObject in its domain | Use obligation/ condition from referencing object | Use maximum occurrence from referencing object | Specialized Class (CV_Coverage) | |
| 4 | CV_ContinuousCoverage | subclass of coverage that returns a distinct record of feature attribute values for any direct position within its domain | Use obligation/ condition from referencing object | Use maximum occurrence from referencing object | Specialized Class (CV_Coverage) | |
| 5 | domainExtent | the extents of the domain of the coverage | M | N | EX_Extent | ISO 19115 |
| 6 | rangeType | the range of the coverage | M | 1 | RecordType | ISO 19103 |
| 7 | commonPointRule | the procedure to be used for evaluating the coverage at a position that falls either on a boundary between geometric objects or with the boundaries of two or more overlapping geometric objects | M | 1 | CV_CommonPointRule | ISO 19123<br>‘average’<br>‘low’<br>‘high’ |

| | Name/Role Name | Definition | Obligation/Condition | Max Occurrence | Data Type/Class | Domain |
|---|---|---|---|---|---|---|
| 8 | *Role name:* CRS | coordinate system to which the coverage is referenced | M | 1 | SC_CRS | ISO 19111 |
| 9 | *Role name:* domainElement | objects comprising the domain of the coverage | M | N | CV_DomainObject | ISO 19123 |
| 10 | *Role name:* rangeElement | records within the domain of the coverage, where each field of the record provides a value of the same attribute type over the entire domain | O | N | CV_AttributeValues | ISO19123 |
| 11 | CV_DomainObject | aggregation of objects that may include any combination of GM_Objects, TM_Primitives, or spatial or temporal objects | Use obligation/ condition from referencing object | Use maximum occurrence from referencing object | Aggregated Class (GM_Object, TM_GeometricPrimitive) | Lines 12-13 |
| 12 | *Role name:* spatialElement | location of the domain object in space | O | N | GM_Object | ISO 19107 |
| 13 | *Role name:* temporalElement | location of the domain object in time | O | N | TM_GeometricPrimitive | ISO 19108 |
| 14 | CV_AttributeValues | elements from the range of the coverage | Use obligation/ condition from referencing object | Use maximum occurrence from referencing object | Class | Line 15 |
| 15 | Values | a record containing one value for each attribute, as specified by CV_Coverage.rangeType | M | 1 | Record | ISO 19103 |

**Table D.3 - ESM Collection (Figure 3)**

| | Name/Role Name | Definition | Obligation/Condition | Max Occurrence | Data Type/Class | Domain |
|---|---|---|---|---|---|---|
| 1 | ESM_Collection | a collection of ESM coverages and/or point sets and their associated metadata | Use obligation/ condition from referencing object | Use maximum occurrence from referencing object | Aggregated Class (ESM_PointSet, ESM_Coverage) | Lines 2-13 |
| 2 | extent | the combined extents of the components of the ESM Collection | M | 1 | EX_GeographicExtent | ISO 19115 |
| 3 | *Role name:* pointSet | a component of the ESM Collection that may include one or more sets of elevation points | O | N | ESM_PointSet | |
| 4 | *Role name:* coverage | a component of the ESM collection that may include one or more elevation coverages | O | N | ESM_Coverage | |
| 5 | ESM_PointSet | a set of elevation points | Use obligation/ condition from referencing object | Use maximum occurrence from referencing object | Class | Line 6 |
| 6 | domainExtent | the extents of the domain of the ESM_PointSet | M | 1 | EX_GeographicExtent | ISO 19115 |
| 7 | geometry | the geometry of the ESM_PointSet | M | 1 | GM_MultiPoint | ISO 19107 |
| 8 | ESM_Coverage | a coverage feature that describes an elevation surface | Use obligation/ condition from referencing object | Use maximum occurrence from referencing object | Specialized Class CV_Coverage <<Abstract>> | |
| 9 | ESM_GridCoverage | a quadrilateral grid consisting of a set of grid points with intervening cells that form an elevation surface | Use obligation/ condition from referencing object | Use maximum occurrence from referencing object | Specialized Class (ESM_Coverage) | |

| | Name/Role Name | Definition | Obligation/Condition | Max Occurrence | Data Type/Class | Domain |
|---|---|---|---|---|---|---|
| 10 | ESM_TINCoverage | an elevation coverage characterized by a GM_TIN structure | Use obligation/ condition from referencing object | Use maximum occurrence from referencing object | Specialized Class (ESM_Coverage) | |
| 11 | ESM_PointCoverage | a discrete elevation coverage characterized by a finite domain consisting of elevation points (ESM_Point) | Use obligation/ condition from referencing object | Use maximum occurrence from referencing object | Specialized Class (ESM_Coverage) | |

**Table D.4 -** ESM Grid Coverage (Figure 5)

| | Name/Role Name | Definition | Obligation/Condition | Max Occurrence | Data Type/Class | Domain |
|---|---|---|---|---|---|---|
| 1 | ESM_GridCoverage | a quadrilateral grid consisting of a set of grid points with intervening cells that form an elevation surface | Use obligation/ condition from referencing object | Use maximum occurrence from referencing object | Specialized Class (ESM_Coverage) | Lines 2-3 |
| 2 | interpolationType | the interpolation method used to derive a feature attribute value at any direct position within the CV_ValueObject. | M | 1 | CV_InterpolationMethod | ISO 19123 |
| 3 | *Role name:* Evaluator | the entity determining the values of a coverage at a direct position within the domain of the coverage | M | 1 | ESM_Grid | |

**Table D.5 - ESM Grid (Figure 6)**

| | Name/Role Name | Definition | Obligation/ Condition | Max Occurrence | Data Type/Class | Domain |
|---|---|---|---|---|---|---|
| 1 | ESM_Grid | contains the geometric characteristics of an elevation grid | Use obligation/ condition from referencing object | Use maximum occurrence from referencing object | Class | Lines 2-9 |
| 2 | dimension | the dimensionality of the grid | M | 1 | Integer | 2 |
| 3 | axisNames | names of the grid axes | M | 1 | Sequence<CharacterString> | axis names often represent the orientation of the axis relative to the external coordinate reference system |
| 4 | origin | direct position that shall locate the origin of the rectified grid in an external coordinate reference system | M | 1 | DirectPosition | |
| 5 | offsetVectors | the spacing between the grid points and the orientation of the grid axes with respect to the external coordinate reference system identified through the origin attribute | M | 1 | Sequence<Vector> | |
| 6 | extent | specification of the spatial limits of a section of the grid | M | 1 | CV_GridEnvelope | ISO 19123 |
| 7 | sequenceRule | description of how the grid points are ordered for association to the elements of the values sequence | M | 1 | CV_SequenceRule | ISO 19123<br>'linear'; 'Morton' |
| 8 | startSequence | identification of the grid point to be associated with the first record in the values sequence | M | 1 | CV_GridCoordinates | ISO 19123 |
| 9 | *Role name*:<br>Values | the association of the grid points with the elevation values they represent | M | N | ESM_GridValues | |

**Table D.6 - ESM Grid Values (Figure 6)**

| Name/Role Name | Definition | Obligation/Condition | Max Occurrence | Data Type/Domain | Business Rule |
|---|---|---|---|---|---|
| ESM_GridValues | elevation measurements associated with the grid points in the ESM_Grid | Use obligation/ condition from referencing object | Use maximum occurrence from referencing object | Aggregated Class (ESM_Grid) | |
| Values | records within the domain of the grid values | M | 1 | Class / Record <<Type>> | elevation measurement in the unit of measure specified by the metadata (via the vertical CRS) |

## D.4 Coverage Data Types

The coverage data types defined in the following tables are used by the ESM.

**Table D.7 - Coverage Sequence Rule (Figure 6)**

| Name/Role Name | Definition | Obligation/Condition | Max Occurrence | Data Type/Domain | Business Rule |
|---|---|---|---|---|---|
| CV_SequenceRule | data type that contains information for mapping grid coordinates to a position within the sequence of records of feature attribute values | Use obligation/ condition from referencing object | Use maximum occurrence from referencing object | Class <<DataType>> | Defined in ISO 19123 |
| scanDirection | a list of signed axisNames that indicates the order in which grid points shall be mapped to position within the sequence of records of feature attribute values. | M | 1 | Sequence / CharacterString | |
| Type | identification of the type of sequencing method used. | M | 1 | Class / CV_SequenceType <<CodeList>> | |

**Table D.8 - Coverage Grid Envelope (Figure 6)**

| Name/Role Name | Definition | Obligation/Condition | Max Occurrence | Data Type/Domain | Business Rule |
|---|---|---|---|---|---|
| CV_GridEnvelope | data type that provides the grid coordinate values for the diametrically opposed corners of the ESM_Grid. It has two attributes. | Use obligation/ condition from referencing object | Use maximum occurrence from referencing object | Class <<DataType>> | Defined in ISO 19123 |
| High | the maximal coordinate values for all grid points within the CV_Grid | M | 1 | Class / CV_GridCoordinate<br><<DataType>> | |
| Low | the minimal coordinate values for all grid points within the CV_Grid | M | 1 | Class / CV_GridCoordinate<br><<DataType>> | |

**Table D.9 - Coverage Grid Coordinate (Figure 6)**

| Name/Role Name | Definition | Obligation/Condition | Max Occurrence | Data Type/Domain | Business Rule |
|---|---|---|---|---|---|
| CV_GridCoordinate | Data type for holding the grid coordinates of a CV_GridPoint | Use obligation/ condition from referencing object | Use maximum occurrence from referencing object | Class <<DataType>> | Defined in ISO 19123 |
| coordValues | holds one integer value for each dimension of the grid. The ordering of these coordinate values shall be the same as that of the elements of *ESM_Grid.axisNames*. The value of a single coordinate shall be the number of offsets from the origin of the grid in the direction of a specific axis | M | 1 | Sequence / Integer | |

# Annex E
ESM Metadata Specification
(normative)

## E.1 ESM Metadata Strategy

Metadata allows a producer to describe a dataset fully so that users can understand the assumptions and limitations and evaluate the dataset's applicability for their intended use. This annex is based on the DGIWG Metadata Foundation (DMF) standard. It specifies the minimum and recommended sets of metadata elements required for the discovery and exchange of elevation data.

ESM metadata elements shall be encoded in an XML file that is in compliance with the metadata encoding rules described in ISO 19139. The XML file shall be provided separately from the value file. This requirement will enhance the discovery and retrieval of elevation data by allowing queries against a database of XML-only files. The XML metadata may also be carried internal to the value file.

It is important to remember that at one level, all information content can be considered to be metadata. The key aspect of the information required by this annex is that it is required to be documented according to a specified data type and domain that allows it to be well-understood, and easily discovered and retrieved through automated processes.

## E.2 ESM Metadata Elements

ESM metadata elements (mandatory and recommended optional) for describing any geographic dataset provide the basis for the elements listed in Table E.10. This data dictionary, in conjunction with the DMF and ISO 19115-2, serves to define the model for ESM minimum required metadata. The last two elements in the table are ESM extensions to the DMF, and the value domains for these elements are derived from ISO 19115-2. Otherwise, the elements are derived from DMF and the equivalent DMF identifier and requirement class (see A.2) is provided under the element name. The term “dataset”, when used as part of an ESM metadata element name, is synonymous with all types of elevation data resources (aggregations of datasets, individual features and the various classes that compose a feature). The Obligation, Maximum Occurrence, and Value Domain requirement for each element is derived from DMF and/or ISO, with any additional constraints on the corresponding ESM element indicated in the table. In the Obligation column, an ‘M’ indicates that the metadata element is ESM mandatory. An “O” indicates that the element is ESM optional. A “C” indicates that the element is ESM mandatory under the condition provided. The obligation letter code is in bold text when the ESM obligation exceeds the DMF obligation (i.e. when the DMF obligation has been changed from optional to conditional or mandatory for ESM). The Max Occur column is simply an indication of whether DMF allows multiple instances of the element to be included in the metadata file. The contents of the Value Domain column indicate the allowed values for the element. For most elements, these are presented as DMF-defined basic types, complex types and codelists, but ESM-specific constraints on the domain may be specified.

**Table E.10 - ESM Core Metadata**

| | **Name**<br>DMF ID (Requirement Class) | **Definition** | **Obligation** | **Max Occur** | **Value Domain** |
|---|---|---|---|---|---|
| 1 | **Metadata file identifier**<br>MDSID (Core) | unique identifier for this metadata file | **M** | 1 | String<br>Note: DMF strongly recommends a unique identifier (e.g. UUID or URI) or a locator (e.g. URL). |
| 2 | **Parent metadata file identifier**<br>MDPTSID (Common) | file identifier of the metadata to which this metadata is a subset (child) | **C / if parent metadata file exists** | 1 | String |
| 3 | **Metadata language**<br>MDDLOC (Core)<br>+ language | language used for documenting metadata | M | 1 | Locale<br>language = 'eng' |
| 4 | **Metadata character set**<br>MDDLOC (Core)<br>+ encoding | full name of the character coding standard used for the metadata | M | 1 | Locale<br>encoding = 'utf8' |
| 5 | **Metadata Translation**<br>MDTLOC (Common) | locale in which some metadata elements may be translated | O | N | Locale |
| 6 | **Metadata date stamp**<br>MDDATE (Core) | date that the metadata was created | M | 1 | Date |
| 7 | **Metadata point of contact**<br>MDRPTY (Core) | identification of, and means of communication with, person(s) and organizations associated with the dataset | M | N | Responsible Party |

| | Name<br>DMF ID (Requirement Class) | Definition | Obligation | Max Occur | Value Domain |
|---|---|---|---|---|---|
| 8 | **Metadata standard name**<br>MDSTD (Core)<br>+ title | name of the metadata standard (including profile name) used | M | 1 | ‘urn:dgiwg:metadata:dmf’ |
| 9 | **Metadata standard version**<br>MDSTD (Core)<br>+ version | version (profile) of the metadata standard used | M | 1 | ‘1.0’ |
| 10 | **Metadata security constraint level**<br>MDSCST (Common)<br>+ level | name of the handling restrictions on the metadata | **C / based on requirement of security constraint system** | 1 | Security Constraint Level |
| 11 | **Metadata security constraint system**<br>MDSCST (Common)<br>+ system | national or international system used to classify the metadata | **C / based on presence of security constraint level** | 1 | Security Constraint System |
| 12 | **Metadata releasability**<br>MDREL (NATO) | establishes a body to which the metadata can be released | O | N | Releasability Codelist, NATO Body Codelist, or String (a 3-character country code from STANAG 1059 when available). |
| 13 | **Metadata legal constraint**<br>MDLCST (Common) | provides a means to express a set of legal constraints applicable to the metadata | **C / legal constraints exist** | N | Legal Constraint |
| 14 | **Metadata maintenance frequency**<br>MDMFRQ (Common) | information on the frequency with which changes and additions are made to the metadata after the initial metadata is completed | O | 1 | Frequency Codelist |

| | **Name**<br>DMF ID (Requirement Class) | **Definition** | **Obligation** | **Max Occur** | **Value Domain** |
|---|---|---|---|---|---|
| 15 | **Dataset title**<br>RSTITLE (Core) | name by which the cited resource is known | M | 1 | Free Text |
| 16 | **Dataset alternate title**<br>RSALT (Common) | short name, informal name, or name in another language by which the dataset is known | O | 1 | Free Text |
| 17 | **Abstract describing the dataset**<br>RSABSTR (Core) | brief narrative summary of the content of the resource(s) | M | 1 | Free Text |
| 18 | **Collection Tiling Scheme**<br>GPHICS (Common) | reference to a graphic that provides a description of the collection's tiling scheme | **C / if RSTYPE=series and tiling scheme is defined** | 1 | GPHICS.name (file name) and GPHICS.description (= 'TilingScheme') |
| 19 | **Dataset purpose**<br>RSPURP (Core) | A summary of the intentions with which the resource was developed | O | 1 | Free Text |
| 20 | **Metadata type code**<br>RSTYPE (Core) | scope to which the metadata applies | M | 1 | Resource Type Codelist<br>Value = 'dataset', or 'series' for a collection |
| 21 | **Metadata type name**<br>RSTYPN (Core) | name of the hierarchy level for which the metadata is provided | **C / RSTYPE = series** | 1 | Free Text |
| 22 | **Dataset edition**<br>RSED (Core) | version identifier of the resource | O | 1 | String |

| | **Name**<br>DMF ID (Requirement Class) | **Definition** | **Obligation** | **Max Occur** | **Value Domain** |
|---|---|---|---|---|---|
| 23 | **Dataset edition date**<br>RSEDDAT (Core) | reference date of this edition of the resource | O | 1 | Date |
| 24 | **Dataset identifier**<br>RSID (Core) | value uniquely identifying an object within a namespace | **M** | N | Identifier |
| 25 | **Collection Name**<br>RSSERI (Core) | Identifier of the collection, when the dataset is a member of a collection | **C / when dataset is a member of a collection** | 1 | String |
| 26 | **Tile Identifier**<br>RSSHNA (Core) | Identifier of the Tile, when the dataset is a member of a tiled collection | **C / when dataset is a member of a tiled collection** | 1 | String |
| 27 | **Keywords**<br>RSKWDS (Core)<br>+ keyword | commonly used word(s) or formalized word(s) or phrase(s) used to describe the subject. | **M** | N | Controlled Vocabulary Enumerations |
| 28 | **Spatial resolution of the dataset**<br>RSGSD (Core) | factor which provides a general understanding of the density of spatial data in the dataset | **M** | 1 | Distance<br>Note: This distance may be approximate, as it is aimed at providing a general understanding only on the ESM dataset. |
| 29 | **Dataset language**<br>RSLOC (Core)<br>+ language | languages(s) used within the dataset | M | N | Locale<br>language |

| | **Name**<br>DMF ID (Requirement Class) | **Definition** | **Obligation** | **Max Occur** | **Value Domain** |
|---|---|---|---|---|---|
| 30 | **Dataset character set**<br>RSLOC (Core)<br>+ encoding | full name of the character coding standard used for the dataset | M | N | Locale<br>encoding |
| 31 | **Spatial representation type**<br>RSRPTP (Core) | method used to spatially represent geographic information | **M** | 1 | Spatial Representation type Codelist |
| 32 | **Dataset type**<br>DGITYP (Core) | information about the type of geospatial information provided by the dataset | O | 1 | Geospatial Information Type Codelist |
| 33 | **Dataset georeferencing level**<br>RSGFLV (Core) | level of georeferencing of the dataset | O | 1 | Georeferencing Level Codelist |
| 34 | **Dataset level**<br>RSDTLVL (Core) | method of categorizing resolution bands of digital geographic data by equivalence to paper map scales | O | 1 | Data Level Codelist |
| 35 | **Dataset topic category**<br>RSTOPIC (Core) | main theme(s) of the dataset | M | **1** | Topic Category Enumeration<br>‘elevation’ |
| 36 | **Dataset theme**<br>RSTHEME (Core) | provides more precise thematic information enabling discovery of the dataset | O | N | Thematic Codelist |
| 37 | **Dataset environment description**<br>RSENVD (Data) | information on producer’s processing environment, including items such as the software, the computer operating system, file name, and the dataset size. | O | 1 | Free text |

| | **Name**<br>DMF ID (Requirement Class) | **Definition** | **Obligation** | **Max Occur** | **Value Domain** |
|---|---|---|---|---|---|
| 38 | **Value type**<br>GRCINF (Data)<br>+ contentType | type of information represented by the cell value | **M** | 1 | Coverage Content Type CodeList |
| 39 | **Surface type**<br>GRCINF (Data)<br>+ range | description of the attribute described by the measurement value | **M** | 1 | Range |
| 40 | **Special Cell**<br>GRCINF (Data)<br>+specialCell | cell playing a specific role (e.g. no data) in the coverage. When the content type of the coverage is a thematic classification, each thematic class is represented by a special cell. | O | N | Special Cell Values |
| 41 | **Geographic location of the dataset (by coordinates)**<br>RSEXT/boundingBox(Core) | geographic position of the dataset | **C / for unprojected data** | N | Bounding Box<br>Note: RSEXT may be repeated |
| 42 | **Dataset positional extent**<br>RSEXT/boundingPolygon (Core) | the boundary enclosing the dataset, given as a set of (x,y) WGS84 coordinates of a polygon, with the last point replicating the first | **C / for UTM projected data** | 1 | Polygon<br>Note: RSEXT may be repeated |
| 43 | **Dataset temporal extent**<br>RSEXT/temporalExtent (Core) | date and time for the content of the dataset (collection date and time) | O | 1 | Temporal Extent |
| 44 | **Dataset vertical extent**<br>RSEXT/vertcalExtent/minz and maxz (Core) | vertical domain of the dataset expressed using WGS84 ellipsoid | **M** | 1 | Integer |
| 45 | **Coordinate reference system – horizontal**<br>RSRSYS (Core) | identifier used for reference systems | **M** | 1 | String, Anchor or Identifier |

| | **Name**<br>DMF ID (Requirement Class) | **Definition** | **Obligation** | **Max Occur** | **Value Domain** |
|---|---|---|---|---|---|
| 46 | **Coordinate reference system – temporal**<br>RSRSYS (Core) | identifier used for reference systems | **C / for high-resolution datasets** | 1 | String, Anchor or Identifier |
| 47 | **Dataset status**<br>RSSTAT (Common) | Information about the status of the dataset | O | 1 | Status Codelist |
| 48 | **Dataset reference date**<br>RSDATE (Core) | reference date for the cited resource | M | N | Reference Date |
| 49 | **Dataset originator**<br>RSRPTY:originator (Core) | party that created the dataset | **M** | 1 | ResponsibleParty<br>(role = originator) |
| 50 | **Dataset point of contact**<br>RSRPTY:pointOfContact (Core) | party that can be contacted for inquiries regarding or acquisition of the dataset | **M** | N | ResponsibleParty<br>(role = pointOfContact) |
| 51 | **Maintenance frequency**<br>RSMTNC (Common)<br>+ maintenanceFrequency | frequency with which changes and additions are made to the resource after the initial resource is completed | **M** | 1 | Maintenance Information |
| 52 | **Dataset classification**<br>RSSCST (Core)<br>+ level | name of the handling restrictions on the resource | **C / based on requirement of classification system** | 1 | Security Constraint<br>level |

| | **Name**<br>DMF ID (Requirement Class) | **Definition** | **Obligation** | **Max Occur** | **Value Domain** |
|---|---|---|---|---|---|
| 53 | **Dataset classification system**<br>RSSCST (Core)<br>+ system | national or international system used to classify the dataset | **M** | 1 | Security Constraint<br>system |
| 54 | **Dataset releasability**<br>RSREL (NATO) | provides a means to express a set of releasability information applicable to the dataset | O | N | Releasability |
| 55 | **Dataset use constraints**<br>RSUSE (Core) | provides a means to express general use limitations (limitations not implied by security or legal constraints) of the dataset | O | N | Free Text |
| 56 | **Dataset legal constraints**<br>RSLCST (Core) | restrictions and legal prerequisites for accessing and using the resource | **C / legal access/use constraints exist?** | N | Legal Constraint |
| 57 | **Dataset lineage**<br>RSLING (Core) | information about the source, the method of data capture, and any information on the transformation, conversion, or resampling that has been applied to the data, if available | M | 1 | Free Text |
| 58 | **Dataset quality report**<br>RSRQR or RSUQR (Data) | Information related to the result of a quality evaluation of the dataset | **M** | N | Regulated Quality Element or Unregulated Quality Element (see E.5 for definition and minimum requirement) |
| 59 | **Dataset source**<br>RSSRC (Data) | information about the source data used in creating the dataset | O | N | Source |
| 60 | **Method used to estimate values**<br>RSPRST (Data) | information about the method used to estimate elevation values | **C / dataset includes estimated values** | 1 | Process Step |

| | **Name**<br>DMF ID (Requirement Class) | **Definition** | **Obligation** | **Max Occur** | **Value Domain** |
|---|---|---|---|---|---|
| 61 | **Dataset intended usage**<br>RSSPUS (Common) | brief description of ways in which the resource(s) is/are currently or has been used | O | N | Usage |
| 62 | **Dataset distribution format**<br>RSDFMT (Core) | name of the data distribution format(s) and version of the format (date, number, etc.) | M | **1** | Format |
| 63 | **Online resource**<br>RSONLLC (Core) | information about on-line sources from which the dataset, specification or community profile name and extended metadata elements can be obtained | **M** | N | Online Location |
| 64 | **Dataset distribution unit**<br>RSUD (Data) | a description of the unit (tiles, layers, geographic areas, etc.) in which the data is available | O | 1 | Free Text |
| 65 | **Dataset transfer size**<br>RSTS (Data) | estimated size of a unit in the specified transfer format, expressed in megabytes. The transfer size is > 0.0 | O | 1 | Float |
| 66 | **Dataset offline distribution**<br>RSOFDM (Data) | information about offline media through which the dataset can be obtained | O | 1 | Medium |
| 67 | **Instrument identification**<br>ACINS (InstrumentId) | unique identification of the instrument | **O** | **N** | Instrument / Identifier<br>Note: ACINS is repeatable |
| 68 | **Instrument type**<br>ACINS (instrumentType) | name of the type of instrument | **O** | **N** | Instrument / Sensor Type Codelist |

## E.3 ESM Metadata Extension Rules

The rules for creating extensions to required metadata are described in the DMF. These rules allow ESM to extend the DMF by imposing a more stringent obligation and/or a more restrictive domain on an existing DMF metadata element. The rules also allow for additional domain restrictions on existing elements and for additional codes added to DMF codelists. In describing a grid coverage, for example, the *dimension* attribute is mandatory for a description of a grid (Figure 5), but it is included under an optional element in DMF (GRSPREP). Such additional information can be provided in a product specification or other documentation, and also in the metadata.

## E.4 Additional Entities, Elements and Codes (O)

The tables in this annex specify the minimum metadata requirements for compliance with the ESM profile. Additional DMF and ISO 19115-2 metadata beyond that contained in Table E.10 is not prohibited by ESM. Interpolation type (6.6.3 and 6.9.4) is an example of information that must be documented, but is not necessary for inclusion in the resource metadata. Metadata elements not described in DMF can nevertheless be included in an elevation dataset's metadata in accordance with extension rules specified in DMF section B.3. Such extensions should be applied to a dedicated DMF requirement class. The additional elements may represent a profile of the DMF, and may be described either within each metadata instance document, or within an online resource (i.e. a registered profile). Reference to an online registry of metadata elements is a more efficient method, particularly when an entire class of extended elements are required (e.g. a country or organization-specific extension to the ISO MD_SecurityConstraints class) to accommodate additional security requirements within a classification system.

## E.5 Quality Reporting Requirements

ESM quality may be reported as a result of a pre-defined registered data quality measure (Regulated Quality Element) for commonly-used data quality measures or as a result of an unregistered quality measure (Unregulated Quality Element) when the measure is too specific to proceed to its registration. For both the 'regulated' and 'unregulated' measures, the result of the evaluation is either a conformance, quantitative, descriptive, or coverage result (see DMF). If two results are reported, one of them must be a conformance result.

The coverage result is an instance of ISO QE_CoverageResult and is used to report the results of some error propagation estimate measures (see Annex F). These estimates are required for high-resolution ESM datasets (see 7.4.4)

Quality reporting metadata for any ESM dataset should include, at a minimum, a completeness percentage and absolute horizontal and vertical accuracy of the dataset. Both require quantitative results. The completeness percentage is reported via the ISO class DQ_CompletenessCommission. The absolute horizontal and vertical accuracy of the dataset are reported via the ISO class DQ_AbsoluteExternalPositionalAccuracy.

# Annex F
## Error Propagation Estimates

## F.1 Introduction

The use of high resolution elevation data for tasks that require a specified level of geolocation accuracy necessitates the estimation of errors anywhere within the data coverage area. This information shall be documented in the metadata. This annex specifies how to provide the uncertainty data needed to compute estimated horizontal and vertical errors (both absolute and relative) for points in an elevation coverage. Various options are defined to specify the rigorous error propagation for each point or post in the coverage. Options are provided for defining N distinct regions, so that region and cross-region systematic error and relative error covariance data may be specified. Covariance data is defined in ISO 19138:2006 - Data quality measures. Options are also provided for assigning the random error component of covariance data for each point in the coverage or defining nominal random error component covariance data for each region that can then be scaled to unique covariance matrices for each point in the coverage via per-post random error scale factors. In general, specifying the covariance data for N regions will result in less metadata being required for rigorous error propagation, at the possible expense of fidelity.

As geolocation accuracy requirements become more stringent, assigning a single value of horizontal and vertical error for an entire dataset becomes an unsatisfactory solution. Therefore, this profile defines a metadata structure that permits rigorous, high fidelity error estimates to be computed on a post-by-post basis. This is accomplished by defining the fields needed to specify the covariance data for an accompanying dataset. Standard error propagation techniques (i.e., linear combinations of Gaussian random variables) may then be used to compute a unique 3 by 3 covariance matrix for each post in the dataset.

This profile outlines how to define one or more regions and three types of covariance data (systematic, relative and random). The regions are intended to define areas with different error propagation characteristics. With this data a complete set of error propagation covariance data may be specified for each region in a dataset and for each post in a dataset.

## F.2 Required Data Types

The types of data needed to define the error propagation data are illustrated in Figure F.1. For the systematic error, “$\sigma_x$“ represents the predicted systematic error per component within a region, and “$\zeta_{r,c}$ “ is the correlation coefficient between components, “$\Sigma_{GX}$ “ represents the systematic error for region X, and “$\Sigma_G$“ is the full cross-region covariance matrix. Relative error between points within a region can be computed given the distance between two points and the matrices, “$\Phi_U$” and “$\Phi_V$” that express the increase in covariance magnitude per meter. For the random error, “$\sigma_x$“ represents the predicted random error per component at a post and “$\zeta_{r,c}$“ is the correlation coefficient between components. When the random error covariance is defined per region: Random Error Covariance per Post is calculated by:

$$\Sigma_{R(\square r,c)} = \Sigma_{RX} * SF_{r,c}$$

Where, $\Sigma_{R(\square r,c)}$ is the random error per post, $\Sigma_{RX}$ is the random error covariance per region, and $SF_{r,c}$ is a per post scale factor. The random error per post and the scale factor per post are provided in data quality coverages and referenced in the metadata using the QE_CoverageResult class from ISO 19115-2.

Dataset regions may also be specified point-by-point. In this case, for each post in the dataset, a region number is assigned, from 001 to 256. This point-by-point region assignment information is provided in a separate coverage as the dataset point data. Indexing into this coverage is identical to indexing into the dataset elevation coverage. Every post in the dataset must be assigned to a region. This option provides the most flexibility for defining region geometries.

| **Stored Per Region in Metadata** | | **Stored Per Point in Coverage Segment** |
|---|---|---|
| Regions defined by polygon vertices | <- OR -> | Regions defined per post |
| a) Systematic Error per region: $$\Sigma_{GX} = \begin{bmatrix} \sigma_1{}^2 & \sigma_1\sigma_2\zeta_{12} & \sigma_1\sigma_3\zeta_{13} \\ & \sigma_2{}^2 & \sigma_2\sigma_3\zeta_{23} \\ & & \sigma_3{}^2 \\ symmetric & & \end{bmatrix}$$ | <- ONLY | |
| Cross-Region Systematic Error: $$\Sigma_G = \begin{bmatrix} \Sigma_{G1} & \Sigma_{G12} & \Sigma_{G13} & \Sigma_{G14} \\ & \Sigma_{G2} & \Sigma_{G23} & \Sigma_{G24} \\ & & \Sigma_{G3} & \Sigma_{G34} \\ symmetric & & & \Sigma_{G4} \end{bmatrix}$$ | <- ONLY | |
| Region Relative Error: $$\Phi_U = \begin{bmatrix} \frac{d\sigma^2{}_x}{du^2} & \frac{d\sigma_{xy}}{du^2} & \frac{d\sigma_{xz}}{du^2} \\ & \frac{d\sigma^2{}_y}{du^2} & \frac{d\sigma_{yz}}{du^2} \\ Symmetric & & \frac{d\sigma^2{}_z}{du^2} \end{bmatrix}$$ $$\Phi_V = \begin{bmatrix} \frac{d\sigma^2{}_x}{dv^2} & \frac{d\sigma_{xy}}{dv^2} & \frac{d\sigma_{xz}}{dv^2} \\ & \frac{d\sigma^2{}_y}{dv^2} & \frac{d\sigma_{yz}}{dv^2} \\ Symmetric & & \frac{d\sigma^2{}_z}{dv^2} \end{bmatrix}$$ `rotationAngle, thresholdDistance` | <- ONLY | |
| Random Error per Region: $$\Sigma_{RX} = \begin{bmatrix} \sigma_1{}^2 & \sigma_1\sigma_2\zeta_{12} & \sigma_1\sigma_3\zeta_{13} \\ & \sigma_2{}^2 & \sigma_2\sigma_3\zeta_{23} \\ & & \sigma_3{}^2 \\ symmetric & & \end{bmatrix}$$ | AND | Random Error Scale Factor per Post: Scale Factor per post coverage |
| | OR | |

| | | |
|---|---|---|
| | ONLY -> | Random Error per Post: $\Sigma_{R(r,c)} = \begin{bmatrix} \sigma_1{}^2 & \sigma_1\sigma_2\zeta_{12} & \sigma_1\sigma_3\zeta_{13} \\ & \sigma_2{}^2 & \sigma_2\sigma_3\zeta_{23} \\ & & \sigma_3{}^2 \\ \textit{symmetric} & & \end{bmatrix}$ |

**Figure F.1 – Example Covariance Matrix Data Needed for Rigorous Error Propagation.**

Note: The types of data are organized on the left or right depending on whether the data appears as metadata or as values in a coverage.

As an alternative, dataset regions may be specified by polygons. This option permits defining regions via polygon vertex coordinate pairs. Region areas must not overlap or leave gaps. Region areas must cover the entire dataset.

Two types of covariance data need to be specified. The first, systematic error covariance, is provided by metadata specifying the covariance elements for individual regions as well as cross-region covariance elements. The second, random error covariance, is specified through a combination of metadata and coverage elements. Metadata parameters reference the specific coverage segments, as needed.

The covariance elements for systematic and random errors are specified via standard deviations for the diagonal terms, and correlation coefficients for the off-diagonal terms. The actual off-diagonal covariance elements are then computed by multiplying the correlation coefficients with the appropriate, diagonal, standard deviation terms. The diagonal variance terms are computed by squaring the corresponding standard deviations. The covariance elements for relative error are specified as changes in variance (see next section).

## F.3 Calculation of Error Covariance Metadata

This section provides insight into the metadata architecture that allows rigorous error propagation of high resolution elevation data. The first subsection describes how error covariance metadata is to be stored. The second subsection describes how an exploitation tool would use the elevation metadata. The explanation and examples pertain specifically to LiDAR source data; however they can be extended to apply to other systems such as IFSAR and stereo optical. The principles recommended below are described in terms of points and full covariance matrices, but would apply also to the special case of posts.

### F.3.1 Metadata Contents

#### F.3.1.1 Define Regions

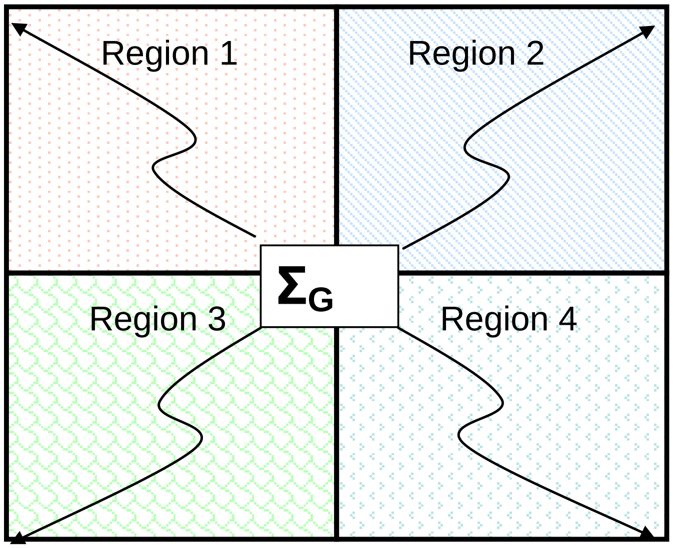
The elevation data shall be partitioned into N distinct regions (one or more) based on data error characteristics. This profile allows 2 methods for partitioning into regions; (1) to define a raster grid of positive integers that identify a post as belonging to one of the N regions; or (2) specify the X,Y coordinates of each vertex defining each of the N polygons or regions, assuring that the edges of adjacent polygons are coincident and there are not any gaps or overlaps between regions.

### F.3.1.2 Provide Cross-Region Systematic Error Covariance Data

Consider for example a product requiring the division into four regions (see Figure E.2). The objective is to specify a full covariance matrix that represents the typical covariance and correlation information associated with multiple ground points appearing across different regions. Then, Equation 1 is the full covariance matrix that shall be provided as metadata:

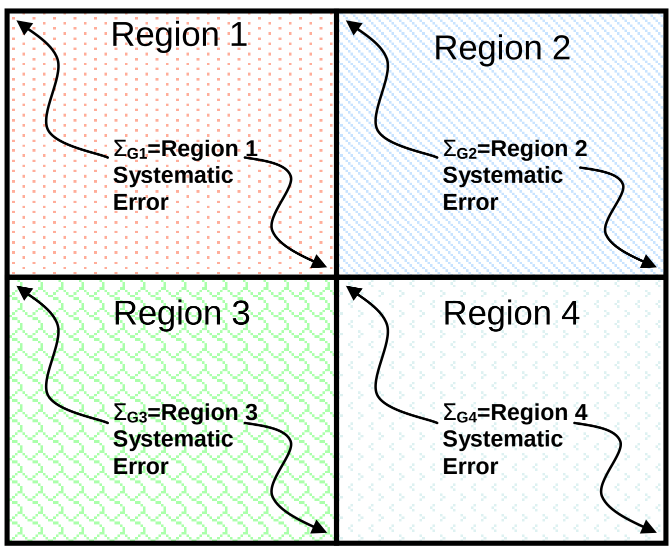
$$\underset{12\times12}{\Sigma_G} = \begin{bmatrix} \Sigma_{G1} & \Sigma_{G12} & \Sigma_{G13} & \Sigma_{G14} \\ & \Sigma_{G2} & \Sigma_{G23} & \Sigma_{G24} \\ & & \Sigma_{G3} & \Sigma_{G34} \\ symmetric & & & \Sigma_{G4} \end{bmatrix} \quad (1)$$

In the LiDAR example, the full ground points covariance matrix, $\Sigma_G$, consisting of 3 by 3 submatrices, can be calculated by performing rigorous error propagation on a set of three condition equations per object point in which observations consist of: a pair of direction angles, a range measurement, and all sensor parameters. The vendor should calculate the covariance matrix to correspond to ground points located at the approximate centers of their associated regions (see Figure F.3). The full simultaneous error propagation must take into account the correlation between sensor parameters in different strips. Also, the input covariance information should exclude high-frequency noise, i.e. random error, which will be handled separately. The availability of an accredited sensor model for the collection system would allow for such error propagation.




$$\underset{12\times 12}{\Sigma_G} = \begin{bmatrix} \Sigma_{G1} & \Sigma_{G12} & \Sigma_{G13} & \Sigma_{G14} \\ & \Sigma_{G2} & \Sigma_{G23} & \Sigma_{G24} \\ & & \Sigma_{G3} & \Sigma_{G34} \\ symmetric & & & \Sigma_{G4} \end{bmatrix}$$

**Figure F.2 – Full Covariance Data for the Systematic Errors of Four Regions**




$$\Sigma_{G,R\#} = \begin{bmatrix} \sigma_1{}^2 & \sigma_1\sigma_2\zeta_{12} & \sigma_1\sigma_3\zeta_{13} \\ & \sigma_2{}^2 & \sigma_2\sigma_3\zeta_{23} \\ & & \sigma_3{}^2 \end{bmatrix}$$

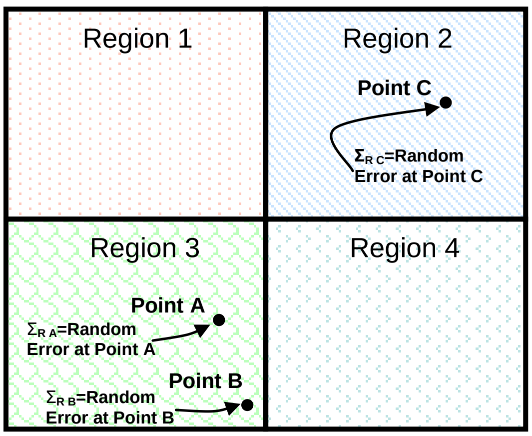
**Figure F.3 – Systematic Error ($\Sigma_{G,R\#}$) per Region**

(where R# represents a Region Number and the dataset consists of four regions)

### F.3.1.3 Provide Random Covariance Data

The random component of predicted error shall be handled on a point by point basis. Following are two strategies to consider: 1) for each point store all 6 independent values required to express a 3 by 3 ground covariance matrix; or 2) for each of the N regions specify the 6 independent values required to express a nominal 3 by 3 random-component ground covariance matrix, and then for each point in the dataset store a scalar value necessary to scale the nominal 3 by 3 ground covariance matrix to arrive at the desired per point values (see Figure F.4).

Strategy 1 will take a large amount of storage space. Strategy 2 is an approximation that will only be valid for narrow field-of-view (i.e., except for a scale factor, the characteristics of the 3D error volume are well modeled by the nominal covariance matrix everywhere in the region). Note that the availability of an accredited sensor model would allow for calculation of the 3 by 3 ground covariance matrix at each point.




$$\Sigma_{R_{(r,c)}} = \begin{bmatrix} \sigma_1{}^2 & \sigma_1\sigma_2\zeta_{12} & \sigma_1\sigma_3\zeta_{13} \\ & \sigma_2{}^2 & \sigma_2\sigma_3\zeta_{23} \\ symmetric & & \sigma_3{}^2 \end{bmatrix}$$

For each Point (P) from 1…n

OR

$$\Sigma_{R,R\#} = \begin{bmatrix} \sigma_1{}^2 & \sigma_1\sigma_2\zeta_{12} & \sigma_1\sigma_3\zeta_{13} \\ & \sigma_2{}^2 & \sigma_2\sigma_3\zeta_{23} \\ symmetric & & \sigma_3{}^2 \end{bmatrix}$$

For each Region (R#) and then scale for each point (P)

$$\Sigma_{R_{(r,c)}} = \Sigma_{R,R\#} * SF_{(r,c)}$$

Where $SF_{P(r,c)}$ is a scale factor per point

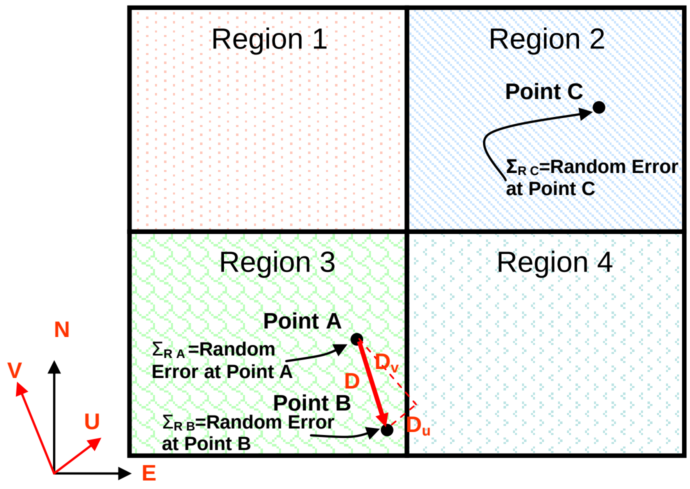
**Figure F.4 – The Random Error ($\Sigma_R$) at a Point (P)**

### F.3.1.4 Provide Relative Covariance Data within a Region

The precision of the relative vector between two points, A and B, appearing within the same region should vary as a function of the horizontal vector between the two points:

$$\Sigma_{AB} = \Sigma_{RA} + \Sigma_{RB} + D_U^2 \cdot \Phi_U + D_V^2 \cdot \Phi_V \quad (2)$$

Where $\Sigma_{randomA}, \Sigma_{randomB}$ are the 3 by 3 matrices, as per Section F.3.1.3, expressing the random error at each point; $D_U, D_V$ represent the horizontal distances in meters between the two points in a local coordinate system that has been rotated from the UTM cartesian coordinate system of the dataset (see Figure E.5); and $\Phi_U, \Phi_V$ are 3 by 3 matrices expressing the increase in covariance magnitude per point separation squared (measured in meters squared) along the U and V axes. As illustrated in the example below, the local (U-V) space is necessary to provide the flexibility to account for covariance growth resulting from the data collection / generation that may not occur parallel to the UTM coordinate system. A maximum distance can also be specified such that the magnitude of elements of $\Sigma_R$ do not exceed specified maximums.




$$\Phi_U = \begin{bmatrix} \frac{d\sigma_x^2}{du^2} & \frac{d\sigma_{xy}}{du^2} & \frac{d\sigma_{xz}}{du^2} \\ & \frac{d\sigma_y^2}{du^2} & \frac{d\sigma_{yz}}{du^2} \\ Symmetric & & \frac{d\sigma_z^2}{du^2} \end{bmatrix}$$

$$\Phi_v = \begin{bmatrix} \frac{d\sigma_x^2}{dv^2} & \frac{d\sigma_{xy}}{dv^2} & \frac{d\sigma_{xz}}{dv^2} \\ & \frac{d\sigma_y^2}{dv^2} & \frac{d\sigma_{yz}}{dv^2} \\ Symmetric & & \frac{d\sigma_z^2}{dv^2} \end{bmatrix}$$

$$\Sigma_R = \Sigma_{randomA} + \Sigma_{randomB} + D_u^2 \cdot \Phi_u + D_v^2 \cdot \Phi_v$$

**Figure F.5 – Relative Covariance of Vector R Within a Region**

As an example of how a vendor would calculate the $\Phi_U, \Phi_V$ matrices to provide in the HRE metadata, consider an airborne LiDAR platform flying along the *U* axis and scanning perpendicular to the *U* axis in the *V* direction. Then, using rigorous error propagation facilitated by CSM function calls, the vendor can calculate the covariance matrices of the vectors between pairs of points as a function of their separation distances in the *U* and *V* directions, i.e. $D_U, D_V$. The vendor would solve for the increase in covariance magnitude per meters squared, $\Phi_U, \Phi_V$, assuming that relative error increases linearly as follows:

$$\Sigma_{AB} = \Sigma_{RA} + \Sigma_{RB} + D_U^2 \cdot \Phi_U + D_V^2 \cdot \Phi_V \qquad (3)$$

Given that a counterclockwise rotation angle of $\theta$ rotates the X axis (about the Z, or up, axis) to align with the U axis, we can apply the changes associated with $\Phi_U, \Phi_V$ using the ground distances ( $D_X, D_Y$ ) and the following equation:

$$\Sigma_{AB} = \Sigma_{RA} + \Sigma_{RB} + \Phi_U \left(D_X \cos\theta + D_Y \sin\theta\right)^2 + \Phi_V \left(-D_X \sin\theta + D_Y \cos\theta\right)^2 \quad (4)$$

## F.3.1.5 Error data discussion

To help clarify the error data discussed above, consider a derivation of the results just presented. Imagine that data points of interest are segregated into non-overlapping geographic regions. Let each region be designated by the letter 'G' followed by a unique number. Let each point within a region be designated by the same region designation followed by a unique lowercase alphabetic label (e.g. we have point a in region G1, also designated as G1a). We are interested in the errors in spatial position of such data points.

Let $\mathbf{P}_{G1a}$ be a 3D vector specifying the position of point G1a in a suitable reference frame. Express $\mathbf{P}_{G1a}$ as the sum of a vector that specifies the position of region G1 (designated as $\mathbf{S}_{G1}$) and a 3D vector that gives the position of point G1a relative to $\mathbf{S}_{G1}$ (designate this vector as $\mathbf{r}_{G1a}$). Then

$$\mathbf{P}_{G1a} = \mathbf{S}_{G1} + \mathbf{r}_{G1a} \qquad (5)$$

The quantities in equation (5) are all subject to errors. Designate the deviation from the mean of any quantity i with the symbol ($\delta$). Then

$$\delta \mathbf{P}_{G1a} = \delta \mathbf{S}_{G1} + \delta \mathbf{r}_{G1a} \qquad (6)$$

Now we can identify the errors $\delta \mathbf{S}_{G1}$ with the systematic errors in section F.3.1.2 and the errors $\delta \mathbf{r}_{G1a}$ with the random errors in section E.3.1.3.

Three by three covariance matrices between a pair of 3D vectors can be written as

$$\delta_{GIGJ} \equiv \langle \delta \mathbf{S}_{GI} \;\; \delta \mathbf{S}^{T}_{GJ} \rangle \qquad (7)$$

Where the brackets denote expectation value and $\mathbf{S}^T$ indicates the transpose (a row vector) of the column vector **S**, so that the product in (7) is an outer product. As written, equation (7) gives the covariances for the systematic errors $\delta \mathbf{S}_{GI}$ and $\delta \mathbf{S}_{GJ}$. If the terms for region numbers I ≠ J are non-zero, it indicates that the errors in specifying the location of region I are not independent of the errors in locating region J. If the set of covariance matrices for N regions are gathered into a 3N x 3N matrix, the result is equation (1), in section F.3.1.2.

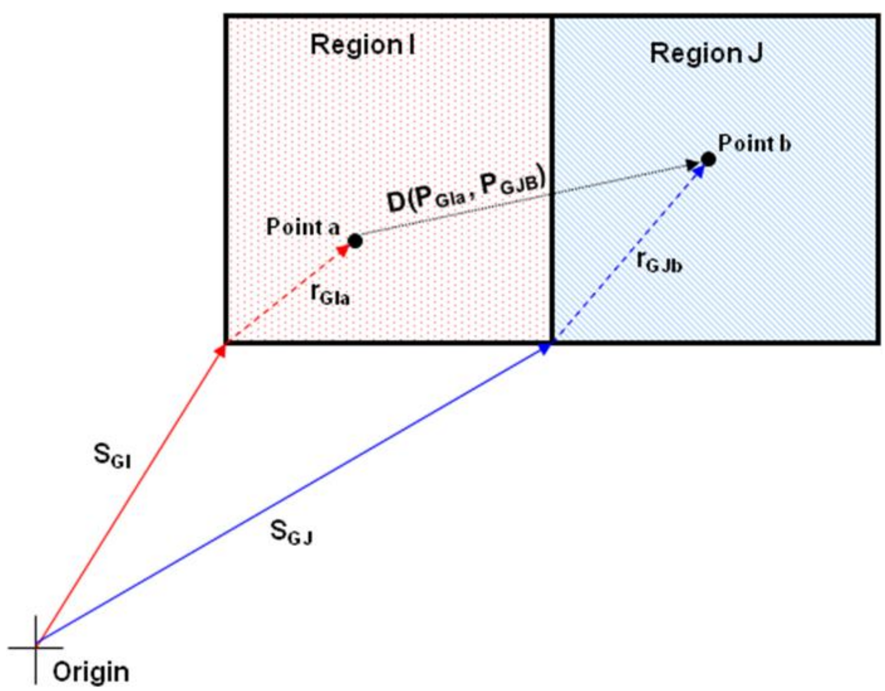



**Figure F.6 – Systematic and Random Error Vector Representation**

Now consider the covariance matrix between a vector locating point GIa, $\mathbf{P}_{GIa}$, and a vector locating point GJb, $\mathbf{P}_{GJb}$. This can be written as

$$\Sigma \square (\mathbf{P}_{GIa}\mathbf{P}_{GJb}) \equiv \langle \delta \mathbf{P}_{GIa} \;\; \delta \mathbf{P}^{T}_{GJb} \rangle \equiv \Sigma_{GIGJ} + \Sigma_{GIaGJb} + \Sigma_{GIGJb} + \Sigma_{GIaGJ} \quad (8)$$

The four terms on the right are obtained by using equation (6) in the middle expression in (8), expanding out the product and denoting the individual product terms as covariance matrices using notation to differentiate between systematic and random error terms. The first of the terms on the right is defined by equation (7), the second is a similar expression for covariances between random errors, and the third and fourth terms involve covariances between systematic errors and random errors. Here, the definition of separate regions implies that covariances of random errors across regions are zero ($\Sigma_{GIaGJb} \equiv 0$, $I \neq J$) and that the covariances of random errors with systematic errors are always zero. With these assumptions equation (8) becomes

$$\Sigma(\square \mathbf{P}_{GIa}\mathbf{P}_{GJb}) = \Sigma_{GIGJ} \qquad I \neq J \quad (9)$$

$$\Sigma\square(\mathbf{P}_{GIa}\mathbf{P}_{GJb}) = \Sigma_{GIGI} + \Sigma_{GIaGIb} \qquad I = J \quad (10)$$

If a = b, equation (10) is essentially equation (15) in section F.3.2.1. Taken together, equations (9) and (10) are used in the formulation of equation (16) in section F.3.2.2.

Finally, consider the covariances for a vector connecting two points (so that we may arrive at an expression for the relative error between two points). Let the vector from point $\mathbf{P}_{GJb}$ to point $\mathbf{P}_{GIa}$ be denoted as $\mathbf{D}(\mathbf{P}_{GIa}\mathbf{P}_{GJb}) \equiv \mathbf{P}_{GIa} - \mathbf{P}_{GJb}$. Then the error in **D** is

$$\delta\, \mathbf{D}(\mathbf{P}_{GIa}\mathbf{P}_{GJb}) = \delta\, \mathbf{P}_{GIa} - \delta\, \mathbf{P}_{GJb} \qquad (11)$$

And the covariance matrix among the components of **D** is

$$\Sigma_D(GIa,GJb) = \langle (\delta\, \mathbf{P}_{GIa} - \delta\, \mathbf{P}_{GJb})(\delta\, \mathbf{P}_{GIa} - \delta\, \mathbf{P}_{GJb})^T \rangle \qquad (12)$$

$$= \langle (\delta\mathbf{S}_{GI} - \delta\mathbf{S}_{GJ} + \delta\mathbf{r}_{GIa} - \delta\mathbf{r}_{GJb})(\delta\mathbf{S}_{GI} - \delta\mathbf{S}_{GJ} + \delta\mathbf{r}_{GIa} - \delta\mathbf{r}_{GJb})^T \rangle$$

If I = J (the endpoints of D are both in the same region) then

$$\Sigma_D(GIa,GJb) = \langle (\delta\mathbf{r}_{GIa} - \delta\mathbf{r}_{GIb})(\delta\mathbf{r}_{GIa} - \delta\mathbf{r}_{GIb})^T \rangle \qquad (13)$$

$$= \Sigma_{GIaGJa} + \Sigma_{GIbGIb} - \Sigma_{GIaGJb} - \Sigma_{GIbGJa}$$

This agrees with equation (2) in section F.3.1.4 if we identify the last two terms in equation (13) with $D_U^2\Phi_U + D_V^2\Phi_V$ in equation (2). Equation (13) is the more general form and equation (2) was chosen as a way to provide a simplified approach to specifying the cross-covariance terms in the metadata.

If $I \neq J$ (the endpoints of **D** are in different regions) then the right hand side of equation (12) comprises sixteen terms. If, however, we again assume that covariances of random errors across regions are zero, and that covariances of random errors with systematic errors are zero, (12) becomes

$$\Sigma_D(GIa,GJb) = (\Sigma_{GIGI} + \Sigma_{GIaGIa}) + (\Sigma_{GJGJ} + \Sigma_{GJbGJb}) - \Sigma_{GIGJ} - \Sigma_{GJGI} \qquad (14)$$

This is essentially equation (17) below in section F.3.2.2.1.

## F.3.2 Exploitation

Figure F.7 illustrates a simple example where two points of interest, A and C, appear in different regions. The first sub-section illustrates how an exploitation tool reconstructs a full covariance matrix containing the covariance matrices for points A and C and the joint cross covariance between points A and C. The second sub-section illustrates how an exploitation tool calculates the precision, expressed as a full covariance matrix, of the relative vector between points A and C.

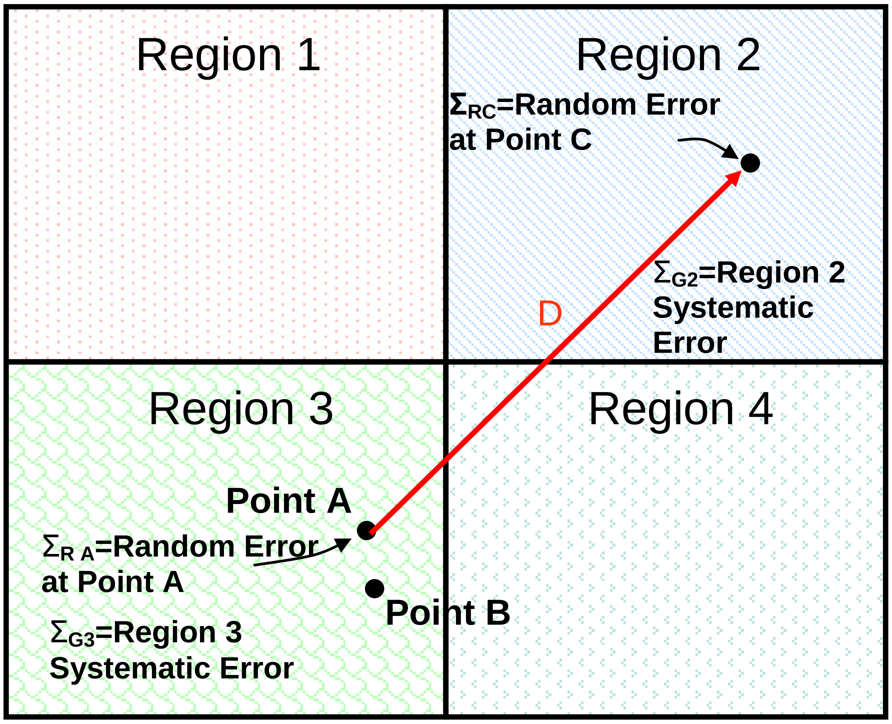



**Figure F.7 – Sample DEM Footprint Consisting of Four Regions with Vector Crossing Regions**

### F.3.2.1 Reconstruction of Full Covariance Matrix for a Single Point

Consider point A in region 3. Then, following is the equation for the full 3 by 3 covariance matrix for point A:

$$\Sigma_{AA} = \left(\Sigma_{G3} + \Sigma_{RA}\right) \qquad (15)$$

### F.3.2.2 Reconstruction of Full Covariance Matrix for Multiple Points

The full 6 by 6 covariance matrix for points A and C is constructed as follows:

$$\Sigma_{AC} = \begin{bmatrix} \Sigma_{G3} + \Sigma_{RA} & \Sigma_{G23} \\ \Sigma_{G23}^{T} & \Sigma_{G2} + \Sigma_{RC} \end{bmatrix} \qquad (16)$$

Where $\Sigma_{RA}, \Sigma_{RC}$ are the random components of precision for points A and C.

#### F.3.2.2.1 Construct Covariance Matrix for Relative Error

Let D denote the relative vector from A to C. Then, following is the equation for the full 3 by 3 covariance matrix for vector D:

$$\Sigma_{DD} = (\Sigma_{G3} + \Sigma_{RA}) + (\Sigma_{G2} + \Sigma_{RC}) - \Sigma_{G23} - \Sigma_{G23}^{T} \quad (17)$$

### F.3.2.2.2 Random Error Covariance at a Point

Consider the case where we would like to isolate the random error covariance at a point (point A) without trying to isolate the system observations that contribute solely to random error. We can calculate the full covariance matrix for points A and B, where B is very close to A, and both A and B have the same precision. Then, we can break this full 6 by 6 matrix down to determine the random component of precision at point A, expressed as a full 3 by 3 matrix as follows:

$$\Sigma_{RA} \cong \frac{1}{2}\left(\Sigma_{AA} + \Sigma_{BB} - \Sigma_{AB} - \Sigma_{AB}^{T}\right) \quad (18)$$

### F.3.2.2.3 Computing the Absolute Error at a Point

One of the common applications of the uncertainty data is to predict the absolute error of a point. This could be performed to determine the absolute accuracy of a single point or it may be an operation where the absolute accuracy of every post is determined to develop a grid of uncertainties for additional visualization / exploitation.

The first step to developing the absolute accuracy is to combine the systematic and random uncertainty estimates for the point(s) of interest as shown in Figure F.8 below.

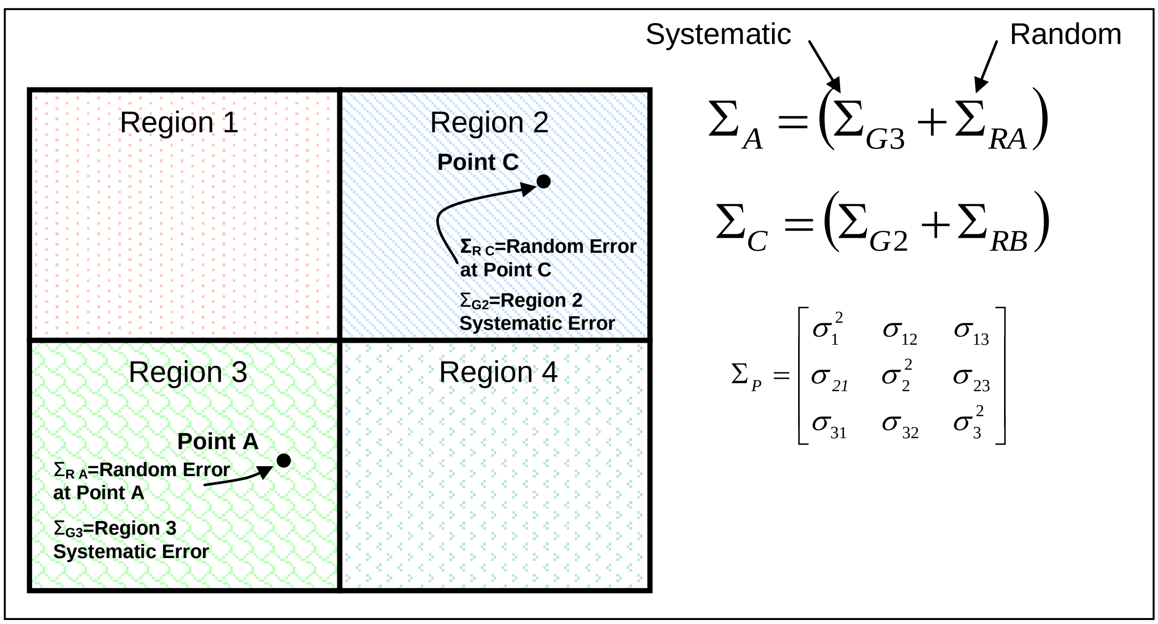



**Figure F.8 – Covariance Data at a Point**

Once developed the covariance matrix ($\Sigma_P$) represents the uncertainty around the point (P). If one were solely interested in the horizontal uncertainty of point P, only the 2x2 covariance elements related to horizontal uncertainty would be evaluated and these would represent an error ellipse of uncertainty around point P (See Figure F.9).

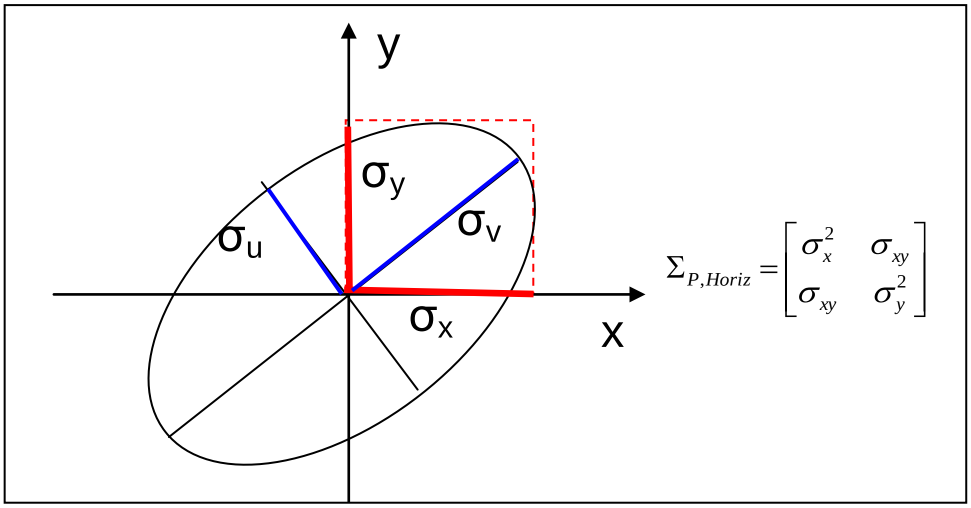



**Figure F.9 – Horizontal Error Ellipse at a Point**

Using the values of the error ellipse, one can also calculate a circular error for the point (P) at a given confidence interval (see Figure F.10). There are several documented methods to calculate the CE90 using the covariance data. In this case, the method referenced by ISO 19138 is shown.

First compute the eigenvalues of the ellipse:

$$\sigma_u^2 = \frac{\sigma_x^2 + \sigma_y^2}{2} + \sqrt{\frac{1}{4}\left(\sigma_x^2 - \sigma_y^2\right)^2 + \left(\sigma_{xy}\right)^2}$$

$$\sigma_v^2 = \frac{\sigma_x^2 + \sigma_y^2}{2} - \sqrt{\frac{1}{4}\left(\sigma_x^2 - \sigma_y^2\right)^2 + \left(\sigma_{xy}^2\right)}$$

Then compute the ratio between them:

$$C = {}^{\sigma_v}\!/_{\sigma_u}$$

Finally, calculate the CE:

$$CE90=(1.6545 - 0.13913C + 0.6324C^2)\sigma_u$$

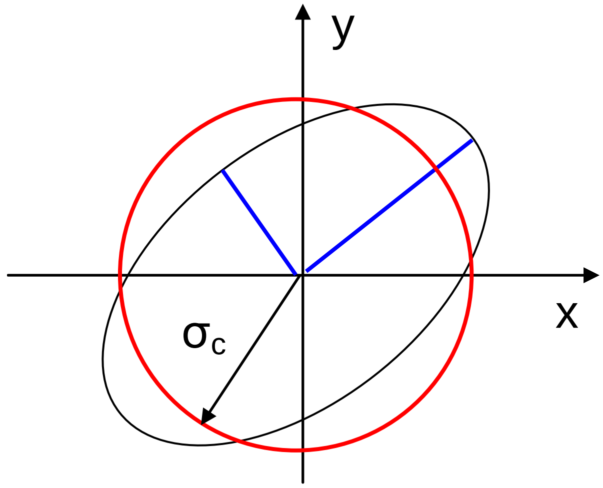



**Figure F.10 – Circular Error from Covariance Data**

In a similar fashion, the covariance element for the variance in the vertical or z direction can also be used to calculate the vertical uncertainty of a point at a given confidence interval. To calculate the LE90 of a point (P), one would calculate:

$$LE90_{ABS,P} = 1.6449\sigma_z$$

# Annex G
Use Case Analysis
(Informative)

## G.1 Introduction

The requirements described by this profile can serve as the core for various application schemas to be developed for elevation data. During development of the profile, operational requirements for terrain elevation and hydrographic surface models were examined. The requirements were captured initially through the development of a set of use cases that depict the cross-section of defense community uses of these models.

## G.2 Initial Scope

The scope of use case development is on content, in particular on the use of processed data, and less so on sensor data and metadata. The use cases are independent of engineering and technology and, therefore, do not include aspects such as data transport/carrier, distribution, networks, software and hardware.

## G.3 Use Case Guidelines

The following guidelines have been derived from the use case analysis.

1. To exchange legacy surface data, the most prevalent geospatial representation will remain as simple grid; however, a simple grid structure is not suitable for the exchange of surface data where resolutions and scales are variable.
2. The collection of spatial data where the surface is in 3 dimensional space requires either a Riemann hyperspatial grid (not addressed by this profile) or TIN geospatial representation.
3. The tiled, quad tree and TIN coverage spatial realizations allow for different levels of data compaction of data over areas with low complexity.
4. Data described using any spatial representation can be processed through a stochastic compression technique (such a ZIP) regardless of whether a data compaction was applied first or not.
5. The reconstruction of high-resolution surface data should use tiling, quad tree or TIN geospatial representation.
6. The spatial representation of two fused coverages (e.g. for change detection) must be the same and the attributes of the coverage functions (resolution, spatial referencing) must also be the same. If they are not the same then a conversion is required. A conversion from one coverage type to another or from one resolution or referencing system to another requires a recalculation or resampling that may result in data loss.
7. Where features and spatial surfaces are to be fused, continuous coverages, such as an elevation grid coverage, must be defined separately from a discrete coverage, such as a transportation layer, even though the two may be coincident.
8. For support to applications requiring the calculation of intersections between the elevation surface and some other coverage, the most appropriate spatial representation for the elevation surface is TIN.

9. Applications providing visual simulation through the 'draping' of a discrete or continuous coverage over an elevation surface are best supported by a TIN geospatial representation of the elevation surface.
10. Mathematical calculations made using hydrographic surfaces are also best supported by the TIN geospatial representation.
11. Line-of-sight applications provide an estimation of the intersection of a straight line with the elevation surface. As such, TIN is again the preferred geospatial representation for line-of-sight.
12. For georectification of surfaces, any coverage type could be used for the control surface; however, compression considerations may be necessary.
13. The preferred geospatial representation for hydrographic sonar survey data is a grid coverage organized as a quad tree. When depth and/or time are represented as a dimension, the grid is organized as a Riemann hyperspatial multidimensional grid.
14. Hydrographic sounding data is best represented as a discrete point coverage. The discrete point coverage effectively represents samples and an interpolation function may be associated with it.

## G.4 Illustrative Use Cases

This Annex will not attempt to provide a comprehensive set of all the uses to which a standardized elevation surface model can be applied. Generally speaking, the standardized model will have the following uses:

- describing existing elevation data holdings in support of cataloguing, discovery, and retrieval
- providing support to applications and services employing elevation data
- providing requirements for the development of elevation data product specifications

Additionally, the profile project team has identified a small set of specific uses that justify the allowed types of geospatial representations and the minimum required metadata specified by this profile:

- Development of product specifications for high-resolution terrain data with metadata for rigorous error propagation
- Standardized description of aggregated survey data, e.g. topographic or hydrographic survey
- Standardized description of measured elevation/depth points, e.g. hydrographic soundings
- A model for providing elevation data for a land/water boundary area within a single dataset
- A model for providing data from multiple collection sessions with different characteristics within a single dataset
- A mapping of metadata elements from existing elevation data encoding formats to the standardized model by web coverage services for format-independent discovery
- A mapping of metadata elements from existing elevation data encoding formats to the standardized model by web processing services for format-independent analysis

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